TERTIARY DINOFLAGELLATE, ACRITARCH, AND CHLOROPHYTE ASSEMBLAGES FROM THE OAK GROVE CORE, VIRGINIA COASTAL PLAIN

by

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Dissertation submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY
in
Geological Sciences

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March, 1987
Blacksburg, Virginia

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(ABSTRACT)

Diverse, well preserved organic-walled phytoplankton assemblages were recovered from the Tertiary section of the Oak Grove core drilled on the Virginia Coastal Plain. Strata penetrated include the Aquia, Marlboro Clay, and Nanjemoy Formations (Paleocene to Eocene) of the Pamunkey Group and the Calvert and Choptank Formations (Miocene) of the Chesapeake Group. The assemblages are composed of 176 dinoflagellate species and subspecies (82 genera), of which 20 species and subspecies and one combination are new; five acritarch species (two genera) and five chlorophyte species (three genera) are also reported.

The biostratigraphic distribution of the 186 species provides information concerning the ages of the formations and the nature of their lithologic contacts. The organic-walled phytoplankton assemblages corroborate the Paleocene (Thanetian) age indicated by the calcareous nannofossils, Foraminifera, ostracodes, and pollen and

spores for the Aquia strata; certain dinoflagellate and pollen species in the lowermost 11.5 m (37.9 ft), however, suggest this basal interval, devoid of other microfossils, could be Paleocene (Danian) in age. An Eocene (Ypresian) age is assigned to the Nanjemoy strata based on the organic-walled phytoplankton, as well as the pollen and spores, calcareous nannofossils, ostracodes, and mollusks. The intervening Marlboro Clay appears to straddle the Paleocene-Eocene boundary based on its dinoflagellate and pollen species. Dinoflagellate species suggest a general Early to Middle Miocene age for the Calvert and Choptank section in the core; diatom samples in the Calvert indicate a late Early to early Middle Miocene age and in the Choptank a middle Middle Miocene age. Lithologic and biostratigraphic evidence suggests the upper and possibly the lower Marlboro Clay contacts represent minor disconformities, in addition to the major disconformity at the Nanjemoy-Calvert boundary; the Calvert-Choptank contact appears conformable.

The ten provisional dinoflagellate zones proposed for the Aquia, Marlboro Clay, and Nanjemoy strata of the core permit correlation with other previously studied Paleocene and Eocene sections of the Virginia and Maryland Coastal Plain. These Lower Tertiary strata are also generally biostratigraphically correlated with numerous coeval European sections, and a composite offshore eastern Canada section.

The dinoflagellate, acritarch, and chlorophyte assemblages are statistically analyzed for paleoenvironmental implications using species diversity indicators (richness, Shannon-Wiener index, evenness)

and analyses patterned after previous palynological studies suggesting correlation of various assemblage parameters and characteristics with particular depositional environments. Results are consistent with sedimentological and foraminiferal-based paleoenvironmental assessments of generally inner shelf marine settings for the Aquia, Nanjemoy, Calvert, and Choptank Formations, and a lagoonal or estuarine setting for the Marlboro Clay. Cluster, principal coordinates, and rank-abundance analyses help to objectively define and characterize six major and 12 smaller clusters of samples related by their species associations through time.

ACKNOWLEDGEMENTS

I wish to express my appreciation to , my dissertation advisor and graduate committee chairman at Virginia Polytechnic Institute and State University, for providing guidance, support, and encouragement during the course of this study. Special thanks are also extended to the other members of my graduate committee, , , and of the Geology Department and of the Biology Department at Virginia Polytechnic Institute and State University, for critically reviewing the manuscript and making helpful suggestions. I am grateful to Unocal Science and Technology Center for use of its graphics, photography, and data processing facilities, and in particular to for his valuable computer programming assistance. Palynological discussions with many of my colleagues and good friends, including , , , , , and , have benefited me greatly. I wish to especially thank my wife Heidi for her assistance on the graphics, as well as her encouragement and moral support which helped me to keep in touch with reality.

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INTRODUCTION

General Statement

This investigation is part of a continuing effort at Virginia Polytechnic Institute and State University to develop a biostratigraphic framework of strata from the Atlantic Coastal Plain and Gulf of Mexico Coastal Plain, based primarily on fossil dinoflagellates, acritarchs, and chlorophytes (organic-walled phytoplankton)*. The work will ultimately allow correlation between sections of both coastal plains, as well as with offshore continental shelves. Upper Cretaceous organic-walled phytoplankton studies of the Atlantic Coastal Plain completed to date in the palynological laboratory include Campanian-Maastrichtian sections in New Jersey, Maryland, and Delaware (May, 1976; Whitney, 1976; Benson, 1976). Gulf Coastal Plain investigations analyzed portions of the Campanian-Maastrichtian interval of Mississippi and Alabama (Rounds, 1982; Jahnke, M.S. in progress); Upper Cretaceous units of Georgia were also studied by Roberts (1980) and Firth (1984). Tertiary studies of the Atlantic

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* Organic-walled phytoplankton as used in this study includes the primitive eukaryotic algal unicells known as dinoflagellates (Division Pyrrhophyta) and acritarchs (dinoflagellate-like cysts of uncertain affinity), as well as chlorophytes (probable cysts of green algae; Division Chlorophyta); "organic-walled" refers to their highly resistant wall composition of sporopollenin - complex bipolymers derived by oxidative polymerization of carotenoids or carotenoid esters. See Evitt (1985) for detailed discussion.

Coastal Plain include those of McLean (1971), Witmer (1975), Goodman (1975), Whitney (1976), and Benson (1976) for Paleocene-Eocene Pamunkey Group sections in Virginia and Maryland. Watkins (1979) studied the Eocene and Ford (1979) the Oligocene intervals of a South Carolina core. Parts of Lower Paleocene Georgia (Firth, 1984) and Alabama (Jahnke, M.S. in progress) sections were also documented.

The present study deals with the dinoflagellate, acritarch, and chlorophyte assemblages from 49 samples collected from the Tertiary strata of the Oak Grove core, a continuously cored stratigraphic test hole drilled in eastern Virginia by the U. S. Geological Survey. The Tertiary units include Aquia, Marlboro Clay, and Nanjemoy strata of the Paleocene-Eocene age Pamunkey Group, and Calvert and Choptank strata of the Miocene age Chesapeake Group. The well preserved, diverse assemblages recovered from these sediments include 82 dinoflagellate genera and 176 species and subspecies, of which 20 species and subspecies and one combination are new. Five acritarch species and five chlorophyte species are also part of the assemblages. The organic-walled phytoplankton are discussed in terms of their taxonomy, morphology, biostratigraphy, and paleoecology.

Objectives of This Study

The Tertiary dinoflagellate, acritarch, and chlorophyte assemblages of the Oak Grove core were investigated with the following objectives in mind:

(1) To discuss and illustrate the species present, and to describe all new taxa;

(2) To determine the biostratigraphic distributions and numerical abundances of the species;

(3) To compare the ages of the formations based on these organic-walled phytoplankton assemblages with other fossil groups;

(4) To establish a tentative palynological zonation;

(5) To biostratigraphically correlate the Paleocene and Eocene strata of the core with coeval rocks from previously studied outcrop localities of the Virginia and Maryland Coastal Plain, as well as from numerous European sections, and a composite offshore eastern Canada section;

(6) To investigate the paleoecological implications of the assemblages by comparing them to previous environment-oriented palynological studies, and by analyzing the species using various statistical analyses.

Previous Studies of Paleocene, Eocene, and Miocene Organic-walled Phytoplankton

Numerous studies which include Paleocene, Eocene, and Miocene dinoflagellates, acritarchs, and chlorophytes have been published for strata in the United States, as well as the Atlantic Continental Shelf. On the Atlantic Coastal Plain, Early Paleocene assemblages of dinoflagellates and acritarchs from Maryland have been investigated by Whitney (1976, 1984) and Benson (1976). Late Paleocene assemblages from Virginia and Maryland were studied by McLean (1971a,b, 1972, 1973a,b, 1974, 1976) and Witmer (1975). Goodman (1975, 1979, 1984) reported on Early Eocene dinoflagellates of Maryland. Dinoflagellate studies of the Gulf Coastal Plain include those by Drugg and Loeblich (1967) and Edwards (1977) on Eocene and Oligocene strata, and Drugg (1970) on Paleocene to Oligocene strata from localities in Alabama and Mississippi. Edwards (1980) documented Paleocene and Eocene assemblages from Georgia. Paleocene dinoflagellates were included in both an investigation by Stanley (1965) on the Cannonball Formation of South Dakota, and Drugg (1967) on the Moreno Formation of California. Stover (1977) published numerous new dinoflagellate taxa from the Oligocene and Lower Miocene strata of the Atlantic corehole #5/5B on the Blake Plateau, offshore South Carolina. Farther north, Paleocene, Eocene, and Miocene dinoflagellates were part of the Mesozoic-Cenozoic biostratigraphic investigation by Williams and Brideaux (1975) on the Grand Banks off Newfoundland. Williams and Bujak (1977) and Barss et al. (1979) summarized the Cenozoic palynostratigraphy of offshore eastern Canada.

As part of the Deep Sea Drilling Project in the northern Atlantic Ocean, Costa and Downie (1979) have documented Paleocene to Miocene assemblages. More recently, Brown and Downie (1983) investigated DSDP Paleocene and Eocene sections, and Edwards (1983) reported on Miocene units. In the North Sea and Labrador Sea, the Paleocene to Miocene dinoflagellates were analyzed by Ioakim (1979).

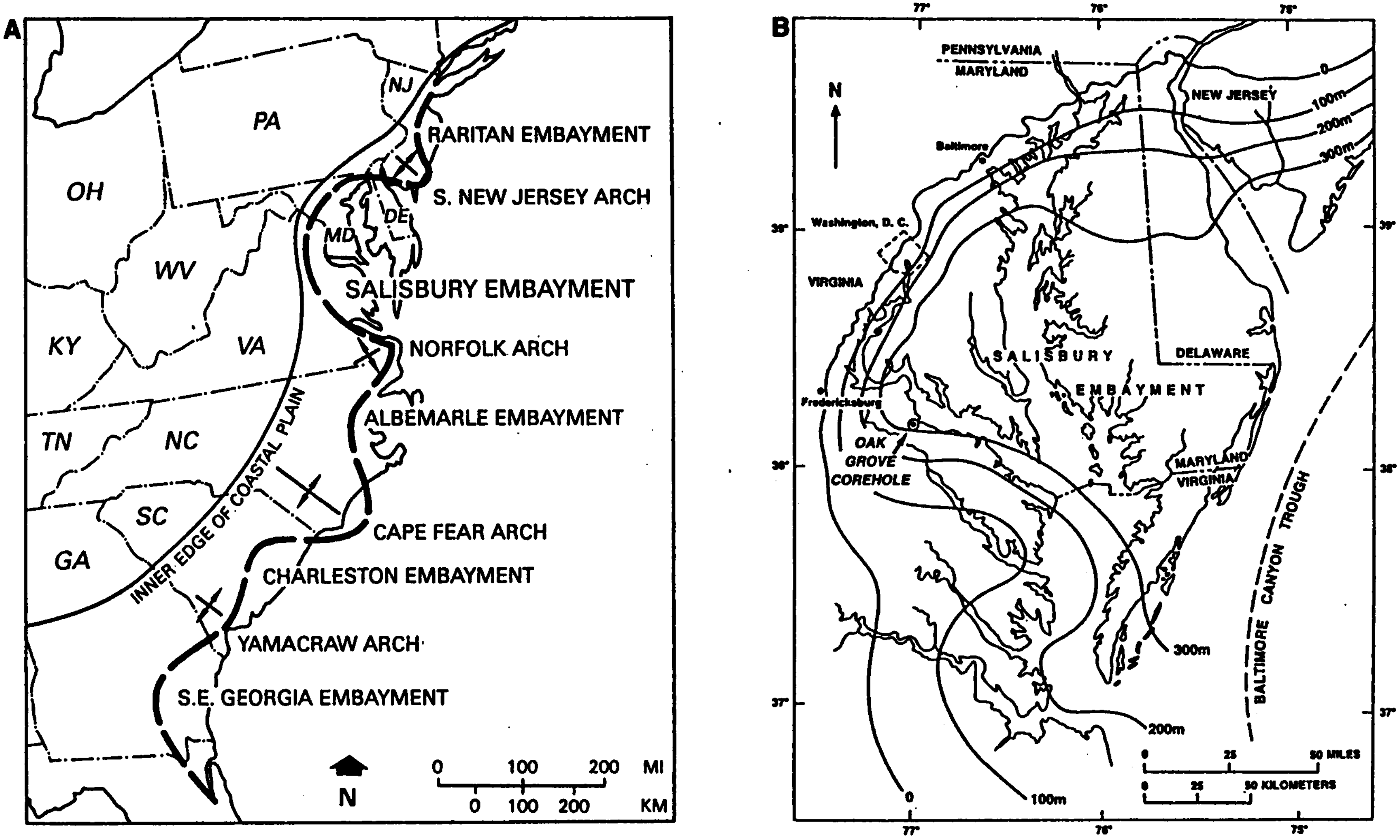
European contributions on Tertiary organic-walled phytoplankton cysts include many publications by Eisenack of Germany and Deflandre of France, as well as papers by Maier (1959), Alberti (1959, 1961), Gocht (1955, 1969), Gerlach (1961), Morgenroth (1966, 1968), DeConinck (1965, 1969, 1972, 1975, 1976a,b,c, 1977, 1979), Gruas-Cavagnetto (1968, 1970), Chateauneuff and Gruas-Cavagnetto (1968, 1970), Benedek (1972), Caro (1973), Caro et al. (1975), Jan de Chene et al. (1975), Eaton (1976), Costa and Downie (1976), Denison (1977), Herngreen (1984), and Heilmann-Clausen (1985). Davey et al. (1966) published an extensive account of Mesozoic and Cenozoic dinoflagellate cysts in England. Other publications on British Tertiary sections include Bujak et al. (1980) and Islam (1983a,b,c).

GEOLOGICAL SETTING AND STRATIGRAPHY

General Statement

The Oak Grove corehole was drilled in the Atlantic Coastal Plain province in the state of Virginia along the Rappahannock River, approximately 80 km (50 mi) northeast of Richmond, and 88 m (55 mi) south of Washington, D. C. The Atlantic Coastal Plain, an undeformed wedge of Cretaceous and Tertiary marine and non-marine clays, silts, sands, and gravels which rests unconformably on Precambrian, Paleozoic, and Mesozoic rocks, extends along the eastern coast of the United States from Cape Cod to Florida. The borehole is located near the southern margin of the Salisbury (=Baltimore-Washington) Embayment, a huge basement synclinal structure (axial trend generally NW-SE) between two structural highs known as the Norfolk Arch and South New Jersey Arch (see Text-fig. 1 A-B).

This study deals with strata from the two lithologic groups penetrated in the Tertiary section of the Oak Grove corehole: the Pamunkey Group and the Chesapeake Group (in ascending order). The predominantly glauconitic quartz sands and clays of the Pamunkey Group (Paleocene-Eocene) constitute the basal Tertiary unit of the Virginia-Maryland Coastal Plain. Deposits of this group overstep Lower and Upper Cretaceous strata of the Potomac Group, and are



Text-fig. 1. (A) Map showing major tectonic features of the U. S. Atlantic Coastal Plain. (Modified from Ward (1984.) (B) Isopach map of Lower Cretaceous sedimentary rocks defining the Salisbury Embayment; note location of the Oak Grove corehole. (Modified from Reinhardt et al., 1980.)

unconformably overlain by the diatomaceous sands and clays of the Chesapeake Group (Miocene), and in some areas by Plio-Pleistocene sands. Oligocene rocks are absent in the vicinity of the corehole.

A concise historical summary and discussion of the subdivisions of the lithologic groups are presented in the following sections.

Brief History

In 1809, Maclure made the first attempt at correlating the strata of the Atlantic Coastal Plain with the reference sections established in Europe. General subdivisions of the Atlantic Coastal Plain rock units were proposed by Finch (1824). Conrad (1832, 1835, 1838) and Rogers (1835, 1836, 1840) were the first geologists to use paleontology in the study of the Tertiary deposits.

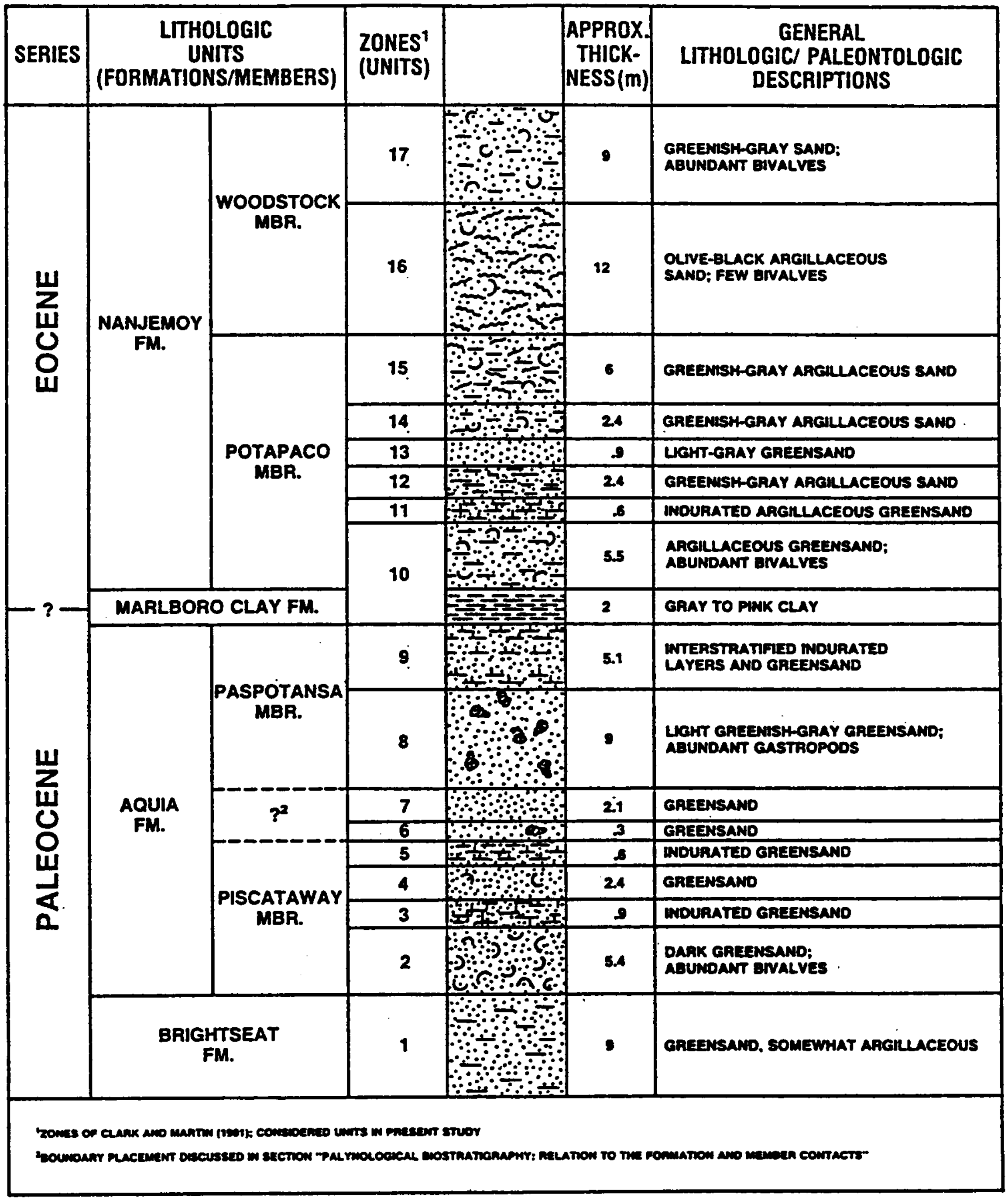
The Pamunkey Formation was established by Darton in 1891, and it was subsequently divided into the Aquia Creek and Woodstock Stages by Clark (1895). Later Clark and Martin (1901) raised this formation to group status. They divided the Pamunkey Group into the Aquia Formation (lower unit) with two members and nine zones, and the Nanjemoy Formation (uppper unit) with two members and eight zones. Two of the zones of the Pamunkey Group have now, however, been elevated to formation rank. The basal zone of the Aquia Formation in Maryland was named the Brightseat Formation by Bennett and Collins (1952). The basal clay of the Nanjemoy Formation was named the Marlboro Clay Member by Darton (1948); this unit was later considered to be a formation by Glaser (1971).

The Chesapeake Formation was also established by Darton in 1891, and the following year it was raised to group status by Dall and Harris (1892). Shattuck (1902) recognized and named three formations in the Chesapeake Group: Calvert, Choptank, and St. Marys Formations (in ascending order). Clark and Miller (1906) named the fourth and uppermost unit of the group the Yorktown Formation.

Pamunkey Group

The Pamunkey Group consists of the Brightseat Formation (formerly Clark and Martin (1901) zone 1), the Aquia Formation (zones 2-9), the Marlboro Clay Formation (basal clay of zone 10), and the Nanjemoy Formation (zones 10-17), in ascending stratigraphic order (see Text-fig. 2). The zones of Clark and Martin (1901) were established on the basis of both lithologic and paleontologic criteria, and therefore do not conform to the modern concept of the *zone* as defined in the Code of Stratigraphic Nomenclature (1983). They are used to some extent in the present study solely as a framework upon which local biostratigraphic correlations can be discussed; to avoid confusion, the zones will be referred to as units.

The Pamunkey Group was considered to be of Eocene age (Clark and Martin, 1901; Shifflett, 1948) until Loeblich and Tappan (1957) as-



SERIES	LITHOLOGIC UNITS (FORMATIONS/MEMBERS)		ZONES[1] (UNITS)	APPROX. THICK-NESS(m)	GENERAL LITHOLOGIC/ PALEONTOLOGIC DESCRIPTIONS
EOCENE	NANJEMOY FM.	WOODSTOCK MBR.	17	9	GREENISH-GRAY SAND; ABUNDANT BIVALVES
			16	12	OLIVE-BLACK ARGILLACEOUS SAND; FEW BIVALVES
		POTAPACO MBR.	15	6	GREENISH-GRAY ARGILLACEOUS SAND
			14	2.4	GREENISH-GRAY ARGILLACEOUS SAND
			13	.9	LIGHT-GRAY GREENSAND
			12	2.4	GREENISH-GRAY ARGILLACEOUS SAND
			11	.6	INDURATED ARGILLACEOUS GREENSAND
			10	5.5	ARGILLACEOUS GREENSAND; ABUNDANT BIVALVES
— ? —	MARLBORO CLAY FM.			2	GRAY TO PINK CLAY
PALEOCENE	AQUIA FM.	PASPOTANSA MBR.	9	5.1	INTERSTRATIFIED INDURATED LAYERS AND GREENSAND
			8	9	LIGHT GREENISH-GRAY GREENSAND; ABUNDANT GASTROPODS
		?[2]	7	2.1	GREENSAND
			6	.3	GREENSAND
		PISCATAWAY MBR.	5	.6	INDURATED GREENSAND
			4	2.4	GREENSAND
			3	.9	INDURATED GREENSAND
			2	5.4	DARK GREENSAND; ABUNDANT BIVALVES
	BRIGHTSEAT FM.		1	9	GREENSAND, SOMEWHAT ARGILLACEOUS

[1] ZONES OF CLARK AND MARTIN (1901); CONSIDERED UNITS IN PRESENT STUDY

[2] BOUNDARY PLACEMENT DISCUSSED IN SECTION "PALYNOLOGICAL BIOSTRATIGRAPHY: RELATION TO THE FORMATION AND MEMBER CONTACTS"

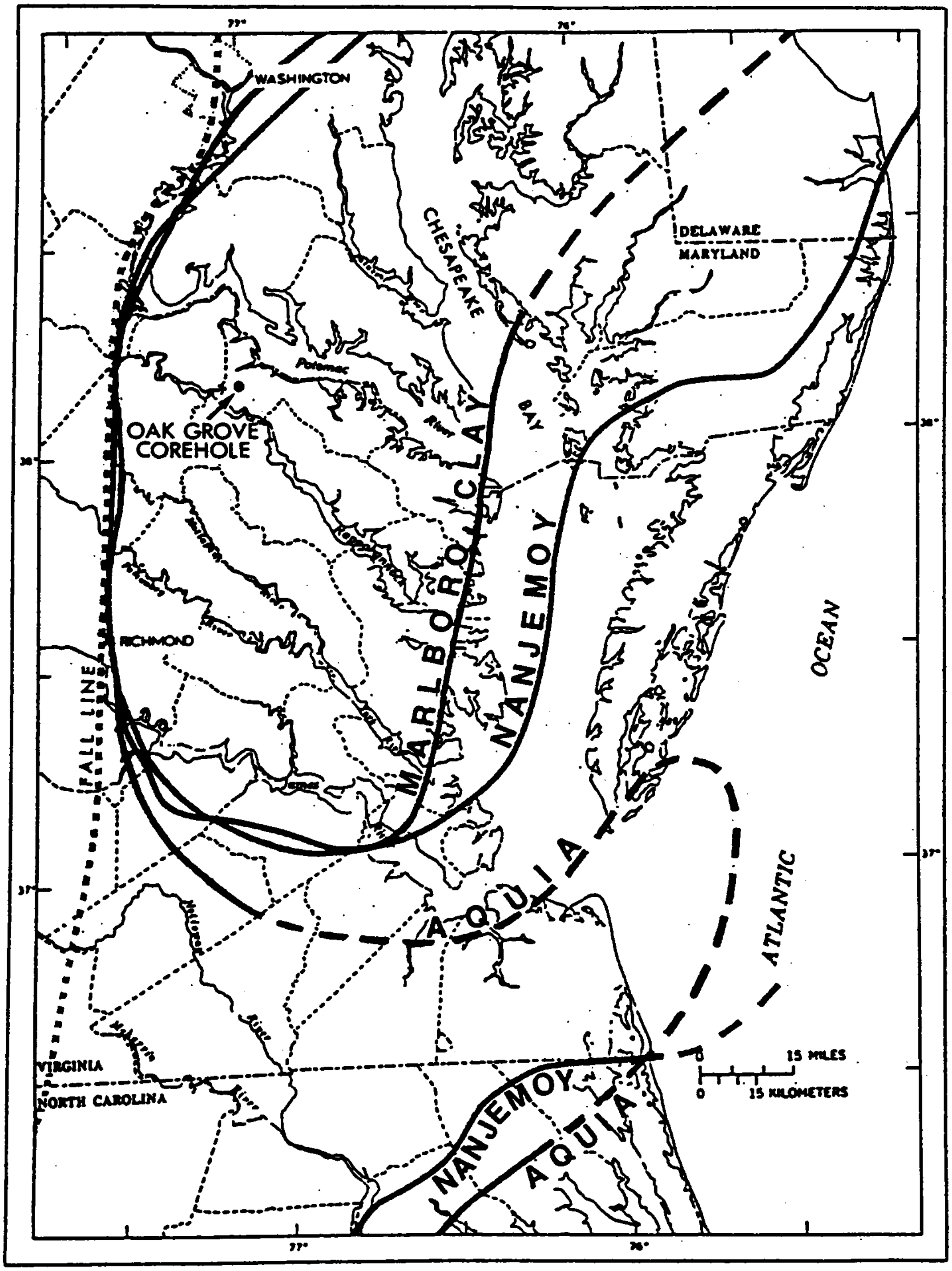
Text-fig. 2. Generalized columnar section of the Pamunkey Group showing lithology and subdivisions. (Modified from Clark and Martin (1901) and Ward (1984).)

signed a Late Paleocene (Sparnacian) age to the Aquia Formation and an Early Eocene (Ypresian) age to the Nanjemoy Formation based on planktonic foraminifers. Similar studies by Berggren (1965) supported these age determinations. Hazel (1968, 1969, 1984) assigned a mid Danian age to the Brightseat Formation based on ostracodes and foraminifers (*Globoconusca daubjergensis* - *Globorotalia trinidadensis* zone). The age of the Marlboro Clay is somewhat problematical; the Paleocene-Eocene boundary may in fact lie within this unit.

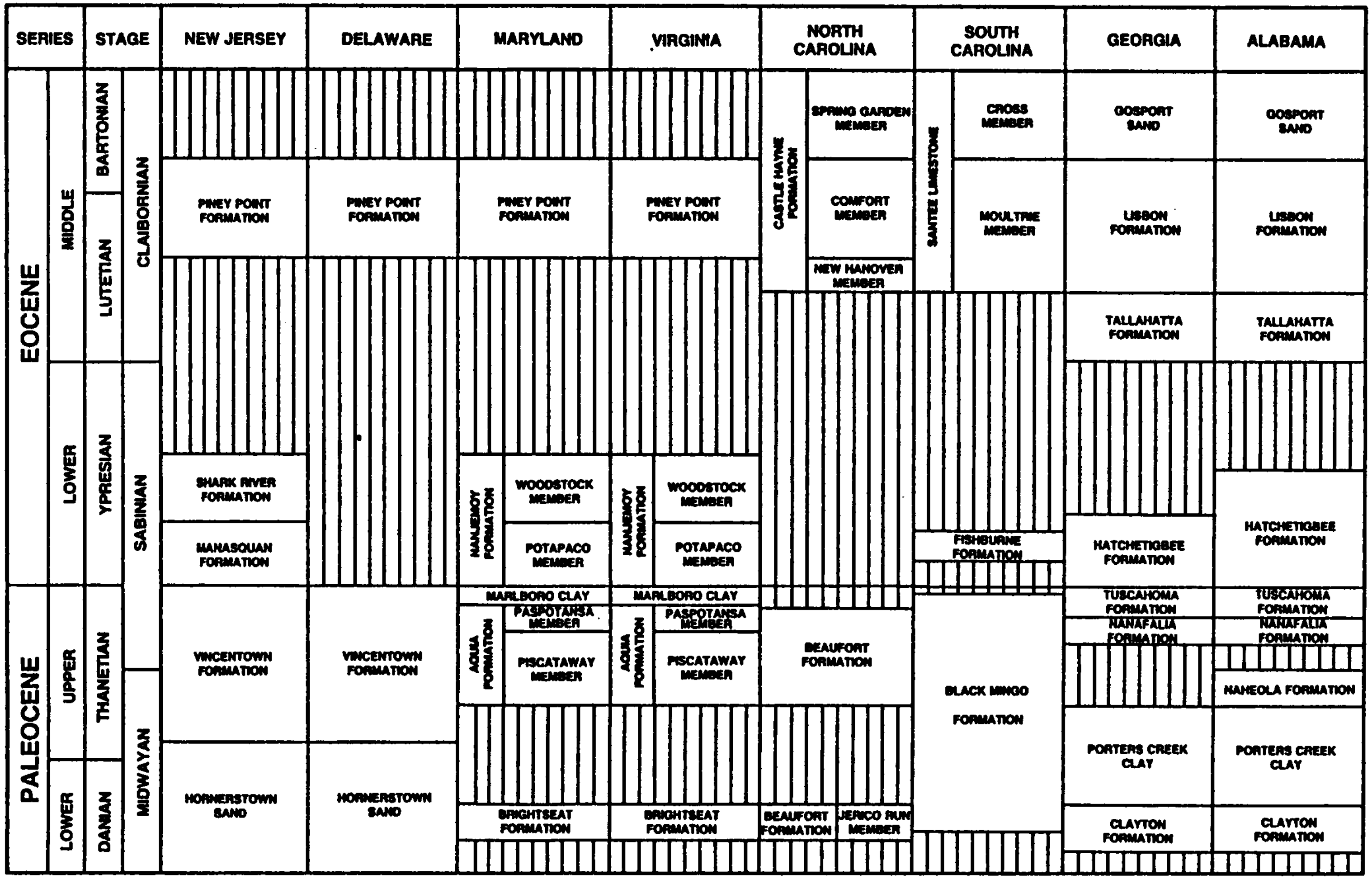
The lithologic units of the Pamunkey Group are briefly summarized in the following sections (for more detail, the reader is referred to Ward (1984) and Beauchamp (1984)). Approximate geographic limits of these formations are shown in Text-fig. 3. A general correlation of the units with equivalent age coastal plain rocks from New Jersey to Alabama is depicted in Text-fig. 4.

Aquia Formation

The type locality of the Aquia Formation is near the confluence of Aquia Creek and the Potomac River in Stafford County, Virginia, about 72 km (45 mi) south of Washington, D. C. The formation is divided into two members, the Piscataway and the Paspotansa, in ascending order. The Piscataway consists of olive gray, poorly sorted, clayey, shelly (e.g., *Ostrea* spp.), glauconitic and quartzose sands, whereas the Paspotansa is generally characterized by olive gray-black,



Text-fig. 3. Geographic limits of the Aquia, Marlboro Clay, and Nanjemoy Formations on the coastal plain of Maryland, Virginia, and North Carolina, based on outcrop and core data (dashed lines approximate limits). Note position of Oak Grove corehole. (Modified from Ward, 1984.)



Text-fig. 4. General correlation chart of Paleocene to Middle Eocene (Danian-Bartonian) age coastal plain formations from New Jersey to Alabama. (Modified from Ward, 1984.)

thick-bedded, well sorted, fine, silty, micaceous, glauconitic sands with numerous scattered and bedded *Turritella mortoni* . The Piscataway - Paspotansa boundary was originally defined between units 7 and 8; recently Ward (in press), based on a restudy of many localities, recommended that units 6 and 7 be included in the Paspotansa Member (see Text-fig. 2).

The arcuate outcrop belt of the Aquia Formation extends from Petersburg, Virginia, to southern Kent County, Maryland. The formation strikes generally north, and dips to the east at about 2.2 to 2.7 m/km (12 to 15 ft/mi). At the type locality the Aquia is approximately 30 m (100 ft) thick; downdip it increases to 90 m (300 ft).

Megafossil assemblages include over 100 species of mollusks (see Ward (1984) for complete listing), as well as fishes, crocodiles, and turtles. Among the microfossils are foraminifers, ostracodes, calcareous nannofossils, dinoflagellates, acritarchs, chlorophytes, and pollen and spores.

Marlboro Clay

Darton (1948) named the Marlboro Clay Member for exposures near Upper Marlboro in Prince Georges County, Maryland. Because this distinctive unit apparently meets the criteria for formational rank, Glaser (1971) referred to it in his report as the Marlboro Clay Formation; he did not, however, designate a type locality (best exposure is in southern Maryland, a few meters southwest of Md. Route 224 just 0.4 km (0.6 mi) southwest of Mason Springs in Charles County). In this study the unit will be referred to simply as the Marlboro Clay.

The strike of the Marlboro Clay is generally north, and its dip approximates that of the Aquia Formation. The finely laminated, plastic clay, which ranges up to 9 m (30 ft) thick, is essentially silvery-gray to pale red, with yellowish-gray to reddish silt interbeds. Its upper contact with the Nanjemoy Formation is also generally sharp, but is locally considerably burrowed.

Some small mollusks have been recovered from the Marlboro Clay. Microfossils include a limited number of species of arenaceous foraminifers and dinoflagellates, acritarchs, and chlorophytes, as well as pollen and spores.

Nanjemoy Formation

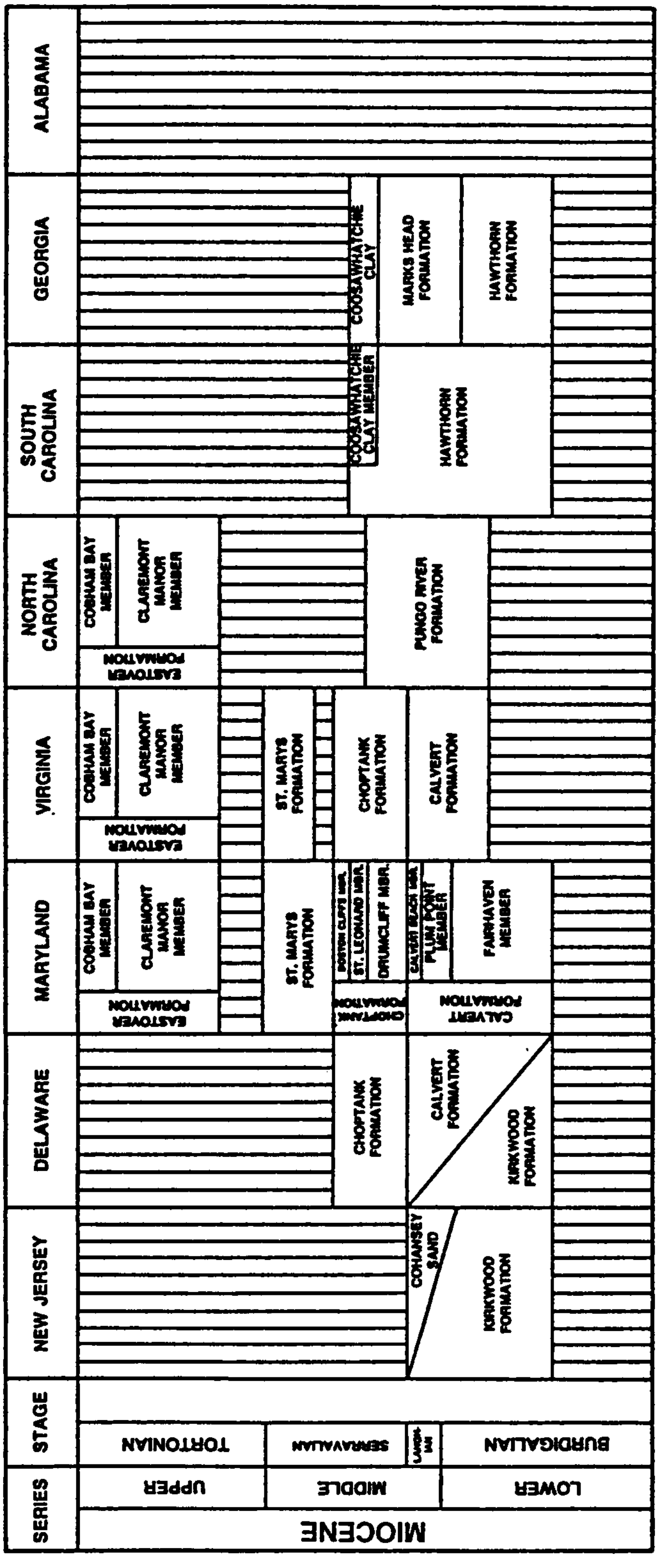
The type locality of the Nanjemoy Formation is in Charles County, Maryland, at the headwaters of Nanjemoy Creek, about 8 km (5 mi) south of Pisgah. Outcrops of the formation extend from Petersburg, Virginia, to eastern Anne Arundel County, Maryland. Its strike and dip are similar to that of the Aquia Formation. The unit is about 37.5 m (125 ft) thick at its type locality, but it thickens to about 60 m (200 ft) downdip.

Like the Aquia Formation, two members are also recognized in the Nanjemoy Formation: the Potapaco and Woodstock, in ascending stratigraphic order. The Potapaco is a predominantly gray to pink, bioturbated clay, with poorly sorted glauconitic silts and sands; the bivalve *Venericardia potapacoensis* is abundant in this member. The Woodstock consists of primarily olive black, very fine, well sorted, silty, glauconitic sands; *V. ascia* is prevalent in this unit.

Among the 50 species of mollusks found in the Nanjemoy Formation, pelecypods are the most abundant (see Ward (1984) for complete listing). Vertebrate fossils, other than some fishes, are rare. Microfossils include foraminifers, ostracodes, calcareous nannofossils, dinoflagellates, acritarchs, and pollen and spores. Fossil fruits (e.g., *Wetherellia*) and wood are relatively abundant in the upper Nanjemoy (Tiffany, 1984).

Chesapeake Group

Unconformably overlying the Pamunkey Group are the gray-green silty clays and sands and diatomaceous clays of the Miocene Chesapeake Group. Only the Calvert and Choptank Formations are present in the Oak Grove core; the younger St. Marys and Yorktown Formations are absent at the corehole location. A general correlation of these Virginia Coastal Plain units with coeval rocks from New Jersey to Alabama is presented in Text-fig. 5.



Text-fig. 5. General correlation chart of Miocene (Burdigalian-Tortonian) age coastal plain formations from New Jersey to Alabama. (Modified from Ward, 1984.)

Calvert Formation

The Calvert Formation, which unconformably overlies the Nanjemoy Formation (and other older units), was named for the Calvert Cliffs, Calvert County, Maryland. Outcrops extend from northern Prince Georges County, Maryland, to Petersburg, Virginia. The strike of the unit is north, and the dip is east at about 1.9 m/km (10 ft/mi). The formation, approximately 60 m (200 ft) thick, is divided into two members, separated by an unconformity. The Fairhaven Member (lower unit) is a sequence of olive gray-green, fine clayey sands and silts, with a distinctive diatomaceous silt or clay near the middle. The Plum Point Marls Member (upper unit) consists of olive green, fine clayey sands with dense, greenish-brown and bluish-gray, silty and sandy clay beds.

Mollusks, brachiopods, shark teeth, marine vertebrate bone fragments, and conifer and angiosperm plants comprise most of the megafossil assemblage. Included among the microfossils are diatoms, sparse foraminifers, radiolaria, dinoflagellates, acritarchs, chlorophytes, spores, and abundant pollen.

Choptank Formation

The Choptank Formation, which conformably overlies the Calvert Formation, was named for the Choptank River, Talbot County, Maryland. The best exposures are in the Calvert Cliffs between Parker Creek and

Cove Point, and the Boston Cliffs. Its strike and dip generally approximate that of the Calvert Formation. The unit, about 22.5 m (75 ft) thick, consists of dark green or blue, fine clayey silts and sands with two yellow or brown, shelly sand members. The formation is subdivided into five members (in ascending stratigraphic order): Calvert Beach, Drumcliff, St. Leonard, Boston Cliffs, and Canoy.

Megafossils include some vertebrates (e.g., whales, turtles, porpoises, crocodiles, shark teeth) and poorly preserved mollusks. Among the microfossils are sparse foraminifers, diatoms, dinoflagellates, and acritarchs, in addition to abundant pollen.

METHODS OF STUDY

Sampling Procedure

The Oak Grove Core was sampled at the U. S. Geological Survey National Center in Reston, Virginia. Each sample taken from the core was 6-8 cm (2.5-3.0 in) thick; the slice was then divided into four subsamples to be processed for the following microfossil groups: (1) foraminifers and ostracodes; (2) calcareous nannofossils; (3) diatoms; and (4) dinoflagellates, acritarchs, and chlorophytes, as well as pollen and spores. The samples were placed in plastic bags, sealed, and numbered. Numbers of the organic-walled phytoplankton samples are listed in the log of the Virginia Polytechnic Institute and State University Palynology Laboratory. Specific information and stratigraphic positions of the study samples are included in the section "Paleontological Samples from the Oak Grove Core".

Sample Preparation

All samples were processed using standard acid maceration techniques. Equal amounts of sediment were extracted from each sample bag and crushed. Sediments were then treated with concentrated hydrochloric acid and hydrofluoric acid (52%) to release the palynomorphs from the carbonate and silicate matrix, respectively.

The samples were subsequently oxidized with sodium hypochlorite (5%) to dissolve much of the organic debris and treated with ammonium hydroxide to eliminate oxidation products. At this point, the remaining sediments were sieved through a 20 micron mesh to remove as much of the clay-size fraction as possible. Palynomorphs were concentrated by centrifugation of the residues in zinc bromide (specific gravity = 2.0). To darken the typically pale, translucent palynomorphs for more effective micrography and photomicrography, the organic residues were acetolyzed with sulfuric acid and acetic anhydride. Finally, slides were prepared using glycerine jelly as the mounting medium.

Analytical Procedures

Slides prepared from the 49 Tertiary samples collected from the Oak Grove core all contained palynomorphs, including organic-walled phytoplankton and pollen and spores. The dinoflagellate, acritarch, and chlorophyte species were analyzed with respect to their taxonomy, morphology, size range, intraspecific variability, numerical and relative abundances, stratigraphic distribution, and paleoenvironmental implications. Only general observations are included for the pollen and spore assemblages.

Measurements were made on numerous specimens of each of the organic-walled phytoplankton species. Size ranges are listed for morphological features such as the main body, processes, horns, and various ornaments. All dimensions are in micrometers (um).

In counting palynomorph specimens to determine the species numerical and relative abundances, at least two slides of each sample were used to preclude any possible single slide bias. A total of 300 dinoflagellate, acritarch, and chlorophyte specimens were counted for all but three of the samples used in this study; Shaw (1964) showed statistically that this number will reveal most of the species present. For Samples 319, 320, and 321 in the Marlboro Clay, specimens were extremely scarce and as a result only 10 were counted in each of these samples. Specimens of a particular species that were encountered during the course of the study but not observed in the count are indicated by the symbol (+) on Chart 3 (in back pocket). Categories of the species numerical and relative abundances are as follows:

Abundant:	more than 75 specimens (greater than 25 percent)
Common:	between 46 and 75 specimens (between 15 and 25 percent)
Sparse:	between 15 and 45 specimens (between 5 and 15 percent)

Rare:	between 3 and 14 specimens (between 1 and 5 percent)
Extremely rare:	less than 3 specimens (less than 1 percent)

Three biostratigraphic distribution charts have been prepared: (1) range bases of the species in ascending order; (2) range tops of the species in descending order; and (3) numerical abundances of the species arranged in alphabetical order (see Charts 1, 2, and 3; in back pocket). The charts were generated on a PALPLOT program at the Unocal Research Center, Brea, California.

Various statistical techniques were also used in analyzing the assemblages for paleoecological purposes. Species diversity (richness, Shannon-Wiener index, and evenness) curves were plotted. In addition, cluster analysis and principal coordinates analysis were run using PROCDENDRO and PROCPCOORD computer programs within the Ecological Analysis Package provided to Unocal Research by R. W. Smith of Ecological Data Analysis, Ojai, California. All of these numerical techniques are described in the section "Paleoenvironmental Implications: Statistical Methods".

Location of Specimens

All slides are stored in the Virginia Polytechnic Institute and State University Palynological Laboratory (VPISUPL). The sample and slide numbers are engraved on the left side of the slide. Specimen locations are coordinated in millimeters to the right (R), and above (+), the lower left corner of the cover slip. For example, a specimen with coordinates (R10.5;+5.5) would be located 10.5 mm to the right of the lower left corner of the cover slip and 5.5 mm above it.

Microscopy and Photomicrography

An Olympus Vanox microscope was used to study the palynomorphs. Plan-apochromatic objectives were employed in brightfield illumination. Nomarski interference contrast illumination was occasionally used to better resolve the more lightly stained and/or low relief specimens.

Specimens were photographed with the Olympus PM-10A camera system, using Kodak High Contrast Copy Film. The film was developed in Kodak D-19 developer, for five minutes at 21 degrees C (70 degrees F). Prints were made on Kodak Polycontrast Rapid F-RC paper (medium weight), using filters to adjust the contrast.

OAK GROVE, VIRGINIA, COREHOLE AND ASSOCIATED STUDY LOCALITIES

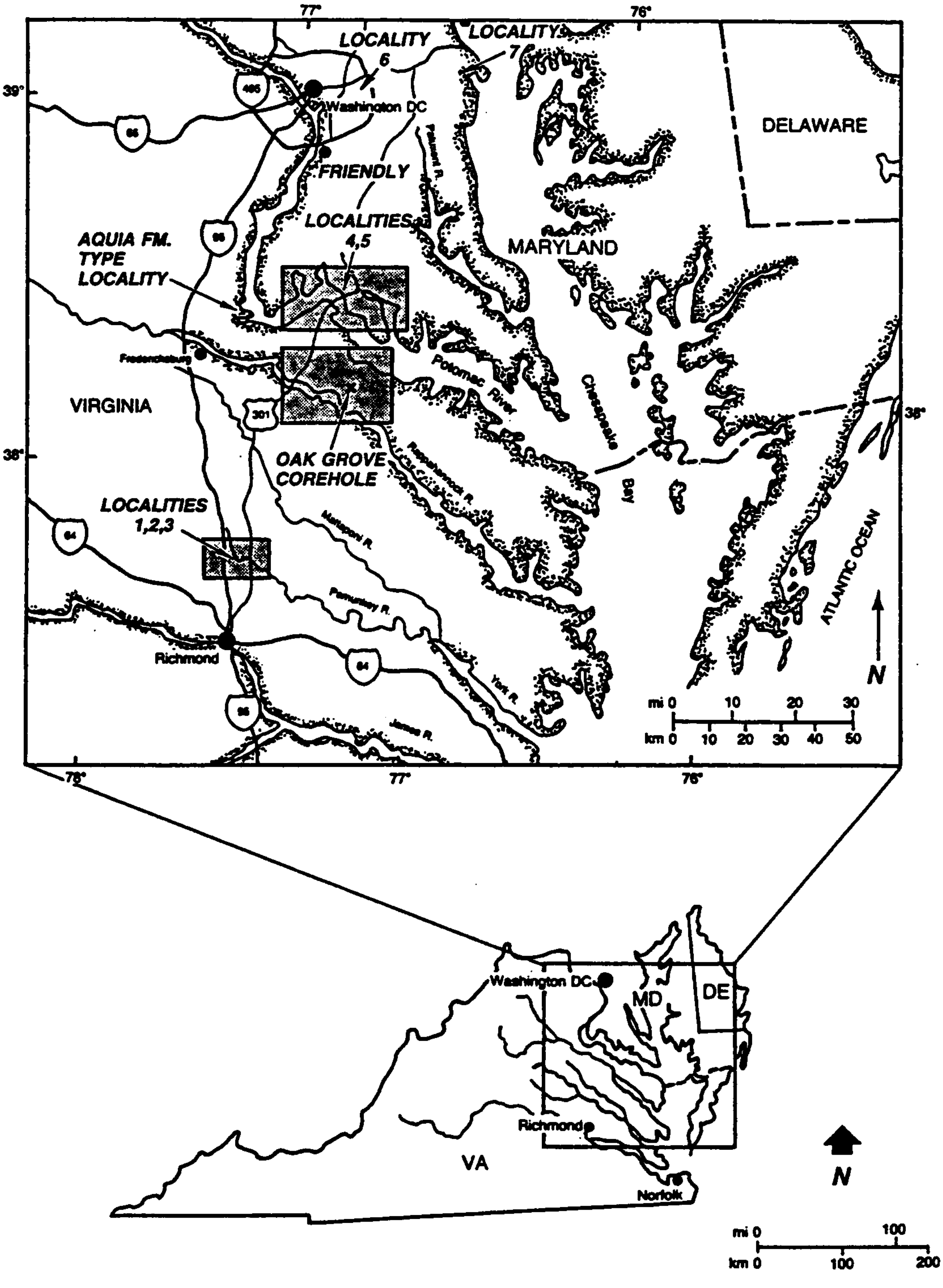
Location and Depth of the Oak Grove Corehole

The Oak Grove corehole, located 3.9 km (2.4 mi) west-southwest of Oak Grove, Westmoreland County, Virginia, near the junction of Virginia Routes 634, 636, and 637, was drilled as a continuously cored stratigraphic test hole between March and May of 1976 by the U. S. Army Corps of Engineers (under contract to the U. S. Geological Survey). Text-fig. 6 shows the general location of the corehole in the Virginia-Maryland Coastal Plain setting; the detailed map in Text-fig. 7 indicates its specific location. Its geographical coordinates are 38°, 10', 0" N. Latitude and 77°, 2', 31" W. Longitude on the U. S. Geological Survey Rollins Fork, Virginia, Quadrangle Map (7.5 minute series).

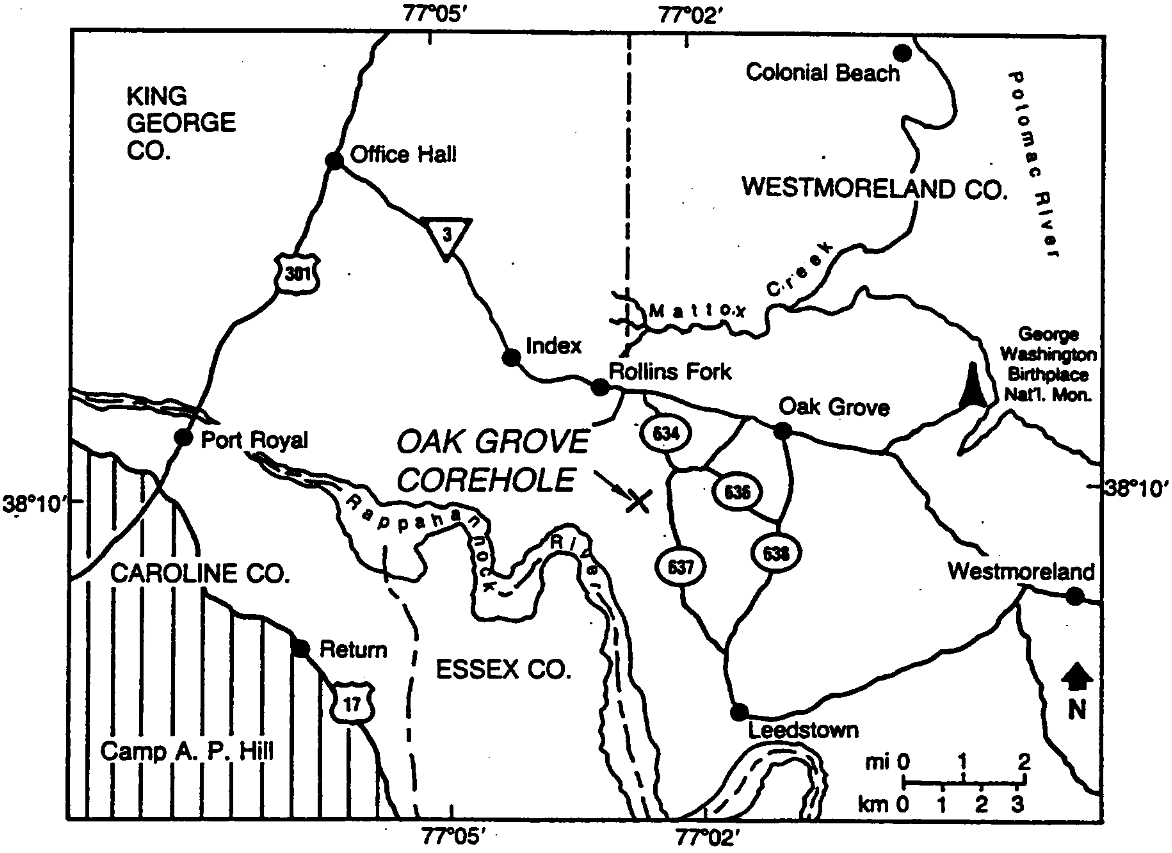
The well head of the Oak Grove corehole is at an elevation of 54.8 m (180 ft) above sea level. A continuous core was drilled from a depth of 24.4 m (80 ft) to 420.6 m (1379.6 ft) below the well head, bottoming out in the Lower Cretaceous Potomac Group.

Lithostratigraphy of the Oak Grove Core

In general, the arkosic Potomac Group (Lower Cretaceous) is disconformably overlain by the glauconitic Pamunkey Group (Paleocene



Text-fig. 6. Map of the Virginia-Maryland Coastal Plain showing the locations of the Oak Grove corehole and associated studies (Aquia Fm. type section, Friendly, Md. section, and Localities 1-7). See Text-figs. 7 and 9 for detailed maps of stippled areas.



Text-fig. 7. Detailed map showing the location of the Oak Grove corehole.

and Eocene), with the Cretaceous-Tertiary boundary encountered at a depth of 138.9 m (455.9 ft) below the well head. Disconformably overlying the Pamunkey Group is the siliceous Chesapeake Group (Miocene). The uppermost unit in this region, the Upland Gravels (Miocene?-Pliocene), was not cored.

Aquia Formation lithology, consisting of essentially medium to dark green, thick bedded, well sorted, glauconitic silts and sands with some shelly beds, is reported from the Cretaceous-Tertiary contact up to a depth of 103.6 m (339.9 ft) below the well head. Most of the sediments analyzed contained less than 10% clay (predominantly illite). Two relatively thin, carbonate-cemented beds occur between 117.3 m (384.9 ft) and 118.8 m (389.8 ft). Mollusk shells are appreciably weathered and only the large bivalves and the gastropod *Turritella mortoni* are preserved. Much of the Aquia has been bioturbated, but evidence of definite burrowing is lacking. Although there appears to be no lithologic differentiation, the lowermost 11.5 m (37.9 ft) could conceivably be of Danian age based on certain dinoflagellate and pollen species. This interval has been designated Brightseat equivalent-basal Aquia? strata in this study (for discussion see the section "Palynological Biostratigraphy: Ages of the Formations").

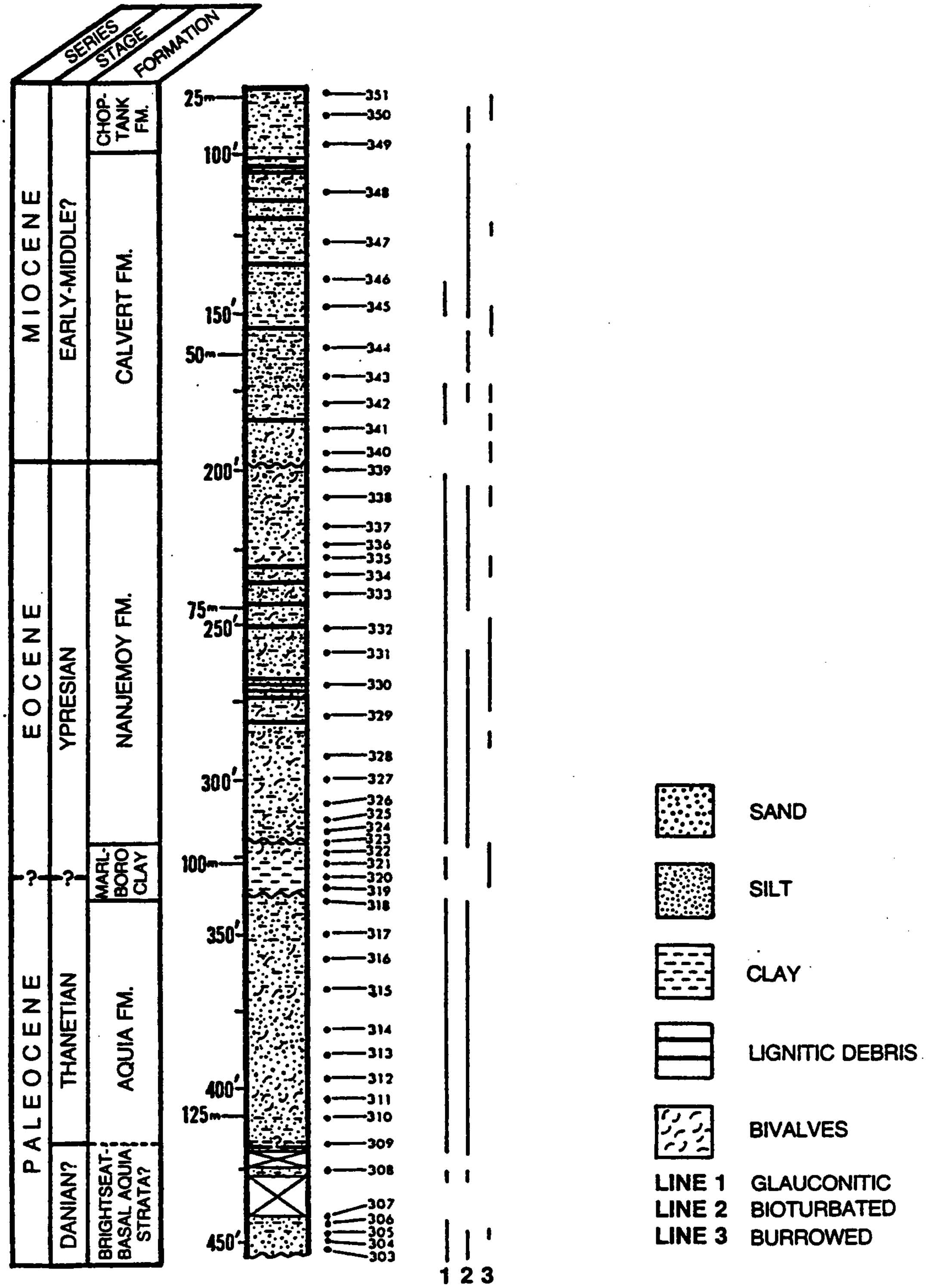
The Marlboro Clay unit extends from a depth below the well head of 103.6 m (339.8 ft) to 98.2 m (322.2 ft), and consists of predominantly brownish clays with mixed reddish and grayish hues. The clay is essentially of a kaolinitic-illitic composition. Although much of the unit reveals no structure, some cross lamination of the clay is visible, as well as distorted bedding suggestive of bioturbation. The lower contact with the Aquia Formation has been described as gradational, with a transition over a 10 cm interval from medium and fine glauconitic sand containing rounded clay clasts, through clays with sand pods and stringers, into massive, faintly laminated red clay (see Text-fig. 5A of Reinhardt et al., 1980). Palynomorph assemblages recovered from samples taken above and below this interval reflect an apparent sudden and distinct environmental change with a possible hiatus of some extent (see the section "Palynological Biostratigraphy: Relation to the Formation and Member Contacts" for further discussion of this boundary). The upper contact with the Nanjemoy Formation is relatively sharp; the upper two meters of the Marlboro Clay are extensively burrowed (with Nanjemoy glauconitic sands filling the burrows) obscuring much of the contact.

The variably clayey, dark greenish gray to greenish black, fine to medium (some coarse) grained, glauconitic sands of the Nanjemoy Formation range from 98.2 m (322.2 ft) to 60.8 m (199.5 ft) below the well head. Study of the lithologic log reveals a basal clayey silt overlain by 10 m and 18 m coarsening upward sequences (from silty clays to fine sands). The clay content in the Nanjemoy ranges from a low of about 15% by weight to as much as 80% in the clayey beds and is primarily illite. Bedding in this unit is predominantly thick to massive. In addition to shells, lignitic debris and fish scales are locally concentrated along bedding planes. Clay clasts are found throughout the Nanjemoy. Evidence of burrowing is more apparent in the Nanjemoy than in the Aquia sediments. The uppermost Nanjemoy strata appear weathered and shell-leached, and are coarser, better sorted, and more micaceous than the overlying Calvert strata.

Disconformably overlying the Nanjemoy Formation is the Calvert Formation, consisting of predominantly grayish to olive green, fine sands with some clays and diatomaceous clay beds; it extends from a depth of 60.8 m (199.5 ft) to 30.5 m (100.1 ft) below the well head. The basal 3 m (10 ft) are comprised of a poorly sorted sand with quartz grains and phosphatic shell fragments in a fine grained matrix; some small scale erosional contacts are evident. A highly diatomaceous interval (part of the uppermost Fairhaven Member) occurs from a depth of 57.8 M (190 ft) to 54.8 m (180 ft). The Calvert sediments are bioturbated throughout, with some burrowed horizons. Lignitic debris is most prevalent in the uppermost 10 m (33 ft). The clay is mainly illitic (53-81%), but it must be noted that these percentages are considerably higher than equivalent sediments analyzed from Calvert County, Maryland.

Conformably overlying the Calvert Formation are the dark greenish gray, clayey silts of the Choptank Formation from a depth of 30.5 m (100.1 ft) to 24.4 m (80 ft) below the well head. Although much of the unit is bioturbated, some burrows were observed in the upper 1.5 m (5 ft). The clay is predominantly illite (about 50%).

A columnar section of the Oak Grove core is depicted in Text-fig. 8. Much of the sedimentological information presented in this study



Text-fig. 8. Columnar section of the Oak Grove core Tertiary strata.

is based on the lithostratigraphic report by Reinhardt et al. (1980b) and the lithologic log prepared by Estabrook and Reinhardt (1980).

Paleontological Samples from the Oak Grove Core

Of a total of 155 samples collected in the Tertiary section of the core for all microfossil groups and mollusks, forty-nine samples were chosen in this study to be processed for analysis of the organic-walled phytoplankton microfossils. Most sample intervals are 3 to 4 m (10 to 13 ft), with somewhat closer spacing in the lower part of the Brightseat equivalent-basal Aquia? strata and in the Marlboro Clay. Samples were selected as close as possible to the formational boundaries. Sixteen samples are from the 35.3 m (116.1 ft) of the Brightseat equivalent-basal Aquia? and Aquia strata, five from the 5.4 m (17.6 ft) of the Marlboro Clay, sixteen from the 37.4 m (122.7 ft) of the Nanjemoy strata, and twelve from the 36.4 m (119.5 ft) of the Calvert and Choptank strata.

Stratigraphic positions of the samples used in this study are shown on the columnar section in Text-fig. 8. Depths below the well head in both meters (m) and feet (ft) for each sample are listed in Table 1.

Paleontological Studies of the Oak Grove Core

The microfossil and megafossil investigations conducted on the Tertiary strata of the Oak Grove core have been summarized in Gibson et al. (1980). The nine paleontologists involved in these studies are listed in Table 2.

The interval designated Brightseat equivalent-basal Aquia? strata in this study contains only dinoflagellates, acritarchs, chlorophytes, pollen and spores. Recovered from the Aquia Formation were dinoflagellates, acritarchs, chlorophytes, pollen, spores, calcareous nannofossils, planktonic and benthonic foraminifers, and ostracodes. The Marlboro Clay yielded dinoflagellates, acritarchs, chlorophytes, pollen, spores, freshwater algae, agglutinated foraminifers, and some small mollusks. In the Nanjemoy Formation, dinoflagellates, acritarchs, chlorophytes, pollen, spores, calcareous nannofossils, ostracodes, planktonic and benthonic foraminifers, and mollusks (pelecypods and gastropods) were recovered. The Calvert and Choptank Formations produced dinoflagellates, acritarchs, chlorophytes, pollen, spores, diatoms, and radiolarians; marine vertebrate bone fragments, shark teeth, plant fragments, and broken phosphatic brachiopods were also found in these units.

Table 1. List of the 49 samples processed and analyzed from the Oak Grove core Tertiary strata with their depths below the well head in meters (m) and feet (ft).

VPISUPL SAMPLE NO.	DEPTHS		VPISUPL SAMPLE NO.	DEPTHS	
	(M)	(FT)		(M)	(FT)
303	138.9	455.8	328	88.7	291.0
304	138.3	453.8	329	85.0	279.0
305	137.1	449.8	330	83.1	272.7
306	135.9	445.8	331	79.6	261.0
307	134.9	442.5	332	76.8	252.0
308	130.3	427.5	333	73.5	241.1
309	127.6	418.5	334	72.1	236.5
310	125.9	413.0	335	70.4	231.0
311	124.3	409.7	336	68.9	226.0
312	121.3	398.0	337	67.1	220.0
313	118.0	387.2	338	63.7	209.0
314	116.1	381.0	339	61.1	200.5
315	112.3	368.5	340	60.4	198.0
316	109.9	360.5	341	57.6	189.0
317	107.0	351.0	342	55.4	181.8
318	103.9	340.8	343	52.1	171.0
319	103.5	339.5	344	49.6	162.8
320	102.1	335.0	345	45.4	149.0
321	100.4	329.5	346	42.4	139.0
322	99.1	325.0	347	38.4	126.0
323	98.4	323.0	348	33.9	111.2
324	98.1	322.0	349	29.3	96.0
325	97.3	319.3	350	26.8	88.0
326	95.2	312.1	351	24.4	80.0
327	91.4	300.0			

Table 2. List of the nine U. S. Geological Survey and university paleontologists (with specific disciplines) involved in studies of the Oak Grove core Tertiary strata.

PALEONTOLOGIST	AFFILIATION	SPECIALTY
ANDREWS, G. W.	U.S. GEOLOGICAL SURVEY WASHINGTON, D.C.	DIATOMS (MIOCENE)
BYBELL, L. M.	U.S. GEOLOGICAL SURVEY WASHINGTON, D.C.	CALCAREOUS NANNOFOSSILS (PALEOCENE AND EOCENE)
FREDERIKSEN, N. O.	U.S. GEOLOGICAL SURVEY RESTON, VA.	POLLEN AND SPORES (PALEOCENE AND EOCENE)
GIBSON, T. G.	U.S. GEOLOGICAL SURVEY WASHINGTON, D.C.	FORAMINIFERS (PALEOCENE AND EOCENE)
HANSEN, T.	YALE UNIVERSITY NEW HAVEN, CT.	MOLLUSKS (EOCENE)
HAZEL, J. E.	U.S. GEOLOGICAL SURVEY WASHINGTON, D.C.[1]	OSTRACODES (PALEOCENE AND EOCENE)
McLEAN, D. M.	VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY BLACKSBURG, VA.	DINOFLAGELLATES AND ACRITARCHS (PALEOCENE, EOCENE, MIOCENE)
VAN NIEUWENHUISE, D. S.	UNIVERSITY OF SOUTH CAROLINA COLUMBIA, S.C.	OSTRACODES (PALEOCENE AND EOCENE)
WITMER, R. J.	U.S. GEOLOGICAL SURVEY MENLO PARK, CA.[2]	DINOFLAGELLATES AND ACRITARCHS (PALEOCENE, EOCENE, MIOCENE)

[1] PRESENTLY EMPLOYED AT AMOCO RESEARCH CENTER, TULSA, OK.

[2] PRESENTLY EMPLOYED AT UNOCAL RESEARCH CENTER, BREA, CA.

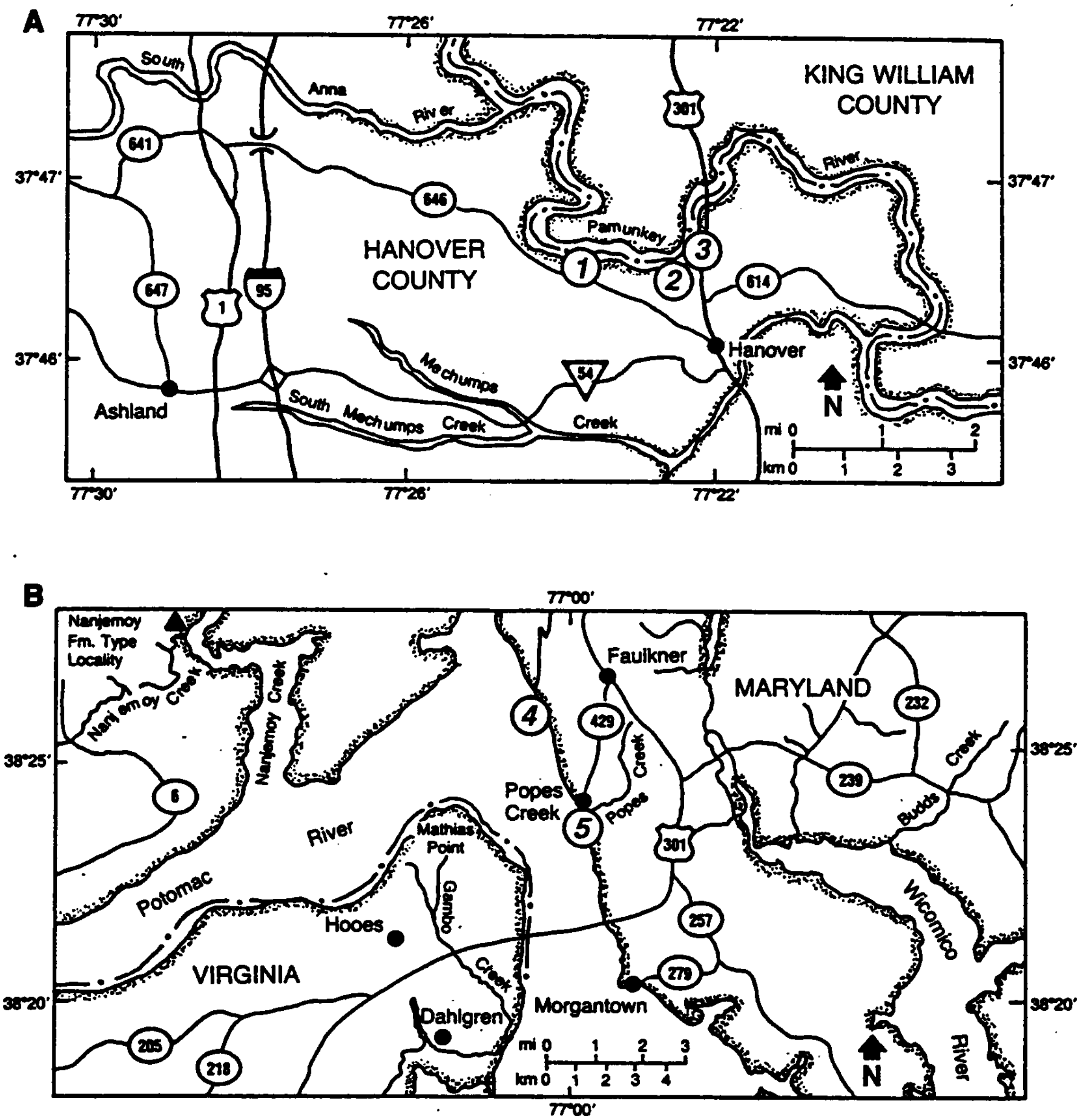
Associated Study Localities

Portions of the Tertiary strata of the Oak Grove core have been correlated with local outcrop localities on the Virginia-Maryland Coastal Plain based on dinoflagellate biostratigraphy. The following three studies were used in this correlation:

McLean (1971, p. 14-17)--Aquia Formation type locality and nearby Potomac Creek locality with sections of Aquia and Nanjemoy strata in Stafford County, Virginia, and locality near Friendly, Maryland, in Prince Georges County, Maryland, south of Washington, D. C., with section of Aquia strata (see general map in Text-fig. 6).

Witmer (1975, p. 10-13)--three localities with sections of Aquia, Marlboro Clay, Nanjemoy, and St. Marys strata in Hanover County, Virginia, just north of Richmond (see Localities 1, 2, and 3 on general map in Text-fig. 6 and detailed map in Text-fig. 9(A).

Goodman (1975, p. 15-17)--two localities with sections of Nanjemoy and Calvert strata in Charles County, Maryland, south of Washington, D. C. (see Localities 4 and 5 on general map in Text-fig. 6 and detailed map in Text-fig. 9(B).



Text-fig. 9. Detailed maps showing (A) Localities 1, 2, and 3 and (B) Localities 4 and 5.

Brief references are also made in this investigation to two studies of Maryland Coastal Plain outcrop localities and a study on a core drilled on the Georgia Coastal Plain:

Whitney (1976, p. 20-23)--Brightseat Formation type locality and nearby localities with sections of Brightseat strata in Prince Georges County, Maryland, east of Washington, D. C. (see composite Locality 6 on general map in Text-fig. 6).

Benson (1976, p. 174-175)--locality with section of Brightseat strata resting atop the Cretaceous - Tertiary unconformity at Round Bay, Maryland, Anne Arundel County, Maryland, east of Washington, D. C. (see Locality 7 on general map in Text-fig. 6).

Firth (1984, p. 31)--section of Lower Clayton (Danian) strata from the U.S.G.S. Albany corehole located in eastern Dougherty County, Georgia (lat. 31^{o}, 31', 05" N.; long. 84^{o}, 06', 42" W. on Albany East 7.5 min. series quadrangle map).

RESULTS OF THE PALYNOLOGICAL INVESTIGATION OF THE OAK GROVE CORE

Palynological Biostratigraphy

A. General Distribution

Because the primary concern of this investigation centers on organic-walled phytoplankton, specifically dinoflagellates, acritarchs, and chlorophytes, the land-derived palynomorphs which are part of the total sample residue have not been studied in detail. General comments pertaining to the observed land plant pollen and spore assemblages, however, are presented in the section "Systematic Palynology: Pollen and Spores". The pollen and spore biostratigraphy has been documented by Frederiksen in Gibson et al. (1980) for much of the Aquia, Marlboro Clay, and Nanjemoy strata of the core (see species diversity curve included in Text-fig. 14 and range chart in Appendix II(A) of the present study).

Any calcareous and siliceous phytoplankton present in the sediments sampled were dissolved by the chemical maceration process required to extract the organic-walled cysts. Most samples, except those in the Marlboro Clay, contained some microforaminiferal chamber linings.

The biostratigraphic distribution of the species of dinoflagellates, acritarchs, and chlorophytes are recorded on Charts

1, 2, and 3 (in back pocket). The species are ordered with range bases in ascending order on Chart 1 and range tops in descending order on Chart 2. Numerical abundances are listed for all species which are alphabetically ordered on Chart 3. Species diversity curves are included in Text-fig. 14.

Species restricted to strata of a particular formation in the Oak Grove core are listed below. The number of species occurring for the first or last time within the lithologic units is also noted. These distributions are from a single locality, and in many cases may represent only local biostratigraphic ranges. Because of some ambiguity in distinguishing the lithologic contacts between the members of the Aquia (Piscataway and Paspotansa) and Nanjemoy (Potapaco and Woodstock) Formations in the Oak Grove core, palynomorph distributions are discussed below in the more general formation context.

Aquia strata

The following 47 species are restricted to these strata (or at least range no higher in the section; some are known from Cretaceous rocks elsewhere):

Alisocysta cf. *A. margarita*
Andalusiella rhombohedra
Apteodinium retiolum n. sp.
Ascostomocystis hydria
Batiacasphaera sp. A
Caligodinium amiculum
Cassidium paleocenicum n. sp.
Cladopyxidium saeptum

*Conneximura fimbriata**
Cordosphaeridium biarmatum
Cordosphaeridium giganteum n. sp.
Danea? sp.*
Deflandrea dartmooria
Fibradinium annetorpense
Fibrocysta paratabulata n. sp.
Fibrocysta rotunda n. sp.
Fibrocysta sp. A*
*Florentinia ferox**
Forma A
Fromea laevigata
Hafniasphaera cf. *H. septata*
Hystrichokolpoma mentitum
Hystrichosphaeridium cf. *H. tubiferum**
Impagidinium speciosum n. sp.
Impagidinium cf. *I. speciosum* n. sp.
Impagidinium sp. A
Isabelidinium cooksoniae
Micrhystridium cf. *M. fragile*
Micrhystridium cf. *M. variabile*
Nematosphaeropsis pertusa n. sp.
Nematosphaeropsis cf. *N. pertusa* n. sp.
*Oligosphaeridium complex**
Palaeoperidinium pyrophorum
Palambages sp. A
Phelodinium magnificum
Samlandia reticulifera subsp. *minor* n. subsp.
Spinidinium cf. *S. essoi*
Spiniferites cornutus subsp. A*
Spiniferites cornutus subsp. B*
Spiniferites cornutus subsp. C
Spiniferites crassipellis subsp. B
Spiniferites cf. *S. pterotus**
Spiniferites ramuliferus
Tanyosphaeridium variecalamum
Thalassiphora delicata
Turbiosphaera filosa
Xenikoon australis

Of the above listed species, those marked with an asterisk are restricted to the interval between Samples 303 and 309, which may be of Danian age, and is tentatively designated Brightseat equivalent-basal Aquia? strata (refer to the section "Palynological Biostratigraphy: Ages of the Formations").

Sixty species occur for the first time within the Aquia strata of the core (including those present in the basal sample, some of which are known to have ranges that extend into the Cretaceous elsewhere) and continue into the younger units.

Marlboro Clay strata

Only one species, *Apectodinium* sp. A, was found to be restricted to these sediments. The ranges of two species extending into older rocks terminate within these strata; no species occur for the first time in this unit and continue into younger sediments.

Nanjemoy strata

A total of 47 species were found to be restricted to these strata in the core. They include the following:

Achilleodinium biformoides
Adnatosphaeridium multispinosum-vittatum complex
Apteodinium australiense
Areoligera spp. complex
Biconidinium longissimum
Cordosphaeridium inodes subsp. *robustum*
Cordosphaeridium solaster
Deflandrea wardenensis
Dinopterygium cladoides
Dinopterygium fehmarnense
Fibrocysta coalitospinosa n. sp.
Fibrocysta cf. *F. lappacea*
Forma B
Forma C

Forma D
Glaphyrocysta ordinata
Glaphyrocysta sp. B
Heteraulacacysta campanula
Homotryblium caliculum
Homotryblium pallidum-tenuispinosum complex
Homotryblium tasmaniense
Hystrichokolpoma eisenackii
Impletosphaeridium kroemmelbeinii
Kisselovia coleothrypta
Membranilarnacia leptoderma
Muratodinium fimbriatum
Operculodinium brevispinosum n. sp.
Operculodinium cf. *O. brevispinosum* n. sp.
Operculodinium israelianum
Palambages sp. B
Paucisphaeridium inversibuccinum
Phthanoperidinium echinatum
Phthanoperidinium cf. *P. tritonium*
Polysphaeridium cf. *P. zoharyi*
Renidinium? sp. A
Samlandia chlamydophora
Senagalinium? asymmetricum
Spinidinium macmurdoense
Spinidinium paratabulatum n. sp.
Spiniferites sp. A
Tubidermodinium sulcatum
Wetzeliella hampdenensis
Wetzeliella lunaris
Wetzeliella samlandica
Wetzeliella varielongituda
Wetzeliella sp. A
Wilsonidium tabulatum

Twelve species appear for the first time in the Nanjemoy Formation and range into younger units, and 45 species ranging into older sediments terminate within this unit.

Calvert strata

Five species were recovered from only these strata:

Chiropteridium partispinatum
Cordosphaeridium? amputatospinosum n. sp.
Cyclopsiella elliptica
Forma E
Pentadinium laticinctum subsp. *granulatum*

Ten species have first occurrences within these strata and range higher in the section; nine species with ranges into older units terminate within these strata.

Choptank strata

Only two species are restricted to these sediments:

Lejeunecysta sp. A
Impagidinium sp. B

Twenty-seven other species range into this uppermost unit of the core from older rocks.

B. Ages of the Formations

The entire Pamunkey Group was considered to be of Eocene age (Clark and Martin, 1901; Shifflett, 1948) until Loeblich and Tappan (1957) assigned a Late Paleocene (Sparnacian) age to the Aquia Formation and an Early Eocene (Ypresian) age to the Nanjemoy Formation based on planktonic Foraminifera. Later studies by Berggren (1965) corroborated these age determinations. Hazel (1969, 1984), Hansen (1977), and Bybell and Govoni (1977) have suggested that the base of the Aquia Formation is early Late Paleocene (Selandian) in age, and not late Early Paleocene as postulated by Nogan (1964).

The ages of each of the lithologic units in the Tertiary section of the Oak Grove core as suggested by the biostratigraphic distribution of the dinoflagellate, acritarch, and chlorophyte species are discussed below. The reference ranges of those species used in dating the units have been taken from numerous published studies worldwide. Ages of the units as indicated by the other fossil groups studied in the core are also noted (the reader is referred to Appendix II for range charts of (A) pollen and spores, (B) benthonic foraminifers, (C) calcareous nannofossils, and (D) mollusks prepared by other paleontologists).

Aquia strata

The basal strata of the core from Samples 303 to 309 (base to about 127.6 m (418.5 ft)) may be Early Paleocene (Danian) in age, based primarily on the presence of *Palaeoperidinium pyrophorum* (range generally considered Cretaceous to Danian); a tentatively assigned *Danea?* sp., which may be related to the Danian age *Danea californica*, was also observed in this section of the core. Neither of these forms, nor any of the following taxa also recovered in this interval of the Oak Grove core, were recorded in the basal Aquia by either McLean (1971) at the Aquia Formation type locality or by Witmer (1975) at localities near Richmond, Virginia:

Conneximura fimbriata
Florentinia ferox
Forma A
Isabelidinium cooksoniae
Oligosphaeridium complex
Palambages sp. A
Tanyosphaeridium variecalamum

Species ranging no higher than this basal Oak Grove core interval that have also been reported from various Danian age coastal plain sections include:

Danian Brightseat Fm., Maryland (Whitney, 1976, 1984):

Florentinia ferox (as *F. laciniata*)
Forma A
Palaeoperidinium pyrophorum

Danian Brightseat Fm., Maryland (Benson, 1976):

Palaeoperidinium pyrophorum (as *P. basilium*)
Spiniferites cornutus subsp. A (as *S.* cf. *S. cornutus*)
Tanyosphaeridium variecalamum

Danian Clayton Fm., Georgia (Firth, 1984):

Conneximura fimbriata
Spiniferites cornutus subsp. A
Tanyosphaeridium variecalamum

A number of dinoflagellate species are common to this basal Tertiary Oak Grove core section, an Upper Danian unit near Linhamn in southern Sweden studied by DeConinck (1975), and Danian sections in northern Europe investigated by Morgenroth (1968). Species found in both the basal Tertiary core interval and the Swedish unit include:

Danea? sp. *(?= D. mutabilis (=D. californica))*
Fibradinium annetorpense
Florentinia ferox (=Silicisphaera ferox)
Glaphyrocysta exuberans complex *(=Cyclonephelium reticulosum)*
Oligosphaeridium complex
Palaeoperidinium pyrophorum
Palambages sp. A (?=*Palambages* sp.)

Those species common to both the Oak Grove core section and Morgenroth's (1968) Danian section include:

Cladopyxidium saeptum (=Microdinium saeptum)
Conneximura fimbriata (=Hystrichokolpoma? fimbriata)
Danea? sp. *(?=D. mutabilis (=D. californica))*
Fibradinium annetorpense

In a recent study of a Paleocene core in Denmark, however, Heilmann-Clausen (1985) reports at least four of the species restricted to this lowermost Tertiary section in the Oak Grove core as ranging into Selandian (=Thanetian) age sediments, further complicating the issue of the age of this basal Aquia? interval. The species include:

Conneximura fimbriata
Florentinia ferox
Palaeoperidinium pyrophorum
Tanyosphaeridium variecalamum (as *T. xanthiopyxides*)

Both Foraminifera and calcareous nannofossils are absent in this lower section of the core. The pollen and spore assemblages, reported by Frederiksen in Gibson et al. (1980), present somewhat conflicting evidence for the age of this interval. *Choanopollenites conspicuus* (Groot and Groot) Tschudy, known only from Lower Paleocene rocks of the Gulf Coast and the Lower Paleocene Brightseat Formation of Maryland, was recovered in one sample in this basal section. Pollen species typically found in Lower Paleocene strata of the Atlantic and Gulf of Mexico Coastal Plains, however, were not observed in the Oak Grove core. *Carya* pollen, with a known lower range limit of mid Upper Paleocene, was found in the core from a depth of 137.6 m (451 ft) up into the Nanjemoy Formation; Frederiksen points out tha *Carya* could conceivably range lower in the section in Virginia than farther south. Based on sporomorphs, a tentative Danian age is suggested for this basal section.

On the basis of the foregoing discussion, these lowermost sediments in the core will be tentatively referred to as Brightseat equivalent-basal Aquia? strata. If these lowermost strata are in fact part of the Aquia Formation, the basal Aquia may actually be Danian (probably uppermost?) in age in certain areas. That the assemblages in this interval are lowermost Thanetian, based on dinoflagellate biostratigraphy presented in the recent Danish publication by Heilmann-Clausen (1985), cannot be ruled out.

The remainder of the Aquia strata from Samples 310 to 318 (approximately 125.9 m (413 ft) to 103 m (340.9 ft)) appears to be Late Paleocene (Thanetian) in age based on dinoflagellate ranges. The following species, not known to range into younger than Thanetian units elsewhere, occur for the last time in this section of strata:

Cladopyxidium saeptum
Fibradinium annetorpense
Phelodinium magnificum
Xenikoon australis

Those species which first appear in this section and reportedly range no older than Thanetian in age include:

Adnatosphaeridium robustum
Apectodinium homomorphum complex
Deflandrea phosphoritica
Eocladopyxis peniculata

Heilmann-Clausen (1985) recently reported on a diverse dinoflagellate assemblage from a cored Selandian (=Thanetian) age section in Denmark. Among the numerous species that are in common with, but not necessarily restricted to, the Aquia strata of the Oak Grove core are:

Adnatosphaeridium robustum
Alisocysta cf. *A. margarita (?=Alisocysta* sp. 1)
Apectodinium homomorphum complex
  (as *A. homomorphum/hyperacanthum/quinquelatum)*
Caligodinium saeptum (as *C. aceras)*
Cladopyxidium saeptum
Deflandrea dartmooria (?=Ceratiopsis speciosa)
Elytrocysta densobaculata n. sp./obscurotabulata n. sp.
  (?=*Membranosphaera* sp. B)
Fibradinium annetorpense
Fromea laevigata
Glaphyrocysta exuberans complex *(?=G. pastielsii)*
Glaphyrocysta sp. A *(?=G. ordinata)*
Hafniasphaera septata
Hystrichosphaeridium tubiferum
Inversidinium exilimurum (as *Palaeotetradinium minusculum)*
Kallosphaeridium brevibarbatum
Lingulodinium machaerophorum
Microdinium ornatum

Spiniferites crassipellis (as *Achomosphaera crassipellis)*
Thalassiphora delicata
Xenikoon australis (as Insertae sedis 1)

Numerous dinoflagellate species recovered from the Oak Grove core Aquia have also been documented by Edwards (1980) in Upper Paleocene (Thanetian) age Gulf of Mexico Coastal Plain units, such as the Nanafalia and Tuscahoma Formations (NP-7 through NP-9 Zones). The order of first and last occurrences of some taxa, however, vary between the two areas.

Other microfossil groups studied in this section of the Oak Grove core include ostracodes, calcareous nannoplankton, and Foraminifera. Ostracode assemblages from 123 m (403.6 ft) to 103.6 m (339.9 ft) all fall within the Thanetian range zone of *Haplocytheridea leei* (Hazel and van Nieuwenhuise in Gibson et al., 1980). The Thanetian foraminiferal zone P-4 was recognized from a depth of 117.2 m (384.5 ft) to 115.4 m (378.6 ft) by Gibson in Gibson et al. (1980). The Thanetian calcareous nannoplankton zones NP-5 through NP-9 were recorded from a depth of 125.9 m (413.1 ft) to the top of the Aquia strata (Bybell in Gibson et al., 1980). Pollen and spore distributions suggest a Late Paleocene age for this section of the core (Frederiksen in Gibson et al., 1980).

Marlboro Clay

Dinoflagellate biostratigraphic distribution does not reveal the specific age of the Marlboro Clay. The concurrent presence in the unit of the following species suggest it could be either Thanetian or Ypresian in age, or perhaps straddle the boundary:

Apectodinium homomorphum complex
Horologinella apiculata
Hystrichokolpoma unispinum
Kallosphaeridium brevibarbatum
Senagalinium? dilwynense

The ranges of other species reported in sediments no younger than Thanetian in age elsewhere terminate before reaching the Marlboro Clay in the core, and the ranges of those species reportedly extending into rocks no older than Ypresian in age begin above the unit. The age of the Marlboro Clay, based on dinoflagellates, therefore remains questionable.

No calcareous nannofossils were recovered from the Marlboro Clay. The agglutinated Foraminifera could not be used as age indicative, as their ranges reported from other regions are poorly understood. The ranges of certain pollen suggest the Paleocene-Eocene boundary may lie within the Marlboro Clay (possibly midway in these strata). The range of *Momipites* sp. (known to range to the top of the Paleocene elsewhere) terminates at 102.1 m (334.9 ft), whereas that of *Platycarya* sp. (not found in sediments older than Early Eocene in the southeastern U. S. and Rocky Mts.) begins at 98.8 m (324.2 ft). The Early

Eocene *Platycarya swastocoida* is first found in the lowermost Nanjemoy strata of the core (Frederiksen in Gibson et al., 1980).

Nanjemoy strata

The distribution of dinoflagellate species supports an Early Eocene (Ypresian) age for the Nanjemoy strata in the Oak Grove core. Species restricted to the Nanjemoy which have been previously recorded from other areas in only Early Eocene units include:

Cordosphaeridium inodes subsp. *robustum*
Cordosphaeridium solaster
Tubidermodinium sulcatum

The following species not reported from older than Ypresian sediments elsewhere begin their ranges in the lower to middle part of the Nanjemoy strata in the core:

Achilleodinium biformoides
Adnatosphaeridium multispinosum-vittatum complex
Apteodinium australiense
Deflandrea wardenensis
Dinopterygium fehmarnense
Heteraulacacysta campanula
Homotryblium pallidum-tenuispinosum complex
Hystrichokolpoma eisenackii
Kisselovia coleothrypta
Melitasphaeridium pseudorecurvatum
Millioudodinium giuseppei subsp. *major*
Nematosphaeropsis pusulosa
Paucisphaeridium inversibuccinum
Phthanoperidinium echinatum
Polysphaeridium zoharyi
Samlandia chlamydophora
Tectatodinium pellitum
Wetzeliella hampdenensis
Wetzeliella lunaris

Wetzeliella samlandica
Wilsonidium tabulatum

Species with ranges terminating in the middle to upper part of the Nanjemoy strata of the core that have not been found elsewhere in rocks younger than Ypresian in age include:

Adnatosphaeridium robustum
Hafniasphaera septata
Hystrichosphaeridium tubiferum
Kallosphaeridium brevibarbatum
Microdinium ornatum
Spiniferites ramosus subsp. *multibrevis*

Species which are common to both the Nanjemoy strata of the core and at least one of the Lower Eocene stratigraphic sections from Europe of offshore Canada (see the section "Biostratigraphic Correlation: Oak Grove Core and European Sections/Offshore Eastern Canada Sections" for specific studies) include the following:

Achilleodinium biformoides
Adnatosphaeridium multispinosum-vittatum complex
Apectodinium homomorphum complex
Apteodinium australiense
Cordosphaeridium? callosum
Cordosphaeridium fibrospinosum
Cordosphaeridium inodes
Cordosphaeridium inodes subsp. *robustum*
Cordosphaeridium multispinosum
Cordosphaeridium solaster
Deflandrea phosphoritica
Deflandrea wardenensis
Dinopterygium cladoides
Dinopterygium fehmarnense
Diphyes colligerum
Eocladopyxis peniculata
Fibrocysta bipolare
Fibrocysta radiata
Glaphyrocysta ordinata
Homotryblium pallidum-tenuispinosum complex

Hystrichokolpoma eisenackii
Hystrichokolpoma rigaudiae
Hystrichosphaeridium tubiferum
Impletosphaeridium kroemmelbeinii
Impletosphaeridium rugosum
Kallosphaeridium brevibarbatum
Kisselovia coleothrypta
Lingulodinium machaerophorum
Melitasphaeridum pseudorecurvatum
Microdinium ornatum
Millioudodinium giuseppei subsp. *major*
Muratodinium fimbriatum
Operculodinium centrocarpum
Paleocystodinium golzowense
Polysphaeridium zoharyi
Rottnestia borussica
Samlandia chlamydophora
Spiniferites cingulatus
Spiniferites crassipellis
Spiniferites pseudofurcatus
Spiniferites ramosus subsp. *multibrevis*
Spiniferites ramosus subsp. *ramosus*
Systematophora placacantha
Tectatodinium pellitum
Thalassiphora pelagica
Tubidermodinium sulcatum
Wetzeliella samlandica
Wetzeliella varielongituda
Wilsonidium tabulatum

Assuming the boundary between the Potapaco and Woodstock Members of the Nanjemoy strata is at a subtle lithologic change near the 75 m (246 ft) level in the core (see the section "Palynological Biostratigraphy: Relation to the Formation and Member Contacts"), comparisons of dinoflagellate range distributions with European zones suggest more precise age assignments for these members. The Potapaco (lower unit) appears to be late Early Ypresian in age, whereas the Woodstock (upper unit) is most likely Middle to Late Ypresian in age (see the section "Biostratigraphic Correlation: Oak Grove Core and European Sections").

Also recovered from the Nanjemoy strata of the Oak Grove core were ostracodes, calcareous nannofossils, pollen and spores, Foraminifera, and mollusks. The ostracode assemblages studied by Hazel and van Nieuwenhuise (in Gibson et al., 1980) at a depth of 95 m (311.7 ft) indicate an early Early Eocene age for these strata. Ostracodes in the section from 87.5 m (287.1 ft) to 68 m (223.1 ft) suggest a latest Sabinian to Claibornian age (Early Eocene, Gulf Coast, U.S.A.). Calcareous nannofossils found from 98.1 m (322 ft) to 69.2 m (227 ft) indicate that these strata represent zones NP-10 through NP-12 of Ypresian age (Bybell in Gibson et al., 1980). Pollen (particularly juglandaceous types) and spore distribution supports an Early Eocene age for the Nanjemoy strata (Frederiksen in Gibson et al., 1980). Mollusks (especially oysters) indicate an Early Eocene age for most of the Nanjemoy sediments in the core, although the uppermost part could be as young as Middle Eocene (Hansen in Gibson et al., 1980). No age was reported for the Foraminifera.

Calvert/Choptank strata

Only a questionable Early to Middle Miocene age can be assigned to the Calvert and Choptank strata of the core based on dinoflagellate ranges. The following species with ranges beginning in the lower part of the Calvert sediments have not been recorded elsewhere in rocks older than Early Miocene:

Spiniferites mirabilis
Tuberculodinium vancampoae
Tuberculodinium? sp. (sensu Williams and Brideaux 1975)

Species which range into the uppermost Calvert strata or into the Choptank unit and suggest that these rocks may be as young as Middle Miocene in age include:

Cyclopsiella vieta
Palaeocystodinium golzowense
Pentadinium laticinctum subsp. *granulatum*
Polysphaeridium zoharyi

It must be noted that although *Polysphaeridium zoharyi* does not range into rocks younger than Middle Miocene in age on the Grand Banks, Newfoundland (Williams and Brideaux, 1975), it has been recorded by Wall (1967) in Quaternary sediments of the Caribbean Sea.

The presence of *Chiropteridium partispinatum* (range: Early Miocene) in the basal part of the Calvert strata and the occurrence of *Distatodinium paradoxum* (range: Middle Oligocene to Early Miocene) throughout these strata indicate that they may be entirely of Early Miocene age.

Andrews (in Gibson et al., 1980) reports two intervals within the Calvert strata of the Oak Grove core which contain diatoms previously recorded from the Calvert Formation at Calvert Cliffs, Maryland: (1) Shattuck's (1904) bed 3 of the Fairhaven Member (58.5 m (192 ft) to 53.4 m (175 ft)) with an age of late Early Miocene; and (2) beds 14 and 15 (39.9 m (131 ft) to 32.6 m (107 ft)) with an age of early Middle Miocene. Although these strata in the core are essentially barren of foraminifers, extrapolation from the Calvert Cliffs (Gibson in Gibson et al., 1980) would place them in planktonic Foraminifera zones N-8 through N-11 of Blow (1969).

One diatomaceous sample in the Choptank lithology of the Oak Grove core at a depth of 29.3 m (96 ft) yielded diatoms indicative of beds 18 and 19 of the Choptank Formation of the Chesapeake Bay region. Bracketing of an early Middle Miocene age for the underlying upper Calvert Formation and a late Middle Miocene K-Ar age for the overlying St. Marys Formation (Blackwelder and Ward, 1976) suggests an approximate middle Middle Miocene age for the Choptank Formation. The typically sparse Foraminifera found in the Choptank are not age-diagnostic.

No calcareous nannofossils were recovered from either the Calvert or Choptank sediments of the Oak Grove core. This absence is likely the result of post depositional leaching.

Pollen and spore assemblages were recovered in the Miocene units of the core. They were not studied in detail in this investigation, nor by any other palynologist to date.

C. Relation to the Formation and Member Contacts

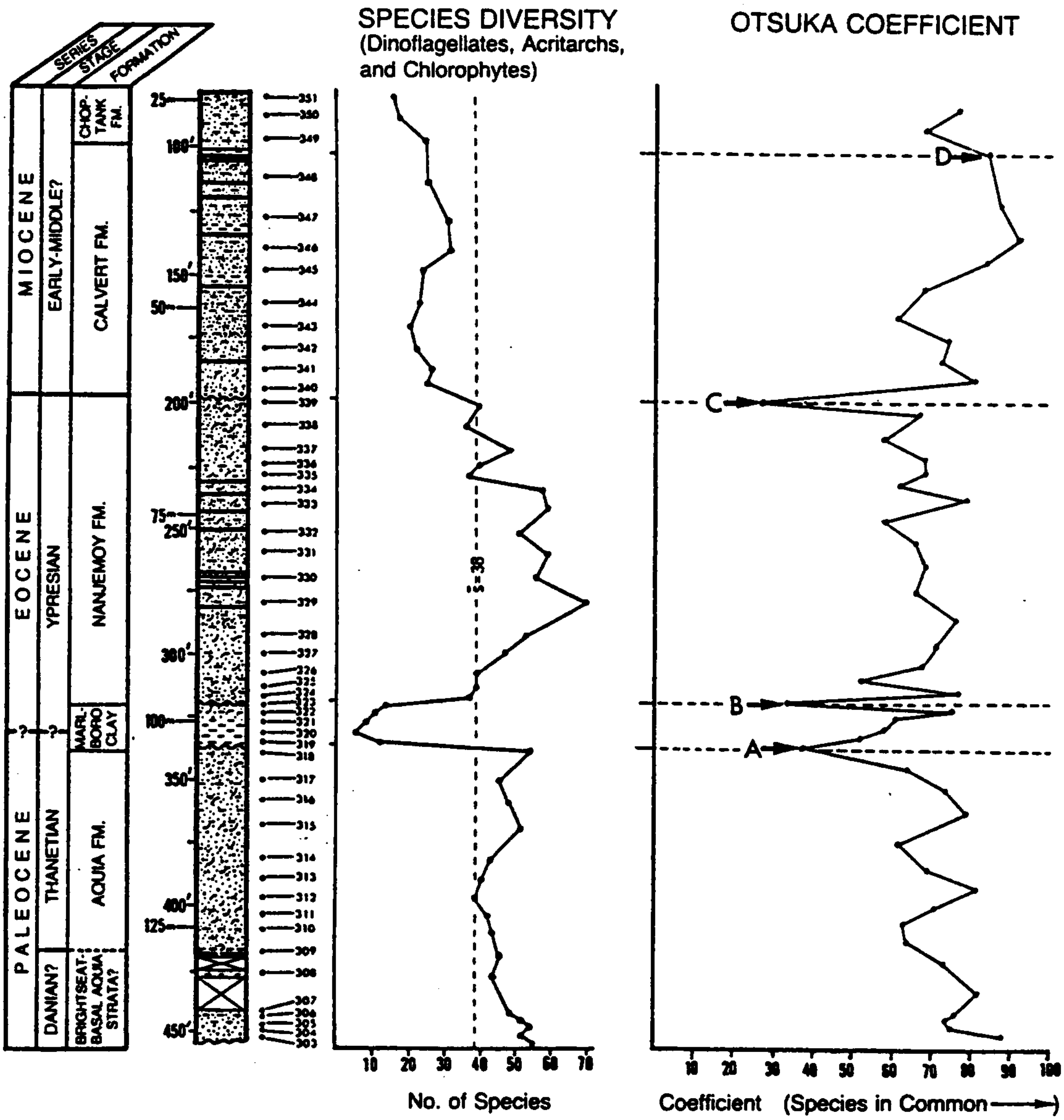
The nature of each of the formational interfaces in the Tertiary strata of the Oak Grove core is discussed below in terms of the lithologic characteristics and the biostratigraphic distribution of the species of dinoflagellates, acritarchs, and chlorophytes near the boundary. Lithologic descriptions of these contacts are based on the lithostratigraphic report and log prepared by Reinhardt et al. (1980) and Estabrook and Reinhardt (1980), as well as personal inspection of the core. Comments are also included for the apparent contacts between the two members of both the Aquia and Nanjemoy Formations.

Each of the boundaries is characterized by the ranges and diversities of the phytoplankton. In addition, a curve has been plotted for the Otsuka coefficients, numbers expressing the relationship between adjacent samples (Hazel, 1970). This indicator has been found to be useful in identifying disconformable surfaces (see Text-fig. 10); the higher the coefficient the more species the two adjacent samples have in common, and conversely, the lower the coefficient the more disparate the two samples are.

Tectonic activity has certainly influenced the deposition of the Tertiary sediments in this region of the coastal plain. The effects of subsurface structures on formation thicknesses and the nature of their contacts are briefly discussed.

Formation contacts

Aquia-Marlboro Clay contact. This boundary is described by Reinhardt et al. (1980) as gradational over an approximately 10 cm section of core, from a friable glauconite sand with isolated clay clasts in the



$$\text{Otsuka Coefficient} = \frac{C}{\sqrt{N_1N_2}} \times 100$$

C = Number of Species in Common to Two Samples
N_1 = Total Number of Species in One of the Samples
N_2 = Total Number of Species in the Other Sample

Text-fig. 10. Graphic curves of species diversity (richness) and Otsuka coefficients (points plotted between samples) for dinoflagellate, acritarch, and chlorophyte assemblages of the Oak Grove core samples. Data listed in Appendix I(A).

Aquia Formation to a dense clay with some sand laminae in the Marlboro Clay. Personal observation of the core suggests that this thin interval of mixed lithologies could be the result of storm activity and infaunal reworking of sediments in a relatively shallow water setting over a period of time. Palynological evidence derived from samples taken from below and above this interval reflects distinctly different paleoenvironments; it is difficult to tell if any substantial hiatus is represented at the formational contact. Diversity drastically decreases from 54 dinoflagellate, acritarch, and chlorophyte species in the uppermost Aquia sample to 12 in the lowermost Marlboro Clay sample (see Text-fig. 10). The Otsuka coefficients range from 60.5 to 88.5 throughout the Aquia strata, and from 51.6 to 75.2 in the Marlboro Clay. At the Aquia-Marlboro Clay contact, the coefficient drastically decreases from 63.5 (in the Aquia) to 39.6 (across the contact) and increases again to 51.6 (in the Marlboro Clay), reflecting dissimilar samples across the interface and possibly a hiatus (see contact A in Text-fig. 10). The ranges of 61 organic-walled phytoplankton species extend across this boundary, but most are not represented by any appreciable abundance or consistency until in the overlying Nanjemoy strata. The ranges of 12 species terminate, and no species begin their ranges near this contact.

A discontinuity is likewise indicated at the Aquia-Marlboro Clay contact at Locality 3 (refer to Text-figs. 6 and 9-A) investigated by Witmer (1975). The ranges of 22 dinoflagellate, acritarch, and chlorophyte species terminate at this boundary and two appear for the first time. Diversity drops from 38 species in the Aquia to 18 species in the Marlboro Clay.

Marlboro Clay-Nanjemoy contact. The extensively burrowed upper two meters of the dense Marlboro Clay appears to be disconformably overlain by the silty clays of the Nanjemoy Formation. The contact is burrowed with glauconitic silts and sands of the Nanjemoy filling in the burrows in the Marlboro Clay. Biostratigraphic distribution of the organic-walled phytoplankton species suggests a disconformity at this boundary. Two species' ranges terminate and seven begin, with 58 species ranging across the interface. Thirteen species are present in the uppermost Marlboro Clay; the number increases to 38 in the basal Nanjemoy sample (see Text-fig. 10). At the contact, the Otsuka coefficients markedly decrease from a high of 75.2 in the uppermost Marlboro Clay to 35.9 across the boundary and increase to 77.9 in the lowermost Nanjemoy. The dissimilar samples across this horizon supports evidence for a disconformable surface (see contact B in Text-fig. 10).

Nanjemoy-Calvert contact. This interface is disconformable in the Oak Grove core, separating the glauconitic Nanjemoy Formation from the siliceous Calvert Formation. The disconformity reflects a significant span of time from the late Early Eocene into the Early(?) Miocene; a hiatus of from 15 to 30 million years is calculated for this area of the coastal plain depending on the particular location along this irregular, sloping surface (Jordan and Smith, 1983). Folding and faulting associated with northeast-southwest trending structures have resulted in variable truncation of the Nanjemoy by erosion (Mixon and Powars, 1984). Corroborating the evidence for a major disconformity at the Nanjemoy-Calvert boundary, the ranges of 23 dinoflagellate, acritarch, and chlorophyte species terminate and eight begin; twenty-four species range across the contact. Species diversity drops from 40 in the uppermost Nanjemoy to 24 in the lowermost Calvert strata near this horizon (see Text-fig. 10). Otsuka coefficients show a pronounced change across the disconformity. The coefficients range from 51.3 to 79.3 in the Nanjemoy, and from 60.6 to 92.1 in the Calvert. At the contact, the sequence of coefficients is 67.6 (in the uppermost Nanjemoy), 29.1 (across the contact), to 80.1 (in the lowermost Calvert). The obvious disconformity is clearly revealed by the Otsuka coefficients (see contact C in Text-fig. 10).

Calvert-Choptank contact. The lithologic differences between the Calvert and Choptank Formations near the boundary are minimal. Very fine quartz sands of the Calvert grade into the silty clays of the Choptank. Ranges of four dinoflagellate species end at this contact, and no new ranges of species begin. Twenty-seven species range across the interface of these two units. Twenty-six species are present in both the uppermost Calvert and lowermost Choptank samples (see Text-fig. 10). The Otsuka coefficients curve shows no obvious decrease peak, which is present at the interfaces discussed above (see contact D in Text-fig. 10). Palynological, as well as lithologic, evidence indicates that this contact is likely gradational in nature.

Member contacts

Piscataway-Paspotansa contact (Aquia Formation). The position of the boundary between the Piscataway and Paspotansa Members of the Aquia Formation is currently being re-evaluated by U. S. Geological Survey geologists. Based on both lithology and fossils, Clark and Martin (1901) originally established their zones 1 through 7 in the Piscataway Member and zones 8 and 9 in the Paspotansa Member at the type section; the present study will refer to these inappropriately defined zones as units (see Text-fig. 2). Recently Ward (in press) has recommended that the contact separating the members be placed between units 5 and 6 where the most significant lithologic and textural changes typically occur in outcrop. In the Oak Grove core, however, a possible member contact is suggested by only subtle textural changes recorded by Estabrook and Reinhardt (1980) in the 110 m (364 ft) to 113 m (372 ft) depth range. A pronounced biostratigraphic discontinuity exists in this interval, between what appear to be units 4 and 5 (Samples 314 and 315) based on dinoflagellate range comparisons with the type section. Five dinoflagellate species' ranges terminate and 11 ranges begin. The succession of Otsuka coefficients is 69.2 directly below the horizon, 60.5 across the horizon, to 79.6 directly above the horizon (see Text-fig. 10). This discontinuity may reflect some sort of break in sedimentation or removal of sediment at the contact between the two members of the Aquia Formation in the core. Foraminiferal species ratios and diversities also indicate a change and probable paleobathymetric minimum near this level. More detailed sampling is needed to more closely correlate microfossil and lithologic data which would help to pinpoint and characterize this boundary. Additional discussion is presented in the section "Biostratigraphic Correlation: Oak Grove Core and Atlantic Coastal Plain Sections".

Potapaco-Woodstock contact (Nanjemoy Formation). The boundary between the typically more clayey Potapaco Member and the sandier Woodstock Member of the Nanjemoy Formation was placed by Clark and Martin (1901) between their units 15 and 16 (see Text-fig. 2). In the Oak Grove core, however, the contact between the members is difficult to delineate lithologically, and as a result was first chosen at approximately the 84.1 m (276 ft) depth based more on mollusk biostratigraphic comparisons with Clark and Martin (1901) studies than on lithology (Gibson et al., 1980). Higher in the core, near the 75 m (246 ft) level, relatively subtle lithologic and textural changes from clayey sands to sands (see Text-fig. 2 of Reinhardt et al., 1980; Estabrook and Reinhardt, 1980) may more likely represent the contact between the members. Dinoflagellate biostratigraphy in fact reflects a distinct discontinuity in this interval (between Samples 332 and 333) where the ranges of 13 dinoflagellate species begin and five terminate. Otsuka coefficient succession is as follows: 66.3 directly below the horizon, 58.7 across the horizon, and 79.3 directly above the horizon (see Text-fig. 10). As was similarly pointed out for the member contact in the Aquia Formation, some sort of break in continuous sedimentation may be reflected at the boundary separating the two members of the Nanjemoy Formation in the core; Ward (1984) in fact has described a disconformable boundary between the Potapaco and Woodstock Members at many outcrop localities. Further discussion can be found in the section "Biostratigraphic Correlation: Oak Grove Core and Atlantic Coastal Plain Sections".

Tectonic Influence on Contacts

The contact separating the Lower Eocene Nanjemoy Formation and the Miocene Calvert Formation is an obvious disconformity. Other formational contacts in the core (e.g., Marlboro Clay - Nanjemoy) may represent disconformities on a much smaller scale. Even the lithologically subtle member contacts of both the Aquia and the Nanjemoy Formations are likely the result of some kind of disruption in the sedimentary regime or change in the depositional environment. Conspicuous disconformities supported by strong lithologic and biostratigraphic evidence, as well as other contacts suspected of reflecting a hiatus based primarily on fossil criteria, are all more or less a response to the underlying tectonics in the region. Most of these surfaces in this part of the coastal plain are most probably caused to a large extent by erosion (submarine and subaerial?) or non-deposition during discontinuous arching of a northeast-southwest trending subsurface structural lineament known as the Skinkers Neck Structure (see Text-fig. 3 of Mixon and Powars, 1984). Variable thicknesses of Aquia, Marlboro Clay, and Nanjemoy sediments along this structure suggest broad flexuring (and reverse faulting?) during at least the Late Paleocene and Early Eocene (Mixon and Powars, 1984; Edwards, personal communication). This type of folding and faulting would be consistent with the general compressive nature of stresses occurring along this portion of eastern North America in Late Mesozoic and Cenozoic time. (The reader is referred to Brown et al. (1972) for detailed discussion of tectonic development of sedimentary troughs (e.g., Salisbury Embayment) and cross structures, and Schlee and Klitgord (1986) for synthesis of the structure of the North American Atlantic continental margin.)

D. Zonation of the Paleocene-Eocene Strata

A tentative zonation based on dinoflagellates is herein proposed for the Aquia, Marlboro Clay, and Nanjemoy (Paleocene and Eocene) strata in the Oak Grove core. The distinctive morphologies and the relatively high abundances of the nominate species render them especially effective zonal markers. In addition to the core, the biostratigraphic distributions of species recorded at the Aquia type section (McLean, 1971) and other Aquia sections (Witmer, 1975) in

Virginia, as well as a Nanjemoy section (Goodman, 1975, 1979, 1984) in Maryland, were also considered in this preliminary zonation. More sections of the Calvert and Choptank Formations need to be investigated before a zonation is attempted for these units.

The zones have been erected in this study using the concepts and methods of biostratigraphic zonation discussed by Murphy (1977). Briefly stated, the requisites of a zone include definition, characterization, and identification. The lower boundary of each zone is *defined* by the first occurrence of a single species (e.g., Species A), and its upper boundary by the first occurrence of another single species (e.g., Species B) found higher in the section. The bounded zone would then be referred to as Zone A-B, with the limits of the biostratigraphic unit clearly defined in the name itself. It must be stressed that the second species (Species B) is not found in that particular zone. In addition to defining species, the restriction and the first and last occurrences of other species' ranges (including those that overlap) help to *characterize* the zone. These species are useful in recognizing the zone outside the area in which it was established. New characterizing species may be subsequently added to a zone. Finally, *identification* of the zone involves the ability to recognize and correlate the biostratigraphic unit with sections nearby as well as on a worldwide scale.

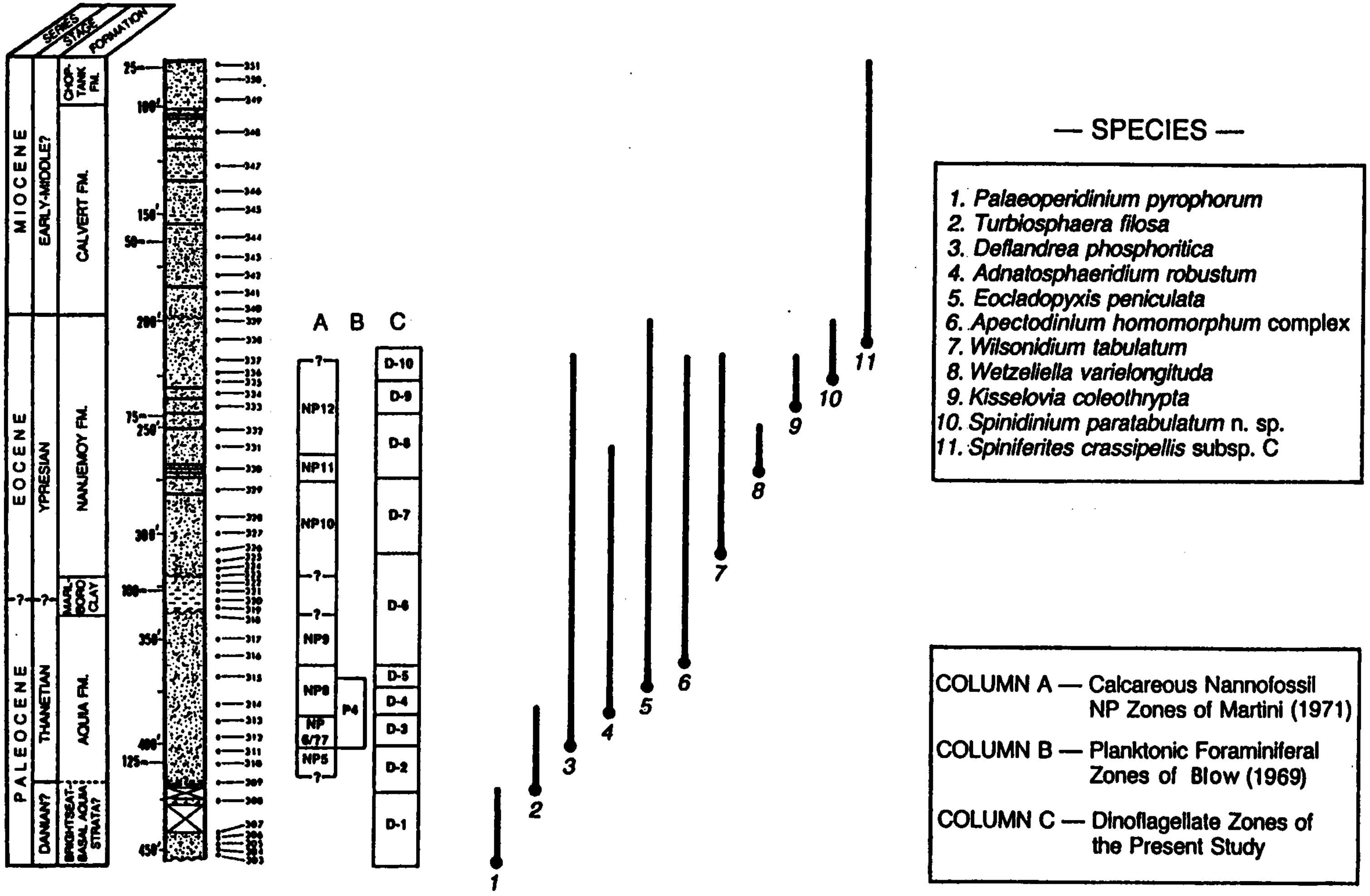
The provisional zones established in the Paleocene and Eocene strata of the core have each been assigned a name in the manner described above. Comments are included on the relative abundance (for categories, see the section "Analytical Procedures") of those species represented by the greatest numbers of specimens in the zone, primarily as an aid in local correlation. For convenience, each of the zones has been designated D-1 through D-10 (see Text-fig. 11; refer also to Charts 1-3 in back pocket). The zones are outlined in ascending stratigraphic order below.

Palaeoperidinium pyrophorum-Turbiosphaera filosa "Basal" Zone

Abbreviated designation: D-1
Stratigraphic distribution in core: Samples 303-309
Age: Danian?

Definition: The zone extends from the first occurrence of *Palaeoperidinium pyrophorum* in the basal core sample to, but not including, the first occurrence of *Turbiosphaera filosa*.

Characterization: Species restricted to this basal zone include *Conneximura fimbriata, Danea?* sp., *Fibrocysta* sp. A, *Florentinia ferox, Hystrichosphaeridium* cf. *H. tubiferum, Impagidinium* sp. A, *Isabelidinium cooksoniae, Oligosphaeridium complex, Palambages* sp. A, *Spiniferites cornutus* subsp. A, *Spinferites cornutus* subsp. B, *Spiniferites* cf. *S. pterotus,* and *Tanyosphaeridium variecalamum.*



Text-fig. 11. Biostratigraphic distribution of the dinoflagellate species which define Dinoflagellate Zones D-1 through D-10 of the Paleocene and Eocene strata of the Oak Grove core.

Comments: Because this zone lies atop the Cretaceous-Tertiary unconformity, the lower boundary therefore cannot be defined, and is herein referred to as a "basal" zone. It must be noted that *Palaeoperidinium pyrophorum* has been reported from Cretaceous units, but has not generally been observed in younger than Early Paleocene age rocks.

Species with the greatest relative abundance in the D-1 Zone include *Cordosphaeridium giganteum* n. sp. (Rare to Common), *Glaphyrocysta exuberans* complex (Rare to Abundant), *Fibradinium annetorpense* (Sparse to Common), and *Elytrocysta obscurotabulata* n. sp. (Sparse to Common).

Turbiosphaera filosa-Deflandrea phosphoritica Zone

Abbreviated designation: D-2

Stratigraphic distribution in core: Samples 310-311

Age: Thanetian

Definition: The zone extends from the first occurrence of *Turbiosphaera filosa* to, but not including, the first occurrence of *Deflandrea phosphoritica*.

Characterization: Only *Hystrichokolpoma mentitum* is restricted to this zone. The uppermost part of the D-2 Zone is characterized by the last appearance of Forma A; the base of the zone is marked by the first appearances of *Fromea laevigata, Nematosphaeropsis trabeculata* n. sp., and *Senagalinium obscurum.*

Comments: Species of relatively high abundance include *Fibradinium annetorpense* (Sparse to Abundant), *Glaphyrocysta exuberans* complex (Common to Abundant), and *Xenikoon australis* (Rare to Common).

Deflandrea phosphoritica-Adnatosphaeridium robustum Zone

Abbreviated designation: D-3

Stratigraphic distribution in core: Samples 312-313

Age: Thanetian

Definition: The zone extends from the first occurrence of *Deflandrea phosphoritica* to, but not including, the first occurrence of *Adnatosphaeridium robustum.*

Characterization: The only species restricted to the D-3 Zone is *Nematosphaeropsis* cf. *N. pertusa* n. sp. *Alisocysta* cf. *A. margarita* occurs for the first time and *Fibradinium annetorpense* occurs for the last time near the base of this zone.

Comments: Species occurring in relatively high numbers within this zone include *Deflandrea dartmooria* (Rare to Sparse), *Glaphyrocysta* *exuberans* complex (Rare to Abundant), and *Turbiosphaera filosa* (Sparse to Abundant).

Adnatosphaeridium robustum-Eocladopyxis peniculata Zone

Abbreviated designation: D-4

Stratigraphic distribution in core: Sample 314

Age: Thanetian

Definition: The zone extends from the first occurrence of *Adnatosphaeridium robustum* to, but not including, the first occurrence of *Eocladopyxis peniculata*.

Characterization: Species with ranges that terminate in the zone include *Alisocysta* cf. *A. margarita, Cordosphaeridium giganteum* n. sp., *Thalassiphora delicata, Turbiosphaera filosa* , and *Xenikoon australis*. Occurring for the first time in this zone is *Cassidium paleocenicum* n. sp.

Comments: Species which are relatively abundant include *Glaphyrocysta* sp. A (Abundant), *Paralecaniella indentata* (Sparse), and *Thalassiphora delicata* (Abundant).

Eocladopyxis peniculata-Apectodinium homomorphum complex Zone

Abbreviated designation: D-5

Stratigraphic distribution in core: Sample 315

Age: Thanetian

Definition: The zone extends from the first occurrence of *Eocladopyxis peniculata* to, but not including, the first occurrence of *Apectodinium homomorphum* complex.

Characterization: The ranges of *Deflandrea dartmooria* and *Nematosphaeropsis pertusa* n. sp. terminate in this zone. The following species occur for the first time: *Cordosphaeridium biarmatum, Fibrocysta paratabulata* n. sp., *Fibrocysta rotunda* n. sp., *Hystrichokolpoma tumescens, Hystrichokolpoma rigaudiae, Impagidinium speciosum* n. sp., *Impagidinium* cf. *I. speciosum* n. sp., *Kallosphaeridium brevibarbatum, Lentinia ruginosa* n. sp., and *Spiniferites crassipellis* subsp. B.

Comments: Species occurring in relatively high numbers in the D-5 Zone include *Eocladopyxis peniculata* (Sparse) and *Glaphyrocysta* sp. A (Abundant).

Apectodinium homomorphum complex-*Wilsonidium tabulatum* Zone

Abbreviated designation: D-6

Stratigraphic distribution in core: Samples 316-325

Age: Thanetian/Ypresian

Definition: The zone extends from the first occurrence of *Apectodinium homomorphum* complex to, but not including, the first occurrence of *Wilsonidium tabulatum.*

Characterization: Restricted species include *Apteodinium retiolum* n. sp. and *Spinferites cornutus* subsp. C in the basal part of the zone, in addition to *Apectodinium* sp. A, *Hystrichokolpoma unispinum* (range terminates at top of zone), and *Wetzeliella* cf. *W. irtyschensis.* Species terminating their ranges in the lower part of this zone are *Caligodinium amiculum, Cladopyxidium saeptum, Micrhystridium* cf. *M. fragile*, and *Phelodinium magnificum.* The following species with ranges beginning lower in the section terminate at the Aquia-Marlboro Clay contact (disconformity) in the basal part of the D-6 Zone in the core: *Andalusiella rhombohedra, Ascostomocystis hydria, Cassidium paleocenicum* n. sp., *Cordosphaeridium biarmatum, Fibrocysta paratabulata* n. sp., *Fibrocysta rotunda* n. sp., *Impagidinium speciosum* n. sp., *Hafniasphaera* cf. *H. septata, Micrhystridium* cf. *M. variabile* and *Spiniferites crassipellis* subsp. B. Occurring for the first time at the base of this zone are *Fibrocysta bipolare* and *Lingulodinium* *machaerophorum*. Species beginning their ranges in the upper part of the D-6 Zone at the Marlboro Clay-Nanjemoy contact (disconformity) include: *Adnatosphaeridium multispinosum-vittatum* complex, *Cordosphaeridium inodes* subsp. *robustum*, *Dinopterygium cladoides*, *Fibrocysta* cf. *F. lappacea*; *Millioudodinium giuseppei* subsp. *major*, *Muratodinium fimbriatum*, and *Operculodinium israelianum*.

Comments: Near the base of this zone, *Adnatosphaeridium robustum* (Sparse to Common), *Elytrocysta obscurotabulata* n. sp. (Rare to Abundant), *Eocladopyxis peniculata* (Rare to Sparse), and *Glaphyrocysta* sp. A (Abundant) are most abundant, whereas in the upper section of the zone *Adnatosphaeridium multispinosum-vittatum* complex (Common to Abundant), *Apectodinium homomorphum* complex (Rare to Abundant), and *Senagalinium? dilwynense* (Abundant) occur in high numbers. It must be noted that the D-6 Zone crosses two disconformities (Aquia-Marlboro Clay and Marlboro Clay-Nanjemoy contacts). The D-6 Zone generally correlates with the European *Wetzelliella (Apectodinium) hyperacantha* Zone of Costa and Downie (1976).

Wilsonidium tabulatum-Wetzeliella varielongituda Zone

Abbreviated designation: D-7

Stratigraphic distribution in core: Samples 326-329

Age: Ypresian

Definition: The zone extends from the first occurrence of *Wilsonidium tabulatum* to, but not including, the first occurrence of *Wetzeliella varielongituda*.

Characterization: *Cordosphaeridium solaster* and *Glaphyrocysta* sp. B are restricted to the D-7 Zone. Species with ranges beginning at or near the base of the zone include Forma B, *Melitasphaeridium pseudorecurvatum*, *Tectatodinium pellitum*, and *Wetzeliella hampdenensis*. Those species which begin their ranges in the upper part of the D-7 Zone are *Achilleodinium biformoides*, *Areoligera* spp., *Fibrocysta coalitospinosa* n. sp., *Homotryblium tasmaniense*, *Nematosphaeropsis pusulosa*, *Polysphaeridium zoharyi*, *Polysphaeridium* cf. *P. zoharyi*, *Renidinium?* sp. A, *Tubidermodinium sulcatum*, and *Wetzeliella samlandica*. The following species terminate their ranges in the upper part of the zone: *Cordosphaeridium multispinosum*, *Fibrocysta* cf. *F. lappacea*, *Glaphyrocysta exuberans* complex, *Glaphyrocysta* sp. A, *Spiniferites ramosus* subsp. *granomembranaceus*, *Systematophora placacantha*, and *Trichodinium hirsutum*.

Comments: The following species occur in high relative abundance at various horizons within the zone: *Adnatosphaeridium multispinosum-vittatum* complex, *Deflandrea phosphoritica*, *Systematophora placacantha*, *Wetzeliella hampdenensis*, and *Wilsonidium* *tabulatum*. The D-7 Zone is approximately correlative with the *Wilsonidium tabulatum* Zone in Switzerland of Jan du Chene (1977).

Wetzeliella varielongituda-Kisselovia coleothrypta Zone

Abbreviated designation: D-8

Stratigraphic distribution in core: Samples 330-332

Age: Ypresian

Definition: The zone extends from the first occurrence of *Wetzeliella varielongituda* to, but not including, the first occurrence of *Kisselovia coleothrypta*.

Characterization: Restricted species in this zone are *Apteodinium australiense*, *Biconidinium longissimum*, *Operculodinium* cf. *O. brevispinosum* n. sp., and *Wetzeliella varielongituda*. Both *Membranilarnacia leptoderma* and *Phthanoperidinium echinatum* occur for the first time at the base of the D-8 Zone. Those species which terminate their ranges at the base of or near the middle of the zone include *Adnatosphaeridium robustum*, *Cordosphaeridium inodes* subsp. *robustum*, *Elytrocysta obscurotabulata* n. sp., *Exochosphaeridium bifidum*, Forma B, *Hystrichokolpoma tumescens*, *Hystrichosphaeridium tubiferum*, *Lentinia ruginosa* n. sp., *Renidinium?* sp., *Spiniferites* sp. A, and *Trigonopyxidia ginella*.

Comments: Species of highest relative abundance within the zone include *Adnatosphaeridium multispinosum-vittatum* complex (Rare to Common), *Biconidinium longissimum* (Rare to Common), *Elytrocysta obscurotabulata* n. sp. (Rare to Common), *Eocladopyxis peniculata* (Rare to Sparse), Forma B (Sparse), *Thalassiphora pelagica* (Rare to Sparse), and *Wetzeliella samlandica* (Rare to Abundant). The D-8 Zone generally correlates with the European *Wetzeliella (W.) varielongituda* Zone of Costa and Downie (1976).

Kisselovia coleothrypta-Spinidinium paratabulatum n. sp. Zone

Abbreviated designation: D-9

Stratigraphic distribution in core: Samples 333-334

Age: Ypresian

Definition: The zone extends from the first occurrence of *Kisselovia coleothrypta* to, but not including, the first occurrence of *Spinidinium paratabulatum* n. sp.

Characterization: Restricted species include *Paucisphaeridium inversibuccinum*, *Senagalinium? asymmetricum*, and *Spinidinium macmurdoense*. Species with first occurrences at the base of the zone are *Apteodinium labyrinthum* n. sp., *Cleistosphaeridium* *diversispinosum, Deflandrea wardenensis, Homotryblium caliculum, Homotryblium pallidum-tenuispinosum* complex, *Hystrichokolpoma eisenackii, Samlandia chlamydophora,* and *Wetzeliella lunaris.* Those species with last appearances at the top of the D-9 Zone include *Cordosphaeridium fibrospinosum, Cordosphaeridium gracile, Elytrocysta obscurotabulata* n. sp., Forma C, *Inversidinium exilimurum, Lentinia spinigera* n. sp., *Operculodinium brevispinosum* n. sp., *Polysphaeridium* cf. *P. zoharyi,* and *Spiniferites crassipellis* subsp. A.

Comments: The species represented by the greatest numbers of specimens in this zone are Forma C (Abundant) and *Spiniferites macmurdoense* (Abundant). The D-9 Zone correlates in general with the European *Wetzeliella (W.) coleothrypta* Zone of Costa and Downie (1976).

Spinidinium paratabulatum n. sp.- *Spiniferites crassipellis* subsp. C Zone

Abbreviated designation: D-10

Stratigraphic distribution in core: Samples 335-337

Age: Ypresian

Definition: The zone extends from the first occurrence of *Spinidinium paratabulatum* n. sp. to, but not including, the first occurrence of *Spiniferites crassipellis* subsp. C.

Characterization: *Phthanoperidinium* cf. *P. tritonium* and *Wetzelliella* sp. A are restricted to this zone. In addition to *Spinidinium paratabulatum* n. sp., the range of *Glaphyrocysta ordinata* begins at the base of the D-10 Zone. Species with ranges that terminate at the top of the zone include *Apectodinium homomorphum* complex, *Deflandrea phosphoritica, Fibrocysta coalitospinosa* n. sp., *Fibrocysta radiata, Homotryblium tasmaniense, Kisselovia coleothrypta, Renidinium membraniferum, Samlandia chlamydophora,* and *Tubidermodinium sulcatum*. The ranges of *Fibrocysta bipolare* and *Senagalinium obscurum* end within this zone.

Comments: Species in the zone with relatively high abundance include *Areoligera* spp. complex (Rare to Abundant), *Cleistosphaeridium diversispinosum* (Rare to Common), *Deflandrea phosphoritica* (Abundant), *Eocladopyxis peniculata* (Abundant), and *Wetzeliella hampdenensis* (Rare to Common).

Biostratigraphic Correlation

A. Oak Grove Core and Atlantic Coastal Plain Sections

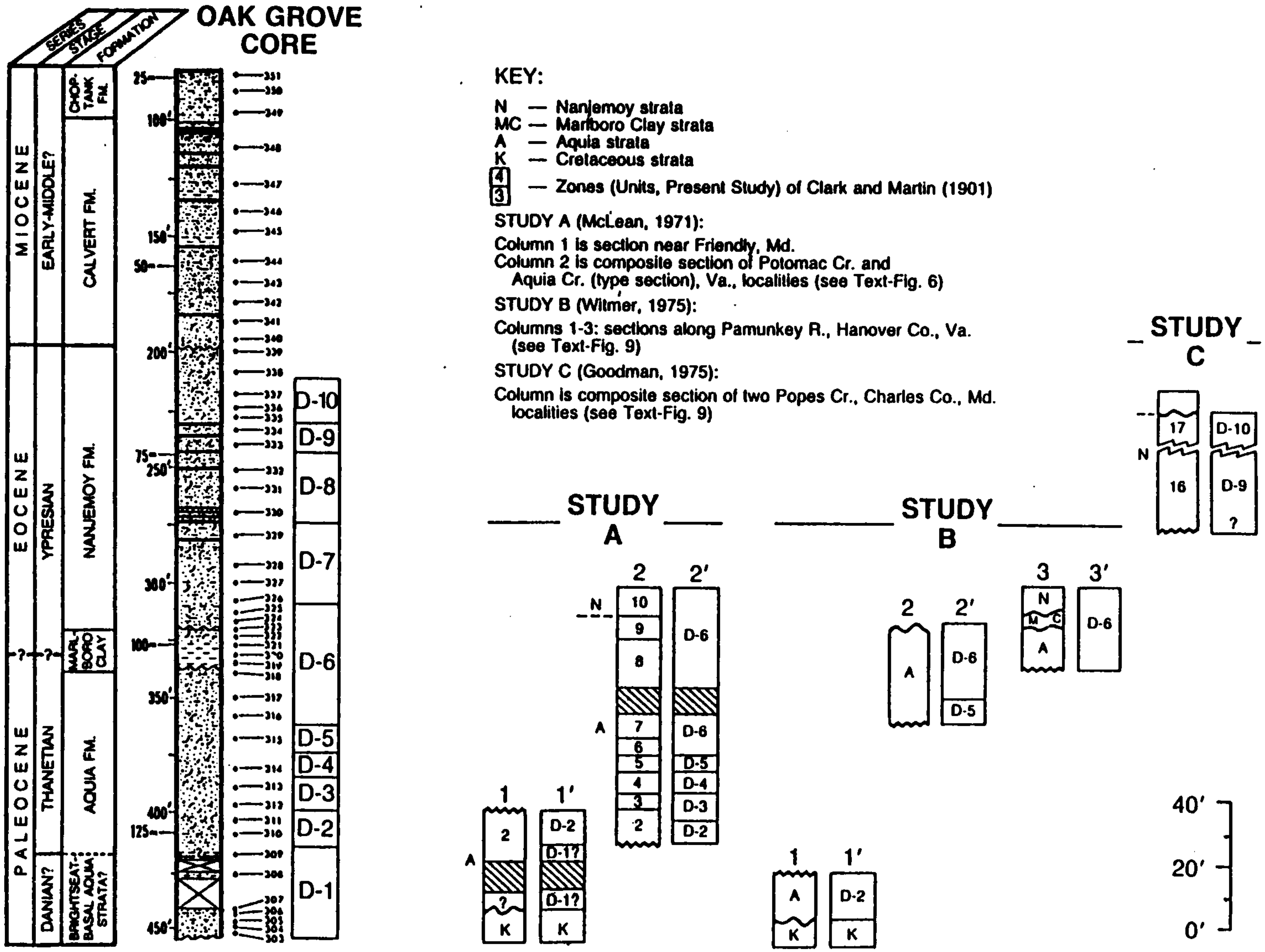
Virginia and Maryland

McLean (1971), Witmer (1975), and Goodman (1975, 1979, 1984) have previously reported on the biostratigraphic distributions of the dinoflagellate, acritarch, and chlorophyte assemblages from outcrop sections including Aquia, Marlboro Clay, and Nanjemoy strata on the coastal plain of Virginia and Maryland. Brief descriptions of these study localities are presented in the section "Associated Study Localities", and their locations are shown on the general map in Text-fig. 6 and on detailed maps in Text-fig. 9 (A and B). In this investigation, the outcrop sections have been biostratigraphically correlated with the Paleocene and Eocene strata of the Oak Grove core. Chart 4 (in back pocket) depicts the biostratigraphic distributions of dinoflagellate species common to the core and the outcrops which proved useful in recognizing the provisional zones of the present study, as well as probable correlative horizons within some of the zones. The key at the far right of the chart lists the dinoflagellate species corresponding to the numbered biostratigraphic ranges, and the abbreviations used in the stratigraphic columns. Columns A through D, shown to the right of the Oak Grove core section, represent the following: (A) calcareous nannofossil zones reported by Bybell in Gibson et al. (1980); (B) planktonic foraminiferal zones reported by Gibson in Gibson et al. (1980); (C) provisional dinoflagellate zones established in the present study; and (D) zones of Clark and Martin (1901). The numbered zones erected by Clark and Martin were based on a combination of both lithology and paleontology of the Aquia and Nanjemoy Formations at the same localities more recently studied by McLean (1971) and Goodman (1975). These zones are difficult to delineate in the Oak Grove core; nevertheless, they do provide a useful framework for making additional biostratigraphic comparisons of dinoflagellate species distributions of the outcrop localities and the core. The present study, however, will use the term unit in place of the Clark and Martin zone.

The provisional zones D-1 through D-10 that can be recognized at each of the sections of the three coastal plain outcrop localities are discussed below. The number of the identifying and characterizing dinoflagellate species used in correlating each of the localities is noted. Refer to Text-fig. 12 for a diagrammatic representation.

(1) Aquia Formation at Friendly, Maryland, and Aquia and Nanjemoy Formations at the Potomac Creek and Aquia Creek (Aquia type section), Virginia, localities (McLean, 1971)--18 significant correlative species:

At least part of the *Palaeoperidinium pyrophorum-Turbiosphaera filosa* (D-1) "Basal" Zone may be represented in the strata between the



Text-fig. 12. Suggested dinoflagellate zonation for sections from three Virginia-Maryland Coastal Plain studies.

Cretaceous-Tertiary boundary (near Sample 3377) and a horizon about 3 m (10 ft) above the covered interval (directly below Sample 3371) at the Friendly, Maryland, locality. This suggestion is based on relative position below the first occurrence at Sample 3371 of *Turbiosphaera filosa*, the basal defining species of Zone D-2. The defining species of Zone D-1, *Palaeoperidinium pyrophorum*, was not recorded by McLean (1971) in these basal sediments. Many of the species found in the D-1 Zone of the Oak Grove core are also present in these basal Friendly, Maryland, strata, although none have ranges restricted to this zone. The D-1 "Basal" Zone of the core may be Danian in age, representing lowermost Aquia strata older than that found at the type section (see the section "Palynological Biostratigraphy: Ages of the Formations" for detailed discussion of this interval). The base of the *Turbiosphaera filosa-Deflandrea phosphoritica* (D-2) Zone is at Sample 3371 at the Friendly, Maryland, locality. In ascending stratigraphic order, the bases of the zones recognized at the Aquia Creek, Virginia, locality (type section) are as follows: (a) *Deflandrea phosphoritica- Adnatosphaeridium robustum* (D-3) Zone at Sample 3389; (b) *Adnatosphaeridium robustum-Eocladopyxis peniculata* (D-4) Zone at Sample 3385; (c) *Eocladopyxis peniculata-Apectodinium homomorphum* complex (D-5) Zone at Sample 3384; and (d) *Apectodinium homomorphum* complex-*Wilsonidium tabulatum* (D-6) Zone at Sample 3391. The base of the D-7 Zone does not appear to be present at this locality.

Consistent last occurrences (range tops) of a few dinoflagellate species appear to be important biostratigraphic events of correlative value in the Aquia Formation, based on studies of the type section (McLean, 1971) and U. S. Geological Survey cores drilled in recent years in northern Virginia (Edwards, Goodman, and Witmer, 1983; Edwards, personal communication). The most reliable range tops include *Fibradinium annetorpense* in the D-3 Zone, *Xenikoon australis* in the D-4 Zone, and possibly *Deflandrea dartmooria* in the D-5 Zone. Because counts were not recorded for individual species at the Aquia type section and in the recently drilled U.S.G.S. wells, comparisons based on numerical abundances cannot be made with the Oak Grove core zonation.

Using Clark and Martin (1901) units as a framework for dinoflagellate biostratigraphy at the Aquia type locality (McLean, 1971), Aquia strata in the core between Samples 310 and 316 likely represent at least units 2, 3?, 4, 5, and 6. Useful dinoflagellate species' ranges include (in alphabetical order): *Adnatosphaeridium robustum*, *Apectodinium homomorphum* complex, *Apteodinium retiolum* n. sp., *Cassidium paleocenicum* n. sp., *Deflandrea dartmooria*, *D. phosphoritica*, *Eocladopyxis peniculata*, *Fibradinium annetorpense*, *Fibrocysta bipolare*, *Lingulodinium machaerophorum*, *Nematosphaeropsis pertusa* n. sp., *Thalassiphora delicata*, *Turbiosphaera paratabulata* n. sp., *T. rotunda* n. sp., and *Xenikoon australis* (see Chart 4). The lack of significant biostratigraphic events in the uppermost Aquia makes it difficult to determine if any portions of units 7, 8, or 9 are present.

(2) Aquia, Marlboro Clay, and Nanjemoy Formations at three localities along the Pamunkey River, Hanover County, Virginia (Witmer, 1975)--18 significant correlative species:

At Locality 1 (see Text-fig. 9-A), the 3.6 m (12 ft) of Aquia strata resting on the Cretaceous unconformity appear to represent at least part of the *Turbiosphaera filosa-Deflandrea phosphoritica* (D-2) Zone. *Glaphyrocysta exuberans* complex (=*Areoligera* sp.) is particularly abundant in this zone at this outcrop as it is in the Oak Grove core. The *Palaeoperidinium pyrophorum-Turbiosphaera filosa* (D-1) Zone strata were either eroded or not deposited before deposition of D-2 Zone strata on the unconformity.

At Locality 2, the 7.6 m (25 ft) of Aquia strata represent at least parts of both the *Eocladopyxis peniculata-Apectodinium homomorphum* complex (D-5) Zone (up to but not including Sample 182) and the *Apectodinium homomorphum* complex-*Wilsonidium tabulatum* (D-6) Zone. Generally, biostratigraphic distributions, relative abundances, and species diversities are similar to those described for the Oak Grove core zones. Unconformably overlying the Aquia strata are sediments of the Miocene St. Marys Formation.

At Locality 3, all of the Aquia, Marlboro Clay, and Nanjemoy strata sampled fall within the *Apectodinium homomorphum* complex-*Wilsonidium tabulatum* (D-6) Zone. Precisely where the approximately 2 m (6 ft) of Aquia outcrop section fit into the D-6 Zone of the upper part of the formation is uncertain. High relative abundance peaks of *Apectodinium homomorphum* complex *(=Wetzeliella homomorpha)* and *Elytrocysta obscurotabulata* n. sp. (=*Membranosphaera tabulata* n. sp.) are apparently correlative. The extent of section missing at the disconformities bounding the Marlboro Clay is not known. Based primarily on species abundance comparisons, the one sample in the Marlboro Clay is very similar to samples from the lower part of this unit in the Oak Grove core. Species in common in all samples observed by the writer from sections of the Marlboro Clay, including the type section at Marlboro, Maryland, include *Apectodinium homomorphum* complex, *Hystrichokolpoma unispinum, Senagalinium? dilwynense,* and *Wetzeliella* cf. *W. irtyschensis*. Species diversities in the three outcrop samples of the Nanjemoy are considerably lower than in the basal Nanjemoy of the core. High peaks of *Apectodinium homomorphum* complex, *Muratodinium fimbriatum,* and *Senagalinium? dilwynense* are probably correlative. Conspicuously missing in the outcrop samples is *Adnatosphaeridium multispinosum-vittatum* complex, which is abundant in the Oak Grove core.

Dinoflagellate range comparisons with the Aquia type section allow general recognition of Clark and Martin (1901) units at the Pamunkey River outcrop sites as follows: Locality 1--unit 2; Locality 2--at least units 5 through 8?; Locality 3--unit 9? (see Witmer (1975) for details).

(3) Nanjemoy Formation at two localities along Popes Creek, Charles County, Maryland (Goodman, 1975)--14 significant correlative species:

Nanjemoy strata at both localities (see Text-fig. 9-B) are described by Clark and Martin (1901) as approximately 13 m (42 ft) of the Woodstock Member. The strata from Sample 244 up to the barren interval at the top of the section at Locality 4 represent at least part of the *Kisselovia coleothrypta-Spinidinium paratabulatum* n. sp. (D-9) Zone. The lowermost 2.5 m (8 ft) of this section below Sample 244 may be part of the *Wetzeliella varielongituda-Kisselvia coleothrypta* (D-8) Zone (see discussion below). At Locality 5, at least part of the *Spinidinium paratabulatum* n. sp.-*Spiniferites crassipellis* subsp. C (D-10) Zone is represented in the exposed Woodstock strata from Samples 264 to 271.

Biostratigraphic distribution in the Oak Grove core indicates a discontinuity (possible disconformity?) between the D-8 and D-9 Zones at what appears to be a subtle lithologic break between the Potapaco and Woodstock Members (see the section "Palynological Biostratigraphy: Relation to the Formation and Member Contacts"). Two dinoflagellates (*Wetzeliella varielongituda* and *Biconidinium longissimum*) recorded by Goodman (1975) as *W. articulata?* and *Fusidinium tabulatum* n. sp. in the basal Woodstock Member, were not observed above this possible disconformable horizon in the core. These species do not therefore co-occur with *Kisselovia coleothrypta* as they do in the lower

Woodstock at Popes Creek (see Chart 4). This may be the result of differences in sample spacing between the core and the outcrop sites, or possible non-deposition or submarine erosion at the disconformity in the core. The high abundance peaks of *Spinidinium macmurdoense* and *Deflandrea phosphoritica* recorded in Samples 333 to 336 of the core and Samples 244 to 250 in the Woodstock at Popes Creek likely reflect correlative strata.

The boundary between Clark and Martin (1901) units 16 and 17 of the Woodstock Member is thought to be near Sample 335 in the Oak Grove core, based on the range base of *Spinidinium paratabulatum* n. sp. at this level. Goodman (1975) recorded this taxon as *S. bilineatum* n. sp. in only unit 17 samples of the Woodstock. The very distinctive *Wetzeliella* sp. A recovered in Sample 337 of the core was observed by Goodman (1975) as *W. coalita* n. sp. exclusively in unit 17.

* * * * *

Over the past few years, the U. S. Geological Survey has drilled additional coreholes on the Virginia Coastal Plain between the Rappahannock and Potomac Rivers. Lucy Edwards of the U.S.G.S. (Reston, Va.) is currently documenting the dinoflagellate species distributions in these cores. Her work suggests that while many of the zones of the present study can be recognized, a few in particularly the upper Aquia may have to be ultimately revised when the data from all the wells and outcrops are comprehensively analyzed. Edwards, Goodman, and Witmer (1983) show a preliminary range chart constructed by graphic correlation (technique modified from Shaw, 1964) which incorporates three coastal plain coreholes (Ashton, Lake Jefferson, and Fort McLean) with the Oak Grove corehole, including by inspection Nanjemoy outcrop sections from southern Maryland. A planned formal zonation based on the present study, ongoing U.S.G.S. studies, as well as data presented by Witmer (1975), Goodman (1975, 1979, 1984), Witmer and Goodman (1980), Edwards and Witmer (1983), and Edwards, Goodman, and Witmer (1984), will provide an integrated Paleocene and Eocene organic-walled phytoplankton biostratigraphy for this region of the Atlantic Coastal Plain.

New Jersey

A former V.P.I.& S.U. palynology graduate student kindly permitted me to study 23 palynomorph microscope slides he prepared from samples collected from Lower Tertiary Rancocas Group and Manasquan Formation sections on the New Jersey Coastal Plain (Minard and Owens, 1960; Jordan and Smith, 1983). One set containing five samples from the Hornerstown Formation (lower Rancocas Group) and six samples from the Vincentown Formation (upper Rancocas Group) are from a locality near New Egypt (just north of Fort Dix), New Jersey. Another set of 12 samples was collected from the Manasquan Formation just west of Asbury Park, New Jersey. These slides provided an ideal opportunity to test the recognition of the provisional dinoflagellate zones in coeval coastal plain strata some distance to the northeast from the Oak Grove corehole.

Based on Foraminifera, the Hornerstown Formation has been assigned a Paleocene (Danian and part Landenian, or Thanetian) age (Loeblich and Tappan, 1957; Olsson, 1970; Youssefnia, 1978). The biostratigraphic distribution of the approximately 25 dinoflagellate and acritarch species observed in the available greensand samples of the Hornerstown Formation suggests a Danian to Landenian (=Thanetian) age as well. The provisional *Palaeoperidinium pyrophorum-Turbiosphaera filosa* (D-1) "Basal" Zone and at least part of the *Turbiosphaera filosa-Deflandrea phosphoritica* (D-2) Zone are recognizable in these samples. Palynomorph assemblages are very similar to those recovered from the Brightseat equivalent-basal Aquia? and lowermost Aquia strata of the Oak Grove core.

Conformably overlying the Hornerstown strata at the New Egypt, New Jersey, locality is the Vincentown Formation, consisting of greensands abruptly grading into calcareous sands near a well defined brachiopod bed. Foraminifera studies (Loeblich and Tappan, 1957; Olsson, 1970; Youssefnia, 1978) suggest a Paleocene (Landenian, or Thanetian) age for the Vincentown Formation. Although identifying species are absent, characterizing species of approximately 20 dinoflagellate and acritarch taxa observed support the Landenian (=Thanetian) age. The uppermost part of the *Turbiosphaera filosa - Deflandrea phosphoritica* (D-2) Zone, the *Deflandrea phosphoritica-Adnatosphaeridium robustum* (D-3) Zone, and the

Adnatosphaeridium robustum-Eocladopyxis peniculata (D-4) Zone can be recognized in these Vincentown samples.

The Manasquan Formation has been assigned an Early to Middle Eocene age on the basis of Foraminifera (Miller, 1956; Ulrich, 1976). The biostratigraphic distribution of the approximately 25 dinoflagellate and acritarch species observed in these 12 marl samples suggests an Early Eocene (Ypresian) age for this particular part of the Manasquan. The *Kisselovia coleothrypta-Spinidinium paratabulatum* n. sp. (D-9) Zone can definitely be recognized; palynomorph assemblages are very similar to those recovered in the middle part of the Nanjemoy strata of the Oak Grove core.

B. Oak Grove Core and European Sections

In addition to the local coastal plain correlations, an attempt has also been made to biostratigraphically correlate the Aquia, Marlboro Clay, and Nanjemoy strata of the Oak Grove core with various European sections. Listed below are brief descriptions of the composite stratigraphic columns for each of the European regions, as well as the principal studies involved and numbers of useful dinoflagellate species common to the core and the individual composite sections.

(1) S. E. England: Composite section from Studland, Alum Bay, Whitecliff Bay, Sheppey, and Herne Bay of the London and Hampshire Basins in southeastern England (Williams, 1963;

Williams and Downie, 1966a,b,c; Hussain, 1967; Eaton, 1971, 1976; Downie et al., 1971; Bujak, 1973; Costa and Downie, 1976; Bujak et al., 1980a)--11 species.

(2) Belgium/Netherlands: Composite section from boreholes at Kallo, Kortemark, Merelbeke, Ooigem, Orchies, Poperinge, Sint Jan, and Tielt of Belgium, and Woensdrecht of the Netherlands, in addition to outcrops at Aalbeke, Lauwe, and Melle-Heusden of Belgium (DeConinck, 1965, 1969, 1972, 1976a,b,c, 1977)--16 species.

(3) N. Germany: Composite section from northern Germany and Belgium (Morgenroth, 1966a) and two Meckelfeld boreholes in northern Germany (Gocht, 1969)--6 species.

(4) N. E. Spain: Section from Campo in the central part of the Spanish Pyrenees (Caro, 1973; Caro et al., 1975)--8 species.

(5) Switzerland: Section from Canton D'Obwald in central Switzerland (Jan du Chene, 1977)--11 species.

(6) E. France: Composite section from localities in Haute-Savoie in eastern France (Jan du Chene et al., 1975)--8 species.

(7) Paris Basin: Composite section from the Paris Basin in northern France (Gruas-Cavagnetto, 1968, 1970; Chateauneuf and Gruas-Cavagnetto, 1968, 1978)--3 species.

The suggested biostratigraphic correlation of the Aquia, Marlboro Clay, and Nanjemoy strata of the core with the European composite sections is shown in Chart 5 (in back pocket). Refer to the key at the extreme right of the chart for the list of dinoflagellate species corresponding to the numbered biostratigraphic ranges, as well as the stratigraphic/time-stratigraphic abbreviations used in the composite sections. Columns A, B, and C, shown directly to the right of the Oak Grove core column, respectively depict the calcareous nannofossil zones (reported by Bybell in Gibson et al, 1980), planktonic foraminiferal zones (reported by Gibson in Gibson et al., 1980), and provisional dinoflagellate zones (proposed in the present study). The section "Palynological Biostratigraphy: Zonation of the Paleocene - Eocene Strata" describes the dinoflagellate zones D-1 through D-10 referred to in the discussion that follows. The column of standard zones of calcareous nannofossils (NP zones of Martini, 1971) and dinoflagellates, directly to the right of the Oak Grove core dinoflagellate ranges, has been modified from Text-fig. 5 of Costa and Downie (1976) and is intended only as a reference.

The presence of *Palaeoperidinium pyrophorum,* as well as the concurrence of *Glaphyrocysta exuberans* complex, *Hystrichosphaeridium tubiferum,* and *Isabelidinium cooksoniae,* suggests that the segment of the Oak Grove core designated the Brightseat equivalent-basal Aquia? strata (D-1 Zone) is generally correlative with the Basaler Formation of Danian-Montian age in Switzerland. The first occurrence of *Turbiosphaera filosa*, marking the base of the D-2 Zone, is recorded near the Danian-Thanetian boundary in the core and in the basal part of the Paleocene of the Campo section in the Spanish Pyrenees. The initial appearance of *Eocladopyxis peniculata* in the core, delineating the base of the D-5 Zone, is also recorded at the base of the Thanetian age Bottom Beds (predominantly marine facies underlying the more estuarine Woolwich and Reading Beds) in southeastern England.

The first occurrence of the genus *Apectodinium* is an important biostratigraphic datum throughout much of the world. This horizon which marks the base of the *Apectodinium homomorphum* complex-*Wilsonidium tabulatum* (D-6) Zone in the upper Aquia of the Oak Grove core is biostratigraphically equivalent with the base of the *Apectodinium hyperacanthum (=Wetzeliella (W.) hyperacantha)* Zone in Europe. This significant datum is generally coincident with the base of the calcareous nannofossil NP-9 Zone in both the core and in Europe. It is recognized in the Thanetian age Bottom Beds in southeastern England, the Late Landenian (L-2) age Sables d'Ostende-ter-Streep of Belgium, the Late Palaozan age sediments of northern Germany, the Middle Paleocene age sediments of northeastern Spain, the Ilerdian age Gubersandstein of Switzerland, the Thanetian age section of the Gres des Viroins of eastern France, and the upper part of the Sables de Bracheux of Thanetian (T-III) age in the Paris

Basin (*Wetzeliella* W-1 Zone). Costa and Downie (1976) note that this initial *Wetzeliella* (now *Apectodinium*) horizon has also been recorded in Greenland, the North Sea Basin, northern France, the U.S.S.R., and likely Australia and New Zealand.

As the present study was nearing completion, a dinoflagellate zonation of a Paleocene section in the Viborg No. 1 core from central Jylland, Denmark, was published by Heilmann-Clausen (1985). Although timing did not permit a detailed comparison between the uppermost Danian and Selandian (=Thanetian) age units of the Danish core and the Aquia strata of the Oak Grove core, some general remarks can be made. At least 25 dinoflagellate species recovered in this age interval appear to be common to both areas (see the section "Palynological Biostratigraphy: Ages of the Formations"). Whereas the range tops of *Palaeoperidinium pyrophorum, Fibradinium annetorpense,* and *Xenikoon australis* are staggered and found respectively at the top of the D-1 Zone, the base of the D-3 Zone, and the base of the D-4 Zone in the Aquia, their last occurrences all coincide at the top of Zone 3 (possible disconformity?) in the lower Holmehus Formation of the Viborg core. The base of Zone 5 in the Viborg core, marked by first occurrences of *Apectodinium homomorphum, Adnatosphaeridium robustum,* and *Lingulodinium machaerophorum*, is likely correlative with the base of the D-6 Zone in the Aquia. The highest abundances of the species of *Apectodinium* in Zone 6 of the Upper Selandian Olst Formation of the Viborg core may correlate with the influx of specimens of *Apectodinium homomorphum* complex in the uppermost Aquia sample in the D-6 Zone. A more comprehensive correlation with this Selandian section must await further study, and will be presented in a future formal publication.

The Nanjemoy strata in the Oak Grove core from Sample 324 to 332 (=Potapaco Member; upper D-6, and D-7 and D-8 Zones) are likely equivalent to the late Early Ypresian age *Eatonicysta ursulae* (LC-2) Assemblage Zone (Bujak et al, 1980a) and *Wetzeliella similis* and *Wetzeliella varielongituda* Zones (Costa and Downie, 1976) of southern England, based on the biostratigraphic distribution of *Adnatosphaeridium multispinosum-vittatum* complex, *Wetzeliella varielongituda* and *Kisselovia coleothrypta*. The interval from about Sample 333 to the top of the unit (=Woodstock Member; D-9 and D-10 Zones) is correlative with at least the Middle to Late Ypresian age *Kisselovia reticulata* (LC-3).Assemblage Zone (Bujak et al., 1980a) of southern England, based primarily on *Kisselovia coleothrypta*. Due to a lack of identifying and characterizing species and questions of zone definition, however, it is difficult to distinguish other zones (e.g., *Homotryblium abbreviatum* (B-1) Zone) that may be present in whole or in part above the LC-3 Zone in the uppermost Nanjemoy. Islam (1983b,c), for example, feels that the bases of the LC-3 Zone and what is called the overlying B-1 Zone may in fact coincide. Until this problem is resolved, further zone assignment in these uppermost Nanjemoy sediments remains questionable. Biostratigraphic range bases of *Melitasphaeridium pseudorecurvatum* and *Paucisphaeridium inversibuccinum* (in lieu of *Wilsonidium tabulatum*), *Wetzeliella varielongituda,* and *Kisselovia coleothrypta*, in that order, as well as

Apteodinium australiense, Deflandrea wardenensis, Polysphaeridium zoharyi, and *Samlandia chlamydophora*, can be correlated between the Nanjemoy strata of the core (D-7, D-8, and D-9 Zones) and the Ypresian Argile D'Ypres of Belgium and the Netherlands. Correlation of the Nanjemoy strata with the Eocene section of northern Germany is limited by too few taxa in common. The identifying species of the D-8 and D-9 Zones, *Wetzeliella varielongituda* and *Kisselovia coleothrypta*, in the core are recorded at the same stratigraphic level in the Eozan 3 strata of the German study; perhaps closer spacing of samples would differentiate the bases. In the Nanjemoy strata (D-9 Zone) of the Oak Grove core, the initial occurrence of *Kisselovia coleothrypta*, as well as *Homotryblium pallidum-tenuispinosum* complex, can be correlated with those in the Ilerdian age sediments of northeastern Spain. In addition to the species of the *Apectodinium homomorphum* complex with ranges beginning at the base of the Ilerdian age upper Gubersandstein in Switzerland, the first occurrences of *Adnatosphaeridium multispinosum-vittatum* complex, *Wilsonidium tabulatum,* and *Kisselovia coleothrypta* can be correlated between the Nanjemoy strata (D-7, D-8, and D-9 Zones) and Ilerdian age upper Gubersandstein and Schoni Sandstein of Switzerland. The peak abundance of *Wilsonidium tabulatum* in the D-7 Zone of the core may be correlative with similar high numbers recorded in the Swiss Schlieren Flysch. The D-8 and D-9 Zones in the Nanjemoy of the Oak Grove core appear to correlate with the Ilerdian-Cuisian age Sables de Laon and Formation de Varengeville (*Wetzeliella* W-5 and W-6 Zones) of the Paris Basin, on the basis of the initial appearances of *Wetzeliella varielongituda* and *Kisselovia coleothrypta*. In the Haute-Savoie section of eastern France, the range base of *Adnatosphaeridium multispinosum* likely correlates with *A. multispinosum-vittatum* complex in the basal Nanjemoy. The first occurrences of *Wilsonidium tabulatum* and *Kisselovia coleothrypta* are curiously reversed in the Ilerdian-Ypresian strata.

C. Oak Grove Core and Offshore Eastern Canada Sections

The biostratigraphic distribution of dinoflagellate species from the Aquia, Marlboro Clay, and Nanjemoy strata of the Oak Grove core is compared with the distribution from the Lower Tertiary sediments of the Grand Banks off Newfoundland, the Scotian Shelf off Nova Scotia, and the Labrador Shelf off Labrador. Published investigations of dinoflagellate biostratigraphy of the offshore eastern Canada area include Gradstein et al. (1975), Williams and Brideaux (1975), Williams (1975), Gradstein and Williams (1976), Williams and Bujak (1977), and Barss et al. (1979).

The comparison of the ranges of 19 dinoflagellate species common to both the Oak Grove core and the Canadian shelf area is shown in Chart 5 (in back pocket). The key at the right side of the chart indicates the species corresponding to the numbered ranges and the abbreviations used in the column.

The occurrence of *Palaeoperidinium pyrophorum* has been used to define Danian age sediments in both the Oak Grove core (D-1 Zone) and the offshore eastern Canada shelf. The highest occurrences of *Tanyosphaeridium variecalamum* and *Fibradinium annetorpense* are reported as coincident with that of *Palaeoperidinium pyrophorum* in the Early Paleocene age strata of offshore Canada, but their ranges terminate somewhat higher than does *P. pyrophorum* in the Aquia strata of the Oak Grove core; this is likely the result of the widely spaced sampling intervals used in the offshore Canada studies. *Turbiosphaera filosa*, which is recorded as ranging throughout the Paleocene age rocks of the Canadian shelf, has a more restricted range in the Paleocene sediments in the core (D-2, D-3, and D-4 Zones). Although the range of *Hafniasphaera septata* terminates in approximately mid Early Eocene age strata of both areas (D-8 Zone in the core), it begins in the Early Paleocene of the Virginia coastal plain and the Late Paleocene of the Canadian shelf. The ranges of *Apectodinium homomorphum* complex, *Eocladopyxis peniculata, Fibrocysta bipolare,* and *Lingulodinium machaerophorum* begin in the Late Paleocene age strata of both the Oak Grove core (D-5 and D-6 Zones) and offshore Canada.

The first occurrences of *Adnatosphaeridium multispinosum-vittatum* complex (upper D-6 Zone), as well as *Melitasphaeridium pseudorecurvatum* and *Polysphaeridium zoharyi* (lower D-7 Zone), *Wetzeliella varielongituda* (base of D-8 Zone), and *Deflandrea wardenensis, Homotryblium pallidum-tenuispinosum* complex, *Hystrichokolpoma eisenackii*, and *Kisselovia coleothrypta* (base of D-9 Zone) permit a general biostratigraphic correlation between the

Ypresian age Nanjemoy strata of the Oak Grove core and the Early Eocene age sediments of the eastern Canadian Continental Shelf.

Paleoenvironmental Implications

A. General Statement

Because of the paucity of dinoflagellate ecological studies and the preliminary nature of much of the ecological data gathered to date, paleoecological interpretations based on fossil dinoflagellates must remain tentative. Researchers have attempted to determine what parameters influence the composition, abundance, and distribution of the associations of thecae living in the water column (biocoenoses), as well as the accumulations of cysts in the sediments (thanatocoenoses). Williams, D. B. (1971a) has summarized the environmental factors which most likely affect the productivity of dinoflagellate biosoenoses: (1) incident radiation (function of latitude and time of year) and effective radiation (dependent on viscosity, density, and clarity of the photic zone); (2) temperature; (3) salinity; (4) major nutrients (e.g., phosphates) and trace elements; and (5) hydrodynamic and physical controls (upwelling and currents). A complex interaction of these environmental constraints control the distribution of the biocoenoses living in the photic zone, and ultimately the thanatocoenoses which become the fossil assemblages. The reader is referred to Williams, D. B. (1971b), Reid and Harland (1977), and Wall et al. (1977) for cyst distribution studies, as well as Reid (1974, 1975), Dale (1976), Reid and Harland

(1977), and Evitt (1980, 1981, 1985, p. 37-43) for discussions of encystment and theca-cyst relationships.

The dinoflagellate, acritarch, and chlorophyte cysts recovered from a single palynological sample represent to some degree the associations of these organisms that lived, but not necessarily co-existed, in generally the same environmental setting over an extended period of time. The paleoecological significance of the number of species and numerical abundance of specimens is difficult to evaluate for any one sample. More meaningful information can be gained by studying trends and patterns of assemblage composition, in addition to fluctuations of species and specimen numbers.

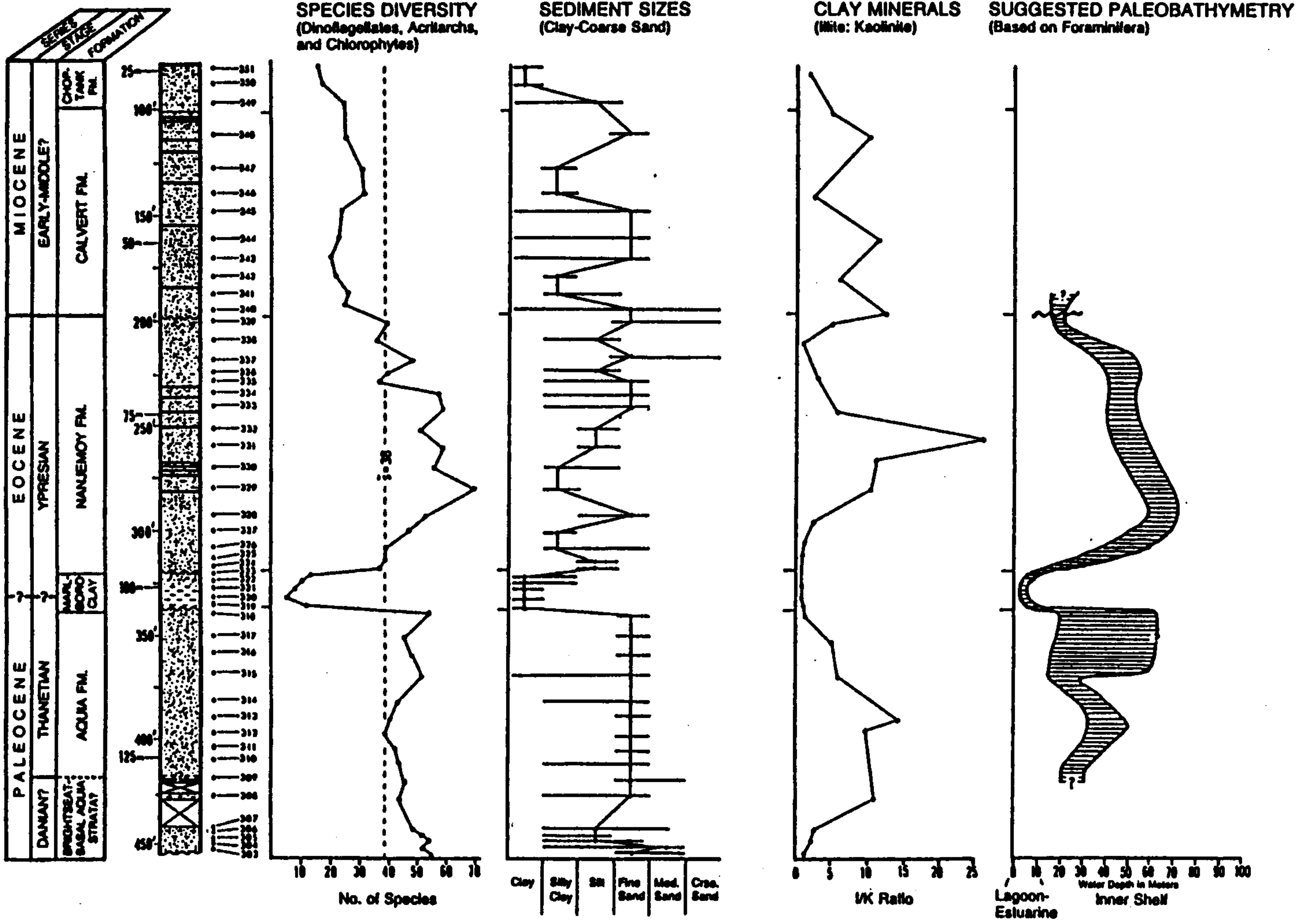
This section will discuss the composition and characteristics of the Tertiary dinoflagellate, acritarch, and chlorophyte assemblages of the Oak Grove core. Various diversity and multivariate analyses of the palynomorph species are described, plotted, and the results discussed. Species diversity data of pollen and spores, benthonic and planktonic Foraminifera, calcareous nannofossils, and mollusks are also included. Dinoflagellate species are investigated in terms of their general generic and morphologic groups; pertinent palynological reference studies are briefly described. The organic-walled phytoplankton assemblages are analyzed in the context of a sedimentological and foraminiferal paleobathymetric framework presented in the following section.

B. Sedimentology and Foraminiferal Paleobathymetry

All paleoenvironmental information reported in sedimentological and Foraminifera-based paleobathymetric studies of the Oak Grove core Tertiary units is summarized below. Sediment sizes, bedding, and mineralogy (including clay analyses) are briefly reviewed for all formations. Water depth assessments are available for the Aquia, Marlboro Clay, and Nanjemoy strata.

The lithostratigraphy of the Tertiary formations in the core is presented in the section "Oak Grove, Virginia, Corehole and Associated Study Localities: Lithostratigraphy of the Oak Grove Core" (based primarily on descriptions by Estabrook and Reinhardt, 1980). For convenient reference, a concise sedimentological summary is included for each unit in the following discussion. A generalized sediment size analysis is plotted in Text-fig. 13 as an illustrative aid. Each horizontal bar represents the range of sediment sizes at that particular level; a line runs through the dominant size fractions. The major minerals noted in the core descriptions include quartz, glauconite, muscovite/biotite, phosphate, and the heavy minerals magnetite/ilmenite.

Of particular interest in the Aquia and Nanjemoy sediments is the abundant authigenic glauconite. Because of its potential paleoecological significance, a short discussion is warranted. Based on present-day glauconite occurrences in the literature, Cloud (1955) concluded that this mineral is forming in mainly normal to near normal



Text-fig. 13. Graphic curves of dinoflagellate, acritarch, and chlorophyte species diversity (richness), sediment size analyses, kaolinite-illite ratios, and suggested foraminiferal paleobathymetry for the Tertiary strata of the Oak Grove core. Refer to text for discussion. Numerical data for species diversity curve listed in Appendix I(B).

salinity marine waters on continental shelves away from large rivers. Although primary glauconite has been recorded in a wide water depth range (20 m to 725 m; 60 ft to 2400 ft), it seems to be most prevalent in all but the shallowest part of the neritic zone. Its formation is facilitated by the presence of decaying organic matter in reducing conditions, at least near the sediment-water interface; it can also form in micro-reducing environments (e.g., foraminiferal tests and fecal remains) in generally oxygenated water (Burst, 1958). Relatively cool waters appear to be most conducive to glauconite formation, and in fact recent German, Hungarian, and Swedish research, summarized by Benson et al. (1985), suggests that cold, upwelled waters moving into the more shallow marginal seas is a significant controlling factor. Although formation of glauconite-rich sediments is believed to be a very slow process, the importance of a requisite slow rate of detrital influx is now being questioned.

Clay mineral analyses may also provide information pertaining to their depositional environments. Clays in the Oak Grove core were semi-quantitatively analyzed by M. H. Hess of the U.S.G.S. (see p. 11-12 of Reinhardt et al., 1980b); the curve shown in Text-fig. 13 of the present study represents the ratio of illite (I) to kaolinite (K) throughout the section. Clay studies by Porrenga (1966) and Edzwald and O'Melia (1975) have demonstrated that the percentage of illite with respect to kaolinite generally increases seaward from deltaic and estuarine settings. Very low I : K ratios (for example, less than 1.0 in curve of Text-fig. 13) would presumably suggest proximity to shore, and higher ratios greater distances from shore. Because of possible diagenetic alteration of clays, the ratios can only be considered general indicators to be used with other parameters.

The proposed depths of water on the paleobathymetric curve (see Text-fig. 13) are based on both numbers and types of Foraminifera species, as well as planktonic to benthonic ratios, reported by Gibson in Gibson et al. (1980); refer to Gibson (1968) and Gibson and Buzas (1973) for interpretative basis. The curve represents the ranges of possible water depths (in meters) of deposition for the Aquia (lowest sample with Foraminifera at 125.9 m (413 ft) core depth), Marlboro Clay, and Nanjemoy sediments in the core. Poor recovery prevented analyses of the Calvert and Choptank units. Depths on the scale less than 10 m are considered lagoonal or estuarine settings, and those generally between 10 m and 70 m constitute an inner neritic shelf environment.

Pamunkey Group

The Pamunkey Group, with a thickness of 77.6 m (254 ft) in the core, consists generally of two shelly, glauconitic silty and sandy units (Aquia and Nanjemoy Formations) separated by a distinctly different gray to red clay (Marlboro Clay). This package of sediments was deposited atop an old Cretaceous surface in a long, shallow depression which trended northeast-southwest from present-day eastern Stafford County, Virginia, into the central portions of Charles County and Prince Georges County, Maryland (Shifflett, 1948; Ward, 1984); see Text-fig. 3 for approximate geographic limits.

Aquia Formation

General Setting. Paleontological and sedimentological evidence suggests that the Aquia sea was situated on a nearshore (inner neritic) shelf and was generally characterized by variable current activity in relatively well oxygenated waters with probable reducing conditions near the sediment-water interface. Sediments accumulated slowly in slightly fluctuating water depths of approximately 15 m to 60 m or slightly greater (based on foraminiferal and mollusk data), gradually shallowing in Late Aquia time (Ward, 1984; Beauchamp, 1984). An isopach map of the Aquia sediments (see p. 37 of Shifflett, 1948) reveals its greatest thickness of about 52 m (170 ft) along the axis of the basin. The estimated location of the Oak Grove corehole at the southernmost extreme of this map places it between the projected 110 ft and 120 ft isopach lines; the Aquia is reported as 115 ft thick in the core.

Sedimentology. The Aquia Formation is represented by massively bedded, fine to medium grained greensands in the Oak Grove core; there is no obvious lithologic evidence for Brightseat strata (Reinhardt et al., 1980b). Palynomorphs recovered from the lowermost 12 m (38 ft), however, suggest that if this is indeed Aquia lithology, it represents section slightly older than the basal Aquia at the type locality (see the section "Palynological Biostratigraphy: Ages of the Formations"); referred to as the Brightseat equivalent-basal Aquia? interval, it will be considered herein as part of Aquia deposition. The predominantly greenish-black Aquia sediments are bioturbated throughout, with preserved burrows observed in only the basal part of the unit. Bivalves are found scattered in the core above a depth of about 124.5 m (409 ft), with some local concentrated beds. In addition to abundant quartz and some muscovite/biotite horizons, authigenic glauconite is present in high percentages (up to 65% of sand fraction). Much of the Aquia contains less than 10% clay by weight. Clay mineral ratios of illite (up to 80% in some samples) to kaolinite support a shelf environment away from any significant deltaic or estuarine influence.

Foraminiferal Paleobathymetry. At the stratigraphically lowest sample containing Foraminifera (Sample 310), a shallow marine depth of 30 m or less is indicated, based on 16 benthonic species and a planktonic proportion of about 0.5%. Water depths appear to have slightly increased thereafter to about the Sample 313 horizon, and then shoaled and may have reached a minimum (30 m or less?) just below Sample 315. A small disconformity may exist between Samples 315 and 316, as suggested by an abrupt change in benthonic foraminiferal assemblages, as well as the pattern of first and last occurrences of dinoflagellates. Above Sample 316, the water depths fluctuated between 15 m and 60 m (or somewhat greater) to the top of the Aquia.

Marlboro Clay

General Setting. Foraminiferal and other paleontological evidence suggests that the Marlboro Clay was likely deposited in a very nearshore, brackish water lagoon or estuary. Redeposited Paleozoic and Late Cretaceous age pollen and spores (Frederiksen in Gibson et al., 1980), relatively high kaolinite percentages, and abundant heavy minerals reflect an eroding Piedmont source to the west (Reinhardt and Mixon, 1980).

Sedimentology. Kaolinite (up to 50% in some samples) dominates over illite in this brown, red, and gray, mostly structureless, plastic clay with rare glauconitic sands; this corroborates an estuarine or very nearshore setting. Swirled bedding suggests some soft sediment deformation and bioturbation. Well-rounded zircons and tourmaline dominate the heavy mineral suite. The Aquia-Marlboro Clay boundary has been reported as gradational, and the Marlboro Clay-Nanjemoy contact as relatively sharp. Both may in fact represent small disconformities.

Foraminiferal Paleobathymetry. Foraminiferal evidence suggests a drastic and abrupt change from neritic conditions in the Aquia to lagoonal/estuarine water depths of less than 10 m in the Marlboro Clay. A sample in the uppermost 0.1 m (0.3 ft) of the Aquia yielded

34 calcareous species, whereas a sample in the lowermost 0.3 m (1 ft) of the Marlboro Clay produced only six agglutinated forms. The low diversity agglutinated assemblage in the clays suggests a brackish water setting (based on similar Marlboro Clay recoveries by Nogan, 1964); a rather sudden increase in water depths is indicated in the basal Nanjemoy directly above the contact.

Nanjemoy Formation

General Setting. The Nanjemoy sea must have been very similar to the inner neritic setting of the Aquia sea. Water depths probably ranged from about 15 m to 70 m or slightly greater. Nanjemoy sea level may have fluctuated somewhat more than that of the Aquia.

Sedimentology. The dominant sediment sizes of the clayey greensands of the Nanjemoy strata in the core vary throughout the unit considerably more than in the Aquia greensands. The Nanjemoy section can best be described as a basal clayey silt (part of a transgression?) overlain by two coarsening-up sequences (regressions with an intervening transgression?) of silty clays to fine sands with thicknesses of about 10 m (33 ft) between core depths 96 m (317 ft) and 86 m (284 ft) and 18 m (60 ft) between core depths 86 m (284 ft) and 68 m (225 ft); alternating dominant sediment sizes characterize the upper 7.6 m (25 ft) of this unit. The lithologic change from predominantly silts to fine sands at about the 75 m (248 ft) level may represent a subtle disconformable contact between the Potapaco and Woodstock Members (see the section "Palynological Biostratigraphy: Relation to the Formation and Member Contacts"); large burrows are present near this level. Although bedding is mostly massive in the Nanjemoy, distinct textural changes, as well as shell lags, thin shell beds, and fish scale and lignite debris horizons, define thinner bedding planes in some intervals. Mottled lithologies are particularly common in the clayey sequences. Bioturbated sediments with some discrete in-filled burrows are similar to those described for the overlying Miocene Calvert strata. Highly polished, subangular to rounded quartz grains and rounded, lobate, and accordion-shaped glauconite grains are the main mineralogical components. Clays in the Nanjemoy range from 15% by weight in the silts and sands to approximately 80% in the primarily clayey beds. Illite is highly dominant over kaolinite in the middle part of the Nanjemoy section (near 78 m (257 ft) level). In the lowermost 3 m (10 ft) of the unit directly above the Marlboro Clay, I : K ratios are slightly less than 1.0. The illite to kaolinite curve supports generally deepening shelf waters subsequent to the Marlboro Clay lagoonal setting, with a gradual shallowing into the upper Nanjemoy core section; the relatively high kaolinite percentage near a leached zone at the 64 m (211 ft) core level is believed to be due to fresh water diagenesis.

Foraminiferal Paleobathymetry. Benthic species richness (17 species) and planktonic percentages (about 3%) suggest inner neritic water depths of less than 30 m for the basal transgressive strata. A maximum water depth of approximately 60 m to 70 m is indicated near Sample 328, based on 39 benthonic species and a planktonic percentage of about 20%. Foraminiferal data reflect a very gradual shallowing thereafter, with one possible slight deepening episode near Sample 337. Approximately 10 benthonic species and very low planktonic ratios are indicative of shoaled water depths of about 15 m to 20 m in the uppermost 6.1 m (20 ft) of the Nanjemoy.

Chesapeake Group

The Chesapeake Group is represented in the Oak Grove core by the siliceous Calvert and Choptank Formations, containing both land-derived quartz and marine diatoms and sponge debris. This marine sedimentary sequence was deposited atop an eroded Nanjemoy terrain subaerially exposed for a period of from 15 to 30 millions years, depending on location.

Calvert Formation

General Setting. Marine invertebrate and vertebrate paleontological studies of cores and outcrops indicate that Calvert sediments were deposited on a shallow, nearshore (possibly inner neritic) shelf.

Sedimentology. The Nanjemoy-Calvert contact is both texturally and compositionally sharp. The Calvert strata in the core are primarily fine sands, silts, and silty clays, with some diatomaceous clays in the lower part; coarse sands and shell lags mark erosional contacts very near the boundary. Although considerably bioturbated, the Calvert exhibits some relict bedding which alternates from thin to rather massive. Horizontal, in-filled vertical, and back-filled U-shaped burrows are preserved at some horizons. Fine lignitic particles, as well as shark teeth, fish scales, bone fragments, and bivalve molds, are distributed throughout. The high illite (up to 81% in some samples) to kaolinite (up to 10%) ratios support a shelf setting.

Foraminiferal Paleobathymetry. Poor recovery of foraminifers from these strata precluded paleobathymetric assessment.

Choptank Formation

General Setting. The Choptank environment of deposition was likely very similar to the nearshore shelf postulated for the Calvert.

Sedimentology. Deposited conformably atop the Calvert strata are the relatively thick bedded, silty clays and clayey silts of the Choptank Formation. Some burrowed and bioturbated horizons were noted. Angular quartz, pyrite, and muscovite are part of the sand/coarse silt fraction. Clay analyses revealed higher percentages of illite (up to 50%) than kaolinite (up to 20%).

Foraminiferal Paleobathymetry. Poor recovery of foraminifers from these strata precluded paleobathymetric assessment.

C. Statistical Analyses of the Organic-walled Phytoplankton Assemblages

The first part of this section briefly describes the numerical techniques used to statistically analyze the dinoflagellate, acritarch, and chlorophyte species for paleoecological purposes. This study employed various types of species diversity curves, as well as cluster analysis and principal coordinates analysis. The second part of this section discusses the results of the statistical analyses of the Tertiary assemblages in the Oak Grove core.

Statistical Methods

Species Diversity Indicators. The three types of species diversity measurements used in this investigation include richness, Shannon-Wiener index, and evenness (see Text-fig. 14). The most basic of these curves plots the richness, or simply the total number, of species of dinoflagellates, acritarchs, and cholorphytes in the samples. Two inherent weaknesses of the richness curve include its dependence on the count size of the sample and its inability to measure dominance of individual species within a sample.

The Shannon-Wiener index (H) is a logarithmic measurement that minimizes the problems encountered in varying sample sizes, and reflects both numbers of species (richness) and significant dominance of any species in a sample. It is defined as:

$$H = -\sum_{i=1}^{s} p_i \ln p_i$$

where s is the number of species (richness) in the sample, and p_i is the proportion of the ith species in the sample, i.e., the number of specimens of a particular species divided by the total number of specimens (Buzas, 1979). In this study the curve is plotted on a scale of 0.0 to 4.0. Values increase to the right for samples represented by increasing numbers of species which are evenly distributed in abundances; conversely, values decrease to the left for samples of lower species richness and some highly dominated taxa.

The third curve, called evenness (E), is derived by dividing the Shannon-Wiener index (H) by its theoretical maximum (Hmax); the maximum value that H could have for a particular sample is equal to *ln* s (natural logarithm of the total number of species S). It can be expressed as:

$$E = \frac{H}{H_{max}}$$

Evenness essentially shows how equitably the species are distributed in a sample. The value approaches 1.0 when all species have nearly the same abundance and decreases toward 0.0 when individual species are extremely abundant.

Cluster Analysis. This numerical procedure basically shows relationships (similarities and dissimilarities) among objects (observations or variables) in a set. Using a data matrix of observations and variables, a resemblance matrix of either observations based on resemblance of its constituent variables (called Q-mode), or variables based on resemblance of its constituent observations (called R-mode), is produced by means of a resemblance (similarity or dissimilarity) coefficient. Clusters of differing sizes can be delineated depending on the position chosen for the cut-off level of resemblance. Decisions that must be made prior to clustering any data include: mode of analysis, data weighting, transformation, and standardization, type of resemblance coefficient, and clustering method (see Romesburg (1984) for discussion).

In this study a Q-mode analysis was run to group the samples (=observations) in the core on the basis of resemblance of the species composition (=variables) of the organic-walled phytoplankton assemblages. The clusters of samples, with their repetitive, similar assemblages of dinoflagellate, acritarch, and chlorophyte species, are believed to have paleoecological significance and are discussed in detail in the following section "Statistical Results". An R-mode analysis, clustering species based on mutual resemblance of the distribution pattern of the samples, was also run to see which species generally occur together throughout the Tertiary section. A two-way table was produced to display by way of symbols on a single format both cluster analysis modes.

The cluster analyses were generated at the Unocal Research Center, Brea, California, using the PROCDENDRO procedure of the Ecological Analysis computer program written by R. W. Smith of Ecological Data Analysis, Ojai, California. The original data set (numerical range chart) was first transformed, weighted, and standardized. Briefly stated, transformation involved taking the square root of all counts to minimize the effect of extremely abundant species occurrences. Because they are not considered statistically significant, those species occurrences with abundances less than 1% of the assemblage total (i.e., less than 3 specimens) were eliminated before transformation. Weights were then calculated based on a uniqueness factor for each sample. Standardization included dividing the transformed count for each species (in R-mode) and sample (in Q-mode) by its maximum value and then multiplying by the weight from the weighting procedure. A resemblance coefficient subsequently measured the overall resemblance between each pair of species (and samples) in this modified data matrix to produce a square, unitless resemblance matrix for species (and samples). Because true paleoenvironmental conditions are believed to be more accurately reflected by numerical abundance data rather than simple presence-absence data, the quantified Euclidean distance coefficient was chosen. Referred to as a dissimilarity coefficient, it measures the actual distance between objects (species) when they are plotted as points in *n*-dimensional space formed by their attributes (samples), and vice-versa. The Euclidean distance coefficient is simply the square root of the sum of the squares of the differences of the values on the *n* attributes (by Pythagorean theorem) and is expressed as:

$$e_{jk} = \sqrt{\sum_{i=1}^{n} (x_{ij} - x_{ik})^2}$$

where x_{ij} is the value of the *i*th attribute measured on the *j*th object. The range of e_{jk} is between 0.0 and infinity; the closer the value is to 0.0 the more similar two objects are. For e_{jk}, like all dissimilarity coefficients, the distance scale at the top of the dendrogram runs from 0.0 at the right (most similar linkages) to larger numbers, or *infinity* at the left (least similar linkages).

Principal Coordinates Analysis. This multivariate statistical technique plots observations (samples) in multidimensional space employing the same resemblance matrix of the cluster analysis. Used as a complementary procedure to cluster analysis, it allows one to more effectively evaluate the clusters of the dendrogram. Because principal coordinates analysis positions samples geometrically as points in space, it consequently overcomes two weaknesses of cluster analysis: (1) the hierarchical nature of clustering necessarily causes all observations or variables to link up at some level regardless of how randomly distributed they may be; and (2) continued averaging of the resemblance values in the clustering process results in distortion in the lower level branches of the dendrogram.

To reduce the dimensionality of the problem, principal coordinates analysis relates observations (samples) in a data set to major axes called eigenvectors. A transformed sample X sample (Q-mode) resemblance matrix forms the basis for derivation of the eigenvectors (orthogonal axes of an ellipsoid delineated by matrix elements) and eigenvalues (lengths of the axes; eigenvector variance). The maximum variance is accounted for by the first eigenvector, the longest axis of the ellipsoid; the second eigenvector defines the next greatest direction of variance, and so on for a total number of eigenvectors that equals the number of observations. The elements of the extracted eigenvectors describe the coordinates of the samples (see Hazel (1977) for detailed discussion).

Two-dimensional plots representing the array of samples for the first and second, the first and third, and the second and third principal coordinate axes have been included in this study. Principal coordinates analyses were generated with the PCOORD procedure of the EAP computer program used for cluster analysis.

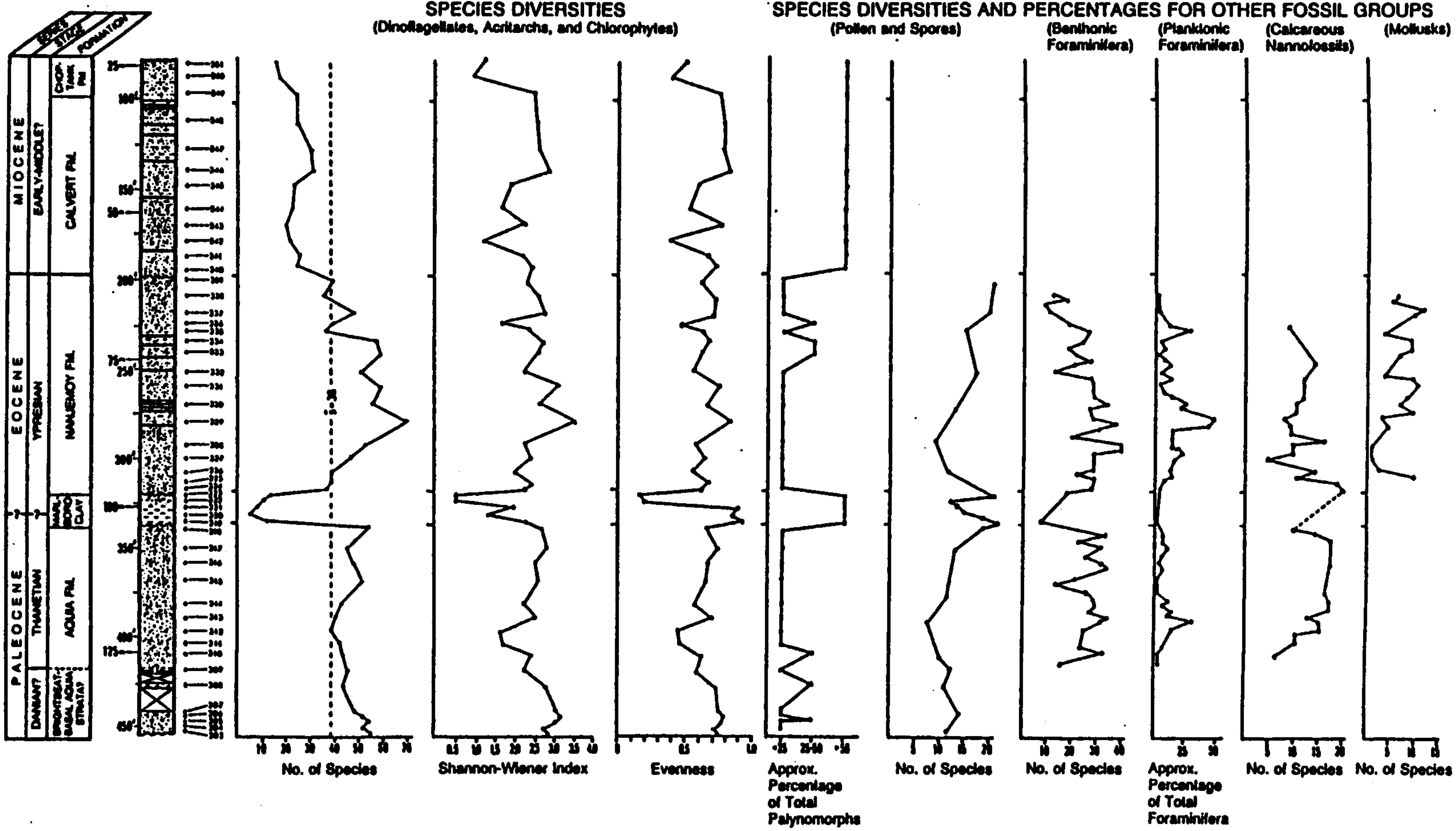
Statistical Results

This section first presents general statistical analyses of the organic-walled phytoplankton assemblages that provide some paleoecological insight into the Tertiary units of the Oak Grove core. Included are various species diversity indicators, as well as analyses patterned after previous investigations that suggest correlation of (1) certain associations, (2) broad taxonomic affinities, and (3) morphological cyst groups of dinoflagellate species with particular paleoenvironmental settings. Following these general paleoecological assessments, the results of cluster analysis, principal coordinates analysis, and rank-abundance analysis performed on the assemblages are discussed.

Species Diversities. Studies of modern marine phytoplankton associations, including dinoflagellates and acritarchs, have shown that species diversities may reflect valuable environmental information, such as indications of relative distance from shore (Hulburt, 1963; Valentine, 1973; Wall et al., 1977; Reid and Harland, 1977). Numbers of species are typically low, but highly dominated, in very nearshore settings of turbulent waters and widely fluctuating temperatures, salinities, and nutrient influx (e.g., estuaries). Further offshore on the continental shelf, however, the complex and varied, but less turbulent, conditions of the neritic environments provide a wide array of niches for a much larger number of species. Finally, in the stable, more homogeneous conditions of the deeper oceans, diversity decreases significantly due primarily to limited nutrients.

Diversity curves plotting richness, Shannon-Wiener index, and evenness of the dinoflagellate, acritarch, and chlorophyte species of the Oak Grove core are presented in Text-fig. 14; also included are species diversities and percentages of pollen and spores, benthonic and planktonic Foraminifera, calcareous nannofossils, and mollusks. Thirty-eight organic-walled phytoplanktpon species is the mean per sample over the entire Tertiary section of the core. Ranges of species richness in the Aquia (38 to 54 species) and Nanjemoy (36 to 69 species) strata are well above the total section mean. In the intervening Marlboro Clay, species per sample drastically decrease, ranging from only 5 to 13. Richness ranges in the Miocene Calvert (20 to 32 species) and Choptank (15 to 26 species) strata are well below the total section mean and considerably lower than the Aquia and Nanjemoy values.

In addition to species richness, the Shannon-Wiener and evenness curves and unusually high abundances of particular dinoflagellate species, as well as diversity data of the other fossil groups, may provide valuable paleoecological information. The basal Aquia? strata yielded relatively high values of both numbers and evenness (equitability) of organic-walled phytoplankton species, followed by a



Text-fig. 14. Graphic curves of dinoflagellate, acritarch, and chlorophyte species diversity (richness, Shannon-Wiener, evenness) and approximate percentages and species diversities of other microfossil groups, including pollen and spores, foraminifers, calcareous nannofossils, and mollusks for the Tertiary strata of the Oak Grove core. Refer to text for discussion. Numerical data for phytoplankton and pollen and spores listed in Appendices I(B) and I(G).

decreasing trend up to about Sample 312. High numbers of *Glaphyrocysta exuberans* complex contribute to the two lowest evenness values of the Aquia in Samples 311 and 312. This species, postulated by Downie et al. (1971) to reflect open sea settings, may have thrived especially well in relatively diverse dinoflagellate associations inhabiting the slightly deepening waters indicated by the Foraminifera. The abrupt Shannon-Wiener/evenness increase from Samples 312 to 313 occurs at about the horizon thought to represent a relative maximum inner neritic water depth; numbers of dinoflagellate species increase only slightly. The lowest number of pollen and spore species was observed near Sample 313, as might be expected with this probable greater distance from shore, but the reason for the decrease in calcareous nannofossil species is unclear. Foraminiferal data suggest a minimum water depth (30 m or less?) just below Sample 315, near a possible disconformable horizon. The interval between Samples 315 and 318 (Paspotansa Member?), reflecting fluctuating inner shelf water depths, is characterized by generally increasing Shannon-Wiener/evenness values, with a decrease in the uppermost sample. The high abundance of *Apectodinium homomorphum* complex, a species believed by Downie et al. (1971) to represent estuarine influence, in Sample 318 may mark the first indications of somewhat brackish water which would ultimately characterize the Marlboro Clay environment. The high numbers of calcareous nannofossil species in the upper Aquia decrease rather sharply in the top two samples, as pollen and spore species increase.

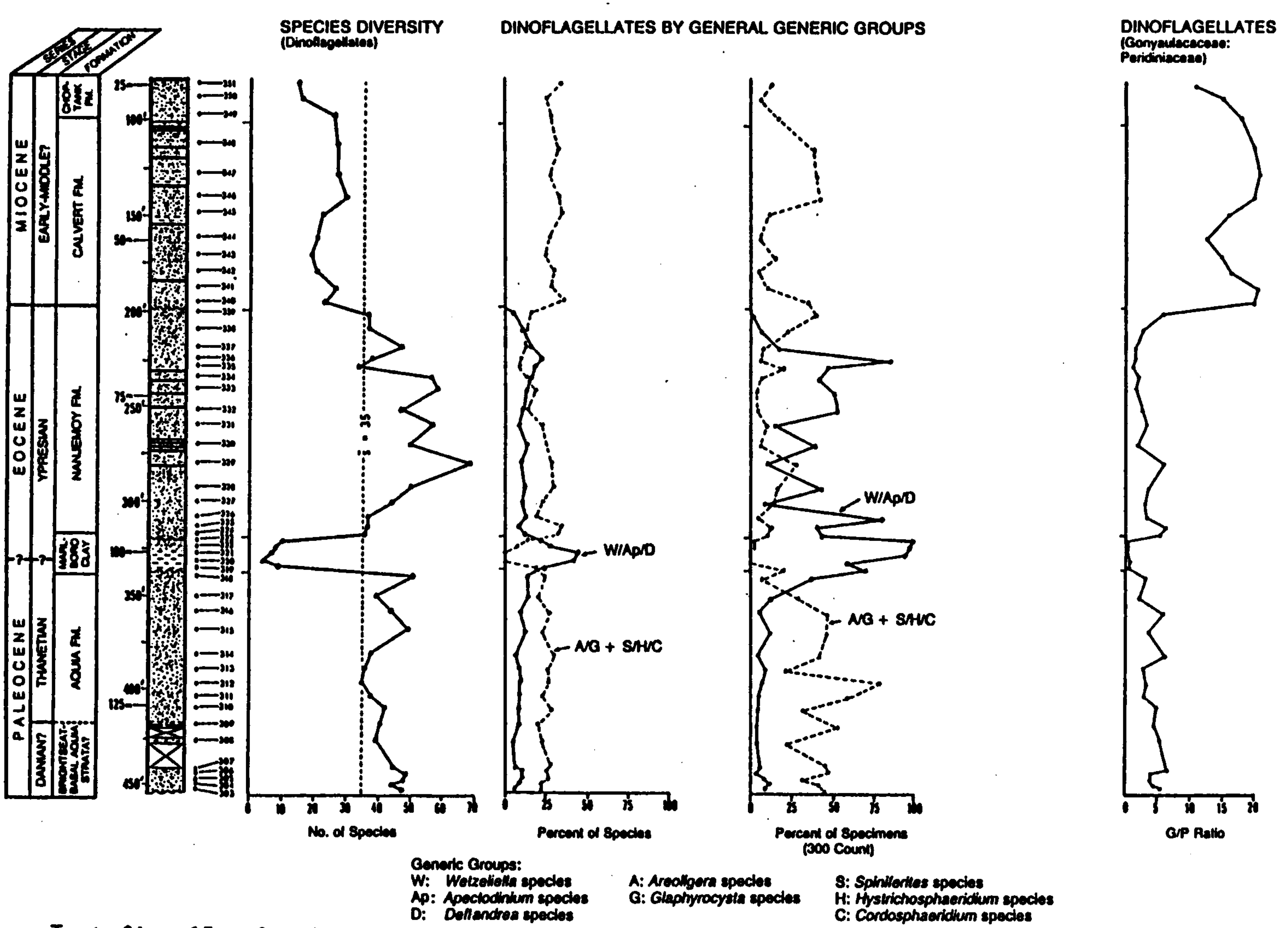
The extremely low numbers of dinoflagellate species in the disconformity-bounded Marlboro Clay are matched by few Foraminifera (agglutinated) species and no calcareous nannofossil species. Pollen and spore species richness is relatively high within the unit; abundant fern spores are accompanied by the freshwater alga *Pseudoschizaea* (Frederiksen in Gibson et al., 1980). Shannon-Wiener/evenness values of the organic-walled phytoplankton suggest two possible intervals in the Marlboro Clay; a lower section between Samples 319 and 321 of rather equally distributed, very low abundance species (less than 6 specimens each in a 30 count); and an upper section between Samples 322 and 323 highly dominated by *Senagalinium? dilwynense* (up to 275 specimens in a 300 count).

In the lowermost Nanjemoy (Samples 324 and 325), an initial transgressive phase produced a richness of organic-walled phytoplankton species close to the total Tertiary core section mean of 38. Relatively high numbers of *Apectodinium homomorphum* complex and *Senagalinium? dilwynense* may reflect a lingering estuarine influence of the preceding Marlboro Clay environment. In an overlying coarsening-up (regressive?) sequence, the Shannon-Wiener/evenness curves fluctuate somewhat, as do diversities of calcareous nannofossil species. Although a relative maximum water depth of about 60 to 70 m is reflected by the Foraminifera in the silty, fine-grained sands of Sample 328 near the top of this sequence, the next higher sample (Sample 329) in fact yielded the highest species richness and Shannon-Wiener/evenness values for the organic-walled phytoplankton of the entire Tertiary section of the core. The diversity data of the assemblages in Sample 329, a silty clay near the base of the next coarsening-up (regressive?) sequence, may actually reflect part of an intervening transgressive pulse. Diversities of pollen and spores are at a low and calcareous nannofossil species peak between Samples 328 and 329. The coarsening-up sequence extends upward to about Sample 336, a silty, medium-grained sand, where a possible slight deepening is suggested by the foraminiferal assemblages. At this horizon, however, organic-walled phytoplankton species richness and Shannon-Wiener/evenness values decrease, with high numbers of *Deflandrea phosphoritica* and *Wetzeliella hampdenensis*, suggested by Downie et al. (1971) to reflect estuarine influence. Similar to the sequence below, increases in diversity indicators are actually seen 1.8 m (6 ft) higher in Sample 337. The diversity peaks of the organic-walled phytoplankton assemblages appear to have lagged slightly behind water depth increases indicated by benthonic and planktonic Foraminifera, suggesting differential response rates by the faunal and floral groups to changes in the environment. In the upper part of the Nanjemoy strata of the core, diversity indicators of the dinoflagellate, acritarch, and chlorophyte species, while fluctuating, show a slight decline in shallowing water depths of about 15 to 20 m. Pollen and spores and mollusks increase in species richness; the absence of calcareous nannofossil species may be the result of leaching.

Only organic-walled phytoplankton diversity data and approximate pollen and spore percentages are presented for the Miocene units in the Oak Grove core. Diatoms were recovered but diversity information is not available. Calcareous nannofossils and Foraminifera were likely leached from these units in the core. In the Calvert strata, Shannon-Wiener/evenness values fluctuate in the lower part of the unit and are generally high in the upper part. Prominent species dominances are marked by the dinoflagellates *Batiacasphaera microreticulata* n. sp. in Sample 324 and *Cleistosphaeridium diversispinosum* complex in Samples 334 and 335. In the Choptank sediments, low equitability in the top two samples can be explained by the extremely high abundance of *Operculodinium centrocarpum*. Land plant spores, and particularly bisaccate pollen, are very abundant with respect to percentages of the total palynomorph assemblage throughout the entire Miocene section of the core; species counts were not made.

Offshore vs. Estuarine Dinoflagellate Associations. In a study of a Lower Tertiary section in southeastern England, Downie et al. (1971) found particular genera of dinoflagellates associated with distinct lithologies representing various paleoenvironments. They identified two associations (*Areoligera* and *Hystrichosphaera*) typically found in sediments deposited in offshore, open sea settings. In the present study, the *Areoligera* association includes species of *Areoligera* and the very closely related *Glaphyrocysta*. The *Hystrichosphaera* association encompasses species of *Spiniferites* (formerly *Hystrichosphaera*), *Hystrichosphaeridium*, and *Cordosphaeridium*. This composite association of species is hereafter designated A/G + S/H/C. The *Wetzeliella* (and *Deflandrea*?) association of Downie et al. (1971), on the other hand, is believed to reflect a very nearshore, possibly estuarine, environment. The present study includes species of *Wetzeliella*, the closely affiliated *Apectodinium, Wilsonidium*, and *Kisselovia*, as well as *Deflandrea* and the morphologically similar *Spinidinium*. This integrated group is referred to as W/Ap/D in the following discussion.

Graphic curves showing the percentages of dinoflagellate species and specimens in terms of their general generic groups throughout the Oak Grove core Tertiary section are presented in Text-fig. 15. Aquia samples are dominated by the A/G + S/H/C associations with respect to percentages of both species and specimens. Only in the uppermost Aquia sample does the W/Ap/D group dominate in specimen percentages. The overlying Marlboro Clay is quite different from the Aquia in that it is made up of all highly dominated W/Ap/D samples. Percentages of A/G + S/H/C species are higher for all but the upper section of Nanjemoy strata. When analyzed by specimen percentages, however, the Nanjemoy displays more fluctuation in association types: first a W/Ap/D dominance in the lowermost section, then alternations of A/G + S/H/C and W/Ap/D dominance, another strong W/Ap/D dominance, and finally an A/G + S/H/C dominance in the uppermost part of the section. For all practical purposes, only A/G + S/H/C groups comprise the Miocene Calvert and Choptank samples.



Text-fig. 15. Graphic curves of dinoflagellate species diversity (richness), percentages of dinoflagellate species and specimens with respect to general generic groups, and gonyaulacacean-peridiniacean ratios for the Tertiary strata of the Oak Grove core. Refer to text for discussion. Numerical data listed in Appendices I(B), I(C), and I(D).

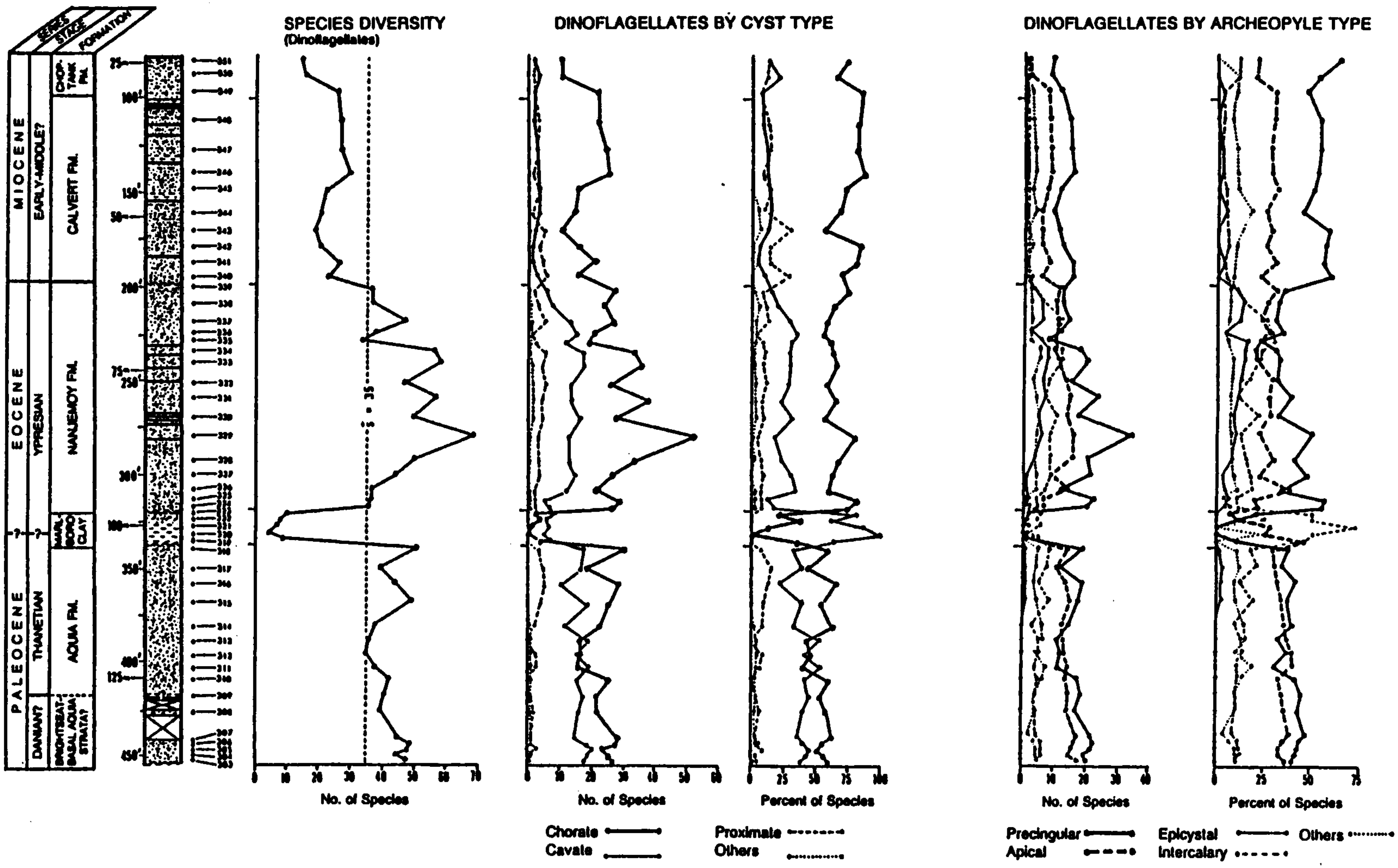
Gonyaulacacean vs. Peridiniacean Dinoflagellate Species. Dinoflagellate ecology studies that have analyzed the composition of assemblages with respect to the broad taxonomic affinities of the component species have demonstrated the value of another apparent environmental indicator known as the gonyaulacacean-peridiniacean (G/P) ratio. The number of dinoflagellate species of gonyaulacacean affinity has been found to be relatively higher than those of peridiniacean affinity in an open marine environment (Schiller, 1937). For example, the mean G/P ratio for cysts from Caribbean Quaternary sediments (Wall, 1967) was computed at 18.0 and for cysts collected very near shore at Woods Hole, Massachusetts (Wall and Dale, 1968) the ratio was determined to be 0.44. This ratio was employed by Harland (1973) in a Cretaceous (Upper Campanian) study in Canada. He noted general increases in the G/P ratio in intervals indicated by foraminiferal studies as open marine settings, and decreasing trends in sections designated as lagoonal/estuarine. In Upper Cretaceous-Paleocene sections of Maryland and Delaware, Whitney (1976) calculated mean G/P values of 1.01 (Mt. Laurel Fm.; nearshore deposition), 0.91 and 1.20 (two lcoalities of Monmouth Fm.; farther from shore), and 2.09 (Brightseat Fm.; farthest from shore in water depths of approximately 300 ft.). A general correlation between fluctuations in G/P ratios and species diversities (richness) was also noted for these units; a similar correspondence of these curves was likewise observed in another study of Upper Cretaceous Merchantville strata in northern Delaware by Whitney (personal communication).

G/P ratios were calculated and plotted for the Oak Grove core dinoflagellate assemblages (see Text-fig. 14). Ranges are similar in the Aquia (2.38 to 7.00) and the Nanjemoy (1.56 to 6.75) strata, though the mean is somewhat higher in the Paleocene Aquia (4.38) than in the Eocene Nanjemoy (3.56). These values are indicative of offshore settings. In contrast, the samples of the stratigraphically intervening Marlboro Clay yielded much lower G/P values (0.20 to 1.00) with a mean of 0.62. These low figures are consistent with the lagoonal or estuarine environment postulated for this unit (compare ratios of 0.44 for Recent very nearshore sediments near Woods Hole of Wall and Dale, 1968). The Miocene dinoflagellate assemblages reflect a drastic change in terms of gonyaulacacean to peridiniacean proportions. Most likely a result of general evolutionary composition change, the G/P ratios are extremely high in the Calvert (13.0 to 21.00; mean of 18.22) and Choptank (11.0 to 18.00; mean of 13.67). An analysis of the Miocene species reveals rather close similarities to Quaternary assemblages (G/P ratios are comparable to Caribbean Sea Quaternary sample ratios of 18.00 of Wall, 1967). The much higher G/P trends in the Miocene to Quaternary assemblages need further evaluation to fully understand their paleoenvironmental implications. The present study shows general correspondence between the G/P and species richness curves, but not consistently on a sample to sample basis. The extreme decrease in numbers of species in the Marlboro Clay does correlate well with the marked drop in G/P ratios.

Dinoflagellate Cyst Morphologies. Another parameter that characterizes dinoflagellate assemblages in terms of general cyst morphologies may have paleoecological significance. Vozzhennikova (1967) suggested that two broad categories of cysts (i. e., cavate and chorate) might have been an ecological response to distance from shore and water depths of their original habitats. Analyzing trends of cyst morphologies, she postulated that the relatively thick walled cavate cysts (typically lacking processes) were found in unstable, very nearshore (possibly turbulent) environments, and the somewhat thinner walled chorate cysts (bearing processes) reflected more open sea settings. The greater surface area provided by the numerous, sometimes elaborate, processes may have aided in their flotation within the photic zone. Results consistent in large part with this environment-influence concept are reported in a dinoflagellate study of the Oligocene Gulf Coast Vicksburg Formation (Scull et al., 1966), as well as acritarch studies of Devonian reef complexes of Alberta, Canada (Staplin, 1961) and Jurassic rocks of Great Britain (Wall, 1965). In the Maryland and Delaware Upper Cretaceous-Paleocene investigation of Whitney (1976) alluded to previously in this section, she found that as percentages of cavate species gradually decreased the chorate species increased from the Mt. Laurel to the Monmouth to the Brightseat strata, postulated as a nearshore to more offshore depositonal sequence.

Numbers and percentages dinoflagellate species with respect to cyst types, including chorate, cavate, proximate, and all others, were calculated and plotted for the Oak Grove core (see Text-fig. 16); cyst types are described in detail in Evitt (1985). The percentages of chorate species are higher than cavate species in most of the Aquia (ranges of 40 to 65% vs. 23 to 51%; cavates slightly higher in Samples 311 and 313), the Nanjemoy (54 to 77% vs. 14 to 38%), the Calvert (55 to 83% vs. 4 to 15%), and the Choptank (67 to 84% vs. 8 to 20%) strata. Cavate species dominate over chorate species, however, in the Marlboro Clay (62 to 100% vs. 0 to 38%). In general, the chorate to cavate ratios further support the gonyaulacacean/peridiniacean analyses which reflect more offshore settings for the Aquia, Nanjemoy, Calvert, and Choptank formations, and a very nearshore, possibly lagoonal or estuarine, setting for the Marlboro Clay. It is unclear why cavate species slightly outnumber chorate species in Aquia samples 311 and 313, postulated to represent somewhat deeper water based on Foraminifera. Proximate species make up relatively small percentages of the assemblages throughout the entire section, with the highest representation in the upper Aquia (up to 13%), lower Calvert (up to 28%), and Choptank (up to 14%) strata.

More for descriptive purposes than as suggestions of any specific paleoenvironmental implications, the dinoflagellate assemblages were also analyzed by archeopyle types, including precingular, apical, epicystal, intercalary, and all others (see Text-fig. 16); the reader is referred to Evitt (1985) for a descriptive review of archeopyles. The most prevalent forms of archeopyles observed in the Aquia, most of the Nanjmeoy, the Calvert, and the Choptank strata are the precingular



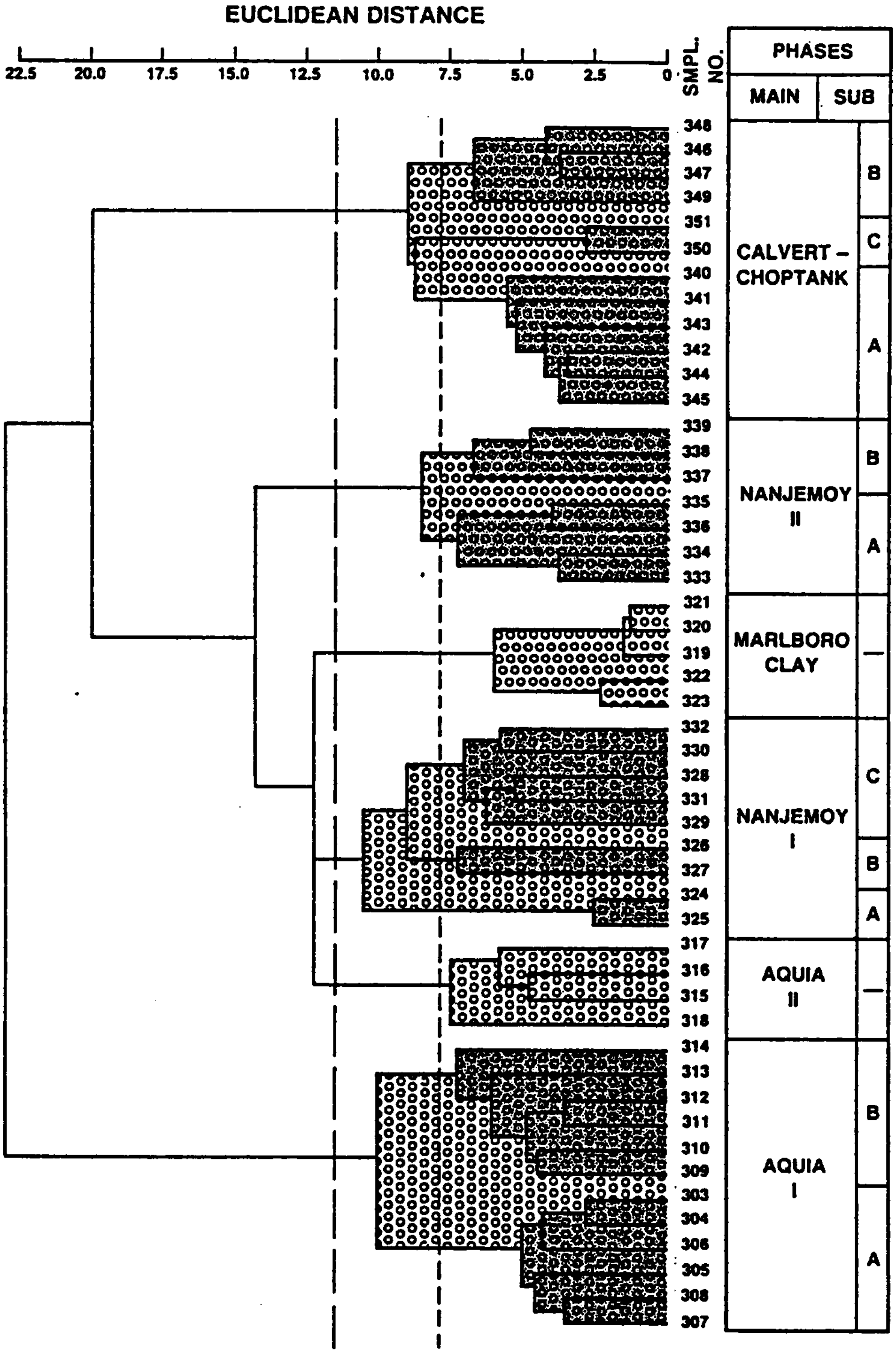
Text-fig. 16. Graphic curves of dinoflagellate species diversity (richness), and numbers and percentages of dinoflagellate species with respect to cyst type (chorate, cavate, proximate, others) and archeopyle type (precingular, apical, epicystal, intercalary, others) for the Tertiary strata of the Oak Grove core. Refer to text for discussion. Explanation of cyst and archeopyle types and numerical data listed in Appendices I(B), I(E), and I(F).

and apical types. In the Aqiua, precingular species slightly outnumber apical species in all but Samples 311, 312, and 313; together these species make up 65 to 87% of the total assemblages. Species with types constituting lesser percentages include intercalary (8 to 21%), epicystal (2 to 3%), and all others (4 to 20%). Assemblage composition by archeopyle type varies from sample to sample somewhat more in the Nanjemoy than in the Aquia. Species with precingular archeopyles represent the highest percentages throughout the Nanjemoy in all but Samples 326 (apical types slightly higher). Similar to the Aquia, precingular and apical species together account for 48 to 80% of the Nanjemoy assemblages. Percentages of species of the remaining types range as follows: intercalary (11 to 30%); epicystal (2 to 18%); all others (3 to 11%). The epicystal percentages are markedly higher in the Nanjemoy, especially the upper part of the unit, than in the Aquia. The Miocene dinoflagellate assemblages are characterized by generally higher percentages of species with precingular archeopyles than is the case in the Paleocene or Eocene units. Precingular species make up 45 to 65% of the Calvert and Choptank assemblages, as compared to only 31 to 40% in the Aquia and 24 to 61% in the Nanjemoy. These high percentages in the Miocene samples reflect the abnormally high proportions of gonyaulacacean taxa (compare G/P curve). Throughout the Calvert and Choptank section, precingular and apical species constitute 70 to 90% of the total assemblages, with the remainder made up of epicystal (0 to 5%), intercalary (3 to 14%), and all other types (0 to 20%).

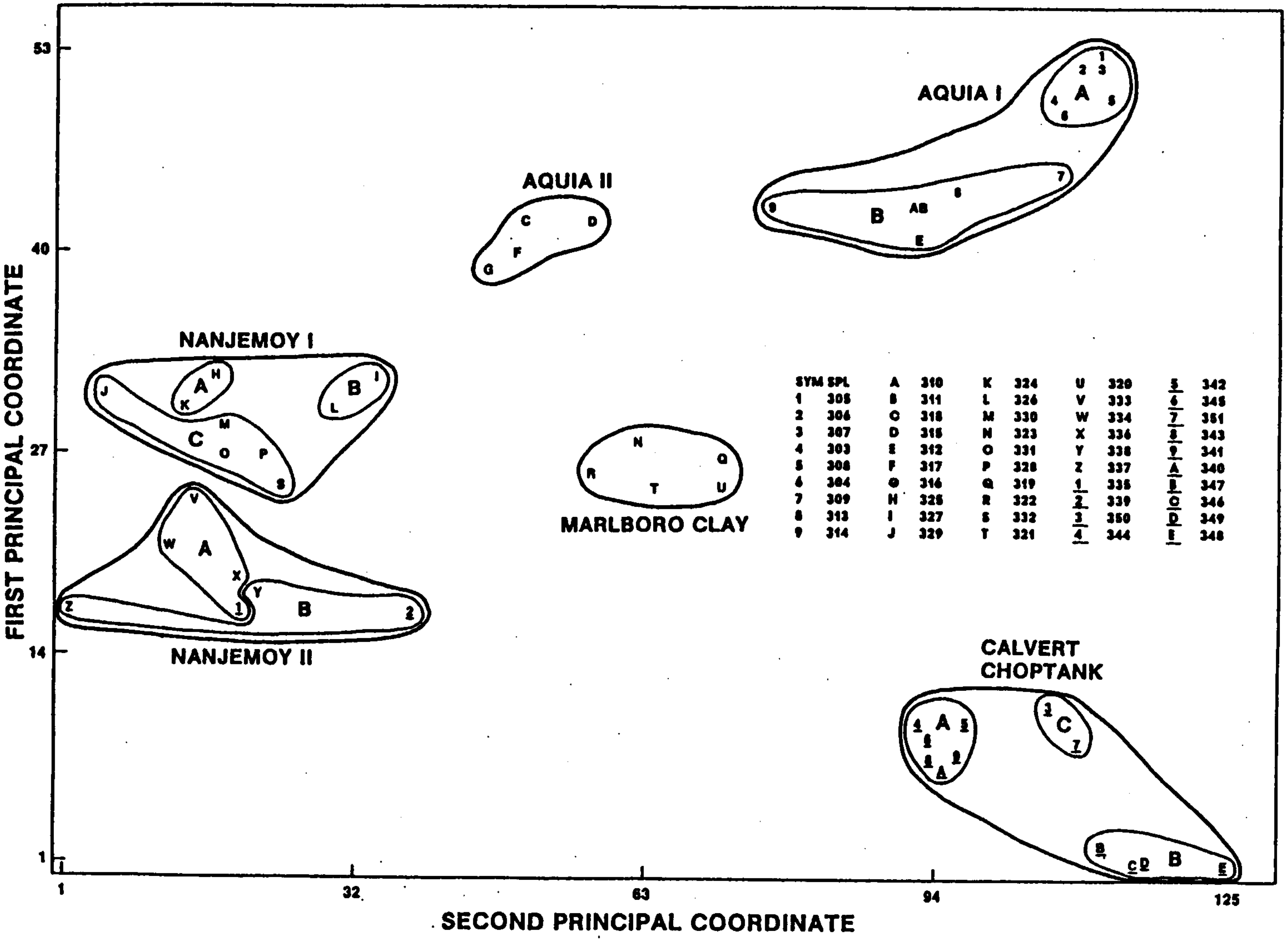
Q-Mode Cluster Analysis/Principal Coordinates Analysis. To objectively define the relationships of the Paleocene through Miocene organic-walled phytoplankton assemblages in the Oak Grove core, a Q-mode cluster analysis was performed on the 49 samples (see Text-fig. 17). The data set was reduced from 186 to 129 species by eliminating those taxa not considered statistically significant with numerical abundances of less than 3 specimens per sample count (less than 1% of assemblage total). Six major clusters are delineated for the Tertiary core samples using a resemblance cut-off level of 11.0 Euclidean distance units; twelve smaller clusters result when a cut-off level of 8.0 is used.

Principal coordinates analysis was subsequently run on the same cluster analysis data set. This complementary technique provides an alternate way with which to view the relationships of the samples and aids in selecting appropriate resemblance cut-off levels for the clusters. The samples are shown as points in two-dimensional plots of the principal coordinates representing the first and second axes (see Text-fig. 18), the first and third axes (see Text-fig. 19), and the second and third axes (see Text-fig. 20).

Each cluster of samples defined by both Q-mode cluster analysis and principal coordinates analysis is herein referred to as a phase, which represents a series of similar associations of species occurring over an extended period of time. Because it is not known if the species recovered from even a single sample actually ever co-existed, no

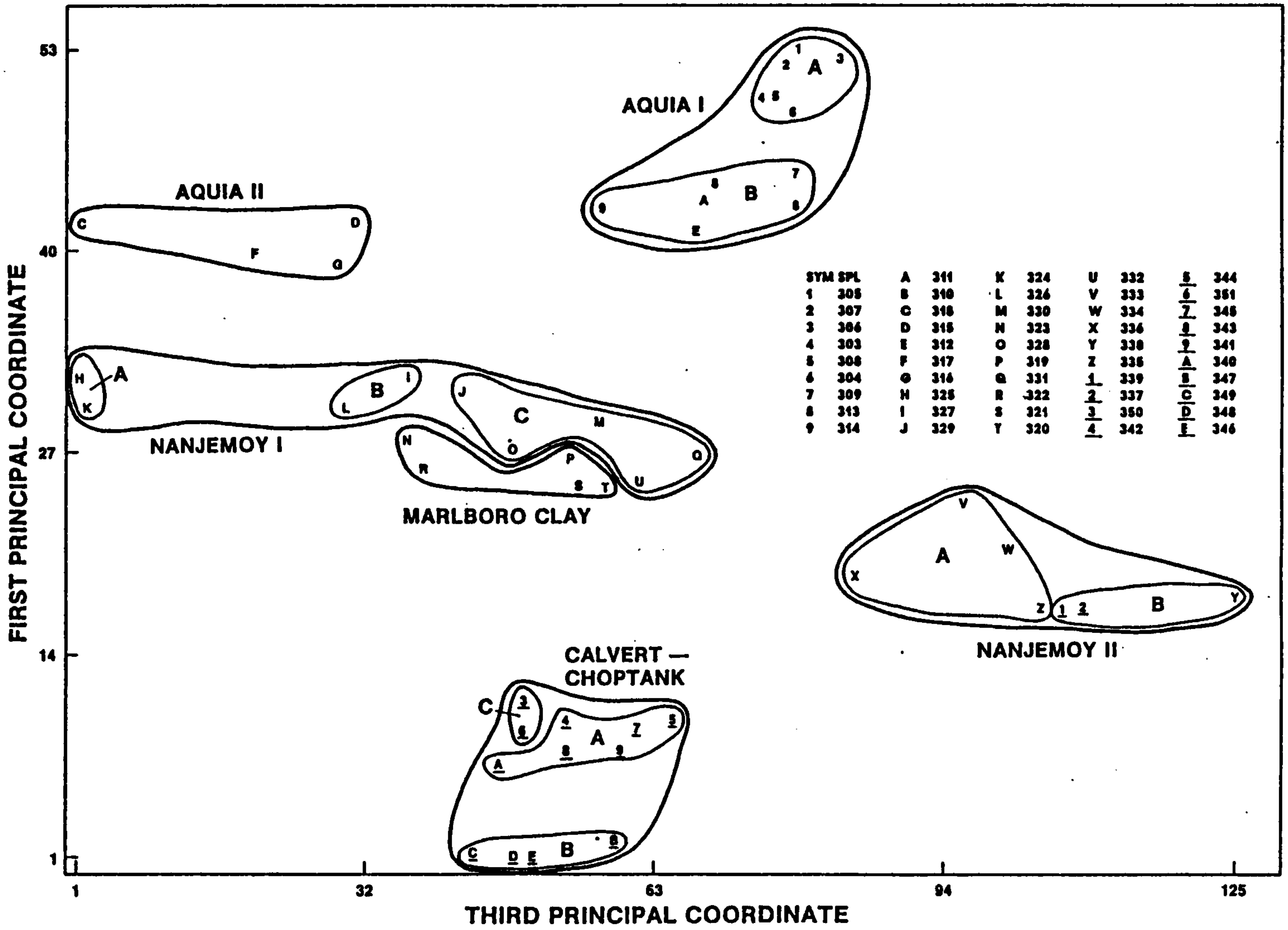


Text-fig. 17. Dendrogram produced by Q-mode cluster analysis (Euclidean distance coefficients) of the Tertiary samples of the Oak Grove core. See text for discussion.



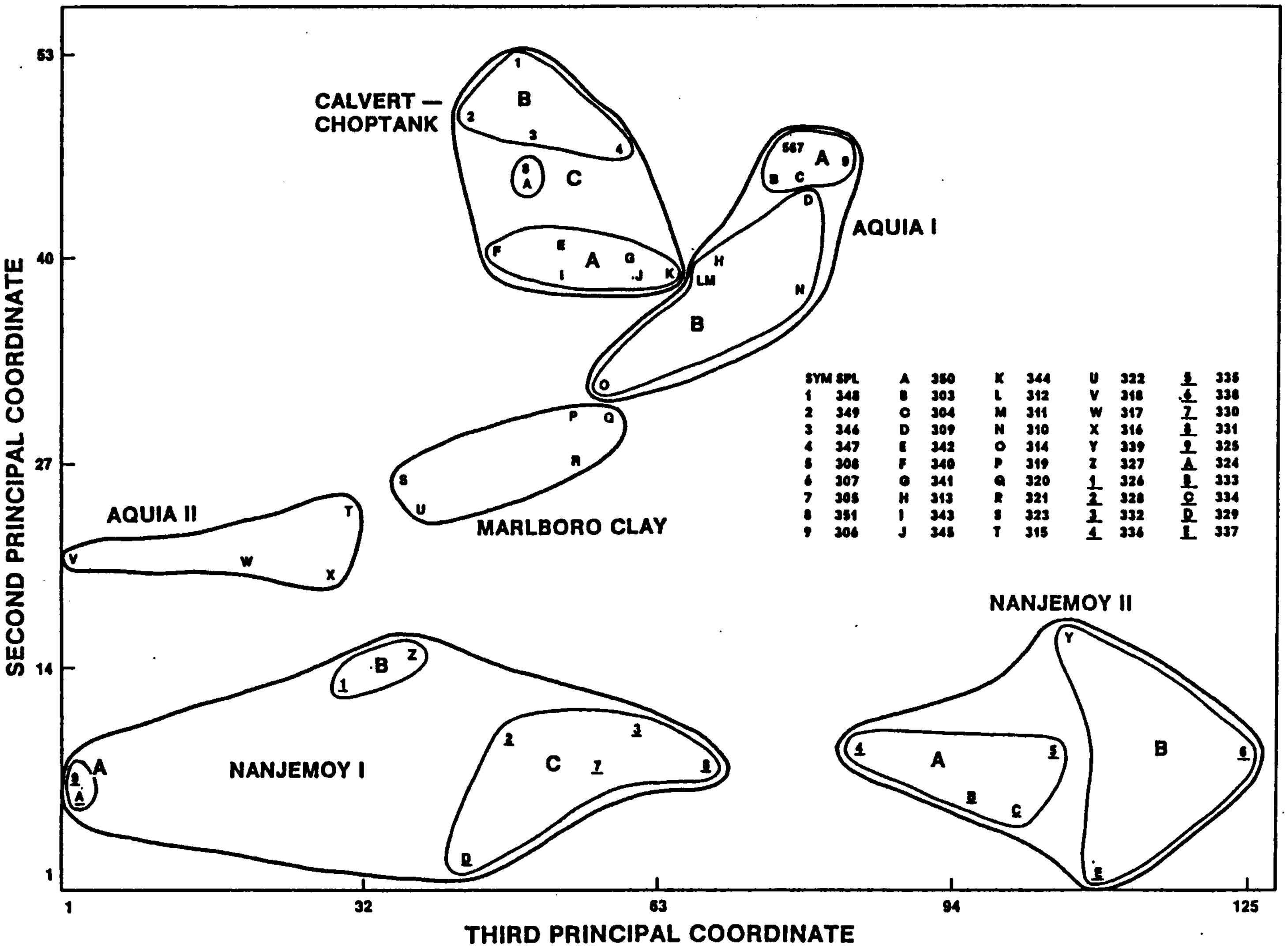
SYM	SPL	A	310	K	324	U	320	$\underline{5}$	342
1	305	B	311	L	326	V	333	$\underline{6}$	345
2	306	C	318	M	330	W	334	$\underline{7}$	351
3	307	D	315	N	323	X	336	$\underline{8}$	343
4	303	E	312	O	331	Y	338	$\underline{9}$	341
5	308	F	317	P	328	Z	337	$\underline{A}$	340
6	304	G	316	Q	319	$\underline{1}$	335	$\underline{B}$	347
7	309	H	325	R	322	$\underline{2}$	339	$\underline{C}$	346
8	313	I	327	S	332	$\underline{3}$	350	$\underline{D}$	349
9	314	J	329	T	321	$\underline{4}$	344	$\underline{E}$	348

Text-fig. 18. Principal coordinates analysis plot (first vs. second axes) of the Oak Grove core Tertiary samples (represented by symbols shown in table). Samples are grouped as indicated by cluster analysis.



SYM	SPL	A	311	K	324	U	332	$\underline{5}$	344
1	305	B	310	L	326	V	333	$\underline{6}$	351
2	307	C	318	M	330	W	334	$\underline{7}$	345
3	306	D	315	N	323	X	336	$\underline{8}$	343
4	303	E	312	O	328	Y	338	$\underline{9}$	341
5	308	F	317	P	319	Z	335	$\underline{A}$	340
6	304	G	316	Q	331	$\underline{1}$	339	$\underline{B}$	347
7	309	H	325	R	322	$\underline{2}$	337	$\underline{C}$	349
8	313	I	327	S	321	$\underline{3}$	350	$\underline{D}$	348
9	314	J	329	T	320	$\underline{4}$	342	$\underline{E}$	346

Text-fig. 19. Principal coordinates analysis plot (first vs. third axes) of the Oak Grove core Tertiary samples (represented by symbols shown in table). Samples are grouped as indicated by cluster analysis.



SYM	SPL	A	350	K	344	U	322	5	335
1	348	B	303	L	312	V	318	6	338
2	349	C	304	M	311	W	317	7	330
3	346	D	309	N	310	X	316	8	331
4	347	E	342	O	314	Y	339	9	325
5	308	F	340	P	319	Z	327	A	324
6	307	G	341	Q	320	1	326	B	333
7	305	H	313	R	321	2	328	C	334
8	351	I	343	S	323	3	332	D	329
9	306	J	345	T	315	4	336	E	337

Text-fig. 20. Principal coordinates analysis plot (second vs. third axes) of the Oak Grove core Tertiary samples (represented by symbols shown in table). Samples are grouped as indicated by cluster analysis.

biological community connotations are implied. In this study, the six major clusters and 12 smaller clusters are respectively designated main phases and sub phases.

Samples of the Aquia strata of the core clustered into two main phases: Aquia I (Samples 303 to 314) and Aquia II (Samples 315 to 318). Subtle lithologic changes and dinoflagellate and foraminiferal biostratigraphy suggest that the boundary (disconformity?) separating the Piscataway and Paspotansa Members may lie between these two clusters (between Samples 314 and 315). Aquia Phase I is further divided into sub phases I-A (Samples 303 to 308) and I-B (Samples 309 to 314); note that the sub phases boundary is not coincident with the basal Aquia? (Danian?) - Aquia (Thanetian) contact. The Marlboro Clay samples represent a distinct cluster, made up of close associations of Samples 322 and 323, as well as Samples 319 to 321. Samples clustered within the Nanjemoy into two main phases: Nanjemoy I (Samples 324 to 332) and Nanjemoy II (Samples 333 to 339). As in the Aquia, evidence based on lithology and dinoflagellate ranges suggests that the disconformable(?) contact separating the Potapaco and Woodstock Members is located between the two clusters (between Samples 324 and 325). Smaller clusters can be recognized within both main phases of the Nanjemoy; Nanjemoy Phase I is comprised of I-A (Samples 324 and 325), I-B (Samples 326 and 327), and I-C (Samples 328 to 332), and Nanjemoy Phase II is made up to II-A (Samples 333 to 336) and II-B (Samples 337 to 339). All of the Miocene samples clustered into one large group, called the Calvert-Choptank Phase. Within this major cluster, three smaller clusters can be defined: sub phase A (Samples 340 to 345), sub phase B (Samples 346 to 349), and sub phase C (Samples 350 and 351). The boundary between sub phases B and C does not coincide with the Calvert-Choptank formational contact.

The general construction of the dendrogram suggests the following conclusions: the Aquia I Phase is rather distinct and unique; the Aquia II, Marlboro Clay, and Nanjemoy I Phase show some degree of similarity to one another, and together are somewhat related to the Nanjemoy II Phase; and the relatively tight cluster of the Calvert-Choptank Phase is only remotely related to the phases preceding it.

R-Mode Cluster Analysis/Rank-Abundance Analysis. In the foregoing discussion of Q-mode cluster analysis, samples clustered together into phases due to similarities in species associations occurring over a particular interval of time. Two types of analyses are useful in distinguishing which species are generally found associated with one another and are to a large extent controlling the sample clusters: (1) R-mode cluster analysis, and (2) rank-abundance analysis. R-mode cluster analysis has been generated on the same 129 species/49 samples data set used in the Q-mode. Ten major clusters of species defined on the R-mode dendrogram are shown along the top of a two-way table which relates samples to species (see Chart 6). A rank-abundance analysis was also performed on those dinoflagellate and acritarch species ranked in the top five numerical abundance positions in each sample.

The biostratigraphic ranges of the 68 species that resulted from this ranking are shown in Chart 7; the peaks represent the percent abundance of a particular species when it is among the top five abundance ranks in that assemblage (see Appendix I(H) for actual percentages).

Each of the main and sub phases of the Tertiary units in the core will be discussed in terms of species composition. The main phases are dominated by particular species groups defined in the R-mode. In addition, each sub phase is characterized by species represented by the most abundant specimens (rank-abundance chart). The ranges of the Shannon-Wiener (H) diversities within the sub phases are arbitrarily denoted in parentheses as follows: H less than 1.5 (low); H of 1.5 to 2.5 (moderate); and H greater than 2.5 (high).

Aquia Phase I is made up of primarily R-mode species groups 1, 2, 4, and 8. Species in the Aquia I-A sub phase (H-high) with the highest abundances include *Cordosphaeridium giganteum* n. sp., *Elytrocysta obscurotabulata* n. sp., *Fibradinium annetorpense*, and *Glaphyrocysta exuberans* complex. Increasing in abundance into the succeeding Aquia I-B phase (H-moderate) are *Glaphyrocysta exuberans* complex and *Fibradinium annetorpense*; other top ranked forms include *Glaphyrocysta* sp. A and *Turbiosphaera filosa*, with *Deflandrea dartmooria, Elytrocysta obscurotabulata* n. sp., *Thalassiphora delicata*, and *Xenikoon australis* sharing the second through fifth ranks. Aquia Phase II (H-high) contains species from R-mode groups 2, 3 (exclusive), 4, and 8. *Glaphyrocysta* sp. A is the consistently highest ranked species, except in the uppermost Aquia sample where

Apectodinium homomorphum complex is the most abundant; *Adnatosphaeridium robustum, Deflandrea phosphoritica, Elytrocysta obscurotabulata* n. sp., and *Eocladopyxis peniculata* are other taxa that ranked in the top five.

Only species from R-mode groups 2, 4, and 8 are found in the Marlboro Clay Phase (H-low/moderate). *Senagalinium? dilwynense* ranks number one in abundance throughout the phase; *Apectodinium homomorphum* complex, *Apectodinium* sp. A, and *Elytrocysta obscurotabulata* n. sp. are among others that rank in the top five positions of these very low richness assemblages.

Nanjemoy Phase I assemblages are comprised of diverse species from R-mode groups 2 through 8. In the Nanjemoy I-A sub phase (H-moderate), *Adnatosphaeridium multispinosum-vittatum* complex ranks first in abundance followed by *Apectodinium homomorphum* complex in the second rank, and *Senagalinium? dilwynense, Muratodinium fimbriatum*, and *Operculodinium israelianum* distributed in the third through fifth ranks. The Nanjemoy I-B sub phase (H-moderate) is characterized by top ranked *Wilsonidium tabulatum* and *Systematophora placacantha*, with *Deflandrea phosphoritica* in a close second rank position. In the Nanjemoy I-C sub phase (H-high), the top abundance ranks are shared by *Wetzeliella hampdenensis* and alternations of *Adnatosphaeridium multispinosum-vittatum* complex and *Wetzeliella samlandica*. Among other abundant species that are distributed in ranks two through five are *Biconidinium longissimum, Elytrocysta densobaculata* n. sp., *Eocladopyxis peniculata*, Forma B, Forma C, and *Thalassiphora pelagica*.

Most of the species in the Nanjemoy Phase II assemblages are from R-mode groups 4, 6, 7, and 8. The top ranked species in the Nanjemoy II-A sub phase (H-moderate/high) are *Spinidinium macmurdoense* in the lower part and *Deflandrea phosphoritica* in the upper part; among the species ranking two through five throughout the interval are *Areoligera* spp., Forma C., and *Wetzeliella hampdenensis.* The succeeding Nanjemoy II-B sub phase (H-moderate/high) is characterized by *Eocladopyxis peniculata* and *Glaphyrocysta ordinata* as the most abundant species, with *Achilleodinium biformoides, Cleistosphaeridium diversispinosum* complex, *Homotryblium pallidum-tenuispinosum* complex, *Lingulodinium machaerophorum*, and *Wetzeliella lunaris* among those distributed in the next four ranks.

The Calvert-Choptank Phase assemblages contain only species from R-mode groups 8, 9, and 10. In sub phase A (H-low/moderate), after an initial peak abundance of *Cordosphaeridium? amputatospinosum* n. sp., the interval is marked by top ranked abundances of *Batiacasphaera microreticulata* n. sp. and *Cleistosphaeridium diversispinosum* complex; *Apteodinium labyrinthum* n. sp., Forma E, *Lingulodinium machaerophorum*, and *Millioudodinium giuseppei* are among others that rank in the top five. Sub phase B (H-moderate) is characterized by *Spiniferites crassipellis* subsp. C, *Operculodinium centrocarpum, Batiacasphaera microreticulata* n. sp., and *Hystrichokolpoma rigaudiae* (in uppermost part) sharing the first two abundance ranks.

The top two Miocene samples constitute sub phase C (H-low) with *Operculodinium centrocarpum* clearly in the top ranked position, and

Lingulodinium machaerophorum, Impagidinium sp. B, and *Spiniferites crassipellis* subsp. C in the second and third ranks.

SUMMARY AND CONCLUSIONS

This study reports on the taxonomy, as well as the biostratigraphic and paleoecological implications, of the diverse, well preserved Tertiary organic-walled phytoplankton assemblages recovered from the Oak Grove core drilled on the Virginia Coastal Plain. Formations penetrated by the corehole include the Aquia, Marlboro Clay, and Nanjemoy of the Pamunkey Group (Paleocene and Eocene) and the Calvert and Choptank of the Chesapeake Group (Miocene). Eighty-two dinoflagellate genera made up of 176 species and subspecies are reported, of which 20 species and subspecies and one combination are new. Five acritarch species from two genera and five chlorophyte species from three genera are also recorded.

The biostratigraphic distribution of the 186 dinoflagellate, acritarch, and chlorophyte species (see Charts 1, 2, and 3) provided information concerning the ages of the formations and nature of their lithologic contacts, and the dinoflagellate zonation permitted correlation with other time-equivalent sections. Organic-walled phytoplankton assemblages corroborate the ages reported for the Aquia and Nanjemoy Formations on the basis of other microfossil groups. The Aquia in the core, at least from Sample 310 to the top of the unit, can be dated as Paleocene (Thanetian). Calcareous nannofossils representing Zones NP-5 through NP-9, Foraminifera of the P-4 Zone, ostracodes of the *Haplocytheridea leei* Zone, and the pollen and spores indicate a Thanetian age as well for this interval. Based on certain dinoflagellate and pollen species, the section below Sample 310 is assigned a questionable Danian age, and herein designated Brightseat equivalent-basal Aquia? strata. Re-evaluation of some of the Paleocene pollen and spore ranges may eventually allow for a more definite and specific age assignment; calcareous nannofossils and Foraminifera are absent from this basal interval. Organic-walled phytoplankton species in the Nanjemoy strata indicate an Eocene (Ypresian) age. Calcareous nannofossils defining Zones NP-10 through NP-12, and ostracodes, pollen and spores, and mollusks are all indicative of an Ypresian age; the foraminiferal assemblages were not age-dated. The ranges of the dinoflagellates and acritarchs, as well as certain pollen, suggest that the intervening Marlboro Clay may straddle the Paleocene-Eocene boundary. No calcareous nannofossils were recovered in this unit, and the agglutinated Foraminifera present are not age-diagnostic. The Calvert and Choptank strata in the core can only be assigned a general Early to Middle Miocene age on the basis of dinoflagellates. Diatoms from a few Calvert samples indicate a late Early to early Middle Miocene age, and a possible middle Middle Miocene age for a sample in the Choptank. No age information on the sparse Foraminifera is available for these units. The absence of calcareous nannofossils can likely be explained by leaching.

Organic-walled phytoplankton species distributions and diversities, as well as Otsuka coefficient analysis of the samples, have been used to help determine the nature of the contacts of the formations and their members. Based on both lithologic and paleontological evidence, the relatively sharp Marlboro Clay - Nanjemoy contact appears disconformable. The Aquia - Marlboro Clay boundary has been described as gradational, although paleontological evidence suggests distinctly different paleoenvironmental conditions on either side of the contact which may reflect a hiatus. Within the Aquia, discontinuities in dinoflagellate ranges suggest a possible hiatus (small disconformity?) is present at a subtle lithologic change between Samples 314 and 315 which may mark the boundary dividing the Piscataway and Paspotansa Members. Similar evidence exists in the Nanjemoy to suggest a possible minor disconformity separates the Potapaco and Woodstock Members between Samples 332 and 333. Otsuka coefficients clearly point out the obvious disconformity between the Early Eocene age Nanjemoy and Early Miocene age Calvert strata. The Calvert-Choptank contact appears conformable on both palynological and lithologic evidence.

Ten provisional dinoflagellate zones are herein proposed for the Paleocene to Eocene age units of the core. Each zone is defined by the range bases of two species (hyphenated designation), and is characterized by range bases and tops, as well as abundances, of many other species. The tentative zones permit correlation of these units with previous Paleocene and Eocene dinoflagellate studies of Virginia and Maryland Coastal Plain sections (McLean, 1971; Witmer, 1975; Goodman, 1975); see Chart 4. Preliminary studies indicate that, with some modifications, the zonation and correlations of the present study can be successfully extended to Paleocene and Eocene age sediments cored by other U.S.G.S. coastal plain wells drilled in the past few years (Edwards, Goodman, and Witmer, 1984; Edwards, personal communication). Twenty-seven dinoflagellate species in the Oak Grove core proved useful in generally biostratigraphically correlating the Paleocene to Eocene age Aquia, Marlboro Clay, and Nanjemoy sequence with coeval European sections in England, Belgium/Netherlands, Germany, Spain, Switzerland, France, and Denmark, as well as a composite offshore eastern Canada section (see Chart 5).

Using a paleobathymetric framework based primarily on Foraminifera and sedimentology (see Text-fig. 13), the organic-walled phytoplankton assemblages in the core have been statistically analyzed for possible paleoenvironmental implications. Analyses included species diversity measurements (richness, Shannon-Wiener index, and evenness), as well as concepts postulated in previous palynological studies which correlated certain associations, broad taxonomic affinities, and morphological cyst groups of dinoflagellate species with particular paleoenvironments (see Text-figs. 14, 15, 16). Most of the statistical results generally support similar, somewhat fluctuating, inner neritic water depths for the Aquia and Nanjemoy seas. Separating these two marine shelf settings, however, was the lagoonal or estuarine environment of the Marlboro Clay. A Miocene marine transgression over a Nanjemoy erosional surface resulted in generally inner shelf water depths for the Calvert and Choptank seas.

Other statistical techniques employed, including Q-mode and R-mode cluster analyses and principal coordinates analysis, objectively defined groups within the 49 Tertiary samples. The clusters of samples (Q-mode) as related by their associations of dinoflagellate, acritarch, and chlorophyte species, are presumed to reflect at least some paleoecological control. In this study, a series of samples representing similar species associations through time is referred to as a phase. Six major clusters (main phases) and 12 smaller clusters (sub phases) have been delineated (see Text-figs. 17, 18, 19, 20). Samples of the Aquia clustered into two main phases (Aquia I and II), apparently separated by the disconformable(?) Piscataway-Paspotansa Member contact; Aquia I further subdivided into sub phases I-A and I-B. The Nanjemoy samples similarly resulted in two main phases, possibly separated by a disconformity(?) between the Potapaco and Woodstock Members; smaller clusters were defined in the Nanjemoy I (I-A, I-B, I-C) and Nanjemoy II (II-A and II-B). Separating the Aquia II and Nanjemoy I Phases is the Marlboro Clay Phase. The Miocene Calvert-Choptank Phase clustered into three sub phases (A, B, C). Clustering species (R-mode) and defining the species with the highest abundances (rank-abundance analysis) helped in determining those taxa important in controlling the phases (see Charts 6 and 7).

SYSTEMATIC PALYNOLOGY

General Statement

Included in this section are descriptions of new dinoflagellate species, as well as comments on all other previously described dinoflagellate, acritarch, and chlorophyte taxa recovered in the Tertiary strata of the Oak Grove core. New taxa were named in accordance with the International Code of Botanical Nomemclature. "Composition of Scientific Words" by Brown (1956) was used as a guide in the formulation of new names.

Dinoflagellates are identified at the species level where possible. Most acritarchs and chlorophytes are either identified as informal species or compared at the species level. The land-derived palynomorphs, although not treated taxonomically, are discussed in general in the following section "Pollen and Spores".

The taxonomy of the microfossils encountered in this investigation can be summarized as follows:

Dinoflagellates:

Total genera: 82

Total informal genera (Forma): 5

Total species and subspecies: 176

New species/subspecies (n. sp./n. subsp.): 20

New combinations (n. comb.): 1

Cited (published) species/subspecies: 106

Compared species (cf.): 14

Informal species/subspecies/etc. (sp./spp./subsp.): 24

Species complexes: 6

Acritarchs:

Total genera: 2

Total species: 5

Cited (published) species: 2

Compared species (cf.): 2

Informal species (sp./spp.): 1

Chlorophytes:

Total genera: 3

Total species: 5

Informal species (sp./spp.): 5

Some of the new dinoflagellate species described in this section were previously included as new manuscript taxa by McLean (1971) in his study of the Aquia and Nanjemoy Formations of northern Virginia and Maryland, and by Goodman (1975) in his investigation of the Nanjemoy strata of Maryland. These taxa have been renamed and redescribed on the basis of the specimens of this study.

A range of microfossil dimensions is presented for all palynomorphs included in this study. Relative abundances for the individual species are given for each of the units in which they were recovered. Categories used for specimen frequencies can be found in the section "Analytical Procedures". Previously reported occurrences from journal articles and theses and dissertations have been compiled for cited (formally published) species and subspecies.

Pollen and Spores

Although land plant pollen and spores recovered in the samples have not been studied in detail, a few general observations can be made. The approximate abundance of pollen and spores (as less than 25%; 25-50%; and greater than 50% of the total sample palynomorph assemblage) throughout the Tertiary strata of the Oak Grove core is shown in a curve in Text-fig. 14. Some of the pollen and spores from each of the Tertiary units are included on Plate 38.

Trilete spores attain their greatest abundance in the Marlboro Clay, and are rare throughout the remainder of the section. Bissacate pollen grains (e.g., *Pinus*) are most common in the Paleocene and Miocene strata of the core. All other pollen grains, including porate, colpate, and colporate types, are most prevalent in the Marlboro Clay (up to about 75% of the total palynomorph residue) and the Miocene strata (up to about 55%). It must be noted that some of the smallest angiosperm pollen grains were likely lost during the 20um sieving of the sample residues.

Morphological Terminology

Most of the terms used in discussing dinoflagellate morphology in this section can be found in the "Glossary of the Terminology Applied to Dinoflagellate Amphiesmae and Cysts and Acritarchs", published by the American Association of Stratigraphic Palynologists (Contributions Series No. 2, 1973). The reader is also referred to "Sporopollenin Dinoflagellate Cysts" by Evitt (1985), "Fossil and Living Dinoflagellates" by Sarjeant (1974, chapter 6, p. 63-83), and Davey, Downie, Sarjeant, and Williams (1966, p. 10-17). Some of the more commonly employed terms are listed below alphabetically and defined in the general context as they are used in this study.

annulate--a complex (one per paraplate) of processes arranged in a circle.

antapex--the posterior end of the cyst.

apex--the anterior end of the cyst.

archeopyle--the excystment aperture in the wall of the cyst.

bacula--small, cylindrical, rod-like projections arising from the main body.

cyst--the complete, resistant, organic-walled, fossil remains including wall layers, processes, ornamentation, etc.

dorsal--the side of the cyst which is opposite the parasulcus (longitudinal furrow).

endocyst--the body comprised of the endophragm in a bi-layered cyst.

endophragm--the inner wall layer of a bi-layered cyst.

ectophragm--the outermost, thin membrane, reticulum, or trabeculate network interconnecting the tips of projections on the main body.

epicyst--the part of the cyst anterior of the paracingulum.

horn--the extensions of the periphragm; expressed as apical, antapical, or lateral.

hypocyst--the part of the cyst posterior of the paracingulum.

left--the side of the cyst (apex up) to the left of the longitudinal midline when the dorsal side faces the observer.

levigate--smooth or unornamented (in reference to the surface of the cyst).

levorotatory--a descending type of paracingulum in which the left end of the paracingulum is higher than the right end when the ventral side of the cyst faces the observer.

main body--the central body of process-bearing cysts.

operculum--the covering of the archeopyle.

paracingulum--the transverse furrow around the cyst in an approximately equatorial position, reflected as paraplates and/or processes; former position of transverse flagellum of the theca.

paraplate--a polygonal part of the cyst wall, usually bounded by parasutures, which occupies a position equivalent to that occupied by a plate of the theca (=plate-equivalent).

parasulcus--the longitudinal furrow on the ventral side of the cyst, reflected as small paraplates and/or processes, dividing the cyst into right and left halves; former position of longitudinal flagellum of the theca.

parasuture--the boundary between the paraplates.

paratabulation--the formula indicating the arrangement and the number of paraplates on the cyst.

pericyst--the body comprised of the periphragm in a bi-layered cyst.

pericoel--the cavity between the endophragm and periphragm.

periphragm--the outer wall layer of a bi-layered cyst.

process--a columnar or spine-like projection arising from the periphragm; tips are simple or branched; distributed as one or multiple per paraplate, or randomly.

right--the side of the cyst (apex up) to the right of the longiludinal midline when the dorsal side faces the observer.

scabrate--ornamented with sparse, fine grains (in reference to the surface of the cyst).

septa--membranous wall arising perpendicularly from the cyst wall along parasutures.

simulate--a complex (one per paraplate) of processes aligned parallel to and within the parasutures.

soleate--a complex (one per paraplate) of processes arranged in a semicircle.

trabeculae--narrow, solid rods interconnecting the tips of processes or projections on the main body.

ventral--the side of the cyst which bears the parasulcus (longitudinal furrow).

Classification Used in This Study

Several classifications have been devised for fossil dinoflagellates. Sarjeant and Downie (1966) established a morphological system for this microfossil group in which they categorized form genera into cyst families. More recently, Norris (1978) and Artzner et al. (1979) erected classifications in which they separated genera into numerous families, employing what seem to be unnatural and unduly limited morphological parameters. Wall and Dale (1968) tried to incorporate both modern and fossil dinoflagellates into a scheme with an evolutionary emphasis striving to tie together more closely modern thecae and fossil cysts. Unfortunately, many of the evolutionary lineages are still questionable or insufficiently understood.

Because of the seemingly artificial framework and ambiguity upon which the available classification systems were conceived, the present author has chosen to organize the dinoflagellate genera under only three general groups, or families, based primarily on paratabulation pattern and/or archeopyle type. The families used are as follows:

(1) Family GONYAULACACEAE: For genera which have a paratabulation formula generally similar to that of *Gonyaulax* or *Pyrodinium* (3-4', 0-4?a, 5-6", 6c, 5-6"', 1p, 1"") and/or an apical, precingular, apical-precingular combination, or epicystal archeopyle typically exhibited by species of these genera; also tentatively included in this group are taxa with one of the forementioned typical archeopyle types suggestive of a gonyaulacoid affinity but with very little other evidence of paratabulation.

(2) Family PERIDINIACEAE: For genera which have a paratabulation pattern generally similar to that of *Peridinium* (4', 2-3a, 6-7", 6c, 5-6"', 0p, 2"") and an intercalary (and rarely apical?) archeopyle.

(3) Family UNCERTAIN: For genera which cannot be logically assigned to either of the above groups because the paratabulation and/or archeopyle type is uncertain or somewhat atypical.

This study will honor many of the new, emended, and transferred taxa proposed by Stover and Evitt (1978) in a comprehensive analysis of 279 dinoflagellate genera with complete species lists. The recent index of fossil dinoflagellate genera and species compiled by Lentin and Williams (1985) also proved very helpful in updating the systematics of this study.

Of the five species of acritarchs included in this investigation, two belong to the subgroup Sphaeromorphitae and three are assigned to Acanthomorphitae (of Downie, Evitt, and Sarjeant, 1963).

Two classes, Chlorophyceae and Prasinophyceae, are represented by the five informal chlorophyte (green algae) species recovered from the core.

Species List

Dinoflagellate, acritarch, and chlorophyte species recorded in the Tertiary samples of the Oak Grove core are listed below in the order in which they are discussed in the section "Systematic Descriptions".

Division PYRRHOPHYTA Pascher
  Class DINOPHYCEAE Fritsch 1935
    Order PERIDINIALES Haechel 1894
      Family GONYAULACACEAE Lindemann 1928
        Achilleodinium biformoides (Eisenack 1954) Eaton 1976
        Adnatosphaeridium multispinosum-vittatum complex
        Adnatosphaeridium robustum (Morgenroth 1966) DeConinck 1975

Alisocysta cf. *A. margarita* (Harland 1979) Stover and Evitt 1978

Apteodinium australiense (Deflandre and Cookson 1955) Williams 1978

Apteodinium cf. *A. cribrosum* Cookson and Eisenack 1968

Apteodinium labyrinthum n. sp.

Apteodinium retiolum n. sp.

Areoligera spp. complex

Batiacasphaera microreticulata n. sp.

Batiacasphaera sp. A

Cassidium paleocenicum n. sp.

Chiropteridium partispinatum (Gerlach 1961) Brosius 1963

Chlamydophorella urna Cookson and Eisenack 1960

Cladopyxidium saeptum (McLean 1972) Stover and Evitt 1978

Cleistosphaeridium diversispinosum complex

Conneximura fimbriata (Morgenroth 1968) May 1980

Cordosphaeridium? amputatospinosum n. sp.

Cordosphaeridium biarmatum Morgenroth 1966

Cordosphaeridium? callosum (Morgenroth 1966) Stover and Evitt 1978

Cordosphaeridium fibrospinosum (Davey and Williams 1966) Davey 1969

Cordosphaeridium giganteum n. sp.

Cordosphaeridium gracile (Eisenack 1954) Davey and Williams 1966

Cordosphaeridium inodes (Klumpp 1953) Eisenack 1963

Cordosphaeridium inodes subsp. *robustum* Gocht 1969

Cordosphaeridium multispinosum Davey and Williams 1966

Cordosphaeridium solaster Morgenroth 1966

Danea? sp.

Dapsilidinium pseudocolligerum (Stover 1977) Bujak, Downie, Eaton, and Williams 1980

Dinopterygium cladoides Deflandre 1935

Dinopterygium fehmarnense (Lentin and Williams 1973) Stover and Evitt 1978

Diphyes colligerum (sensu Cookson 1965)

Diphyes colligerum (Forma A)

Diphyes colligerum (Forma B)

Distatodinium paradoxum (Brosius 1963) Eaton 1976

Elytrocysta densobaculata n. sp.

Elytrocysta obscurotabulata n. sp.

Eocladopyxis peniculata Morgenroth 1966

Exochosphaeridium bifidum (Clarke and Verdier 1967) Clarke, Davey, Sarjeant, and Verdier 1968

Fibradinium annetorpense Morgenroth 1968

Fibrocysta bipolare (DeConinck 1969) Stover and Evitt 1978

Fibrocysta coalitospinosa n. sp.

Fibrocysta cf. *F. lappacea* (Drugg 1970) Stover and Evitt 1978

Fibrocysta radiata (Morgenroth 1966) Stover and Evitt 1978

Fibrocysta sp. A

Florentinia ferox (Deflandre 1937) Duxbury 1980

Glaphyrocysta exuberans complex

Glaphyrocysta ordinata (Williams and Downie 1966) Stover and Evitt 1978

Glaphyrocysta sp. A

Glaphyrocysta sp. B

Hafniasphaera septata (Cookson and Eisenack 1967) Hansen 1977

Hafniasphaera cf. *H. septata* (Cookson and Eisenack 1967) Hansen 1977

Heteraulacacysta campanula Drugg and Loeblich 1967

Homotryblium caliculum Bujak 1980

Homotryblium pallidum-tenuispinosum complex

Homotryblium tasmaniense Cookson and Eisenack 1967

Hystrichokolpoma eisenackii Williams and Downie 1966

Hystrichokolpoma mentitum McLean 1974

Hystrichokolpoma rigaudiae Deflandre and Cookson 1955

Hystrichokolpoma tumescens McLean 1974

Hystrichokolpoma unispinum Williams and Downie 1966

Hystrichosphaeridium tubiferum (Deflandre 1937) Davey and Williams 1966

Hystrichosphaeridium cf. *H. tubiferum* (Deflandre 1937) Davey and Williams 1966

Hystrichosphaeridium tubiferum subsp. *brevispinum* (Davey and Williams 1966) Lentin and Williams 1973

Hystrichosphaeridium spp.

Hystrichosphaeropsis ovum Deflandre 1935

Impagidinium speciosum n. sp.

Impagidinium cf. *I. speciosum* n. sp.

Impagidinium sp. A

Impagidinium sp. B

Kallosphaeridium brevibarbatum DeConinck 1969

Lingulodinium machaerophorum (Deflandre and Cookson 1955) Wall 1967

Melitasphaeridium pseudorecurvatum (Morgenroth 1966) Bujak, Downie, Eaton, and Williams 1980

Membranilarnacia leptoderma (Cookson and Eisenack 1958) Eisenack 1963

Microdinium ornatum Cookson and Eisenack 1960

Millioudodinium giuseppei subsp. *major* (Morgenroth 1966) Stover and Evitt 1978

Muratodinium fimbriatum (Cookson and Eisenack 1967) Drugg 1970

Nematosphaeropsis pertusa n. sp.

Nematosphaeropsis cf. *N. pertusa* n. sp.

Nematosphaeropsis pusulosa (Morgenroth 1966) Stover and Evitt 1978

Nematosphaeropsis trabeculata n. sp.

Oligosphaeridium complex (White 1842) Davey and Williams 1966

Operculodinium brevispinosum n. sp.

Operculodinium cf. *O. brevispinosum* n. sp.

Operculodinium centrocarpum (Deflandre and Cookson 1955) Wall 1967

Operculodinium israelianum (Rossignol 1962) Wall 1967

Operculodinium multispinosum n. sp.

Operculodinium variespinosum n. sp.

Paucisphaeridium inversibuccinum (Davey and Williams 1966) Bujak, Downie, Eaton, and Williams 1980

Pentadinium laticinctum subsp. *granulatum* Gocht 1969

Polysphaeridium zoharyi (Rossignol 1962) Bujak, Downie, Eaton and Williams 1980

Polysphaeridium cf. *P. zoharyi* (Rossignol 1962) Bujak, Downie, Eaton, and Williams 1980

Renidinium membraniferum Morgenroth 1968

Renidinium? sp. A

Rottnestia borussica (Eisenack 1954) Cookson and Eisenack 1961

Samlandia chlamydophora Eisenack 1954

Samlandia reticulifera (Cookson and Eisenack 1965) subsp. *minor* n. subsp.

Spiniferites cingulatus (O. Wetzel 1933) Sarjeant 1970

Spiniferites cornutus subsp. A

Spiniferites cornutus subsp. B

Spiniferites cornutus subsp. C

Spiniferites crassipellis subsp. A

Spiniferites crassipellis subsp. B

Spiniferites crassipellis subsp. C

Spiniferites mirabilis (Rossignol 1963) Sarjeant 1970

Spiniferites monilis (Davey and Williams 1966) Sarjeant 1970

Spiniferites cf. *S. pterotus* (Cookson and Eisenack) Sarjeant 1970

Spiniferites pseudofurcatus (Klumpp 1953) Sarjeant 1970

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

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

Spiniferites ramosus subsp. *membranaceus* (Rossignol 1964) n. comb.

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

Spiniferites ramosus subsp. *ramosus* (Davey and Verdier 1971) Lentin and Williams 1973

Spiniferites ramuliferus (Deflandre 1937) Reid 1964

Spiniferites sp. A

Spiniferites sp. B

Spiniferites sp. C

Systematophora placacantha (Deflandre and Cookson 1955) Davey, Downie, Sarjeant, and Williams 1969

Tanyosphaeridium variecalamum Davey and Williams 1966

Tectadodinium pellitum Wall 1967

Thalassiphora delicata (Williams and Downie 1966) Eaton 1976

Thalassiphora pelagica (Eisenack 1954) Eisenack and Gocht 1960

Trichodinium hirsutum Cookson 1965

Tubidermodinium sulcatum Morgenroth 1966

Turbiosphaera filosa (Wilson 1967) Archangelsky 1969

Turbiosphaera rotunda n. sp.

Turbiosphaera paratabulata n. sp.

Family PERIDINIACEAE Ehrenberg 1832

Andalusiella rhombohedra (Benson 1976) Stover and Evitt 1978

Apectodinium homomorphum complex

Apectodinium sp. A

Biconidinium longissimum Islam 1983

Deflandrea dartmooria Cookson and Eisenack 1965

Deflandrea phosphoritica Eisenack 1938

Deflandrea wardenensis Williams and Downie 1966

Isabelidinium cooksoniae (Alberti 1959) Lentin and Williams 1977

Kisselovia coleothrypta (Williams and Downie 1966) Lentin and Williams 1976

Lejeunecysta? sp. A

Lentinia ruginosa n. sp.

Lentinia spinigera n. sp.

Palaeocystodinium golzowense Alberti 1961

Palaeoperidinium pyrophorum (Ehrenberg 1838) Sarjeant 1967

Phelodinium magnificum (Stanley 1965) Stover and Evitt 1978

Phthanoperidinium echinatum Eaton 1976

Phthanoperidinium cf. *P. tritonium* Eaton 1976

Senagalinium? asymmetricum (Wilson 1967) Stover and Evitt 1978

Senagalinium? dilwynense (Cookson and Eisenack 1965) Stover and Evitt 1978

Senagalinium obscurum (Drugg 1967) Stover and Evitt 1978

Spinidinium cf. *S. essoi* Cookson and Eisenack 1967

Spinidinium macmurdoense (Wilson 1967) Lentin and Williams 1976

Spinidinium paratabulatum n. sp.

Wetzeliella hampdenensis Wilson 1967

Wetzeliella cf. *W. irtyschensis* Alberti 1961

Wetzeliella lunaris Gocht 1969

Wetzeliella samlandica Eisenack 1954

Wetzeliella varielongituda Williams and Downie 1966

Wetzeliella sp. A

Wilsonidium tabulatum (Wilson 1967) Lentin and Williams 1976

Family UNCERTAIN

Ascostomocystis hydria Drugg and Loeblich 1967

Caligodinium amiculum Drugg 1970

Forma A

Forma B

Forma C

Forma D

Forma E

Fromea fragilis (Cookson and Eisenack 1962) Stover and Evitt 1978

Fromea? laevigata (Drugg 1967) Stover and Evitt 1978

Horologinella apiculata Cookson and Eisenack 1962

Impletosphaeridium kroemmelbeinii Morgenroth 1966

Impletosphaeridium rugosum Morgenroth 1966

Impletosphaeridium? sp. A

Inversidinium exilimurum McLean 1973

Paralecaniella indentata (Deflandre and Cookson 1955) Elsik 1977

Trigonopyxidia ginella (Cookson and Eisenack 1960) Downie and Sarjeant 1965

Tuberculodinium vancampoae (Rossignol 1962) Wall 1967

Tuberculodinium? sp. (sensu Williams and Brideaux 1975)

Xenikoon australis Cookson and Eisenack 1960

Group ACRITARCHA Evitt 1963

Subgroup SPHAEROMORPHITAE Downie, Evitt, and Sarjeant 1963

Cyclopsiella elliptica Drugg and Loeblich 1967

Cyclopsiella vieta Drugg and Loeblich 1967

Subgroup ACANTHOMORPHITAE Downie, Evitt, and Sarjeant 1963

Micrhystridium cf. *M. fragile* Deflandre 1937

Micrhystridium cf. *M. variabile* Valensi 1953

Micrhystridium spp.

Division CHLOROPHYTA

Class CHLOROPHYCEAE

Order CHLOROCOCCALES

Family CHLOROCOCCACEAE

Palambages sp. A

Palambages sp. B

Palambages sp. C

Class PRASINOPHYCEAE

Order HALOSPHAERALES

Family PTEROSPERMATACEAE

Cymatiosphaera spp.

Pterospermopsis spp.

Systematic Descriptions

Division PYRRHOPHYTA Pascher
Class DINOPHYCEAE Fritsch 1935
Order PERIDINIALES Haechel 1894
Family GONYAULACACEAE Lindemann 1928

Genus *Achilleodinium* Eaton 1976

Achilleodinium biformoides (Eisenack 1954) Eaton 1976

Pl. 5, figs. 5-9

1954. *Hystrichosphaeridium biformoides* Eisenack, p. 68, pl. 11, figs. 16-20.

1963. *Baltisphaeridium biformoides* Downie and Sarjeant, p. 91.

1965. *Hystrichokolpoma biformoides* (Eisenack 1954) Eisenack, p. 151, pl. 14, fig. 2.

1966. *Hystrichokolpoma biformoides* (Eisenack 1954) Eisenack 1965 in Morgenroth, p. 28, pl. 6, figs. 9-10.

1976. *Achilleodinium biformoides* (Eisenack 1954) Eaton, p. 234-236, pl. 1, figs. 1-6; text-fig. 4.

Comments: Cysts of this study most closely resemble the German lower Eocene forms illustrated by Morgenroth (1966). Both bear a long, relatively slender antapical process, in contrast to the shorter, broader antapical process on the British Eocene specimens included by Eaton (1976) in his new combination and emendation. Oak Grove core specimens are generally larger than most previously documented forms. The cyst displays a large precingular archeopyle (Type P), with displacement of paraplate 3". Paratabulation, recorded as $', 0a, 6", 6c, 5"', 1p, 1"", is reflected by two general types of processes: (1) precingular and postcingular (2"-5") processes are large, hollow, irregularly shaped, with circular to polygonal shaped bases and distal tips (closely or partically open) with spines or tubules; process walls are striate and typically fenestrate; (2) apical, paracingular, parasulcal, precingular 6", and postcingular 1"'are small, slender, and distally buccinate (open) or bifid (closed). The antapical process is long, with bubules and spines near its closed, nearly pointed tip. The endophragm is about 2um thick, and the periphragm, externally reticulate with some scattered grana, is less than 1um thick.

Dimensions: Observed range (20 specimens measured): main body length 62-80um and width 60-7-um; process lengths up to 25um and widths up to 28um; antapical process lengths up to 34um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Sparse.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966a); Upper Eocene of Belgium (Rozen, 1965); Upper Eocene of East Prussia (Eisenack, 1954, 1965); Upper Eocene of northern Germany (Agelopoulos, 1967); Middle and Upper Oligocene of northern Germany (Benedek, 1972); Lower Eocene of Belgium (DeConinck, 1973, 1976a); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Eocene of England (Eaton, 1976; Bujak et al., 1980a); Middle and Upper Eocene of Alabama, U.S.A. (Edwards, 1977); Upper Paleocene and Eocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1980a); Lower Eocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Lower Eocene of the Netherlands (DeConinck, 1977); Eocene of the Rockall Plateau (Costa and Downie, 1979); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984); Composite range based on worldwide occurrences--Lower Eocene to Upper Oligocene (Helby et al., 1984).

Genus *Adnatosphaeridium* Williams and Downie 1966

Adnatosphaeridium multispinosum-vittatum complex

Pl. 2, figs. 1-7

1966. *Adnatosphaeridium multispinosum* Williams and Downie,

p. 216-217, pl. 24, fig. 5; text-fig. 57.

1966. *Adnatosphaeridium vittatum* Williams and Downie, p. 215, pl. 24, figs. 3, 7; text-fig. 56.

Comments: In this study it is difficult to distinguish between *Adnatosphaeridium multispinosum* and *A. vittatum* based on the characteristics described by Williams and Downie (1966c). Considerable interspecific variability exists between these species. Features of both species can be observed on a single cyst. As a result, these forms have been assigned to an *A. multispinosum--A. vittatum* complex. Within a single population, variability is most pronounced in process type and distribution. Cysts transitionally grade from those with predominantly slender processes to others with progressively broader types; the latter most likely result from a fusing together of the former. Whereas some forms bear well developed annulate and soleate complexes, others reveal more weakly developed complexes. Distally processes are usually interconnected by trabeculae, both within complexes and from one complex to another. The trabeculae are typically serrate or denticulate, and may bear individual, short spines. Some cysts in this study with a relatively fine trabeculate network approach *A. multispinosum-vittatum* complex. In the upper part of the Lower Eocene strata of the core, forms have been recovered which have only a few of the processes distally interconnected; they begin to closely resemble cysts that have in this study been referred to the *Cleistosphaeridium diversispinosum* complex. The two complexes are seemingly related. DeConinck (1977) has recovered similar forms from the Ypresian of the Netherlands which he has designated *Adnatosphaeridium* cf. *A. vittatum* (see his pl. 1, figs. 5-6). Paratabulation is recorded as 4', 0a, 6", ?c, 5-6?"', 1p, 1""; the archeopyle is apical (Type $\bar{A}$). The main body may bear one or two antapical lobes up to 8um long; complete specimens also reveal a central apical lobe. The endophragm is about 1um thick, externally levigate; the periphragm is about 0.5um thick, externally scabrate to granulate. Study specimens of this complex are larger than the British Eocene forms of *A. multispinosum* and *A. vittatum*.

Dimensions: Observed range (25 specimens measured): main body length (incl. opercula) 85-100um; (excl. opercula) 50-80um; main body width 57-90um; process lengths up to 35um; process widths 2-12um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Abundant.

Previously reported occurrences: Lower Eocene of England (Williams and Downie, 1966c); Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Eocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Eocene of England (Eaton, 1976; Bujak et al., 1980a); Lower Eocene of the Netherlands (DeConinck, 1977); Upper Paleocene and Lower Eocene of England (Denison, 1977); Lower Eocene of the Rockall Plateau (Costa and Downie, 1979); Lower Eocene of Labrador and Upper Paleocene of the North Sea (Ioakim, 1979); Lower and Middle Eocene of eastern Netherlands (Herngreen, 1984); Composite range based on worldwide occurrences (for *Adnatosphaeridium multispinosum*)--Lower and Middle Eocene (Helby et al., 1984).

Adnatosphaeridium robustum (Morgenroth 1966)
DeConinck 1975

Pl. 2, figs. 8-12

1966. *Cannosphaeropsis robusta* Morgenroth, p. 19, pl. 4, fig. 1.
1975. *Adnatosphaeridium robustum* (Morgenroth 1966) DeConinck, p. 47-48.

<u>Comments:</u> Intratabular processes, interconnected distally by trabeculae up to 7um thick which are often fenestrate, are distributed with a paratabulation of 4', 0a, 6", ?c, 5?"', 1p?, 2?"". Typically multiple processes arise from a single paraplate. The archeopyle is apical (Type $\bar{A}$), with a simple, free operculum. Isolated opercula most commonly reveal four apical processes. Some cysts bear two blunt antapical horns with a relatively large process arising from each. The cyst appears to be single layered, externally microrugulate to microreticulate.

Dimensions: Observed range (25 specimens measured): main body (excl. opercula) length 51-62um and width 52-76um; process lengths up to 37um and width up to 7um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Sparse; Eocene strata: Extremely rare to Sparse.

Previously reported occurrences: Eocene of Germany (Morgenroth, 1966); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Lower Eocene of England (Eaton, 1976; Bujak et al., 1980a); Lower Eocene of southern Netherlands (DeConinck, 1977); Lower Eocene of Labrador (Ioakim, 1979); Lower and Middle Eocene of southern England (Islam, 1983); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Lower Eocene of eastern Netherlands (Herngreen, 1984); Upper Paleocene and Lower Eocene of Virginia and Maryland, U.S.A. (Edwards, 1984).

Genus *Alisocysta* Stover and Evitt 1978

Alisocysta cf. *A. margarita* (Harland 1979)
Stover and Evitt 1978

Pl. 12, figs. 9-14

<u>Comments:</u> The genus *Alisocysta* Stover and Evitt 1978 is a senior synonym of *Agerasphaera*, erected by Harland (1979) to accomodate cysts that are generally similar to *Eisenackia* (Deflandre and Cookson 1955) McLean 1973, but bear simulate processes (membranous walls) rather than raised pad-like structures. Oak Grove core specimens closely resemble forms from the Thanet Sands of southeastern England designated *Agerasphaera margarita* by Harland (1979), now *Alisocysta margarita* (Harland 1979) Stover and Evitt (1978). Specimens recovered in this study, however, differ from the English forms by: (1) their somewhat larger main body (length 44-52um (excl. operculum) X width 42-53um vs. length 34-44um X width 36-46um); (2) their generally higher membranous process walls (height up to 15um vs. height up to 10um); and (3) consistently lacking the random thickenings in the intratabular process areas observed by Harland (1979). *Alisocysta* cf. *A. margarita* is similar to *Hystrichokolpoma mentitum* McLean 1974 (pl. 8, figs. 1-5; compare also pl. 12, figs. 15-17 of the present study) in general size and appearance. Processes of the former, however, are distally open whereas those of the latter are distally closed. Al-

though a new species is not being erected in this study, a detailed description is included below for completeness.

Description: Cyst main body spheroidal to slightly ellipsoidal, bearing hollow, open-tipped, box-like, simulate processes (structural variation discussed below). Cyst wall bi-layered; processes, formed of periphragm indicate paratabulation of 4', 0a, 6", 6c, 6"', 1c, 1"". Archeopyle apical (Type $\bar{A}$) with simple, free operculum; corresponds to four apical paraplates and an apical pore closing paraplatelet. Paracingulum and parasulcus bear processes. Paracingulum levorotatory; ends separated vertically up to about one paracingulum width and transversely up to about three paracingulum widths. Parasulcus bears anterior and posterior parasulcal processes with two pairs of smaller proceses between them. Of the anterior-most pair, the left process is the larger and designated 1"' (number of postcingular paraplates arbitrarily indicated as six, by interpreting this reduced process in the parasulcus as the 1"', which is typical of modern thecae); the other pair is between the 6c and 1p processes.

Endophragm up to 1um thick, externally levigate to finely granulate. Periphragm up to 2um thick, fibrous with a microreticulate external appearance. Processes of variable construction ranging from those that are hollow, box-like, nearly parallel-sided, open-tipped with frayed edges, formed of a thin, faintly striate membrane, which may or may not have interspersed a few finely fibrous supports, to those that consist almost entirely of the finely fibrous structures (appearing as small process arranged in simulate complexes) with no thin membrane developed, or is at least partially torn away. Fibrous structures range in width from very narrow (1-2um) to comprising substantial portions of the process wall. Bases of all processes essentially four- or five- sided, and nearly equidimensional, except those of the paracingular processes which are rectangular. Postcingular processes 3"', 4"', and 5"' among largest, postcingular processes 1"' and 6"' and parasulcal processes among smallest on cyst. Apical pore closing paraplatelet bears small process in midst of four apical processes.

Dimensions: Observed range (7 specimens measured): main body length (excl. opercula) 44-52um and width 42-53um; process lengths up to 15um and widths up to 13um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Genus *Apteodinium* Eisenack 1958

Apteodinium australiense (Deflandre and Cookson 1955)
Williams 1978

Pl. 12, figs. 5-8

1955. *Gymnodinium australiense* Deflandre and Cookson, p. 248, pl. 5, fig. 1.

1967. *Scriniodinium (S.) australiense* (Deflandre and Cookson 1955) Eisenack, p. 195.

1978. *Apteodinium australiense* (Deflandre and Cookson 1955) Williams, p. 794.

Comments: Oak Grove core specimens of *Apteodinium australiense* are characterized by a thick, spongy periphragm up to 6um thick; the endophragm is levigate and only up to about 2um thick. The apical horn ranges up to 10um long. Low parasutural ridges outline the paraplates, although only six precingular and five postcingular paraplates can be recorded with any degree of certainty. The precingular archeopyle (Type P) results from the loss of paraplate 3".

Dimensions: Observed range (10 specimens measured): pericyst length 94-112um and width 72-88um.

Stratigraphic occurrence: Eocene strata: Rare.

Previously reported occurrences: Middle Miocene of Australia (Deflandre and Cookson, 1955); Upper Eocene of Australia (Cookson and Eisenack, 1965a); Lower Eocene of Belgium (DeConinck, 1969, 1973, 1976a); Paleocene of Virginia and Maryland, U.S.A. (McLean, 1971); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Upper Eocene to Miocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Composite range based on worldwide occurrences--Lower Eocene to Miocene (Helby et al., 1984).

Apteodinium cf. *A. cribrosum* Cookson and Eisenack 1968

Pl. 1, figs. 1-4

Comments: Eocene specimens from the Oak Grove core referred to *Apteodinium* cf. *A. cribrosum* are considerably larger than the Upper Cretaceous forms from the Gingin Brook No. 4 borehole of Western Australia, but are otherwise morphologically similar. From the endophragm, less than 1um thick, arise densely distributed fibers which are connected distally by an ectophragm of fine trabeculae. Fibers are longest in the antapical (up to 7um long) and apical (up to 8um long) regions and along the paracingulum (up to 6um long). The cysts bears a narrow, deeply invaginated parasulcus and rather weakly developed paracingulum which is strongly levorotatory (up to two and one-half paracingulum widths). Paratabulation is not discernible. The archeopyle is precingular (Type P).

Dimensions: Observed range (4 specimens measured): overall length 96-114um and width 90-98um; endocyst length 82-94um and width 78-83um; fiber lengths 3-8um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Santonian/Campanian? of Western Australia (Cookson and Eisenack, 1968); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979).

Apteodinium labyrinthum n. sp.

Pl. 1, figs. 5-8

Derivation of species name: Latin, *labyrinthus*, structure with winding passages--in reference to the labyrinth-like external appearance of the cyst.

Description: Cyst angularly ellipsoidal, bearing relatively short, bluntly pointed apical horn. Cyst wall bi-layered; numerous bacula arising from endophragm are distally interconnected by trabeculae and portions of thin ectophragm. Paratabulation not discernible. Archeopyle precingular (Type P) with simple, free operculum. Paracingulum indented, strongly levorotatory; ends separated vertically up to about two and one-half paracingulum widths and transversely up to about one paracingulum width. Parasulcus deeply invaginated.

Apical bulge up to 3um long in endocyst and a coalescence of broad bacula and other irregularly shaped, finely fibrous elements constitute apical horn. Endophragm, finely fibrous, about 1.5um thick; bears finely fibrous bacula and other irregularly shaped branching supports up to 4um long and 5um wide over most of cyst; bacula along paracingulum sutures up to 5um long and on apical horn up to 6um long. Bacula and other supports interconnected distally by trabeculae and discontinuous thin ectophragm up to 0.5um thick, fine fibrous to microfenestrate; external appearance of cyst is labyrinth-like.

Dimensions: Holotype L X W: 106um X 88um. Observed range (4 specimens measured): overall length 104-112um and width 88-94um; endocyst length 86-95um and width 70-76um; apical horn lengths up to 13um.

Discussion and comparison with similar species: Distinctive features of the new species include a relatively short, bluntly pointed apical horn, bi-layered cyst wall separated by bacula and other irregularly shaped supports, and a labyrinth-like external appearance.

Apteodinium labyrinthum is morphologically similar to *A. retiolum* (n. sp., this study). The latter bears only bacula interconnected distally by fine trabeculae, however, and the former has both bacula and other irregularly shaped structures supporting trabeculae and a discontinuous thin ectophragm.

The bacula and other supports arising from the endophragm of the new species are not nearly as densely distributed as the fibers of *A. cribrosum* Cookson and Eisenack 1968 (p. 112, fig. 1-L).

A. labyrinthum differs from *A. conjunctum* Eisenack and Cookson 1960 (pl. 1, figs. 7-8), and *A. granulatum* Eisenack 1958 (p. 23, figs. 8-14) in possessing a thin, discontinuous ectophragm.

Holotype: Pl. 1, figs. 5-8; VPISUPL Sample 341, Slide AP-1, Coords. R17.4;+10.6.

Stratigraphic occurrence: Eocene strata: Extremely rare; Miocene strata: Extremely rare.

Apteodinium retiolum n. sp.

Pl. 1, figs. 9-12

Derivation of species name: Latin, *retiolum*, small net--in reference to the net-like external appearance of the cyst.

Description: Cyst angularly ellipsoidal, bearing relatively short, bluntly pointed apical horn. Cyst wall bi-layered; densely distributed bacula arising from endophragm are distally interconnected by thin trabeculae. Paraplates outlined by larger than average bacula, indicating paratabulation of 3-4', 6", 6c, 6?c, 1p?, 1"". Archeopyle precingular (Type P) with simple, free operculum; corresponds to paraplate 3". Paracingulum indented, strongly levorotatory; ends separated vertically up to two paracingulum widths and transversely up to one paracingulum width. Parasulcus deeply invaginated, deflected around paraplate 6c.

Apical bulge up to 2um long in endocyst and a lattice-like network of long bacula interconnected by trabeculae constitute apical horn. Endophragm up to 1um thick; bears bacula up to 2um long and less than 1um thick over most of cyst; bacula along parasutures up to 3um long and in apical horn up to 4um ong. Bacula interconnected distally by thin trabeculae about 0.5um thick (=ectophragm), creating a microreticulate, or net-like, external appearance.

Dimensions: Holotype L X W: 64um X 48um. Observed range (5 specimens measured): overall length 60-80um and width 47-64um; endocyst length 48-62um and width 37-59um; apical horn lengths up to 10um.

Discussion and comparison with similar species: The new species is characterized by a relatively short, bluntly pointed apical horn, bi-layered wall separated by bacula, paratabulation indicated by alignment of larger than average bacula, and the net-like external appearance.

Apteodinium retiolum generally resembles the Aptian age species of *A. conjunctum* Eisenack and Cookson 1960 (pl. 1, figs. 7-8), and *A. granulatum* Eisenack 1958 (pl. 23, figs. 8-14). The new species, however, has a bi-layered cyst wall with bacula supporting the outer layer. In *A. conjunctum*, surface ornamentation is not discussed, but bacula are not apparent on the cyst wall in the photographs of the holotype. *A. granulatum* is described as bearing grana on the outer surface.

Holotype: Pl. 1, figs. 9-12; VPISUPL Sample 317, Slide AO-39, Coords. R15.7;+14.8.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Genus *Areoligera* (Lejeune-Carpentier 1938) Williams and Downie 1966

Comments: This study will follow the guidelines of Stover and Evitt (1978) in differentiating the *Areoligera-Cyclonephelium-Glaphyrocysta* morphologically related group of cysts. Their synopsis for *Areoligera* encompasses only those taxa with a lenticular main body bearing complexly branched, typically arcuate, penitabular process groups (gonyaulacoid paratabulation indicated). Refer to the comments given for species of *Glaphyrocysta* in this dissertation for comparison.

Areoligera spp. complex

Pl. 7, figs. 1-4

Areoligera cf. *A. senonensis*:

1966. *Areoligera* cf. *A. senonensis*-Lejeune-Carpentier 1938 in Williams and Downie, p. 230, pl. 25, fig. 6; text-fig. 64.
1976. *Areoligera* cf. *A. senonensis* Lejeune-Carpentier 1938 in Eaton, p. 244, pl. 3, figs. 4-5.

Areoligera cf. *A. medussetiformis*:

1966. *Areoligera* cf. *A. medussetiformis* (O. Wetzel 1933)

Lejeune-Carpentier 1938 in Williams and Downie, p. 229, pl. 29, fig. 4.

1976. *Areoligera* cf. *A. medussetiformis* (O. Wetzel 1933) in Eaton, p. 246, pl. 3, fig. 7.

Areoligera cf. *A. coronata*:

1966. *Areoligera* cf. *A coronata* (O. Wetzel 1933) Lejeune-Carpentier 1938 in Williams and Downie, p. 228-229, pl. 25, fig. 5; text-fig. 63.

1976. *Areoligera* cf. *A. coronata* (O. Wetzel 1933) Lejeune-Carpentier 1938 in Eaton, p. 245, pl. 3, fig. 6.

Comments: The *Areoligera* spp. complex of this study consists of morphologically variable forms generally resembling the *Areoligera senonensis* complex of British Eocene cysts discussed by Eaton (1976), primarily those types he has designated *A.* cf. *A. senonensis*, *A.* cf. *A medusettiformis*, and *A.* cf. *A. coronata*. Most morphotypes recovered in the Oak Grove core bear process complexes on both the dorsal and ventral surfaces, with small, central, process-free areas. Cysts are lenticular in shape and bear spine-like processes that may be simple (as in *A. senonensis*), interconnected by trabeculae at varying positions along their shanks (as in *A. medusettiformis*), or fused for variable distances along their shanks (as in *A. coronata*). *Areoligera* cf. *A. medusettiformis* and *A.* cf. *A. coronata* types are most dominant in this study. Processes are arranged in soleate, annulate, and linear (paracingular) complexes, indicating a paratabulation of 4', 0a, 6", 6?c, 5"', 1p, 1"". The archeopyle is apical (Type $\bar{A}$).

Dimensions: Observed range (25 specimens measured): main body length (excl. opercula) 54-72um and width 54-80um; process lengths up to 28um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Abundant.

Previously reported occurrences: Lower Eocene of England (Williams and Downie, 1966c); Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Eocene of England (Eaton, 1976; Bujak et al., 1980a); Upper Paleocene and Lower Eocene of England (Denison, 1977); Paleocene to Middle Eocene of Labrador and the North Sea (Ioakim, 1979); Upper Paleocene and Lower Eocene of the Rockall Plateau (Costa and Downie, 1979); Upper Paleocene and Eocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Lower and Middle Eocene of southern England (Islam, 1983a,c); Lower Eocene of eastern Netherlands (Herngreen, 1984).

Genus *Batiacasphaera* Drugg 1970

Batiacasphaera microreticulata n. sp.

Pl. 1, figs. 13-17

Derivation of species name: Greek, *mikros*, small, little + Latin, *reticulatus*, net-like--in reference to the fine reticulate ornamentation.

Description: Cyst generally spheroidal. Cyst wall single-layered, bearing a fine reticulum of extremely low septa. Paratabulation not apparent. Archeopyle apical (Type $\bar{A}$) with free operculum. Paracingulum and parasulcus not delineated.

Autophragm up to 1um thick bears a fine network of microsepta (up to 1um high), imparting a microreticulate external appearance (mesh openings 0.25-0.5um).

Dimensions: Holotype cyst diameter 54um. Observed range (25 specimens measured): cyst diameter 48-56um.

Discussion and comparison with similar species: The new species is characterized by its spheroidal shape, relatively large apical archeopyle, and microreticulate ornamentation.

Batiacasphaera microreticulata closely resembles *B. sphaerica* Stover 1977 (p. 73, pl. 1, figs. 4-6), and both may in fact be environmental variants of the same species. The autophragm of the latter, however, is described as granulate, punctoreticulate, or a combination of both, whereas the new taxon displays no variation and is consistently microreticulate. In addition, *B. microreticulata* (48-56um) measures considerably larger than *B. sphaerica* (32-40um). Any alignment of septa is lacking, resulting in an aparatabulate cyst. No accessory archeopyle parasutures are developed.

Holotype: Pl. 1, figs. 13-16; VPISUPL Sample 349, Slide AP-26, Coords. R14.3;+4.3.

Stratigraphic occurrence: Miocene strata: Rare to Common.

Batiacasphaera sp. A

Pl. 1, figs. 18-20

Comments: These small sub-spheroidal cysts recovered from the Paleocene strata of the Oak Grove core bear a very fine reticulum formed by low septa (up to 0.5um high), imparting a microreticulate external appearance (mesh openings 0.25-0.5um). Paratabulation is not apparent. The archeopyle is apical (Type $\bar{A}$) with a free operculum.

Batiacasphaera sp. A is similar to *Batiacasphaera microreticulata* (n. sp., this study) and *B. sphaerica* Stover 1977 (p. 73, pl. 1, figs. 4-6), but is smaller, not as consistently spheroidal, and bears shorter septa and a finer microreticulum.

Dimensions: Observed range (5 specimens measured): cyst length 31-42um and transdiameter 30-40um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Genus *Cassidium* Drugg 1967

Cassidium paleocenicum n. sp.

Pl. 31, figs. 7-8

Derivation of species name: Paleocene--in reference to the geologic time series in which the species was recovered.

Description: Cyst spheroidal to slightly ellipsoidal; single wall layer less than 2um thick bears densely distributed foveae 1-3um in diameter. Accessory archeopyle parasutures suggest six precingular paraplates; other evidence of paratabulation not apparent. Archeopyle apical (Type $\bar{A}$) with simple, free operculum. Paracingulum and parasulcus not delineated.

Dimensions: Holotype overall L X W: 80um X 74um. Observed range (6 specimens measured): overall length 75-86um and width 73-80um.

Discussion and comparison with similar species: *Cassidium paleocenicum* differs from the generally similar *C. fragilis* (Harris 1965) Drugg 1967 (p. 22, pl. 3, figs. 15-16) in its wall construction; the former has a relatively thin, foveate wall, whereas the latter has a thick, rugulate to reticulate wall.

Holotype: Pl. 31, figs. 7-8; VPISUPL Sample 316, Slide AO-35, Coords. R4.2;+7.3.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Genus *Chiropteridium* Gocht 1960

Chiropteridium partispinatum (Gerlach 1961) Brosius 1963

Pl. 16, figs. 1-3

1961. *Membranophoridium partispinatum* Gerlach, p. 201-203, pl. 29, figs. 3, 6.

1963. *Chiropteridium partispinatum* (Gerlach 1961) Brosius, p. 48.

Comments: Only one intact and a few fragmented specimens of *Chiropteridium partispinatum* were recovered in the Miocene strata of the core; they compare in size and morphology to Gerlach's (1961) German Oligocene forms. Simple spine-like and membranous processes with spiney distal terminations are concentrated primarily along the periphery of the cyst; paratabulation could not be determined. Excystment is by an apical archeopyle (Type A). The endophragm up to 2um thick is coarsely fibrous; the periphragm is finely fibrous.

Dimensions: Observed range (1 intact specimen measured): main body length 76um and width 80um; process lengths up to 23um.

Stratigraphic occurrence: Miocene strata: Extremely rare.

Previously reported occurrences: Middle and Upper Oligocene of Germany (Gerlach, 1961; Brosius, 1963; Benedek, 1972); Upper Eocene of the Norwegian-Greenland Sea (Manum, 1976); Lower Miocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Oligocene/Miocene transition of the North Sea (Ioakim, 1979).

Genus *Chlamydophorella* Cookson and Eisenack 1958

Chlamydophorella urna Cookson and Eisenack 1960

Pl. 32, figs. 1-4

1960. *Chlamydophorella urna* Cookson and Eisenack, p. 10, pl. 3, fig. 7.

Comments: Oak Grove core specimens of *Chlamydophorella urna* are slightly larger than the Albian to Cenomanian age cysts from Australia described by Cookson and Eisenack (1960). The ambitus of the holotype (see their pl. 3, fig. 7) is more angular than that of most study specimens. Paraplates are often weakly outlined by parasuturally aligned, slightly enlarged bacula. The relatively broad paracingulum, best revealed in optical cross-section as a depression at the edges of the cyst, is just anterior of the equatorial mid-line. Accessory archeopyle parasutures suggest six precingular paraplates. Although paratabulation of the operculum is indeterminate, its outline resembles that of *Microdinium ornatum* Cookson and Eisenack 1960, whose operculum consists of four apical and four anterior intercalary paraplates. The cyst wall is bi-layered; an endophragm about 1um thick bears bacula up to 2.5um high which in turn support a thin ectophragm. Forms with coarser and longer bacula (up to 4um long) were recovered from the basal interval (Samples 303 to 317) in the Aquia strata and have been included in this species.

Dimensions: Observed range (10 specimens measured): overall length 38-48um and width 31-44um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare.

Previously reported occurrences: Albian to Cenomanian of Australia (Cookson and Eisenack, 1960); Paleocene of Virginia and Maryland, U.S.A. (McLean, 1971); Paleocene of Virginia, U.S.A. (Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Maastrichtian of Georgia, U.S.A. (Firth, 1984).

Genus *Cladopyxidium* McLean 1972

Cladopyxidium saeptum (McLean 1972)
Stover and Evitt 1978

Pl. 32, figs. 5-8

1972. *Cladopyxidium septatum* McLean, p. 861-863, pl. 1, figs. 1-12.

1978. *Cladopyxidium saeptum* (McLean 1972) Stover and Evitt, p. 29-30.

Comments: Specimens from the Paleocene of the Oak Grove core are identical to the Paleocene and Upper Cretaceous cysts from Maryland and northern Virginia described by McLean (1972). The cyst's single wall layer up to 1.5um thick bears septa up to 3um high that outline the paraplates. The general form and position of the semicircularly shaped apical plates 2' and 3' of the modern thecate species *Cladopyxis hemibrachiata* Balech 1964, and the similar circular archeopyle of *Cladopyxidium septatum* suggested to McLean (1972) that paraplates 2' and 3' are likewise involved in archeopyle formation of the fossil form. Two specimens with attached opercula composed of at least two paraplates were observed in the present study (see pl. 32, fig. 8). After re-examining the holotypes and numerous specimens, Stover and Evitt (1978) concluded that *Cladopyxidium septatum* McLean 1972 and *Microdinium saeptum* Morgenroth 1968 are in fact the same species, and erected the new combination *Cladopyxidium saeptum*. In addition, they re-interpreted the paratabulation as 4', 3-4a, 6", 6c, 6"', 1p, 1"". The 4a paraplate shown on the sketch in figure 10 of plate 1 of McLean (1972) indeed seems to be more appropriately considered part of the apical series.

Dimensions: Observed range (5 specimens measured): overall length 31-37um and width 28-34um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Previously reported occurrences: Paleocene and Upper Cretaceous of Maryland and Paleocene of Virginia, U.S.A. (McLean, 1975); Paleocene of Virginia, U.S.A. (Witmer, 1975).

Genus *Cleistosphaeridium* Davey, Downie, Sarjeant, and Williams 1966

Cleistosphaeridium diversispinosum complex

Pl. 16, figs. 4-8

1966. *Cleistosphaeridium diversispinosum* Davey, Downie, Sarjeant, and Williams, p. 167, pl. 10, fig. 7.

Comments: Cysts generally conforming to the description of *Cleistosphaeridium diversispinosum* given by Davey et al. (1966b) have been referred to a *C. diversispinosum* complex in this study because of the extreme variability encountered, especially in process type. Many forms bear slender processes with predominantly expanded (usually denticulate) or furcate tips, or more rarely bifid, aculeate, or acuminate tips. Processes may be fused proximally a variable distance of their lengths. Two or more processes are occasionally joined by trabeculae along their shanks. In fact on some forms a distal expansion of one process may be connected to an adjacent process tip, and it apppears that this complex may be closely related to the *Adnatosphaeridium multispinosum-vittatum* complex. It is interesting to note that in both complexes process shanks are often distinctly perforate. For purposes of this study, the *C. diversispinosum* complex includes those forms on which most of the processes are in no way distally interconnected. Processes are either randomly distributed or arranged in weakly to moderately developed annulate, soleate, and linear complexes; process bases may be connected by weakly and discontinuously developed parasutural ridges. Paratabulation is tentatively suggested as 4', 0a, 6?", 6?c, 5-6?"', 1p?, 1"". Excystment is by an apical archeopyle (Type $\overline{A}$); isolated opercula bear four process complexes. Although the main body is most often generally spheroidal, some are slightly modified by one (more rarely two) antapial lobes. The bi-layered cyst wall is constructed of an endophragm up to 1um thick and a somewhat thinner periphragm, which is externally levigate, scabrate, or granulate.

<u>Dimensions:</u> Observed range (25 specimens measured): main body length (excl. opercula) 44-54um and width 44-60um; process lengths up to 26um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Abundant; Miocene strata: Rare.

Previously reported occurrences: Campanian of Alberta, Canada (Harland, 1973); Lower Eocene of England (Davey et al., 1966b; Denison, 1977; Bujak, 1980); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Lower Eocene of the North Sea (Ioakim, 1979); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983).

Genus *Connexiumura* May 1980

Connexiumura fimbriata (Morgenroth 1968) May 1980

Pl. 12, figs. 18-20

1968. *Hystrichokolpoma? fimbriata* Morgenroth, p. 547-548, pl. 45, figs. 7-8.

1980. *Connexiumura fimbriata* (Morgenroth 1968) May, p. 45-46, pl. 1, figs. 11-15.

Comments: *Connexiumura fimbriata* is distinguished by its unique maze-like external appearance, resulting from the distribution of both process walls and accessory walls. The low, perforate parasutural folds at the bases of all fimbriate wall impart a bead-like aspect. Hollow, open polygonal-based, simulate processes indicate a paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". A bifurcate or trifurcate spine-like structure is located at the apex, possibly reflecting the apical pore closing paraplatelet. Excystment is by a precingular (Type P) archeopyle. Specimens of this study conform in size to those described by May (1980). The endophragm is up to 1.5um thick and externally levigate; the periphragm is approximately 1um thick and levigate to finely scabrate.

Dimensions: Observed range (7 specimens measured): main body length 43-52um and width 40-50um; process lengths up to 25um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Previously reported occurrences: Danian of Denmark (Morgenroth, 1968; Hansen, 1977); Maastrichtian and Danian of Maryland, U.S.A. (Benson, 1976); Campanian and Maastrichtian of New Jersey (May, 1976, 1980) and Mississippi and Alabama, U.S.A. (Rounds, 1980); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984); Composite range based on worldwide occurrences--Upper Campanian to Lower Paleocene (Helby et al., 1984).

Genus *Cordosphaeridium* (Eisenack 1963) Davey 1969

Cordosphaeridium? amputatospinosum n. sp.

Pl. 3, figs. 1-4

Derivation of species name: Latin, *amputatus*, cut off, shortened + Latin, *spinosus*, spiney--in reference to the truncated processes.

Description: Cyst main body generally spheroidal, bearing fibrous, distally truncated processes. Cyst wall bi-layered; proceses formed of periphragm, distributed as multiple processes per paraplate. Archeopyle precingular (Type P) with simple, free operculum; likely corresponds to paraplate 3". Paracingulum not well delineated. Parasulcus may bear variable number of small processes.

Endophragm up to 2um thick, densely and finely fibrous. Periphragm up to 2.5um thick, coarsely fibrous. Processes fibrous, flattened to ovoidal in cross-section, tapering, distally truncated with a slightly flared open tip; two or more may be fused up to two-thirds of their lengths, and occur as multiple number per paraplate.

Dimensions: Holotype main body diameter 87um; process lengths up to 24um. Observed range (10 specimens measured): main body diameter 84-92um; process lengths up to 25um.

Discussion and comparison with similar species: The new species is characterized by a coarsely fibrous periphragm and truncated, fibrous processes. Because its paratabulation could not be determined, it has been questionably assigned to the genus *Cordosphaeridium*. The precingular archeopyle and fibrous processes are features otherwise consistent with this genus.

Cordosphaeridium? amputatospinosum superficially resembles *C. multispinosum* Davey and Williams 1966b (p. 89-90, pl. 3, fig. 6); the truncated processes of the former, however, are not distally serrate or digitate as in the latter. Some processes may be fused proximally in the new species, but this is not apparent in *C. multispinosum*. In addition, the main body diameter of *Cordosphaeridium? amputatospinosum* (84-92um) is considerably larger than that of *C. multispinosum* (45-59um).

Holotype: Pl. 3, figs. 1-4; VPISUPL Sample 340, Slide AO-95, Coords. R4.8;+12.3.

Stratigraphic occurrence: Miocene strata: Rare.

Cordosphaeridium biarmatum Morgenroth 1966

Pl. 3, figs. 5-7

1966. *Cordosphaeridium biarmatum* Morgenroth, p. 21, pl. 4, figs. 6-7.

Comments: This species is characterized by a slightly ellipsoidal cyst bearing both slender and broad processes. The paracingular processes are typically slender (up to 6um wide) and cylindrical; two or three processes may sometimes be proximally fused per paraplate. Remaining processes, particularly the postcingulars, are considerably broader (up to 30um wide). The processes, occasionally fenestrate, are constructed of fibers that arise from the coarsely fibrous periphragm, and indicate a paratabulation of 4', 0a, 6", 6c, 5-6?"', 1p, 1"". The archeopyle is precingular (Type P). Oak Grove core specimens are larger than the German Eocene forms.

Dimensions: Observed range (5 specimens measured): main body length 71-79um and width 68-74um; process lengths up to 28um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966a; Gocht, 1969); Eocene of the Grand Banks, Newfoundland, Canada

(Williams and Brideaux, 1975); Upper Danian of southern Sweden (DeConinck, 1975); Lower Eocene of southern Netherlands (DeConinck, 1977); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983).

Cordosphaeridium? callosum (Morgenroth 1966)
Stover and Evitt 1978

Pl. 8, figs. 12-13

1966. *Cordosphaeridium callosum* Morgenroth, p. 21, pl. 4, figs. 8-10.

1978. *Cordosphaeridium? callosum* (Morgenroth 1966) Stover and Evitt, p. 147.

Comments: Oak Grove core forms conform in size and morphology to the Lower Eocene specimens of *Cordosphaeridium callosum* described by Morgenroth (1966a). The endophragm is about 1um thick, externally levigate. The periphragm ranging up to 3um thick is fibrous, and bears processes constructed of a loose network of intertwining fibers, distally capitate or slightly flared. Cysts bear 20 to 45 processes whose distribution seems to be generally random, although some specimens suggest a possible arrangement of one to three per paraplate. The archeopyle is likely not precingular, as presumed by Morgenroth (1966a), but based on its outline may in fact be apical (Type A) in position. If the archeopyle is shown conclusively to be other than precingular, the species will require transfer to another genus. Stover and Evitt (1978) have provisionally retained this species in *Cordosphaeridium*.

Dimensions: Observed range (8 specimens measured): main body diameter 20-28um; process lengths up to 10um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Eocene of Germany (Morgenroth, 1966a); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1984); Lower Eocene of southern Netherlands (DeConinck, 1977); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.

Cordosphaeridium fibrospinosum

(Davey and Williams 1966) Davey 1969

Pl. 3, figs. 8-10

1966. *Cordosphaeridium fibrospinosum* Davey and Williams, p.. 86, pl. 5, fig. 5.

1969. *Cordosphaeridium fibrospinosum* (Davey and Williams 1966) Davey, v. 12, p. 36.

Comments: Specimens observed in this study are morphologically similar to the British Eocene forms described by Davey and Williams (1966) and the South African cysts discussed by Davey (1969). Virginia specimens, however, have a thicker main body wall (4um vs. 0.5um), with an endophragm up to 2um thick and a fibrous periphragm up to 3um thick. Processes, typically as broad as long, of a loosely fibrous construction, indicate a paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". The archeopyle is precingular (Type P).

Dimensions: Observed range (8 specimens measured): main body length 62-75um and width 57-70um; process lengths up to 31um and widths up to 30um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Paleocene of South Dakota, U.S.A. (Stanley, 1965); Eocene of England (Davey and Williams, 1966); Lower Eocene of Germany (Gocht, 1969); Maastrichtian of Texas, U.S.A. (Zaitzeff and Cross, 1970); Oligocene of Germany (Benedek, 1972); Paleocene of Spain (Caro, 1973); Lower Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Lower Eocene of

Maryland, U.S.A. (Goodman, 1975, 1979); Paleocene of Virginia, U.S.A. (Witmer, 1975); Lower Eocene of England (Eaton, 1976); Maastrichtian and Danian of Maryland, U.S.A. (Whitney, 1976, 1984; Benson, 1976); Campanian and Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980); Upper Paleocene and Lower Eocene of southeastern England (Denison, 1977); Middle and Upper Eocene of Alabama, U.S.A. (Edwards, 1977); Lower Oligocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Upper Paleocene and Lower Eocene of the Rockall Plateau (Costa and Downie, 1979); Eocene and Oligocene of eastern Canada (Barss et al., 1979); Lower Eocene of Labrador and Lower and Middle Eocene of the North Sea (Ioakim, 1979); Oligocene of South Carolina, U.S.A. (Ford, 1979); Paleocene of Georgia and Alabama, U.S.A. (Edwards, 1980); Campanian and Maastrichtian of Mississippi and Alabama, U.S.A. (Rounds, 1982); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Composite range based on worldwide occurrences--Upper Cretaceous (Santonian) to Lower Oligocene (Helby et al., 1984).

Cordosphaeridium giganteum n. sp.

Pl. 3, figs. 11-14

Derivation of species name: Latin, *giganteus*, of giants, gigantic--in reference to the large size of the cyst.

Description: Cyst main body spheroidal to ellipsoidal, bearing large, fibrous processes. Cyst wall bi-layered; processes formed of periphragm, indicating paratabulation of 4', 0a, 6", 6c, 6"', 1p, 1"". Archeopyle precingular (Type P) with simple, free operculum; corresponds to paraplate 3". Paracingulum and parasulcus bear processes. Paracingulum levorotatory, with ends separated vertically up to about three paracingulum widths and transversely up to about four paracingulum widths. Parasulcal area delineated by anterior and posterior parasulcal processes with two pairs of smaller processes between them.

Endophragm up to 1.5um thick, externally levigate. Periphragm fibrous, up to 4um thick. Processes fibrous, intratabular, paraplate-centered (one per paraplate). Apical processes are relatively thin and may be interconnected; the small process in midst of apical processes likely represents apical pore closing paraplatelet. Precingular processes typically round in cross-section, flared distally; some bases are U-shaped in cross-section (open toward cyst posterior). Paracingulum reflected by flattened processes with elongate bases. Postcingular processes large, with the 2"', 3"', and 4"' distinctively U-shaped in cross-section (open toward cyst anterior). Antapical process large, fibrous, hollow.

Dimensions: Holotype main body L X W: 84um X 74um; process lengths up to 40um. Observed range (20 specimens measured): main body length 84-105um and width 74-97um; process lengths up to 58um.

Discussion and comparison with similar species: Characteristic features include the large, fibrous processes, the thick, fibrous cyst wall, and the distinctive U-shaped postcingular processes.

Because modern dinoflagellate thecae often bear a reduced 1"' plate, the left process of the anterior-most pair of small processes (may be absent) is regarded as the 1"', resulting in six postcingular paraplates.

Cordosphaeridium giganteum is different from other described species of the genus primarily in its U-shaped construction of the posterior processes.

Cordosphaeridium sp. 2 of Gocht 1969 (p. 47, pl. 3, fig. 9, text-fig. 33), bearing somewhat shorter U-shaped postcingular processes, can likely be accomodated by the new species.

Holotype: Pl. 3, figs. 11-13; VPISUPL Sample 305, Slide AO-9, Coords. R11.3;+6.5.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Sparse.

Cordosphaeridium gracile (Eisenack 1954)
Davey and Williams 1966

1938. *Hystrichosphaera* cf. *ramosa* Ehrenberg in Eisenack, p. 186, text-fig. 1.

1954. *Hystrichosphaeridium inodes* subsp. *gracilis* Eisenack, p. 66, pl. 3, fig. 17; pl. 10, figs. 3-8; p. 112, figs. 7, 21.

1963. *Cordosphaeridium inodes* subsp. *gracilis* (Eisenack 1954) Eisenack, p. 261, pl. 29, fig. 3.

1966. *Cordosphaeridium gracile* (Eisenack 1954) Davey and Williams, p. 84-86, pl. 3, fig. 8; pl. 11, figs. 4, 6, 7.

Comments: Lower Tertiary specimens from the Oak Grove core are comparable to the Eocene London Clay specimens of Davey and Williams (1966b). Long, slender, fibrous, intratabular processes are distributed with a paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". Paracingular processes are flattened in cross-section. Distally the processes are flared, often recurved; some processes branch into a characteristic Y-shape. The archeopyle is precingular (Type P). The cyst wall is composed of an endophragm up to 2um thick and fibrous periphragm up to 3um thick.

Dimensions: Observed range (15 specimens measured): main body length 65-89um and width 64-80um; process lengths up to 48um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Lower Oligocene of Germany (Eisenack, 1938, 1954); Oligocene to Miocene of Germany (Gerlach, 1961); Lower Eocene of Germany (Morgenroth, 1966); Middle Eocene of northern Germany (Gocht, 1969); Middle and Upper Oligocene of Germany (Benedek, 1972); Eocene of England (Davey and Williams, 1966b; Eaton, 1976; Bujak, 1980; Bujak et al., 1980a); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Paleocene and Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Maastrichtian to Lower Oligocene of eastern Canada (Williams and Bujak, 1977); Middle Eocene to Oligocene of Alabama , U.S.A. (Edwards, 1977); Upper Paleocene and Lower Eocene of Labrador and Paleocene to Oligocene of the North Sea (Ioakim, 1979); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Paleocene and Lower Eocene of Alabama and Georgia, U.S.A. (Edwards, 1980); Composite range based on worldwide occurrences--Campanian to Upper Oligocene (Helby et al., 1984).

Cordosphaeridium inodes (Klumpp 1953) Eisenack 1963

Pl. 3, figs. 18-20

1953. *Hystrichosphaeridium truncigerum* Cookson, p. 114, pl. 2, figs. 21-23.

1953. *Hystrichosphaeridium inodes* Klumpp, p. 391-392, pl. 18, figs. 1-2.

1963. *Cordosphaeridium inodes* (Klumpp 1953) Eisenack, p. 261, pl. 29, fig. 3.

Comments: Observed specimens are generally larger than the German Eocene specimens described by Klumpp (1953). As similarly noted by Klumpp on the German forms and by Davey and Williams (1966b) on the British Eocene cysts, intraspecific variability is most evident in process size and number per paraplate. Within a population, specimens range from those with relatively slender, long processes (some of which likely represent forms transitional to *Cordosphaeridium gracile*), to shorter, more robust types. Many cysts bear one process per paraplate, whereas others have up to four or five clustered on a paraplate; variability in number of processes per paraplate is sometimes encountered on a single specimen. Paratabulation is noted as 4', 0a, 6", 6c, 5-6"', 1p, 1"". Up to six parasulcal processes are typically formed. Excystment is by a precingular (Type P) archeopyle.

The cyst wall is composed of an endophragm up to 3um thick and a fibrous periphragm up to 2um thick.

Dimensions: Observed range (25 specimens measured): main body length 68-91um and width 63-82um; process lengths up to 43um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Sparse; Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Eocene of Germany (Klumpp, 1953); Oligocene of Australia (Cookson, 1953); Eocene of Australia (Deflandre and Cookson, 1955); Upper Eocene to Middle Miocene of Germany (Gerlach, 1961); Lower and Middle Eocene of Germany (Eisenack, 1963); Upper Oligocene of Belgium (Brosius, 1963); Upper Eocene of Belgium (Rozen, 1965); Lower Eocene of Belgium (DeConinck, 191965, 1969); Eocene of England (Davey and Williams, 1966b; Downie et al., 1971); Eaton, 1976; Bujak et al., 1980a); Lower Eocene of northern Germany (Morgenroth, 1966; Gocht, 1969); Paleocene of Tasmania and Australia (Cookson and Eisenack, 1967); Danian of California, U.S.A. (Drugg, 1967); Danian of Denmark and Germany (Morgenroth, 1968); Paleocene and Eocene of northern France (Chateauneuf and Gruas-Cavegnetto, 1968; Gruas-Cavegnetto, 1968m 1970); Oligocene of Germany (Benedek, 1972); Upper Paleocene and Lower Eocene of Spain (Caro, 1973); Paleocene of Virginia, U.S.A. (Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Eocene of the Grand Banks, Newfoundland, Canada

(Williams, and Brideaux, 1975); Maastrichtian and Danian of Maryland, U.S.A. (Whitney, 1976, 1984); Middle Eocene to Lower Oligocene of Alabama, U.S.A. (Edwards, 1977); Maastrichtian and Danian of Denmark (Hansen, 1977); Upper Paleocene and Lower Eocene of southeastern England (Denison, 1977); Lower Eocene of southern Netherlands (DeConinck, 1977); Oligocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Maastrichtian to Lower Oligocene of eastern Canada (Williams and Bujak, 1977, Bujak et al., 1980a); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Lower and Middle Eocene of the Rockall Plateau (Costa and Downie, 1979); Eocene of Labrador and Paleocene to Oligocene of the North Sea (Ioakim, 1979); Upper Paleocene and Lower Eocene of Alabama and Georgia, U.S.A. (Edwards, 1980); Danian of Georgia, U.S.A. (Firth, 1984).

Cordosphaeridium inodes subsp. *robustum* Gocht 1969

Pl. 4, figs. 1-3

1969. *Cordosphaeridium inodes* subsp. *robustum*, p. 42, pl. 2, figs. 1-2.

Comments: Two specimens recovered from the Eocene strata of the Oak Grove core appear identical in size and morphology to the German Eocene forms of Gocht (1969). The archeopyle is precingular (Type P).

Paratabulation, indicated by intratabular, relatively short, robust, fibrous, distally flared processes, is 4', 0a, 6", 6c, 6"', 1p, 1"". The thick cyst wall is composed of an endophragm up to 2um thick and a fibrous periphragm up to 4um thick.

Dimensions: Observed range (2 specimens measured): main body length 60-80um and width 58-76um; process lengths up to 20um and widths up to 17um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Eocene of Germany (Gocht, 1969).

Cordosphaeridium multispinosum Davey and Williams 1966

Pl. 4, figs. 4-6

1966. *Cordosphaeridium multispinosum* Davey and Williams, p. 89-90, pl. 3, fig. 6.

Comments: Specimens of *Cordosphaeridium multispinosum* in the Oak Grove core differ from the Eocene London Clay forms described by Davey and Williams (1966b) primarily in process development. Specimens of the present study typically bear processes that may branch and are distally more flared than those of the holotype (refer to their pl. 3, fig. 6). They are distributed two or three per paraplate, indicating a paratabulation of 4', 0a, 6", 6c, 5-6"', 1p, 1"". An alignment of processes into six longitudinal rows was not apparent on the Virginia specimens. Excystment is by a precingular archeopyle (Type P). The cyst wall is bi-layered, with an endophragm up to 1um thick and fibrous periphragm up to 3um thick.

Dimensions: Observed range (5 specimens measured): main body length 70-82um and width 69-79; process lengths up to 29um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Eocene of England (Davey and Williams, 1966; Bujak, 1980); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Lower and Middle Eocene of England (Eaton, 1976); Lower Eocene of Belgium (DeConinck, 1976a); Lower Eocene of the Netherlands (DeConinck, 1977); Middle and Upper Eocene of the North Sea (Ioakim, 1979); Paleocene and Lower Eocene of Alabama and Georgia, U.S.A. (Edwards, 1980); Campanian and Maastrichtian of Mississippi and Alabama, U.S.A. (Rounds, 1982).

Cordosphaeridium solaster Morgenroth 1966

Pl. 4, figs. 7-9

1966. *Cordosphaeridium solaster* Morgenroth, p. 25, pl. 5, figs. 8-9.

Comments: A sole specimen of *Cordosphaeridium solaster* recovered from the Eocene strata is closely comparable in morphology and size to the German Eocene forms described by Morgenroth (1966). Paratabulation could not be determined from the distribution of the approximately 40 processes on the cyst. The processes are constructed of loosely bound fibers and typically bifurcate or trifurcate distally. The precingular archeopyle (Type P) is large with rounded margins. Based on the archeopyle shape, it appears that Morgenroth (1966) has oriented his holotype (pl. 5, fig. 8) upside-down. The levigate endophragm is about 1um thick and fibrous periphragm is about 3um thick, appearing externally reticulate.

Stover and Evitt (1978) have tentatively transferred this species to *Exochosphaeridium*, although they state that there is no information on a differentiated apical tuft. Because no tuft was observed on the specimen recovered in this study, it is herein retained in *Cordosphaeridium*.

Dimensions: Observed range (1 specimen measured): main body length 64um and width 60um; process lengths up to 17um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966a); Lower Eocene of Belgium (DeConinck, 1967a).

Genus *Danea?* (Morgenroth 1968) Drugg 1970

Danea? sp.

Pl. 5, figs. 1-4

Comments: A number of *Danea*-like cysts were recovered in the Brightseat equivalent-lower Aquia? strata of the core. Specimens range from forms superficially resembling "typical" *Danea mutabilis* (Morgenroth, 1968, pl. 43, figs. 5-6) with relatively long intratabular processes to forms with greatly reduced processes. A quill-like appendage up to 28um long is located at the apex; in addition, an apical protuberance up to 6um long may be present. An antapical process up to 26um long often encircles a protuberance up to 13um long. The cyst displays a precingular (Type P) archeopyle; paratabulation is recorded as 4', 0a, 6", 6c, 5"', 1p, 1"". The cyst wall appears to be constructed of an endophragm up to 2um thick and fibrous periphragm up to 3um thick.

Dimensions: Observed range (10 specimens measured): main body length 92-110um and width 58-88um; process lengths up to 22um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Genus *Dapsilidinium* Bujak, Downie, Eaton, and Williams 1980

Dapsilidinium pseudocolligerum (Stover 1977) Bujak, Downie, Eaton, and Williams 1980

Pl. 6, figs. 7-8

1842. *Xanthidium tubiferum* White, pl. 4, fig. 10.

1844. *Xanthidium tubiferum simplex* White, pl. 8, fig. 9.

1961. *Hystrichosphaeridium simplex* (White 1844) Gerlach, p. 190, pl. 28, fig. 10; text-figs. 20-22.

1977. *Polysphaeridium pseudocolligerum* Stover, p. 74-75, pl. 1, figs. 14-19.

1980. *Dapsilidinium pseudocolligerum* (Stover 1977) Bujak, Downie, Eaton, and Williams, p. 27-28.

Comments: The cysts recovered from the Miocene strata of the Oak Grove core are comparable in size and general morphology to the Oligocene/Miocene forms from the Atlantic corehole No. 5/5B, Blake Plateau, described by Stover (1977). The spheroidal main body bears numerous tapering, typically striate processes which are distally buccinate, more rarely capitate. Closely appressed to an extremely thin endophragm is a thin periphragm bearing minute, densely distributed, perpendicularly oriented rodlets.

Dimensions: Observed range (6 specimens measured): main body diameter 36-52um; process lengths up to 22um.

Previously reported occurrences: Middle and Upper Oligocene and Middle Miocene of Germany (Gerlach, 1961); Upper Oligocene of Germany (Brosius, 1963); possibly as *P. pastielsii*, Eocene of England (Davey and Williams, 1966b); Oligocene of Germany (Benedek, 1972); possibly as *P. pastielsii*, Upper Eocene and Oligocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Oligocene and Lower Miocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Middle Miocene of the Rockall Plateau (Edwards, 1983).

Genus *Dinopterygium* Deflandre 1935

Dinopterygium cladoides Deflandre 1935

Pl. 33, fig. 13

1935. *Dinopterygium cladoides* Deflandre, p. 231, pl. 8, fig. 6.

1960. *Oodnadattia tuberculata* Eisenack and Cookson, p. 6, pl. 2, figs. 10-14; text-fig. 1.

Comments: All specimens observed in the core are oriented with the wide paracingular flange parallel to the slide. Poor preservation precludes determination of the paratabulation; the formula has been recorded as 4', 0a, 6", ?c, 6"', 1p, 1"" by Stover and Evitt (1978). Parasutural ridges delineate the paraplates which are ornamented with fine, densely distributed tubercles. Ornamentation of the German Eocene cysts (see Morgenroth, 1966, pl. 2, fig. 11) appears coarser than that of the Oak Grove core forms. The archeopyle is epicystal (Type AP).

Dimensions: Observed range (8 specimens measured): maximum diameter of main body (polar view): 64-80um; flange widths 8-14um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Senonian of France (Deflandre, 1935); Lower Cretaceous of Australia (Deflandre and Cookson, 1955; Eisenack and Cookson, 1960); Albian of France (Davey and Verdier, 1971); Lower Eocene of Belgium (Reissinger, 1950; DeConinck, 1969, 1973, 1976a); Middle and Upper Oligocene of Germany (Benedek, 1972); Eocene, Oligocene, and Miocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Middle and Upper Eocene of Alabama, U.S.A. (Edwards, 1977); Eocene and Oligocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Lower Eocene of southern Netherlands (DeConinck, 1977); Eocene of England (Denison, 1977; Bujak et al., 1980a; Islam, 1983a).

Dinopterygium fehmarnense (Morgenroth 1966)
Stover and Evitt 1978

Pl. 34, figs. 8-10

1966. *Goniodoma polyedricum* Morgenroth, p. 7, pl. 2, figs. 7-8.

1971. *Heteraulacacysta polyedricum* (Morgenroth 1966) Eisenack and Kjellstrom, p. 445.

1973. *Heteraulacacysta fehmarnensis* (Morgenroth 1966) Lentin and Williams, p. 67-68.

1978. *Dinopterygium fehmarnense* (Morgenroth 1966) Stover and Evitt, p. 204-205.

Comments: Low parasutural ridges of the autophragm appear to reflect the same paratabulation as recorded for *Heteraulacacysta campanula*, i.e., 4', 0a, 6", ?c, 6?"', 1p, 1"". Excystment occurs by an epicystal archeopyle (Type $\overline{\mathrm{AP}}$). The autophragm is ornamented with intratabular tubercles up to 2um wide and 1.5um high, over which an extremely thin ectophragm is stretched.

Dimensions: Observed range (5 specimens measured): pericyst length 58-72um and width 60-72um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966a); Middle and Upper Oligocene of Germany (Benedek, 1972); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Upper Paleocene of Alabama and Georgia, U.S.A. (Edwards, 1980).

Genus *Diphyes* (Cookson 1965) Downie and Williams 1966

Comments: A complex of cysts belonging to the genus *Diphyes* was recovered throughout the Paleocene and Eocene strata of the core. In addition to forms conforming to the description of *Diphyes colligerum* of Cookson (1965) with obvious apical archeopyles (Type $\overline{A}$), other morphologically similar cysts with variable archeopyle development have been observed. For purposes of the present study, they have been divided into two general groups, *Diphyes colligerum* (Forma A) and *Diphyes colligerum* (Forma B), primarily on the basis of dominant process type. Within Forma A and Forma B the following archeopyle types exist: apical (Type $\overline{A}$) with the loss of paraplates 1'-4', precingular (Type P) with the loss of paraplate 3", and combination (Type $\overline{A+P}$) with the loss of paraplates 1'-4' + 3". In addition to their distinctive large antapical process, the cysts bear numerous smaller processes which appear randomly distributed on most specimens. On a few cysts, however, a gonyaulacacean paratabulation (4', 6", ?c, 6"', 1p, 1"") can be inferred from the distribution of processes and fused process groups; archeopyle sutures, outline shapes of the archeopyle and base of the anatapical process. Each of the three morphologic groups of *Diphyes* observed in this study is briefly discussed below.

This *Diphyes colligerum*-complex of cysts has been further analyzed in a separate investigation by Goodman and Witmer (1985). The research is based on specimens from the Oak Grove core Aquia and Nanjemoy strata, as well as from a Nanjemoy outcrop locality studied by Goodman (1975).

Diphyes colligerum (sensu Cookson 1965)

Pl. 6, figs. 4-6

1953\. *Hystrichosphaeridium* sp. C of Cookson, pl. 2, figs. 29-30.

1955\. *Hystrichosphaeridium colligerum* Deflandre and Cookson, p. 278, pl. 7, fig. 3.

1963\. *Baltisphaeridium colligerum* (Deflandre and Cookson 1955) Downie and Sarjeant, p. 91.

1965\. *Diphyes colligerum* (Deflandre and Cookson 1955) Cookson, p. 86, pl. 9, fig. 1-12.

Comments: In the present study, only those cysts referable to *Diphyes colligerum* which display an obvious apical archeopyle (Type $\bar{A}$) with no evident accessory archeopyle sutures are included in this group. Oak Grove core specimens bear both the distinctive wide, bulbous antapical process found on the Senonian and Eocene Australian forms of Cookson (1965), and the more narrow, straight-sided antapical process. Remaining processes on the cyst distally taper to either capitate or buccinate tips; proximally some processes are variably fused. The periphragm of the thin bi-layered cyst is ornamented with minute, perpendicularly oriented rodlets, imparting a microgranulate external appearance.

Dimensions: Observed range (8 specimens measured): main body diameter 28-40um; antapical process process lengths 10-20um and widths 8-20um; remaining process lengths up to 16um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Marlboro Clay: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Australia (Deflandre and Cookson, 1955); Senonian and Eocene of Australia (Cookson, 1965); Paleocene of Australia (Harris, 1965); Paleocene of South Dakota, U.S.A. (Stanley, 1965); Eocene of Germany (Morgenroth, 1966a); Eocene of England (Davey and Williams, 1966b); Lower Tertiary of Tasmania (Cookson and Eisenack, 1967a); Lower Eocene of Belgium (DeConinck, 1969, 1976a); Paleocene of Virginia and Maryland, U.S.A. (McLean, 1971); Miocene of Japan (Matsuoka, 1974); Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Paleocene of Virginia, U.S.A. (Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Eocene of England (Eaton, 1976); Middle Eocene of the Norwegian Greenland Sea (Manum, 1976); Upper Paleocene and Lower Eocene of southeast England (Denison, 1977); Middle Eocene to Oligocene of Alabama, U.S.A.(Edwards, 1977); Lower Eocene of southern Netherlands (DeConinck, 1977); Paleocene and Eocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Lower and Middle Eocene of the Rockall Plateau (Costa and Downie, 1979); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Lower Eocene of Labrador and the North Sea (Ioakim, 1979); Paleocene of Alabama and Georgia, U.S.A. (Edwards, 1980); Composite range based on worldwide occurrences--Maastrichtian to Eocene (Helby et al., 1984).

Diphyes colligerum (Forma A)

Pl. 6, figs. 9-12, 16

Comments: The cysts assigned to Forma A bear the characteristic large antapical process and approximately 50 smaller processes, most of which terminate in capitate (rarely acuminate) tips. Two and occasionally three processes are fused proximally a variable distance along their shanks. Inferred paratabulation is gonyaulacacean. The paracingulum is reflected by an approximate alignment of a variable number of processes; the parasulcal area bears small processes up to 8um long. The endophragm is up to 1um thick, externally levigate; the periphragm is about 0.5um thick, externally microgranulate.

Dimensions: Observed range (10 specimens measured): main body diameter 32-42um; capitate process lengths up to 20um; antapical process lengths 14-24um and widths 9-14um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Marlboro Clay: Extremely rare; Eocene strata: Extremely rare to Rare.

Diphyes colligerum (Forma B)

Pl. 6, figs. 13-15, 17

Comments: Cysts of the Forma B group are morphologically similar to *Diphyes colligerum* (sensu Cookson 1965) but have developed Type P or Type $(\overline{A + P})$ archeopyles; those with Type $\overline{A}$ archeopyles show some evidence of sutures indicating precingular paraplate involvement. The large antapical process exhibits a sparsely denticulated tip. Remaining processes (40-50) taper to dominantly buccinate tips. As with the other two groups, two or three processes may be fused near their bases. An equatorial alignment of processes suggests a paracingulum; small processes in the parasulcal region range up to 9um long. The endophragm is up to 1um thick, externally levigate; the pericingulum is nearly 1um thick, externally microgranulate.

Dimensions: Observed range (8 specimens measured): main body diameter 34-42um; buccinate process lengths up to 19um; antapical process lengths 15-21um and widths 8-14um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare to Rare.

Genus *Distatodinium* Eaton 1976

Distatodinium paradoxum (Brosius 1963) Eaton 1976

Pl. 13, figs. 12-13

1963. *Hystrichosphaeridium paradoxum* Brosius, p. 41, pl. 4, figs. 1-6; text-fig. 2.

1969. *Tanyosphaeridium paradoxum* (Brosius 1963) Gocht, p. 54, pl. 7, figs. 5-8; text-fig. 39.

1969. *?Oligosphaeridium paradoxum* (Brosius 1963) Davey and Williams, p. 5.

1972. *Tanyosphaeridium paradoxum* (Brosius 1963) Gocht 1969 in Benedek, p. 35, pl. 9, fig. 12; pl. 10, fig. 6.

1976. *Distatodinium paradoxum* (Brosius 1963) Eaton, p. 265-266, pl. 9, fig. 6.

Comments: Because the main body walls are thin and apparently fragile, most specimens of *Distatodinium paradoxum* are badly crumbled. The elongated cysts bear about 17-20 processes with flattened, blade-like, or tubular shanks up to 3um wide and distal tips constructed of bifurcating and trifurcating branchlets. Eaton (1976) believes that the processes are parasutural in position, but this fact could not be confirmed in the Oak Grove core forms. Paratabulation is tentatively suggested as 4', 0a, 6", 0c, 5-6"', 1p?, 1?""; the archeopyle appears to be apical (Type Ā). Study specimens compare in size with the British Upper Eocene forms of Eaton (1976).

Dimensions: Observed range (7 specimens measured): main body length approximately 35-45um and width 25-35um; process lengths up to 21um.

Stratigraphic occurrence: Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Middle and Upper Oligocene of northern Germany (Brosius, 1963; Gocht, 1969; Benedek, 1972); Lower Miocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Middle Oligocene to Lower Miocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Upper Oligocene of South Carolina, U.S.A. (Ford, 1979); Upper Oligocene of the North Sea (Ioakim, 1979).

Genus *Elytrocysta* Stover and Evitt 1978

Elytrocysta densobaculata n. sp.

Pl. 32, figs. 17-20

Derivation of species name: Latin, *densus*, thick, close, dense + Latin, *baculata*, covered with sticks, rods (bacula)--in reference to the very dense baculate ornamentation.

Description: Cyst ellipsoidal. Cyst wall bi-layered with layers separated by densely distributed bacula. Accessory archeopyle parasutures suggest seven precingular paraplates. Other parasutures may be visible as thinnings of the endophragm. Archeopyle apical (Type $\overline{\mathrm{AI}}$a) with ventrally attached operculum; questionably corresponds to four apical and four anterior intercalary paraplates (see Discussion below).

Endophragm up to 1um thick bears minute, densely distributed bacula up to 1.5um high which support a thin, levigate ectophragm less than 0.25um thick.

Dimensions: Holotype L X W: 38um X 34um. Observed range (25 specimens measured): overall length 30-43um and width 29-40um.

Discussion and comparison with similar species: The dense baculate ornamentation and apical archeopyle characterize the new species.

Although opercular paratabulation could not be determined with certainty, four apical and four anterior intercalary paraplates are indicated because the operculum outline resembles that of *Fibradinium annetorpense* and *Microdinium ornatum*, both of which have this formula; additionally, on a few forms parasutures divide the dorsal edge of the operculum into what appear to be four small anterior intercalary paraplates. Although most cysts do not reveal the archeopyle, on those in which one is visible, six long accessory archeopyle parasutures may be developed (often nearly extending to the paracingulum).

The new species superficially resembles and may ultimately be shown to be synonymous with *Elytrocysta druggii* (formerly *Membranosphaera maastrichtica* (Samoilovitch ex Norris and Sarjeant 1965) Drugg 1965), which was transferred to the new genus and set up as a new type species by Stover and Evitt (1978); see Drugg (1967, p. 29, pl. 5, figs. 12-13) for comparison. *Elytrocysta densobaculata*, however, invariably bears bacula which support an ectophragm, whereas *E. druggii* is described as bearing short processes or grana, with only one specimen revealing a thin, outer filmy layer.

The distribution of bacula is much denser and the expression of paratabulation (except for the accessory archeopyle parasutures) is less distinct in *Elytrocysta densobaculata* than in *E. obscurotabulata* (n. sp., this study).

Holotype: Pl. 32, figs. 17-18; VPISUPL Sample 317, Slide AO-39, Coords. R10.9;+3.9.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Sparse; Marlboro Clay: Rare; Eocene strata: Extremely rare to Common.

Elytrocysta obscurotabulata n. sp.

Pl. 33, figs. 1-5

Derivation of species name: Latin, *obscurus*, indistinct, obscure + Latin, *tabulata*, tabulated--in reference to the often indistinctly paratabulated cyst.

Description: Cyst ellipsoidal. Cyst wall bi-layered with layers separated by numerous bacula. Paraplates delineated, often weakly, by aligned, larger than average bacula, indicating paratabulation of 4?', 4a?, 7", 6c + tr. (transitional paraplate), 6"', 1p, 1"". Archeopyle apical (Type $\overline{\mathrm{AI}}$a) with ventrally attached compound operculum; questionably corresponds to four apical and four anterior intercalary paraplates (see *Discussion* below). Precingular paraplates partially divided by accessory archeopyle parasutures. Paracingulum indicated by slightly enlarged bacula; levorotatory with ends separated vertically and transversely up to about one-half paracingulum width.

Parasulcus broad posteriorly and narrows toward paracingulum. Endophragm up to 1um thick bears numerous bacula up to 1.5um high which support a thin, levigate ectophragm less than 0.25um thick.

Dimensions: Holotype L X W: 42um X 40um. Observed range (25 specimens measured): overall length 31-44um and width 30-40um.

Discussion and comparison with similar species: Diagnostic features include an ectophragm supported by numerous bacula, aligned, slightly enlarged bacula outlining paraplates, and an apical archeopyle.

Paratabulation could not be determined on the operculum. Because the outline of the archeopyle resembles that of *Fibradinium annetorpense* and *Microdinium ornatum*, four apical and four anterior intercalary paraplates are also believed to be present in the new species. In all cases, the margins of paraplates 1", 2", and 6" are relatively straight, whereas those of paraplates 3", 4", and 5" are gable-shaped. Paraplate 7" may or may not be present directly anterior of the transitional paraplate.

The new species is similar in appearance to *Membranosphaera* (now *Elytrocysta* sp. of Drugg 1967 (p. 30, pl. 5, fig. 11)); *Elytrocysta obscurotabulata* displays at least some evidence of paratabulation, however, and the species illustrated by Drugg does not.

Elytrocysta obscurotabulata differs from *E. densobacula* (n. sp., this study) by bearing less densely distributed, and somewhat more robust bacula, and by having parasutures vaguely expressed by linear thickenings of the endophragm.

E. obscurotabulata also bears a resemblance to *Chlamydophorella urna* Cookson and Eisenack 1960 (p. 10, pl. 3, fig. 7); in *C. urna*, however, the endophragm and ectophragm are separated by distinctly longer, and more robust (tubular?) bacula.

Holotype: Pl. 33, figs. 1-3; VPISUPL Sample 330, Slide AO-68, Coords. R14.9;+9.7.

Stratigraphic occurrence: Paleocene strata: Rare to Sparse; Marlboro Clay: Extremely rare to Sparse; Eocene strata: Extremely rare to Rare.

Genus *Eocladopyxis* Morgenroth 1966

Eocladopyxis peniculata Morgenroth 1966

Pl. 33, figs. 14-16

1966. *Eocladopyxis peniculatum* Morgenroth, p. 7-8, pl. 3, figs. 2-3.

1976. *Eocladopyxis peniculata* Morgenroth 1966 in McLean, p. 347-351, pl. 1, figs. 1-12; text-fig. 1.

Comments: The German Eocene specimens of *Eocladopyxis peniculata* (main body diameter 37-40um) of Morgenroth (1966) are appreciably smaller than the cysts recovered from the Oak Grove core (main body diameter 51-70um). Study specimens, however, do compare in size to the Paleocene Aquia Formation forms studied by McLean (1971, 1976). Excystment occurs by means of an epicystal archeopyle (Type $\overline{4A+6P}$). Although the hypocyst is typcially preserved as a complete unit, the epicystal compound operculum is not. A number of complete cysts were examined. Individual paraplates formed of the granulate periphragm about 1.5um thick rest upon the thinner, levigate endophragm; paratabulation is recorded as 4', 0a, 6", 6c, 6"', 1p, 1"". The paraplates are ornamented with acuminate spines which are elevated and supported by fine fibrils. McLean (1976) has revised the original description of *E. peniculata*, and suggests that this species may in fact be the Early Tertiary forerunner of the modern dinoflagellate *Pyrodinium bahamense* Plate 1906.

Dimensions: Observed range (25 specimens measured): main body diameter 51-70um; spine lengths up to 14um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Common; Eocene strata: Extremely rare to Common.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1984); Upper Paleocene and Lower Eocene of southern England (Denison, 1977); Lower Eocene of southern Netherlands (DeConinck, 1977); Upper Paleocene to Middle Oligocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Eocene of Labrador and Eocene to Oligocene of the North Sea (Ioakim, 1979); Upper Paleocene of Alabama, U.S.A. (Edwards, 1980); Upper Paleocene and Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Genus *Exochosphaeridium* Davey, Sarjeant, Downie, and Williams 1966

Exochosphaeridium bifidum (Clarke and Verdier 1967) Clarke, Davey, Sarjeant, and Verdier 1968

Pl. 4, figs. 10-12

1967. *Exochosphaeridium bifidum* Clarke and Verdier, p. 72-73, pl. 17, figs. 5-6; text-fig. 30.

1968. *Exochosphaeridium bifidum* (Clarke and Verdier 1967) Clarke, Davey, Sarjeant, and Verdier, v. 17, p. 182.

Comments: Virginia Paleocene and Eocene specimens are comparable in morphology and size to the Cenomanian-Campanian specimens of Clarke and Verdier (1967) from the Isle of Wight. Processes are coarsely and loosely fibrous at the bases, more finely and densely fibrous on the shanks, and taper distally with bifid or capitate tips. Some processes are fused proximally up to slightly over one-half their length. A distinctive, coarsely fibrous apical tuft-like process typically bears at least two prongs. The archeopyle is precingular (Type P). Paratabulation could not be determined. The cyst wall is composed of an endophragm up to 1um thick and a fibrous periphragm (externally appearing microreticulate to reticulate) up to 2um thick.

Dimensions: Observed range (15 specimens measured): main body length 62-77um and width 48-68um; process lengths up to 23um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Cenomanian to Campanian of the Isle of Wight, England (Clarke and Verdier, 1967); Maastrichtian of Texas, U.S.A. (Zeitzeff and Cross, 1970); Upper Cretaceous of western Australia (Cookson and Eisenack, 1974); Upper Campanian and Maastrichtian of Holland and Belgium (Wilson, 1974); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Paleocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Maastrichtian of Maryland, U.S.A. (Benson, 1976); Campanian and Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980); Danian of California, U.S.A. (Damassa, 1979); Campanian and Maastrichtian of Mississippi and Alabama, U.S.A. (Rounds, 1982).

Genus *Fibradinium* Morgenroth 1968

Fibradinium annetorpense Morgenroth 1968

Pl. 32, figs. 9-13

1968. *Fibradinium annetorpense* Morgenroth, p. 538, pl. 42, figs. 4-7.

Comments: Although somewhat larger, specimens from the lower Paleocene section of the Oak Grove core are otherwise comparable to the German Eocene specimens described by Morgenroth (1968). A description which includes additional information for the species follows.

Description: Cyst ellipsoidal, hypocyst slightly longer than epicyst. Cyst wall bi-layered. Paratabulation reflected by parasutural folds of periphragm (up to 3.5um high) is recorded as 4', 4a, 7", 6c + tr (transitional paraplate), 6"', 1p, 1"". Archeopyle apical (Type AIa) with simple, ventrally attached operculum; corresponds to four apical and four anterior intercalary paraplates. Paracingulum essentially unspiraled. Parasulcus narrow at paracingulum, but widens gradually toward antapex. Cyst wall composed of endophragm up to 1um thick and periphragm up to 0.5um thick, externally granulate.

Dimensions: Observed range (25 specimens measured): overall length 36-45um and width 33-42um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Abundant.

Previously reported occurrences: Danian of Germany (Morgenroth, 1968); Paleocene of Maryland, U.S.A. (McLean, 1971); Paleocene of Virginia, U.S.A. (Witmer, 1975); Upper Danian and Middle Paleocene of southern Sweden (DeConinck, 1975); Campanian, Maastrichtian, and Danian of Maryland, U.S.A. (Whitney, 1976, 1984); Maastrichtian and Lower Paleocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Danian and Lower Thanetian of Alabama and Georgia, U.S.A. (Edwards, 1980); Lower Paleocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984).

Genus *Fibrocysta* Stover and Evitt 1978

Fibrocysta bipolare (Cookson and Eisenack 1965)
Stover and Evitt 1978

Pl. 9, figs. 12-14

1965. *Cordosphaeridium bipolare* Cookson and Eisenack, p. 135, pl. 16, figs. 7-8.

1969. *Amphorosphaeridium bipolare* (Cookson and Eisenack 1965) Davey, v. 12, p. 35 (transfer to this genus rejected).

1969. *Lanternosphaeridium bipolare* (Cookson and Eisenack 1965) DeConinck, p. 38, pl. 11, figs. 1-6, 15-16.

1978. *Fibrocysta bipolare* (Cookson and Eisenack 1965) Stover and Evitt, p. 155.

Comments: Cysts of the present study are comparable to the Lower Eocene forms from Belgium investigated by DeConinck (1969). The large, nearly square-shaped precingular archeopyle (Type P) occupies much of the dorsal epicyst. Coarsely fibrous processes are typically nearly parallel-sided and distally may be somewhat flared. Paratabulation, difficult to determine because of the presence of one to three processes per paraplate, appears to be 4', 0a, 6", 6c, 5-6"', 1p, 1"". Slight protuberances of the endocyst, as well as finely fibrous, simple to foliate appendages up to 30um long, are situated at the apex and antapex of the cyst. The endophragm is about 1um thick; the fibrous periphragm is up to 2um thick.

Dimensions: Observed range (12 specimens measured): main body length 75-100um and width 51-70um; process lengths up to 26um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Paleocene of Australia (Cookson and Eisenack, 1965b, 1967b); Lower Eocene of Germany (Gocht, 1969); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Lower Eocene of Belgium (DeConinck, 1969, 1973, 1976a); Middle and Upper Oligocene of Germany (Benedek, 1972); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Lower Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Lower Eocene of the Netherlands (DeConinck, 1977); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Composite range based on worldwide occurrences--Upper Campanian to Lower Eocene (Helby et al., 1984).

Fibrocysta coalitospinosa n. sp.

Pl. 10, figs. 5-8

<u>Derivation of species name:</u> Latin, *coalitus*, united, grown together + Latin, *spinosus*, spiney--in reference to the clusters of processes variably united.

<u>Description:</u> Cyst main body ellipsoidal, bearing clusters of fibrous processes, including a large, distinctive process at the apex and antapex. Cyst wall bi-layered; processes formed of the periphragm, suggesting a paratabulation of 4', 0a, 6", 6c, 5-6?"', 1p, 1"". Archeopyle precingular (Type P) with simple, free operculum; corresponds to paraplate 3". Paracingulum and parasulcus bear processes. Paracingulum levorotatory with ends separated vertically up to about one paracingulum width and transversely up to about four paracingulum widths. Parasulcus bears a variable number of small processes. ,br Endophragm up to 2um thick, externally levigate. Periphragm up to 3um thick, fibrous. Processes coarsely fibrous, constructed of bundles of fibrils, often variably fused, distally square-tipped to branched; single or arranged in general clusters or soleate to annulate complexes. Apical cluster of processes coalesce around a central, densely fibrous shaft and taper to a point. Antapical process relatively long and broad with some terminal extensions.

Dimensions: Holotype main body L X W: 72um and 66um; apical cluster length 40um; antapical process length 32um; remaining process lengths up to 22um. Observed range (5 specimens measured): main body length 72-116um and width 66-96um; apical cluster lengths up to 40um; antapical process lengths up to 32um; remaining process lengths up to 30um.

Discussion and comparison with similar species: Process distribution primarily differentiates *Fibrocysta coalitospinosa* from *F. radiata* (Morgenroth 1966, p. 37-38, pl. 10, figs. 10-11) Stover and Evitt 1978, and *F. bipolare* (Cookson and Eisenack 1965, p. 135, pl. 16, figs. 7-8) Stover and Evitt 1978; the new species bears processes that are typically arranged in clusters or soleate/annulate complexes reflecting paratabulation, whereas the other species have more randomly distributed processes and lack the distinctive pointed apical cluster of processes and rather broad antapical process found on *F. coalitospinosa*. In addition, no apical or antapical protuberances which characterize *F. radiata* and *F. bipolare* are present on the new species.

The processes of *F. coalitospinosa* are fewer in number and longer than those of *F. lappacea* (Drugg 1970, p. 812-813, figs. 4A-D, 5A-D) Stover and Evitt 1978.

Holotype: Pl. 10, figs. 5-8; VPISUPL Sample 334, Slide AO-77, Coords. R12.7;+14.4.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Fibrocysta cf. *F. lappacea* (Drugg 1970)
Stover and Evitt 1978

Pl. 9, figs. 9-11

Comments: Specimens from the Lower Ecoene of the Oak Grove core superficially resemble the Lower Eocene forms described by Drugg (1970) from the Wilcox Formation of Alabama. The cyst bears numerous, nearly parallel-sided to slightly tapered, coarsely and loosely fibrous processes. Paratabulation is indeterminate. Fibrous appendages (up to 16um long) located at the apex and antapex are not as conspicuous as are those of the Alabama forms. Study specimens, however, lack the apical and antapical protuberances on the endocyst, and alignment of paracingular processes, apparent on Drugg's specimens. Excystment is by a precingular archeopyle (Type P). A bi-layered cyst wall is formed of an endophragm up to 1.5um thick and coarsely fibrous periphragm up to 2.5um thick.

Dimensions: Observed range (3 specimens measured): main body 74-84um and width 65-70um; process lengths up to 14um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Fibrocysta radiata (Morgenroth 1966)
Stover and Evitt 1978

Pl. 10, figs. 1-4

1966\. *Lanternosphaeridium radiatum* Morgenroth, p. 37-38, pl. 10, figs. 7-9.

1978\. *Fibrocysta radiata* (Morgenroth 1966) Stover and Evitt, p. 155.

Comments: Study specimens of *Fibrocysta radiata* are larger than those described by Morgenroth (1966) from the Lower Eocene of Fehmarn, Germany. The archeopyle is precingular (Type P). Coarsely fibrous processes are slightly flared with numerous irregular distal extensions; two or more processes may be fused proximally. Paratabulation is uncertain because of the multiple processes per paraplate. Apical and antapical elongate, branching, finely fibrous tuft-like appendages range up to 26um long. The cyst wall is constructed of an endophragm up to 1um thick and a fibrous periphragm up to 3um thick.

Dimensions: Observed range (7 specimens measured): main body length 74-90um and width 54-65um; process lengths up to 27um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Lwoer Eocene of the southern Netherlands (DeConinck, 1977); Lower and Middle Eocene of the Rockall Plataeau (Costa and Downie, 1979); Eocene of southern England (Bujak et al., 1980a; Islam, 1983a,c).

Fibrocysta sp. A

Pl. 9, figs. 15-16

Comments: The main body of these cysts is ellipsoidal and bears an antapical protuberance up to 8um long. A densely fibrous appendage also extends from both the apex and the antapex. Relatively narrow, discrete, fibrous processes occur as one, or more commonly multiple, per paraplate, suggesting a typical gonyaulacacean paratabulation. Paracingular processes are broad and flattened; the paracingulum is only slightly levorotatory. The archeopyle is precingular (Type P). The endophragm and periphragm are each about 1um thick; the former is levigate and latter fibrous.

Dimensions: Observed range (3 specimens measured): main body length 86-90um and width 58-64um; process lengths up to 20um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Genus *Florentinia* Davey and Verdier 1973

Florentinia ferox (Deflandre 1937) Duxbury 1980

Pl. 13, figs. 14-16

1937. *Hystrichosphaeridium ferox* Deflandre, p. 16-17, pl. 14, fig. 3.

1963. *Baltisphaeridium ferox* (Deflandre 1937) Downie and Sarjeant, p. 91.

1966. *Hystrichokolpoma ferox* (Deflandre 1937) Williams and Downie, p. 181.

1976. *Silicisphaera ferox* (Deflandre 1937) Davey and Verdier, p. 72.

1980. *Florentinia ferox* (Deflandre 1937) Duxbury, p. 121.

Comments: Specimens of *Florentinia ferox* recovered in this study closely resemble the original holotype of Deflandre (1937, pl. 14, figs. 3-4), as well as the French Turonian forms described and illustrated by Davey and Verdier (1976) in establishing their new combination of this species. The distinctive archeopyle involves a combination of apical and precingular paraplates (Type Āa + P), with the apical paraplates 1'-4' usually remaining attached ventrally and paraplate 3" typically missing. Processes reflect a paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". Davey and Verdier (1976) report basically three types of processes, including those of simple or double- or triple- pronged construction. Actually the processes might best be grouped into two general classes: (1) simple tapering processes which terminate with single, double, or triple prongs (apical, antapical, paracingular, and parasulcal processes); and (2) larger, broader processes arising from sub-rounded to sub-angular polygonal bases which terminate with multiple prongs (precingular and postcingular processes). Distally the prongs are truncated, with some appearing to be open and others pinched closed. The cyst wall is composed of an endophragm up to 1um thick and a densely granulate periphragm which is slightly thicker.

Dimensions: Observed range (20 specimens measured): main body length 43-67um and width 40-57um; process lengths up to 23um and widths up to 22um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Previously reported occurrences: Senonian of France (Deflandre, 1937; Deflandre and Courteville, 1939); Upper Aptian of Germany (Eisenack, 1958); Lower Hauterivian of Germany (Gocht, 1959); Cenomanian of Germany (Alberti, 1961), Albian and Cenomanian of Australia (Cookson and Eisenack, 1962); Albian and Cenomanian of England (Cookson and Hughes, 1964); Danian of California, U.S.A. (Drugg, 1967); Cenomanian to Santonian of England (Clarke and Verdier, 1967); Middle Cretaceous of Australia (Cookson and Eisenack, 1968); Lower Eocene of Belgium (DeConinck, 1969, 1976a); Cenomanian and Turonian of England (Davey, 1969); Danian? of Argentinia (Heisecke, 1970); Upper Albian to Danian of Alberta, Canada (Singh, 1971); Upper Albian of France (Davey and Verdier, 1973); Upper Danian of southern Sweden (DeConinck, 1975); Maastrichtian of Maryland, U.S.A. (Benson, 1976); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976); Campanian and Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980); Danian of the North Sea (Ioakim, 1979); Campanian and Maastrichtian of Mississippi and Alabama, U.S.A. (Rounds, 1982).

Genus *Glaphyrocysta* Stover and Evitt 1978

Glaphyrocysta exuberans complex

Pl. 7, figs. 5-12

1948. *Membranilarnax pterospermoides* O. Wetzel in Pastiels, p. 46, pl. 5, figs. 11-14.

1955. *Cyclonephelium exuberans* Deflandre and Cookson, p. 285 (nom. nud.)

1966. *Cyclonephelium exuberans* Deflandre and Cookson 1955 in Williams and Downie, p. 225, text-fig. 61.

1978. *Glaphyrocysta exuberans* (Deflandre and Cookson 1955) Stover and Evitt, p. 50.

Comments: Deflandre and Cookson (1955) assigned the Belgium Lower Eocene forms of *Membranilarnax pterospermoides* Pastiels 1948 to their new species *Cyclonephelium exuberans*, but in the process chose no holotype. Eaton (1976) designated a holotype (Pastiels, 1948, pl. 5, figs. 11, 13), and in his diagnosis restricted this species to include forms which are devoid of processes on paraplates 3" and 6"; specimens with processes in one or both of these positions he has transferred to *Cyclonephelium* cf. *C. exuberans*. Morphologically similar forms, which are relatively abundant in the lower 17.6 m (Samples 303-312) of the Paleocene strata of the Oak Grove core, consistently bear processes on paraplate 3", but may or may not bear processes on paraplate 6"; occasionally small spine-like processes or process remnants can be seen on paraplate 6". All such cysts, regardless of whether they bear a process complex on paraplate 6" or not, are in this study referred to the *Glaphyrocysta exuberans* complex (species is now in new genus erected by Stover and Evitt (1978)). This complex of cysts is characterized by a large, process-free, central ventral surface and processes which are distally interconnected by trabeculae and/or a fenestrate network, a feature shared with the seemingly closely related *Glaphyrocysta pastielsi* (Deflandre and Cookson 1955) Stover and Evitt 1978 and *G. retiintextum* (Cookson 1965) Stover and Evitt 1978. Higher in the Paleocene strata of the core, cysts which have a much smaller, process-free, central dorsal and ventral area and processes which are interconnected by trabeculae (but never a fenestrate network) to varying degrees become more dominant; these cysts have been designated *Glaphyrocysta* sp. A. It is not known whether the *G. exuberans* complex and *Glaphyrocysta* sp. A cysts represent an evolutionary lineage or reflect changes in local paleoenvironmental conditions; nevertheless, they have been segregated as they appear to be biostratigraphically significant. McLean (1971) reports forms similar to the *G. exuberans* complex of this study in the basal Aquia Formation (type section) in strata that Nogan (1964) believes were likely deposited in other than normal marine conditions (based on Foraminifera). A description is included for completeness.

Description: Cyst main body generally circular in dorso-ventral view; antapex may bear one or two bluntly rounded lobes (left is larger); equatorial section reveals flattened to slightly concave ventral side and somewhat convex dorsal side. Processes generally arranged as arcuate or annulate complexes indicating paratabulation of 4', 0a, 6", ?c, 5"', 1p?, 1"". Archeopyle apical (Type $\overline{A}$) with simple, free operculum; corresponds to four apical paraplates. Paracingulum vaguely reflected on some specimens by variable number of processes. Parasulcal extends from parasulcal notch on edge of archeopyle to posterior parasulcal process.

Cyst wall bi-layered. Endophragm up to 1um thick, externally levigate, closely appressed to periphragm. Periphragm up to 0.5um thick, externally levigate to microreticulate. Processes spine-like, solid, relatively long, arranged in arcuate to annulate complexes; adjacent processes within a complex may be fused varying distances along their lengths. Complexes typically interconnected distally by a network of fine trabeculae resulting in a net-like appearance, or by a coarser, fenestrate membrane, which is present only on periphery of cyst and is not present over dorsal or ventral surfaces (best observed along periphery in ventral view).

Central ventral area of most cysts commonly free of processes; some bear small processes in this area. Apical processes usually annulate complexes. Precingular processes predominantly arcuate complexes; some paraplates reflected by groups of randomly distributed processes. Arcuate complexes 3" and 3"' bisected by longitudinal midline of cyst. Paraplate 6" may be devoid of processes, or may bear small, spine-like process(es); occasionally only a remnant of process bases can be observed in this position. Antapical processes arranged in annulate complex.

Dimensions: Observed range (20 specimens measured): main body length (excl. opercula) 57-73um and width 68-85um; process lengths 20-50um; three complete specimens recovered with main body length 80-86um and width 78-83um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Abundant.

Glaphyrocysta ordinata (Williams and Downie 1966)
Stover and Evitt 1978

Pl. 7, figs. 19-20

1966. *Cyclonephelium ordinatum* Williams and Downie, p. 225, pl. 25, fig. 3; text-fig. 62.

1978. *Glaphyrocysta ordinata* (Williams and Downie 1966) Stover and Evitt, p. 50.

Comments: A paratabulation of 4', 0a, 6", ?c, 5"', 1p, 1"" is delineated by predominantly linear and arcuate complexes consisting of slender, distally capitate or acuminate processes that are typically united by a fenestrate membrane a variable distance along their lengths. In many complexes the membrane is so constructed as to impart a multiple arch-like effect. Fine trabeculae may also interconnect individual processes and complexes. Some complexes (e.g., 2', 3' 1"") are soleate or annulate and on some paraplates the processes are restricted to the periphery of the cyst. Paraplate 6" is often devoid of any processes. The main body may bear one or two antapical lobes. The endophragm is less than 1um thick, externally granulate; the periphragm is about half as thick, externally levigate to scabrate. The archeopyle is apical (Type $\bar{A}$); isolated opercula reveal four apical complexes.

Dimensions: Observed range (15 specimens measured): main body length (excl. opercula) 72-80um and width 70-81um; process lengths up to 40um; two complete specimens recovered with main body length 90-93um and width 80-84um.

Stratigraphic occurrence: Eocene strata: Rare to Abundant.

Previously reported occurrences: Lower Eocene of England (Williams and Downie, 1966c; Downie et al., 1971; Bujak, 1980; Bujak et al., 1980a); Lower and Middle Eocene of Germany (Gocht, 1969); Middle Eocene of northern France (Gruas-Cavagnetto, 1970); Paleocene and Lower Eocene of Spain (Caro, 1973); Paleocene and Lower Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Lower and Middle Eocene of England (Eaton, 1976); Lower Eocene of the Norwegian Greenland Sea (Manum, 1976); Lower Eocene of southeastern England (Denison, 1977); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Lower and Middle Eocene of the Rockall Plateau (Costa and Downie, 1979); Lower Eocene of Labrador and the North Sea (Ioakim, 1979); Lower and Middle Eocene of southern England (Islam, 1983a); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983).

Glaphyrocysta sp. A

Pl. 7, figs. 13-16

Comments: Forms referred to *Glaphyrocysta* sp. A are closely related to and likely derived from the *G. exuberans* complex. This group of cysts, recovered in its greatest abundance in the Upper Paleocene strata of the core, differs from *G. exuberans* complex in the following respects: (1) the former consistently bears an arcuate process complex on paraplate 6", whereas the latter often bears no process or only a small, spine-like process in this position; (2) the dorsal and ventral process-free areas of the former are much smaller than those of the latter; and (3) the processes of the former may be interconnected near the distal tips by trabeculae but they lack the fenestrate network development (especially evident in ventral view) of the latter. Some transitional forms have been observed. Processes are arranged in arcuate, soleate, and annulate complexes, indicating a paratabulation of 4', 0a, 6", ?c, 5"', 1p, 1"". Excystment occures by an apical archeopyle (Type Ā). Similar forms were recovered by McLean

(1971) in the upper strata of the Aquia Formation at its type section, interpreted by Nogan (1964) on the basis of Foraminifera, to be of normal marine deposition.

Dimensions: Observed range (25 specimens measured): main body length (excl. opercula) 56-75um and width 58-82um; process lengths up to 32um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare.

Glaphyrocysta sp. B

Pl. 7, figs. 17-18

Comments: Cysts assigned to *Glaphyrocysta* sp. B generally resemble Grand Banks Eocene forms of Williams and Brideaux (1975) referred to *Cyclonephelium* sp. E (pl. 28, fig. 1) and *Cyclonephelium* sp. (pl. 27, fig. 4). Relatively broad processes and clusters of slender processes are distally interconnected by a thin microfenestrate membrane, imparting a canopy effect; no membrane is developed over the central dorsal and ventral areas. Some cysts exhibit rather large dorsal and ventral process-free central areas, whereas others bear a few small processes, especially in the dorsal region. Paratabulation is typical for the genus. Excystment occurs by an apical archeopyle (Type $\bar{A}$).

Both the levigate endophragm and the microgranulate periphragm are about 0.5um thick.

Dimensions: Observed range (9 specimens measured): main body length (excl. opercula): 66-82um and width 68-80um; process lengths up to 24um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Sparse.

Genus *Hafniasphaera* Hansen 1977

Hafniasphaera septata (Cookson and Eisenack 1967) Hansen 1977

Pl. 20, figs. 13-16, 21

1961. *Hystrichosphaera crassipellis* Deflandre and Cookson 1955 in Gerlach, p. 177, pl. 27, fig. 5; text-figs. 16, 17, 23.
1967. *Baltisphaeridium septatum* Cookson and Eisenack, p. 253, pl. 42, figs. 6-10.
1971. *Spiniferites septatus* (Cookson and Eisenack 1967) McLean, p. 729-730, pl. 88, figs. 1-9.
1977. *Hafniasphaera septata* (Cookson and Eisenack 1967) Hansen, p. 16-17, fig. 22A-E.

Comments: Specimens of the present study are similar in morphology and size to those observed from the Aquia Formation of Maryland and northern Virginia by McLean (1971). The cyst exhibits a precingular arceopyle (Type P). Paratabulation, indicated by typically weakly developed parasutural ridges, is recorded as 3', 0a, 6", 6c, 5?"', 1p, 1"". Ridges are especially weakly defined on the ventral hypocyst. Processes, with bases of distinctive "bubble-like elements", are segmented with transverse septa. The cyst wall is composed of an endophragm up to 1.5um thick and a periphragm (of bubble-like construction) up to 7um thick. Some specimens recovered from the Aquia Formation near Richmond, Virginia (Witmer, 1975) also have extremely thick outer wall layers.

Dimensions: Observed range (25 specimens measured): main body diameter 43-55um; process lengths up to 17um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Previously reported occurrences: Paleocene of Australia (Cookson and Eisenack, 1967); Paleocene of Maryland and Virginia, U.S.A. (McLean, 1971); Paleocene of Virginia, U.S.A. (Witmer, 1975); Paleocene and Lower Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975) and eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Campanian, Maastrichtian, and Danian of Maryland, U.S.A.

(Whitney, 1976; 1984); Lower Paleocene of Denmark (Hansen, 1977); Lower Eocene of the Rockall Plateau (Costa and Downie, 1979); Danian of the North Sea (Ioakim, 1979); Paleocene of Alabama and Georgia, U.S.A. (Edwards, 1980); Composite range based on worldwide occurrences--Paleocene to Lower Eocene (Helby et al., 1984).

Hafniasphaera cf. *H. septata*
(Cookson and Eisenack 1967) Hansen 1977

Pl. 20, figs. 17-20

Comments: Cysts superficially resembling *Hafniasphaera septata*, bearing processes which lack the characteristic transverse septa in the shanks and the bubble-like elements at the bases, are designated *Hafniasphaera* cf. *H. septata*. Paratabulation and archeopyle type are the same as for *H. septata*. The endophragm is about 1um thick, and the periphragm up to 2um thick is constructed of bubble-like elements, imparting a microreticulate external appearance to the cyst. The outer wall is generally thinner than that of *H. septata*.

Dimensions: Observed range (5 specimens measured): main body diameter 36-45um; process lengths up to 14um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Genus *Heteraulacacysta* Drugg and Loeblich 1967

Heteraulacacysta campanula Drugg and Loeblich 1967

Pl. 34, figs. 5-7

1967. *Heteraulacacysta campanula* Drugg and Loeblich, p. 183-184, pl. 1, figs. 6, 7, 8a-c; text-fig. 2.

<u>Comments:</u> Only a few cysts referable to *Heteraulacacysta campanula* were recovered in this study, and they are generally comparable to the Alabama Eocene forms of Drugg and Loeblich (1967). Paratabulation, expressed by low parasutural ridges of the autophragm, appears to be 4', 0a, 6", ?c, 6?"', 1p?, 1"". Excystment is by an epicystal archeopyle (Type $\overline{\text{AP}}$). A distinctive paracingular flange ranges up to 4um in width. The autophragm is faintly microreticulate to microgranulate.

<u>Dimensions:</u> Observed range (3 specimens measured): main body length 57-62um and width 48-60um.

<u>Stratigraphic occurrence:</u> Eocene strata: Extremely rare.

Previously reported occurrences: Middle Eocene of Alabama, U.S.A. (Drugg and Loeblich, 1967); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Middle and Upper Eocene of Alabama, U.S.A. (Edwards, 1977); Lower Oligocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Upper Oligocene of South Carolina, U.S.A. (Ford, 1979).

Genus *Homotryblium* Davey and Williams 1966

Homotryblium caliculum Bujak 1980

Pl. 34, figs. 11-13

1980. *Homotryblium caliculum* Bujak, p. 62-64, pl. 16, fig. 1.

Comments: Oak Grove core specimens are slightly larger than the English forms from the Upper Eocene Barton Beds described by Bujak (1980). A generally spheroidal main body bears infundibular (funnel-shaped) and caliculate (goblet-shaped; for which species was named) processes with serrate to digitate edges. The archeopyle is epicystal (Type $\overline{\text{AP}}$ or AP); no intact opercula were observed in this study. Bujak (1980) reports the paratabulation as 4', 0a, 6", xc, 6"', 1p, 1"", p.s., and that all opercular paraplates are detached. A bi-layered cyst wall consists of a levigate endophragm up to 0.5um thick and thin periphragm that bears minute, densely distributed, perpendicularly oriented fibrils (less than 0.5um long) which impart a microgranulate external appearance.

Dimensions: Observed range (5 specimens measured): main body diameter 44-54um; process lengths up to 18um; mid-shank process widths up to 9um; distal tip process widths up to 16um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1984); Upper Eocene of England (Bujak, 1980; Bujak et al., 1980a); Lower and Middle Eocene of southern England (Islam, 1983a,b).

Homotryblium pallidum/tenuispinosum complex

Pl. 34, figs. 14-16

1966. *Homotryblium pallidum* Davey and Williams, p. 102-103, pl. 12, figs. 4, 6; text-fig. 22.

1966. *Homotryblium tenuispinosum* Davey and Williams, p. 101-102, pl. 4, fig. 11; pl. 12, figs. 1, 5, 7; text-fig. 21.

Comments: As described by Davey and Williams (1966b), both *Homotryblium pallidum* and *H. tenuispinosum* bear a granulate periphragm and processes of variable width and distal termination; they state that the former differs from the latter by its thinner wall and generally wider processes with more variable distal tips and a proximal marking about the base. Because the Oak Grove core specimens appear to exhibit gradational characteristics of both species, they are herein referred to a *Homotryblium pallidum/tenuispinsum* complex. It is certainly not obvious on what basis Bujak et al. (1980b) differentiated English forms designated *H. pallidum* (see their pl. 1, figs. 1-3) and *H. tenuispinosum* (see their pl. 1, figs. 4-6). Future studies may in fact show these two species to be conspecific. Although most study specimens are hypocysts, numerous complete cysts were also recovered. Paratabulation is recorded as 4', 0a, 6", 6c, 6"', 1p, 1"". The archeopyle is epicystal (Type $\overline{2A + 6P}$); the operculum consists of two apical paraplates (one with the 1' process and another with the 2', 3', and 4' processes), and six precingular paraplates (one process per paraplate). Refer to Forma AC of Evitt (1967, p. 78-79, pl. 9, figs. 7-16). Epicystal paraplates, delineated by linear thinnings of the periphragm, typically break apart after excystment. The periphragm of the bi-layered cyst is microgranulate to granulate.

Dimensions: Observed range (15 specimens measured): main body diameter 40-55um; process lengths up 31um; process widths 2-8um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Abundant.

Previously reported occurrences: Lower Eocene of Belgium (DeConinck, 1969, 1976a); Eocene of England (Davey and Williams, 1966b; Eaton, 1976; Denison, 1977; Bujak et al., 1980a,b); Lower Eocene of Spain (Caro, 1973); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975) and eastern Canada (Williams and Bujak, 1977; Barss et al, 1979); Eocene and Oligocene of the Rockall Plateau (Costa and Downie, 1979); Eocene of Labrador and the North Sea (Ioakim, 1979); Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Homotryblium tasmaniense Cookson and Eisenack 1967

Pl. 34, figs. 17-18

1967. *Homotryblium tasmaniense* Cookson and Eisenack, p. 133-134, pl. 20, figs. 1-2.

Comments: No complete cysts of *Homotryblium tasmaniense* were recovered in the Oak Grove core. Hypocystal hemispheres reveal a paratabulation of 6c, 6"', 1p, 1"". The archeopyle is epicystal, possibly Type $\overline{2A+6P}$, the type represented in the *Homotryblium pallidum*-

tenuispinosum complex of this study. In that case, the operculum would bear four apical and six precingular processes. Most cysts bear typically broad (up to 7um wide) processes. The endophragm is less than 1um thick; the periphragm is ornamented with densely distributed, short bacula up to 2um high.

Dimensions: Observed range (5 specimens measured): main body diameter 50-64um; process lengths up to 26um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Paleocene of Tasmania (Cookson and Eisenack, 1967a); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984).

Genus *Hystrichokolpoma* (Klumpp 1953)
Williams and Downie 1966

Hystrichokolpoma eisenackii Williams and Downie 1966

Pl. 5, figs. 10-12

1954. *Hystrichokolpoma cinctum* Klumpp 1953 in Eisenack, p. 64, pl. 10, figs. 11-14.

1966. *Hystrichokolpoma eisenackii* Williams and Downie, p. 176-178, pl. 17, figs. 1-3; text-fig. 46.

Comments: Specimens observed in the Lower Eocene strata of the Oak Grove core are comparable to the British London Clay forms of Williams and Downie (1966a). The large, bulbous processes are tapered and open distally, typically bearing one or two small, tubular extensions. At the antapex is located a larger than average, closed process. Each of the six cingular paraplates bears two slender processes. Paratabulation is recorded as 4?', 0a, 6", 6c, 5"', 1p, 1"". The cyst displays an apical archeopyle (Type $\bar{A}$); no opercula were observed. The cyst wall is bi-layered: the levigate to scabrate endophragm is up to 3um thick; the levigate periphragm is less than 1um thick.

Dimensions: Observed range (4 specimens measured): main body length (excl. opercula) 65-70um and width 56-62um; process lengths up to 40um and widths up to 38um; slender processes up to 4um in width; antapical process lengths up to 46um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Lower Oligocene of Germany (Eisenack, 1954); Lower Eocene of England (Downie and Williams, 1966a; Denison, 1977); Eocene and Middle Oligocene of Germany (Gocht, 1969); Lower Eocene of Belgium (DeConinck, 1976a); Eocene of the Norwegian

Greenland Sea (Manum, 1976); Eocene of England (Eaton, 1976; Bujak, 1980; Bujak et al., 1980); Lower Eocene of southern Netherlands (DeConinck, 1977), Eocene of Labrador and the North Sea (Ioakim, 1979); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983).

Hystrichokolpoma mentitum McLean 1974

Pl. 12, figs. 15-17

1974. *Hystrichokolpoma mentitum* McLean, p. 68-69, pl. 8, figs. 1-5; text-fig. 1.

Comments: Only a few specimens of *Hystrichokolpoma mentitum* were observed in this study. The delicate simulate processes, which appear distally closed, indicate a paratabulation of 4', 0a, 6", 6c, 6?"', 1p, 1"". Typically, however, these fragile processes are torn away, leaving only remnants of low ridges where the periphragm pulls away from the endophragm at the process bases. In these cases, the specimens might be mistaken for *Eisenackia circumtabulata* Drugg 1967 (p. 15, pl. 1, figs. 12-13). The endophragm up to 2um thick and the periphragm up to 1um thick are both levigate to faintly microgranulate. Excystment is by an apical archeopyle (Type $\overline{\text{A}}$).

Dimensions: Observed range (3 specimens measured): main body length 44-48um and width 40-43um; process lengths up to 13um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Previously reported occurrences: Paleocene of Virginia and Maryland, U.S.A. (McLean, 1974).

Hystrichokolpoma rigaudiae Deflandre and Cookson 1955

Pl. 5, figs. 13-15

1955. *Hystrichokolpoma rigaudiae* Deflandre and Cookson, p. 279-281, pl. 6, figs. 6, 10; text-fig. 42.

Comments: Study specimens of *Hystrichokolpoma rigaudiae* are similar to the Australian Eocene/Miocene forms described by Deflandre and Cookson (1955). Note that their description is based on an inverted holotype (see their pl. 6, fig. 6). The cyst bears two types of processes which indicate a paratabulation of 4?', 0a, 6", 6c, 5"', 1p, 1"": (1) slender paracingular processes, two per paraplate, often fused along their bases and buccinate to irregularly branched at their tips; and (2) large, broad processes, closed, with subquadrate bases and irregular terminations at their tips. The antapical process is long and distally drawn out to a point. The archeopyle is apical (Type $\bar{A}$). Although no opercula were observed in the study, Goodman (1975) recovered one specimen in the Nanjemoy Formation with the operculum in place; the apical process complex, constructed of apparently four fused processes, is distally open with two recurved extensions on either side of the opening (see his pl. 1, fig. 9). Oak Grove core specimens possess endophragms about 1um thick, scabrate to microgranulate, and thinner periphragms which are levigate to scabrate.

Dimensions: Observed range (8 specimens measured): main body length (excl. opercula) 44-55um and width 40-57um; antapical process lengths up to 38um; other process lengths up to 28um and widths up to 20um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare; Miocene strata: Extremely rare.

Previously reported occurrences: Eocene and Miocene of Australia (Deflandre and Cookson, 1955); Miocene and Oligocene of Germany (Gerlach, 1961); Pleistocene of Israel (Rossignol, 1962); Quaternary of the Mediterranean Sea (Rossignol, 1964); Upper Eocene of Australia (Cooksnon and Eisenack, 1965a); Lower Eocene of Belgium (DeConinck, 1965, 1976a); Lower Eocene of England (Williams and Downie, 1966a); Paleocene of Australia (Cookson and Eisenack, 1967a); Miocene of Japan and Sea of Japan (Shimakura et al., 1971; Matsuoka, 1974); Oligocene of Germany (Benedek, 1972); Paleocene of Virginia, U.S.A. (Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Eocene to Miocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975) and eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle Oligocene to Middle Miocene of the Norwegian Greenland Sea (Manum, 1976); Upper Paleocene and Lower Eocene of southeastern England (Denison, 1977); Middle Eocene to Lower Oligocene of Alabama, U.S.A. (Edwards, 1977); Oligocene and Lower Miocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Lower Eocene of the eastern Netherlands (DeConinck, 1977); Middle and Upper Eocene (Watkins, 1977) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Upper Eocene to Lower Miocene of Labrador and the North Sea (Ioakim, 1979).

Hystrichokolpoma tumescens McLean 1974

Pl. 6, figs. 1-3

1974. *Hystrichokolpoma tumescens* McLean, p. 66-68, pl. 8, figs. 6-9, text-fig. 1.

Comments: Specimens of *Hystrichokolpoma tumescens*, similar in all respects to the Paleocene forms from Maryland and northern Virginia described by McLean (1974), were recovered from the Paleocene and Eocene strata of the Oak Grove core. Simulate, distally closed, digitate processes with subquadrate bases and paracingular processes with rectangular bases indicate a paratabulation of 4?', 0a, 6", 6c, 6?"', 1p, 1"". The large antapical process is nearly parallel-sided to bulbous; its tip is typically broken open. Within the base of this process is located a protuberance of the main body up to 4um long. The cyst displays an apical archeopyle (Type $\overline{A}$); no opercula were observed. The endophragm is up to 2um thick, and the periphragm is less than 1um thck. Both wall layers are levigate to faintly granulate. The processes often appear slightly striate.

Dimensions: Observed range (7 specimens measured): main body length (excl. opercula) 45-60um and width 33-48um; antapical process lengths up to 39um and widths up to 28um; other process lengths up to 26um and widths up to 22um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Paleocene of Virginia, U.S.A. (McLean, 1974; Witmer, 1975).

Hystrichokolpoma unispinum Williams and Downie 1966

Pl. 5, fig. 16

1966. *Hystrichokolpoma unispinum* Williams and Downie, p. 179-180, pl. 17, figs. 6-7.

Comments: *Hystrichokolpoma unispinum* is distinguished by its large antapical process and relatively broad paracingular processes (one per paraplate). Processes are distally digitate, and typically bear a fenestrate membranous covering. The large, tapering antapical process is drawn out to a point. Paratabulation is expressed as 4', 0a, 6", 6c, 5"', 1p, 1"", with an apical archeopyle (Type $\overline{A}$). The cyst wall is composed of a levigate endophragm and periphragm, each of which is less than 1um thick.

Dimensions: Observed range (3 specimens measured): approximate main body diameter 45-60um; antapical process lengths up to 40um; other process lengths up to 34um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Marlboro Clay: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of England (Williams and Downie, 1966a); Lower Eocene of Belgium (DeConinck, 1969, 1973, 1976a); Lower Eocene of Romania (Baltes, 1969); Lower Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Upper Paleocene of Virginia, U.S.A. (Witmer, 1975); Eocene of the North Sea (Ioakim, 1979).

Genus *Hystrichosphaeridium* (Deflandre 1937)
Davey and Williams 1966

Hystrichosphaeridium tubiferum (Deflandre 1937)
Davey and Williams 1966

Pl. 8, figs. 1-4

1838. *Xanthidium tubiferum* Ehrenberg, pl. 1, fig. 16.

1933. *Hystrichosphaera tubifera* (Ehrenberg 1838) O. Wetzel, p. 40, pl. 4, fig. 16.

1937. *Hystrichosphaeridium tubiferum* (Ehrenberg 1838) Deflandre, pl. 12, fig. 14; pl. 13, figs. 2, 4, 5.

1966. *Hystrichosphaeridium tubiferum* (Deflandre 1937) Davey and Williams, p. 56-58, pl. 6, figs. 1, 2; pl. 8, fig. 5; pl. 10, fig. 2, text-fig. 2.

Comments: Oak Grove core forms compare in morphology and size to those described by Davey and Williams (1966b) from the Eocene London

Clay. The apical archeopyle (Type $\bar{A}$) typically includes a large parasulcal notch. Both the British and Virginia specimens exhibit a characteristic dashed circular pattern at the process bases where the periphragm diverges from the endophragm; foliaceous extensions at the process tips is another feature in common. Process distribution indicates a paratabulation of 4', 0a, 6", 6c, 6"', 1p, 1"". The bi-layered cyst wall is constructed of an endophragm up to 1um thick, and a periphragm up to 0.5um thick, both levigate to faintly granulate.

Dimensions: Observed range (25 specimens measured): main body diameter 35-52um; process lengths up to 35um

Stratigraphic occurrence: Paleocene strata: Extremely rare to Sparse; Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Lower Cretaceous (Aptian) to Middle Miocene cosmopolitan species reported from Western and Eastern Europe, Africa, Australia, Canada and the U.S.A.

Hystrichosphaeridium cf. *H. tubiferum*
(Deflandre 1937) Davey and Williams 1966

Pl. 8, figs. 7-9

Comments: A single specimen recovered from the bottom core sample resembles *Hystrichosphaeridium tubiferum*, but differs primarily in bearing considerably broader and shorter processes (mid-shank process widths up to 10um vs. up to 4um; process lengths up to 20um vs. 35um). Because of the length of its processes in ralation to the main body diameter, *Hystrichosphaeridium* cf. *H. tubiferum* cannot be assigned to *H. tubiferum* subsp. *brevispinsum*. The specimen likely represents a form intermediate to these two taxa. The distally serrate and slightly recurved processes arise from subquadrate bases; paracinugular processes are flattened with subrectangular bases. Paratabulation is indicated as 4?', 0a, 6", 6c, 6"', 1p, 1"", with an apical archeopyle (Type $\overline{A}$). The endophragm is about 1um thick; the periphragm, faintly granulate, is up to 0.5um thick.

Dimensions: Observed range (1 specimen measured): main body diameter 43um; process lengths up to 20um and widths up to 10um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Hystrichosphaeridium tubiferum subsp. *brevispinum* (Davey and Williams 1966) Lentin and Williams 1973

Pl. 8, figs. 5-6

1966. *Hystrichosphaeridium tubiferum* var. *brevispinum* Davey and Williams, p. 58, pl. 10, fig. 10.

1973. *Hystrichosphaeridium tubiferum* subsp. *brevispinum* (Davey and Williams 1966) Lentin and Williams, p. 80.

Comments: Four poorly preserved specimens of *Hystrichosphaeridium tubiferum* subsp. *brevispinum* were recovered in the Oak Grove core. Short, broad, tubiform processes with the distinctive dashed markings at the bases are distally serrate, and indicate a paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". Excystment is by means of an apical (Type $\bar{A}$) archeopyle. The endophragm is about 1um thick, and the periphragm up to about 0.5um thick is faintly granulate.

Dimensions: Observed range (4 specimens measured): main body diameter 40-50um; process lengths up to 9um and widths up to 10um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Eocene of England (Davey and Williams, 1966b); Paleocene of Virginia, U.S.A. (Witmer, 1975); Upper Danian of southern Sweden (DeConinck, 1975); Campanian and Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980); Lower and Middle Eocene of southern England (Islam, 1983a).

Hystrichosphaeridium spp.

Pl. 8, figs. 10-11

Comments: This group includes various types of undifferentiated small cysts with a spheroidal main body, apical archeopyle (Type $\overline{A}$), and short, often finely fibrous, tubiform processes. Paratabulation is typical for the genus. Some forms generally resemble *Cordosphaeridium minimum* (Morgenroth 1966) Benedek 1972, but their apical archeopyles preclude assignment to this species.

Dimensions: Observed range (10 specimens measured): main body diameter 24-29um; process lengths 7-12um.

Stratigraphic occurrence: Paleocene strata: Extremely rare: Eocene strata: Extremely rare; Miocene strata: Extremely rare.

Hystrichosphaeropsis ovum Deflandre 1935

Pl. 9, figs. 5-8

1935\. *Hystrichosphaeropsis ovum* Deflandre, p. 232, pl. 8, fig. 11.

1937\. *Hystrichosphaera ovum* (Deflandre 1935) Deflandre, p. 67, pl. 12, figs. 1, 2, 3, 10.

1954\. *Hystrichosphaera (Hystrichosphaeropsis)* cf. *ovum* (Deflandre 1935) Deflandre 1937 in Eisenack, p. 63, pl. 12, fig. 14.

1961\. *Hystrichosphaera ovum* Deflandre 1937 in Gerlach, p. 176-177, pl. 27, fig. 4.

1967\. *Hystrichosphaeropsis ovum* Deflandre 1937 in Clarke and Verdier, p. 50, pl. 10, figs. 6-9.

Comments: Specimens referred to *Hystrichosphaeropsis ovum* in the Miocene strata of the Oak Grove core appear morphologically similar to the Senonian forms of Clarke and Verdier (1967) from the Isle of Wight, England. On most cysts of the present study, the endophragm is up to 2um thick and constructed of densely distributed, perpendicularly oriented, fibrous elements which impart a coarsely granulate to reticulate external appearance; on a few forms, however, the endophragm is essentially levigate to microreticulate. The periphragm is about 0.5um thick and typically microgranulate. A similar variability in endophragm ornamentation is noted for the Isle of

Wight specimens. In the present study, all forms have been assigned to *Hystrichosphaeropsis ovum*. Parasutural folds, occasionally weakly developed, of the periphragm reflect a paratabulation of 4', 0a, 6", 6c, 5?'", 1p?, 1"". The cyst bears no processes. Both the apical pericoel, which bears a small horn up to 10um long, and the antapical pericoel, with a relatively large, circular aperture at the extreme posterior position, are large and box-like. The paracingulum is extremely levorotatory, up to two paracingulum widths.

Dimensions: Observed range (7 specimens measured): pericyst length 86-120um and width 56-68um; main body length 49-64um and width 44-60um.

Stratigraphic occurrence: Miocene strata: Rare.

Previously reported occurrences: Senonian of France (Deflandre, 1935, 1937); Senonian of England (Clarke and Verdier, 1967); Upper Eocene to Lower Oligocene of Germany (Eisenack, 1954); Oligocene and Middle Miocene of Germany (Gerlach, 1961); Senonian and Middle Miocene (as *Hystrichosphaeropsis* sp. A) of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975).

Genus *Impagidinium* Stover and Evitt 1978

Impagidinium speciosum n. sp.

Derivation of species name: Latin, *speciosus*, beautiful, handsome, showy--in reference to the striking beauty of this cyst.

Description: Cyst main body spheroidal to ellipsoidal. Cyst wall bi-layered; parasutural folds of the periphragm outline paraplates indicating a paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". Archeopyle precingular (Type P), reduced, with simple, free operculum; corresponds to paraplate 3". Paracingulum levorotatory; ends separated vertically up to about two paracingulum widths and transversely up to about one width. Parasulcus undivided or partially divided by a weakly developed parasutural fold delineating a posterior parasulcal paraplate; rarely a parasutural fold extends part way into parasulcus from paraplate 6c anterior edge.

Except under parasutural folds, endophragm up to 2um thick closely appressed to faintly granulate periphragm up to 1um thick. Parasutural folds merge gonally forming blunt projections up to 12um high.

Dimensions: Holotype pericyst L X W: 96um X 88um; endocyst L X W: 80um X 70um. Observed range (10 specimens measured): pericyst length 80-102umum and width 73-97um; endocyst length 67-84um and width

64-80um; parasutural fold bases up to 7um across; parasutural fold heights up to 9um.

Discussion and comparison with similar species: This new species is characterized by relatively high parasutural folds outlining distinct paraplates, blunt gonal projections, and undivided to partially divided parasulcus, and a reduced precingular archeopyle.

Impagidinium speciosum superficially resembles *I. dispertitum* Cookson and Eisenack 1965 (p. 122-123, pl. 12, figs. 5-7); the parasulcus of the new species, however, is often not divided into paraplates, whereas that of *I dispertitum* is typically separated into three large paraplates.

Impagidinium speciosum differs from the similar *I. victorianum* Cookson and Eisenack 1965 (p. 123, pl. 12, figs. 8-9) in apical and parasulcal paraplate development. The former bears four apical paraplates and a parasulcus not divided into distinct paraplates. The latter is described as having three apical paraplates and a parasulcus partially divided into three paraplates (strongly developed parasuture between posterior and middle paraplates; incompletely developed parasuture between anterior and middle paraplates).

Holotype: Pl. 11, figs. 1-3; VPISUPL Sample 317, Slide AO-39, Coords. R4.6;+8.2.

Stratigraphic occurrence: Paleocene strata: Rare to Sparse.

Impagidinium cf. *I. speciosum* n. sp.

Pl. 11, figs. 4-8

Comments: These forms generally resemble *Impagidinium speciosum* (n. sp., this study), differing primarily in their considerably longer gonal projections and more weakly and discontinuously developed parasutural folds. Gonal projections are hollow and some are distally flared, measuring 5-10um wide and 9-18um high. Parasutural folds between the gonal projections range from very low (up to 3um high) to extremely weakly developed, particularly on the ventral side. Parasutural folds (up to 9um high) on *I. speciosum*, on the other hand, are nearly as high as the gonal projections (up to 12um high). Paratabulation is the same as that of *I. speciosum*. These cysts may well represent environmentally influenced variants of *I. speciosum*, but have nevertheless been tentatively segregated in this study.

Dimensions: Observed range (10 specimens measured): main body length 70-88um and width 64-80um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Impagidinium sp. A

Pl. 11, figs. 9-12

Comments: Specimens of *Impagidinium* sp. A of the Paleocene strata of the Oak Grove core are morphologically similar to *I. dispertitum* (Cookson and Eisenack 1965) Stover and Evitt 1978 and *I. victorianum* (Cookson and Eisenack 1965) Stover and Evitt 1978, although they are much smaller and lack paraplate development on the parasulcus. The paracingulum is strongly levorotatory. Parasutural crests up to a constant height of 8um delineate a paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". The precingular archeopyle (Type P) results from the loss of paraplate 3". The endophragm is up to 1.5um thick, and the microreticulate periphragm is about 0.5um thick.

Dimensions: Observed range (3 specimens measured): main body length 33-48um and width 30-40um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Impagidinium sp. B

Pl. 11, figs. 13-16

Comments: One intact and numerous broken specimens of *Impagidinium* sp. B were recovered in the Miocene strata of the core. The archeopyle is precingular (Type P). Paratabulation is indicated by low, transparent, parasutural crests up to 4um high and is recorded as 4', 0a, 6", 6c, 5"', 1p, 1"". The main body appears to be single-layered, ornamented with coarse grana and bacula; if an endophragm is present, it is extremely thin. This form generally resembles *Impagidinium membranigerum* (Gerlach 1961; see p. 162-164, pl. 26, figs. 1-4, 7; text-figs. 4-5) Stover and Evitt 1978, but is considerably larger.

Dimensions: Observed range (1 intact specimen measured): main body length 90um and width 84um.

Stratigraphic occurrence: Miocene strata: Extremely rare to Rare.

Genus *Kallosphaeridium* DeConinck 1969

Kallosphaeridium brevibarbatum DeConinck 1969

Pl. 4, figs. 13-16

1969. *Kallosphaeridium brevibarbatum* DeConinck, p. 44-45. pl. 13, figs. 14-15.

<u>Comments:</u> Specimens recovered in this study, although generally larger, are morphologically similar to the Belgium Eocene forms described by DeConinck (1969). As is shown for *Lingulodinium machaerophorum* (Deflandre and Cookson 1955) Wall 1967, the ventrally-attached operculum on *Kallosphaeridium brevibarbatum* appears to be composed of four apical and possibly two anterior intercalary paraplates (Type $\overline{\mathrm{AI}}$a archeopyle), when compared with the shape of the operculum and paratabulation of *Gonyaulax polyedra* Stein. Accessory archeopyle parasutures suggest there are six precingular paraplates. On some specimens a paracingulum is indicated by alignment of larger than average bacula. Other paratabulation is not apparent. The endophragm up to 3um thick is composed of dense vertical fibers. Extending up to 5um beyond this wall layer are rather densely distributed setae, bacula, and other finely fibrous elements with irregular distal extensions.

Dimensions: Observed range (15 specimens measured): main body diameter 57-77um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Lower Eocene of Belgium (DeConinck, 1969, 1973, 1976a); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1984); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Lower Eocene of the southern Netherlands (DeConinck, 1977); Upper Paleocene of Alabama and Georgia, U.S.A. (Edwards, 1980); Upper Paleocene and Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Genus *Lingulodinium* (Wall 1967) Wall and Dale 1973

Lingulodinium machaerophorum

(Deflandre and Cookson 1955) Wall 1967

Pl. 4, figs. 17-20

1955. *Hystrichoshpaeridium machaerophorum* Deflandre and Cookson, p. 274, pl. 9, figs. 4, 8.

1961. *Baltisphaeridium machaerophorum* Gerlach, p. 191, pl. 28, fig. 11.

1961. *Hystrichosphaeridium ashdolense* Rossignol, pl. 1, fig. 9.

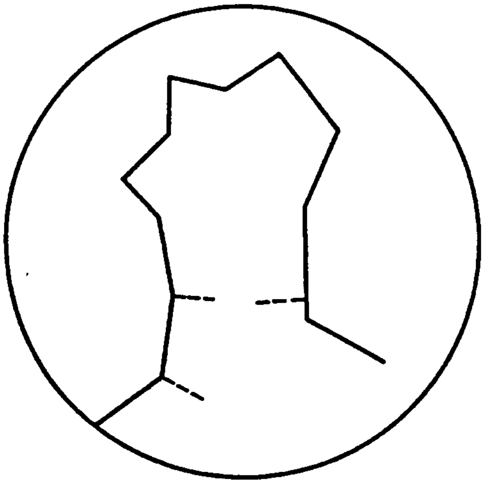
1964. *Baltisphaeridium machaerophorum* (Deflandre and Cookson 1955) Rossignol, p. 90, pl. 2, fig. 14; pl. 3, figs. 20, 21.

1967. *Lingulodinium machaerophorum* (Deflandre and Cookson 1955) Wall, p. 109-110, pl. 15, figs. 16-17; text-fig. 6.

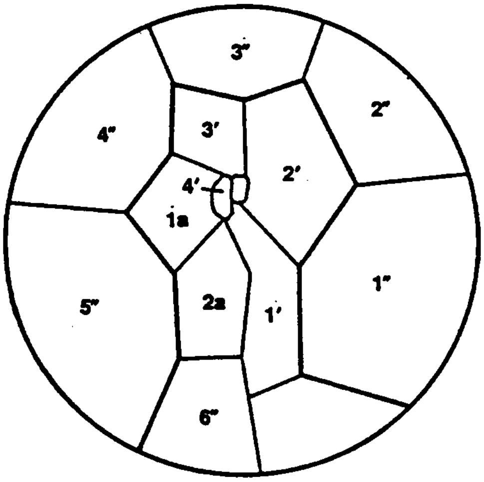
1973. *Lingulodinium machaerophorum* (Deflandre and Cookson 1955) Wall 1967 in Wall, Dale, and Harada, p. 24, pl. 2, figs. 5-6.

Comments: The Oak Grove core specimens are generally somewhat larger than the Late Quaternary Black Sea forms discussed in Wall et al. (1973). Archeopyle formation in this species includes a complex array of precingular types (1P, 2P, 3P, 4P, and 5P) and epicystal types ($\overline{AP}$ and $\overline{AIP}$); most were observed in this study. In the formation of a compound precingular type, an elongated, ventrally-attached, angular projection (lingula) remains. The shape of the lingula compares favorably with the outline of the operculum of *Gonyaulax polyedra* Stein, the living species which may be producing these particular cysts in the oceans today. As illustrated in Text-fig. 21, the four apical and two anterior intercalary paraplates recorded for *G. polyedra* may also be inferred for the typically atabulate lingula of *L. machaerophorum*. Accessory archeopyle parasutures suggest the presence of six precingular paraplates. Paratabulation of the remainder of the cyst is not clear. Both Virginia and Black Sea specimens bear spines vary-

A. ***Lingulodinium machaerophorum*** (APICAL VIEW)



B. ***Gonyaulax polyedra*** (APICAL VIEW)



Text-fig. 21. Comparison of outline of lingula of *Lingulodinium machaerophorum* (Deflandre and Cookson 1955) Wall 1967 from this study (A) with outline of operculum and paratabulation of *Gonyaulax polyedra* Stein (B). Dashed lines in (A) indicate positions of observed faint parasutures.

ing from small, filiform to stout, clavate types with typically bulbous, striate, and sculptured bases. The endophragm is about 1um thick; the periphragm, usually about twice as thick as the endophragm is microgranulate on Paleocene and Eocene forms, but more often setose on Miocene cysts.

Dimensions: Observed range (25 specimens measured): main body diameter 45-77um; process lengths up to 20um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare; Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Middle Miocene of Australia (Deflandre and Cookson, 1955); Middle Miocene of Germany (Maier, 1959); Middle Oligocene to Middle Miocene of Germany (Gerlach, 1961); Quaternary of Israel (Rossignol, 1961, 1962); Quaternary of the Mediterranean Sea (Rossignol, 1964); Lower Eocene of Germany (Morgenroth, 1966); Upper Quaternary of the Caribbean Sea (Wall, 1967); Lower Eocene of Belgium (DeConinck, 1969); Miocene of Japan (Shimakura et al., 1971); Quaternary of the Black Sea (Wall et al., 1973; Wall and Dale, 1974); Oligocene and Miocene of Tasmania and New Zealand (Haskell and Wilson, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Paleocene of Virginia, U.S.A. (Witmer, 1975); Lower Eocene of the Grand Banks, Newfoundland, Canada (Williams and

Brideaux, 1975); Oligocene and Lower Miocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Paleocene to Pliocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Eocene of Labrador and Eocene to Lower Miocene of the North Sea (Ioakim, 1979); Upper Oligocene of South Carolina, U.S.A. (Ford, 1979); Upper Paleocene and Lower Eocene of Alabama and Georgia, U.S.A. (Edwards, 1980); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Miocene of the Rockall Plataeau (Edwards, 1983); Upper Paleocene and Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Genus *Melitasphaeridium* Harland and Hill 1979

Melitasphaeridium pseudorecurvatum (Morgenroth 1966) Bujak, Downie, Eaton, and Williams 1980

Pl. 8, figs. 17-18

1966. *Hystrichosphaeridium pseudorecurvatum* Morgenroth, p. 30-31, pl. 8, figs. 5-6.

1978. *Operculodinium pseudorecurvatum* (Morgenroth 1966) Stover and Evitt, p. 179.

1980. *Melitasphaeridium pseudorecurvatum* (Morgenroth 1966) Bujak, Downie, Eaton, and Williams, p. 30.

Comments: Stover and Evitt (1978) transferred this species from *Hystrichosphaeridium* (Deflandre 1937) Davey and Williams 1966 to *Operculodinium* Wall 1967, presumably because of its precingular archeopyle. It was subsequently transferred to *Melitasphaeridium* Harland and Hill 1979 by Bujak et al. (1980a) who considered features such as a precingular archeopyle and one cylindrical shank process per paraplate more conformable to the diagnosis of this genus. Study specimens were observed to have spheroidal to slightly ellipsoidal main bodies bearing hollow, cylindrical processes with open distal tips consisting of five or six pointed aculeae (up to 5um long) which are slightly recurved. The processes are intratabular, typically one per paraplate, and reflect a paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". Release of paraplate 3" results in a precingular archeopyle (Type P). The paracingulum is levorotatory with the ends separated vertically about one paracingulum width; the parasulcus bears an anterior and posterior process. A two-layered cyst wall is composed of an externally levigate endophragm up to 1um thick, and an externally scabrate periphragm up to 0.5um thick.

Dimensions: Observed range (8 specimens measured): main body length 34-43um and width 28-34um; process lengths up to 18um; process shank widths up to 3um.

Stratigraphic occurrence: Eocene strata: Extremely rare: Miocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966a); Lower Eocene of Belgium (DeConinck, 1969); Lower Eocene of France (Gruas-Cavagnetto, 1970); Middle and Upper Eocene of Germany (Benedek, 1972), Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975) and eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Eocene of England (Eaton, 1976; Denison, 1977; Bujak et al., 1980a); Lower Eocene of the southern Netherlands (DeConinck, 1977); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Upper Paleocene and Lower Eocene of the Rockall Plateau (Brown and Downie, 1983).

Genus *Membranilarnacia* (Eisenack 1963)
Williams and Downie 1966

Membranilarnacia leptoderma (Cookson and Eisenack 1958)
Eisenack 1963

Pl. 21, figs. 13-16

1958. *Membranilarnacia leptoderma* Cookson and Eisenack, p. 50, pl. 10, figs. 7, 9.

1963. *Membranilarnacia leptoderma* (Cookson and Eisenack 1958) Eisenack, p. 101.

Comments: Eocene Oak Grove core specimens resemble the Albian Australian cysts described by Cookson and Eisenack (1958). The apparently single-layered (up to 1.5um thick) main body is finely fibrous and bears fibrous, often fenestrate processes, which support a thin, microfenestrate ectophragm up to 0.5um thick. Processes are predominantly slender (2-5um wide), but some forms bear relatively broad processes (up to 10um wide); they indicate a paratabulation of 4', 0a, 6?", 0c, 6?"', 1p, 1"". Processes range up to 12um long, but most are less than 9um. Some cysts with rather long, slender processes are similar in appearance to *Membranilarnacia ursulae* (Morgenroth 1966) DeConinck 1969; processes on the German forms of this species, however, are about one-half the main body diameter, whereas those of the cysts of this study are less than one-fourth the diameter. Excystment is by an apical archeopyle (Type $\overline{A}$).

Dimensions: Observed range (10 specimens measured): overall maximum diameter 60-88um; main body diameter 46-60um; process lengths up to 12um and widths up to 12um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Albian of Australia (Cookson and Eisenack, 1958); Lower Eocene of Maryland, U.S.A. (Goodman, 1975).

Genus *Microdinium* (Cookson and Eisenack 1960) McLean 1974

Microdinium ornatum Cookson and Eisenack 1960

Pl. 33, figs. 6-8

1960. *Microdinium ornatum* Cookson and Eisenack, p. 6-7, pl. 2, figs. 3-8; text-fig. 2-4.

Comments: Paleocene and Eocene specimens in the Oak Grove core are apparently the same as the Australian Albian/Cenomanian forms described by Cookson and Eisenack (1960). The paratabulation observed on the cysts of this study, however, differs from that given by Cookson and Eisenack (1960), and conforms to the revised paratabulation for *Microdinium* as established by McLean (1974), i.e., 4', 4a, 7", 6c + tr (transitional paraplate), 6"', 1p, 1"". The archeopyle is apical (Type $\overline{\text{AI}}$a), with a ventrally-attached operculum consisting of four apical and four anterior intercalary paraplates. Paraplate boundaries are reflected by aligned bacula up to 1.5um high which arise from the endophragm. The bacula support a thin ectophragm.

Dimensions: Observed range (20 specimens measured): overall length 34-42um and width 26-34um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Upper Cretaceous of Australia (Cookson and Eisenack, 1960); Upper Cretaceous? of Arctic Canada (Manum and Cookson, 1964); Eocene of England (Sarjeant, 1966); Upper Cretaceous of Smolensk region, U.S.S.R. (Vozzhennikova, 1967); Upper Cretaceous of England (Clarke and Verdier, 1967); Maastrichtian and Danian of California, U.S.A. (Drugg, 1967); Lower Eocene of France (DeConinck, 1969); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975).

Genus *Millioudodinium* Stover and Evitt 1978

Millioudodinium giuseppei subsp. *major*
(Morgenroth 1966) Stover and Evitt 1978

Pl. 12, figs. 1-4

1966. *Gonyaulax giuseppei* subsp. *major* Morgenroth, p. 6, pl. 2, figs. 5-6.

1973. *Gonyaulacysta giuseppei* subsp. *major* (Morgenroth 1996) Lentin and Williams, p. 61.

1978. *Millioudodinium giuseppei* subsp. *major* (Morgenroth 1966) Stover and Evitt 1978, p. 174.

Comments: Oak Grove core forms (length 78-112um; width 70-106um) measure larger than the German Eocene specimens (length 67-87um; width 67-78um) described by Morgenroth (1966) as *Gonyaulacysta giuseppei* subsp. *major*. Stover and Evitt (1978) transferred this species into their newly erected genus *Millioudodinium*. The endophragm is about 1um thick, externally levigate; the periphragm is about 1um thick, externally scabrate to microgranulate. The endocyst almost entirely fills the pericyst. Parasutural ridges, 1-4um high, delineate a paratabulation of 4', 0a, 6", 6c, 6"', 1p, 1"". Displacement of paraplate 3" results in a precingular archeopyle (Type P). The paracingulum is levorotatory, up to three paracingulum widths. An apical horn is 6-10um long.

Dimensions: Observed range (15 specimens measured): pericyst length 78-112um and width 70-106um; endocyst length 64-100um and width 60-102um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966a); Middle and Upper Oligocene of Germany (Benedek, 1972); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Lower Eocene of the Rockall Plateau (Costa and Downie, 1979); Lower Eocene of Labrador and the North Sea (Ioakim, 1979); Paleocene to Oligocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Eocene of England (Bujak, 1980; Bujak et al., 1980a); Campanian and Maastrichtian of Mississippi and Alabama, U.S.A. (Rounds, 1982); Upper Paleocene and Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984).

Genus *Muratodinium* Drugg 1970

Muratodinium fimbriatum (Cookson and Eisenack 1967)
Drugg 1970

Pl. 15, figs. 1-4

1967. *Kenleyia fimbriata* Cookson and Eisenack, p. 252, pl. 40, figs. 1-7.

1970. *Muratodinium fimbriatum* (Cookson and Eisenack 1967) Drugg,

p. 818-819, figs. 13 A-H, 14 A-B, 15 A-B.

Comments: Oak Grove core specimens are comparable in size and morphology to the Lower Eocene forms from Alabama studied by Drugg (1970). Paraplates are outlined by lace-like walls up to 24um high (Drugg's specimens bear walls about 15um high) which express a paratabulation of 4', 0a, 6", ?c, 5"', 0p, 1"". Typically a protuberance up to 6um long is located at the antapex of the main body; an occasional very small protuberance is found at the apex. The bi-layered cyst wall is composed of an endophragm about 1um thick an a fibrous periphragm about 2um thick. Free opercula best reveal the external reticulate appearance.

Cysts of *Muratodinium fimbriatum* may superficially resemble initial stage forms of *Thalassiphora pelagica* (Eisenack 1954) Eisenack and Gocht 1960; Gocht (personal communication) believes that they likely belong to the *T. pelagica* ontogenetic scheme.

Dimensions: Observed range (15 specimens measured): main body length 70-102um and width 67-90um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Paleocene of Australia (Cookson and Eisenack, 1967b); Lower Eocene of Alabama, U.S.A. (Drugg, 1970); Lower Eocene of Maryland (Goodman, 1975, 1979, 1984); Lower Eocene of

Virginia, U.S.A. (Witmer, 1975); Paleocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Paleocene and Eocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle Eocene of Alabama, U.S.A. (Edwards, 1977); Lower Eocene of the Rockall Plateau (Costa and Downie, 1979); Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984); Composite range based on worldwide occurrences--Lower Eocene to Lower Middle Eocene (Helby et al., 1984).

Genus *Nematosphaeropsis* (Deflandre and Cookson 1955)
Williams and Downie 1966

Nematosphaeropsis pertusa n. sp.

Pl. 13, figs. 5-8

Derivation of species name: Latin, *pertusus*, perforated--in reference to the typically perforated processes.

Description: Cyst main body ellipsoidal, bearing relatively large gonal processes. Cyst wall bi-layered; parasutural folds of the periphragm outline paraplates indicating paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". Archeopyle precingular (Type P) with simple, free operculum; corresponds to paraplate 3". Paracingulum levorotatory;

ends separated vertically up to two and one-half paracingulum widths and transversely up to two paracingulum widths. Parasulcus relatively long and broad, not divided by parasutures.

Endophragm appressed to periphragm except under parasutural folds and processes. Endophragm up to 2um thick, externally levigate. Periphragm about 0.5um thick, externally microreticulate; may be perforated in some areas. Parasutural folds typically perforated, averaging about 3um high but higher on the apical, antapical, and paracingular regions; merge gonally to form relatively large processes with shanks that are perforated, triangular in cross-section, bearing broad, often complexly constructed trifurcate tips. Terminations of variable lengths extend from trifurcate tips; may connect with tips of adjacent processes to form trabeculae about 1um thick. Apical process hollow, distinctively long and irregularly bifurcate with distal terminations.

Dimensions: Holotype main L X W: 62um X 46um; apical process 40um long; remaining process lengths up to 30um. Observed range (10 specimens measured): main body length 58-70um and width 44-51um; apical process lengths up to 50um; remaining process lengths up to 38um.

Discussion and comparison with similar species: The new species has been assigned to the genus *Nematosphaeropsis* because some specimens bear at least a few processes that are distally interconnected with trabeculae. Process tips on forms with no trabeculae bear relatively long distal terminations; these were presumably interconnected with adjacent process tips and have subsequently broken away, or in some cases may have never fully developed.

Nematosphaeropsis pertusa is differentiated from *N. balcombiana* Deflandre and Cookson 1955 (p. 268-269, pl. 8, fig. 5) and *N. trabeculata* (n. sp., this study) by its long apical process and typically perforated outer wall layer. The new species seems to be closely related to *Spiniferites cornutus* (Gerlach 1961) Sarjeant 1970; the latter, however, bears trifurcate processes with very short bifid terminations and is not trabeculate.

Holotype: Pl. 13, figs. 5-8; VPISUPL Sample 304, Slide AO-5, Coords. R12.3;+20.6.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Nematosphaeropsis cf. *N. pertusa* n. sp.

Pl. 13, figs. 9-11

Comments: This single specimen superfically resembles *Nematosphaeropsis pertusa* (n. sp., this study), but differs in the following respects: (1) paratabulation is expressed by low, weakly developed parasutural ridges; (2) some of the process shanks are perforate and many others are complexly fenestrate; (3) the cyst bears both gonal and intergonal processes; and (4) the relatively thin, bi-layered cyst wall is externally levigate. Excystment is by a precingular (Type P) archeopyle. Trabeculae interconnecting the process tips are about 1um thick.

Dimensions: Observed range (1 specimen measured): main body length 56um and width 38um; process lengths up to 24um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Nematosphaeropsis pusulosa (Morgenroth 1966) Stover and Evitt 1978

Pl. 7, figs. 14-16

1966. *Cannosphaeropsis pusulosa* Morgenroth, p. 8, pl. 2, fig. 6.

1978. *Nematosphaeropsis pusulosa* (Morgenroth 1966) Stover and Evitt, p. 176.

Comments: Oak Grove core specimens are comparable to the German Oligocene forms of Morgenroth (1966b). The cyst displays a precingular archeopyle (Type P). Slender processes, some of which may be fused up to one-half of their lengths, are interconnected distally by fine trabeculae. No parasutural ridges of folds are apparent. The endophragm and periphragm are each about 0.5um thick, externally levigate.

Dimensions: Observed range (5 specimens measured): main body length 40-54um and width 35-40um; process lengths up to 22um.

Stratigraphic occurrence: Eocene strata: Rare.

Previously reported occurrences: Lower Oligocene of Germany (Morgenroth, 1966b); Lower Eocene of Maryland, U.S.A. (Goodman, 1975).

Nematosphaeropsis trabeculata n. sp.

Pl. 13, figs. 1-4

Derivation of species name: Latin, *trabecula*, small rod--in reference to the narrow, solid rods or trabeculae interconnecting processes.

Description: Cyst main body ellipsoidal, bearing relatively large gonal processes. Cyst wall bi-layered; parasutural folds of the periphragm outline paraplates indicating paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". Archeopyle precingular (Type P) with simple, free operculum; corresponds to paraplate 3". Paracingulum levorotatory;

ends separated vertically up to one paracingulum width and transversely up to two paracingulum widths. Parasulcus broad, not divided by parasutures.

Endophragm appressed to periphragm except under parasutural folds and processes. Endophragm up to 1um thick, externally levigate. Periphragm about 0.5um thick, externally levigate to finely granulate. Parasutural folds, variably developed, merge gonally to form relatively large, hollow, trifurcate processes; some smaller, bifurcate proceses may be present. Processes may be fused proximally a variable distance along their shanks. Two large, hollow processes at antapex usually fused proximally up to one-half their length. Process tips interconnected by fine trabeculae up to 1um thick which approximate paraplate outlines. Trabeculae between some or all process tips may be broken away.

Dimensions: Holotype main body L X W: 44um X 34um; antapical processes up to 17um long; remaining process lengths up to 15um. Observed range (25 specimens measured): main body length 39-59um and width 32-43um; antapical process lengths up to 23um; remaining process lengths up to 20um.

Discussion and comparison with similar species: Fine trabeculae and the two large, proximally fused processes at the antapex characterize the new species. On many specimens, the trabeculae, however, can usually be observed extending from the trifurcate tips. Parasutural folds vary from weakly to well developed.

Nematosphaeropsis trabeculata is comparable to *N. balcombiana* Deflandre and Cookson 1955 (p. 268-269, pl. 8, fig. 5), but the main body of the new species is consistently more ellipsoidal and bears two large, proximally fused processes at the antapex.

When most of the trabeculae are broken away, *N. trabeculata* resembles some of the forms of the *Spiniferites ramosus* complex; cysts of the latter, however, bear no trabeculae.

Holotype: Pl. 13, figs. 1-3; VPISUPL Sample 316, Slide AO-35, Coords. R19.5;+3.6.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Sparse.

Genus *Oligosphaeridium* Davey and Williams 1966

Oligosphaeridium complex (White 1842) Davey and Williams 1966

Pl. 8, figs. 19-20

1842. *Xanthidium tubiferum complex* White, p. 39, pl. 4, fig. 11.
1848. *Xanthidium complexum* (White 1842) Bronn, p. 1375.

1940. *Hystrichosphaeridium elegantulum* Lejeune-Carpentier,
p. 22, text-figs. 11-12.

1946. *Hystrichosphaeridium complex* (White 1842) Deflandre, p. 11.

1966. *Oligosphaeridium complex* (White 1842) Davey and Williams,
p. 71-74, pl. 7, figs. 1-2, pl. 10, fig. 3; text-fig. 14.

(For a more complete synonymy, see Davey and Williams (1966b)).

Comments: Specimens of *Oligosphaeridium complex* from this study are comparable to the British Cenomanian forms of Davey and Williams (1966). The tubular processes are distally open, flared, and typically fenestrate (near the tips) with distal aculeate and secate terminations up to 8um long. Paratabulation of this species, which conspicuously lacks paracingular processes, is recorded as 4', 0a, 6", 0c, 5"', 1p, 1"". Excystment is by an apical archeopyle (Type $\overline{A}$). The levigate endophragm and periphragm are each about 0.5um thick.

Dimensions: Observed range (4 specimens measured): main body length (excl. opercula) 37-42um and width 33-37um; process lengths up to 37um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Previously reported occurrences: Lower Cretaceous (Neocomian) to Middle Eocene cosmopolitan species reported from Western and Eastern Europe, Africa, Australia, Canada, and the U.S.A.

Genus *Operculodinium* Wall 1967

Operculodinium brevispinosum n. sp.

Pl. 14, figs. 1-4

Derivation of species name: Latin, *brevis*, short + Latin, *spinosus*, spiney--in reference to the short spines of the cyst.

Description: Cyst spheroidal to slightly ellipsoidal, bearing numerous short spines. Cyst wall bi-layered; spines arising from the periphragm distributed randomly over cyst; aparatabulate. Archeopyle precingular (Type P) with simple, free operculum; likely corresponds to paraplate 3". Paracingulum and parasulcus not delineated.

Endophragm up to 1um thick, externally levigate.. Periphragm up to 3um thick, mat-like, imparting a microgranulate external appearance. Spines acuminate or blunt-tipped, up to 2um long.

Dimensions: Holotype main body diameter 42um; spine lengths up to 2um. Observed range (10 specimens measured): main body length 38-50um and width 36-46um; spine lengths up to 2um.

Discussion and comparison with similar species: Diagnostic features of *Operculodinium brevispinosum* include its spheroidal main body shape, precingular archeopyle, and numerous short spines arising from a mat-like periphragm. Density of spines varies from specimen to specimen.

The new species is comparable to *O. placitum* Drugg and Loeblich 1967 (p. 186-187, pl. 1, figs. 9-11b; text-fig. 4); the main body of the former, however, is more nearly spheroidal and generally larger than that of the latter, and bears spines which are both acuminate and blunt. *O. brevispinosum* is considerably smaller than *O. giganteum* Wall 1967 (p. 16, figs. 9-10); the latter is further differentiated by bearing capitate spines which are typically parasuturally aligned.

The mat-like periphragm of *O. brevispinosum* resembles the outer wall layer of some species of *Tectatodinium* Wall 1967; species included in *Tectatodinium* do not, however, bear spines.

Holotype: Pl. 14, figs. 1-3; VPISUPL Sample 334, Slide AO-77, Coords. R17.9;+4.5.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare.

Operculodinium cf. *O. brevispinosum* n. sp.

. Pl. 14, fig. 5

Comments: A single specimen recovered from the Lower Eocene Nanjemoy strata closely resembles *Operculodinium brevispinosum* (n. sp., this study), but differs by displaying a Type 2P precingular. Because this was the only specimen observed with a precingular archeopyle definitely involving two paraplates (presumably 2" and 3"), it was not at this time incorporated as part of the new species; future studies may show that *O. brevispinosum* does indeed have a Type P or 2P archeopyle. *Bitectatodinium tepikiense* Wilson 1973 (p. 345-354, fig. 2, nos. 1-12) consistently exhibits a Type 2P archeopyle, but bears no spines.

Dimensions: Observed range (1 specimen measured): main body diameter 40um; spine lengths up 2um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Operculodinium centrocarpum (Deflandre and Cookson 1955)
Wall 1967

Pl. 14, figs. 15-17

1953. *Hystrichosphaeridium* sp. in Cookson, p. 115, pl. 2, figs. 26-28.

1955. *Hystrichosphaeridium centrocarpum* Deflandre and Cookson, p. 272, pl. 8, figs. 3-4.

1961. *Baltisphaeridium centrocarpum* (Deflandre and Cookson 1955) Gerlach, p. 192, pl. 28, fig. 9.

1967. *Operculodinium centrocarpum* (Deflandre and Cookson 1955) Wall, p. 111, pl. 16, figs. 1, 2, 5.

Comments: The spheroidal main body bears numerous, finely fibrous processes (some fused proximally) which are distally capitate to finely aculeate. Process lengths are approximately one-fifth to one-third the diameter of the main body. The endophragm is about lum thick and the microgranulate to microreticulate periphragm is slightly thicker. Paratabulation is indeterminate. The archeopyle is precingular (Type P). Main body diameters of the Paleocene and Eocene forms of the Oak Grove core (43-50um) are about the same as those of the Caribbean Sea Upper Quaternary specimens (40-56um) described by Wall (1967). For previously described Miocene cysts, main body diameters range up to 90um; the diameters of the Miocene specimens of the core are 68-78um.

Dimensions: Observed range (25 specimens measured): main body diameter 43-75um; process lengths up to 19um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare; Miocene strata: Extremely rare to Abundant.

Previously reported occurrences: Upper Cretaceous (Maastrichtian) to Recent cosmopolitan species reported from Western and Eastern Europe, Africa, Australia, Canada, U.S.A., and the Atlantic Ocean.

Operculodinium israelianum (Rossignol 1962) Wall 1967

Pl. 14, figs. 13-14

1962. *Hystrichosphaeridium israelianum* Rossignol, p. 132, pl. 2, fig. 3.

1964. *Baltisphaeridium israelianum* (Rossignol 1962) Rossignol, p. 91, pl. 2, fig. 2, pl. 3., figs. 13-14.

1967. *Operculodinium israelianum* (Rossignol 1964) Wall, p. 111, pl. 16, figs. 3-4.

Comments: Wall (1967) states that *Operculodinium israelianum* is fundamentally similar to *O. centrocarpum*, but can be differentiated by its consistently shorter spines. Process tips of the former have been described as acuminate or weakly capitate; distal terminations of specimens of this study are predominantly very finely capitate (high magnification required) or more rarely acuminate. Process lengths vary from about one-seventh to one-tenth the diameter of the main body. The cyst is bi-layered: the endophragm is about 1um thick and the reticulate periphragm is up to 1.5um thick. The archeopyle is precingular (Type P). Oak Grove core forms more closely resemble the Israeli Quaternary specimens of Rossignol (1964) than the Caribbean Sea cysts of Wall (1967), in that they generally bear more numerous and slightly longer processes.

Dimensions: Observed range (8 specimens measured): main body diameter 48-55um; process lengths up to 8um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Quaternary of Israel (Rossignol, 1962, 1964); Quaternary of the Caribbean Sea (Wall, 1967); Quaternary of the Black Sea (Wall and Dale, 1974); Upper Miocene to Pleistocene of Australia (Haskell and Wilson, 1974); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Maastrichtian and Danian of Maryland, U.S.A. (Whitney, 1976); Middle to Upper Eocene of South Carolina, U.S.A. (Watkins, 1979).

Operculodinium multispinosum n. sp.

Pl. 14, figs. 6-8

Derivation of species name: Latin, *multus*, much, many + Latin, *spinosus*, spiney--in reference to the numerous spines of the cyst.

Description: Cyst spheroidal, bearing numerous acuminate spines. Cyst wall bi-layered; spines arising from the periphragm distributed densely and randomly over cyst; aparatabulate. Archeopyle precingular (Type P) with simple, free operculum; likely corresponds to paraplate 3". Paracingulum and parasulcus not delineated.

Endophragm up to 1um thick, externally levigate. Periphragm up to 0.5um thick, externally levigate to microgranulate. Spines hollow, acuminate, up to 6um long.

Dimensions: Holotype main body diameter 33um; spine lengths up to 5um. Observed range (10 specimens measured): main body diameter 30-38um; spine lengths 4-6um.

Discussion and comparison with similar species: *Operculodinium multispinosum* is characterized by a spheroidal main body, precingular archeopyle, and densely distributed acuminate spines.

Operculodinium multispinosum differs from *O. brevispinosum* (n. sp., this study) in bearing longer spines. A smaller main body and more densely distributed acuminate processes distinguish *O. multispinosum* from the comparable *O. israelianum* (Rossignol 1962) Wall 1967 (p. 132, pl. 2, fig. 3) and *O. centrocarpum* (Deflandre and Cookson 1955) Wall 1967 (p. 111, pl. 16, figs. 1, 2, 5). *O. multispinosum* superficially resembles intact specimens of *Eocladopyxis peniculata* Morgenroth 1966 (see McLean, 1976, p. 347-351, pl. 1, figs. 1-12; text-fig. 1 for redescription); the former, however, has a precingular archeopyle, whereas the latter displays an epicystal archeopyle.

Holotype: Pl. 14, figs. 6-8; VPISUPL Sample 337, Slide AO-84, Coords. R15.1;+11.4.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare; Miocene strata: Extremely rare to Rare.

Operculodinium variespinosum n. sp.

Pl. 14, figs. 9-12

Derivation of species name: Latin, *varius*, varying, different + Latin, *spinosus*, spiney--in reference to the various types of short spines on the cyst.

Description: Cyst ellipsoidal, bearing numerous, varying types of spines. Cyst wall bi-layered; spines arising from the periphragm distributed randomly over cyst; aparatabulate. Archeopyle precingular (Type P) with simple, free operculum; likely corresponds to paraplate 3". Paracingulum and parasulcus not delineated.

Endophragm about 0.5um thick, externally levigate. Periphragm up to 2um thick, mat-like, imparting a microgranulate external appearance. Spines may be conical, acuminate, evexate, bulbous, oblate, cylindrical, or legenate, up to 5um long; single cysts may bear most all spines types or predominantly one or two types.

Dimensions: Holotype main body L X W: 52um X 40um; spine lengths up to 3um. Observed range (7 specimens measured): main body length 40-52um and width 32-40um; spine lengths up to 5um.

Discussion and comparision with similar species: The new species is characterized by its ellipsoidal shape, precingular archeopyle, and the varying shapes of its short spines.

Operculodinium variespinosum superficially resembles *O.placitum* Drugg and Loeblich 1967 (p. 186-187, pl. 1, figs. 9-11b; text-fig. 4); the former, however, bears longer and more varied types of spines. *O. variespinosum* is distinguished from *O. brevispinosum* (n. sp., this study) by its more robust and varied forms of spines.

Holotype: Pl. 14, figs. 9-11; VPISUPL Sample 347, Slide AP-19, Coords. R18.0;+14.7.

Stratigraphic occurrence: Miocene strata: Extremely rare to Rare.

Genus *Paucisphaeridium* Bujak, Downie, Eaton, and Williams 1980

Paucisphaeridium inversibuccinum (Davey and Williams 1966) Bujak, Downie, Eaton, and Williams 1980

Pl. 35, figs. 5-7

1966. *?Litosphaeridium inversibuccinum* Davey and Williams, p. 82, pl. 12, fig. 3.

1980. *Paucisphaeridium inversibuccinum* (Davey and Williams 1966) Bujak, Downie, Eaton, and Williams, p. 30-32, pl. 2, figs. 4-5.

Comments: These small cysts bear buccinate processes with aculeate tips. Precingular and postcingular processes are typically connected proximally. Although no archeopyles were observed on the study specimens, an apical archeopyle (Type $\bar{A}$) has been noted on the British Eocene cysts of Downie and Williams (1966b) and Eaton (1976), and on the Lower Eocene Nanjemoy forms of Goodman (1975). Paratabulation is tentatively recorded for the core specimens as 4?', 6", 0c, 5"', 0p, 1?"". Upon re-examination of the holotype, Bujak et al. (1980b) report the formula as 4?', 6", 0c, 6"', 0p, 0"". The endophragm is granulate and the periphragm is levigate. Oak Grove core forms conform in size to the British Eocene cysts.

Dimensions: Observed range (4 specimens measured): main body diameter 16-20um; process lengths 6-10um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Eocene of England (Davey and Williams, 1966b; Eaton, 1976; Bujak et al., 1980a,b); Lower Eocene of Belgium (DeConinck, 1969, 1976a); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1984); Lower Eocene of the southern Netherlands (DeConinck, 1977); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983).

Genus *Pentadinium* Gerlach 1961

Pentadinium laticinctum subsp. *granulatum* Gocht 1969

Pl. 11, figs. 17-20

1969. *Pentadinium laticinctum* subsp. *granulatum* Gocht, p. 29-30, pl. 9, figs. 17-18; text-fig. 20.

<u>Comments:</u> The cysts referred to *Pentadinium laticinctum* subsp. *granulatum* in this study conform rather closely in size and appearance to the German Oligocene forms of Gocht (1969). The endocyst varies from microgranulate to coarsely granulate. Gerlach (1961), on the other hand, mentions only that the outer wall layer is granulate (i.e., "Membran granuliert" and "die Membran der Hullen ist deutlich granuliert"; "hullen" is interpreted as "Externhulle", or outer layer) in *P. laticinctum*. The British Eocene specimens assigned to *P. laticinctum* by Eaton (1976) have distinctly granulate endocysts and may best be accomodated by *P. laticinctum* subsp. *granulatum*. Folds of the periphragm delineate a paratabulation of 1-3', 0a, 5", 5?c, 5"', 0a, 1"". The apex bears either one large paraplate or three indistinctly divided paraplates. The large paracingular fold seems to be separated into five paraplates; the paracingulum is strongly levorotatory, up to three paracingulum widths. Folds bordering the parasulcus are often weakly developed or missing. The precingular archeopyle (Type P) results from the loss of paraplate 3". The endophragm up to 2um thick is constructed of densely distributed, perperndicularly oriented, fiber-like elements which impart an irregularly granulate external appearance. The periphragm which is less than 1um thick is microgranulate.

Dimensions: Observed range (6 specimens measured): pericyst length 98-124um and width 90-114um; endocyst length 80-104um and width 72-86um.

Stratigraphic occurrence: Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Middle Oligocene of Germany (Gocht, 1969); Middle Eocene to Miocene of the Grand Banks, Newfoundland, Canada (Williams, 1974; Williams and Brideaux, 1975); Eocene of England (Eaton, 1976); Upper Eocene to Middle Miocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Oligocene to Lower Miocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Miocene of eastern Netherlands (Herngreen, 1984).

Genus *Polysphaeridium* (Davey and Williams 1966)
Bujak, Downie, Eaton, and Williams 1980

Polysphaeridium zoharyi (Rossignol 1962)
Bujak, Downie, Eaton, and Williams 1980

Pl. 33, figs. 17-20

1962. *Hystrichosphaeridium zoharyi* Rossignol, p. 132, pl. 2, fig. 10.

1967. *Hemicystodinium zoharyi* (Rossignol 1962) Wall, p. 110, pl. 15, figs. 18-20.

1980. *Polysphaeridium zoharyi* (Rossignol 1962) Bujak, Downie, Eaton, and Williams, p. 34.

Comments: Only hypocysts were found in the Oak Grove core. The periphragm, less than 1um thick, is typically microgranulate to granulate. The cyst bears numerous processes with either buccinate (open?) or capitate (closed?) tips; occasionally the tips appear to bear fine aculeae. Paratabulation is not apparent. The archeopyle is epicystal (Type $\overline{\text{AP}}$ of $\overline{\text{AIP}}$); anterior intercalary paraplates may or may not be present.

Islam (1983) considers *Polysphaeridium zoharyi* to be a junior synonym of *P. subtile*; the present study does not recognize this contention.

Dimensions: Observed range (8 specimens measured): main body diameter 42-48um; process lengths up to 13um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare; Miocene strata: Extremely rare.

Previously reported occurrences: Quaternary of Israel (Rossignol, 1962); Quaternary of the Mediterranean Sea (Rossignol, 1964); Quaternary of the Caribbean Sea (Wall, 1967); Eocene and Oligocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Lower Eocene of Belgium (DeConinck, 1976a); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Eocene to Middle Miocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Lower Eocene of the southern Netherlands (DeConinck, 1977); Middle Oligocene to Lower Miocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Lower Eocene of southeast England (Denison, 1977); Upper Oligocene of South Carolina, U.S.A. (Ford, 1979); Lower Miocene of the North Sea (Ioakim, 1979); Lower Eocene of Alabama and Georgia, U.S.A. (Edwards, 1980).

Polysphaeridium cf. *P. zoharyi* (Rossignol 1962) Bujak, Downie, Eaton, and Williams 1980

Pl. 34, figs. 1-2

Comments: A few *Polysphaeridium zoharyi*-like hypocysts were recovered in the Nanjemoy Formation of the core. The distal tips of the processes, however, bear numerous aculeate terminations about 1um long. Whether these forms represent morphological variants of *H. zoharyi* or a new taxa cannot be determined with the small number of poorly preserved cysts. Each wall layer is less than 1um thick; the periphragm is granulate. The archeopyle is apparently epicystal, with an operculum consisting of apical, precingular, and possibly anterior intercalary paraplates. Paratabulation is indeterminate.

Dimensions: Observed range (4 specimens measured): main body diameter approximately 40-50um; process lengths up to 16um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Genus *Renidinium* Morgenroth 1968

Renidinium membraniferum Morgenroth 1968

Pl. 16, figs. 17-20

1968. *Renidinium membraniferum* Morgenroth, p. 552-553, pl. 46, fig. 9; pl. 47, figs. 1-3.

Comments: Forms from the Oak Grove core generally conform to the Danian cysts from Denmark described by Morgenroth (1968). Paraplates are outlined by discontinuous wall-like supports up to 6um high from which extend a thin, perforate, typically discontinuously developed (central part of paraplate usually not covered) ectophragm. As can best be discerned, six precingular, five postcingular, and one antapical (reniform in outline) paraplate are present. The cyst often bears two antapical lobes (left larger than right) and an apical lobe, involving both endophragm and ectophragm. The archeopyle is apical (Type $\overline{A}$). The long, broad parasulcus is rather deeply invaginated.

Dimensions: Observed range (4 specimens measured): overall length (excl. opercula) 65-85um and width 60-80um; main body length 58-71um and width 54-61um; one complete specimen observed with overall length 82um and width 72um and main body length 68um and width 62um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare.

Previously reported occurrences: Danian of Denmark (Morgenroth, 1968); Maastrichtian and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976).

Renidinium? sp. A

Pl. 16, figs. 14-16

Comments: Two distinctive cysts, questionably designated as *Renidinium* sp. A, were recovered in the Nanjemoy Formation of the core. Excystment is by an apical archeopyle (Type $\overline{A}$). The cysts superficially resemble *Renidinium membraniferum* Morgenroth 1968 in general aspect. In *Renidinium?* sp. A, however, ribbon-like bands of ectophragm, held up by rod-like supports, are aligned with the parasutures. Two antapical lobes (left larger than right), involving both endophragm and ectophragm, are developed.

Dimensions: Observed range (2 specimens measured): overall length (excl. opercula) 57-60um and width 60-62um; main body length 44-46um and width 50-52um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Genus *Rottnestia* Cookson and Eisenack 1961

Rottnestia borussica (Eisenack 1954) Cookson and Eisenack 1961

Pl. 9, figs. 1-4

1954. *Hystrichosphaera borussica* Eisenack, p. 62, pl. 9, figs. 5-7.

1955. *Hystrichosphaera borussica* (Eisenack 1954) Deflandre and Cookson, p. 268, pl. 5, figs. 9-10.

1961. *Rottnestia borussica* (Eisenack 1954) Cookson and Eisenack,

p. 42, fig. 1; pl. 1, figs. 8-10; pl. 2, figs. 1-2.

Comments: The forms of *Rottnestia borussica* observed in the Oak Grove core closely resemble the Australian Paleocene cysts recovered by Cookson and Eisenack (1961, pl. 1, fig. 8, text-fig. 1 c-d; 1965c, pl. 19, figs. 9-10). Study specimens bear trifurcate gonal and bifurcate intergonal processes, and parasutural folds that reveal a paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". The apical pericoel is pointed, whereas the antapical pericoel is generally more box-like. A bi-layered cyst wall is constructed of a granulate endophragm about 1um thick and a thinner, levigate periphragm. The archeopyle is precingular (Type P).

Transfers of this species in the past to *Triblastula* (by Morgenroth, 1966, p. 15-16, pl. 7, figs. 9-10) and to *Hystrichosphaeropsis* (by Sarjeant, p. 138-139) are herein rejected.

Dimensions: Observed range (10 specimens measured): main body length 40-51um and width 40-48um; process lengths up to 14um; apical pericoel lengths up to 17um; antapical pericoel lengths up to 14um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Upper Eocene to Lower Oligocene of Germany (Eisenack, 1954); Miocene of Australia (Deflandre and Cookson, 1955); Middle Paleocene and Eocene of Australia (Cookson and Eisenack, 1961); Cenomanian of England (Cookson and Hughes, 1964); Lower Eocene of Belgium (DeConinck, 1965, 1969, 1973, 1976a); Lower Eocene of Germany and Belgium (Morgenroth, 1966); Lower Cretaceous of Romania (Baltes, 1967); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Campanian and Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980); Eocene of the Norwegian Greenland Sea (Manum, 1976); Lower Eocene of the southern Netherlands (DeConinck, 1977); Lower Eocene of the Rockall Plateau (Costa and Downie, 1979), Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Eocene to Lower Miocene of the North Sea (Ioakim, 1979); Upper Paleocene of Alabama and Georgia, U.S.A. (Edwards, 1980); Campanian and Maastrichtian of Mississippi and Alabama, U.S.A. (Rounds, 1982); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Paleocene of eastern Netherlands (Herngreen, 1984).

Genus *Samlandia* Eisenack 1954

Samlandia chlamydophora Eisenack 1954

Pl. 15, figs. 5-8

1954. *Samlandia chlamydophora* Eisenack, p. 76, pl. 11, figs. 12-15.

1954. *Palmnickia lobifera* Eisenack, p. 70, pl. 11, figs. 10-11.

Comments: Specimens of *Samlandia chlamydophora* recovered from the Lower Eocene strata of the Oak Grove core most closely resemble the German Eocene forms illustrated by Morgenroth (1966). Numerous, nearly parallel-sided, support-like processes up to 2um wide and up to 13um long arise from the thick, dense, microgranulate endophrragm up to 4um thick. Extending distally from the supports is a thin, discontinuous, microfenestrate ectophragm about 0.5um thick. At least one specimen was observed to bear very fine supports and nearly continuous ectophragm. The support-like processes are aligned along the paracingulum; although there is general alignment on the remaining areas of some cysts, paratabulation was not determined. The archeopyle is precingular (Type P). At the apex and antapex the ectophragm extends out from the main body up to 20um.

Dimensions: Observed range (8 specimens measured): main body length 72-105um and width 54-80um; overall length 98-148um and width 80-104um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Lower Oligocene of Germany (Eisenack, 1954; Evitt, 1961); Middle Miocene of Germany (Gerlach, 1961); Lower Eocene of Belgium (DeConinck, 1076a); Lower Eocene of Germany and Belgium (Morgenroth, 1966); Middle Oligocene of Germany (Benedek, 1972); Upper Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Middle and Upper Eocene of the Norwegian Greenland Sea (Manum, 1976); Middle Eocene to Oligocene of Alabama, U.S.A. (Edwards, 1977); Lower Eocene of the southern Netherlands (DeConinck, 1977), Lower and Middle Eocene of the Rockall Plateau (Costa and Downie, 1979); Middle and Upper Eocene of Labrador and Eocene and Oligocene of the North Sea (Ioakim, 1979); Middle Eocene to Lower Oligocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.

Samlandia reticulifera (Cookson and Eisenack 1965) subsp. *minor* n. subsp.

Pl. 15, figs. 9-12

Derivation of subspecies name: Latin, *minor*, small--in reference to the small size of the cysts of the subspecies relative to that of the species.

Description: Cyst main body slightly ellipsoidal, bearing small bacula and other irregularly-shaped supports that are distally interconnected by a thin, discontinuous ectophragm. Paratabulation not apparent. Archeopyle precingular (Type P) with simple, free operculum. No evidence of paratabulation and parasulcus.

Endophragm up to 1um thick, externally levigate to finely granulate. Bacula and other irregularly-shpaed supports up to 4um high arise from within endophragm. Ectophragm up to 0.5um thick, discontinuous, consisting primarily of fine trabeculae less than 0.5um wide; imparts a reticulate external appearance to cyst. Ectophragm may rarely be slightly drawn to a point at apex.

Dimensions: Holotype overall L X W: 45um X 43um. Observed range (7 specimens measured): overall length 45-55um and width 43-51um; main body length 38-43um and width 34-41um.

Discussion: This is the first described subspecies of *Samlandia reticulifera* Cookson and Eisenack 1965a, and is distinguished primarily by its much smaller size. The main body of *S. reticulifera* is 80-114um long by 70-95um wide; the length and width of the main body of the new subspecies, however, are only 38-43um by 34-41um, respectively. Also, projections at the apex, antapex, and along the paracingulum in *S. reticulifera* are typically absent in *S. reticulifera* subsp. *minor*.

Holotype: Pl. 15, figs. 9-12; VPISUPL Sample 309, Slide AO-19, Coords. R20.4;+19.3.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Genus *Spiniferites* (Mantel 1850) Sarjeant 1970

Spiniferites cingulatus (O. Wetzel 1933) Sarjeant 1970

Pl. 17, figs. 1-4

1933. *Cymatiosphaera cingulata* O. Wetzel, p. 28, pl. 4, fig. 10.

1954. *Hystrichosphaera cingulata* (O. Wetzel 1933) Deflandre, p. 258.

1955. *Hystrichosphaera cingulata* (O. Wetzel 1933) Deflandre and Cookson, p. 267, pl. 6, figs. 4-5.

1970. *Spiniferites cingulatus* (O. Wetzel 1933) Sarjeant, p. 76.

Comments: This species bears high parasutural crests seemingly supported by simple or finely trifurcate gonal processes. These forms are distinguished from species of *Leptodinium* (Klement 1960) Sarjeant 1969 by the presence of small gonal processes and crests that are typically not of constant height from process to process. Paratabulation is recorded as 4', 0a, 6", 6c, 5"', 1p, 1"", with a precingular archeopyle (Type P). The endophragm is about 1um thick, whereas the periphragm is only about half as thick; both are levigate to scabrate.

Oak Grove core forms are approximately the same size as the British Cenomanian cysts of Davey and Williams (1966a).

Dimensions: Observed range (6 specimens measured): main body length 40-45um and width 34-38um.

Stratigraphic occurrence: Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Cosmopolitan species ranging from Albian/Cenomanian of England to Pleistocene of the eastern Mediterranean Sea region (see Davey and Verdier (1971) for occurrence list); Santonian of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Lower and Middle Eocene of England (Eaton, 1976); Lower Eocene of Belgium (DeConinck, 1976a); Maastrichtian and Paleocene of Labrador and the North Sea and Lower Miocene of the North Sea (Ioakim, 1979).

Spiniferites cornutus (Gerlach 1961) Sarjeant 1970

1961. *Hystrichosphaera cornuta* Gerlach, p. 180-181, pl. 27, figs. 10-12.

1970. *Spiniferites cornutus* (Gerlach 1961) Sarjeant, p. 76.

Comments: Specimens recovered in this study that are generally referable to *Spiniferites cornutus* are informally divided into three subspecies on the basis of apical horn length, parasutural ridge height, and cyst ornamentation. In all cases, paratabulation, outlined by parasutural ridges of variable heights, is noted as 4', 0a, 6", 6c, 5"', 1p, 1""; the archeopyle is precingular (Type P).

Previously reported occurrences: Middle Oligocene to Middle Miocene of Germany (Gerlach, 1961); Eocene of England (Davey and Williams 1966a); Lower Eocene of Belgium (DeConinck, 1969, 1976a); Paleocene of Virginia and Maryland, U.S.A. (McLean, 1971); Danian of Denmark (Wilson, 1971); Middle and Upper Oligocene of Germany (Benedek, 1972); Albian, Cenomanian, and Paleocene of Australia (Cookson and Eisenack, 1974); Paleocene of Virginia, U.S.A. (Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Lower Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Maastrichtian and Danian of Maryland, U.S.A. (Benson, 1976); Upper Paleocene and Lower Eocene of southeast England (Denison, 1977); Upper Paleocene and Eocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Paleocene and Lower Eocene of Labrador and Paleocene to Oligocene of the North Sea (Ioakim, 1979); Danian of Georgia, U.S.A. (Firth, 1984).

Spiniferites cornutus subsp. A

Pl. 18, figs. 1-4

Comments: The single specimen of *Spiniferites cornutus* subsp. A recovered from the Brightseat equivalent-lower Aquia? strata, though similar in most respects to the German Oligocene/Miocene forms of *S. cornutus* described by Gerlach (1961), may in fact more closely resemble a cyst from the Upper Danian of Sweden recorded by DeConinck (1975). He states that Wilson (1971) found a similar form in the Danian of Denmark (Stevns Klint). The apical horn is about four-fifths as long as the main body. Ornamentation is distinctive, consisting of numerous coarse bacula and grana up to 1.5um high. Though most parasutural ridges are relatively low, processes at the apex and antapex, and on opposite sides of the paracingulum, are fused up to two-thirds of their lengths. The endophragm is up to 2um thick, coarsely baculate and granulate; the periphragm is about 0.5um thick, externally scabrate.

Dimensions: Observed range (1 specimen measured): main body length 62um and width 48um; process lengths up to 22um; apical horn length 48um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Spiniferites cornutus subsp. B

Pl. 18, figs. 5-8

Comments: The apical horn of *Spiniferites cornutus* subsp. B is considerably shorter in relation to the length of the main body than that of *S. cornutus* subsp. A (two-fifths as long vs. four-fifths as long). Parasutural ridges are up to 9um high, nearly half as high as the processes. Ornamentation of the endophragm (up to 3um thick) is similar to that of *S. cornutus* subsp. A; the periphragm, however, is more granulate on this form.

Dimensions: Observed range (2 specimens measured): main body length 50-57um and width 42-45um; process lengths up to 17um; apical horn length up to 22um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Spiniferites cornutus subsp. C

Pl. 18, figs. 9-12

Comments: Specimens of this study designated *Spiniferites cornutus* subsp. C resemble *S. cornutus* subsp. *sinefurcatus* (Cookson and

Eisenack 1974) Lentin and Williams 1977. The apical horn is only about one-third as long as the main body. Parasutural ridges range up to 4um high. Both the endophragm up to 2um thick and the periphragm up to 0.5um thick are levigate to somewhat scabrate.

Dimensions: Observed range (2 specimens measured): main body length 60-65um and width 40-42um; process lengths up to 17um; apical horn lengths up to 21um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Spiniferites crassipellis (Deflandre and Cookson 1955) Sarjeant 1970

1955. *Hystrichosphaera crassipellis* Deflandre and Cookson, p. 265, pl. 6, figs. 2-3; text-fig. 20.

1966. *Achomosphaera sagena* Davey and Williams, p. 51, pl. 2, figs. 1-2.

1970. *Spiniferites crassipellis* (Deflandre and Cookson 1955) Sarjeant, p. 76.

Comments: Three general subgroups of *Spiniferites crassipellis* are recognized in this study. Most cysts from the three different groups have a relatively thick, mat-like, microreticulate periphragm. They differ primarily in process type distribution, and development of the parasutural ridges. Because parasutural development is extremely variable, even on a single cyst, those forms referable to *Achomosphaera sagena* Davey and Williams 1966 are herein regarded as variants of *S. crassipellis*. On specimens which bear parasutural ridges, paratabulation has been recorded as 4?', 0a, 6", 6c, 5"', 1p, 1"". The archeopyle is precingular (Type P), reduced.

Further study of these three subgroups may in fact show that they would be more appropriately accomodated by the genus *Hafniasphaera* Hansen 1977. This genus was erected for those *Spiniferites* (or *Achomosphaera*)-like forms with cyst walls constructed of numerous vesicles or vacuoles. These three informal taxa will likely be described as new species within *Hafniasphaera* when formally published.

Previously reported occurrences: Eocene of Australia (Deflandre and Cookson, 1955); Middle Miocene of Germany (Maier, 1959); Middle Oligocene to Middle Miocene to Germany (Gerlach, 1961); Coniacian to Campanian of Germany (Gorka, 1963); Cenomanian to Santonian of England (Davey and Williams, 1966a; Clarke and Verdier, 1967); Lower Eocene of Germany (Morgenroth, 1966; Gocht, 1969); Danian of California, U.S.A. (Drugg, 1967); Lower Eocene of Belgium (DeConinck, 1969, 1976a); Miocene of Romania (Baltes, 1969); Albian of France (Davey and Verdier, 1971); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A.

(Whitney, 1976, 1984); Maastrichtian and Lower Paleocene of Denmark (Hansen, 1977); Lower Eocene of Labrador (Ioakim, 1979); Paleocene to Middle Miocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979).

Spiniferites crassipellis subsp. A

Pl. 17, figs. 5-8

Comments: Most forms designated *Spiniferites crassipellis* subsp. A bear weakly developed parasutural ridges, and on some they are virtually absent. The endophragm is relatively thin; the periphragm, constructed of densely interwoven fibrils, is up to 4um thick. Long, slender gonal processes, triangular in cross-section, are distally trifurcate, with fine bifid terminations; intergonal processes are normally not present.

Dimensions: Observed range (7 specimens measured): main body diameter 43-57um; process lengths up to 16um.

Stratigraphic occurrences: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare.

Spiniferites crassipellis subsp. B

Pl. 17, figs. 9-12

Comments: This subspecies is characterized by multiple (usually two or three) intergonal processes, and the main body is larger than the other two groups. These forms are restricted to the Upper Paleocene strata of the core (Samples 315-318). The endophragm is thin, whereas the periphragm is up to 3um thick, densely microreticulate. Paratabulation is indicated by parasutural ridges which may be discontinuously developed. Processes are long and slender, triangular in cross-section, with long trifurcations (gonal) and bifurcations (intergonal); the tips bear bifid terminations.

Dimensions: Observed range (2 specimens measured): main body diameter 68-73um; process lengths up to 22um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Spiniferites crassipellis subsp. C

Pl. 17, figs. 13-16

Comments: These forms were recovered in the upper Lower Eocene strata and Miocene strata of the core. Paratabulation is reflected by parasutural ridges on all specimens. Gonal processes, trianagular in cross-section, distally bear rather broad trifurcations. Adjacent processes, particularly on the apex and along the paracingulum, may be fused proximally a variable distance along their shanks. The endophragm is up to 1um thick. The periphragm up to 2.5um thick is constructed of mat-like fibrils.

Dimensions: Observed range (12 specimens measured): main body diameter 48-62um; process lengths up to 16um.

Stratigraphic occurrence: Eocene strata: Extremely rare; Miocene strata: Extremely rare to Sparse.

Spiniferites mirabilis (Rossignol 1963) Sarjeant 1970

Pl. 18, figs. 13-16

1962. *Hystrichosphaera mirabilis* Rossignol, p. 132 (described but not illustrated).

1963. *Hystrichosphaera mirabilis* Rossignol, pl. 2, figs. 16-21.

1970. *Spiniferites mirabilis* (Rossignol 1963) Sarjeant, p. 76.

Comments: The most diagnostic feature of *Spiniferites mirabilis* is its large antapical membrane bearing numerous, relatively short processes along its edges. Parasutural ridges are typically weakly and discontinuosly developed; they may be virtually absent on the ventral side. Trifurcate gonal and bifurcate intergonal (up to two) processes arise from the parasutural ridges. Paratabulation is difficult to determine with certainty, but seems to conform to the formula as stated by Wall (1967): 3-4', 0a, 6", 6c, 5-6"', 1p, 1"". The cyst exhibits a precingular archeopyle (Type P). Both the microgranulate endophragm and periphragm are less that 1um thick. Study specimens compare in size with those described by Rossignol.

Dimensions: Observed range (5 specimens measured): main body length 42-66um and width 40-66um; individual process lengths up to 20um; antapical membrane (incl. processes) up to 22um long and 36um wide.

Stratigraphic occurrence: Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Quaternary of the Mediterranean Sea and Israel (Rossignol, 1962, 1963, 1964); Quaternary of the Caribbean Sea (Wall, 1967); Miocene of eastern Canada (Williams and Brideaux, 1977; Barss et al., 1979); Upper Eocene to Pleistocene of the Rockall Plateau (Costa and Downie, 1979); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Middle and Upper Miocene of the Rockall Plateau (Edwards, 1983).

Spiniferites monilis (Davey and Williams 1966) Sarjeant 1970

Pl. 17, figs. 17-20

1966. *Hystrichosphaera monilis* Davey and Williams, p. 45, pl. 5, fig. 2.

1970. *Spiniferites monilis* (Davey and Williams 1966) Sarjeant, p. 76.

Comments: The distinctive parasutures resembling a string of beads appear to be constructed of a linear network of minute bacula and other supports connected by delicate trabeculae on some specimens, and on other forms more like fine bubble-like elements; Davey and Williams (1966a) describe an alignment of granules along the parasutures. The endophragm is less than 1um thick; the periphragm up to 0.5um thick is scabrate to granulate, and on some specimens appears externally as fine mesh as a result of numerous fine, interconnected trabeculae. Processes on Oak Grove forms are generally longer than those of the type material. The archeopyle is precingular (Type P). Paratabulation is noted as 4?', 0a, 6", 6c, 5"', 1p, 1"".

Dimensions: Observed range (6 specimens measured): main body length 42-49um and width 36-44um; process lengths up to 17um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of England (Davey and Williams, 1966a); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Maastrichtian and Danian of Maryland, U.S.A. (Whitney, 1976); Upper Paleocene and Lower Eocene of southeast England (Denison, 1977); Upper Paleocene of the Rockall Plateau (Brown and Downie, 1983).

Spiniferites cf. *S. pterotus* (Cookson and Eisenack 1958) Sarjeant 1970

Pl. 19, figs. 5-8

Comments: One specimen superficially resembling the Western Australia Campanian/Maastrichtian forms originally described as *Cymatiosphaera pterota* by Cookson and Eisenack (1958) was recovered from the Paleocene section of the core. Trifurcate gonal gonal processes do not extend above the relatively high, serrated parasutural ridges. The levigate endophragm is up to 2um thick; the microgranulate periphragm is thinner and bears scattered grana and granulate thickenings on the dorsal paraplates.

Dimensions: Observed range (1 specimen measured): main body length 52um and width 50um; process lengths up to 12um; parasutural ridges up to 12um high.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Spiniferites pseudofurcatus (Klumpp 1953) Sarjeant 1970

Pl. 19, figs. 1-4

1838. *Xanthidium furcatum* Ehrenberg, p. 14, pl. 1, fig. 12.

1933. *Hystrichosphaera furcata* (Ehrenberg 1838) O. Wetzel, p. 387, pl. 16, fig. 11.

1953. *Hystrichokibotium pseudofurcatum* Klumpp, p. 388, pl. 16, figs. 12-14.

1953. *Areoligera incerta* Klumpp, p. 389, pl. 17, figs. 1-2.

1954. *Hystrichosphaeridium alcicornu* Eisenack, p. 65-66, pl. 10, figs. 1-2; text-fig. 5.

1960. *Hystrichosphaera tertiaria* Eisenack and Gocht, p. 515, text-fig. 4.

1966. *Achomosphaera alcicornu* (Eisenack 1954) Davey and Williams in Davey et al., p. 42-43, pl. 4, fig. 1; text-figs. 10-11.

1966. *Hystrichosphaera incerta* (Klumpp 1953) Morgenroth, p. 15, pl. 7, figs. 7-8.

1969. *Hystrichosphaera pseudofurcata* (Klumpp 1953) Gocht, p. 32-33, pl. 4, figs. 12-13; text-fig. 22.

1970. *Spiniferites pseudofurcatus* (Klumpp 1953) Sarjeant, p. 76.

Comments: Oak Grove core specimens of *Spiniferites pseudofurcatus* are similar to Gocht's (1969) Lower Tertiary forms from the Meckelfeld boreholes of northwestern Germany. Gonal processes bear broad, trifurcate distal tips with bifid or irregular terminations. Paratabulation of 4?', 0a, 6", 6c, 5"', 1p, 1"" is outlined by weakly to strongly developed parasutural ridges. Because the development of the ridges is extremely variable, even on a single specimen, those with very weakly developed or even absent ridges are therefore included within *S. pseudofurcatus*, and not in a species of *Achomosphaera*. Excystment is by a precingular archeopyle (Type P). The cyst wall is bi-layered, with an endophragm up to 2um thick and a periphragm up to 1um thick, externally levigate to scabrate.

Dimensions: Observed range (15 specimens measured): main body diameter 64-78um; process lengths up to 37um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare; Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Senonian of Germany (O. Wetzel, 1933); Eocene of Germany (Klumpp, 1953; Eisenack and Gocht, 1960; Morgenroth, 1966); Lower Oligocene of Germany (Eisenack, 1954); Upper Cretaceous of France (Valensi, 1955); Middle and Upper Oligocene of Germany (Gerlach, 1961; Benedek, 1972); Upper Oligocene of Germany (Brosius, 1963); Upper Eocene of Belgium (Rozen, 1965); Eocene of England (Davey and Williams, 1966a); Lower Eocene, Upper Eocene, and Middle Oligocene of Germany (Gocht, 1969); Paleocene of Maryland and Virginia, U.S.A. (McLean, 1971); Paleocene of Virginia, U.S.A. (Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1984); Lower Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Danian of Maryland, U.S.A. (Whitney, 1976, 1984); Upper Paleocene and Lower Eocene of southeast England (Denison, 1977); Lower Eocene of the southern Netherlands (DeConinck, 1977); Oligocene and Lower Miocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Middle Eocene to Oligocene of Alabama, U.S.A. (Edwards, 1977); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Eocene to Miocene of eastern Canada (Willimas and Bujak, 1977; Barss et al., 1979); Paleocene and Lower Eocene of Labrador and Eocene and

Oligocene of the North Sea (Ioakim, 1979); Upper Paleocene and Lower Eocene of the Rockall Plateau (Brown and Downie, 1983).

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

Pl. 19, figs. 9-12

1966. *Hystrichosphaera ramosa* var. *granomembranacea* Davey and Williams, p. 37-38, pl. 4, fig. 4.

1973. *Spiniferites ramosus* subsp. *granomembranaceus* Davey and Williams 1966) Lentin and Williams, p. 130.

Comments: This subspecies is distinguished from the morphologically similar *Spiniferites membranaceus* (Rossignol 1964) Sarjeant 1970 by its granulate main body. Characteristically high parasutural ridges, especially prominent in the apical, antapical, and paracingular regions, range up to three-fourths the height of the processes. Some parasutures are weakly defined. The cyst exhibits a precingular archeopyle (Type P). Paratabulation is 4?', 0a, 6", 6c, 5"', 1p, 1"". The cyst wall is composed of a granulate endophragm less than 1um thick and a levigate periphragm up to 0.5um thick.

Dimensions: Observed range (6 specimens measured): main body length 40-48um and width 34-43um; process lengths up to 23um; parasutural ridges up to 15um high.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of England (Davey and Williams, 1966a); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Campanian and Maastrichtian of Mississippi, U.S.A. (Rounds, 1982); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984).

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

Pl. 19, figs. 13-16

1966. *Hystrichoshphaera ramosa* var. *granosa* Davey and Williams, p. 35, pl. 4, fig. 9.

1970. *Spiniferites ramosus* var. *granosus* (Davey and Williams 1966) Sarjeant, p. 76.

1973. *Spiniferites ramosus* subsp. *granosus* (Davey and Williams 1966) Lentin and Williams, p. 130.

Comments: *Spiniferites ramosus* subsp. *granosus* is distinguished from *S. ramosus* subsp. *ramosus* primarily by its granulate endophragm. Paratabulation is 4', 0a, 6", 6c, 5"', 1p, 1""; the archeopyle is precingular (Type P). Specimens recovered in this study closely resemble the Eocene forms described by Davey and Williams (1966a) from the London Clay.

Dimensions: Observed range (7 specimens measured): main body length 36-46um and width 28-43um; process lengths up to 20um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare; Miocene strata: Extremely rare.

Previously reported occurrences: Eocene of England (Davey and Williams, 1966a); Paleocene of Virginia, U.S.A. (Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Danian of Maryland, U.S.A. (Whitney, 1976, 1984); Maastrichtian and Danian of Maryland, U.S.A. (Benson, 1976); Campanian and Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980); Maastrichtian and Lower Paleocene of Denmark (Hansen, 1977); Upper Paleocene and Lower Eocene of southeast England (Denison, 1977); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Upper Paleocene and

Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984).

Spiniferites ramosus subsp. *membranaceus* (Rossignol 1964) n. comb.

Pl. 19, figs. 17-20

1964. *Hystrichosphaera furcata* var. *membranacea* Rossignol, p. 86, pl. 1, figs. 4, 9, 10; pl. 3, figs. 7, 12.

1966. *Hystrichosphaera ramosa* var. *membranacea* (Rossignol 1964) Davey and Williams, p. 37, pl. 4, figs. 8, 12.

1967. *Hystrichosphaera membranacea* (Rossignol 1964) Wall, p. 102-103, pl. 14, figs. 14-15; text-fig. 2.

1970. *Spiniferites membranaceus* (Rossignol 1964) Sarjeant, p. 76.

1978. *Spiniferites ramosus* subsp. *membranaceus* (Rossignol 1964) n. comb.

<u>Comments:</u> Although Wall (1967) raised this subspecies to species rank, the present study recognizes it as a subspecies because of its apparent close affinities to *Spiniferites ramosus*. It is herein regarded as *S. ramosus* subsp. *membranaceus*. Parasutural ridges may be over three-fourths as high as the processes at the apex, antapex, and along the paracingulum, and rather low along other parasutures. Some forms in the Brightseat equivalent-basal Aquia? strata of the core

bear two relatively large antapical processes, as also illustrated by Rossignol (1964). The archeopyle is precingular (Type P). Paratabulation is 4?', 0a, 6", 6c, 5"', 1p, 1"". Both the endophragm up to 1um thick and the periphragm up to 0.5um thick are levigate.

Dimensions: Observed range (7 specimens measured): main body length 37-47um and width 33-37um; process lengths up to 26um; parasutural ridges up to 20um high.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare; Miocene strata: Extremely rare.

Previously reported occurrences: Quaternary of Israel (Rossignol, 1964); Eocene of England (Davey and Williams, 1966a); Quaternary of the Caribbean Sea (Wall, 1967); Eocene of Spain (Archangelsky, 1969); Lower Paleocene of Spain (Heisecke, 1970); Campanian of Alberta, Canada (Harland, 1973); Middle Oligocene to Lower Miocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Upper Paleocene and Lower Eocene of southeast England (Denison, 1977); Middle and Upper Eocene of South Carolina, U.S.A. (Watkins, 1979); Upper Paleocene and Lower Eocene of the Rockall Plateau (Brown and Downie, 1983).

Spiniferites ramosus subsp. *multibrevis*

(Davey and Williams 1966) Lentin and Williams 1973

Pl. 20, figs. 1-4

1966. *Hystrichosphaera ramosa* var. *multibrevis* Davey and Williams, p. 35-36, pl. 1, fig. 4; pl. 4, fig. 6; text-fig. 9.

1971. *Spiniferites ramosus* var. *multibrevis* (Davey and Williams 1966) Davey and Verdier, p. 33.

1973. *Spiniferites ramosus* subsp. *multibrevis* (Davey and Williams 1966) Lentin and Williams, p. 130.

Comments: Oak Grove core specimens are similar to the British Eocene forms described by Davey and Williams (1966a). The cyst is characterized by numerous short processes, the lengths of which are less than one-half the diameter (or shortest measurement) of the main body. Gonal processes trifurcate and intergonal processes (one to three) bifurcate. On some specimens, low parasutural ridges are developed. Paratabulation is 4?', 0a, 6", 6c, 5"', 1p, 1"", and the archeopyle is precingular (Type P). Both the endophragm and periphragm are about 0.5um thick and levigate to scabrate.

Dimensions: Observed range (8 specimens measured): main body length 40-53um and width 35-40um; process lengths up to 13um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Upper Cretaceous of France (Valensi, 1955); Aptian of Germany (Eisenack, 1958); Neocomian (Hauterivian) to Lower Eocene (Ypresian) of England (Davey and Williams, 1966a); Cenomanian of England and France and Albian of Saskatchewan, Canada (Davey, 1969); Albian of France (Davey and Verdier, 1971); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Campanian and Maastrichtian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Campanian and Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980); Maastrichtian and Lower Paleocene of Denmark (Hansen, 1977).

Spiniferites ramosus subsp. *ramosus*
(Davey and Verdier 1971) Lentin and Williams 1973

Pl. 20, figs. 5-8

1838. *Xanthidium furcatum* Ehrenberg, pl. 1, fig. 14.
1838. *Xanthidium ramosum* Ehrenberg, pl. 1, fig. 15.
1933. *Hystrichosphaera furcata* (Ehrenberg 1838) O. Wetzel, p. 34-35, pl. 2, figs. 35a,b; pl. 5, figs. 1, 5, 9, 15, 16.
1933. *Hystrichosphaera ramosa* (Ehrenberg 1838) O. Wetzel, pl. 5, figs. 7, 8, 10, 11, 12, 18, 19.

1966. *Hystrichosphaera ramosa* (Ehrenberg 1838) var. *ramosa* Davey and Williams, p. 33-34, pl. 1, figs. 1-6, pl. 3, fig. 1; text-fig. 8.

1966. *Spiniferites ramosus* (Ehrenberg 1838) Mantell 1954 in Loeblich and Loeblich, p. 56-57.

1971. *Spiniferites ramosus* (Ehrenberg 1838) var. *ramosus* (Davey and Williams 1966) Davey and Verdier, p. 33-34, pl. 4, figs. 1-3; pl. 7, fig. 5.

1973. *Spiniferites ramosus* subsp. *ramosus* (Davey and Verdier 1971) Lentin and Williams, p. 130.

(For more complete synonymies, see Davey and Williams (1966a) and Kjellstrom (1971).)

Comments: Specimens of this species were observed throughout the Oak Grove core. Gonal processes are trifurcate and intergonal processes are bifurcate. Relatively low parasutural ridges, usually no higher than 2um, indicate a paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". The archeopyle is precingular (Type P). The endophragm up to 1um thick and periphragm about 0.5um thick are both levigate.

Dimensions: Observed range (20 specimens measured): main body length 34-50um and width 31-43um; process lengths up to 20um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Sparse; Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Upper Jurassic (Oxfordian) to Recent; worldwide distribution.

Spiniferites ramuliferus (Deflandre 1937) Reid 1964

Pl. 20, figs. 9-12

1937. *Hystrichosphaeridium ramuliferum* Deflandre, p. 188-189, pl. 14, figs. 5-6; pl. 17, fig. 10.
1963. *Achomosphaera ramulifera* (Deflandre 1937) Evitt, p. 163.
1964. *Spiniferites ramuliferus* (Deflandre 1937) Reid, p. 608.

Comments: Because these specimens exhibit a variable degree of development of the parasutural ridges (as do some other species of *Spiniferites*), the transfer of *Achomosphaera ramulifera* to *Spiniferites ramuliferus* by Reid (1964) is herein recognized. The paracingular processes are typically fused proximally up to three-fourths of their lengths, especially apparent on the ambitus. Of the remaining processes, a few of the study specimens bear a relatively slender type similar to the Cenomanian cysts of Davey and

Williams 1966a (pl. 2, fig. 3). Paratabulation appears to be 4?', 0a, 6", 6c, 5"', 1p, 1""; the archeopyle is up to 1um thick and often granulate; the periphragm is about 0.5um thck, levigate to faintly granulate.

Dimensions: Observed range (5 specimens measured): main body length 40-52um and width 30-38um; process lengths up to 20um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Senonian of France (Deflandre, 1935, 1937); Deflandre and Courteville, 1939; Deflandre and Rigaud, 1955, Valensi, 1955); Maastrichtian of Belgium (Conrad, 1941); Eocene of Belgium (Pastiels, 1948); Danian of Germany (W. Wetzel, 1952); Neocomian of Germany (Gocht, 1959); Upper Oligocene and Middle Miocene of Germany (Gerlach, 1961); Cenomanian of Romania (Baltes, 1963); Turonian and Upper Campanian of Poland (Gorka, 1963); Cenomanian to Lower Eocene (Ypresian) of England (Cookson and Hughes, 1964; Davey and Williams, 1966a); Cenomanian of England and France (Davey, 1969); Albian of France (Davey and Verdier, 1971); Middle and Upper Oligocene of Germany (Benedek, 1972); Maastrichtian and Danian of Maryland, U.S.A. (Whitney, 1976); Maastrichtian and Lower Paleocene of Denmark (Hansen, 1977); Upper Paleocene and Lower Eocene of the Rockall Plateau (Brown and Downie, 1983).

Spiniferites sp. A

Pl. 21, figs. 1-4

Comments: On specimens designated *Spiniferites* sp. A in this study, the endophragm bears sparsely distributed, large grana up to 1um high, and the thin periphragm is essentially levigate. Trifurcate gonal processes are connected by finely serrate parasutural crests up to 6um high, which outline a paratabulation of 4?', 0a, 6", 6c, 5"', 1p, 1"". The cyst exhibits a precingular archeopyle (Type P). The paracingulum is strongly levorotatory, and the parasulcus is long and broad. *Spiniferites* sp. A cysts superficially resemble *S. scabratus* (Wall 1967) Sarjeant 1970; the latter, however, bears "microgranulate sutural septa", whereas in the specimens of this study the endophragm is ornamented with coarse grana and the periphragm is levigate.

Dimensions: Observed range (3 specimens measured): main body length 49-53um and width 38-41um; process lengths up to 20um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Spiniferites sp. B

Pl. 21, figs. 5-8

Comments: Cysts assigned to *Spiniferites* sp. B resemble the Caribbean Quaternary forms designated as *Spiniferites bentori* Rossignol 1964 by Wall (1967, pl. 14, fig. 4). Oak Grove core cysts bear short, trifurcate, gonal processes (5-12um long), whereas the Mediterranean Pleistocene forms of Rossignol (1964, pl. 1, fig. 3; pl. 3, fig. 2) bear distinctively longer processes (15-25um long). Paratabulation is typical for the genus. The archeopyle is precingular (Type P). The endophragm and periphragm are each about 0.5um thick and levigate.

Dimensions: Observed range (3 specimens measured): main body length 60-70um and width 50-54um; process lengths up to 12um.

Stratigraphic occurrence: Miocene strata: Extremely rare to Rare.

Spiniferites sp. C

Pl. 21, figs. 9-12

Comments: These distinctive Miocene cysts display a precingular archeopyle (Type P) and typical *Spiniferites*-type paratabulation. The gonal processes are broad, triangular in cross-section, typically microfenestrate, and distally bear large, broad trifurcations with bifid terminations. Adjacent apical and paracingular processes are usually fused nearly the entire length of their shanks. The paracingulum is strongly levorotatory. The endophragm and periphragm are each less than 0.5um thick; the outer layer is microreticulate.

Dimensions: Observed range (5 specimens measured): main body length 60-70um and width 57-63um; process lengths up to 23um.

Stratigraphic occurrence: Miocene strata: Extremely rare to Rare.

Genus *Systematophora* Klement 1960

Systematophora placacantha (Deflandre and Cookson 1955)
Davey, Downie, Sarjeant, and Williams 1969

Pl. 16, figs. 9-13

1955. *Hystrichosphaeridium placacantha* Deflandre and Cookson, p. 276-277, pl. 9, figs. 1-3.

1963. *Baltisphaeridium placacanthum* (Deflandre and Cookson 1955) Downie and Sarjeant, p. 72, pl. 7, fig. 12.

1966. *Impletosphaeridium placacanthum* (Deflandre and Cookson 1955)

Morgenroth, p. 35-36, pl. 9, figs. 10-11.

1969. *Systematophora placacantha* (Deflandre and Cookson 1955) Davey, Downie, Sarjeant, and Williams, p. 17.

Comments: This species is particularly abundant in Sample 327 of the Lower Eocene strata of the Oak Grove core. A paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"" is indicated by predominantly annulate complexes of slender, tapering processes with bifid tips. They may be fused proximally up to one-half their length; occasionally processes bifurcate, and some may be connected by straight trabeculae. Six separate linear complexes reflect the paracingulum. The archeopyle is apical (Type $\overline{A}$); numerous separated opercula were observed. The microgranulate endophragm is up to 2um thick; the levigate to microreticulate periphragm is about 0.5um thick. *Systematophora placacantha* differs from the morphologically similar *Areoligera senonensis* Lejeune-Carpentier 1938 by bearing annulate (and linear paracingular) complexes on both the dorsal and ventral surfaces of the cyst and by having a nearly hemispheroidal (circular equatorial section) main body; the dorso-ventrally compressed main body of *A. senonensis* bears primarily soleate complexes with a small, process-free area on the ventral surface.

Dimensions: Observed range (30 specimens measured): main body length (excl. opercula) 46-70um and width 50-82um; complete specimens: lengths up to 80um and widths up to 82um; process lengths up to 26um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Rare to Abundant.

Previously reported occurrences: Miocene of Australia (Deflandre and Cookson, 1955); Lower Eocene of Belgium (DeConinck, 1965, 1969, 1973, 1976a); Lower Eocene of Germany and Belgium (Morgenroth, 1966); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Maastrichtian of Maryland, U.S.A. (Benson, 1976); Maastrichtian and Danian of Maryland, U.S.A. (Whitney, 1976, 1984); Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980); Middle Eocene of the Norwegian Greenland Sea (Manum, 1976); Middle and Upper Eocene of Alabama, U.S.A. (Edwards, 1977); Oligocene and Lower Miocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Lower Eocene of the southern Netherlands (DeConinck, 1977); Eocene and Lower Oligocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Upper Oligocene and Lower Miocene of the North Sea (Ioakim, 1979); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Middle and Upper of the Rockall Plateau (Edwards, 1983).

Genus *Tanyosphaeridium* Davey and Williams 1966

Tanyosphaeridium variecalamum Davey and Williams 1966

Pl. 21, figs. 17-18

1966. *Tanyosphaeridium variecalamum* Davey and Williams, p. 98, pl. 6, fig. 7; text-fig. 20.

Comments: Specimens recovered in this study appear identical to the British Cenomanian specimens of Davey and Williams (1966b). Paratabulation of this species, problematical because of the variable number of processes per paraplate, is likely ?', 0a, 6", 6c, 5-6"', 3 or 6"". Parasulcal processes are approximately the same size as the remaining processes. Distally the processes of most specimens are aculeate and slightly recurved. The cyst displays an apical archeopyle (Type $\bar{A}$). The cyst wall is composed of an endophragm up to 1um thick and a granulate periphragm about 0.5um thick.

Dimensions: Observed range (7 specimens measured): main body length (excl. operculum) 33-38um and width 19-22um; process lengths up to 17um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Previously reported occurrences: Cenomanian of England (Davey and Williams, 1966b); Albian to Turonian of England, Cenomanian of France, Albian of Saskatchewan, Canada (Davey, 1969); Upper Campanian of Alberta, Canada (Harland, 1973); Maastrichtian and Lower Paleocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975) and eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Maastrichtian and Danian of Maryland, U.S.A. (Benson, 1976); Maastrichtian of Maryland, U.S.A. (Whitney, 1976, 1984); Campanian and Maastrichtian of Mississippi and Alabama, U.S.A. (Rounds, 1982); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984).

Genus *Tectatodinium* Wall 1967

Tectatodinium pellitum Wall 1967

Pl. 14, figs. 18-20

1967. *Tectatodinium pellitum* Wall, p. 113, pl. 16, figs. 11-12.

Comments: On the Oak Grove core forms, the thickness of the periphragm, composed of a matted network of intertwining fibers, varies from 2-5um. The Caribbean specimens from the Yucatan Basin and Cariaco Trench described by Wall (1967) have total wall thicknesses ranging from 3-7um. The levigate endophragm of the study specimens is about lum thick. Evidence of paratabulation is lacking. The cyst exhibits a precingular archeopyle (Type P).

Dimensions: Observed range (8 specimens measured): main body diameter 44-54um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare; Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Miocene to Recent of the Caribbean Sea (Wall, 1967); Upper Quaternary of the Black Sea (Wall and Dale, 1974); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Lower Eocene of Belgium (DeConinck, 1976a); Lower Eocene of the southern Netherlands (DeConinck, 1977); Upper Eocene to Pleistocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Miocene of the Rockall Plateau (Edwards, 1983); Lower and Middle Eocene of the eastern Netherlands (Herngreen, 1984).

Genus *Thalassiphora* (Eisenack and Gocht 1960) Gocht 1968

Thalassiphora delicata (Williams and Downie 1966) Eaton 1976

Pl. 22, figs. 1-3

1966. *Thalassiphora delicata* Williams and Downie, p. 235, pl. 26, fig. 8.

1976. *Thalassiphora delicata* (Williams and Downie 1966) Eaton, p. 287-289, pl. 16, figs. 1-3; text-figs. 18, 20.

Comments: Lower Paleocene specimens from the Oak Grove core appear similar to the Isle of Wight Bracklesham Beds specimens (Eaton, 1976) and the southeastern England London Clay specimens (Williams and Downie, 1966c). The periphragm consists essentially of a wing lamella, turned over on its margin, and in contact with the endophragm only on the dorsal side. Eaton (1976) has reported the paratabulation, expressed by fine linear thickenings of the periphragm, as 4', 1a, 5", 4c, 5"', 1p, 1""; well preserved specimens of this study support this formula. Small parasulcal paraplates were also observed. Although Williams and Downie (1966c) do not note paratabulation, parasutural thickenings are obvious on their photograph (pl. 26, fig. 8). The archeopyle is precingular (Type P), with loss of the 3" paraplate. A distinctive feature of this species is the extreme offset of the parasulcus to the right side of the cyst.

The large aperture on the ventral surface of the periphragm results from the loss of the 1" paraplate, according to Eaton (1976); this point needs further study. The endophragm, levigate to faintly granulate, is up to 1um thick; the periphragm, usually minutely fenestrate, is up to 0.5um thick.

Because of differences in general cyst construction and paratabulation between *Thalassiphora delicata* and the type species, *T. pelagica*, the former may have to be ultimately removed from this genus; in past personal communication, Professor Gocht (Tubigen University, Germany) expressed a similar contention.

Dimensions: Observed range (25 specimens measured): overall length 85-102um and width 77-112um; main body length 48-57um and width 37-50um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Common.

Previously reported occurrences: Lower Eocene of England (Williams and Downie, 1966a); Lower Eocene of Belgium (DeConinck, 1969, 1973, 1976a); Paleocene of Virginia and Maryland, U.S.A. (McLean, 1975); Paleocene of Virginia, U.S.A. (Witmer, 1975); Eocene of England (Eaton, 1976); Upper Eocene and Oligocene of Alabama, U.S.A. (Edwards, 1977); Upper Paleocene and Lower Eocene of southeast England (Denison, 1977); Lower and Middle Eocene of Labrador and Upper Eocene and

Oligocene of the North Sea (Ioakim, 1979); Upper Paleocene and Lower Eocene of the eastern Netherlands (Herngreen, 1984).

Thalassiphora pelagica (Eisenack 1954) Eisenack and Gocht 1960

Pl. 22, figs. 4-12

1954. *Pterospermopsis pelagica* Eisenack, p. 71, pl. 12, figs. 17-18.

1960. *Thalassiphora pelagica* (Eisenack 1954) Eisenack and Gocht, p. 513-514.

(For a more complete synonymy, see Morgenroth (1966a), Gocht (1968) or Eisenack and Kjellstrom (1971).)

Comments: Some samples yielded populations of variable forms of *Thalassiphora pelagica*, similar to what Gocht (1968, 1969) refers to as initial, intermediate, and "typical" stages in the ontogenetic development of the species. Forms representing the supposed initital stage bear parasutural folds and thickenings suggesting a paratabulation of 4', 0a, 5", ?c, 5"', 0p, 1""; on fully expanded forms, evidence of paratabulation is often only partially visible. Eaton (1976) suggests that the paratabulation of the "typcial" forms of *T. pelagica* is similar to that of *T. delicata*, and that the initial and intermediate forms of Gocht (1968) be excluded from *T. pelagica*. Initial stage forms in this study, however, appear to be different from those cysts referred to *Muratodinium fimbriatum* (Cookson and Eisenack 1967) Drugg 1970; the latter species bears more distinctively vertical, lace-like walls. On the apical and/or antapical poles of the main body of *T. pelagica*, a short protuberance is often found. Loss of paraplate 3" results in a precingular archeopyle Type P). The endophragm up to 4um thick is densely fibrous, constructed of matted, intertwining fibers. The outer layer is more coarsely fibrous, imparting a reticulate appearance; on compact forms it is appressed to the endocyst and up to 3um thick, whereas on intermediate and fully expanded forms it is not appressed and is thinner and more filmy. Part of the outer layer may be missing on the ventral side on the fully expanded forms.

Gocht (in past personal communication) related the following information about *T. pelagica*: (1) From a single sample, he has mounted hundreds of specimens in a completely transitional series from the compact, initial stage forms to fully expanded, "typical" forms. This sequence strongly suggests that in successive stages of development the outer layer gradually pulls away from the main body in a complex manner. Scanning electron micrography has shown that the outer layer is of similar construction on all forms. (2) Many German forms bear a relatively long, process-like extension on the operculum (not observed on the Atlantic Coastal Plain cysts) which he suggests the cysts may have used to attach themselves to the sea floor; upon "inflation" of this outer wall layer they would have perhaps become more buoyant, broken loose, and floated toward the surface. (3) *T. pelagica* likely has four apical and no anterior intercalary parplates. (4) Future study may show ***Muratodinium fimbriatum*** to belong to the ***Thalassiphora*** complex.

Dimensions: Observed range (25 specimens measured): (1) initial stage forms: main body length 90-108um and width 85-92um; compressed processes up to 12um long; (2) intermediate stage forms: main body length 92-109um and width 80-94um; overall length 164-178um and width 130-145um; (3) fully expanded forms: main body length 96-112um and width 90-110um; overall length 176-245um and width 188-210um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare to Sparse; Miocene strata: Extremely rare.

Previously reported occurrences: Lower Oligocene of Germany (Eisenack, 1954); Eocene of Australia (Deflandre and Cookson, 1955); Middle Oligocene to Middle Miocene of Germany (Gerlach, 1961); Upper Eocene of Germany (Eisenack, 1938; Eisenack and Gocht, 1960); Neocomian (Upper Hauterivian to Upper Barremian) of Germany (Alberti, 1961); Eocene of Australia (Cookson and Eisenack, 1961); Upper Oligocene of Germany (Brosius, 1963); Lower Eocene of Germany (Morgenroth, 1966a); Eocene of England (Williams and Downie, 1966c); Eocene of Germany (Gocht, 1968, 1969); Middle and Upper Oligocene of

Germany (Benedek, 1972); Middle Eocene of Australia (Haskell and Wilson, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Danian of Maryland, U.S.A. (Whitney, 1976, 1984); Eocene of England (Eaton, 1976); Eocene of the Norwegian Greenland Sea (Manum, 1976); Oligocene and Lower Miocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Middle Eocene of Alabama, U.S.A. (Edwards, 1977); Upper Paleocene to Lower Eocene of southeast England (Denison, 1977); Upper Maastrichtian and Lower Paleocene of Belgium (Hansen, 1977); Paleocene to Oligocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Lower Eocene of the eastern Netherlands (DeConinck, 1977); Eocene of Labrador and Eocene to Lower Miocene of the North Sea (Ioakim, 1979); Lower and Middle Eocene of the Rockall Plateau (Costa and Downie, 1979); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984).

Genus *Trichodinium* (Eisenack and Cookson 1960)
Clarke and Verdier 1967

Trichodinium hirsutum Cookson 1965

Pl. 21, figs. 19-20

1965. *Trichodinium hirsutum* Cookson, p. 139, pl. 25, figs. 5-13.

Comments: Only a few specimens of *Trichodinium hirsutum* were recovered in the Oak Grove core. The tapered processes, which may occasionally bifurcate or trifurcate, are loosely fibrous at their bases and more densely fibrous on their shanks, with acuminate, bifid, or finely capitate tips. The bifurcate to multifurcate process located at the apex and antapex is distintively longer and more coarsely fibrous than the remaining processes. Paracingular processes may also be slightly longer than the surrounding processes, especially evident at the ambitus. On the single Paleocene form the processes are randomly distributed, whereas on the Eocene cysts they appear to be arranged in clusters. The archeopyle is precingular (Type P). The endophragm is up to 2um thick, and the fibrous periphragm is about 1um thick.

Dimensions: Observed range (3 specimens measured): main body length 65-94um and width 53-85um; process lengths up to 17um; apical process lengths 14-16um; antapical process lengths 17-23um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Paleocene of Australia (Cookson, 1965); Danian of Maryland, U.S.A. (Benson, 1976; Whitney, 1976, 1984); Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980).

Genus *Tubidermodinium* Morgenroth 1966

Tubidermodinium sulcatum Morgenroth 1966

Pl. 35, figs. 17-20

1966. *Tubidermodinium sulcatum* Morgenroth, p. 16-17, pl. 3, figs. 4-6.

Comments: The cysts of *Tubidermodinium sulcatum* recovered in this study are generally not well preserved. The granulate endophragm up to 2um thick bears bacula which support a thin ectophragm. The bacula, which range up to 7um high, flare out distally. Intratabular groups of bacula and parasutural folds of the ectophragm reflect a paratabulation of 4', 0a, 5", ?c, 6?"', 1p, 2"". Excystment is by an epicystal archeopyle (Type $\overline{\text{AP}}$).

Dimensions: Observed range (4 specimens measured): main body length 60-68um and width 56-70um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966a); Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983).

Genus *Turbiosphaera* Archangelsky 1969

Turbiosphaera filosa (Wilson 1967) Archangelsky 1969

Pl. 15, figs. 13-16

1967. *Cordosphaeridium filosum* Wilson, p. 66, figs. 2, 31, 32, 34.

1969. *Turbiosphaera filosa* (Wilson 1969) Archangelsky, p. 408-411, pl. 1, figs. 1-4.

Comments: Specimens recovered from the Paleocene strata are similar to the Argentine Eocene specimens described by Archangelsky (1969). Large, broad processes, constructed of loosely bound bundles of coarse fibers, indicate a paratabulation of 4?', 0a, 6", 6c, 6"', 1p, 1"". The apical cluster appears to expand proximally into four apical processes. Paracingular processes are short and broad; parasulcal processes are the smallest on the cyst. Many forms were observed bearing postcingular processes 3"' and 4"' with U-shaped bases (open toward anterior). The processes are distinctly clustered toward the apical and antapical regions and along the paracingulum. Fibrils up to 12um long are randomly distributed in the intervening areas. A bi-layered cyst wall is formed of an endophragm up to 1um thick and a coarsely fibrous periphragm up to 3um thick, appearing reticulate as a result of the intertwining fibers.

Dimensions: Observed range (12 specimens measured): main body length 77-103um and width 62-85um; process lengths up to 39um.

Stratigraphic occurrence: Paleocene strata: Rare to Abundant.

Previously reported occurrences: Lower Tertiary erratics of Antarctica (Wilson, 1967); Eocene of Argentina (Archangelsky, 1969); Paleocene of Virginia and Maryland, U.S.A. (McLean, 1971); Paleocene of Spain (Caro, 1973); Paleocene of Virginia, U.S.A. (Witmer, 1975; Edwards et al., 1984); Maastrichtian and Paleocene of eastern Canada

(Williams and Bujak, 1977; Barss et al., 1979); Upper Paleocene of Alabama, U.S.A. (Edwards, 1980).

Turbiosphaera rotunda n. sp.

Pl. 10, figs. 13-16

Derivation of species name: Latin, *rotundus*, spherical, round--in reference to the spheroidal main body of the cyst.

Description: Cyst main body spheroidal to slightly ellipsoidal, bearing large, fibrous processes. Cyst wall bi-layered; processes formed of the periphragm, indicating paratabulation of 4', 0a, 6", 6?c, 5"', 1p, 1"". Archeopyle precingular (Type P) with simple, free operculum; corresponds to paraplate 3". Paracingulum and parasulcus bear processes. Paracingulum levorotatory, with ends separated vertically up to about one paracingulum width and transversely up to about three paracingulum widths. Parasulcus delineated at top and bottom by anterior and posterior parasulcal processes.

Endophragm up to 3um thick, externally levigate. Periphragm up to 2um thick, fibrous. Processes fibrous, intratabular, formed by the coalescence of densely distributed fibrils arising perpendicularly from the main body. Apical processes join together and are rounded in cross-section.

Dimensions: Holotype main body L X W: 78um X 78um; overall L X W (incl. processes): 130um X 132um. Observed range (10 specimens measured): main body length 77-88um and width 67-82um; overall length (incl. processes) 109-140um and width (incl. processes) 85-132um.

Discussion and comparison with similar species: Features that characterize *Turbiosphaera rotunda* include the thick-walled, spheroidal main body and the distinctive process formation. Processes on some specimens are somewhat difficult to distinguish.

Turbiosphaera rotunda generally resembles *T. galatea* Eaton 1976 (p. 289, pl. 15, figs. 4-6) recovered from the Lower Eocene interval of the Bracklesham Beds of England. The main body of the new species (length 77-88um and width 69-84um) is more spheroidal than that of *T. galatea* (length 60-80um and width 44-75um). The apical horn is much longer and more pointed in *T. galatea* as well. Whereas the recovery of the new species is restricted to the Upper Paleocene, *T. galatea* is recorded from only the Lower Eocene. The two species are certainly closely related; *T. rotunda* may be the precursor to *T. galatea*.

Turbiosphaera rotunda differs from the superfically similar *Lanternosphaeridium lanosum* Morgenroth 1966 (p. 38, pl. 10, figs. 10-11) most markedly by its spheroidal endocyst and discrete processes; the latter has a more ellipsoidally shaped main body and is apparently atabulate.

The rotund, spheroidal shape of the endocyst distinguishes *T. rotunda* from *T. paratabulata* (n. sp., this study), whose ellipsoidal endocyst bears an apical and antapical protuberance. The united apical processes of *T. rotunda* are rounded in cross-section, whereas those of *T. paratabulata* are generally pointed.

Holotype: Pl. 10, figs. 13-15; VPISUPL Sample 316, Slide AO-35, Coords. R12.2;+9.6.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Turbiosphaera paratabulata n. sp.

Pl. 10, figs. 9-12

Derivation of species name: Greek, *para*, near, beside + Latin, *tabulata*, tabulated--in reference to the paratabulated cyst.

Description: Cyst main body ellipsoidal with short apical and antapical protuberances, bearing large, fibrous processes. Cyst wall bi-layered; processes formed of the periphragm, indicating paratabulation of 4', 0a, 6", 6c, 5"', 1p, 1"". Archeopyle precingular (Type P) with simple, free operculum; corresponds to paraplate 3". Paracingulum and parasulcus bear processes.

Paracingulum levorotatory, with ends separated vertically up to about one paracingulum width and transversely up to about three paracingulum widths.

Endophragm up to 2um thick, externally levigate. Periphragm up to 1.5um thick, fibrous. Processes fibrous, intratabular, formed by the coalescence of densely distributed fibrils arising perpendicularly from the main body. Apical processes join together and taper to a point in cross-section. Paracingular processes elongate and flattened. Protuberances at apex and antapex range from short to elongate, with antapical usually longer; they typically bear finely fibrous, pointed appendages.

Dimensions: Holotype main body L X W: 114um X 66um; overall L X W (incl. processes): 176um X 86um. Observed range (15 specimens measured): main body length 84-127um and width 54-70um; overall length (incl. processes) 134-185um and width (incl. processes) 77-105um.

Discussion and comparison with similar species: Distinguishing characteristics of the new species include the ellipsoidal main body with a protuberance at the apex and antapex, and the distinctive process formation.

Turbiosphaera paratabulata resembles *T. magnifica* described by Eaton (1976, p. 290, pl. 15, figs. 7-9) from the Middle Eocene of England. The new species (overall length 134-185um and overall width 77-105um), however, is generally larger than *T. magnifica* (overall length 110-148um and overall width 62-80um). The former invariably bears apical and antapical protuberances on the main body, whereas no such features are reported for the latter. *T. paratabulata* has a known stratigraphic range of Upper Paleocene (it was not recovered in the Eocene strata of the Oak Grove core); *T. magnifica* has been recorded from only the Middle Eocene of England. It is possible that the new species is an evolutionary predecessor of *T. magnifica*, and may be shown to be synonymous with it in future studies.

Turbiosphaera paratabulata bears a superficial resemblance to *Lanternosphaeridium lanosum* Morgenroth 1966 (p. 38, pl. 10, figs. 10-11); the former possesses individual processes on each paraplate, whereas the latter is constructed of a filmy, fibrous, outer membrane which is not differentiated into discrete processes.

The endocyst of *Turbiosphaera paratabulata* is ellipsoidal with an apical and antapical protuberance; that of *T. rotunda* (n. sp., this study), on the other hand, is more spheroidal and lacks the protuberances. Also, the apical processes of *T. paratabulata* join together to form a point, but those of *T. rotunda* create a more rounded profile.

Holotype: Pl. 10, figs. 9-11; VPISUPL Sample 316, Slide AO-35, Coords. R18.6;+7.7.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Family PERIDINIACEAE Ehrenberg 1838

Genus *Andalusiella* Riegel 1974

Andalusiella rhombohedra (Benson 1976)
Stover and Evitt 1978

Pl. 23, figs. 5-8

1976. *Deflandrea rhombohedra* Benson, p. 195, pl. 9, figs. 10-12.
1978. *Andalusiella rhomobohedra* (Benson 1976) Stover and Evitt, p. 94-95.

Comments: The short, blunt apical horn and relatively prominent left and weakly developed right antapical horns impart a characteristic rounded rhombohedral cyst outline to study specimens of *Andalusiella rhombohedra*. Paratabulation is not evident. An intercalary archeopyle (Type I/I) results from the release of a simple, free operculum corresponding to paraplate 2a. The weakly levorotatory paracingulum is best developed on the dorsal surface and generally not apparent on the ventral surface. The parasulcus is weakly developed. Both the endophragm and periphragm are faintly wrinkled, with the former up to 1um thick and levigate and the latter up to 0.5um thick and levigate to faintly punctate. Lateral pericoels range from virtually absent (periphragm and endophragm closely appressed) up to about 4um wide. The apical horn pericoels measure up to 6um and the left antapical horn pericoels up to 10um. The extremely thin, fragile periphragm is often partially or totally torn away.

Specimens recovered in this investigation differ from the Maryland Danian forms described by Benson (1976) by exhibiting a shorter apical horn with smaller pericoel (4-6um vs. 9-19um), shorter left anatpical horn, and greater cyst width (57-65um vs. 33-40um). The forms recovered in Virginia studies and those from Maryland seem to represent end members of intraspecific variability.

Dimensions: Observed range (10 specimens measured): pericyst length 78-90um and 57-65um; endocyst length 66-79um and width 54-60um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Previously reported occurrences: Upper Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975; Edwards et al., 1984); Lower Paleocene of Maryland, U.S.A. (Benson, 1976).

Genus *Apectodinium* (Costa and Downie 1976) Lentin and Williams 1977

Apectodinium homomorphum complex

Pl. 30, figs. 13-16

Apectodinium homomorphum:

1948: *Hystrichosphaeridium geometricum* Pastiels, p. 41, pl. 14, figs. 1, 2, 4, 8, 11.

1955. *Wetzeliella (Wetzeliella) homomorphum* Deflandre and Cookson, p. 254, pl. 5, fig. 7; text-fig. 19.

1977. *Apectodinium homomorphum* (Deflandre and Cookson 1955) Lentin and Williams, p. 8.

Apectodinium quinquelatum:

1966. *Wetzeliella (Wetzeliella) homomorphum* var. *quinquelata* Williams and Downie, p. 191-192, pl. 18, fig. 7.

1975. *Wetzeliella (Wetzeliella) homomorpha* subsp. *quinquelata* (Williams and Downie 1966) Lentin and Williams, p. 141.

1976. *Wetzeliella (Apectodinium) homomorpha* subsp. *quinquelata* (Williams and Downie 1966) Costa and Downie, p. 608, 614.

1979. *Apectodinium quinquelatum* (Williams and Downie 1966) Costa and Downie, p. 43.

Apectodinium hyperacanthum:

1965. *Wetzeliella (Wetzeliella) hyperacanthum* Cookson and Eisenack, p. 134-135, pl. 16, figs. 3-6.

1976. *Wetzeliella (Apectodinium) hyperccanthum* (Cookson and Eisenack 1965) Costa and Downie, p. 608, 614, pl. 92, fig. 6.

1977. *Apectodinium hyperacanthum* (Cookson and Eisenack 1965) Lentin and Williams, p. 8.

Comments: The morphologically variable cysts included in the *Apectodinium homomorphum* complex encompass forms which could be accomodated by *Apectodinium homomorphum, Apectodinium quinquelatum,* and *Apectodinium hyperacanthum.* This group of cysts reflects a high degree of interspecific variability with many transitional forms, making speciation extremely difficult. Most of the specimens recovered in this study exhibit a pentagonally shaped main body; those with a more nearly ovoidal shape, however, are not rare. Horns and process lengths vary considerably from specimen to specimen.

Most processes, which may appear randomly distributed or vaguely arranged in simulate complexes, are distally open and aculeate, although some are closed and blunt or acuminate. Paratabulation is difficult to determine with certainty. Apical, antapical (left longer than right), and lateral horns range from types which are not particularly prominent to those which are considerably drawn out. Excystment is by an intercalary archeopyle (Type I/I), with loss of paraplate 2a. The endophragm and periphragm, each about 0.5um thick, are levigate to scabrate.

Dimensions: Observed range (25 specimens measured): main body length 50-86um and width 45-82um; individual process lengths up to 20um; horn lengths (incl. processes): apical up to 24um; antapical up to 34um; laterals up to 30um.

Stratigraphic occurrence: Paleocene strata: Rare to Common; Marlboro Clay: Extremely rare; Eocene strata: Extremely rare to Common.

Previously reported occurrences: Lower Eocene of Belgium (Pastiels, 1948; DeConinck, 1965, 1969, 1973, 1976a); Lower Eocene of Australia (Deflandre and Cookson, 1955); Upper Eocene of Germany (Alberti, 1961); Paleocene of Australia, as *W. (A.) hyperacantha* (Cookson and Eisenack, 1965b); Lower Eocene of Germany (Morgenroth, 1966a); Eocene of England (Williams and Downie, 1966b; Eaton, 1976; Bujak et al., 1980a); Paleocene of New Zealand (Wilson, 1967c) and Tasmania (Cookson and Eisenack, 1967a); Paleocene and Lower Eocene of France (Chateauneuf and Gruas-Cavagnetto, 1968, 1978; Gruas-Cavagnetto, 1968, 1970); Paleocene of Virginia, U.S.A. (McLean, 1971); Middle Paleocene to Lower Eocene of Spain (Caro, 1973); Upper Paleocene and Lower Eocene of Virginia, U.S.A. (Witmer, 1975); Paleocene and Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); and eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Lower

Eocene of the Norwegian Greenland Sea (Manum, 1976); Upper Paleocene and Lower Eocene of southeastern England (Denison, 1977); Lower and Middle Eocene of the Rockall Plateau (Costa and Downie, 1979); Lower Eocene of the southern Netherlands (DeConinck, 1979); Upper Paleocene (base of Ilerdian) to Middle Eocene of Labrador and the North Sea (Ioakim, 1979); Upper Paleocene and Lower Eocene of Georgia and Alabama, U.S.A. (Edwards, 1980); Upper Paleocene and Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Upper Paleocene and Lower Eocene of eastern Netherlands (Hergreen, 1984); Upper Paleocene and Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Apectodinium sp. A

Pl. 30, figs. 17-20

Comments: These distinctive cysts which have been designated *Apectodinium* sp. A were recovered from only the Marlboro Clay. The forms which bear a few bluntly tipped processes suggest that they in fact represent environmentally influenced, morphological variants of *Apectodinium homomorphum* complex; no evidence of breakage was observed. Because of taxonomic uncertainty and paucity of specimens, a new species is not erected at this time. A description is included for completeness.

Description: Cyst generally pentagonal in dorso-ventral view, with short, variably developed apical, lateral, and antapical horns. Cyst wall bi-layered; periphragm folded and wrinkled to varying degrees and may bear randomly distributed, short, blunt processes. Paratabulation inderterminate. Archeopyle intercalary (Type I/I); likely corresponds to paraplate 2a. Paracingulum slightly levorotatory, with ends separated vertically up to one-half paracingulum width and transversely up to about one paracingulum width. Parasulcus rather deeply invaginated. Apical horn bluntly rounded, weakly developed; may be absent. Two anatapical horns bluntly tipped, right reduced. Lateral horns short, flat tipped; may show paracingular indentation. Except for horns, endocyst completely fills pericyst.

Endophragm up to 0.5um thick, externally levigate. Periphragm up to 0.5um thick, externally levigate, but may occasionally bear scattered minute grana; moderately to extensively wrinkled and folded. A few short, bluntly rounded processes up to 8um long may be randomly distributed along folds.

Dimensions: Observed range (7 specimens measured): pericyst length 60-70um and width 60-68um; endocyst length 52-64um and width 56-64um.

Stratigraphic occurrence: Marlboro Clay: Rare.

Genus *Biconidinium* Islam 1983

Biconidinium longissimum Islam 1983

Pl. 31, figs. 9-12

1983. *Biconidinium longissimum* Islam, p. 84-85, pl. 1, figs. 3-4; text-fig. 10.

Comments: Oak Grove core specimens recovered from only Samples 331 and 332 of the Lower Eocene Nanjemoy Formation are of similar morphology and size as those described by Islam (1983c) from the Lower Eocene London Clay of the Isle of Sheppey, southern England. Conspecific forms include *Odontochitinopsis?* sp. (DeConinck, 1976, p. 98, pl. 17, figs. 41-43) and Dinoflagellate sp. A (Islam, 1983a, p. 244, pl. 4, figs. 11-12). Paratabulation, indicated by linear thickenings of the periphragm, is recorded as 4', 3a, 7", 6?c, 5"', Op, 2""; the archeopyle is suggested to be a 3I intercalary type. The paracingulum is levorotatory with ends separated vertically up to about one paracingulum width and transversely up to one and one-half paracingulum widths. The number of paraplates on the relatively short parasulcus cannot be determined.

Dimensions: Observed range (25 specimens measured): Pericyst length 124-172um and width 46-67um; endocyst length 43-62um and width 41-60um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Abundant.

Previously reported occurrences: Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Lower Eocene of Belgium (DeConinck, 1976); Lower Eocene of southern England (Islam, 1983b,c); Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Genus *Deflandrea* (Eisenack 1938) Lentin and Williams 1976

Deflandrea dartmooria Cookson and Eisenack 1965

Pl. 24, figs. 1-4

1965. *Deflandrea dartmooria* Cookson and Eisenack, p. 133, pl. 16, figs. 1-2; text-fig. 1.

Comments: Paleocene specimens of this study are somewhat larger than the Australian Paleocene cysts described by Cookson and Eisenack (1965). The cyst exhibits an intercalary archeopyle (Type I/I). Clusters of randomly distributed coni up to 2um high are arranged in paraplates, indicating a paratabulation of 4', 3a, 7", ?c, 5"', 0p, 2""; coni on some specimens tend to be aligned along fine longitudinal folds. Fine linear markings observed in the unornamented pandasutural bands likely reflect the actual plate sutures. On the right side of the parasulcal area is located a distinctive concavo-convex thickening (position of original flagellar pore). Conforming to the original species description, most forms have a nearly parallel-sided hypocyst; some, however, possess slightly convergent or divergent antapical horns. In the bottom 25 meters of the Oak Grove core (Brightseat equivalent-lower Aquia? and lower Aquia strata), a number of specimens bear an unusually long, slender apical horn (up to 72um long) and antapical horns (up to 60um long). Similar forms were also recovered in the Brightseat Formation east of Washington, D. C. (Whitney, 1976) and the lower Aquia Formation near Richmond, Virginia (Witmer, 1975). The cyst wall is composed of an endophragm up to 1um thick and a periphragm up to 0.5um thick.

Dimensions: Observed range (25 specimens measured): pericyst length 140-199um and width 88-112um; endocyst length 62-84um and width 70-88um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Sparse.

Previously reported occurrences: Paleocene of Australia (Cookson and Eisenack, 1965); Paleocene and Lower Eocene of Australia (Stover, 1973); Paleocene of Maryland and Virginia, U.S.A. (McLean, 1971); Paleocene of Virginia, U.S.A. (Witmer, 1975; Edwards et al., 1984); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Maastrichtian and Danian of Maryland, U.S.A. (Benson, 1976); Upper Paleocene and Lower Eocene of eastern Canada (Williams and Bujak, 1977; Barss et al, 1979); Upper Paleocene and Lower Eocene of the North Sea (Ioakim, 1979).

Deflandrea phosphoritica Eisenack 1938

Pl. 25, figs. 5-10

1938. *Deflandrea phosphoritica* Eisenack, p. 187, fig. 6.

Comments: Specimens of *Deflandrea phosphoritica* in this study are larger than most from other studies in Australia and Europe. This species as herein identified exhibits considerable intraspecific variability in pericyst shape and endocyst ornmentation. The pericyst ranges from pentagonally shaped forms with a relatively short apical horn and convergent antapical horns to those with a progressively longer apical horn and less convergent antapical horns. The endocyst is micrgranulate to granulate on the Aquia cysts, but becomes more coarsely granulate to verrucate on the Nanjemoy specimens; it rarely exceeds 1um in thickness. Many of the Lower Eocene forms could likely be accomodated by *D. phosphoritica* subsp. *australis*, but because of apparent intersubspecific variability, they have been generally assigned to *D. phosphoritica* in this study. Paratabulation is indistinctly reflected by fields of minute coni up to 0.5um high on a scabrate to microgranulate periphragm up to 0.5um thick, and is recorded as 4', 3a, 7", ?c, 5"', 0p, 2""; on many forms the fields are extremely difficult to observe. The archeopyle is intercalary (Type I/I), formed by the displacement of paraplate 2a; the archeopyle on the endocyst appears almost apical in position.

Dimensions: Observed range (25 specimens measured): pericyst length 120-160um and width 73-99um; endocyst length 54-94um and width 63-80um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Sparse; Eocene strata: Extremely rare to Abundant.

Previously reported occurrences: Lower Oligocene of East Prussia (Eisenack, 1938); Eocene of Germany (Reissinger, 1950; Klumpp, 1953; Morgenroth, 1966a); Lower Oligocene of Estonia (Eisenack, 1954); Lower Eocene of Australia (Deflandre and Cookson, 1955); Upper Eocene to Lower Oligocene of Germany (Maier, 1959); Lower Tertiary of Germany (Alberti, 1959); Lower Tertiary of Australia (Cookson and Eisenack, 1961; Stover, 1973); Upper Eocene to Upper Oligocene of Germany (Gerlach, 1961); Upper Oligocene of Germany (Brosius, 1963); Eocene of Australia (Cookson and Eisenack, 1965a); Eocene of England (Williams and Downie, 1966c; Eaton, 1976); Upper Eocene to Middle Oligocene of Siberia, U.S.S.R. (Vozzhennikova, 1967); Paleocene to Lower Oligocene of northern France (Chateauneuf and Gruas-Cavagnetto, 1968, 1978); Lower Eocene of Belgium (DeConinck, 1969); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Middle and Upper Oligocene of Germany (Benedek, 1972); Lower Eocene of Spain (Caro, 1973); Middle Eocene to Upper Oligocene and Miocene of Tasmania and New Zealand (Haskell and Wilson, 1975); Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Eocene and Oligocene of the Norwegian Greenland Sea (Manum, 1976); Upper Paleocene and Lower Eocene of southeastern England (Denison, 1977); Eocene of the Netherlands (DeConinck, 1977); Eocene and Oligocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle Eocene to Lower Oligocene of Alabama, U.S.A. (Edwards, 1977); Lower Eocene of southern Netherlands (DeConinck, 1977); Eocene of Labrador and Eocene to Miocene of the North Sea (Ioakim, 1979); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Upper Paleocene of Georgia and Alabama, U.S.A. (Edwards, 1980); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Lower Eocene of eastern Netherlands (Herngreen, 1984); Upper Paleocene and Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Deflandrea wardenensis Williams and Downie 1966

Pl. 23, figs. 3-4

1966. *Deflandrea wardenensis* Williams, p. 233, pl. 26, fig. 5.

Comments: Cysts of *Deflandrea wardenensis* bear two antapical horns of equal length and a blunt, conical apical horn. Specimens do not usually stain well because of the extremely thin cyst walls. The periphragm of this bi-layered cyst, typically finely longitudinally folded, is ornamented with short, randomly distributed spines about 0.5um long. The paracingulum is delineated by aligned spines. Paratabulation is not apparent. The cyst displays an intercalary arecheopyle (Type I/I), apparently formed by the loss of paraplate 2a. Although morphologically similar to the Eocene London Clay forms of England described by Williams and Downie (1966c), Oak Grove core specimens are generally larger.

Dimensions: Observed range (8 specimens measured): pericyst length 68-81um and width 48-56um; endocyst length 40-54um and width 46-51um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Eocene of England (Williams and Downie, 1966c); Lower Eocene of Belgium (DeConinck, 1969, 1976a); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975) and eastern Canada (Williams and Bujak, 1977; Barss et al, 1979); Lower Eocene of southern England (Denison, 1977).

Genus *Isabelidinium* Lentin and Williams 1977

Isabelidinium cooksoniae (Alberti 1959) Lentin and Williams 1977

Pl. 25, figs. 9-10

1959. *Deflandrea cooksoni* Alberti, p. 97, pl. 9, figs. 1-6.
1967. *Australiella cooksoni* (Alberti 1959) Vozzhennikova, p. 132, pl. 61, figs. 2-5.
1975. *Isabelia cooksoni* (Alberti 1959) Lentin and Williams, p. 57.
1977. *Isabelidinium cooksoniae* (Alberti 1959) Lentin and Williams, p. 167.

Comments: Only one specimen was recovered in the basal Paleocene strata of the Oak Grove core. Although this species has been previously observed from primarily Upper Cretaceous sediments, at least one Danian occurrence has been reported (Drugg, 1967); it is difficult to tell if the Oak Grove core specimen is in place or redeposited. The cyst appears aparatabulate. Displacement of what is likely paraplate 2a results in an intercalary archeopyle (Type I/I). A very weakly developed paracingulum is best revealed on the ambitus. The endophragm is about 1.5um thick and the periphragm is about 0.5um thick; each is coarsely granulate.

Dimensions: Observed range (1 specimen measured): pericyst length 106um and width 52um; endocyst length 44um and width 49um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Previously reported occurrences: Upper Senonian of Germany (Alberti, 1959); Senonian of the U.S.S.R. (Vozzhennikova, 1967); Santonian of the Isle of Wight, England (Clarke and Verdier, 1967); Maastrichtian and Danian of California, U.S.A. (Drugg, 1967); (Masstrichtian of Texas, U.S.A. (Zaitzeff and Cross, 1970); Maastrichtian of southern Sweden (Kjellstrom, 1973); Upper Campanian to Upper Maastrichtian of Holland, Belgium, and Denmark (Wilson, 1974); Senonian? of southern Spain (Riegel, 1974); Campanian and Maastrichtian of the District of Mackenzie, N.W.T., Canada (McIntyre, 1974); Senonian of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Campanian and Maastrichtian of Maryland and Delaware, U.S.A. (Whitney, 1976);

Maastrichtian of Maryland, U.S.A. (Benson, 1976); Campanian and Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980); Campanian and Maastrichtian of eastern Canada (Barss et al., 1979); Campanian and Maastrichtian of Mississippi and Alabama, U.S.A. (Rounds, 1982).

Genus *Kisselovia* (Vozzhennikova 1963)
Lentin and Williams 1976

Kisselovia coleothrypta (Williams and Downie 1966)
Lentin and Williams 1976

Pl. 27, figs. 1-4

1966. *Wetzeliella (Wetzeliella) coleothrypta* Williams and Downie, p. 185-186, pl. 18, figs. 8-9; text-fig. 47.

1976. *Kisselovia coleothrypta* (Williams and Downie 1966) Lentin and Williams, p. 136.

Comments: Specimens of *Kisselovia coleothrypta* from the Oak Grove core compare in morphology and size to the Eocene London Clay forms described by Williams and Downie (1966b). The original description states that the right antapical horn is the longer of the two; observations of study specimens, however, show that the left is in fact longer. Paratabulation of 4', 3a, 6", 6?c, 5"', 0p, 1"" is indicated by paraplates of simulate complexes of processes distally interconnected by a thin, filmy ectophragm (not continuous between the paraplates). The archeopyle is intercalary (Type I/I), formed by the loss of paraplate 2a. The endophragm up to 1um thick is microgranulate to granulate; the periphragm and ectophragm, each less than 0.5um thick, are microgranulate.

Dimensions: Observed range (8 specimens measured): overall length 99-154um and width 103-140um; endocyst length 64-98um and width 68-90um; process lengths up to 14um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Lower Eocene of England (Williams and Downie, 1966b; Downie, Husain, and Williams, 1971); Middle Eocene of northern France (Gruas-Cavegnetto, 1970); Lower Eocene of Spain (Caro, 1973); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Eocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Eocene of England (Eaton, 1976); Lower and Middle Eocene of the Norwegian Greenland Sea (Manum, 1976); Lower Eocene of Belgium (DeConinck, 1976a); Lower Eocene of southeastern England (Denison, 1977); Middle Eocene to Oligocene of Alabama, U.S.A. (Edwards, 1977); Oligocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Lower and Middle Eocene of the Paris Basin, France (Chateauneuf and Gruas-Cavegnetto, 1978); Lower Eocene of central Switzerland (Jan du Chene, 1978); Eocene of Labrador and the North Sea (Ioakim, 1979); Lower and Middle Eocene of the Rockall Plateau (Costa and Downie, 1979); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Eocene and Lower Oligocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984); Composite range based on worldwide occurrences--Lower Eocene to Lower Oligocene (Helby et al., 1984).

Genus *Lejeunecysta* (Artzner and Dorhofer 1978)
Bujak 1980

Lejeunecysta? sp. A

Pl. 25, figs. 11-12

Comments: Two poorly preserved specimens of *Lejeunecysta?* have been recovered from the Miocene strata of the core. The paracingulum and parasulcus are delineated by folds. No endocyst was observed. A short, blunt apical horn and two short, equally developed antapical horns are present. Paratabulation is lacking and the archeopyle position cannot be determined with certainty (precingular or intercalary?). The cysts generally resemble *Lejeunecysta hyalina*

(Gerlach, 1961, p. 169, pl. 26, figs. 10-11) Artzner and Dorhofer 1978.

Dimensions: Observed range (2 specimens measured): overall length 66-69um and width 68-70um.

Stratigraphic occurrence: Miocene strata: Extremely rare.

Genus *Lentinia* Bujak 1980

Lentinia ruginosa n. sp.

Pl. 23, figs. 9-12

Derivation of species name: Latin, *ruginosus*, wrinkled, folded--in reference to the finely folded and wrinkled periphragm.

Description: Cyst peridinioid, with relatively long, bluntly-pointed apical horn, and two sharply-pointed antapical horns, of which the right is the longer. Cyst wall bi-layered; coni arising from periphragm arranged in clusters within actual paraplate boundaries (not discernible), indicating paratabulation of 4', 3a, 7", ?c, 5"', Op, 2"". Archeopyle intercalary (Type I/I), large, hexagonal; occupies much of dorsal pericyst above operculum. Simple, free operculum;

corresponds to paraplate 2a. Paraplates 1a and 3a considerably more narrow than 2a. Paracingulum and parasulcus outlined by coni. Paracingulum equatorial; ends separated transversely up to about one and one-half paracingulum widths. Parasulcus broad posteriorly and narrows somewhat toward paracingulum. Concavo-convex thickening (position of original flagellar pore) located on right side of parasulcus directly below paracingulum.

Endophragm up to 1um thick, externally levigate, closely appressed to periphragm except in apical and antapical horns. Periphragm up to 0.5um thick, bearing numerous coni up to 1um high distributed in fields within actual paraplate boundaries; many coni are aligned along the characteristic fine longitudinal folds and wrinkles of the periphragm. Apical paraplate 1' relatively large, nearly diamond-shaped. Center anterior intercalary paraplate 2a forms large hexagonal operculum. Precingular paraplates 2" through 6" are four-sided, and 1" and 7" are three-sided. Individual cingular paraplates not apparent. Postcingular paraplates 2"', 3"', and 4"' are four-sided, and 1"' and 5"' are three-sided. Antapical paraplates 1"" and 2"" located on antapical horns.

Dimensions: Holotype L X W: 104um X 44um; apical horn length 24um; antapical horn lengths up to 35um. Observed range (15 specimens measured): pericyst length 80-107um and width 31-45um; endocyst length 38-48um and width 29-43um; apical horn length 18-29um; antapical horn lengths 16-35um.

Discussion and comparison with similar species: Distinguishing characteristics include a bluntly-pointed apical horn, two sharply-pointed antapical horns, paratabulation expressed by fields of coni (high magnification required to observe paraplates on specimens with minute coni), and fine longitudinal folds and wrinkles. A large hexagonal archeopyle occupies most of the dorsal pericyst above the paracingulum; this results in relatively narrow 1a and 3a paraplates.

Lentinia ruginosa is similar to *Deflandrea* sp. B of Drugg 1967 (p. 19, pl. 2, fig. 10) which can likely be accomodated by the new species. *L. ruginosa*, however, bears a shorter apical horn which tapers to a blunter tip, longer antapical horns of unequal lengths, and a definite paracingulum and parasulcus on all specimens.

The new species also superficially resembles *Ceratiopsis diebelii* (Alberti 1959, p. 99, pl. 9, figs. 18-21) Vozzhennikova 1967, but bears significantly shorter apical and antapical horns.

Lentinia ruginosa differs from *L. spinigera* (n. sp., this study) by being more narrow and elongate, and bearing small coni and longitudinal wrinkles and folds. Both have the characteristically large hexagonal archeopyle.

Holotype: Pl. 23, figs. 9-11; VPISUPL Sample 315, Slide AO-34, Coords. R20.2;+6.5.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare.

Lentinia spinigera n. sp.

Pl. 23, figs. 13-16

Derivation of species name: Latin, *spinigerum*, spine-bearing--in reference to the numerous spines on the pericyst.

Description: Cyst peridinioid, with relatively long bluntly-pointed apical horn and two sharply-pointed antapical horns, of which the right is slightly longer. Cyst wall bi-layered; spines arising from periphragm arranged in clusters within actual paraplate boundaries (not discernible), indicating paratabulation of 4', 3a, 7", ?c, 5"', Op, 2"". Archeopyle intercalary (Type I/I), large, hexagonal; occupies much of dorsal pericyst above paracingulum. Simple, free operculum; corresponds to paraplate 2a. Paraplates 1a and 3a appreciably more narrow than 2a. Paracingulum and parasulcus outlined by spines. Paracingulum slightly levorotatory; ends separated vertically up to about one-half paracingulum width and transversely up to about two and one-half paracingulum widths. Parasulcus broad posteriorly and narrows slightly toward paracingulum. Concavo-convex thickening (position of orignial flagellar pore) located on right side of parasulcus directly beneath paracingulum.

Endophragm up to 1um thick, externally levigate, closely appressed to periphragm except in apical and antapical horns. Periphragm up to 0.5um thick, bearing numerous acuminate spines up to 3um high distributed in fields within actual paraplate boundaries. Apical paraplate 1' relatively large, nearly diamond-shaped. Center anterior intercalary paraplate 2a forms large hexagonal operculum. Precingular paraplates 2" through 6" are four-sided, and 1" and 7" are three-sided. Individual cingular paraplates not discernible. Postcingular paraplates 2"', 3"', and 4"' are four-sided, and 1"' and 5"' are three-sided. Antapical paraplates 1"" and 2"" are present on antapical horns.

Dimensions: Holotype: L X W: 108um X 60um; apical horn length 14um; antapical horn lengths up to 20um. Observed range (15 specimens measured): pericyst length 60-99um and width 48-65um; endocyst length 40-62um and width 40-52um; apical horn length 10-20um; antapical horn lengths 13-21um.

Discussion and comparison with similar species: Diagnostic features include the long bluntly-pointed apical horn and sharply-pointed antapical horns, paratabulation expressed as fields of spines, and a strongly developed paracingulum. A large hexagonal archeopyle occupies most of the dorsal pericyst above the paracingulum, resulting in relatively narrow 1a and 3a paraplates.

Lentinia spinigera most closely resembles *L. serrata* Bujak 1980 (p. 71-72, pl. 18, figs. 7-12, text-figs. 18-19), and may ultimately be shown to be conspecific. It is erected as a new species in this study because of its: (1) considerably larger size (pericyst length 60-99um and width 48-65um vs. length 42-63um and width 32-55um; apical horn length 10-20um vs. 3-7um; antapical horn lengths 13-21um vs. 4-12um); (2) wider range of variability of pericyst shapes; and (3) older stratigraphic range (Upper Paleocene to Lower Eocene of *L. spinigera* vs. Upper Eocene only of *L. serrata*). *Lentinia spinigera* is likely an evolutionary forerunner of the smaller British forms of *L. serrata*.

Lentinia spinigera is differentiated from *Spinidinium sagittulum* (Drugg 1970, p. 809-810, figs. 1 A-C) Lentin and Williams 1976 by having usually concave epicystal sides and generally shorter spines.

The new species resembles *Deflandrea denticulata* Alberti 1959 (p. 102-103, text-fig. 1), but bears definite spines as opposed to the fine "teeth" and bristle-like extensions on the apical and antapical horns of the latter.

Lentinia spinigera is appreciably larger than the morphologically similar *L. wetzelii* (Morgenroth 1966, p. 9, pl. 1, figs. 4-5) Bujak 1980.

Lentinia spinigera is typically broader and more robust than *L. ruginosa* (n. sp., this study), and does not bear longitudinal folds and wrinkles as does the latter.

Holotype: Pl. 23, figs. 13-15; VPISUPL Sample 313, Slide AO-28, Coords. R20.2;+6.5.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare.

Genus *Palaeocystodinium* Alberti 1961

Palaeocystodinium golzowense Alberti 1961

Pl. 25, figs. 13-14

1955. *Ceratium* cf. *fusus incerta* Deflandre and Cookson, p. 293, pl. 8, fig. 1.

1961. *Palaeocystodinium golzowense* Alberti, p. 20, pl. 7, figs. 10-12, pl. 12, fig. 16.

Comments: Oak Grove core specimens are similar to the German Oligocene specimens described by Alberti (1961). The length range for the Virginia specimens (187-241um), however, falls above the range noted for the German forms (125-180um). Apical and antapical horns, approximately equal in length, measure from two-thirds to the total endocyst length. No indication of paratabulation is evident. Position of the archeopyle suggests that it is intercalary (Type I/I); the periarcheopyle is larger than the endoarcheopyle. A bi-layered wall is composed of an endophragm up to 1um thick and a periphragm up to 0.5um thick, each externally levigate.

Dimensions: Observed range (20 specimens measured): pericyst length 187-241um and width 23-40um; endocyst length 66-103um and width 22-38um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare; Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Paleocene and Lower Eocene of Australia (Deflandre and Cookson, 1955); Upper Eocene to Upper Oligocene of Germany (Alberti, 1961); Upper Oligocene of Germany (Brosius, 1962); Paleocene of South Dakota, U.S.A. (Stanley, 1965); Lower Eocene of Belgium (DeConinck, 1969, 1973, 1976a); Paleocene of Virginia and Maryland, U.S.A. (McLean, 1971); Oligocene of Germany (Benedek, 1972); Maastrichtian to Paleocene? of Gabon, W. Africa (Malloy, 1972); Paleocene of Virginia, U.S.A. (Witmer, 1975); Oligocene of the Blake Plateau, offshore South Carolina, U.S.A.

(Stover, 1977); Lower Eocene of southern Netherlands (DeConinck, 1977); Middle Eocene to Lower Oligocene of Alabama, U.S.A. (Edwards, 1977); Upper Paleocene and Lower Eocene of southern England (Denison, 1977); Upper Paleocene to Miocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Paleocene and Lower Eocene of Labrador and Maastrichtian of the North Sea (Ioakim, 1979); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Upper Paleocene and Lower Eocene of eastern Netherlands (Herngreen, 1984); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984).

Genus *Palaeoperidinium* (Deflandre 1934) Sarjeant 1967

Palaeoperidinium pyrophorum (Ehrenberg 1838) Sarjeant 1967

Pl. 26, figs. 6-10

1838. *Peridinium? (Glenodinium?) pyrophorum* Ehrenberg, p. 110, pl. 1, figs. 2, 4.

1854. *Peridinium pyrophorum* Ehrenberg, pl. 37, figs. B1-2.

1934. *Palaeoperidinium pyrophorum* (Ehrenberg 1838) Deflandre, p. 967, text-fig. 1.

1936. *Peridinium conicum* (Gran) Ostenfeld and Schmidt in Deflandre, p. 57, text-fig. 96.

1936. *Palaeoperidinium pyrophorum* (Ehrenberg 1838) Deflandre in Deflandre, p. 175.

1938. *Peridinium pyrophorum* (Ehrenberg 1838) Lejune-Carpentier, p. 1-9, figs. 1-10.

1952. *Peridinium pyrophorum* (Ehrenberg 1838) Lejune-Carpentier in W. Wetzel, p. 407-408, pl. A, fig. 10.

1967. *Palaeoperidinium pyrophorum* (Ehrenberg 1838) Sarjeant, p. 246-247, text-fig. 1-6.

Comments: Lower Paleocene specimens from the Oak Grove core (length 144-170um; width 120-152um) are considerably larger than Ehrenberg's type specimens (length 100-138um; width 69-88um) redescribed by Lejune-Carpentier (1938). No endocyst was observed; if one is present, it is closely appressed to the pericyst. Paraplates, ornamented by a "microreticulate" pattern of polygonal thickenings, are separated by transversely striate pandasutural bands up to 10um wide, indicating a paratabulation of 4', 3a, 7", ?c, 5"', 0p, 2"". The archeopyle is problematical. Sarjeant (1967) considers the cyst to display an epicystal archeopyle, as evidenced by breaks often occurring immediately anterior to the paracingulum. Although most study specimens show no definite archeopyle, a few were observed to exhibit an apparent transapical archeopyle (Type $\overline{\text{AIP}}$), involving paraplates 3', 1a-3a, 3"-5". The compound operculum apparently remains attached along the paracingulum, flipping back into place after excystment in most cases. Gocht and Netzel (1976) have illustrated specimens (see their Figs. 30a-b, 31a-b) exhibiting the type of archeopyle discussed above. Evitt (1975) has confirmed the following species to possess transapical archeopyles: *P. basilium* (Drugg 1967) Drugg 1970; *P. hansonianum* (Lentin and Williams 1973) Evitt 1975; *P. eurypylum* (Manum and Cookson 1964) Evitt 1975. The author concurs with Evitt (1975) that *P. basilium* and *P. conicum* are indeed junior synonyms of *P. pyrophorum*.

Dimensions: Observed range (20 specimens measured): pericyst length 144-170um and width 120-152um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Sparse.

Previously reported occurrences: Senonian of Germany (Ehrenberg, 1838, 1854; Lejune-Carpentier, 1938, Sarjeant, 1967); Senonian and Danian of Baltic region, Denmark (O. Wetzel, 1933); Senonian of France (Deflandre, 1934, 1935, 1936); Danian of Germany (W. Wetzel, 1952, 1955); Upper Maastrichtian and Lower Danian of California, U.S.A. (Drugg, 1967); Upper Maastrichtian and Lower Danian of Denmark (Wilson, 1971); Campanian and Maastrichtian of N.W.T., Canada (McIntyre, 1974); Upper Danian of southern Sweden (DeConinck, 1975); Maastrichtian and Danian of Maryland, U.S.A. (Whitney, 1976m 1984);

Maastrichtian and Danian of Denmark (Hansen, 1977); Maastrichtian and Danian of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Danian of Labrador and the North Sea (Ioakim, 1979); Lower Paleocene of Alabama and Georgia, U.S.A. (Edwards, 1980); Lower Paleocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Genus *Phelodinium* Stover and Evitt 1978

Phelodinium magnificum (Stanley 1965) Stover and Evitt 1978

Pl. 24, figs. 11-12

1965. *Deflandrea magnifica* Stanley, p. 218-219, pl. 20, figs. 1-6.
1978. *Phelodinium magnificum* (Stanley 1965) Stover and Evitt, p. 117-118.

Comments: Paleocene specimens of this study bear longer apical and antapical horns than the South Dakota specimens of *Phelodinium magnificum* described by Stanley (1965). The cyst exhibits a large, hexagonal, intercalary archeopyle (Type I/I). Paratabulation is not apparent. The endophragm and periphragm are each about 0.5um thick, the latter finely, longitudinally folded and wrinkled, and ornamented with sparse minute coni.

Dimensions: Observed range (10 specimens measured): pericyst length 93-125um and width 77-100um; endocyst width 79-90um and width 71-85um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Previously reported occurrences: Paleocene of South Dakota, U.S.A. (Stanley, 1965); Maastrichtian and Danian of California, U.S.A. (Drugg, 1967); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Campanian and Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980); Maastrichtian and Danian of Maryland, U.S.A. (Benson, 1976); Maastrichtian and Lower Paleocene of eastern Canada (Williams and Bujak, 1977); Danian of the North Sea (Ioakim, 1979); Campanian and Maastrichtian of Mississippi and Alabama, U.S.A. (Rounds, 1982); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984); Paleocene of Virginia and Maryland, U.S.A. (Edwards, 1984).

Genus *Phthanoperidinium* Drugg and Loeblich 1967

Phthanoperidinium echinatum Eaton 1976

Pl. 26, figs. 13-16

1976. *Phthanoperidinium echinatum* Eaton, p. 298-299, pl. 17, figs. 8, 9, 12; text-fig. 23-B

Comments: Oak Grove core forms are somewhat larger than the British Eocene forms described by Eaton (1976). Low, occasionally reticulate, parasutural folds, along which are aligned numerous hair-like projections (up to 3um long) with bulbous tips, outline a paratabulation of 4', 3a, 7", ?c, 5"', 0p, 2"". Accessory archeopyle parasutures typically extend down from the intercalary archeopyle (Type I with loss of paraplate 2a) on either side of paraplate 4"); on some specimens paraplates 2a and 4" may be missing. Both the short, blunt apical horn and the left antapical horn are up to 4um long; the right antapical horn is not developed. The endophragm and periphragm are each about 0.5um thick, externally levigate.

Dimensions: Observed range (12 specimens measured): pericyst length 44-59um and width 35-45um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Eocene of England (Eaton, 1976); Eocene of Labrador and the North Sea (Ioakim, 1979); Eocene of the Rockall Plateau (Brown and Downie, 1983).

Phthanoperidinium cf. *P. tritonium* Eaton 1976

Pl. 26, figs. 17-20

Comments: A single specimen recovered from the Eocene strata of the Oak Grove core superficially resembles the holotype of *Phthanoperidinium tritonium* Eaton 1976 (pl. 17, fig. 3). The periphragm of *P. tritonium* is levigate, whereas the study specimen is reticulate. Spines up to 6um long are located along the parasutural crests. Paratabulation is 4?', 3a, 7", ?c, 5"', 0p, 2"". The archeopyle is intercalary (Type I), formed by the displacement of paraplate 2a. Paraplate 4" remains attached only along its paracingular boundary.

Dimensions: Observed range (1 specimen measured): pericyst length 48um and width 40um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Genus *Senagalinium* (Jain and Millepied 1973)
Stover and Evitt 1978

Senagalinium? asymmetricum (Wilson 1967)
Stover and Evitt 1978

Pl. 23, figs. 1-2

1967. *Deflandrea asymmetrica* Wilson, p. 62-63, figs. 17-21.
1978. *Senagalinium? asymmetricum* (Wilson 1967) Stover and Evitt, p. 123.

Comments: Cysts of *Senagalinium? aysmmetricum* appear to be closely related to those of *Spinidinium macmurdoense*. Both bear a greatly reduced right antapical horn (note that Wilson (1967a) erroneously states that the left is reduced), and a blunt, rectangularly shaped apical horn, and exhibit intercalary archeopyles (Type Ia/I) with the operculum of the periphragm (paraplate 2a) attached along its posterior edge. This species displays no apparent paratabulation. The periphragm bears some scattered grana. Antarctic specimens of Wilson (1967a) are larger than the Oak Grove core forms.

Dimensions: Observed range (5 specimens measured): pericyst length 59-70um and width 44-50um; endocyst length 48-56um and width 43-49um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Erratics (Paleocene-Oligocene?) of Antarctica (Wilson, 1967a); Eocene of Spain (Archangelsky, 1969); Middle Paleocene to Upper Eocene of New Zealand and Tasmania (Haskell and Wilson, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Campanian and Maastrichtian of New Jersey, U.S.A. (May, 1976, 1980).

Senagalinium? dilwynense (Cookson and Eisenack 1965)
Stover and Evitt 1978

Pl. 26, figs. 1-2

1965. *Deflandrea dilwynensis* Cookson and Eisenack, p. 141, pl. 18, figs. 6-9.

1978. *Senagalinium? dilwynense* (Cookson and Eisenack 1965) Stover and Evitt, p. 123.

Comments: Oak Grove core specimens are comparable in size and morphology to the Australian Paleocene specimens described by Cookson and Eisenack (1965c). This species is especially abundant in the

Marlboro Clay where dinoflagellate species diversity (richness) is low. Of the two antapical horns, the left is the longer. The cyst, displaying an intercalary archeopyle (Type I/I), shows no discernible paratabulation. Endocyst shapes range from nearly spheroidal to rounded-pentagonal, with a relatively large apical pericoel. Scattered sparse grana typcially ornament the finely, longitudinally folded periphragm. The endophragm and periphragm are each about 0.5um thick.

Dimensions Observed range (25 specimens measured): pericyst length 52-70um and width 46-58um; endocyst length 40-50um and width 44-55um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Marlboro Clay: Extremely rare to Abundant; Eocene strata: Extremely rare to Abundant.

Previously reported occurrences: Paleocene of Australia (Cookson and Eisenack, 1965c); Paleocene of Virginia, U.S.A. (McLean, 1971); Lower Eocene of Virginia, U.S.A. (Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Danian of Maryland, U.S.A. (Benson, 1976; Whitney, 1976, 1984); Upper Paleocene and Lower Eocene of eastern Netherlands (Herngreen, 1984).

Senagalinium obscurum (Drugg 1967) Stover and Evitt 1978

Pl. 26, figs. 3-5

1967\. *Deflandrea obscura* Drugg, p. 17, pl. 2, figs. 8-9, pl. 9, fig. 5.

1978\. *Senagalinium obscurum* (Drugg 1967) Stover and Evitt, p. 123.

Comments: Paleocene and Eocene specimens of the Oak Grove core are slightly larger than the California Maastrichtian/Danian specimens described by Drugg (1967). Although paratabulation is typically not evident on the cysts recovered in this study, faint linear thinnings of the periphragm were observed (using interference contrast) on the dorsal epicyst of a few specimens. The cyst displays an intercalary archeopyle (Type I/I). Considerable intraspecific variability was noted, especially in general pericyst shape and ornamentation. Forms range from a nearly pentagonal shape with relatively straight sides to a more nearly rounded shape with slightly convex sides. Some specimens bear only scattered grana, whereas others are ornamented with a denser distribution (not arranged in paraplates). Of the two unequally developed anatapical horns, the left is always longer. The cyst wall is composed of a thin endophragm and periphragm, each up to 0.5um thick, closely appressed.

Dimensions: Observed range (25 specimens measured): pericyst length 58-72um and width 48-63um; endocyst length 43-58um and width 47-62um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare.

Previously reported occurrences: Maastrichtian and Danian of California, U.S.A. (Drugg, 1967); Paleocene of Virginia and Maryland, U.S.A. (McLean, 1971); Paleocene of Virginia, U.S.A. (Witmer, 1975); Campanian and Maastrichtian of Maryland and Delaware, U.S.A. (Whitney, 1976); Lower Eocene of Belgium (DeConinck, 1976a).

Spinidinium (Cookson and Eisenack 1962)
Lentin and Williams 1976

Spinidinium cf. *S. essoi* Cookson and Eisenack 1967

Pl. 26, figs. 11-12

Comments: Cysts recovered in the Paleocene strata of this study are smaller but otherwise appear generally similar to the Paleocene forms of *Spinidinium essoi* from Tasmania described by Cookson and Eisenack (1967a); unfortunately all are crumbled and poorly preserved. The endocyst does not completely fill the pericyst, resulting in a relatively large pericoel. Capitate spines up to 4um long appear to be roughly linearly distributed delineating paraplates, but because of the state of preservation paratabulation could not be determined. The short apical horn is flat-tipped; the acuminate left antapical horn is longer than the right. No archeopyle was observed.

Dimensions: Observed range (4 specimens measured): pericyst length 68-80um and width 60-66um; endocyst length 46-54um and width 52-56um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Spinidinium macmurdoense (Wilson 1967) Lentin and Williams 1976

Pl. 25, figs. 1-8

1967. *Deflandrea macmurdoense* Wilson, p. 60-62, figs. 2a, 11-16, 22.

1976. *Spinidinium macmurdoense* (Wilson 1967) Lentin and Williams, p. 64.

Comments: *Spinidinium macmurdoense* is abundant in the middle portion of the Lower Eocene strata of the Oak Grove core. Observed specimens are generally smaller than the Antarctic Lower Tertiary forms of Wilson (1967a). Population variability is expressed by pericyst shape, as well as length, termination, and placement of spines. In optical cross-section, the sides of the hypocyst and endocyst may appear nearly straight or slightly concave or convex. Spines, typically aligned along ridges and coalesced proximally, range from 1um to 6um in length. Most forms bear spines that are distally finely capitate; some aberrant types have spines with slightly flared tips. Many of the observed cysts bear only a single row of spines along the edges of the operculum; Wilson's (1967a) forms reveal a row on the lateral sides of the operculum as well as on the adjacent anterior intercalary paraplates. In addition, many of the cysts in this study exhibit a row of spines along the base of the posteriorly attached operculum, separating the 2a from the 3" paraplate; these spines are apparently lacking on the Antarctic forms. The archeopyle is therefore considered intercalary (Type Ia/I). Paraplates are most clearly defined on the dorsal epicyst; on the dorsal hypocyst and ventral side, paratabulation is vague. The parasulcus is extremely broad. The left antapical horn is considerably longer than the right.

Dimensions: Observed range (30 specimens measured): pericyst length 58-74um and width 40-52um; endocyst length 40-54um and width 36-48um.

Stratigraphic occurrence: Eocene strata: Abundant.

Previously reported occurrences: Eocene? of Antarctica (Wilson, 1967a); Eocene of Spain (Archangelsky, 1969); Lower Paleocene of Spain

(Heisecke, 1970); Upper Eocene of Tasmania and New Zealand (Haskell and Wilson, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979); Lower Eocene of Labrador (Ioakim, 1979).

Spinidinium paratabulatum n. sp.

Pl. 24, figs. 13-16

Derivation of species name: Greek, *para*, near, beside + Latin, *tabulata*, tabulated--in reference to the paratabulated cyst.

Description: Cyst peridinioid, with blunt apical horn and long, sharply pointed left antapical horn; right antapical horn weakly developed or absent. Cyst wall bi-layered; spines arising from periphragm arranged in double rows, outlining a paratabulation of 4', 3a, 7", ?c, 5"', 0p, 2"". Archeopyle intercalary (Type Ia/I) with simple, posteriorly attached operculum; corresponds to paraplate 2a. Paracingulum slightly levorotatory; ends separated vertically up to one-half paracingulum width and transversely up to two paracingulum widths. Parasulcus, relatively long and broad, deeply invaginated, lacks ornamentation.

Endophragm about 0.5um thick, externally levigate. Periphragm about 0.5um thick, externally levigate to scabrate; wall layers appressed except within horns. Spines up to 3um long, with bulbous tips, generally aligned on both sides of parasutures; may be randomly distributed on some paraplates.

Dimensions: Holotype L X W: 60um X 40um; apical horn 9um; antapical horn 8um long. Observed range (15 specimens measured): pericyst length 48-60um and width 36-44um; endocyst length 39-45um and width 32-40um; apical horn lengths up to 10um; antapical horn lenghts up to 9um.

Discussion and comparison with similar species: *Spinidinium paratabulatum* is characterized by its relatively small size, a paratabulation expressed by double rows of spines, and an operculum which often remains attached along its posterior margin.

The new species most closely resembles *Spinidinium macmurdoense* (Wilson 1967a, p. 60-62, figs. 2a, 11-16, 22) Lentin and Williams 1976, but differs by: (1) its generally smaller size with shorter apical and antapical horns; (2) bearing shorter spines (not usually connected by any sort of crest); and (3) displaying double rows of spines with a more pronounced paratabulation on both the dorsal and ventral surfaces.

Spinidinium paratabulatum superficially resembles the following *Spinidinium* species: *S. echinoideum* (Cookson and Eisenack 1960, p. 2, pl. 1, figs. 5-6) Lentin and Williams 1976; *S. essoi* Cookson and Eisenack 1967a (p. 135, pl. 19, figs. 1-8); *S. lanterna* Cookson and Eisenack 1970 (p. 144-145, pl. 12, figs. 1-3); *S. styliniferum* Cookson and Eisenack 1962 (p. 489, pl. 1, figs. 1-5), and *S. vestitum* Brideaux (p. 99-101, pl. 29, figs. 99-103). The new species, however, exhibits a much more obvious paratabulation pattern than the others.

Spinidinium paratabulatum is different from *Lentinia spinigera* (n. sp., this study) by bearing double rows of spines along the parasutures; the latter displays fields of spines.

Expression of paratabulation differentiates *S. paratabulatum* from similar appearing species of *Deflandrea*, for example, *D. denticulata* Alberti 1959 (p. 102-103, text-fig. 1) and *D. spinulosa* Alberti 1959 (p. 95, pl. 8, figs. 8-9); the former is distinctly paratabulate, whereas the others reveal no apparent paratabulation.

Holotype: Pl. 24, figs. 13-16; VPISUPL Sample 337, Slide AO-84, Coords. R11.4;+12.4.

Stratigraphic occurrence: Eocene strata: Extremely rare to Sparse.

Genus *Wetzeliella* (Eisenack 1938) Lentin and Williams 1976

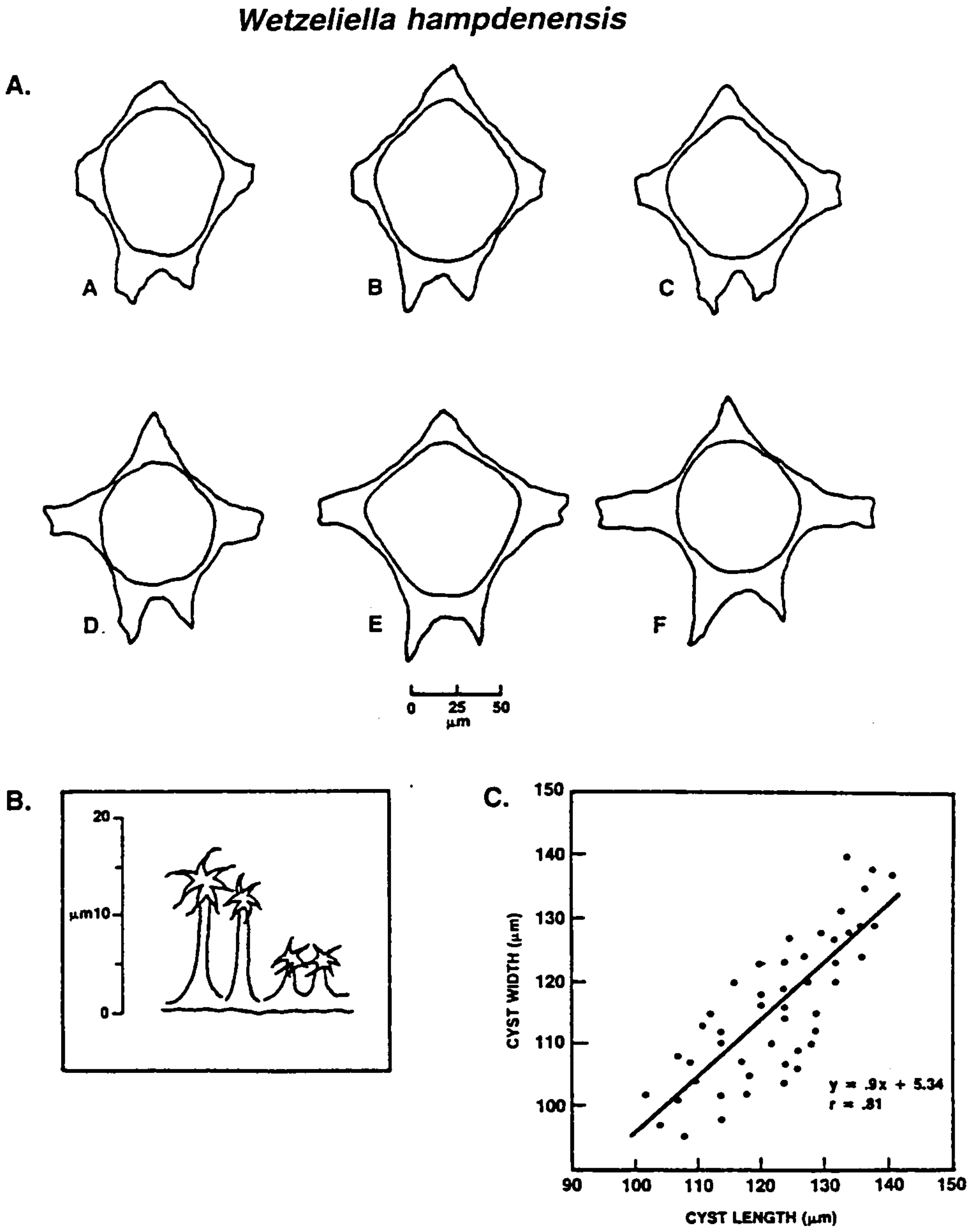
Wetzeliella hampdenensis Wilson 1967

Pl. 27, figs. 5-10

1967. *Wetzeliella hampdenensis* Wilson, p. 480-481, figs. 17, 19.

Comments: The forms in this study referred to *Wetzeliella hampdenensis* show a greater degree of intraspecific variability (see Text-fig. 22) than do the New Zealand Middle Eocene cysts of Wilson (1967c), especially in process type and pericyst shape. The cyst bears numerous processes up to 18um long, except on the horns where they are considerably shorter; distally they are aculeate (aculeae up to 4um long). Intratabular fields and simulate complexes of processes vaguely reflect a paratabulation of 4', 3a, 7", ?c, 5"', 0p, 2"". Excystment is by an intercalary archeopyle (Type I/I), with the loss of paraplate 2a. The endophragm is about 1um thick and the periphragm is about 0.5um thick; each is levigate to microgranulate. Endocyst shape varies from spheroidal or ellipsoidal to generally pentagonal, with the extent of pericoel varying from specimen to specimen. The left antapical horn is always longer than the right; Wilson (1967c) incorrectly states the opposite.

The German Eocene forms designated *Wetzeliella (W.)* sp. 1 by Gocht (1969) can likely be accomodated by *W. hampdenensis*. A species



Text-fig. 22. A. Scale drawings of a series of morphologically variable cysts (processes omitted) of *Wetzeliella hampdenensis* from a single sample (no. 328) in the Nanjemoy Formation. B. Sketch showing various process types. C. Cyst length-width scatter diagram (50 specimens).

similar to *W. hampdenensis* is *W. (W.) articulata* subsp. *conopia* (Williams and Downie, 1966b, p. 184, pl. 18, fig. 5) Lentin and Williams 1973, both bearing the distinctive long aculeae on the process tips; they may prove to be synonymous.

Dimensions: Observed range (50 specimens measured): pericyst length 94-144um and width 92-126um; endocyst length 64-102um and width 64-90um; process lengths up to 18um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Abundant.

Previously reported occurrences: Middle Eocene of New Zealand (Wilson, 1967c); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1984); Lower and Middle Eocene of southern England (Islam, 1983a,c); Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Wetzeliella cf. *W. irtyschensis* Alberti 1961

Pl. 27, figs. 11-12

Comments: A few specimens comparable to *Wetzeliella irtyschensis* were recovered from the Oak Grove core. Cysts of this study are generally smaller and bear shorter processes than the Lower Oligocene forms from Kasachstan, U.S.S.R. studied by Alberti (1961). The bi-layered cyst, composed of a very thin endophragm and periphragm, each less than 0.5um thick, is ornamented with short processes up to 5um long with blunt or aculeate tips. Paratabulation is indeterminate. The archeopyle is intercalary (Type I/I).

Dimensions: Observed range (4 specimens measured): pericyst length 86-96um and width 80-100; endocyst length 65-82um and width 68-84um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Wetzeliella lunaris Gocht 1969

Pl. 27, figs. 13-18

1969. *Wetzeliella lunaris* Gocht, p. 13-15, pl. 10, figs. 1-3;
text-fig. 6.

Comments: *Wetzeliella lunaris* is characterized by a greatly reduced right antapical horn and an endocyst that is not usually appressed to the pericyst. A paratabulation of 4', 3a, 7", ?c, 5"', 0p, 2"" is generally reflected by processes arranged in simulate complexes and intratabular clusters. Processes range up to 16um long and are distally bifid, finely aculeate or capitate; processes on the horns are considerably shorter (2-6um long). On some forms the endocyst is nearly spheroidal, whereas on others it is more tetragonal to pentagonal in shape. The cyst displays an intercalary archeopyle (Type I/I). The endophragm is up to 1um thick, externally scabrate to microgranulate; the periphragm is less than 0.5um thick, externally levigate to scabrate.

Dimensions: Observed range (15 specimens measured): pericyst length 120-160um and width 102-150um; endocyst length 80-98um and width 76-88um; process lengths up to 16um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Sparse.

Previously reported occurrences: Lower Eocene of Germany (Gocht, 1969); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Lower and Middle Eocene of England (Eaton, 1976); Lower Eocene of Labrador and the North Sea (Ioakim, 1979); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Lower and Middle Eocene of eastern Netherlands (Herngreen, 1984).

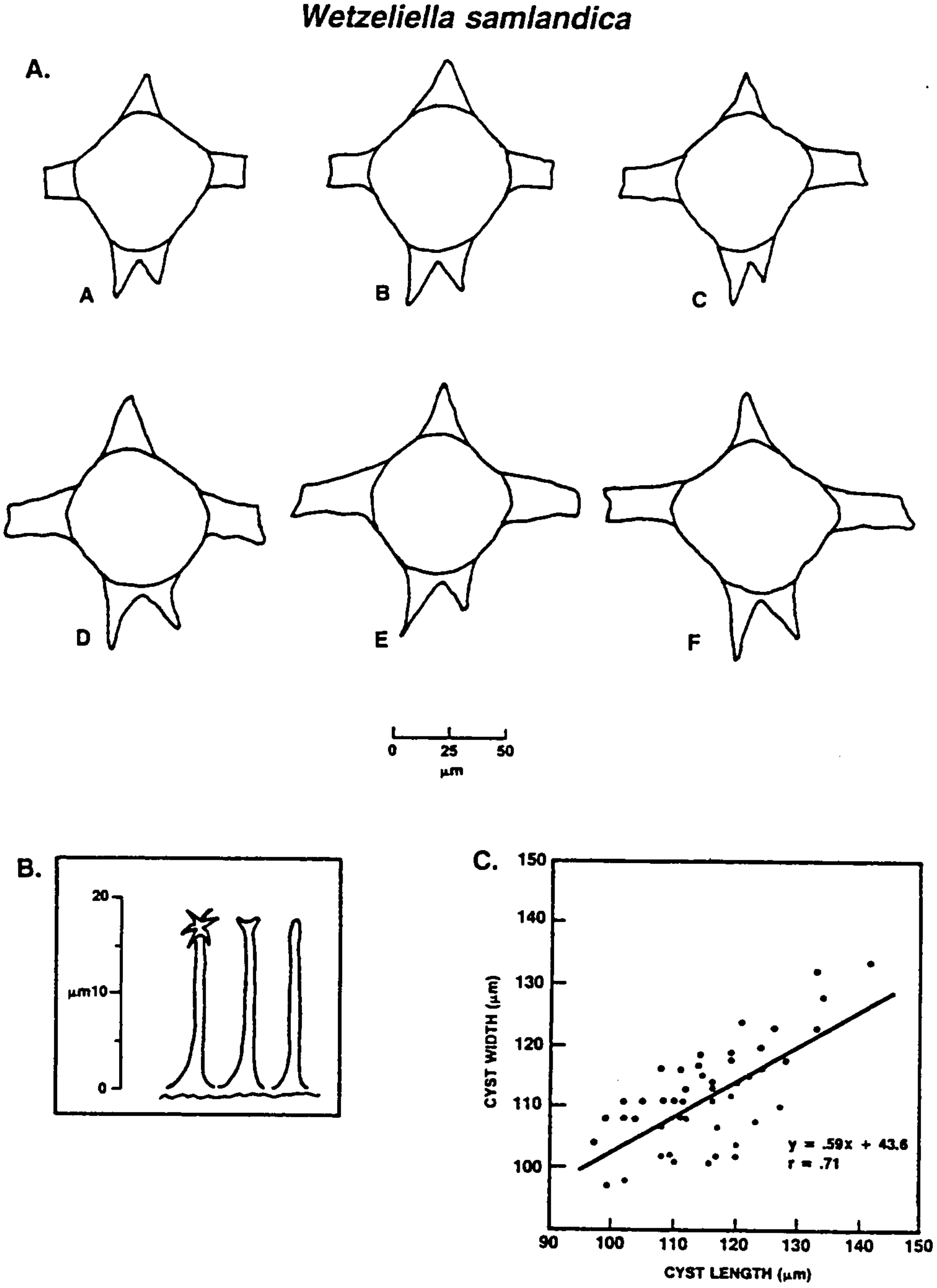
Wetzeliella samlandica Eisenack 1954

Pl. 28, figs. 1-15

Pl. 29, figs. 1-5

1954. *Wetzeliella samlandica* Eisenack, p. 59, pl. 8, figs. 11-12.

Comments: *Wetzeliella samlandica* is particularly abundant in Sample 332 of the Lower Eocene Nanjemoy strata of the Oak Grove core. In a single sample population, the species exhibits a considerable range of variability in horn development (see Text-fig. 23). Some cysts bear a short, weakly developed apical horn, whereas on others it is longer and drawn out. Antapical horns are always strongly developed, and the left is invariably longer. Greatest variability is displayed in the development of the lateral horns. Shape of the endocyst ranges from ellipsoidal to pentagonal, and may partially extend into the lateral horns. A paratabulation of 4', 3a, 7", ?c, 5"', 0p, 2"" is indistinctly indicated by intratabular groups and simulate complexes of processes. Except for the short processes on the horns, this species is characterized by exceptionally long processes (up to 26um long), when compared with other *Wetzeliella* species; distally they are predominantly finely aculeate and bifid, more rarely evexate. Loss of paraplate 2a results in an intercalary archeopyle (Type I/I). The endophragm is microgranulate to granulate, about 1um thick; the periphragm is levigate to scabrate, about 0.5um thick.



Text-fig. 23. A. Scale drawings of a series of morphologically variable cysts (processes omitted) of *Wetzeliella samlandica* from a single sample (no. 332) in the Nanjemoy Formation. B. Sketch showing various process types. C. Cyst length-width scatter diagram (50 specimens).

Dimensions: Observed range (50 specimens measured): pericyst length 97-142um and width 96-134um; endocyst length 61-80um and width 60-80um; process lengths up to 26um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Abundant.

Previously reported occurrences: Eocene of Germany (O. Wetzel, 1935; Klumpp, 1953; Morgenroth, 1966a; Gocht, 1969); Lower Oligocene of Germany (Eisenack, 1954); Lower Oligocene of Siberia, U.S.S.R. (Vozzhennikova, 1967); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984); Lower Eocene of southern Netherlands (DeConinck, 1977); Lower Eocene of Labrador and the North Sea (Ioakim, 1979); Lower and Middle Eocene of southern England (Islam, 1983a).

Wetzeliella varielongituda Williams and Downie 1966

Pl. 30, figs. 6-12

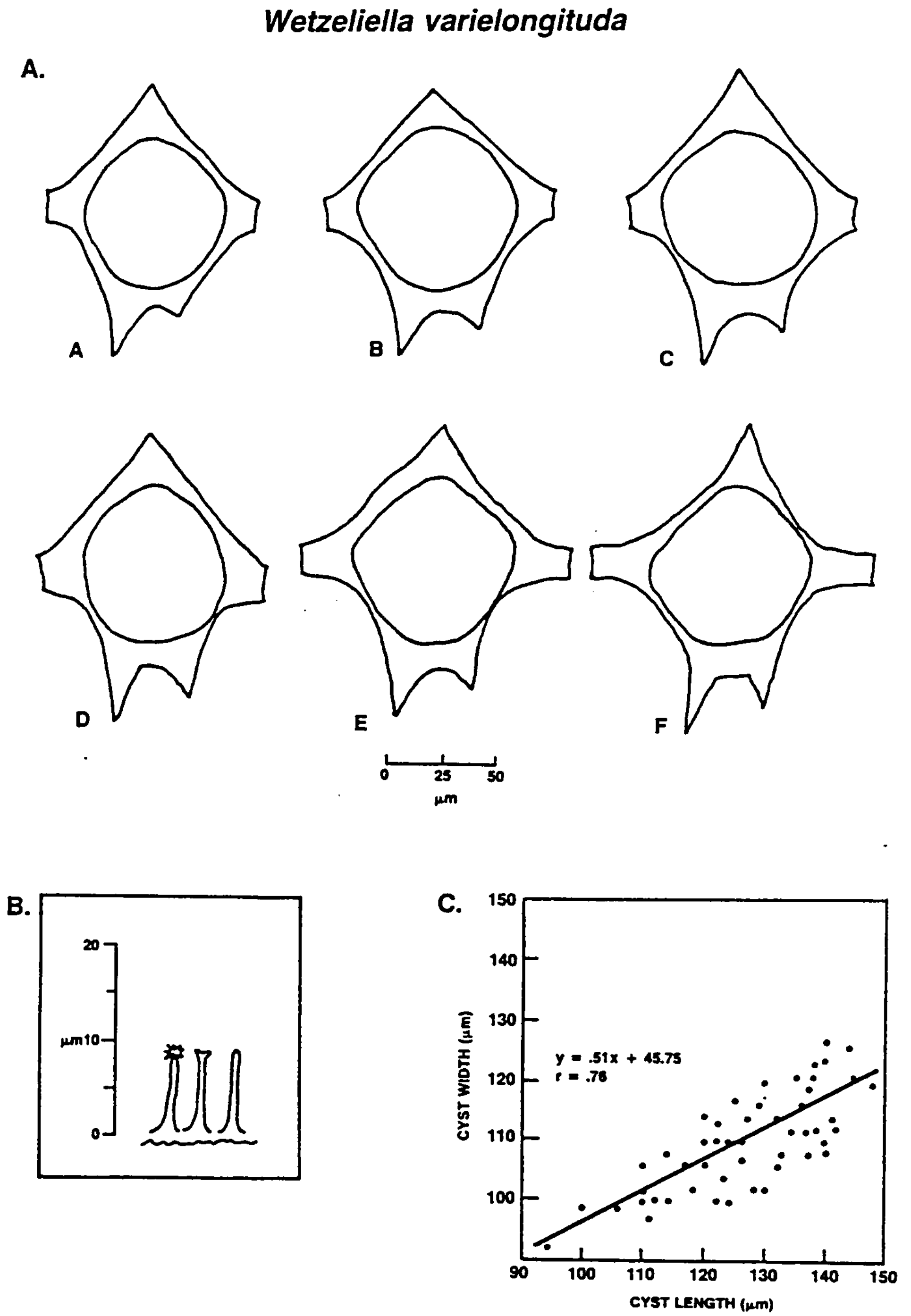
1966. *Wetzeliella varielongituda* Williams and Downie, p. 196-197, pl. 20, figs. 4, 8.

Comments: Forms referred to *Wetzeliella varielongituda* in this study are characterized by a relatively large pericoel, short processes, and a broad apical and often greatly reduced right antapical horn (see

Text-fig. 24). The spheroidally to pentagonally shaped endocyst is almost never in contact with the pericyst in dorso-ventral view. The epicystal sides on many of the cysts are nearly straight or very slightly concave and converge at approximately a right angle to form the distinctively broad apical horn. Lateral horns vary in length, but most are broad and relatively short. Antapical horns are variably fused, creating a large antapical pericoel, with a dominant left and much shorter right antapical horn. Processes range up to 12um long, but most along the ambitus are much shorter (2-8um long); distally they are very finely aculeate or bifid, more rarely evexate or acuminate. Intratabular clusters and simulate complexes of processes suggest a paratabulation of 4', 3a, 7", ?c, 5"', 0p, 2"". Excystment is by an intercalary archeopyle (Type I/I). The endophragm is up to 3um thick, externally granulate, and the periphragm is about 0.5um thick, externally microgranulate.

The Oak Grove core forms closely resemble the series of specimens illustrated by Gocht 1969 (pl. 10, figs. 4-5; text-figs. 13a-e); both studies include some forms with relatively long, drawn out lateral horns. The Eocene forms described by Williams and Downie (1966; see holotpye, pl. 20, fig. 4) and those studied by Vozzhennikova (1967) apparently bear only short lateral horns.

Dimensions: Observed range (50 specimens measured): pericyst length 101-140um and width 95-140um; endocyst length 70-96um and width 68-92um; process lengths 2-12um.



Text-fig. 24. A. Scale drawings of a series of morphologically variable cysts (processes omitted) of *Wetzeliella varielongituda* from a single sample (no. 331) in the Nanjemoy Formation. B Sketch showing various process types. C. Cyst length-width scatter diagram (50 specimens).

Stratigraphic occurrence: Eocene strata: Rare.

Previously reported occurrences: Eocene of England (Williams and Downie, 1966a; Eaton, 1976); Upper Eocene and Lower Oligocene of the U.S.S.R. (Vozzhennikova, 1967); Lower and Middle Eocene of Germany (Gocht, 1969); Lower Eocene of Belgium (DeConinck, 1972, 1976a); Lower Eocene of Maryland, U.S.A. (Goodman, 1984); Eocene of the Grand Banks, Newfoundland (Williams and Brideaux, 1975) and eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Lower and Middle Eocene of the Paris Basin, France (Chateauneuff and Gruas-Cavegnetto, 1978); Lower Eocene (Upper Ilerdian) of Labrador and the North Sea (Ioakim, 1979); Lower Eocene of the Rockall Plateau (Costa and Downie, 1979; Brown and Downie, 1983); Lower Eocene of eastern Netherlands (Herngreen, 1984); Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Wetzeliella sp. A

Pl. 27, figs. 19-20

Comments: Cysts referred to *Wetzeliella* sp. A, restricted to the upper part of the Nanjemoy strata in the core, are characterized by coalesced antapical horns, creating a relatively large antapical pericoel. These forms may be morphological variants of *Wetzeliella* *hampdenensis*; both groups bear processes with similar aculeate tips. A new species is not established at this time for these cysts; a complete description, however, is given below.

Description: Cyst generally pentagonal in dorso-ventral view with well developed apical and lateral horns; dominant left and much reduced right antapical horns coalesced. Cyst wall bi-layered; processes formed of the periphragm, arranged as simulate complexes and intratabular clusters, indicating a paratabulation of 4', 3a, 7", ?c, 5"', 0p, 2"". Archeopyle intercalary (Type I/I) with simple, free operculum; corresponds to paraplate 2a. Paracingulum and parasulcus vaguely reflected. Endocyst may or may not be entirely in contact with pericyst, other than in horns where pericoel is always developed. Endophragm up to 1um thick, externally microgranulate. Periphragm up to 0.5um thick, externally levigate to scabrate. Processes relatively long (up to 17um), hollow, distally aculeate, more rarely bifid.

Dimensions: Observed range (7 specimens measured): pericyst length 128-170um and width 110-140um; endocyst length 66-96um and width 68-86um; process lengths up to 17um.

Stratigraphic occurrence: Eocene strata: Rare.

Previously reported occurrences: Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979, 1984).

Genus *Wilsonidium* Lentin and Williams 1976

Wilsonidium tabulatum (Wilson 1967) Lentin and Williams 1976

Pl. 30, figs. 1-5

1967. *Wetzeliella tabulata* Wilson, p. 473-475, figs. 4-7, 10, 11; text-fig. 2.

1976. *Wilsonidium tabulatum* (Wilson 1967) Lentin and Williams, p. 140.

Comments: Oak Grove core specimens conform in morphology and size to the New Zealand Eocene forms described by Wilson (1967c). This species is especially abundant in Sample 326 of the Lower Eocene strata. Within a population, forms range from those which bear extremely short, spine-like processes (some cysts have very few spines) to those with progressively longer, distally evexate types (up to 10um long). The processes are parasuturally aligned, clearly revealing a paratabulation of 4', 3a, 7", ?c, 5"', 0p, 2"". All horns are well developed. The left antapical horn is always longer (not shorter as Wilson states). The intercalary archeopyle (Type I/I) is formed by loss of paraplate 2a. The bi-layered cyst wall is composed of an endophragm, each about 0.5um thick and externally levigate to scabrate. Endocyst shape varies from spheroidal to strongly pentagonal; the inner body is not appressed to the pericyst.

Dimensions: Observed range (50 specimens measured): pericyst length 110-152um and width 100-132um; endocyst length 60-96um and width 68-94um; process lengths 0.5 - 1.0um.

Stratigraphic occurrence: Paleocene strata: Rare; Eocene strata: Extremely rare to Abundant.

Previously reported occurrences: Upper Eocene of New Zealand (Wilson, 1967c); Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Lower Eocene of Virginia and Maryland, U.S.A. (Edwards et al., 1984).

Family UNCERTAIN

Genus *Ascostomocystis* Drugg and Loeblich 1967

Ascostomocystis hydria Drugg and Loeblich 1967

Pl. 31, fig. 1

1967. *Ascostomocystis hydria* Drugg and Loeblich, p. 187, pl. 3, figs. 13-15; text-fig. 5.

Comments: Most specimens observed resemble the holotype of Drugg and Loeblich (1967). The thin periphragm closely adheres to the ellipsoidal inner body ventrally and dorsally, but extends out a variable distance along the periphery of the cyst. On some forms the pericyst and/or endocyst exhibit a slight transverse indentation at the mid section (possibly a paracingulum). An aperture up to 14um in transdiameter at one end of the cyst may represent an apical archeopyle. The endophragm about 1um thick is levigate to scabrate; the levigate periphragm is less than 0.5um thick.

Dimensions: Observed range (7 specimens measured): pericyst length 71-110um and width 57-85um; endocyst length 60-99um and width 48-76um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Alabama, U.S.A. (Drugg and Loeblich, 1967); Lower Eocene of Virginia, U.S.A. (Edwards et al., 1984).

Genus *Caligodinium* Drugg 1970

Caligodinium amiculum Drugg 1970

Pl. 31, figs. 2-3

1970. *Caligodinium amiculum* Drugg, p. 814-815, figs. 8a-b, figs. 9a-e.

Comments: Paleocene specimens of the present study compare closely with the Danian Alabama forms described by Drugg (1970). The archeopyle is apical (Type $\overline{A}$). Some of the attached opercula appear to be partially broken into three paraplates, similar to what is described for the holotype. Occasionally cysts exhibit apparent accessory archeopyle parasutures. The main body is constructed of a single wall up to 2um thick, externally finely granulate. The porous, filmy covering (kalyptra) adhering to the main body typically contains considerable organic debris.

<u>Dimensions:</u> Observed range (15 specimens measured): overall length (including kalyptra) 80-102um and width 57-71um; main body length 62-80um and width 43-50um.

<u>Stratigraphic occurrence:</u> Paleocene strata: Extremely rare to Rare.

<u>Previously reported occurrences:</u> Danian of Alabama, U.S.A. (Drugg, 1970); Paleocene of Virginia, U.S.A. (Edwards et al., 1984).

Forma A

Pl. 32, figs. 14-16

<u>Comments:</u> These distinctive cysts, possibly belonging the Microdiniaceae, are found only in the lower Paleocene section of the Oak Grove core. Parasutural ridges up to 5um high and 1.5um wide are formed of the endophragm, flare distally, and support a thin ectophragm; on every cyst observed, some of the ridges are very weakly developed or completely missing. Paraplates delineated by the ridges indicate a paratabulation of ?', ?a, 6-7?", 6c, 6"', 1p, 1"". The archeopyle is apical and the operculum ventrally attached: Type $\bar{\mathrm{A}}$a or

Type AIa, depending on the presence of anterior intercalary paraplates. The paracingulum is relatively broad (up to 8um) and just anterior of the equatorial mid-line of the cyst.

Dimensions: Observed range (7 specimens measured): main body length 27-37um and width 25-32um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Previously reported occurrences: Maastrichtian of Maryland, U.S.A. (Whitney, 1976); Maastrichtian and Danian of Maryland, U.S.A. (Benson, 1976).

Forma B

Pl. 34, figs. 3-4

Comments: These levigate, single-walled, nearly spheroidal cysts of unknown affinity are found in the Nanjemoy strata of the core. They superficially resemble the forms designated Forma P by Evitt 1967 (pl. 3, figs. 10-15), which exhibit an intercalary archeopyle (Type 3I) with an operculum divided into three paraplates (1a-3a). Study specimens, however, display archeopyles whose shapes suggest them to be precingular (Type 2P or 3P); the opercula with a thickened rim along the margin bear no parasutures. Most cysts are slightly folded and compressed. Evitt (personal communication) believes these forms do indeed differ from his Upper Cretaceous specimens from Texas and New Jersey, primarily in archeopyle type.

Dimensions: Observed range (25 specimens measured): overall diameter 76-92um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Sparse.

Forma C

Pl. 33, figs. 9-12

Comments: Cysts designated Forma C were recovered from the Nanjemoy strata of the core. Specimens range from those consisting of a spheroidal main body bearing numerous slender, flexuous, acuminate spines (prevalent in Sample 331; see fig. 9) to those with most of the spines torn away, leaving holes in the periphragm (prevalent in Sample 334; see figs. 11 and 12). The former type superficially resembles *Impletosphaeridium whitei* (Deflandre and Courteville 1939) Morgenroth 1966a, whereas the latter is similar to *Eisenackia? scrobiculata* Morgenroth 1966a. Paratabulation is reflected by parasutural thinnings of the periphragm. Some forms suggest the excystment may involve a number of the precingular paraplates or be epicystal (similar to *Lingulodinium machaerophorum* (Deflandre and Cookson 1955) Wall 1967).

Dimensions: Observed range (15 specimens measured): main body diameter 72-90um; processes (when present) up to 19um long.

Stratigraphic occurrence: Eocene strata: Extremely rare to Common.

Forma D

Pl. 35; figs. 9-12

Comments: Densely distributed, short, slender processes arising from the small spheroidal main body are variably interconnected by fine trabeculae resulting in a complexly constructed network. Above this outer network extend numerous, small, tapering processes up to 5um long. Paratabulation is indeterminate. The archeopyle appears to be apical (Type $\overline{A}$) with rounded margins. The endophragm is extremely thin; the finely fibrous periphragm is less than 1um thick.

Dimensions: Observed range (7 specimens measured): overall diameter 32-42um; main body diameter 20-25um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Forma E

Pl. 36, figs. 11-14

Comments: These Miocene forms designated Forma E superficicially resemble species of the genus *Thalassiphora* (Eisenack and Gocht 1960) Gocht 1968. A thin, filmy, finely fibrous, often fenestrate ectophragm, which completely envelopes the main body (closely appressed on the dorsal surface), is drawn out into a number of seemingly incipient blunt processes. Paratabulation cannot be determined with certainty at the present time. Evitt (personal communication) has studied a similar complex of cysts from Miocene age rocks of Virginia in which he has observed forms ranging from those with pronounced processes to inflated types with only slightly drawn out protuberances. The rounded archeopyle appears to a precingular Type P.

Dimensions: Observed range (5 specimens measured): overall length 100-130um and width 100-122um; main body length 56-64um and width 50-60um.

Stratigraphic occurrence: Miocene strata: Extremely rare.

Genus *Fromea* Cookson and Eisenack 1958

Fromea fragilis (Cookson and Eisenack 1962)
Stover and Evitt 1978

Pl. 36, figs. 5-6

1962. *Palaeostomocystis fragilis* Cookson and Eisenack, p. 496-497, pl. 7, figs. 10-11.

1978. *Fromea fragilis* (Cookson and Eisenack 1962) Stover and Evitt, p. 48.

Comments: Paleocene specimens from the Oak Grove core, though considerably smaller, are morphologically similar to the Australian Aptian to Cenomanian age forms described by Cookson and Eisenack (1962). A transverse fold (paracingulum?) and a longitudinal, keel-like fold (parasulcus?) were observed on most specimens. Typically one end of the cyst is broken open (apical archeopyle?). No paratabulation is evident. The single-layered, faintly granulate cyst wall is less than 1um thick.

Dimensions: Observed range (10 specimens measured): overall length 68-105um and width 43-70um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Marlboro Clay: Extremely rare.

Previously reported occurrences: Aptian, Albian?, and Cenomanian of Australia (Cookson and Eisenack, 1962); Upper Cretaceous of the Canadian Arctic (Manum and Cookson, 1964); Upper Albian of Alberta, Canada (Brideaux, 1971); Campanian and Maastrichtian of N.W.T., Canada (McIntyre, 1974); Paleocene of Virginia, U.S.A. (Witmer, 1975; Edwards et al., 1984); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Campanian and Maastrichtian of Mississippi and Alabama, U.S.A. (Rounds, 1982); Maastrichtian and Danian of Georgia (Firth, 1984).

Fromea? laevigata (Drugg 1967) Stover and Evitt 1978

Pl. 36, fig. 4

1967. *Palaeostomocystis laevigata* Drugg, p. 35, pl. 6, figs. 14-15.
1978. *Fromea? laevigata* (Drugg 1967) Stover and Evitt, p. 48.

Comments: The specimens recovered in the Lower Paleocene strata generally conform to Drugg's (1967) forms from Maastrichtian to Danian age rocks of California. The outer wall is levigate, less than 1um thick. The apparently fragile inner body easily crumbles. Stover and Evitt (1978) provisionally placed this species in *Fromea* Cookson and Eisenack 1958.

Dimensions: Observed range (2 specimens measured): overall length 75-78um and width 23-26um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Previously reported occurrences: Maastrichtian and Danian of California, U.S.A. (Drugg, 1967); Lower Paleocene of Maryland, U.S.A. (McLean, 1971); Maastrichtian of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975).

Genus *Horologinella* Cookson and Eisenack 1962

Horologinella apiculata Cookson and Eisenack 1962

Pl. 35, fig. 8

1962. *Horologinella apiculata* Cookson and Eisenack, p. 272, pl. 37, fig. 4.

Comments: This extremely small, distinctive, hourglass-shaped species has a bi-layered wall. On most specimens the inner body conforms generally to the shape of the outer body. Both wall layers are levigate and less than 0.5um thick. A small protuberance is located at one end of the cyst.

Dimensions: Observed range (5 specimens measured): overall cyst length 16-20um and width 17-20um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Previously reported occurrences: Campanian of Western Australia (Cookson and Eisenack, 1962a); Paleocene of New Zealand (Wilson, 1967); Campanian and Maastrichtian of N.W.T., Canada (McIntyre, 1974); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984).

Genus *Impletosphaeridium* Morgenroth 1966

Impletosphaeridium kroemmelbeinii Morgenroth 1966

Pl. 35, fig. 1

1966. *Impletosphaeridium kroemmelbeinii* Morgenroth, p. 34-35, pl. 9, figs. 4-5.

Comments: Only two specimens conforming in size and morphology to *Impletosphaeridium kroemmelbeinii* were recovered in the Eocene strata of the core. The spheroidal main body bears numerous slender, rod-like and blake-like processes which are distally bifurcate and multifurcate; tips bear fine, branching aculeae. Paratabulation is not apparent, and no archeopyle was observed.

Dimensions: Observed range (2 specimens measured): main body diameter 30-34um; process lengths up to 16um.

Stratigraphic occurrence: Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966a); Middle and Upper Eocene of England (Eaton, 1976); Lower and Middle Eocene of southern England (Islam, 1983a).

Impletosphaeridium rugosum Morgenroth 1966

Pl. 34, figs. 19-20

1966. *Impletosphaeridium rugosum* Morgenroth, p. 36, pl. 10, figs. 2-3.

Comments: Oak Grove core specimens are comparable to the German Eocene cysts described by Morgenroth (1966). Most forms bear finely ribbed, tubiform processes that are linked proximally by low, linear ribs or folds. Some cysts with distinctly fibrous processes, however, appear to lack or have only weakly developed connecting folds. Distally most processes are slightly recurved and some are interconnected by fine fibers. The relatively large apical archeopyle (Type A) includes a broad parasulcul notch. Paratabulation could not be determined. The endophragm is about 1um thick; the periphragm up to 0.5um thick appears microreticulate.

Dimensions: Observed range (10 specimens measured): main body diameter 26-30um; process lengths up to 10um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare.

Previously reported occurrences: Lower Eocene of Germany (Morgenroth, 1966); Paleocene of Virginia, U.S.A. (McLean, 1971; Witmer, 1975); Lower Eocene of Maryland, U.S.A. (Goodman, 1975, 1979).

Impletosphaeridium? sp. A

Pl. 35, figs. 2-4

Comments: These relatively small cysts with a spheroidal main body bear numerous erect, interconnected, fibrous, membrane-like processes which are distally flared and seemingly randomly distributed. The endophragm is about 1um thick and the finely fibrous periphragm is less than 0.5um thick. A paratabulation pattern is not apparent. The archeopyle appears to be apical with a ventrally attached operculum. These forms, found only in the Miocene strata of the Oak Grove core, have been tentatively assigned to the genus *Impletosphaeridium* Morgenroth 1966.

Dimensions: Observed range (10 specimens measured): main body diameter 28-40um; process lengths up to 10um.

Stratigraphic occurrence: Miocene strata: Extremely rare to Sparse.

Genus *Inversidinium* McLean 1973

Inversidinium exilimurum McLean 1973

Pl. 36, figs. 1-3

1973. *Inversidium exilimurum* McLean, p. 729-732, pl. 90, figs. 1-9.

Comments: McLean (1973a) erected a new genus and species for these problematical Paleocene cysts that closely resemble German Eocene forms described by Alberti (1961) as *Wetzeliella (Rhombodinium?) minusculum*. Subsequently, Stover and Evitt (1978) placed *W. minusculum* in *Palaeotetradinium* (Deflandre 1936) Stover and Evitt 1978; in addition, they consider *Inversidinium exilimurum* McLean 1973 to be a junior synonym of *Palaeotetradinium minusculum* (Alberti 1961) Stover and Evitt 1978. Certain differences between *P. minusculum* and *I. exilimurum*, however, need to be resolved. The endocyst of the former nearly fills the pericyst (see pl. 1, fig. 10 and pl. 12, fig. 4 of Alberti (1961)), whereas in the latter it is always restricted to the part of the cyst with the blunt end. Furthermore, Alberti (1961) described two protrusions from the blunt end of the cyst separated by a longitudinal split; on *I. exilimurum* no such protrusions have been observed and a convex fold is developed almost the entire length of the cyst (see pl. 36, fig. 3 of the present study). Proper orientation of this cyst is unclear. McLean (1973a), and apparently

Alberti (1961), consider the cyst to be of a general peridinioid shape with the pointed end as apical. This results in an atypical truncated antapex with an antapical archeopyle. On the other hand, in their enendation of *Palaeotetradinium*, Stover and Evitt (1978) orient the cyst with the blunt end and the apex with a resultant apical archeopyle. Until apparent differences between these two similar cysts are understood, and the holotype of *P. minusculum* is closely examined and the German forms are better documented, the present study will recognize *I. exilimurum*. Oak Grove core specimens precisely conform with the Paleocene forms described by McLean (1973a). No features suggestive of paratabulation are evident. The transverse and longitudinal convex folds of the periphragm likely reflect a paracingulum and parasulcus. The endophragm and periphragm are each about 0.5um thick, the latter levigate to occasionally faintly granulate.

Dimensions: Observed range (15 specimens measured): pericyst length 38-60um and width 34-44um; endocyst length 23-28um and width 21-30um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Marlboro Clay: Extremely rare; Eocene strata: Extremely rare.

Previously reported occurrences: Paleocene of Virginia and Maryland, U.S.A. (McLean, 1973a); Paleocene of Virginia, U.S.A. (Witmer, 1975);

Lower Eocene of Maryland, U.S.A. (Goodman, 1975); Maastrichtian to Lower Eocene of Labrador (Ioakim, 1979).

Genus *Paralecaniella* Cookson and Eisenack 1970

Paralecaniella indentata (Deflandre and Cookson 1955)
Elsik 1977

Pl. 36, figs. 9-10

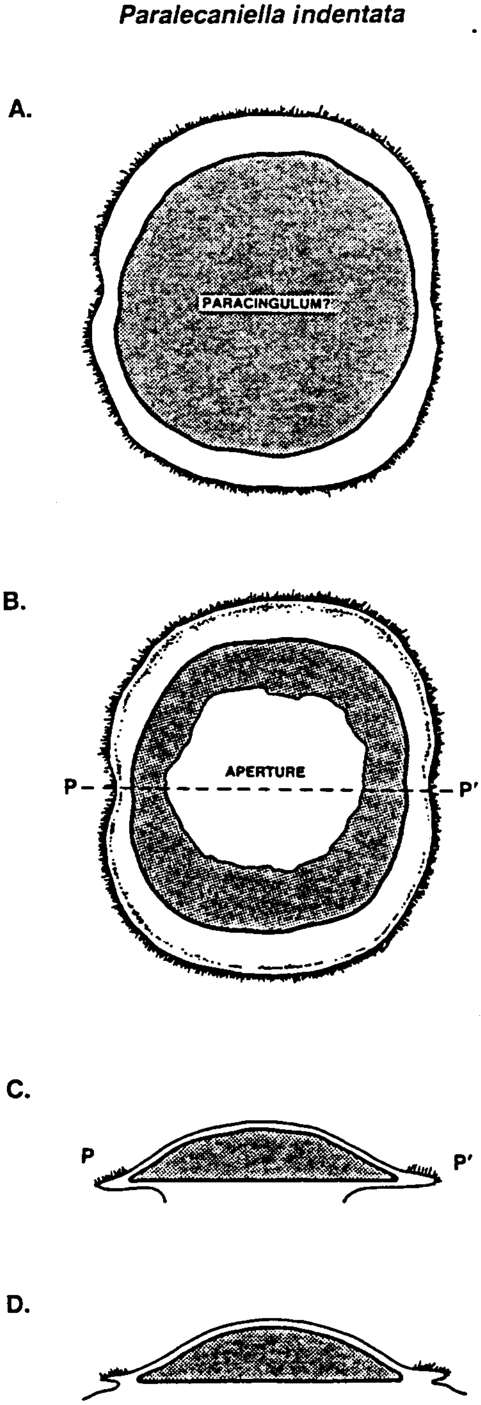
1955. *Epicephalopyxis indentata* Deflandre and Cookson, p. 292-293 pl. 9, figs. 5-7; text-fig. 56.

1970. *Paralecaniella indentata* (Deflandre and Cookson 1955) Cookson and Eisenack, p. 323.

1977. *Paralecaniella indentata* (Deflandre and Cookson 1955) Elsik, p. 95-102, pl. 1, figs. 1-16; pl. 2, figs. 1-14; text-fig. 1.

Comments: Cookson and Eisenack (1970) assigned these forms of questionable affinity to the Division Chlorophyta (green algal cysts). Elsik (1977), however, transferred the group to the Division Pyrrophyta because many cysts show evidence of a paracingulum and what is apparently a type of epicystal archeopyle. On some specimens of this study, a large, irregular aperture in the outer wall layer can be observed on the flattened side; on other forms this entire flattened side is either intact or entirely missing. These features may have functioned as excystment apparati. Elsik (1977) states that half specimens have the shape of shallow saucers, whereas Deflandre and Cookson (1955) originally described the cysts as deeply dome shaped. Although no Oak Grove core specimens were seen in cross-section, Whitney (1976) illustrates a form in cross-section (see her pl. 18, fig. 17) that is indeed rather strongly dome shaped. It is herein suggested that complete cysts are in fact dome shaped, and that excystment occurred by loss of a part of or the entire flattened side (see Text-fig. 25). Orientation of the cyst is problematical. If the dome is considered apical, the flange may then represent the paracingulum. However, if one of the ends (in plan view) is apical, then the indentations in the flange in an approximate equatorial position may be the paracingulum. Some cysts were observed to be connected together along the lace-like network on the outer edge of the flange. Specimens from the Oak Grove core are considerably larger than those from the Australian Pebble Point Formation and the Lower Tertiary strata from the Gulf of Alaska.

Dimensions: Observed range (25 specimens measured): overall length 68-127um and width 62-116um; endocyst length 54-82um and width 53-77um.



Text-fig. 25. Suggested morphology and excystment features of *Paralecaniella indentata* (Deflandre and Cookson 1955) Elsik 1977. A. Apical? view. B. Anapical view showing aperture on flattened side. C. Cross-section along line P-P' (oriented with aperture down). D. Cross-section showing how outer wall may fold out on flattened side on some specimens.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Common; Eocene strata: Extremely rare to Rare; Miocene strata: Extremely rare.

Previously reported occurrence: Paleocene, Eocene, and Miocene of Australia (Deflandre and Cookson, 1955); Paleocene of Australia (Cookson and Eisenack, 1965c, 1970); Upper Cretaceous of England (Clarke and Verdier, 1967); Paleocene of Virginia and Maryland, U.S.A. (McLean, 1971); Paleocene of Virginia, U.S.A. (Witmer, 1975); Upper Danian of southern Sweden (DeConinck, 1975); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Lower Tertiary of the Gulf of Alaska (Elsik, 1977); Upper Eocene to Miocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle and Upper Eocene of the Labrador (Ioakim, 1979); Upper Paleocene and Lower Eocene of the Rockall Plateau (Brown and Downie, 1983); Paleocene to Miocene of eastern Netherlands (Herngreen, 1984); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984).

Genus *Trigonopyxidia* Cookson and Eisenack 1961

Trigonopyxidia ginella (Cookson and Eisenack 1960)
Downie and Sarjeant 1965

Pl. 37, figs. 9-10

1960. *Trigonopyxis ginella* Cookson and Eisenack, p. 11, pl. 3, figs. 18-20.

1961. *Trigonopyxidia ginella* (Cookson and Eisenack 1960) Cookson and Eisenack, p. 75

1965. *Trigonopyxidia ginella* (Cookson and Eisenack 1960) Downie and Sarjeant, p. 148.

Comments: Both the inner and outer body of the cyst are triangularly shaped with rounded vertices. A large cavity exists between both bodies. Typically one vertex of the outer body is broken open; the nearest vertex of the inner body may occasionally show a partial break. These openings may represent excystment features. The levigate inner cyst wall is up to 1um thick; the outer wall is about 0.5um thick, levigate to scabrate.

Dimensions: Observed range (10 specimens measured): inner body length 35-38um and width 34-39um; outer body length 45-67um and width 51-88um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare.

Previously reported occurrences: Upper Albian to Cenomanian of Western Australia (Cookson and Eisenack, 1960, 1961); Cenomanian of England (Cookson and Hughes, 1964); Campanian to Cenomanian of Arctic Canada (Manum and Cookson, 1964); Paleocene of the U.S.S.R. (Vozzhennikova, 1967); Campanian and Maastrichtian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Maastrichtian and Danian of Georgia, U.S.A. (Firth, 1984).

Genus *Tuberculodinium* Wall 1967

Tuberculodinium vancampoae (Rossignol 1962) Wall 1967

Pl. 35, figs. 15-16

1962. *Pterospermopsis vancampoae* Rossignol, p. 134, pl. 2, fig. 1.

1967. *Tuberculodinium vancampoae* (Rossignol 1962) Wall, p. 114-115.

Comments: Miocene forms of *Tuberculodinium vancampoae* from the Oak Grove core compare in size and morphology to the Quaternary Caribbean Sea cysts described and illustrated by Wall (1967). Most cysts appear discoidal, which may be the result of post-depositional compression. The endocyst bears tuberculate processes up to 10um wide and 20um long which support a thin ectophragm. Processes are typically constructed of a stout, bulbous base, with somewhat smaller bulbous distal element (shaped like a figure "8" in lateral view). Paratabulation and archeopyle type could not be determined on the study specimens. Stover and Evitt (1978), however, do report the paratabulation as 5-8', 8-13", 6-13"', 3-11"" and the archeopyle type as antapical (involving two or three paraplates). Wall and Dale (1971) have demonstrated that this cyst is produced by the living *Pyrophacus* and have transferred it to that genus. The present author has nevertheless chosen to retain the fossil genus name and not place it in a separate family.

Dimensions: Observed range (6 specimens measured): approximate overall diameter 80-110um.

Stratigraphic occurrence: Miocene strata: Extremely rare.

Previously reported occurrences: Pleistocene of Israel and the Mediterranian Sea region (Rossignol, 1962, 1964); Quaternary of the Caribbean Sea (Wall, 1967); Miocene of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975); Lower Miocene of the Blake Plateau, offshore South Carolina, U.S.A. (Stover, 1977); Lower Miocene of the North Sea (Ioakim, 1979); Middle and Upper Miocene of the Rockall Plateau (Edwards, 1983); Miocene of eastern Netherlands (Herngreen, 1984).

Tuberculodinium? sp. (sensu Williams and Brideaux 1975)

Pl. 35, figs. 13-14

Comments: Specimens recovered in the Miocene strata of the core closely resemble those illustrated by Williams and Brideaux (1975, pl. 35, fig. 2). The cysts bear numerous short processes up to 12um long with transverse septa in the shanks and bifid tips. No ectophragm was observed; its assignment to *Tuberculodinium* is therefore questionable. Paratabulation and archeopyle type is indeterminate.

Dimensions: Observed range (5 specimens measured): approximate main body diameter 80-100um.

Stratigraphic occurrence: Miocene strata: Extremely rare.

Previously reported occurrences: Quaternary of the Grand Banks, Newfoundland, Canada (Williams and Brideaux, 1975).

Genus *Xenikoon* Cookson and Eisenack 1960

Xenikoon australis Cookson and Eisenack 1960

1960. *Xenikoon australis* Cookson and Eisenack, p. 16, pl. 3, figs. 16-17.

Pl. 36, figs. 7-8

Comments: Virginia Paleocene specimens are similar to the Australian Upper Cretaceous cysts described by Cookson and Eisenack (1960). Some forms exhibit a roughly square opening with ragged margins below the apex. An equatorial indentation, seen best along the ambitus, likely indicates the paracingulum. Evidence of paratabulation is lacking. A large apial pericoel is characteristic of *Xenikoon australis*. Several groups of two or three attached cysts were observed, suggesting that this species may have grown in small clusters (as in *Palambages* spp.). The cyst wall is composed of an endophragm up to 1um thick and a periphragm up to 0.5um thick, each levigate to sparsely granulate.

Dimensions: Observed range (25 specimens measured): pericyst length 62-82um and width 45-61um; endocyst length 45-65um and width 42-60um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Common.

Previously reported occurrences: Upper Turonian? to Campanian of Australia (Cookson and Eisenack, 1960); Lower Cretaceous of Australia (Eisenack, 1961); Paleocene of Virginia and Maryland, U.S.A. (McLean, 1971); Paleocene of Virginia, U.S.A. (Witmer, 1975; Edwards et al., 1984); Campanian, Maastrichtian, and Danian of Maryland and Delaware, U.S.A. (Whitney, 1976, 1984); Maastrichtian of Maryland, U.S.A. (Benson, 1976); Campanian and Maastrichtian of Alabama and Mississippi, U.S.A. (Rounds, 1982); Maastrichtian of Georgia, U.S.A. (Firth, 1984).

Group ACRITARCHA Evitt 1963

Subgroup Sphaeromorphitae Downie, Evitt, and Sarjeant 1963

Genus *Cyclopsiella* Drugg and Loeblich 1967

Cyclopsiella elliptica Drugg and Loeblich 1967

Pl. 31, fig. 4

1967. *Cyclopsiella elliptica* Drugg and Loeblich, p. 190, pl. 3, figs. 1-6; text-fig. 7.

Comments: Miocene forms recovered from the core are generally larger than the Gulf Coast Oligocene specimens described by Drugg and Loeblich (1967). The circular aperture (up to 11um in diameter) near one end of the cyst is reminiscent of pylomes found on Lower Paleozoic acritarchs such as *Asketopalla* and *Dicommopalla*; I concur with Stover and Evitt (1978) that species of *Cyclopisella* are indeed acritarchs. The inner body wall is levigate to scabrate; the thin outer wall bears grana or short spines up to 2um long. A flange up to 5um wide may be found along the circumference.

Dimensions: Observed range (7 specimens measured): overall length 68-80um and width 62-75um.

Stratigraphic occurrence: Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Oligocene of Mississippi, U.S.A. (Drugg and Loeblich, 1967); Lower Eocene of the Norwegian Greenland Sea (Manum, 1976); Upper Eocene to Miocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Lower Oligocene of the North Sea (Ioakim, 1979).

Cyclopsiella vieta Drugg and Loeblich 1967

Pl. 31, figs. 5-6

1967. *Cyclopsiella vieta* Drugg and Loeblich, p. 192-194, pl. 3, figs. 7-9; text-fig. 8.

Comments: Oak Grove core specimens of *Cyclopsiella vieta* are comparable to the Oligocene forms from the Glendon Limestone of Mississippi described by Drugg and Loeblich (1967). The circular aperture (up to 13um in diameter) which is often bordered by a low rim likely represents a pylome (acritarch excystment feature?); a dense, dark plug is in place on occasional specimens. The typically wrinkled outer wall up to 0.5um thick extends beyond the main body, forming a flange up to

7um wide at the circumference. The inner wall up to 1um thick is levigate to scabrate. Some specimens are represented by only the thin, wrinkled outer body, and others appear to have split along the circumference. Two cysts were observed to be joined at the flange; this same phenomenon was seen on *Xenikoon australis* of the present study (see Pl. 36, fig. 8), suggesting the possibility that these cysts may have been linked in chains.

Dimensions: Observed range (15 specimens measured): overall length 68-107um and width 62-91um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Eocene strata: Extremely rare to Rare; Miocene strata: Extremely rare to Rare.

Previously reported occurrences: Oligocene of Mississippi, U.S.A. (Drugg and Loeblich, 1967); Paleocene of Virginia, U.S.A. (Witmer, 1975); Maastrichtian of Maryland, U.S.A. (Whitney, 1976, 1984); Benson, 1976); Oligocene of eastern Canada (Williams and Bujak, 1977; Barss et al., 1979); Middle and Upper Eocene (Watkins, 1979) and Upper Oligocene (Ford, 1979) of South Carolina, U.S.A.; Oligocene and Lower Miocene of the North Sea (Ioakim, 1979).

Subgroup Acanthomorphitae Downie, Evitt, and Sarjeant 1963

Genus *Micrhystridium* (Deflandre 1937) Downie and Sarjeant 1963

Micrhystridium cf. *M. fragile* Deflandre 1937

Pl. 37, fig. 1

Comments: These acritarchs recovered from the Paleocene strata of the Oak Grove core appear identical to the California Danian forms recorded by Drugg (1967, p. 34, pl. 6, fig. 5). The spheroidal to polygonally-shaped main body bears 7 to 18 tapering, pointed processes. The endoderm and ectoderm are each about 0.5um thick.

Dimensions: Observed range (8 specimens measured): main body diameter 19-26um; process lengths up to 9 um.

Stratigraphic occurrence: Paleocene strata: Extremely rare.

Micrhystridium cf. *M. variabile* Valensi 1953

Pl. 37, fig. 2

Comments: Acritarchs similar to Drugg's (1967) forms (see his pl. 6, fig. 7) are present in the Paleocene and Eocene strata of the core. The spheroidal main body bears numerous captitate processes. The endoderm and ectoderm are each less than 0.5um thick.

Dimensions: Observed range (25 specimens measured): main body diameter 22-28um; process lengths up to 8um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Sparse; Eocene strata: Extremely rare to Rare.

Micrhystridium spp.

Pl. 37, figs. 3-4

Comments: A number of undesignated species of *Micrhystridium* were recovered. They are scattered throughout the core with questionable biostratigraphic value and are herein simply referred to *Micrhystridium* spp. Most species are represented by specimens consisting of spheroidal, bi-layered main bodies with short spines or tubercles.

Dimensions: Observed range (25 specimens measured): main body diameter 13-26um; process and assorted ornamentation up to 3um high.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare; Marlboro Clay: Extremely rare to Rare; Eocene strata: Extremely rare to Rare; Miocene strata: Extremely rare to Rare.

Division CHLOROPHYTA
Class CHLOROPHYCEAE
Order CHLOROCOCCALES
Family CHLOROCOCCACEAE

Genus *Palambages* O. Wetzel 1961

Comments: Specimens of *Palambages* recovered from the Oak Grove core have been divided into three general groups: Sp. A, Sp. B., and Sp. C. Although the affinity of this genus is uncertain, the cysts are believed to be chlorophytes. Manum and Cookson (1964) state that most of the spheroidal cells appear to occur in clusters of powers of 2 (i.e., 8, 16, 32, etc.), as do extant colonial green algae.

Palambages sp. A

Pl. 37, figs. 12-13

Comments: Clusters of approximately eight or 16 cells were observed. Most of the spheres, ornamented with coarse grana and baculate or clavate elements, have relatively large openings. These colonies resemble the Cretaceous forms designated Form C by Manum and Cookson (1964, p. 24, pl. 7, fig. 7), as well as Upper Danian to Middle Paleocene forms referred to *Palambages morulosa* (O. Wetzel 1961) Gocht and Wille 1972 by DeConinck (1975).

Dimensions: Observed range (15 cells measured): cell diameter 41-51um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Palambages sp. B

Pl. 37, figs. 14-15

Comments: Many of these colonies consist of 16 small, levigate to faintly granulate cells, although other clusters of more numerous cells (approximately 32 or 64) were also observed. The cells are connected to one another by small strands. Some of the spheres exhibit an irregularly shaped aperture. This group appears to be similar to Form A of Manum and Cookson (1964, p. 64, pl. 7, figs. 3-6).

Dimensions: Observed range (25 cells measured): cell diameter 18-26um.

Stratigraphic occurrence: Paleocene strata: Extremely rare to Rare.

Palambages sp. C

Pl. 37, figs. 16-17

Comments: The small, spheroidal cells of this group of *Palambages* are approximately the same size and occur in colonies of about the same number as *Palambages* sp. B. They differ by bearing densely distributed setae up to 2um long. Only a few cells display an aperture.

Dimensions: Observed range (15 cells measured): cell diameter 17-24um.

Stratigraphic occurrence: Eocene strata: Extremely rare to Sparse.

Class PRASINOPHYCEAE
Order HALOSPHAERALES
Family PTEROSPERMATACEAE

Genus *Cymatiosphaera* (O. Wetzel 1933) Deflandre 1954

Cymatiosphaera spp.

Pl. 37, figs. 5-6

Comments: Because of their small numbers and apparently limited biostratigraphic significance, individual species of *Cymatiosphaera* have not been identified. Generally, specimens bear septa up to 4um high delineating polygonal fields on a spheroidal main body. The endoderm is up to 1um thick and the ectoderm in typically much thinner.

Dimensions: Observed range (10 specimens measured): main body diameter 10-34um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Marlboro Clay: Extremely rare to Rare; Eocene strata: Extremely rare; Miocene strata: Extremely rare.

Genus *Pterospermopsis* W. Wetzel 1952

Pterospermopsis spp.

Pl. 37, figs. 7-8

Comments: Most of the forms which could be accomodated by the genus *Pterospermopsis* are variable in morphology and size; they are found throughout the Tertiary section of the core and have been generally referred to *Pterospermopsis* spp. The endoderm ranges up to 2um thick, whereas the ectoderm is approximately 0.5um thick. Relatively large cysts resembling the California Maastrichtian-Danian specimens of *Pterospermopsis danica* W. Wetzel 1952 (see Drugg, 1967, pl. 6, fig. 10) were recovered from the Paleocene strata.

Dimensions: Observed range (12 specimens measured): overall diameter 51-95um; main body diameter 28-48um.

Stratigraphic occurrence: Paleocene strata: Extremely rare; Marlboro Clay: Extremely rare to Rare; Eocene strata: Extremely rare; Miocene strata: Extremely rare.

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ILLUSTRATIONS OF MICROFOSSILS

Explanation of Plates

The microscope slides prepared from the samples used in this study are stored in the Virginia Polytechnic Institute and State University Palynology Laboratory (VPISUPL). Photographed specimens are coordinated in millimeters to the right (R), and above (+), the lower left corner of the slide's coverslip (e.g., R10.5+15.1). Length and width dimensions of specimens are designated as L X W. Measurements are given in micrometers (um).

PLATE 1

Figs. 1-4: *Apteodinium cribrosum* Cookson and Eisenack 1968. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Overall L X W: 114um X 94um. Fig. 4: Detailed view of wall structure; bacula up to 4um long. VPISUPL Sample 337, Slide AO-86, Coords. R11.5;+1.1.

Figs. 5-8: *Apteodinium labyrinthum* n. sp. HOLOTYPE (Figs. 5-8): Figs. 5-7: Dorsal view (focused through specimen) revealing precingular archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view. Overall L X W: 106um X 88um. Fig. 8: Detailed view of wall structure; bacula up to 2um long. VPISUPL Sample 341, Slide AP-1, Coords. R17.4;+10.6.

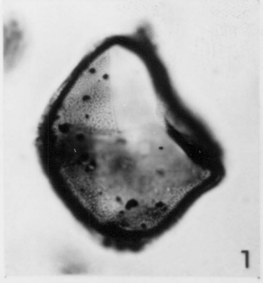
Figs. 9-12: *Apteodinium retiolum* n. sp. HOLOTYPE (Figs. 9-12): Figs. 9-11: Three focal levels of specimen. Fig. 9: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 10: Optical cross-sectional view. Fig. 10: Ventral view. Overall L X W: 64um X 48um. Fig. 12: Detailed view of wall structure; bacula up to 2um long. VPISUPL Sample 317, Slide AO-39, Coords. R15.7;+14.8.

Figs. 13-17: *Batiacasphaera microreticulata* n. sp. HOLOTYPE (Figs. 13-16): Figs. 13-15: Three focal levels of specimen. Fig. 13:

Apical view showing apical archeopyle with operculum in place. Fig. 14: Optical cross-sectional view. Fig. 15: Antapical view (focused through specimen). Diameter 54um. Fig. 16: Detailed view of trabeculate network; trabeculae about 0.5um thick. VPISUPL Sample 349, Slide AP-26, Coords. R14.3;+4.3. Fig. 17: Apical view (focused through specimen) of another specimen with apical archeopyle evident. Diameter 54um. VPISUPL Sample 342, Slide AP-3, Coords. R6.2;+8.4.

Figs. 18-20: *Batiacasphaera* sp. A. Three focal levels of specimen. Fig. 18: Apical view revealing apical archeopyle. Fig. 19: Optical cross-sectional view. Fig. 20: Antapical view (focused through specimen). Diameter 33um. VPISUPL Sample 305, Slide AO-8, Coords. R15.4;+10.3.

PLATE 1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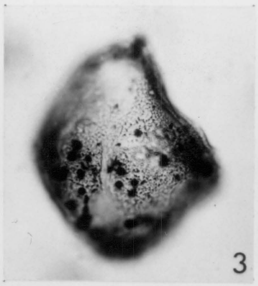
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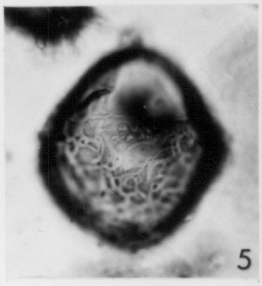
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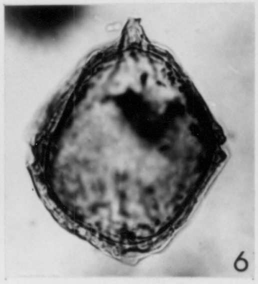
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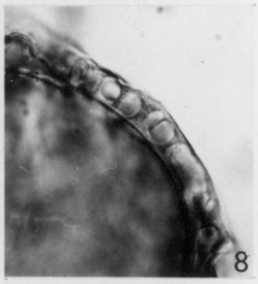
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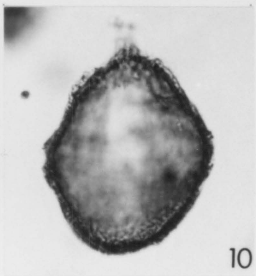
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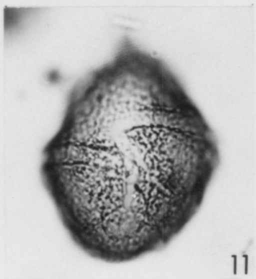
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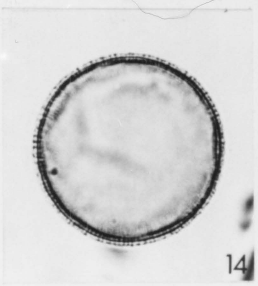
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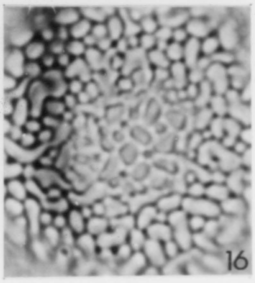
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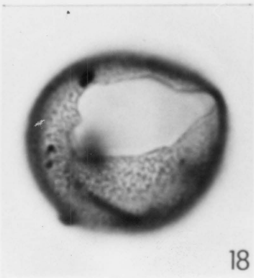
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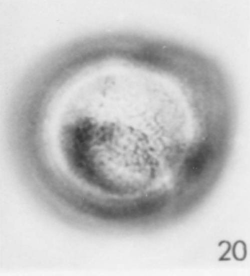
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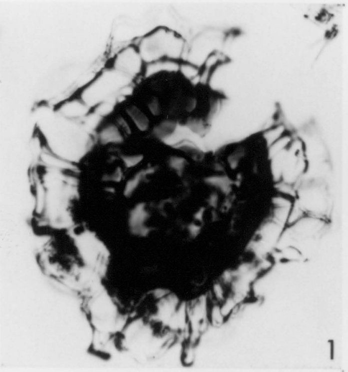
PLATE 2

Figs. 1-7: *Adnatosphaeridium multispinosum-vittatum* complex. Figs. 1-2: Two focal levels of specimen with attached operculum. Fig. 1: Dorsal view (focused through specimen). Fig. 2: Ventral view. Main body width 90um; processes up to 32um long. VPISUPL Sample 324, Slide AO-48, Coords. R15.9;+11.4. Fig. 3: Optical cross-sectional view of another specimen showing antapical lobes. Main body width 78um; processes up to 30um long. VPISUPL Sample 324, Slide AO-48, Coords. R8.5;+9.0. Figs. 4-7: Specimens from a population (Sample 328, Slide AO-63) showing various types of process development ranging from all slender shanks to thicker, fused shanks. Fig. 4: Main body width 60um; processes up to 30um long. Coords. R9.3;+15.8. Fig. 5: Main body width 70um; processes up to 34um long. Coords. R10.4;+15.2. Fig. 6: Main body width 55um; processes up to 35um long. Coords. R2.9;+13.9. Fig. 7: Main body width 52um; processes up to 30um long. Coords. R8.4;+13.5.

Figs. 8-12: *Adnatosphaeridium robustum* (Morgenroth 1966) DeConinck 1975. Figs. 8-10: Three focal levels of specimen. Main body L (excl. operculum) X W: 60um X 54um; processes up to 35um long. VPISUPL Sample 316, Slide AO-35, Coords. R10.5;+3.5. Figs. 11: Apical view of specimen showing precingular processes. Main body width 58um; processes up to 32um long. VPISUPL Sample 317, Slide

AO-39, Coords. R17.8;+9.6. Fig. 12: Isolated operculum; maximum width 44um. VPISUPL Sample 317, Slide AO-39, Coords. R17.4;+21.1.

PLATE 2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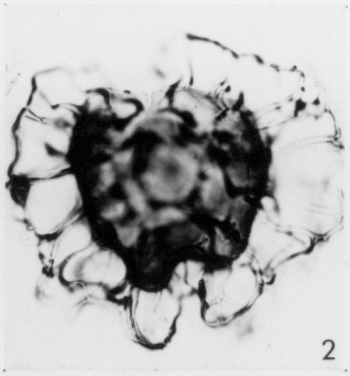
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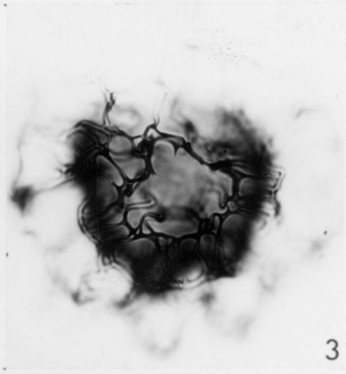
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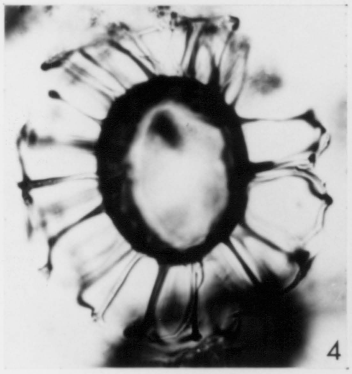
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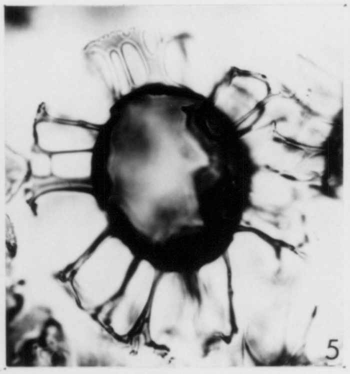
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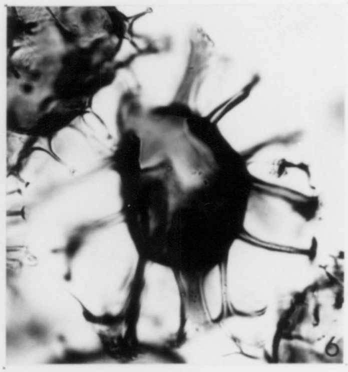
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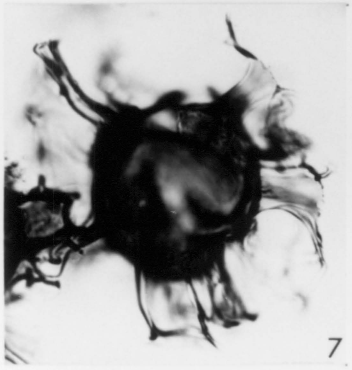
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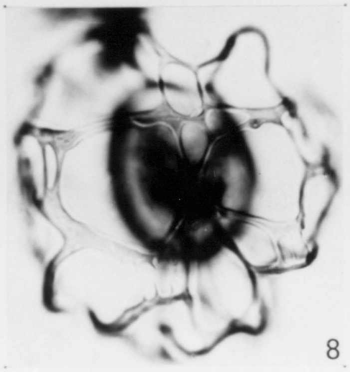
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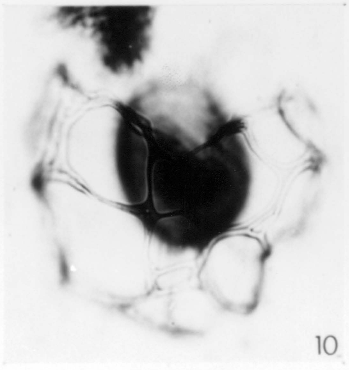
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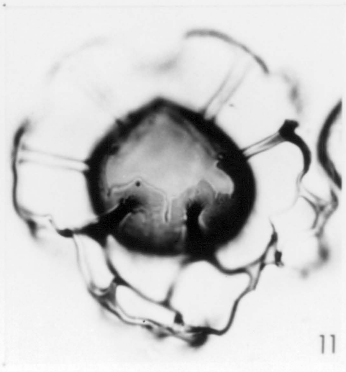
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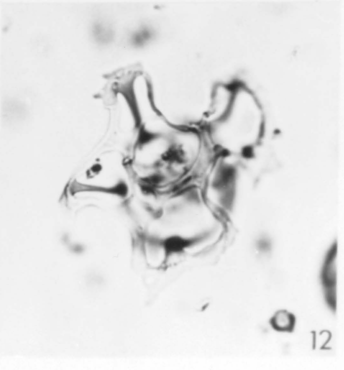
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PLATE 3

Figs. 1-4: *Cordosphaeridium? amputatospinosum* n. sp. HOLOTYPE (Figs. 1-4): Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Main body L X W: 86um X 88um; processes up to 24um long. Fig. 4: Detailed view of process (24um long). VPISUPL Sample 340, Slide AO-95, Coords. R4.8;+12.3.

Figs. 5-7: *Cordosphaeridium biarmatum* Morgenroth 1966. Three focal levels of specimen. Fig. 5: Dorsal view showing precingular archeopyle. Fig. 6: Optical cross-sectionl view. Fig. 7: Ventral view (focused through specimen). Main body L X W: 80um X 76um; processes up to 30um long. VPISUPL Sample 316, Slide AO-35, Coords. R16.5;+8.8.

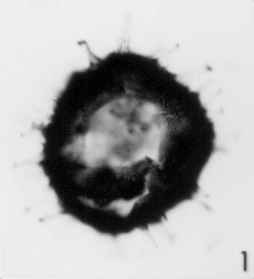
Figs. 8-10: *Cordosphaeridium fibrospinosum* (Davey and Williams 1966) Davey 1969. Three focal levels of specimen. Fig. 8: Dorsal view with precingular archeopyle visible. Fig. 9: Optical cross-sectional view. Fig. 10: Ventral view (focused through specimen). Main body L X W: 71um X 68um; processes up to 28um long. VPISUPL Sample 306, Slide AO-10, Coords. R17.9;+13.4.

Figs. 11-14: *Cordosphaeridium giganteum* n. sp. HOLOTYPE (Figs. 11-13): Figs. 11-13: Three focal levels of specimen. Fig. 11: Dorsal view showing precingular archeopyle and large postcingular processes with U-shaped bases. Fig. 12: Optical cross-sectional view. Fig. 13: Ventral view (focused through specimen). Main body L X W: 84um X 74um; processes up to 40um long. VPISUPL Sample 305, Slide AO-9, Coords. R11.3;+6.5. Fig. 14: Dorsal view of another specimen with attached operculum bearing process with U-shaped base. Main body L X W: 100um X 90um; processes up to 48um long. VPISUPL Sample 303, Slide AO-3, Coords. R16.7;+5.0.

Figs. 15-17: *Cordosphaeridium gracilis* (Eisenack 1954) Davey and Williams 1966. Three focal levels of specimen. Fig. 15: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 16: Optical cross-sectional view. Fig. 17: Ventral view. Main body L X W: 80um X 70um; processes up to 40um long. VPISUPL Sample 316, Slide AO-35, Coords. R11.2;+3.0.

Figs. 18-20: *Cordosphaeridium inodes* (Klumpp 1953) Eisenack 1963. Three focal levels of specimen. Fig. 18: Dorsal view (focused through specimen) displaying precingular archeopyle. Fig. 19: Optical cross-sectional view. Fig. 20: Ventral view. Main body L X W: 60um X 52um; processes up to 34um long. VPISUPL Sample 327, Slide AO-59, Coords. R13.8;+4.0.

PLATE 3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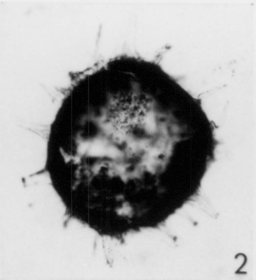
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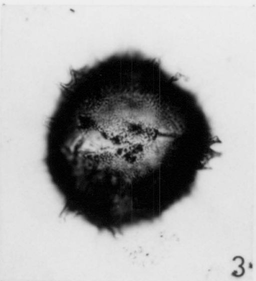
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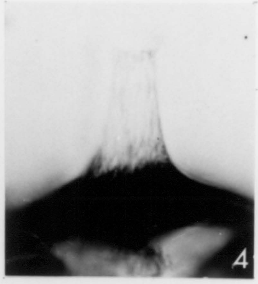
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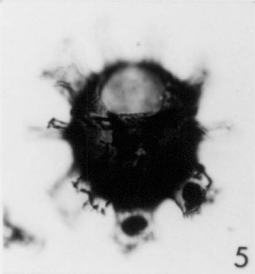
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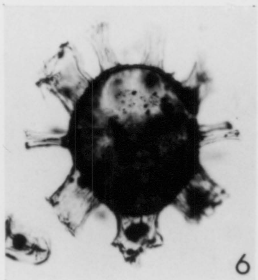
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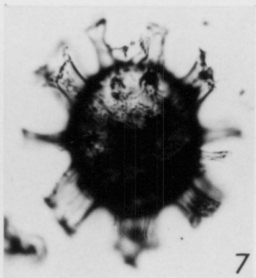
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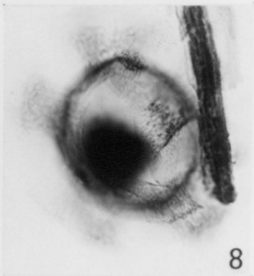
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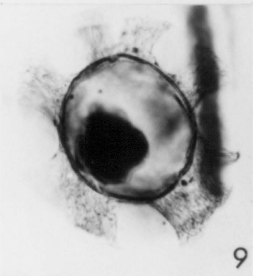
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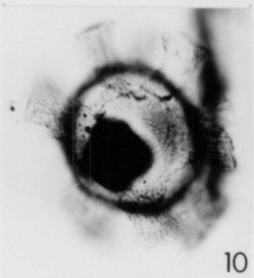
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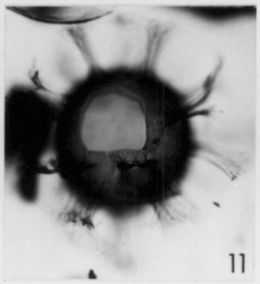
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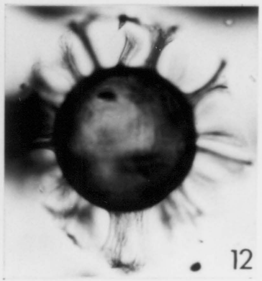
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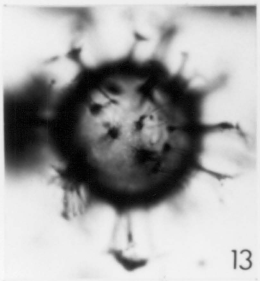
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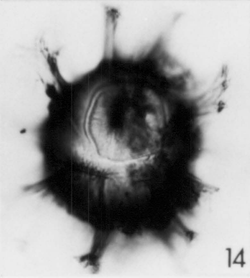
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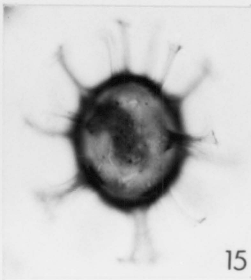
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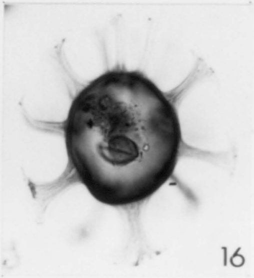
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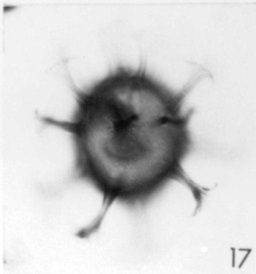
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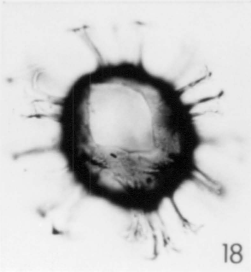
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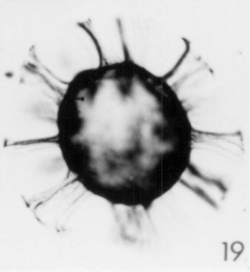
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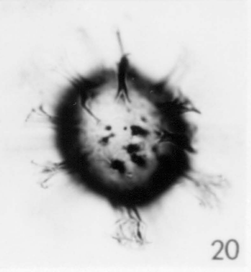
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PLATE 4

Figs. 1-3: *Cordosphaeridium inodes* subsp. *robustum* Gocht 1969. Three focal levels of specimen. Fig. 1: Dorsal view showing precingular archeopyle. Fir. 2: Optical cross-sectional view. Fig. 3: Ventral view (focused through specimen). Main body L X W: 80um X 76um; processes up to 20um long. VPISUPL Sample 324, Slide AO-48, Coords. R15.6;+7.8.

Figs. 4-6: *Cordosphaeridium multispinosum* Davey and Williams 1966. Three focal levels of specimen. Fig. 4: Dorsal view with precingular archeopyle evident. Fig. 5: Optical cross-sectional view. Fig. 6: Ventral view (focused through specimen). Main body L X W: 77um X 74um; processes up to 30um long. VPISUPL Sample 324, Slide AO-48, Coords. R10.5;+17.5.

Figs. 7-9: *Cordosphaeridium solaster* Morgenroth 1966. Three focal levels of specimen. Fig. 7: Dorsal view (focused through specimen) showing precigular archeopyle. Fig. 8: Optical cross-sectional view. Fig. 9: Ventral view. Main body L X W: 64um X 60um; processes up to 17um long. VPISUPL Sample 328, Slide AO-63, Coords. R4.3;+6.5.

Figs. 10-12: *Exochosphaeridium bifidum* (Clarke and Verdier 1967) Clarke, Davey, Sarjeant, and Verdier 1968. Three focal levels of specimen. Fig. 10: Dorsal view revealing precingular archeopyle.

Fig. 11: Optical cross-sectional view. Fig. 12: Ventral view (focused through specimen). Main body L X W: 62um X 60um; processes up to 20um long. VPISUPL Sample 303, Slide AO-1, Coords. R4.0;+12.5.

Figs. 13-16: *Kallosphaeridium brevibarbatum* DeConinck 1969. Figs. 13-14: Two focal levels of specimen. Fig. 13: Dorsal view; note accessory archeopyle parasutures. Fig. 14: Ventral view (focused through specimen) showing ventrally-attached operculum. Main body width 72um. VPISUPL Sample 317, Slide AO-39, Coords. R0.3;+14.8. Figs. 15-16: Two focal levels of another specimen. Fig. 15: Apical view with operculum in place. Fig. 16: Optical cross-sectional view. Main body diameter 60um. VPISUPL Sample 318, Slide AO-41, Coords. R15.1;+9.2.

Figs. 17-20: *Lingulodinium machaerophorum* (Deflandre and Cookson 1955) Wall 1967. Fig. 17: Antapical view of specimen with relatively pointed processes. Main body diameter 77um; processes up to 20um long. VPISUPL Sample 340, Slide AO-96, Coords. 7.0;+4.6. Figs. 18-19: Two focal levels of another specimen showing ventrally-attached lingula (tongue-like appendage) in Fig. 18 and the outline of the operculum in Fig. 19. Main body diameter 52um; processes up to 16um long. VPISUPL Sample 331, Slide AO-70, Coords. R9.8;+18.4. Fig. 20: Optical cross-sectional view of specimen with clavate-shaped processes (up to 9um long).

PLATE 4


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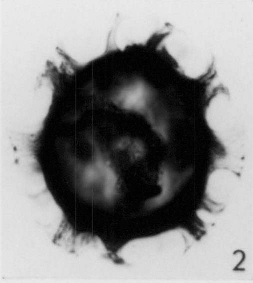
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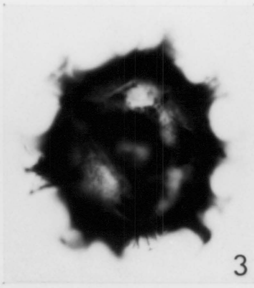
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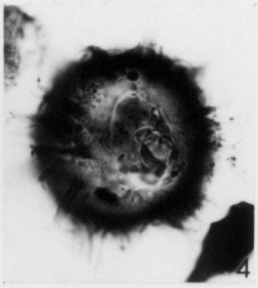
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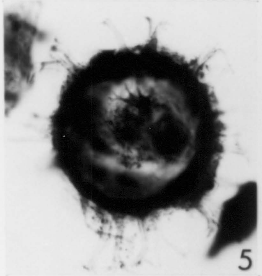
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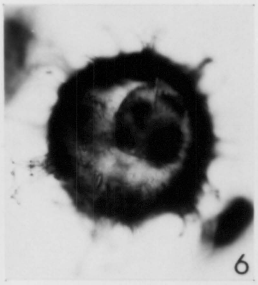
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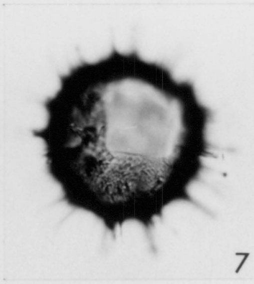
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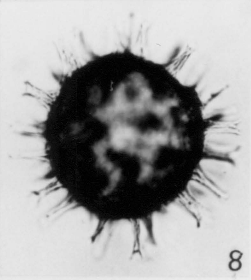
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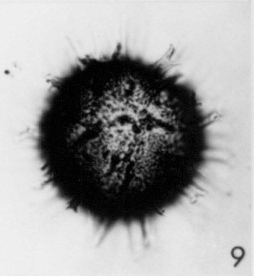
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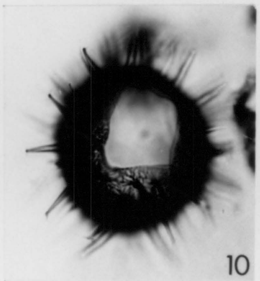
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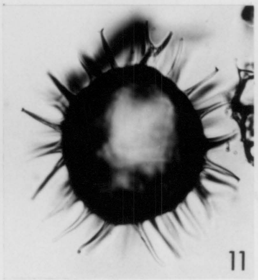
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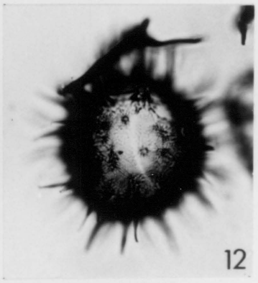
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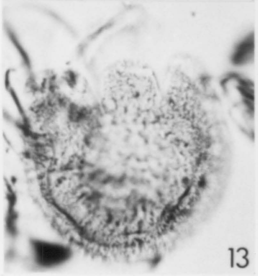
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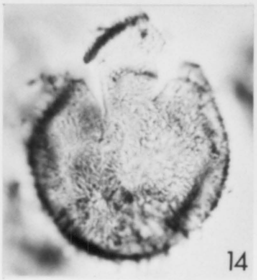
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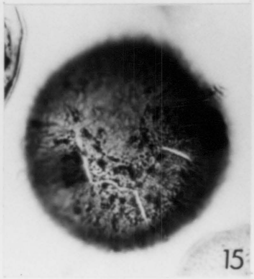
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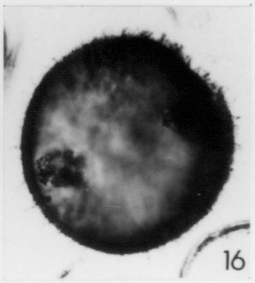
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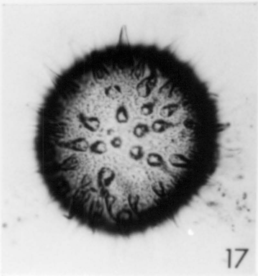
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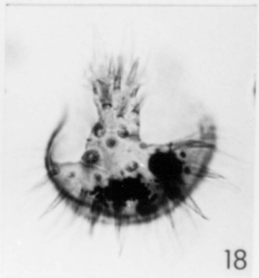
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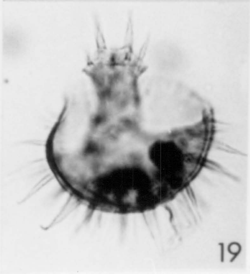
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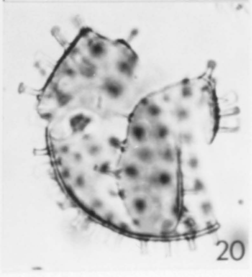
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PLATE 5

Figs. 1-4: *Danea?* sp. Figs. 1-3: Three focal levels of specimen with relatively long processes. Fig. 1: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Main body L X W: 94um X 58um; processes up to 20um long. VPISUPL Sample 306, Slide AO-10, Coords. R5.0;+16.6. Fig. 4: Dorsal view of another specimen with much shorter processes. Main body L X W: 110um X 88um; processes up to 20um long. VPISUPL Sample 307, Slide AO-15, Coords. R16.3;+15.4.

Figs. 5-9: *Achilleodinium biformoides* (Eisenack 1954) Eaton 1976. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view (focused through specimen) revealing precingular archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view showing relatively broad antapical process. Main body L X W: 64um X 56um; antapical process 24um long; remaining processes up to 14um long. VPISUPL Sample 338, Slide AO-87, Coords. R10.3;+6.8. Figs. 8-9: Two focal levels of another specimen. Fig. 8: Dorsal view (focused through specimen) exhibiting attached operculum. Fig. 9: Optical cross-sectional view; note more slender antapical process on this form. Main body L X W: 66um X 58um; processes up to 19um long. VPISUPL Sample 338, Slide AO-87, Coords. R7.7;+6.6.

Figs. 10-12: *Hystrichokolpoma eisenackii* Williams and Downie 1966. Three focal levels of specimen. Fig. 10: Left lateral view. Fig. 11: Optical cross-sectional view. Fig. 12: Right lateral view (focussed through specimen); note long, bulbous antapical process (46um long). Main body L X W: 66um X 62um; remaining processes up to 40um long. VPISUPL Sample 336, Slide AO-82, Coords. R2.5;+0.9.

Figs. 13-15: *Hystrichokolpoma rigaudiae* Deflandre and Cookson 1955. Three focal levels of specimen. Fig. 13: Dorsal view; note quadrate process bases. Fig. 14: Optical cross-sectional view. Fig. 15: Ventral view (focused through specimen). Main body L (excl. operculum) X W: 50um X 50um; antapical process 38um long; remaining processes up to 28um. VPISUPL Sample 336, Slide Ao-82, Coords. R6.5;+3.6.

Fig. 16: *Hystrichokolpoma unispinum* Williams and Downie 1966. Optical cross-sectional view of specimen; note long antapical process (34um long). Main body diameter approximately 57um; remaining processes up to 28um long. VPISUPL Sample 325, Slide AO-52, Coords. R15.5;+7.6.

PLATE 5


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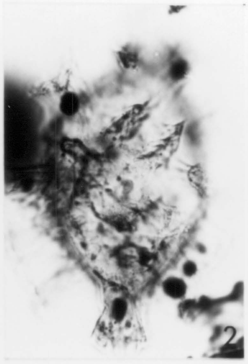
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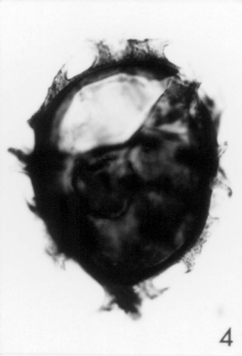
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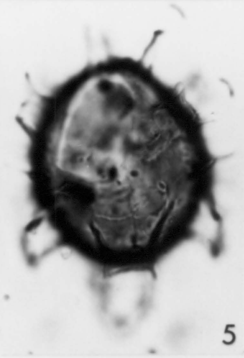
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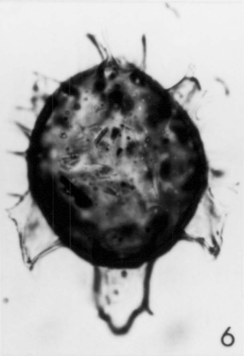
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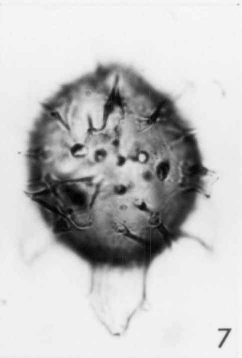
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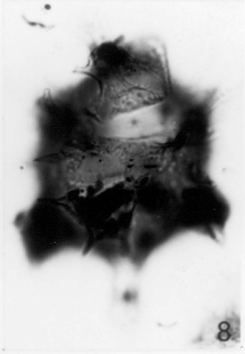
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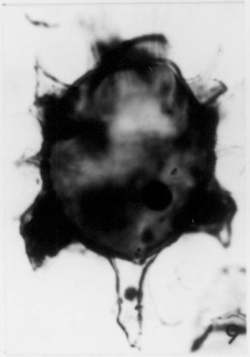
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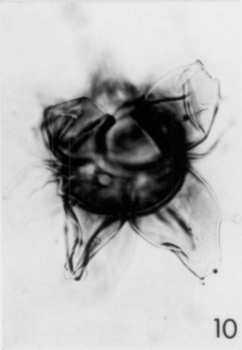
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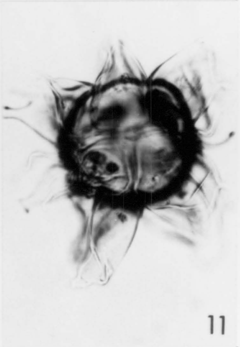
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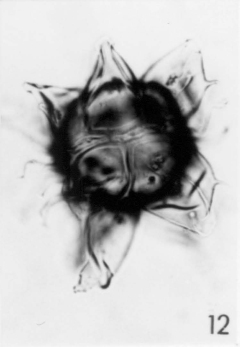
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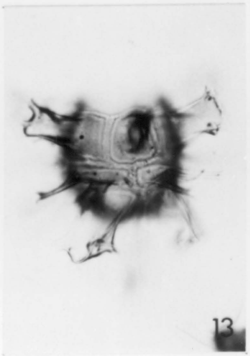
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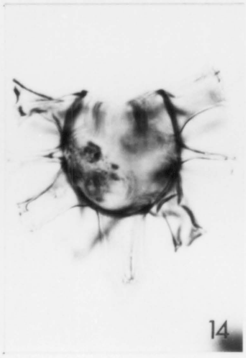
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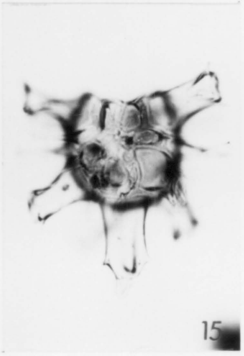
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PLATE 6

Figs. 1-3: *Hystrichokolpoma tumescens* McLean 1974. Three focal levels of specimen. Fig. 1: Dorsal view: Fig. 2: Optical cross-sectional view; note large antapical process (34um long). Fig. 3: Ventral view (focused through specimen). Main body L (excl. operculum) X W: 56um X 36um; remaining processes up to 21um long. VPISUPL Sample 316, Slide AO-35, Coords. R3.2;+13.5.

Figs. 4-6: *Diphyes colligerum* (sensu Cookson 1965). Fig. 4: Optical cross-sectional view of specimen with apical archeopyle and tapering antapical process (19um long). Main body diameter 44um; remaining processes up to 16um long. VPISUPL Sample 331, Slide AO-70, Coords. R12.5;+18.0. Figs. 5-6: Two focal levels of another specimen with a more bulbous antapical process (23um long). Main body diameter 38um; remaining processes up to 18um long. VPISUPL Sample 337, Slide AO-84, Coords. R15.4;+18.5.

Figs. 7-8: *Polysphaeridium pseudocolligerum* Stover 1977. Two focal levels of specimen. Fig. 7: Apical view showing apical archeopyle. Fig. 8: Optical cross-sectional view. Main body diameter 59um; processes up to 29um long. VPISUPL Sample 349, Slide AP-26, Coords. R2.6;+18.0 (both figures Interference Contrast).

Figs. 9-12, 16: *Diphyes colligerum* (Forma A). Figs. 9-11: Three focal levels of specimen. Fig. 9: Dorsal view showing precingular archeopyle. Fig. 10: Optical cross-sectional view. Fig. 11: Ventral view (focused through specimen); note doubly-terminated process and broad antapical process (19um long). Main body diameter 37um; remaining processes up to 17um long. Fig. 16: Detailed view of process (16um long) with capitate tip. VPISUPL Sample 329, Slide AO-64, Coords. R17.8;+3.0. Fig. 12: Dorsal view of another specimen with combination archeopyle (Type A+P). Main body diameter 42um; processes up to 20um long. VPISUPL Sample 325, Slide AO-52, Coords. R5.0;+17.1 (all figures Interference Contrast).

Figs. 13-15, 17: *Diphyes colligerum* (Forma B). Figs. 13-15: Three focal levels of specimen. Fig. 13: Dorso-lateral view (focused through specimen) displaying combination archeopyle (Type A+P). Fig. 14: Optical cross-sectional view; note numerous terminations on broad antapical process (18um long). Fig. 15: Ventro-lateral view. Main body diameter 38um; remaining processes up to 16um long. Fig. 17: Detailed view of process (15um long) with buccinate tip. VPISUPL Sample 337, Slide AO-86, Coords. R15.0;+10.3 (all figures Interference Contrast).

PLATE 6


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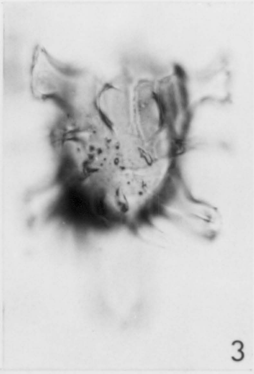
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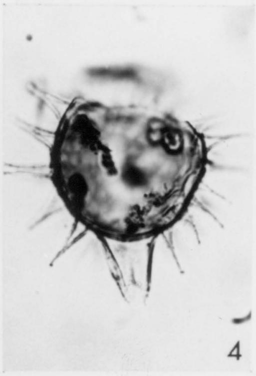
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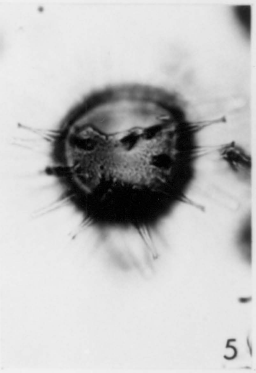
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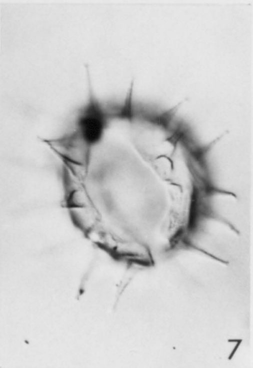
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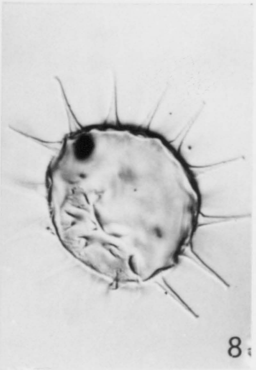
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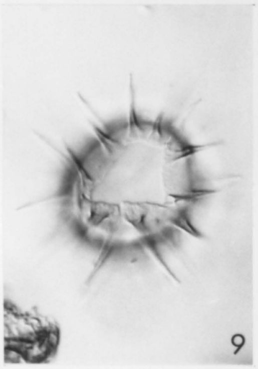
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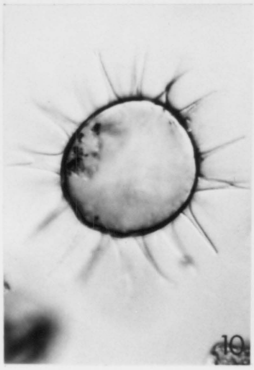
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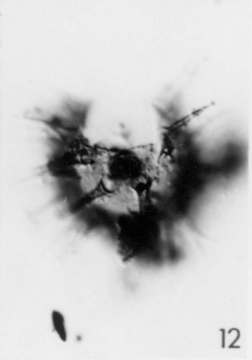
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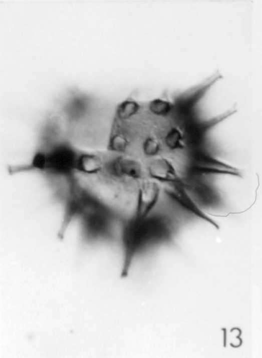
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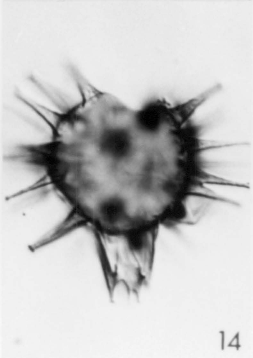
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PLATE 7

Figs. 1-4: *Areoligera* sp. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen). Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Main body L (excl. operculum) X W: 60um X 62um; processes up to 26um long. VPISUPL Sample 335, Slide AO-80, Coords. R7.3;+7.6. Fig. 4: Dorsal view of another specimen. Main body L (excl. operculum) X W: 58um X 52um; processes up to 24um long. VPISUPL Sample 335, Slide AO-80, Coords. R7.2;+7.6.

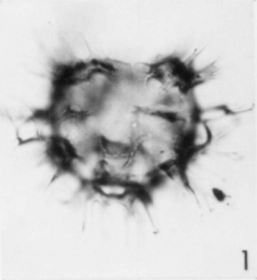
Figs. 5-12: *Glaphyrocysta exuberans* complex. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view (focused through specimen). Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view. Main body L (excl. operculum) X W: 68um X 77um; processes up to 30um long. Fig. 8: Detailed view of fenestrate network interconnecting process tips; trabeculae up to 0.5um thick. VPISUPL Sample 309, Slide AO-19, Coords. R8.1;+13.0. Fig. 9: Ventral view (focused through specimen) of another specimen with operculum in place. Main body L X W: 84um X 80um; processes up to 40um long. VPISUPL Sample 306, Slide AO-10, Coords. R16.0;+7.6. Figs. 10-11: Two focal levels of another specimen. Fig. 10: Dorsal view. Fig. 11: Ventral view (focused through specimen). Main body L (excl. operculum): 60um X 72um; processes up to 30um long. VPISUPL Sample 316, Slide AO-35, Coords. R6.9;+10.4. Fig. 12: Isolated operculum (focused through specimen) with four apical process complexes; maximum measurement 54um. VPISUPL Sample 312, Slide AO-24, Coords. R12.3;+6.4.

Figs. 13-16: *Glaphyrocysta* sp. A. Three focal levels of specimen. Fig. 13: Dorsal view. Fig. 14: Optical cross-sectional view. Fig. 15: Ventral view (focused through specimen). Main body L (excl. operculum) X W: 64um X 66um; processes up to 28um long. Fig. 16: Detailed view of processes (up to 26um long). VPISUPL Sample 316, Slide AO-35, Coords. R7.0;+10.8.

Figs. 17-18: *Glaphyrocysta* sp. B. Two focal levels of specimen. Fig. 17: Dorsal view (focused through specimen). Fig. 18: Ventral view. Main body L (excl. operculum) X W: 80um X 80um; processes up to 24um long. VPISUPL Sample 329, Slide AO-64, Coords. R20.8;+16.6.

Figs. 19-20: *Glaphyrocysta ordinata* Williams and Downie 1966. Two focal levels of specimen. Fig. 19: Dorsal view (focused through specimen). Fig. 20: Ventral view; note parasutural notch. Main body L X W: 90um X 80um; processes up to 26um long. VPISUPL Sample 339, Slide AO-91, Coords. R10.7;+15.8.

PLATE 7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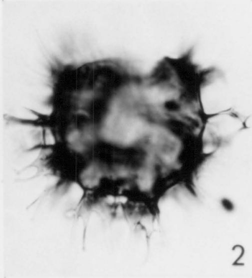
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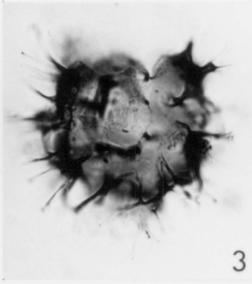
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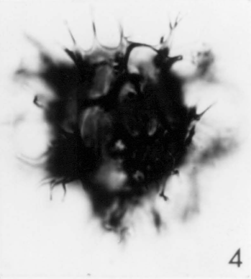
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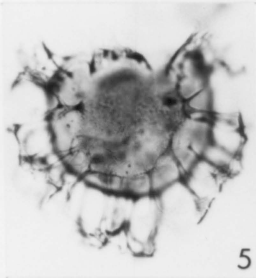
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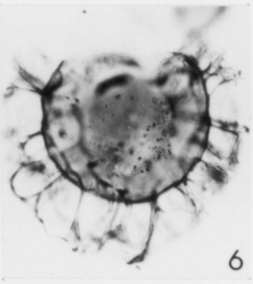
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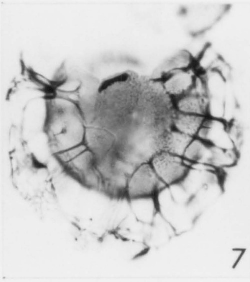
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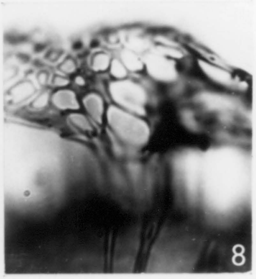
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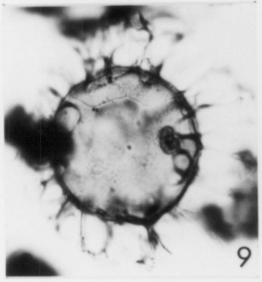
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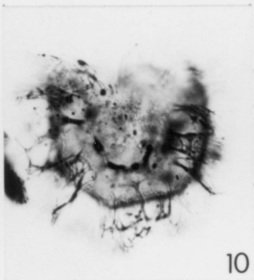
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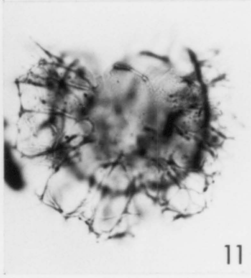
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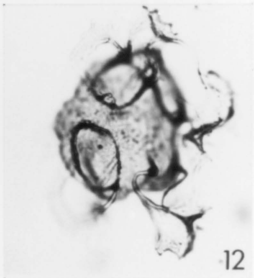
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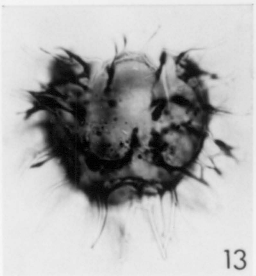
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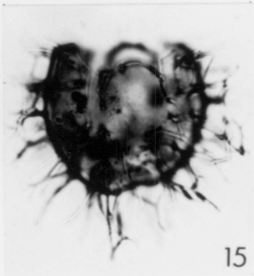
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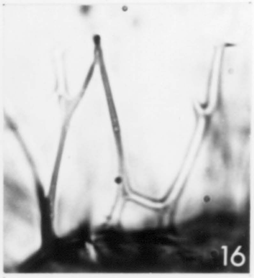
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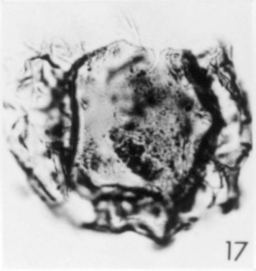
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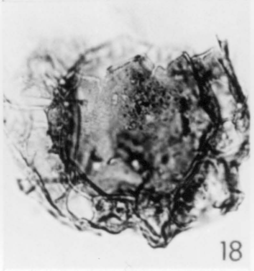
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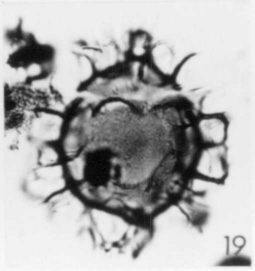
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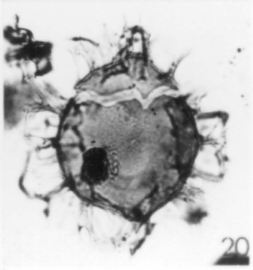
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PLATE 8

Figs. 1-4: *Hystrichosphaeridium tubiferum* (Deflandre 1937) Davey and Williams 1966. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view (focused through specimen). Main body diameter 38um; processes up to 30um long. VPISUPL Sample 312, Slide AO-25, Coords. R9.0;+16.5. figs. 4: Apical view of another specimen showing apical archeopyle and precingular processes. Main body diameter 46um; processes up to 30um long. VPISUPL Sample 306, Slide AO-10, Coords. R4.1;+13.6.

Figs. 5-6: *Hystrichosphaeridium tubiferum* subsp. *brevispinum* (Davey and Williams 1973) Lentin and Williams 1973. Two focal levels of specimen. Fig. 5: Dorso-lateral view (focused through specimen). Fig. 6: Optical cross-sectional view. Main body diameter approximately 40um; processes up to 12um long. VPISUPL Sample 305, Slide AO-9, Coords. R14.3;+9.6.

Figs. 7-9: *Hystrichosphaeridium* cf. *H. tubiferum* (Deflandre 1937) Davey and Williams 1966. Three focal levels of specimen bearing relatively broad processes. Fig. 7: Left lateral view. Fig. 8: Optical cross-sectional view. Fig. 9: Right lateral view (focused through specimen). Main body diameter 45um; processes up to 16um long. VPISUPL Sample 303, Slide AO-1, Coords. R16.6;+13.9.

Figs. 10-11: *Hystrichosphaeridium* spp. Optical cross-sectional views of two specimens. Fig. 10: Main body diameter 26um; processes up to 12um long. VPISUPL Sample 348, Slide AP-23, Coords. R11.5;+13.8. Fig. 11: Main body diameter 25um; processes up to 7um long. VPISUPL Sample 316, Slide AO-35, Coords. R7.6;+4.3.

Figs. 12-13: *Cordosphaeridium? callosum* (Morgenroth 1966) Stover and Evitt 1978. Two focal levels of specimen. Fig. 12: View of uncertain orientation (focused through specimen) showing archeopyle (type uncertain); note operculum inside main body. Fig. 13: Optical cross-sectional view. Main body diameter 25um; processes up to 6um long. VPISUPL Sample 334, Slide AO-77, Coords. R6.6;+12.1.

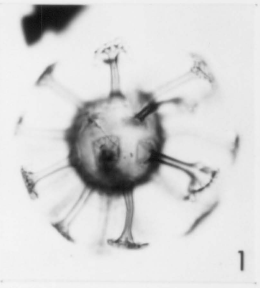
Figs. 14-16: *Nematosphaeropsis pusulosa* (Morgenroth 1966) Stover and Evitt 1978. Three focal levels of specimen. Fig. 14: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 15: Optical cross-sectional view. Fig. 16: Ventral view focused on trabeculate network. Main body L X W: 40um X 36um; processes up to 20um long. VPISUPL Sample 329, Slide AO-64, Coords. R8.1;+2.8.

Figs. 17-18: *Melitasphaeridium pseudorecurvatum* (Morgenroth 1966) Bujak et al. 1980. Fig. 17: Dorsal view with precingular archeopyle evident. Main body L X approximate W: 38um X 30um; processes up to

14um long. Fig. 18: Detailed view of process (13um long). VPISUPL Sample 329, Slide AO-64, Coords. R12.5;+14.7.

Figs. 19-20: *Oligosphaeridium complex* (White 1842) Davey and Williams 1966. Two focal levels of specimen. Fig. 19: Lateral view focused on process tips. Fig. 20: Optical cross-sectional view. Main body diameter 40um; processes up to 29um long. VPISUPL Sample 306, Slide AO-10, Coords. R4.6;+13.0.

PLATE 8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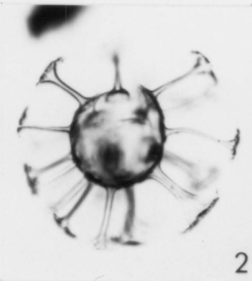
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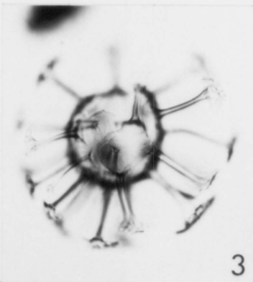
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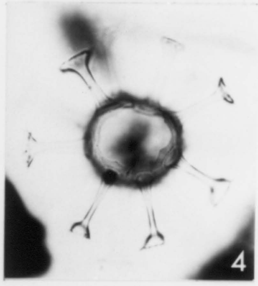
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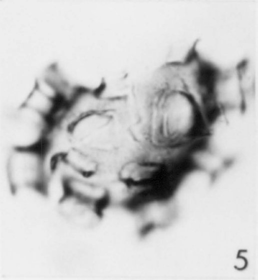
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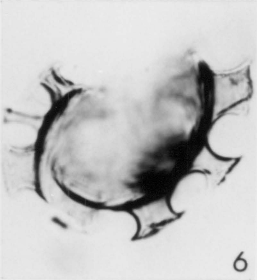
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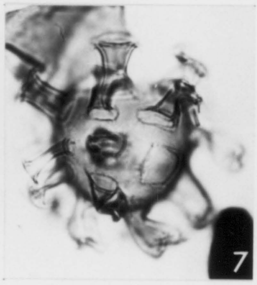
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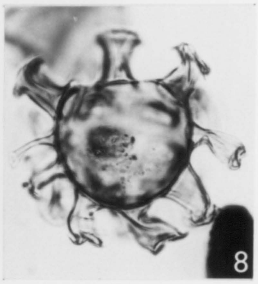
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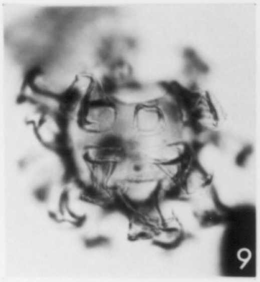
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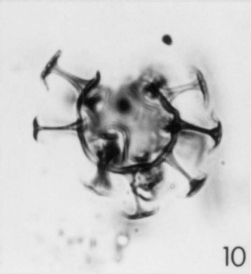
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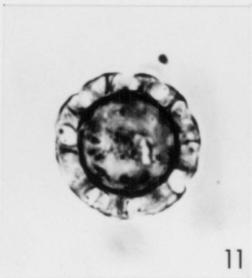
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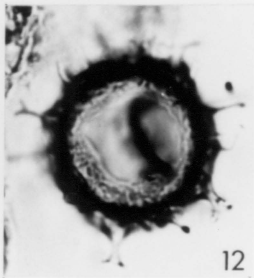
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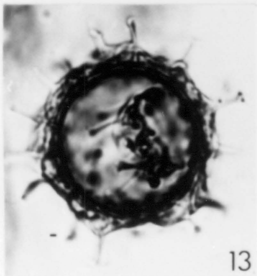
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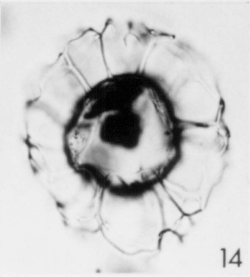
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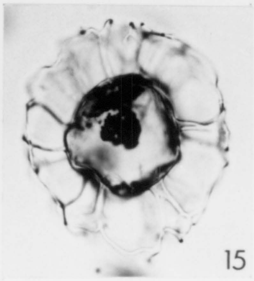
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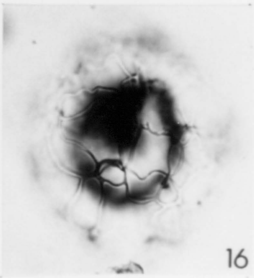
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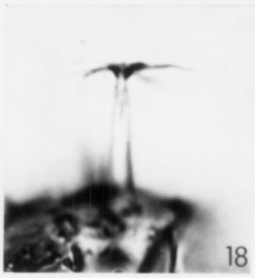
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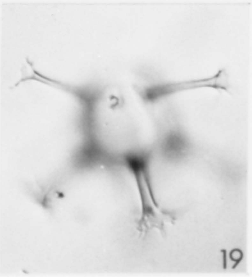
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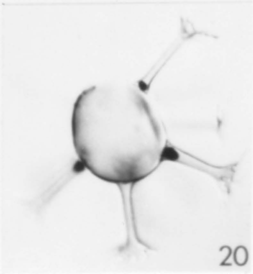
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PLATE 9

Figs. 1-4: *Rottnestia borussica* (Eisenack 1954) Cookson and Eisenack 1961. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorso-lateral view (focused through specimen) showing precingular archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventro-lateral view. Main body L X W: 48um X 41um; processes up to 12um long. Fig. 4: Detailed view of box-like antapical pericoel; approximate L X W: 10um X 30um. VPISUPL Sample 307, Slide AO-15, Coords. R9.1;+15.0.

Figs. 5-8: *Hystrichoshpaeropsis ovum* Deflandre 1935. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view (focused through specimen) exhibiting precingular archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view. Main body L X W: 54um X 52um; overall L X W: 96um X 68um. VPISUPL Sample 348, Slide AP-21, Coords. R6.0;+5.3. Fig. 8: Oblique ventral view of another specimen showing aperture at base of antapical pericoel. Approximate pericoel width 52um. VPISUPL Sample 348, Slide AP-21, Coords. R7.4;+7.7.

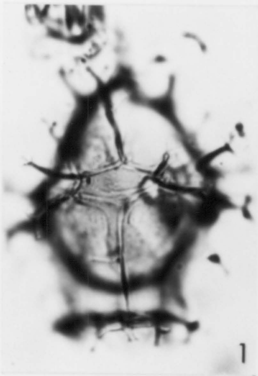
Figs. 9-10: *Fibrocysta* cf. *F. lappacea* (Drugg 1970) Stover and Evitt 1978. Three focal levels of specimen. Fig. 9: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 10: Optical cross-sectional view. Fig. 11: Ventral view. Main body L X W: 74um

X 65um; processes up to 14um long. VPISUPL Sample 324, Slide AO-48, Coords. R14.4;+16.4.

Figs. 12-14: *Fibrocysta bipolare* (Cookson and Eisenack 1965) Stover and Evitt 1978. Three focal levels of specimen. Fig. 12: Dorsal view showing large precingular archeopyle. Fig. 13: Optical cross-sectional view. Fig. 14: Ventral view (focused through specimen). Main body L X W: 82um X 51um; processes up to 26um long. VPISUPL Sample 316, Slide AO-35, Coords. R5.0;+16.5.

Figs. 15-16: *Fibrocysta* sp. A. Two focal levels of specimen. Fig. 15: Lateral view. Fig. 16: Optical cross-sectional view. Main body L X W: 88um X 60um; processes up to 20um long. VPISUPL Sample 303, Slide AO-2, Coords. R16.9;+13.5.

PLATE 9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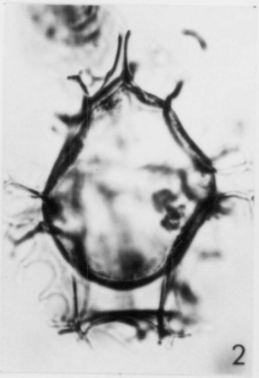
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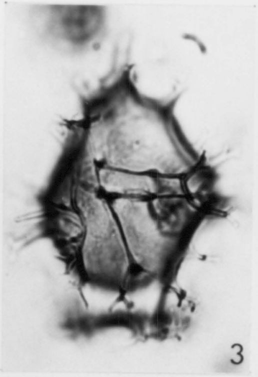
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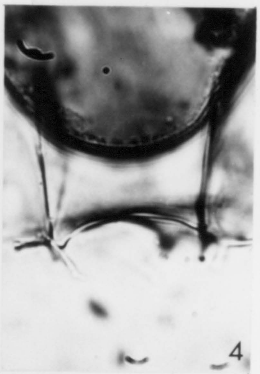
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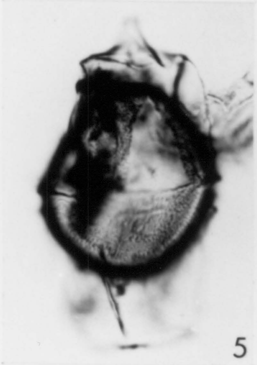
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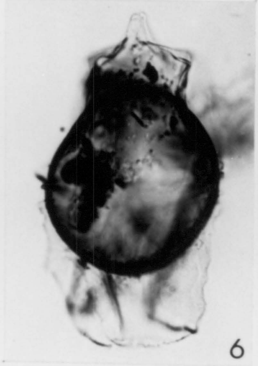
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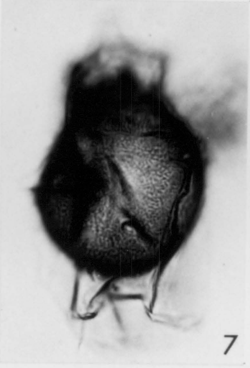
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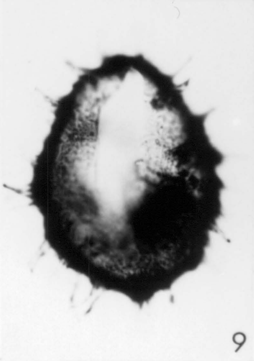
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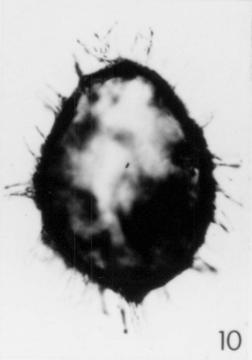
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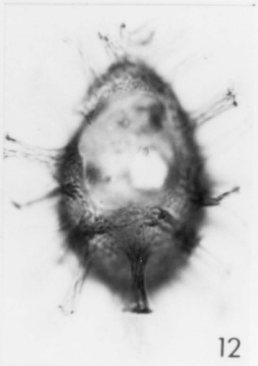
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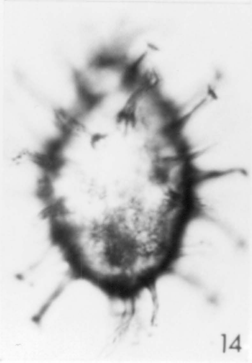
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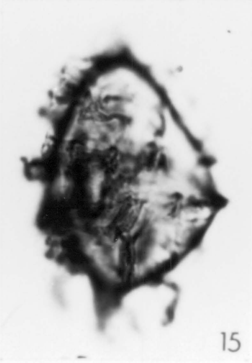
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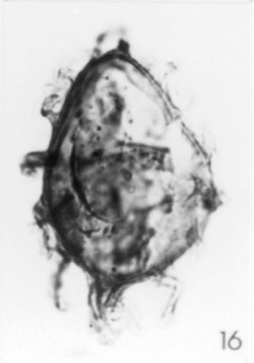
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PLATE 10

Figs. 1-4: *Fibrocysta radiata* (Morgenroth 1966) Stover and Evitt 1978. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view showing precingular archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view (focused through specimen). Main body L X W: 90um X 70um; processes up to 22um long. Fig. 4: Detailed view of apical tuft-like appendage (about 40um long). VPISUPL Sample 329, Slide AO-64, Coords. R16.3;+3.7.

Figs. 5-8: *Fibrocysta coalitospinosa* n. sp. HOLOTYPE (Figs. 5-8): Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view revealing precingular archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view (focused through specimen). Main body L X W: 84um X 74um; processes up to 24um long. Fig. 8: Detailed view of apical cluster of processes and central fibrous shaft (about 30um long). VPISUPL Sample 334, Slide AO-77, Coords. R12.7;+14.4.

Figs. 9-12: *Turbiosphaera paratabulata* n. sp. HOLOTYPE (Figs. 9-11): Three focal levels of specimen. Fig. 9: Dorsal view (focused through specimen) exhibiting precingular archeopyle. Fig. 10: Optical cross-sectional view. Fig. 11: Ventral view; note small parasutural processes. Main body L X W: 114um X 66um; overall L X W: 176um X 86um. VPISUPL Sample 316, Slide AO-35, Coords. R18.6;+7.7. Fig. 12: Lateral view of another specimen with long apical (17um long) and antapical (18um long) protuberances of main body. Main body L X W: 84um X 66um. VPISUPL Sample 316, Slide AO-35, Coords. R5.2;+14.3.

Figs. 13-16: *Turbiosphaera rotunda* n. sp. HOLOTYPE (Figs. 13-15): Three focal levels of specimen. Fig. 13: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 14: Optical cross-sectional view. Fig. 15: Ventral view. Main body L X W: 78um X 78um; overall L X W: 130um X 132um. VPISUPL Sample 316, Slide AO-35, Coords. R12.2.;+9.6. Fig. 16: Lateral optical cross-sectional view of another specimen with operculum inside endocyst. Main body L X W: 90um X 76um; processes up to 30um long. VPISUPL Sample 316, Slide AO-38, Coords. R1.5;+7.7.

PLATE 10


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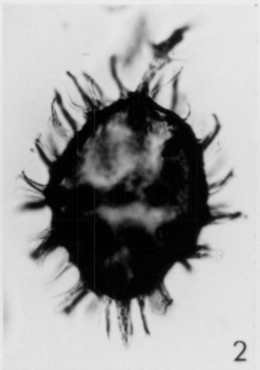
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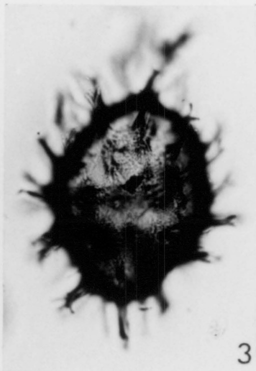
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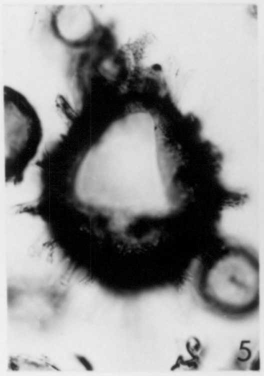
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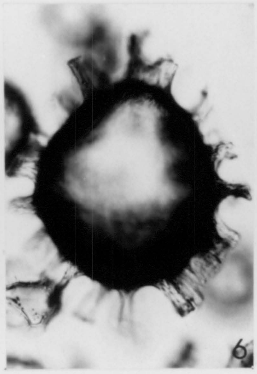
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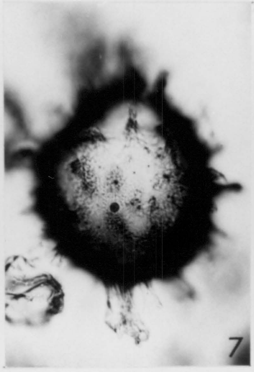
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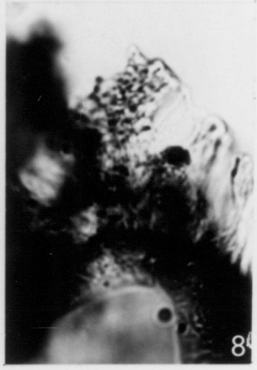
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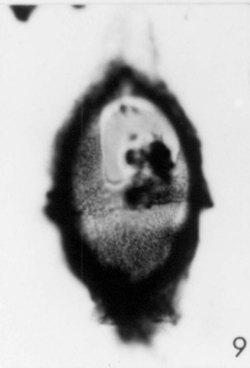
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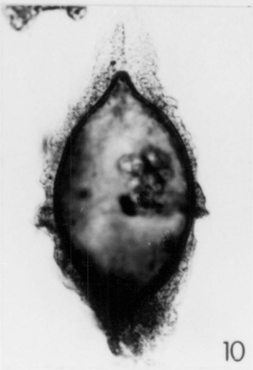
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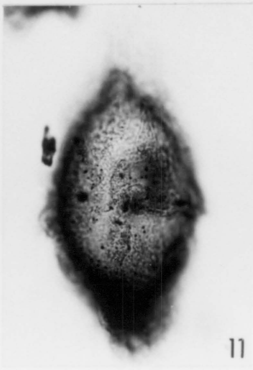
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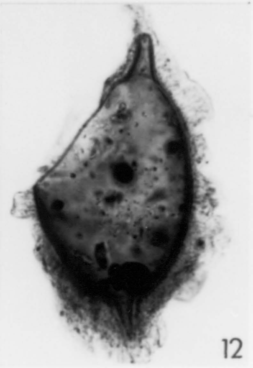
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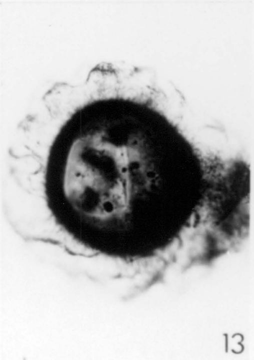
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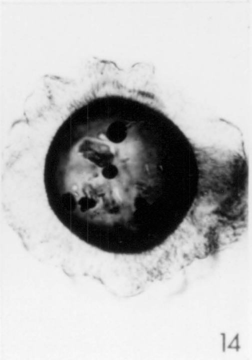
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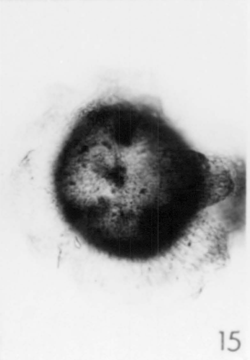
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PLATE 11

Figs. 1-3: *Impagidinium speciosum* n. sp. HOLOTYPE (Figs. 1-3): Three focal levels of specimen. Fig. 1: Dorso-lateral view (focused through specimen) revealing precingular archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventro-lateral view. Overall L X W: 96um X 88um. VPISUPL Sample 317, Slide AO-39, Coords. R4.6;+8.2.

Figs. 4-8: *Impagidinium* cf. *I. speciosum* n. sp. Figs. 4-6: Three focal levels of specimen. Fig. 4: Dorsal view. Fig. 5: Optical cross-sectional view; note relatively long gonal projections. Fig. 6: Ventral view (focused through specimen). Overall L X W: 106um X 100um. VPISUPL Sample 315, Slide AO-33, Coords. R18.8;+16.6. Figs. 7-8: Optical cross-sectional views of two specimens showing variation in gonal projections. Fig. 7: Overall L X W: 98um X 100um; projections up to 19um long. VPISUPL Sample 315, Slide AO-34, Coords. R4.1;+9.3. Fig. 8: Overall L X W: 108um X 98um; projections up to 20um long. VPISUPL Sample 315, Slide AO-33, Coords. R13.2;+10.9.

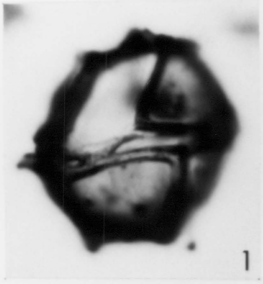
Figs. 9-12: *Impagidinium* sp. A. Figs. 9-11: Three focal levels of specimen. Fig. 9: Dorso-lateral view. Fig. 10: Optical cross-sectional view. Fig. 11: Ventro-lateral view (focused through specimen). Overall L X W: 33um X 30um. Fig. 12: Detailed view of wall structure (up to 6um high). VPISUPL Sample 305, Slide AO-9, Coords. R14.0;+12.8.

Figs. 13-16: *Impagidinium* sp. B. Figs. 13-15: Three focal levels of specimen. Fig. 13: Dorsal view showing precingular archeopyle with operculum in place.

Fig. 14: Optical cross-sectional view. Fig. 15: Ventral view (focused through specimen). Overall L X W: 90um X 84um. Fig. 16: Detailed view of wall structure; grana and bacula up to 5um high. VPISUPL Sample 351, Slide AP-29, Coords. R4.7;+10.7.

Figs. 17-20: *Pentadinium laticinctum* subsp. *granulatum* Gocht 1969. Figs. 17-19: Three focal levels of specimen. Fig. 17: Dorso-lateral view (focused through specimen) showing precingular archeopyle with operculum in place. Fig. 18: Optical cross-sectional view. Fig. 19: Ventro-lateral view. Overall L X W: 102um X 108um. VPISUPL Sample 342, Slide AP-4, Coords. R3.9;+5.9. Fig. 20: Dorsal view of another specimen. Overall L X W: 110um X 108um. VPISUPL Sample 344, Slide AP-11, Coords. R18.3;+10.6.

PLATE 11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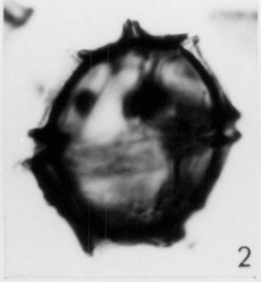
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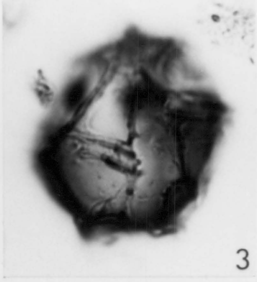
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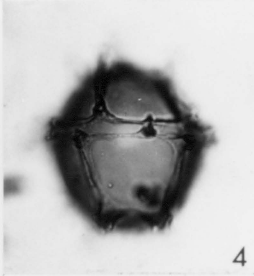
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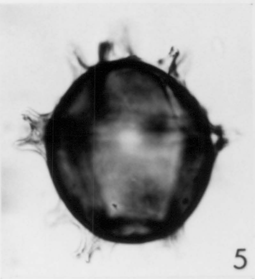
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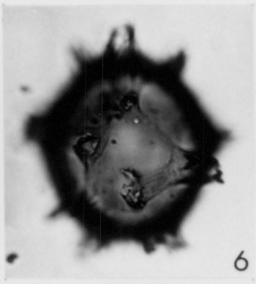
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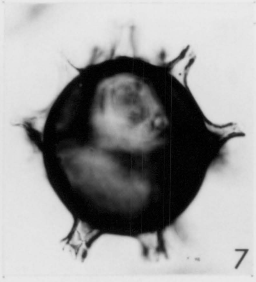
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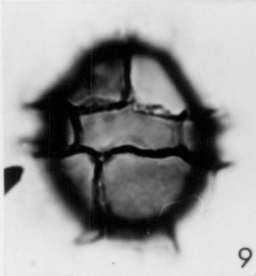
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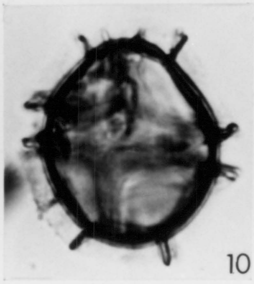
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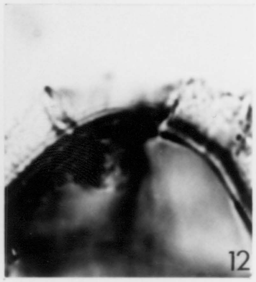
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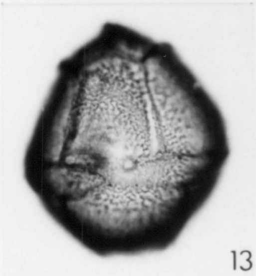
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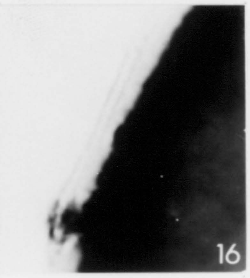
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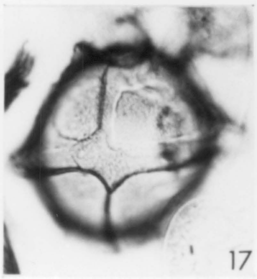
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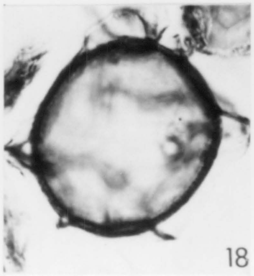
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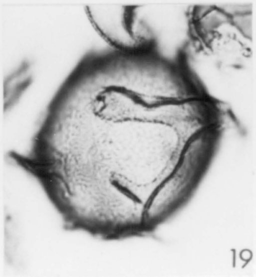
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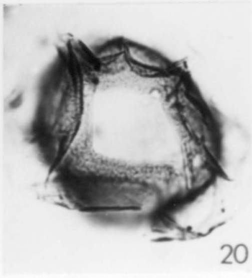
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PLATE 12

Figs. 1-4: *Millioudodinium giuseppei* subsp. *major* (Morgenroth 1966) Stover and Evitt 1978. Figs. 1-2: Two focal levels of specimen. Fig. 1: Dorsal view showing barely visible precingular archeopyle. Fig. 2: Ventral view (focused through specimen). Overall L X W: 110um X 90um. VPISUPL Sample 324, Slide AO-49, Coords. R13.8;+13.4. Fig. 3: Ventral view of another specimen; note parasutures. Overall L X W: 90um X 90um. Fig. 4: Detailed view of wall structure; periphragm thickness up to about 3um. VPISUPL Sample 324, Slide AO-50, Coords. R11.0;+3.5.

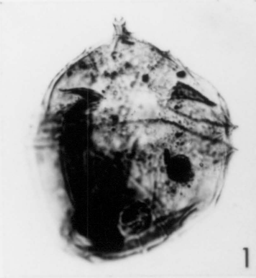
Figs. 5-8: *Scriniodinium (Scriniodinium) australiense* (Deflandre and Cookson 1955) Eisenack 1967. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorso-lateral view (focused through specimen) showing precingular archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventro-lateral view. Overall L X W: 94um X 74um. Fig. 8: Detailed view of wall structure; periphragm thichness up to about 5.5um. VPISUPL Sample 332, Slide AO-75, Coords. R7.7;+9.9.

Figs. 9-14: *Alisocysta* cf. *A. margarita* Harland 1979. Figs. 9-11: Three focal levels of specimen. Fig. 9: Dorsal view (focused through specimen); note apical archeopyle. Fig. 10: Optical cross-sectional view. Fig. 11: Ventral view. Main body L (excl. operculum) X W: 40um X 44um; processes up to 10um long. Fig. 12: Detailed view of process (9um long). VPISUPL Sample 314, Slide AO-29, Coords. R3.4;+8.7. Fig. 13: Optical cross-sectional view of another specimen with processes of different contruction. Main body L (excl. operculum) X W: 50um X 60um; processes up to 12um long. Fig. 14: Detailed view of process (11um long). VPISUPL Sample 312, Slide AO-24, Coords. R14.5;+20.9.

Figs. 15-17: *Hystrichokolpoma mentitum* McLean 1974. Three focal levels of specimen. Fig. 15: Dorsal view. Fig. 16: Optical cross-sectional view. Fig. 17: Ventral view (focused through specimen). Main body L X W: 44um X 40um; processes up to 13um long. VPISUPL Sample 310, Slide AO-20, Coords. R19.0;+5.8.

Figs. 18-20: *Conneximura fimbriata* (Morgenroth 1968) May 1980. Three focal levels of specimen. Fig. 18: Left lateral view. Fig. 19: Optical cross-sectional view. Fig. 20: Right lateral view (focused through specimen). Main body L X W: 52um X 50um; processes up to 25um long. VPISUPL Sample 307, Slide AO-15, Coords. R5.5;+9.2.

PLATE 12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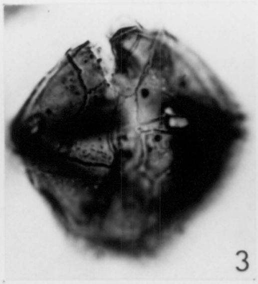
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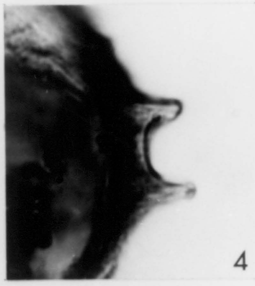
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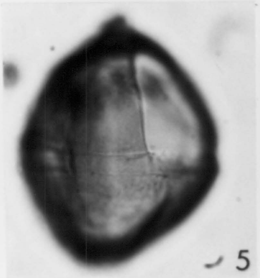
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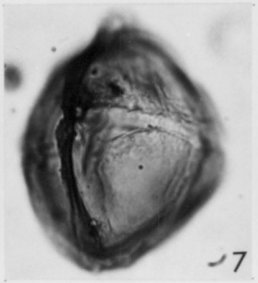
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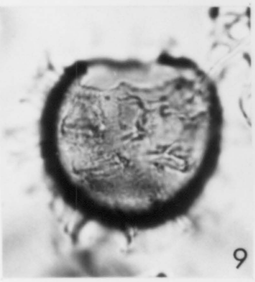
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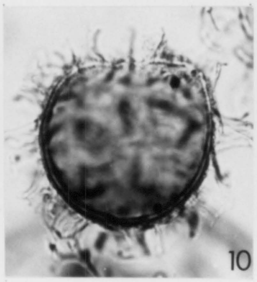
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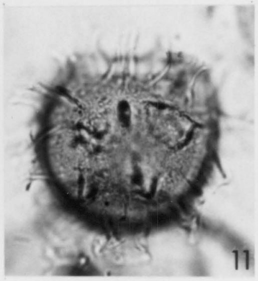
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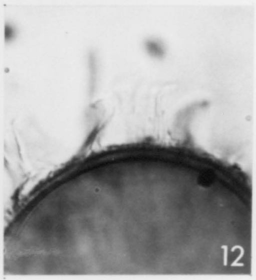
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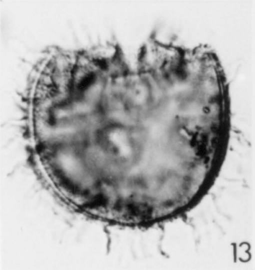
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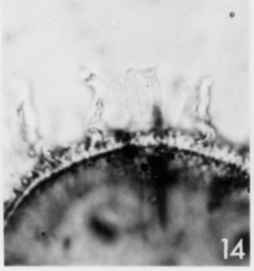
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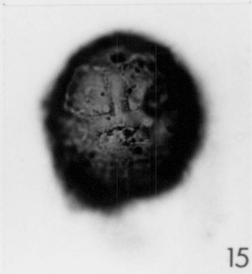
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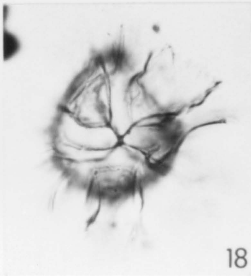
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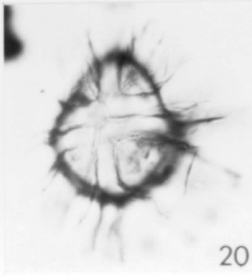
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PLATE 13

Figs. 1-4: *Nematosphaeropsis trabeculata* n. sp. HOLOTYPE (Figs. 1-3): Figs. 1-3: Three focal levels of specimen with most of the trabeculae interconnecting the process tips still present; characteristic larger antapical processes most evident in Fig. 2. Fig. 1: Right-lateral view; small spheroid barely visible within cyst main body is *Micrhystridium* acritarch. Fig. 2: Optical cross-sectional view. Fig. 3: Left-lateral view (focused through specimen). Main body L X W: 44um X 34um; antapical processes up to 17um long; remaining processes up to 15um long. VPISUPL Sample 316, Slide AO-35, Coords. R19.5;+3.6. Fig. 4: Dorsal view of another specimen displaying precingular archeopyle with partially dislodged operculum; specimen has most of its trabeculae torn away,,but some remnants can be seen on a few of the process tips. Main body L X W: 42um X 35um; processes up to 17um long. VPISUPL Sample 314, Slide AO-29, Coords. R17.7;+17.5.

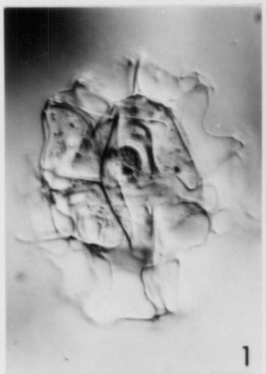
Figs. 5-8: *Nematosphaeropsis pertusa* n. sp. HOLOTYPE (Figs. 5-8): Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view. Main body L X W: 62um X 46um; processes (other than apical) up to 30um long. Fig. 8: Detailed view of apical process (40um long). VPISUPL Sample 304, Slide AO-5, Coords. R21.3;+20.6.

Figs. 9-11: *Nematosphaeropsis* cf. *N. pertusa* n. sp. Three focal levels of specimen. Fig. 9: Dorso-lateral view. Fig. 10: Optical cross-sectional view; note precingular operculum within endocyst. Fig. 11: Ventro-lateral view (focused through specimen). Main body L X W: 56um X 38um; processes up to 24um long. VPISUPL Sample 312, Slide AO-25, Coords. R17.3;+16.8.

Figs. 12-13: *Distatodinium paradoxum* (Brosius 1963) Eaton 1976. Lateral views of two specimens; note branching process tips. Fig. 12: Main body approximate width 30um; processes up to 18um long. VPISUPL Sample 346, Slide AP-14, Coords. R4.0;+19.1. Fig. 13: Main body approximate width L X W: 35um X 20um; processes up to 20um long. VPISUPL Sample 351, Slide AP-29, Coords. R12.0;+18.8.

Figs. 14-16: *Silicisphaera ferox* (Deflandre 1937) Davey and Verier 1976. Three focal levels of specimen. Fig. 14: Dorso-lateral view showing precingular archeopyle. Fig. 15: Optical cross-sectional view. Fig. 16: Ventro-lateral view (focused through specimen). Main body L X W: 67um X 57um; processes up to 23um long. VPISUPL Sample 307, Slide AO-16, Coords. R18.3;+11.5.

PLATE 13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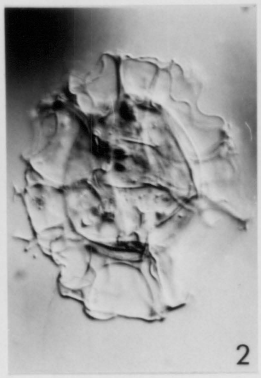
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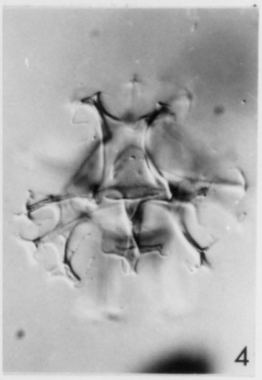
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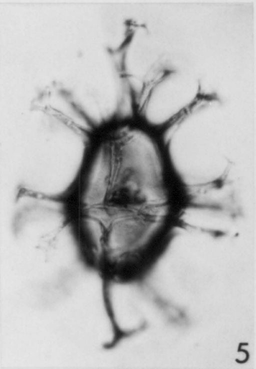
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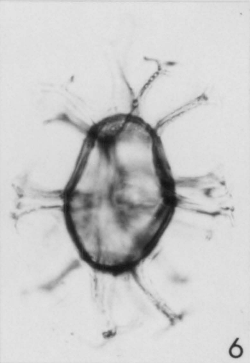
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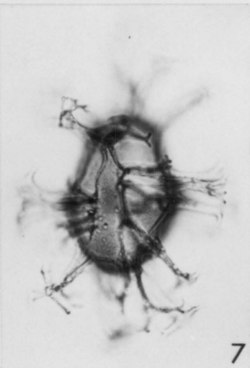
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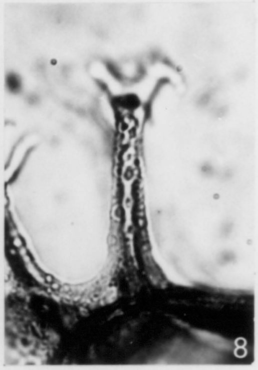
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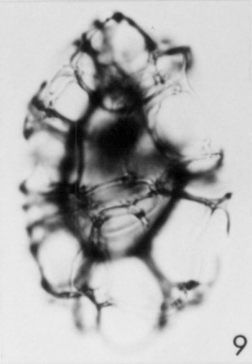
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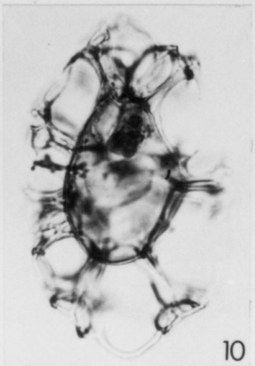
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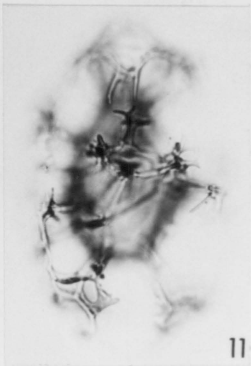
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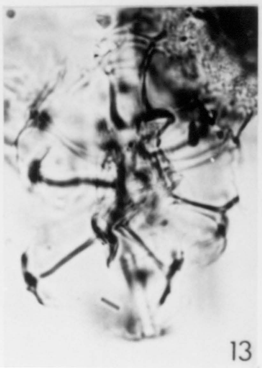
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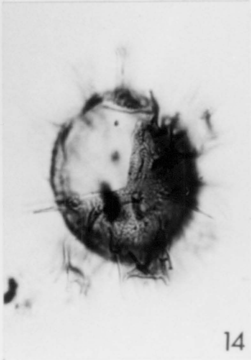
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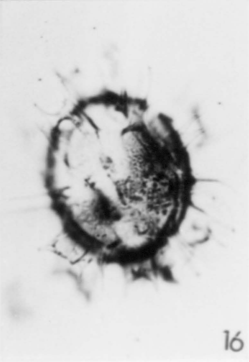
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PLATE 14

Figs. 1-4: *Operculodinium brevispinosum* n. sp. HOLOTYPE (Figs. 1-3): Figs. 1-2: Two focal levels of specimen. Fig. 1: Dorsal view. Fig. 2: Optical cross-sectional view. Main body diamter approximately 42um. Fig. 3: Detailed view of wall; spines up to 2um long. VPISUPL Sample 334, Slide AO-77, Coords. R17.9;+4.5. Fig. 4: Optical cross-sectional view of another specimen showing variety of spines. Main body diameter 50um; spines up to 2um long. VPISUPL Sample 331, Slide AO-70, Coords. R9.9;+7.3.

Fig. 5: *Operculodinium* cf. *O. brevispinosum* n. sp. Dorsal view of specimen with precingular (Type 2P) archeopyle. Main body diameter 40um; spines up to 2um long. VPISUPL Sample 331, Slide AO-70, Coords. R9.7;+18.7.

Figs. 6-8: *Operculodinium multispinosum* n. sp. HOLOTYPE (Figs. 6-8): Figs. 6-7: Two focal levels of specimen. Fig. 6: Dorsal view (focused through specimen) with precingular archeopyle evident. Fig. 7: Optical cross-sectional view. Main body diameter 33um. Fig. 8: Detailed view of spines (up to 5um long). VPISUPL Sample 337, Slide AO-84, Coords. R15.1;+11.4.

Figs. 9-12: *Operculodinium variespinosum* n. sp. HOLOTYPE (Figs. 9-11): Fig. 9: Dorsal view displaying precingular archeopyle. Fig.

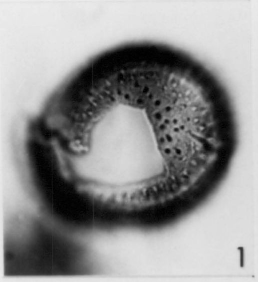
10: Optical cross-sectional view. Main body L X W: 52um X 40um. Fig. 11: Detailed view of spines (up to 3um long). VPISUPL Sample 347, Slide AP-19, Coords. R18.0;+14.7. Fig. 12: Optical cross-sectional view of another specimen showing other spine types. Main body L X W: 46um X 38um; spines up to 4um long. VPISUPL Sample 349, Slide AP-26, Coords. R11.8;+12.1.

Figs. 13-14: *Operculodinium israelianum* (Rossignol 1962) Wall 1967. Two focal levels of specimen. Fig. 13: Lateral view. Fig. 14: Optical cross-sectional view. Main body diameter 54um; spines up to 5um long. VPISUPL Sample 324, Slide AO-48, Coords. R16.2;+8.1.

Figs. 15-17: *Operculodinium centrocarpum* (Deflandre and Cookson 1955) Wall 1967. Three focal levels of specimen. Fig. 15: Dorsal view showing precingular archeopyle. Fig. 16: Optical cross-sectional view. Fig. 17: Ventral view (focuseed through specimen). Main body diameter 68um; spines up to 17um long. VPISUPL Sample 351, Slide AP-29, Coords. R9.7;+15.4.

Figs. 18-20: *Tectotodinium pellitum* Wall 1967. Figs. 18-19: Two focal levels of specimen. Fig. 18: Dorsal view exhibiting precingular archeopyle. Fig. 19: Optical cross-sectional view. Diamter 49um. VPISUPL Sample 339, Slide AO-91, Coords. R12.5;+19.3. Fig. 20: Optical cross-sectional view of another specimen with thick wall. Diameter 54um. VPISUPL Sample 334, Slide AO-77, Coords. R18.1;+5.4.

PLATE 14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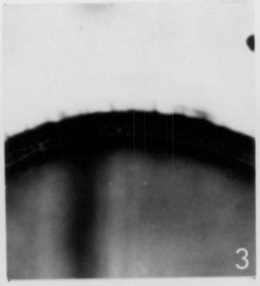
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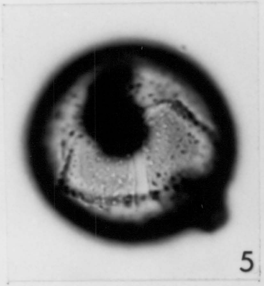
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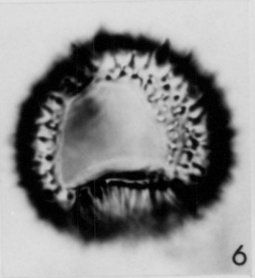
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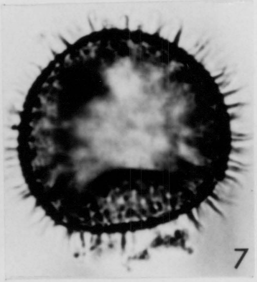
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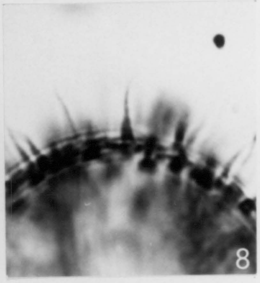
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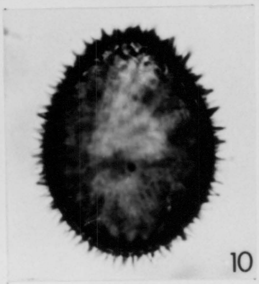
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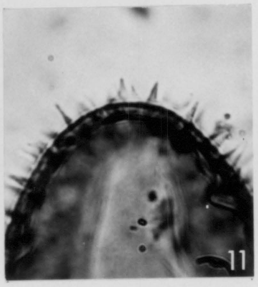
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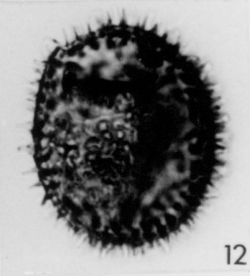
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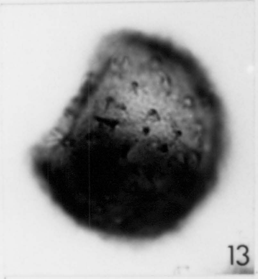
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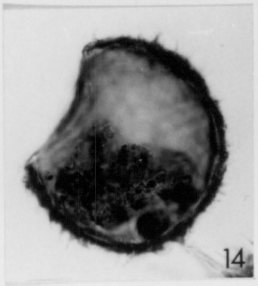
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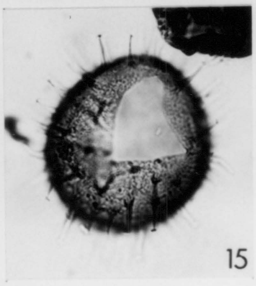
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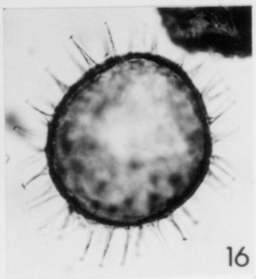
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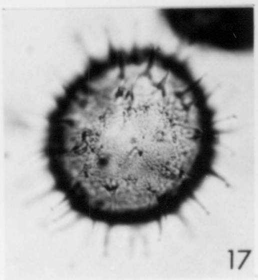
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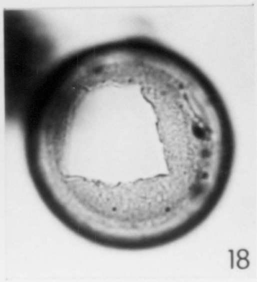
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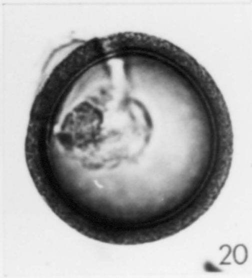
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PLATE 15

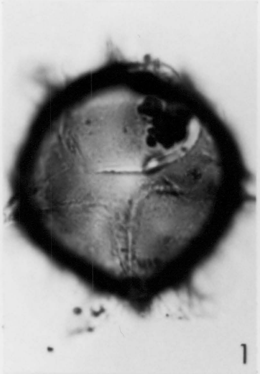
Figs. 1-4: *Muratodinium fimbriatum* (Cookson and Eisenack 1967) Drugg 1970. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen) showing precingular archeopyle with operculum in place. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Main body L X W: 72um X 68um; walls up to 15um high. Fig. 4: Detailed view of lace-like wall (about 14um high). VPISUPL Sample 331, Slide AO-70, Coords. R8.6;+18.2.

Figs. 5-8: *Samlandia chlamydophora* Eisenack 1954. Figs. 5 -7: Three focal levels of specimen. Fig. 5: Dorsal view revealing precingular archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view (focused through specimen). Main body L X W: 105um X 80um; individual columns up to 13um long. Fig. 8: Detailed view of periphragm at apex; individual columns about 11um long. VPISUPL Sample 336, Slide AO-82, Coords. R8.5;+7.0.

Figs. 9-12: *Samlandia reticulifera* subsp. *minor* n. subsp. HOLOTYPE (Figs. 9-12): Figs. 9-11: Three focal levels of specimen. Fig. 9: Dorsal view (focused through specimen) exhibiting precingular archeopyle with operculum in place. Fig. 10: Optical cross-sectional view. Fig. 11: Ventral view. Main body L X W: 38um X 34um. Fig. 12: Detailed plan view of trabeculate periphragm; individual trabeculae about 0.5um thick. VPISUPL Sample 309, Slide AO-19, Coords. R20.4;+19.3.

Figs. 13-16: *Turbiosphaera filosa* (Wilson 1967) Archangelsky 1969. Figs. 13-15: Three focal views of specimen. Fig. 13: Dorsal view showing precingular archeopyle. Fig. 14: Optical cross-sectional view. Fig. 15: Ventral view (focused through specimen). Main body L X W: 94um X 76um; processes up to 27um long. Fig. 16: Detailed view of process (27um long). VPISUPL Sample 312, Slide AO-24, Coords. R5.7;+15.8.

PLATE 15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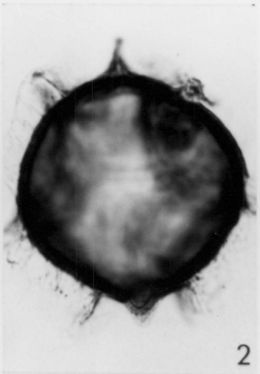
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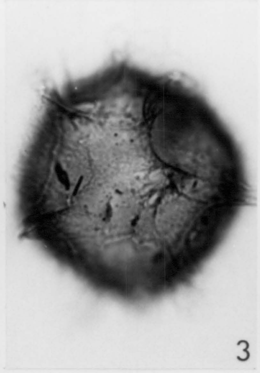
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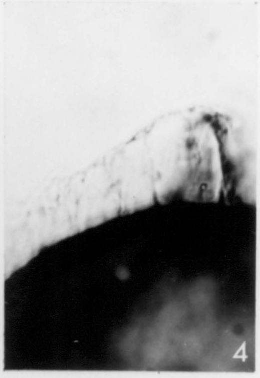
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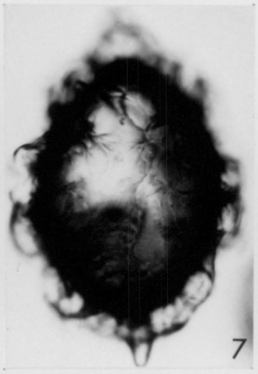
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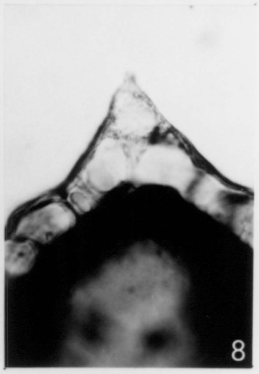
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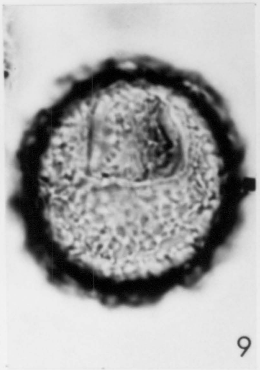
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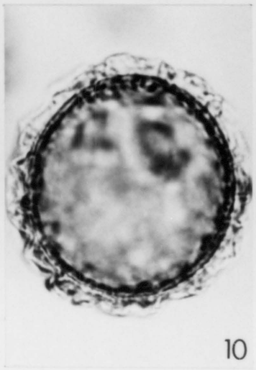
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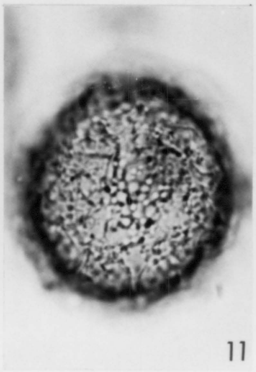
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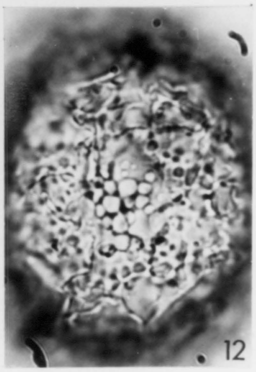
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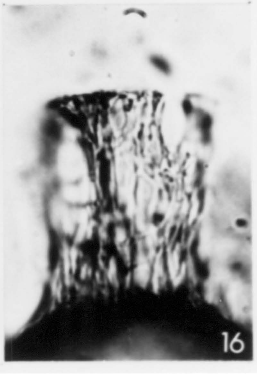
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PLATE 16

Figs. 1-3: *Chiropteridium partispinatum* (Gerlach 1961) Brosius 1963. Three focal levels of specimen. Fig. 1: Dorsal view. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view (focused through specimen). Main body L X W: 76um X 80um; processes up to 22um long. VPISUPL Sample 341, Slide AP-1, Coords. R20.8;+17.3.

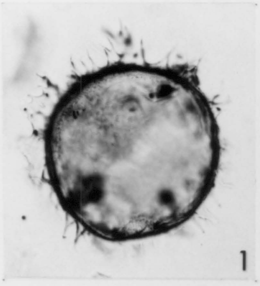
Figs. 4-8: *Cleistosphaeridium diversispinosum* complex. Fig. 4: Apical view (focused through specimen) showing apical archeopyle. Maximum width 50um; processes up to 20um long. VPISUPL Sample 337, Slide AO-83, Coords. R17.7;+12.5. Figs. 5-6: Two focal levels of specimen with seemingly random and some soleate/annulate process complex development; note variable distal process tips (compare this specimen with one illustrated in Fig. 8). Fig. 5: Dorsal view. Fig. 6: Ventral view (focused through specimen). Main body L (excl. operculum) X W: 50um X 62um; processes up to 22um long. Fig. 7: Detailed view of processes (up to 20um long) with flared tips. VPISUPL Sample 337, Slide AO-83, Coords. R11.0;+11.4. Fig. 8: Dorsal view (focused through specimen) of another form in this species complex with soleate to annulate process complexes; specimen displays processes with extremely variable tips. Main body L (excl. operculum) X W: 50um X 56um; processes up to 28um long. VPISUPL Sample 337, Slide AO-83, Coords. R11.0;+11.4.

Figs. 9-13: *Systematophora placacantha* (Deflandre and Cookson 1955) Davey et al., 1969. Figs. 9-10: Two focal levels of specimen; note annulate precingular and postcingular and linear paracingular process complexes. Fig. 9: Dorsal view. Fig. 10: Ventral view (focused through specimen). Main body L (excl. operculum) X W: 58um X 64um; processes up to 26um long. VPISUPL Sample 306, Slide AO-10, Coords. R7.6;+15.2. Fig. 11: Dorsal view of complete specimen with operculum in place. Main body L X W: 68um X 61um; processes up to 26um long. VPISUPL Sample 307, Slide AO-15, Coords. R11.7;+20.3. Figs. 12-13: Two focal levels of another specimen. Fig. 12: Apical view (focused through specimen) showing apical archeopyle. Fig. 13: Antapical view displaying large antapical process complex. Maximum width 68um; processes up to 22um long. VPISUPL Sample 327, Slide AO-59, Coords. R11.6;+6.3.

Figs. 14-16: *Renidinium* sp. A. Three focal levels of specimen. Fig. 14: Dorsal view (focused through specimen). Fig. 15: Optical cross-sectional view. Fig. 16: Ventral view. Overall L (excl. operculum) X W: 60um X 62um; main body L (excl. operculum) X W: 46um X 52um. VPISUPL Sample 329, Slide AO-64, Coords. R5.3;+7.3.

Figs. 17-20: *Renidinium membraniforum* Morgenroth 1968. Figs. 17-19: Three focal levels of specimen. Fig. 17: Dorsal view (focused through specimen). Fig. 18: Optical cross-sectional view. Fig. 19: Ventral view. Overall L (excl. operculum) X W: 71um X 77um; main body L (excl. operculum) X W: 60um X 68um. VPISUPL Sample 315, Slide AO-34, Coords. R5.4;+15.1. Fig. 20: Ventral view of another complete specimen with operculum in place. Overall L X W: 82um X 72um; main body L X W: 68um X 62um. VPISUPL Sample 315, Slide AO-33, Coords. R19.9;+2.6.

PLATE 16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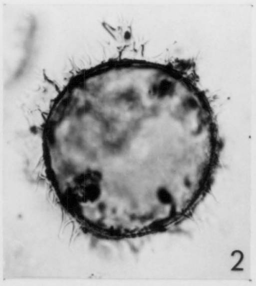
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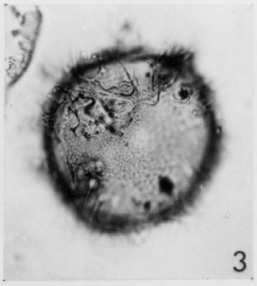
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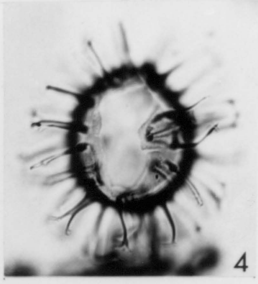
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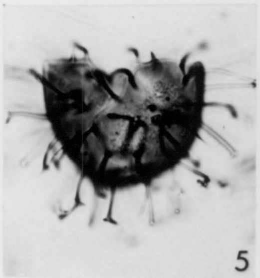
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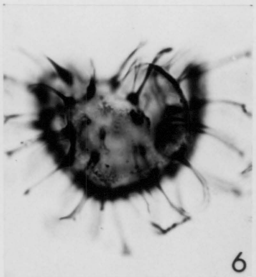
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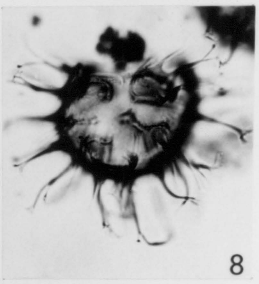
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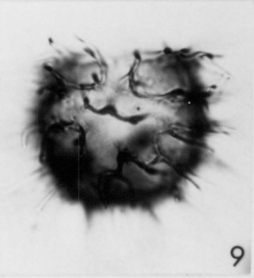
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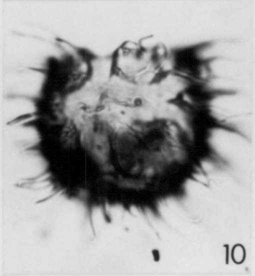
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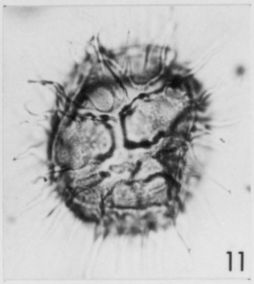
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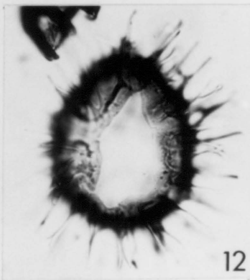
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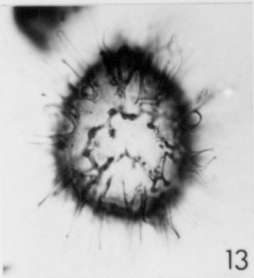
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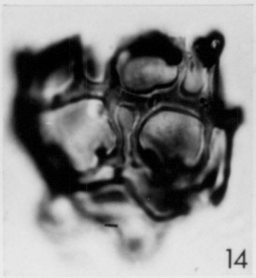
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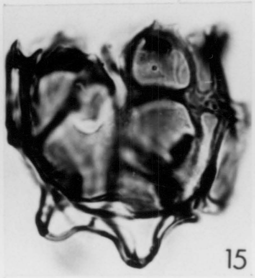
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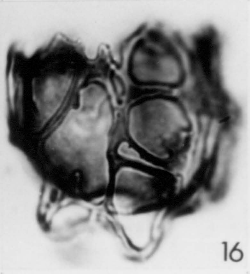
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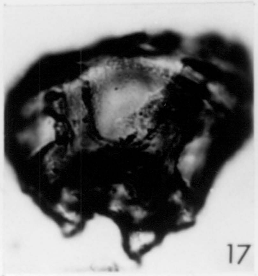
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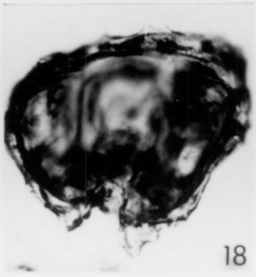
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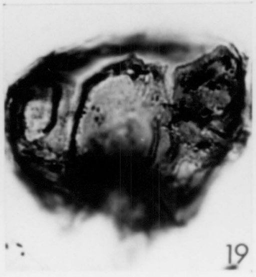
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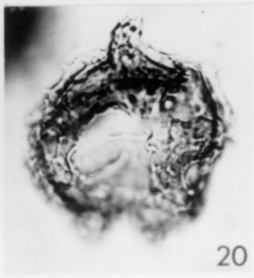
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PLATE 17

Figs. 1-4: *Spiniferites cingulatus* (O. Wetzel 1933) Sarjeant 1970. Three focal levels of specimen. Fig. 1: Dorso-lateral view; precingular archeopyle is to upper right of specimen. Fig. 2: Optical cross-sectional view. Fig. 3: Ventro-lateral view (focused through specimen). Main body L X W: 40um X 32um; processes up to 9um long. Fig. 4: Detailed view of crest and process (up to 7um high). VPISUPL Sample 339, Slide AO-92, Coords. R8.2;+6.9.

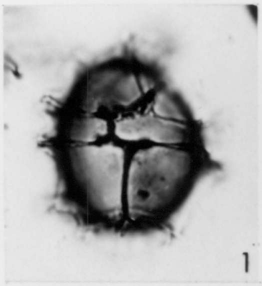
Figs. 5-8: *Spiniferites crassipellis* subsp. A. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view showing precingular archeopyle.. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view (focused through specimen). Main body diameter 43um; processes up to 17um long. Fig. 8: Detailed view of process (17um long). VPISUPL Sample 329, Slide A)-64, Coords. R9.6;+18.3.

Figs. 9-12: *Spiniferites crassipellis* subsp. B. Figs. 9-11: Three focal levels of specimen. Fig. 9: Left lateral view. Fig. 10: Optical cross-sectional view. Fig. 11: Right lateral view (focused through specimen). Main body diameter 70um; processes up to 22um. Fig. 12: Detailed view of process (19um long). VPISUPL Sample 318, Slide AO-41, Coords. R1.6;+2.5.

Figs. 13-16: *Spiniferites crassipellis* subsp. C. Figs. 13-15: Three focal levels of specimen. Fig. 13: Dorso-lateral view (focused through specimen) displaying precingular archeopyle. Fig. 14: Optical cross-sectional view. Fig. 15: Ventro-lateral view. Main body diameter 50um; processes up to 16um long. Fig. 16: Detailed view of process (15um long). VPISUPL Sample 351, Slide AP-29, Coords. R17.0;+4.0.

Figs. 17-20: *Spiniferites monilis* (Davey and Williams 1966) Sarjeant 1970. Figs. 17-19: Three focal levels of specimen. Fig. 17: Dorsal view; note partially dislodged operculum in precingular archeopyle. Fig. 18: Optical cross-sectional view. Fig. 19: Ventral view (focused through specimen). Main body L X W: 42um X 38u; processes up to 16um long. Fig. 20: Detailed plan view of mesh-like surface (openings up to 0.5um). VPISUPL Sample 331, Slide AO-70, Coords. R6.8;+17.1.

PLATE 17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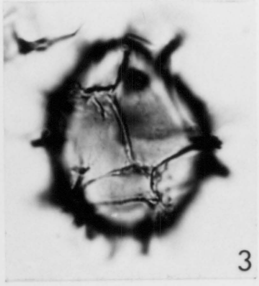
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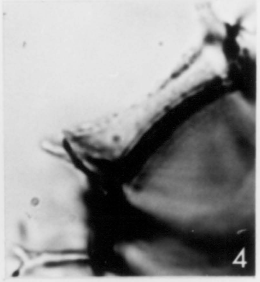
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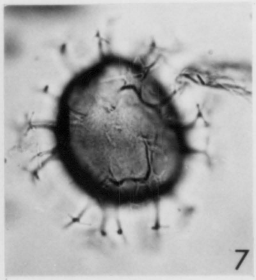
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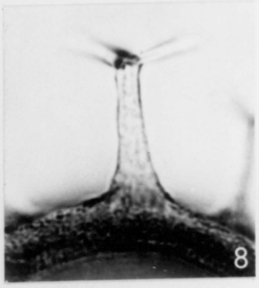
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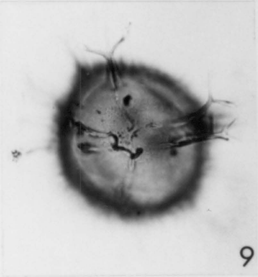
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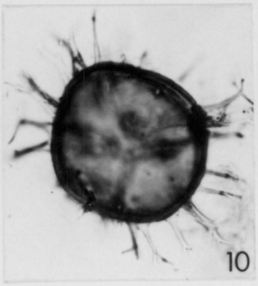
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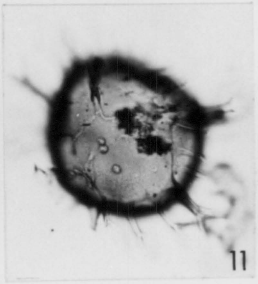
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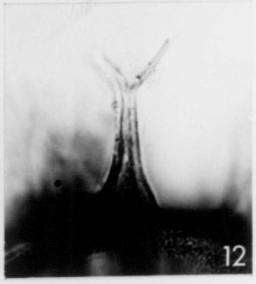
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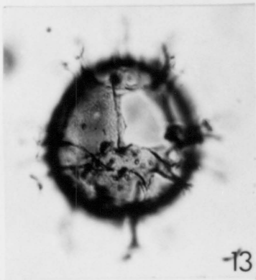
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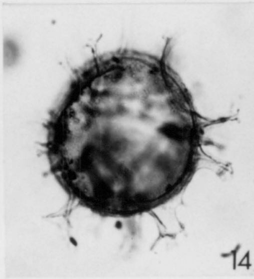
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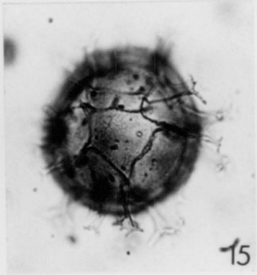
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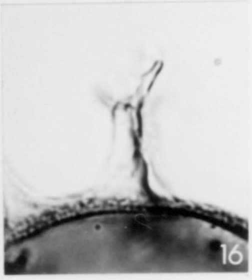
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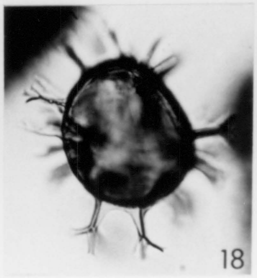
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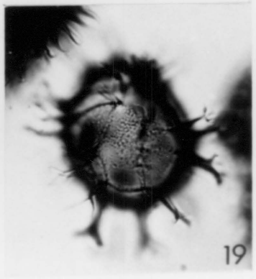
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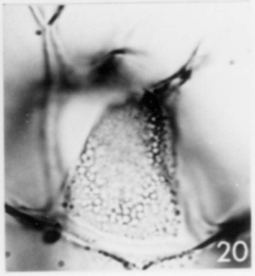
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PLATE 18

Figs. 1-4: *Spiniferites cornutus* subsp. A. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen) showing precingular archeopyle with operculum in place. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Main body L X W: 66um X 48um; processes up to 22um long. Fig. 4: Detailed view of extremely long apical process (45um long). VPISUPL Sample 305, Slide AO-8, Coords. R16.0;+10.3.

Figs. 5-8: *Spiniferites cornutus* subsp. B. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view (focused through specimen) exhibiting precingular archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view. Main body L X W: 57um X 45um; processes up to 17um long. Fig. 8: Detailed view of long apical process (22um long). VPISUPL Sample 307, Slide AO-16, Coords. R14.2;+5.6.

Figs. 9-12: *Spiniferites cornutus* subsp. C. Figs. 9-11: Three focal levels of specimen. Fig. 9: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 10: Optical cross-sectional view. Fig. 11: Ventral view. Main body L X W: 60um X 40um; processes up to 17um long. Fig. 12: Detailed view of long apical process (20um long). VPISUPL Sample 317, Slide AO-39, Coords. R9.3;+11.6.

Figs. 13-16: *Spiniferites mirabilis* (Rossignol 1963) Sarjeant 1970. Figs. 13-15: Three focal levels of specimen. Fig. 13: Dorsal view. Fig. 14: Optical cross-sectional view; note large antapical pericoel and numerous small processes on this structure. Fig. 15: Ventral view (focused through specimen). Main body L X W: 66um X 60um; processes up to 17um long. Fig. 16: Detailed view of antapical pericoel; L X W: 18um X 27um. VPISUPL Sample 340, Slide AO-95, Coords. R4.7;+11.7.

PLATE 18


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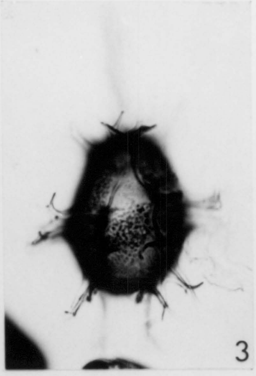
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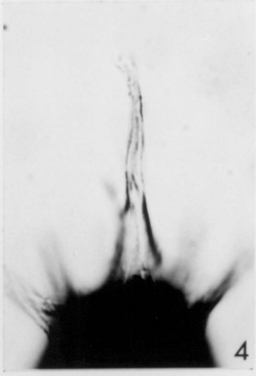
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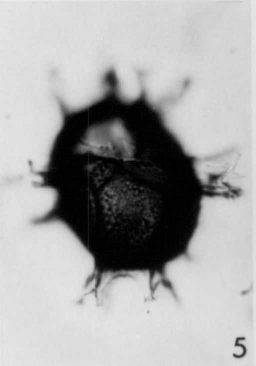
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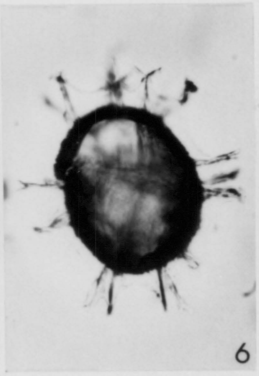
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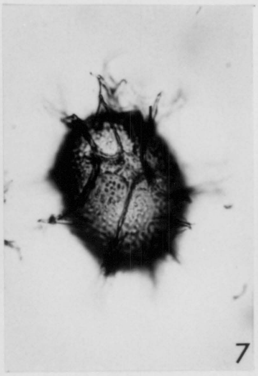
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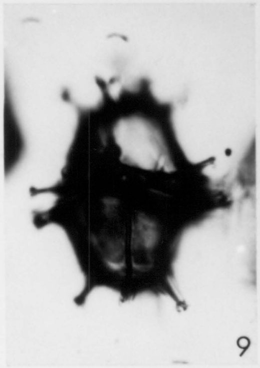
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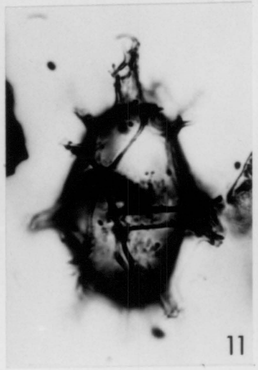
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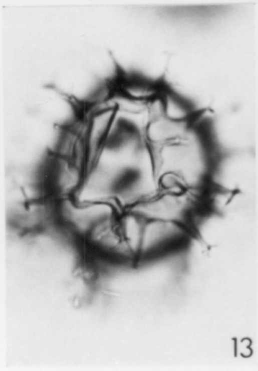
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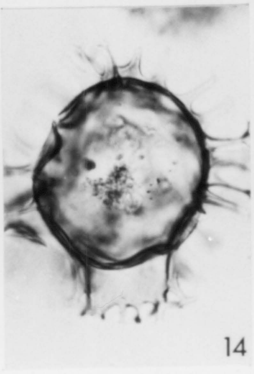
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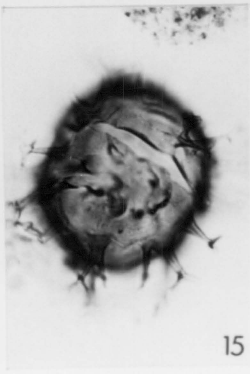
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PLATE 19

Figs. 1-4: *Spiniferites pseudofurcatus* (Klumpp 1953) Sarjeant 1970. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen) with precingular archeopyle clearly visible. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Main body L X W: 66um X 60um; processes up to 26um long. Fig. 4: Detailed view of process (23um long). VPISUPL Sample 329, Slide AO-64, Coords. R5.9;+10.5.

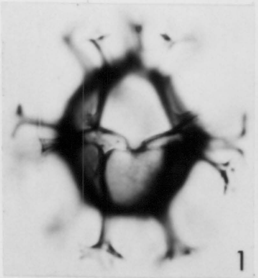
Figs. 5-8: *Spiniferites* cf. *S. pterotus* (Cookson and Eisenack 1959) Sarjeant 1970. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view showing precingular archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view (focused through specimen). Main body L X W: 52um X 50um; processes up to 12um long. Fig. 8: Detailed view of crest and process (up to 11um high). VPISUPL Sample 309, Slide AO-19, Coords. R13.8;+11.7.

Figs. 9-12: *Spiniferites ramosus* subsp. *granomembranaceus* (Davey and Williams 196) Lentin and Williams 1973. Figs. 9-11: Three focal levels of specimen. Fig. 9: Right lateral view. Fig. 10: Optical cross-sectional view; note extensive membrane development. Fig. 11: Left lateral view (focused through specimen). Main body L X W: 41um X 37um; individual processes up to 18um long. Fig. 12: Detailed view of membrane (height incl. processes up to 20um). VPISUPL Sample 303, Slide AO-2, Coords. R20.6;+17.2.

Figs. 13-16: *Spiniferites ramosus* subsp. *granosus* (Davey and Williams 1966) Lentin and Williams 1973. Figs. 13-15: Three focal levels of specimen. Fig. 13: Dorso-lateral view (focused through specimen). Fig. 14: Optical cross-sectional view. Fig. 15: Ventro-lateral view. Main body L X W: 37um X 28um; processes up to 13um long. Fig. 16: Detailed view of processes (up to 12um long). VPISUPL Sample 303, Slide AO-2, Coords. R12.5;+17.2.

Figs. 17-20: *Spiniferites ramosus* subsp. *membranaceus* (Rossignol 1964) n. comb. Figs. 17-19: Three focal levels of specimen. Fig. 17: Dorsal view displaying precingular archeopyle. Fig. 18: Optical cross-sectional view. Fig. 19: Ventral view (focused through specimen). Main body L X W: 37um X 36um; individual processes up to 20um long. Fig. 20: Detailed view of membrane (height incl. processes up to 18um). VPISUPL Sample 307, Slide AO-15, Coords. R1.7;+6.8.

PLATE 19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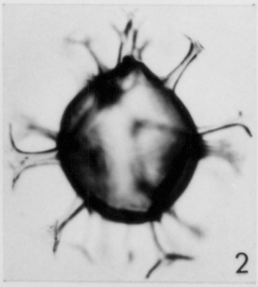
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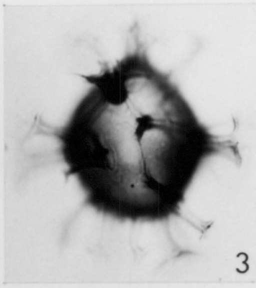
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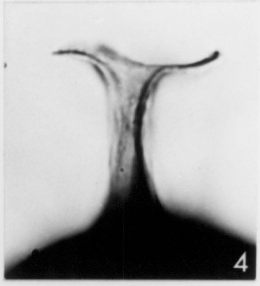
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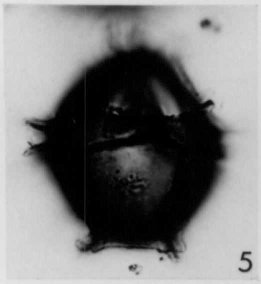
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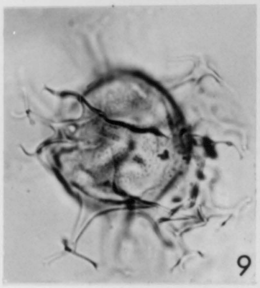
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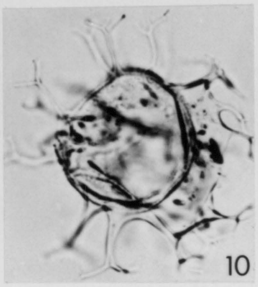
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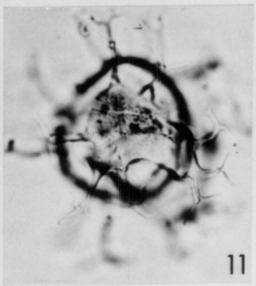
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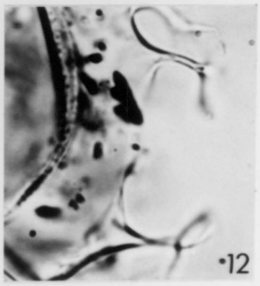
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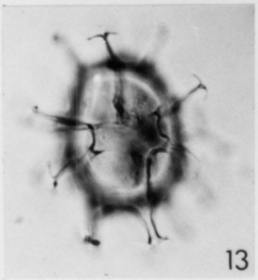
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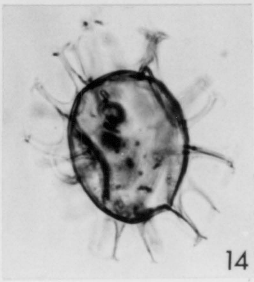
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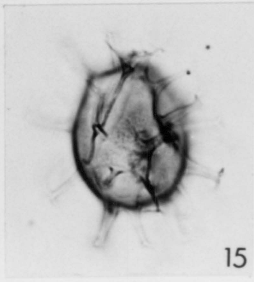
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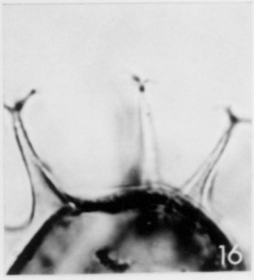
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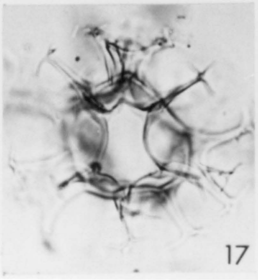
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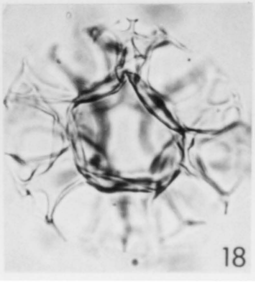
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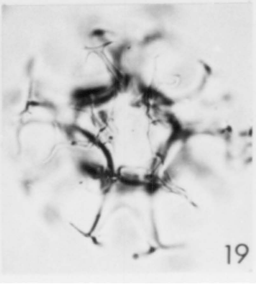
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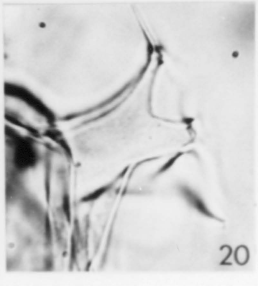
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PLATE 20

Figs. 1-4: *Spiniferites ramosus* subsp. *multibrevis* (Davey and Williams 1966) Lentin and Williams 1973. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen) showing precingular archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Main body L X W: 46um X 40um; processes up to 13um long. Fig. 4: Detailed view of processes (up to 12um long). VPISUPL Sample 331, Slide AO-71, Coords. R17.8.;+4.8.

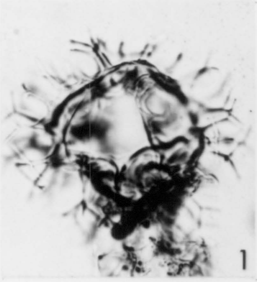
Figs. 5-8: *Spiniferites ramosus* subsp. *ramosus* (Davey and Verdier 1971) Lentin and Williams 1973. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view exhibiting precingular arecheopyle with partially dislodged operculum. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view (focused through specimen). Main body L X W: 40um X 32um; processes up to 15um long. Fig. 8: Detailed view of apical processes (up to 8um long). VPISUPL Sample 303, Slide AO-2, Coords. R11.4;+15.0.

Figs. 9-12: *Spiniferites ramuliferus* (Deflandre 1937) Reid 1964. Fig. 9: Dorsal view displaying precingular archeopyle with operculum in place. Fig. 10: Optical cross-sectional view; note fused paracingular processes. Fig. 11: Ventral view (focused through specimen). Main body L X W: 40um X 36um; processes up to 20um long. Fig. 12: Detailed view of membrane developed between paracingular processes (up to 16um long). VPISUPL Sample 306, Slide AO-10, Coords. R17.3;+13.9.

Figs. 13-16, 21: *Hafniasphaera septata* (Cookson and Eisenack 1967) Hansen 1977. Figs. 13-15: Three focal levels of specimen. Fig. 13: Dorsal view showing precingular archeopyle. Fig. 14: Optical cross-sectional view. Fig. 15: Ventral view (focused through specimen). Main body diameter 45um; processes up to 14um. VPISUPL Sample 316, Slide AO-35, Coords. R20.6;+7.0. Fig. 16: Optical cross-sectional view of another specimen with extremely thick main body wall. Main body diameter 54um; processes up to 17um long. Fig. 21: Detailed view of process (14um long). VPISUPL Sample 307, Slide AO-15, Coords. R5.7;+14.4.

Figs. 17-20: *Hafniasphaera* cf. *H. septata* (Cookson and Eisenack 1967) Hansen 1977. Figs. 17-19: Three focal levels of specimen. Fig. 17: Dorsal view showing precingular archeopyle. Fig. 18: Optical cross-sectional view. Fig. 19: Ventral view (focused through specimen). Main body L X W: 50um X 40um; processes up to 13um long. Fig. 20: Detailed view of process (12um long). VPISUPL Sample 306, Slide AO-10, Coords. R17.6;+14.7.

PLATE 20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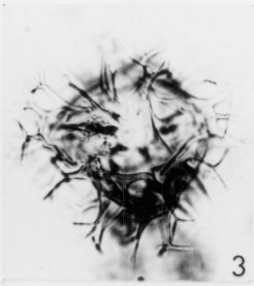
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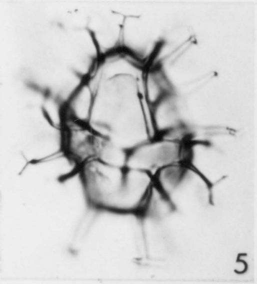
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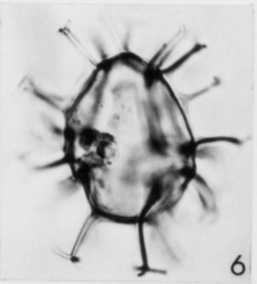
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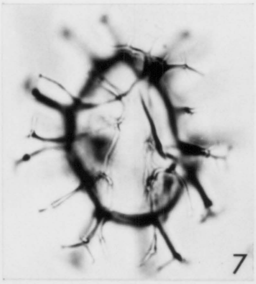
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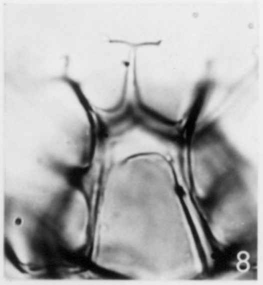
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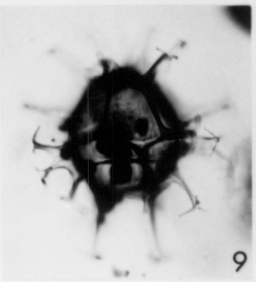
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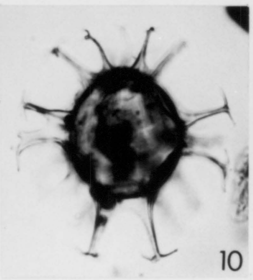
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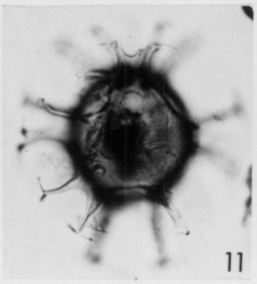
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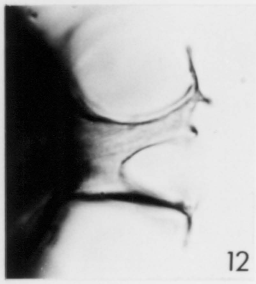
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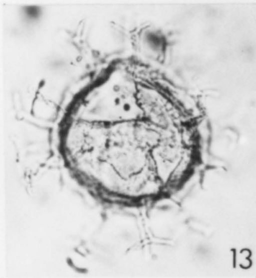
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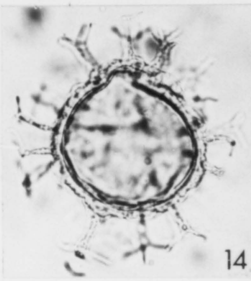
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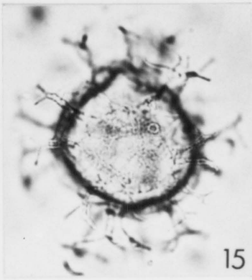
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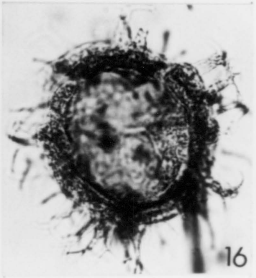
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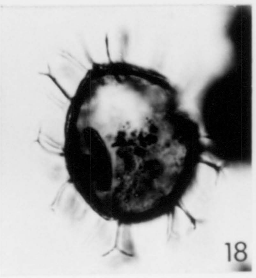
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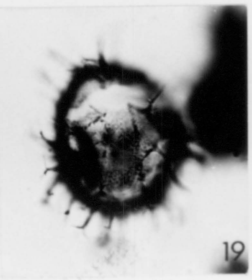
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PLATE 21

Figs. 1-4: *Spiniferites* sp. A. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorso-lateral view (focused through specimen) displaying precingular archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventro-lateral view; note large grana. Main body L X W: 48um X 38um; processes up to 17um long. Fig. 4: Detailed view of process (16um long). VPISUPL Sample 329, Slide AO-64, Coords. R8.6;+3.8.

Figs. 5-8: *Spiniferites* sp. B. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view showing precingular archeopyle with partially dislodged operculum. Fig. 6: Ventral view (focused through specimen). Main body L X W: 62um X 52um; processes up to 12um long. Fig. 8: Detailed view of process (10um long). VPISUPL Sample 351, Slide AP-29, Coords. R6.4;+11.2.

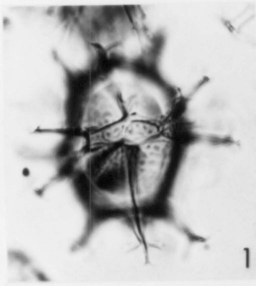
Figs. 9-12: *Spiniferites* sp. C. Figs. 9-11: Three focal levels of specimen. Fig. 9: Dorso-lateral view exhibiting precingular archeopyle. Fig. 10: Optical cross-sectional view. Fig. 11: Ventro-lateral view (focused through specimen). Main body L X W: 68um X 60um; processes up to 22um long. Fig. 12: Detailed view of processes (up to 17um long). VPISUPL Sample 351, Slide AP-29, Coords. R5.7;+16.8.

Figs. 13-16: *Membranilarnacia leptoderma* (Deflandre and Cookson 1955) Wall 1967. Figs. 13-14: Two focal levels of specimen. Fig. 13: Dorso-lateral view (focused through specimen) showing apical archeopyle with attached operculum. Fig. 14: Optical cross-sectional view. Main body diamter 48um; processes up to 8um long. VPISUPL Sample 337, Slide AO-83, Coords. R5.2;+5.3. Fig. 15: Dorsal view (focused through specimen) of another specimen. Main body diameter 44um; processes up to 13um long. Fig. 16: Detailed view of process (12um long) supporting microfenestrate ectophragm. VPISUPL Sample 337, Slide AO-83, Coords. R13.7;+8.2.

Figs. 17-18: *Tanyosphaeridium variecalamum* Davey and Williams 1966. Fig. 17: Lateral view. Main body L (excl. operculum) X W: 38um X 21um; processes up to 14um long. VPISUPL Sample 306, Slide AO-10, Coords. R3.0;+8.7. Fig. 18: Oblique apical view of another specimen. Main body width approximately 20um; processes up to 16um long. VPISUPL Sample 304, Slide AO-5, Coords. R17.4;+18.4.

Figs. 19-20: *Trichodinium hirsutum* Cookson 1965. Two focal levels of specimen. Fig. 19: Dorso-lateral view. Fig. 20: Ventro-lateral view (focused through specimen). Main body L X W: 94um X 85um; processes up to 16um long. VPISUPL Sample 306, Slide AO-10, Coords. R4.4;+12.1.

PLATE 21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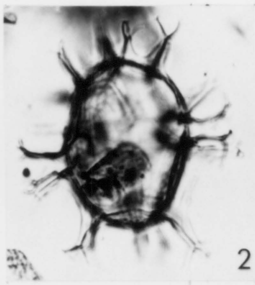
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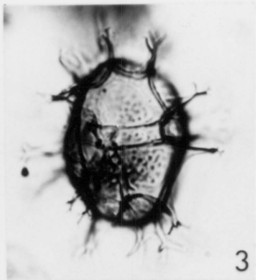
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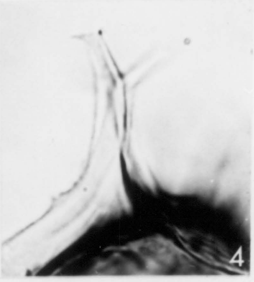
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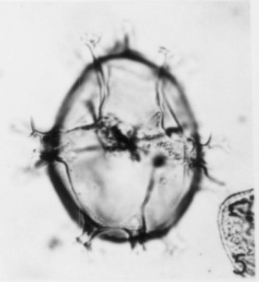
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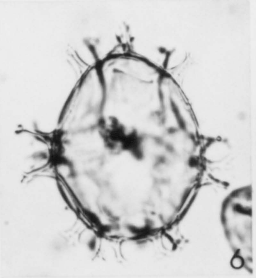
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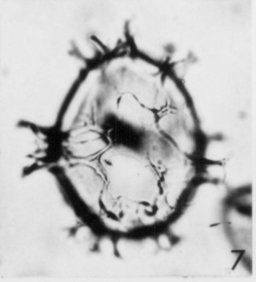
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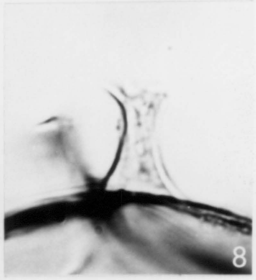
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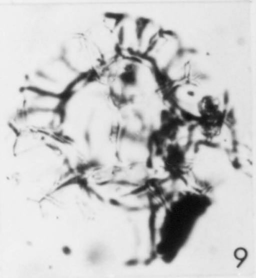
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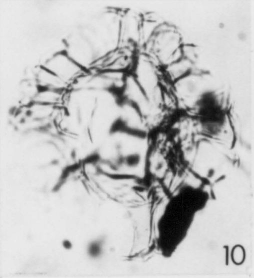
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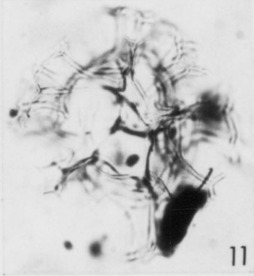
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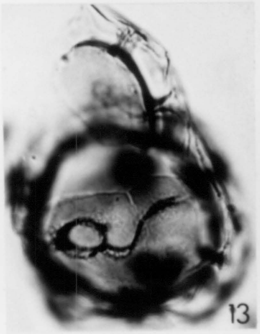
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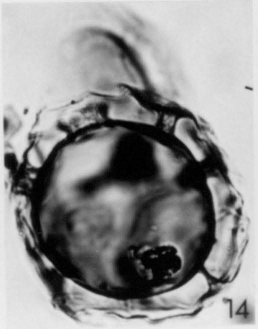
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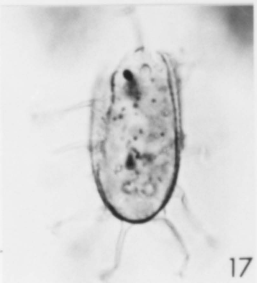
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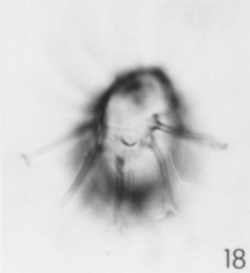
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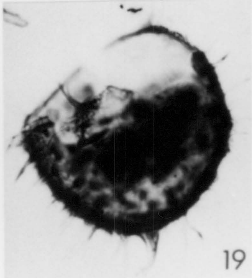
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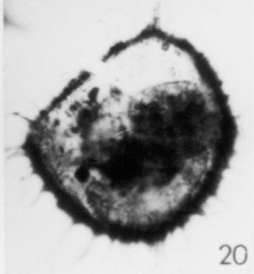
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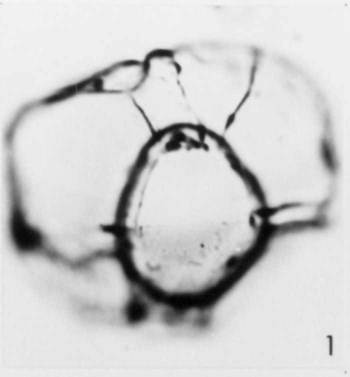
PLATE 22

Figs. 1-3: *Thalassiphora delicata* (Williams and Downie 1966) Eaton 1966. Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen) displaying precingular archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view; note paracingular paraplates. Main body L X W: 55um X 48um; overall L X W: 94um X 110um. VPISUPL Sample 314, Slide AO-29, Coords. R12.8;+16.3.

Figs. 4-12: *Thalassiphora pelagica* (Eisenack 1954) Eisenack and Gocht 1960. Figs. 4-6: Three focal levels of specimen. Fig. 4: Dorsal view (focused throguh specimen) showing precingular archeopyle. Fig. 5: Optical cross-sectional view. Fig. 6: Ventral view. Main body L X W: 100um X 90um; overall L X W: 240um X 200um. VPISUPL Sample 331, Slide AO-70, Coords. R11.4;+8.2. Figs. 7-11: Array of specimens from a population (Sample 330) ranging from initial stage types to more expanded forms. Fig. 7: Main body L X W: 108um X 90um; overall L X W: 140um X 138um. Slide AO-68, Coords. R14.7;+2.2. Fig. 8: Main body L X W: 104um X 80um; overall L X W: 168um X 132um. Slide AO-68, Coords. R14.5;+5.1. Fig. 9: Main body L X W: 100um X 92um; overall L X W: 170um X 140um. Slide AO-68, Coords. R13.5;+8.9. Fig. 10: Main body L X W: 98um X 90um; overall L X W: 158um X 150um. Slide AO-68, Coords. R14.5;+5.1. Fig. 11: Main body L X W: 104um X 112um; overall L X W: 176um X 188um. Slide AO-69, Coords. R18.0;+8.7. Fig. 12: Lateral view of specimen from same population (Sample 330); note operculum inside main body. Main body L X W: 100um X 90um; overall L X W: 180um X 114um. Slide AO-68, Coords. R13.3;+8.5.

PLATE 22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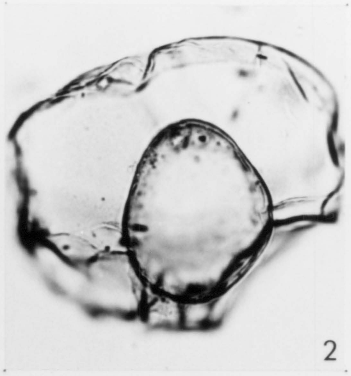
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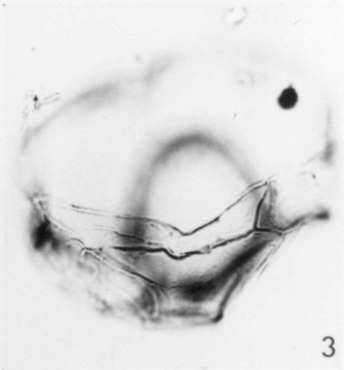
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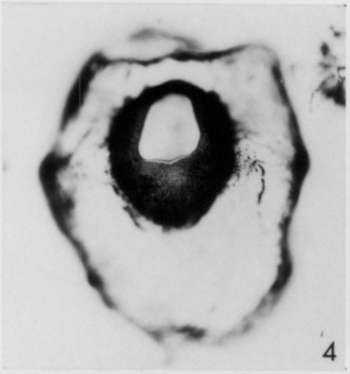
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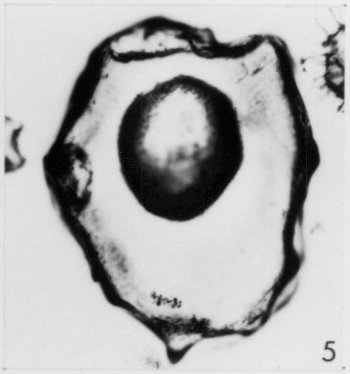
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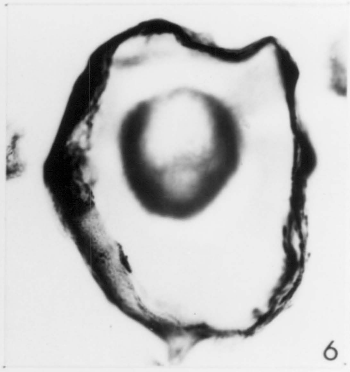
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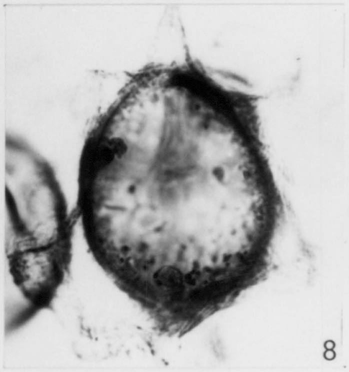
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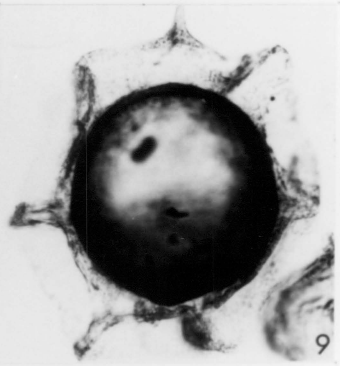
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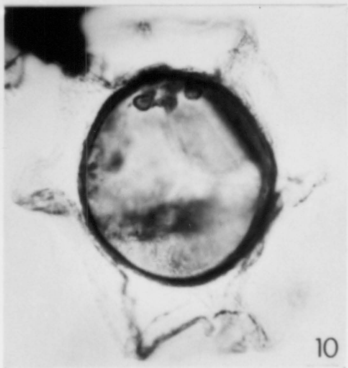
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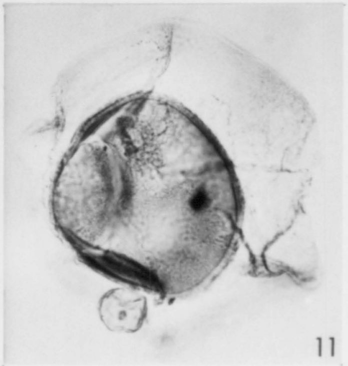
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PLATE 23

Figs. 1-2: *Senagalinium? asymmetricum* (Wilson 1967) Stover and Evitt 1978. Two focal levels of specimen. Fig. 1: Dorsal view showing intercalary archeopyle with partially displaced operculum. Fig. 2: Ventral view (focused through specimen). Overall L X W: 66um X 50um. VPISUPL Sample 334, Slide AO-77, Coords. R15.5;+9.9 (both figures Interference Contrast).

Figs. 3-4: *Deflandrea wardenensis* Williams and Downie 1966. Two focal levels of specimen. Fig. 3: Dorsal view. Fig. 4: Ventral view (focused through specimen). Overall L X W: 72um X 50um. VPISUPL Sample 337, Slide AO-84, Coords. R18.5;+7.0 (both figures Interference Contrast).

Figs. 5-8: *Andalusiella rhombohedra* (Benson 1976) Stover and Evitt 1978. Three focal levels of specimen. Fig. 5: Dorsal view (focused through specimen) displaying intercalary archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view. Overall L X W: 81um X 62um. VPISUPL Sample 317, Slide AO-39, Coords. R20.9;+17.5. Fig. 8: Isolated endocyst; L X W: 46um X 42um. VPISUPL Sample 305, Slide AO-9, Coords. R18.2;+14.6 (all figures Interference Contrast).

Figs. 9-12: *Lentinia ruginosa* n. sp. HOLOTYPE (Figs. 9-11): Figs. 9-10: Two focal levels of specimen. Fig. 9: Dorsal view (focused through specimen). Fig. 10: Ventral view. Overall L X W: 104um X 44um. Fig. 11: Detailed plan view of folds (up to 2um wide). VPISUPL Sample 315, Slide AO-34, Coords. R20.2;+6.5. Fig. 12: Optical cross-sectional view of another specimen; note large intercalary archeopyle. Overall L X W: 99um X 37um. VPISUPL Sample 317, Slide AO-40, Coords. R6.5;+7.0. (all figures Interference Contrast).

Figs. 13-16: *Lentinia spinigera* n. sp. HOLOTYPE (Figs. 13-15): Fig. 13-15: Three focal levels of specimen. Fig. 13: Dorsal view showing large intercalary archeopyle. Fig. 14: Optical cross-sectional view. Fig. 15: Ventral view (focused through specimen); note paraplates of spines. Overall L X W: 108um X 60um. VPISUPL Sample 313, Slide AO-28, Coords. R20.2;+6.5. Fig. 16: Optical cross-sectional view of another smaller specimen demonstrating variable pericyst shape. Overall L X W: 68um X 58um. VPISUPL Sample 329, Slide AO-64, Coords. R11.5;+8.6 (all figures Interference Contrast).

PLATE 23


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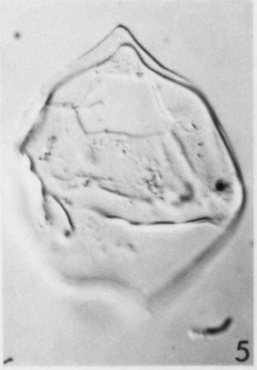
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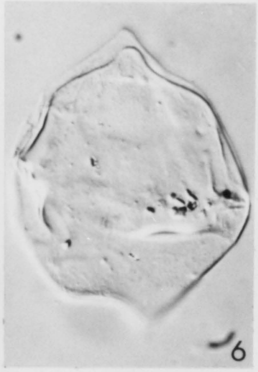
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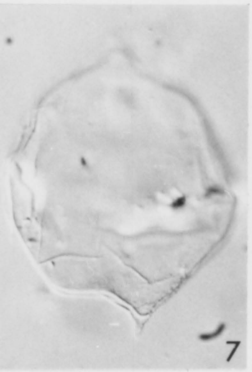
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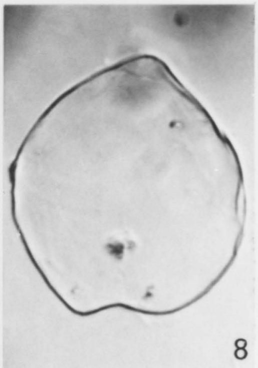
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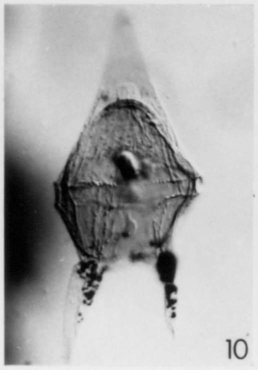
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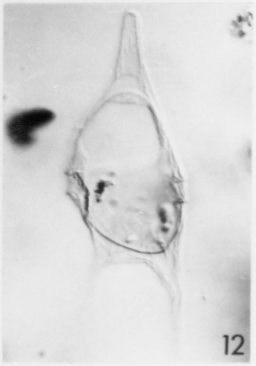
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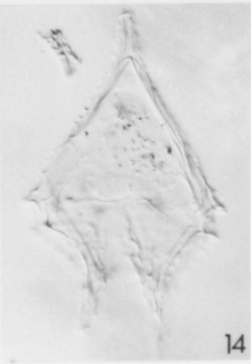
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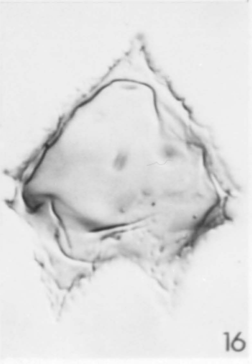
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PLATE 24

Figs. 1-4: *Deflandrea dartmooria* Cookson and Eisenack 1965.. Figs. 1-2: Two focal levels of specimen. Fig. 1: Dorsal view showing intercalary archeopyle. Fig. 2: Ventral view (focused through specimen); note paraplates of coni. Overall L X W: 164um X 97um. VPISUPL Sample 314, Slide AO-29, Coords. R15.4;+6.4. Figs. 3-4: Two specimens demonstrating variable pericyst shapes. Fig. 3: Overall L X W: 168um X 90um. VPISUPL Sample 312, Slide AO-24, Coords. R17.3;+6.3. Fig. 4: Overall L X W: 190um X 108um. VPISUPL Sample 303, Slide AO-2, Coords. R4.7;+7.0.

Figs. 5-10: *Deflandrea phosphoritica* Eisenack 1938. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view (focused through specimen) exhibiting intercalary archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view. Overall L X W: 144um X 96um. VPISUPL Sample 317, Slide AO-40, Coords. R3.6;+15.8. Fig. 8: Optical cross-sectional view of another specimen with more nearly parallel-sided hypocyst. Overall L X W: 156um X 94um. VPISUPL Sample 317, AO-40, Coords. R21.8;+13.9. Fig. 9: Optical cross-sectional view of variant form with pentagonally-shaped endocyst. Overall L X W: 154um X 100um. VPISUPL Sample 317, Slide AO-39, Coords. R9.0;+5.1. Fig. 10: Dorsal view of specimen from Nanjemoy strata; note coarsely granulate to verrucate ornamentation. Overall L X W: 146um X 100um. VPISUPL Sample 336, Slide AO-82, Coords. R8.8;+6.1.

Figs. 11-12: *Phelodinium magnificum* (Stanley 1965) Stover and Evitt 1978. Two focal levels of specimen. Fig. 11: Dorsal view displaying large intercalary archeopyle. Fig. 12: Ventral view (focused through specimen). Overall L X W: 110um X 82um. VPISUPL Sample 317, Slide AO-40, Coords. R6.0;+9.2.

Figs. 13-16: *Spinidinium paratabulatum* n. sp. HOLOTYPE (Figs. 13-16): Figs. 13-15: Three focal levels of specimen; note double row of spines indicating paratabulation in dorsal and ventral views. Fig. 13: Dorsal view (focused through specimen). Fig. 14: Optical cross-sectional view. Fig. 15: Ventral view. Overall L X W: 60um X 40um. Fig. 16: Detailed view of spines (up to 3um long). VPISUPL SAmple 337, Slide AO-84, Coords. R11.4;+12.4.

PLATE 24


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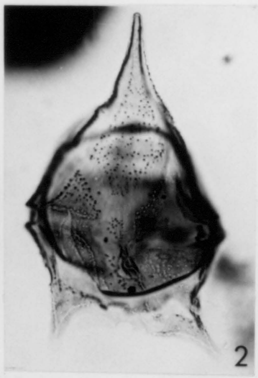
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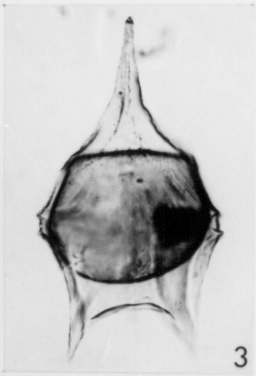
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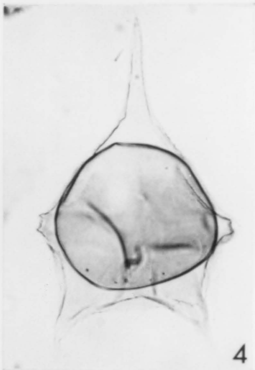
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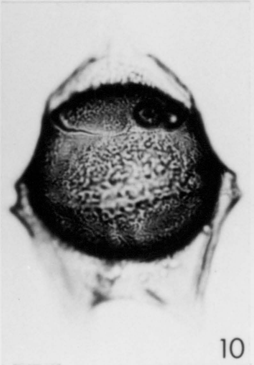
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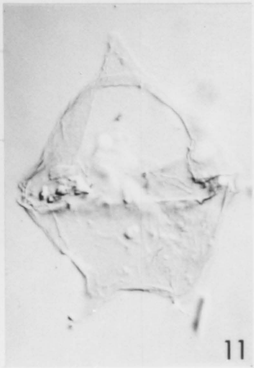
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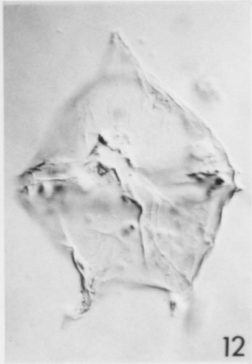
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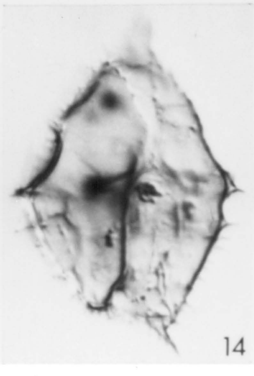
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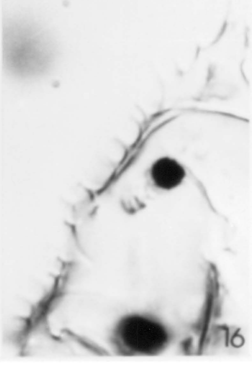
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PLATE 25

Figs. 1-8: *Spinidinium macmurdoense* (Wilson 1967) Lentin and Williams 1976. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen) showing intercalary archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Overall L X W: 60um X 44um. Fig. 4: Detailed view of spines (up to 5um long). VPISUPL Sample 334, Slide AO-77, Coords. R16.8;+15.0. Figs. 5-8: Specimens from a population (Sample 334, Slide AO-77) showing range of cyst shapes. Fig. 5: Overall L X W: 72um X 45um. Coords. R19.7; +20.3. Fig. 6: Overall L X W: 68um X 48um. Coords. R19.2;+20.2 Fig. 7: Overall L X W: 60um X 40um. Coords. R15.7;+2.2. Fig. 8: Overall L X W: 60um X 43um. Coords. R19.4;+20.4 (all figures Interference Contrast).

Figs. 9-10: *Isabelidinium cooksoniae* (Alberti 1959) Lentin and Williams 1977. Two focal levels of specimen. Fig. 9: Dorsal view (focused through specimen); note intercalary archeopyle. Fig. 10: Ventral view. Overall L X W: 106um X 52um. VPISUPL Sample 308, Slide AO-18, Coords. R12.2;+12.7.

Figs. 11-12: *Lejeunecysta?* sp. A. Two focal levels of specimen. Fig. 11: Dorsal view (focused through specimen). Fig. 12: Ventral view. Overall L X W: 68um X 66um. VPISUPL Sample 350, Slide AP-28, Coords. R14.0;+16.8 (both figures Interference Contrast).

Figs. 13-14: *Palaeocystodinium golzowense* Alberti 1961. Two focal levels of specimen. Fig. 13: Dorsal view (focused through specimen); note intercalary archeopyle. Fig. 14: Optical cross-sectional view. Overall L X W: 202um X 30um. VPISUPL Sample 315, Slide AO-34, Coords. R17.7;+17.4.

PLATE 25


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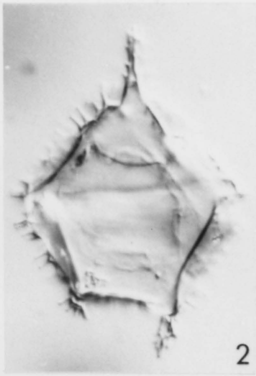
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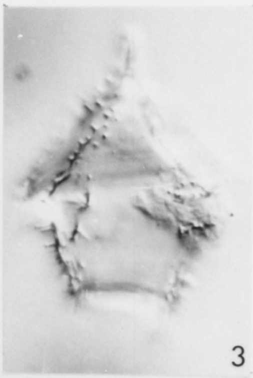
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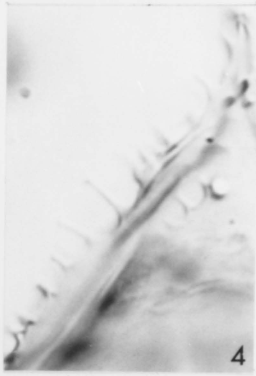
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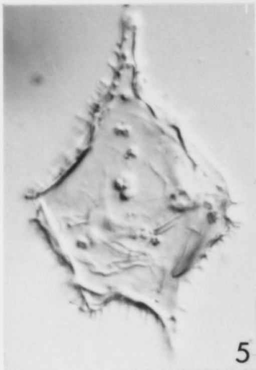
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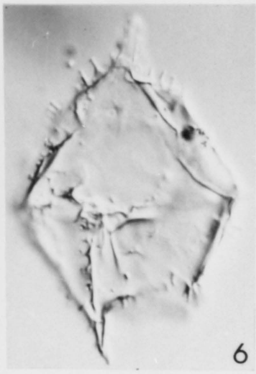
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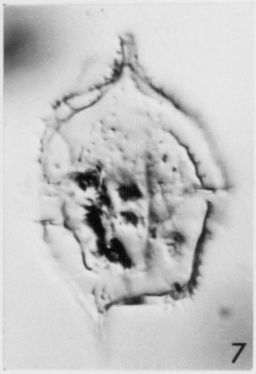
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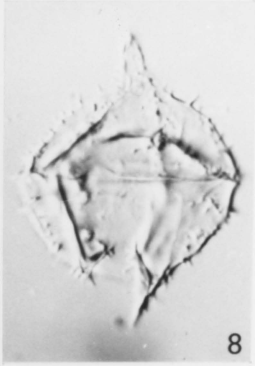
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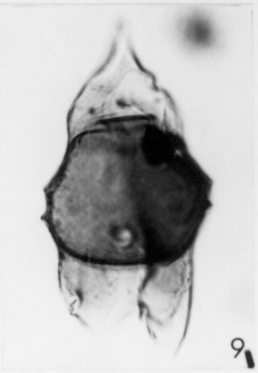
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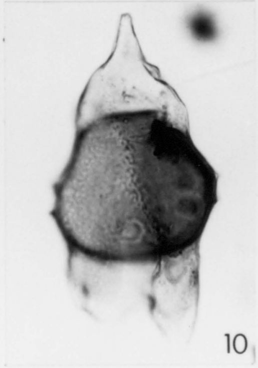
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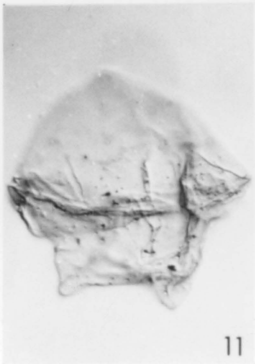
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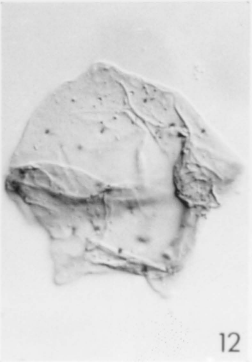
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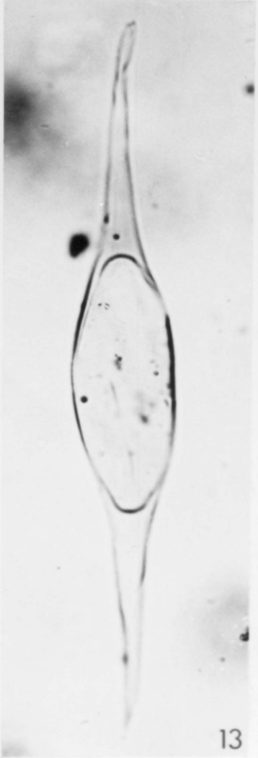
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PLATE 26

Figs. 1-2: *Senagalinium? dilwynense* (Cookson and Eisenack 1965) Stover and Evitt 1978. Two focal levels of specimen. Fig. 1: Dorsal view (focused through specimen). Fig. 2: Ventral view. Overall L X W: 66um X 55um. VPISUPL Sample 323, Slide AO-47, Coords. R8.2;+7.0 (both figures Interference Contrast).

Figs. 3-5: *Senagalinium obscurum* (Drugg 1967) Stover and Evitt 1978. Three focal levels of specimen. Fig. 3: Dorsal view (focused through specimen); note intercalary archeopyle. Fig. 4: Optical cross-sectional view. Fig. 5: Ventral view. Overall L X W: 72um X 62um. VPISUPL Sample 317, Slide AO-39, Coords. R15.7;+11.2 (all figures Interference Contrast).

Figs. 6-10: *Palaeoperidinium pyrophorum* (Ehrenberg 1838) Sarjeant 1967. Figs. 6-7: Two focal levels of specimen. Fig. 6: Dorsal view. Fig. 7: Ventral view (focused through specimen); note transversely-striate pandasutural bands. Overall L X W: 146um X 124um. VPISUPL Sample 303, Slide AO-2, Coords. R5.2;+15.3. Figs. 8-9: Two focal levels of another specimen; compare both views for indication of apparent transapical archeopyle. Fig. 8: Dorsal view. Fig. 9: Ventral view (focused through specimen). Overall L X W: 140um X 134um. Fig. 10: Detailed view of pandasutural bands (up to

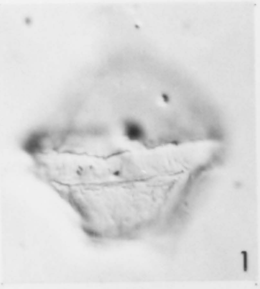
9um wide). VPISUPL Sample 303, Slide AO-1, Coords. R16.8;+2.1 (both figures Interference Contrast).

Figs. 11-12: *Spinidinium* cf. *S. essoi* Cookson and Eisenack 1967. Two focal levels of specimen. Fig. 11: Dorsal view (focused through specimen). Fig. 12: Ventral view. Overall L X W: 74um X 66um. VPISUPL Sample 305, Slide AO-9, Coords. R14.9;+2.4 (both figures Interference Contrast).

Figs. 13-16: *Phthanoperidinium echinatum* Eaton 1976. Figs. 13-15: Three focal levels of specimen. Fig. 13: Dorsal view; note intercalary archeopyle and paraplate 4". Fig. 14: Optical cross-sectional view. Fig. 15: Ventral view (focused through specimen). Overall L X W: 46um X 32um. Fig. 16: Detailed view of hari-like projections (up to 3um long) with bulbous tips. VPISUPL Sample 337, Slide AO-85, Coords. R9.5;+17.0.

Figs. 17-20: *Phthanoperidinium* cf. *P. tritonium* Eaton 1976. Figs. 17-19: Three focal levels of specimen. Fig. 17: Dorso-lateral view. Fig. 18: Optical cross-sectional view. Fig. 19: Ventro-lateral view (focused through specimen). Overall L X W: 48um X 40um. Fig. 20: Detailed view of spines (up to 6um long). VPISUPL Sample 337, Slide AO-83, Coords. R17.4;+3.0.

PLATE 26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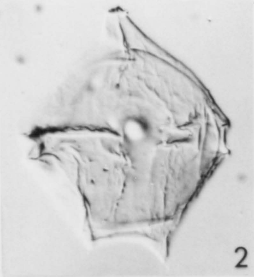
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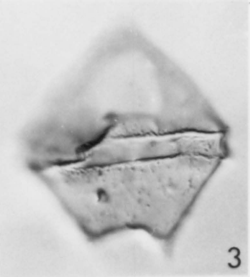
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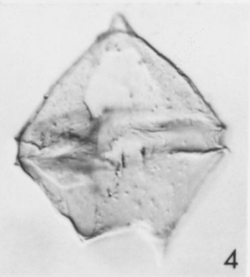
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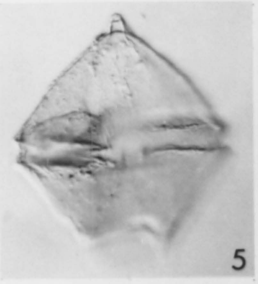
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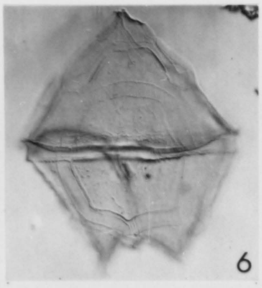
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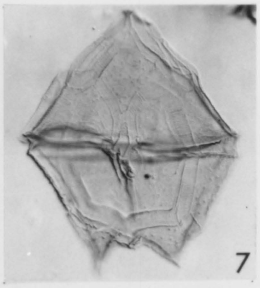
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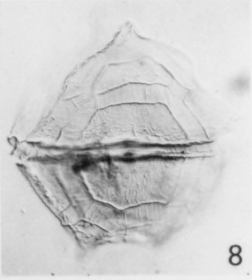
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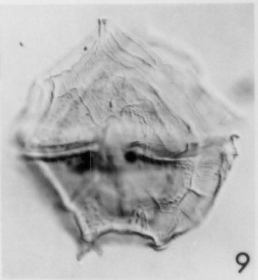
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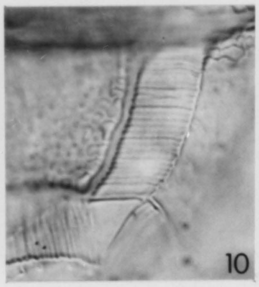
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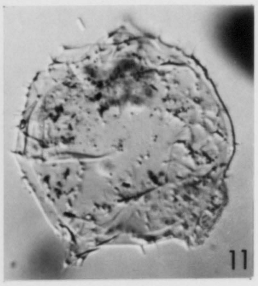
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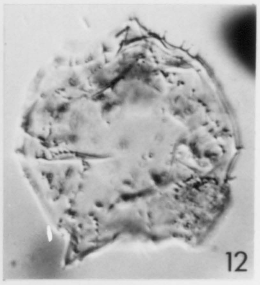
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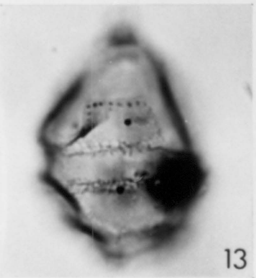
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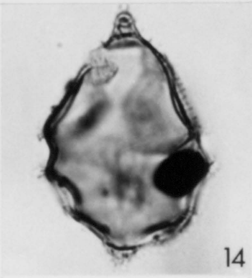
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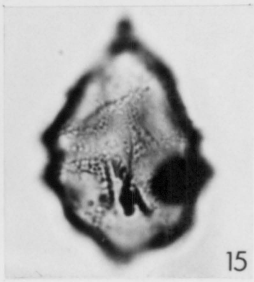
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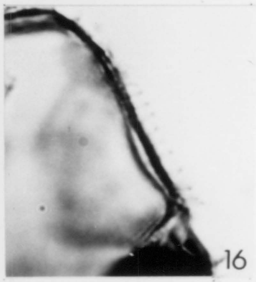
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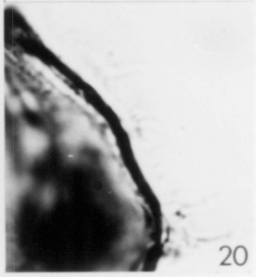
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PLATE 27

Figs. 1-4: *Kisselovia coleothrypta* (Williams and Downie 1966) Lentin and Williams 1976. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view showing intercalary archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view (focused through specimen). Pericyst L X W: 140um X 130um; processes up to 11um long. Fig. 4: Detailed plan view of thin ectophragm (about 0.5um thick) supported by processes on individual paraplates. VPISUPL Sample 337, Slide AO-84, Coords. R2.7;+14.2.

Figs. 5-10: *Wetzeliella hampdenensis* Wilson 1967. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view (focused through specimen) exhibiting intercalary archeopyle. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view. Pericyst L X W: 136um X 120um; processes up to 15um long. Fig. 8: Detailed view of process (15um long). VPISUPL Sample 328, Slide AO-63, Coords. R7.6;+7.0. Figs. 9-10: Two additional specimens from the same population (Sample 328, Slide AO-63) demonstrating variability. Fig. 9: Pericyst L X W: 120um X 114um; processes up to 15um long. Coords. R16.2;+10.8. Fig. 10: Pericyst L X W: 148um X 130um; processes up to 16um long. Coords. R9.8;+9.3.

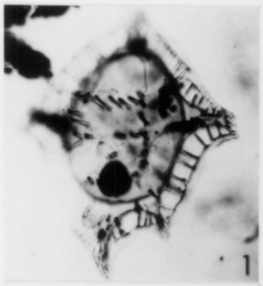
Figs. 11-12: *Wetzeliella* cf. *W. irtyschensis* Alberti 1961. Fig. 11: Optical cross-sectional view of specimen. Pericyst L X W: 97um X

90um. Fig. 12: Detailed view of short processes (up to 3um long). VPISUPL Sample 318, Slide AO-41, Coords. R3.1;+18.2.

Figs. 13-18: *Wetzeliella lunaris* Gocht 1969. Figs. 13-15: Three focal levels of specimen. Fig. 13: Dorsal view (focused through specimen) exhibiting intercalary archeopyle with operculum in place. Fig. 14: Optical cross-sectional view; note much reduced right antapical horn. Fig. 15: Ventral view. Pericyst L X W: 130um X 108um; processes up to 12um long. Fig. 16: Detailed view of processes (up to 12um long). VPISUPL Sample 334, Slide AO-77, Coords. R8.4;+4.2. Figs. 17-18: Two additional specimens from the same population (Sample 334, Slide AO-77) demonstrating variability. Fig. 17: Pericyst L X W: 122um X 98um; processes up to 14um long. Coords. R13.0;+9.2. Fig. 18: Pericyst L X W: 130um X 122um; processes up to 13um long. Coords. R13.8;+4.4.

Figs. 19-20: *Wetzeliella* sp. A. Two focal levels of specimen. Fig. 19: Dorsal view displaying intercalary archeopyle; note coalesced antapical horns (40um long). Fig. 20: Ventral view (focused through specimen). Pericyst L X W: 131um X 120um; processes up to 16um long. VPISUPL Sample 337, Slide AO-86, Coords. R20.2;+1.8.

PLATE 27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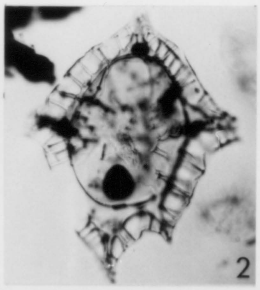
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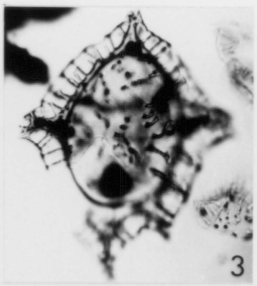
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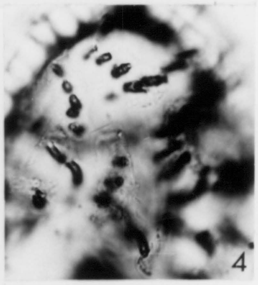
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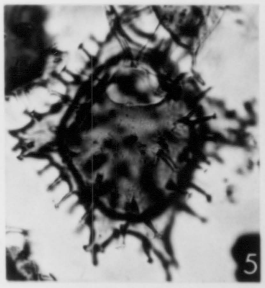
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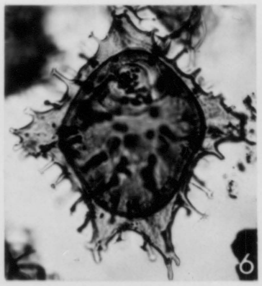
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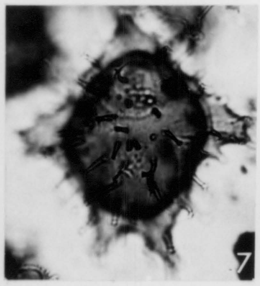
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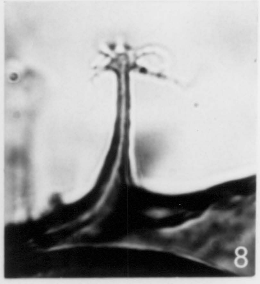
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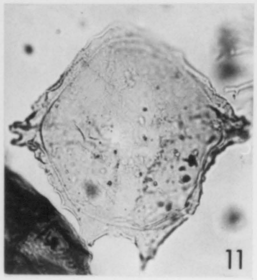
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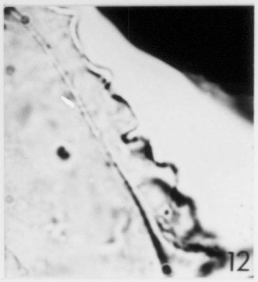
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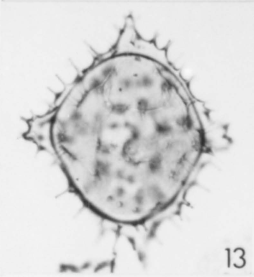
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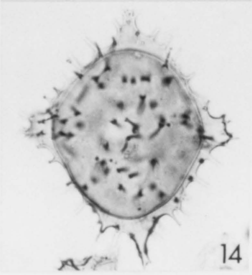
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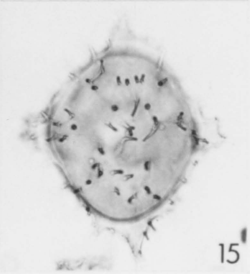
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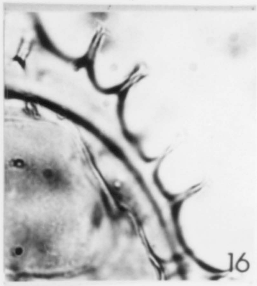
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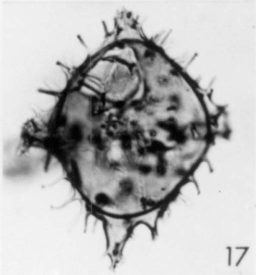
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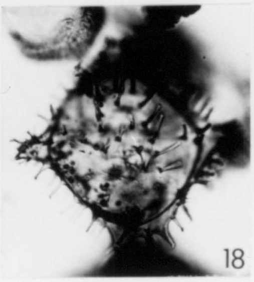
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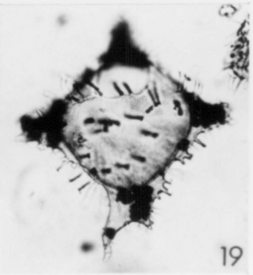
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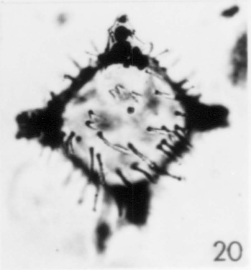
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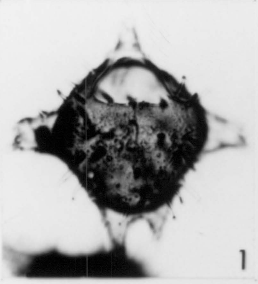
PLATE 28

Figs. 1-15: *Wetzeliella samlandica* Eisenack 1954. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view showing intercalary archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view (focused through specimen). Pericyst L X W: 120um X 128um; processes up to 15um long. Fig. 4: Detailed view of antapical horns; left (23um long) is invariably longer of the two. VPISUPL Sample 332, Slide AO-74, Coords. R9.0;+7.1. Figs. 5-10: Specimens from a single population (Sample 332) showing cyst variability, especially in lateral horn development. Fig. 5: Pericyst L X W: 120um X 110um; processes up to 15um long. Slide AO-74, Coords. R12.3;+5.8. Fig. 6: Pericyst L X W: 114um X 112um; processes up to 18um long. Slide AO-74, Coords. R13.0;+5.7. Fig. 7: Pericyst L X W: 120um X 104um; processes up to 14um long. Slide AO-74, Coords. R14.54;+9.2. Fig. 8: Pericyst L X W: 146um X 140um; processes up to 17um long. Slide AO-74, Coords. R11.8;+6.9. Fig. 9: Pericyst L X W: 130um X 130um; processes up to 15um long. Slide AO-75, Coords. R10.4;+5.3. Fig. 10: Pericyst L X W: 128um X 144um; processes up to 14um long. Slide AO-74, Coords. R15.9;+5.5. Figs. 11-13: Three focal levels of specimen in lateral orientation. Fig. 11: Optical cross-sectional view. Fig. 12: View focused on lateral horn tip. Pericyst length 132um and depth 46um. Fig. 13: Detailed view of lateral horn tip (12um wide). VPISUPL Sample 332, Slide AO-75, Coords. R12.3;+5.8. Fig. 14: Scanning electron micrograph of specimen showing intercalary archeopyle in pericyst and archeopyle in endocyst. Archeopyle approximately 35um wide and processes up to 15um long. Fig. 15: Scanning electron micrograph of broken specimen showing small pores in endophragm and processes (up to 16um long) arising from periphragm. VPISUPL Sample 332.

PLATE 28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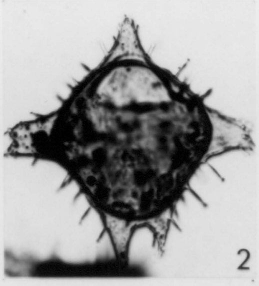
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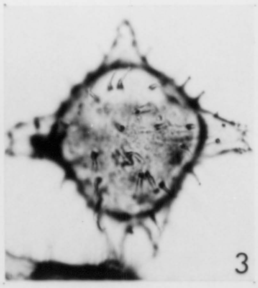
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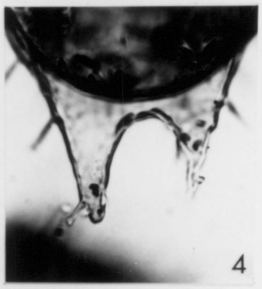
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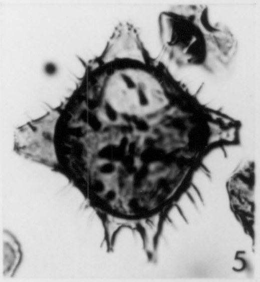
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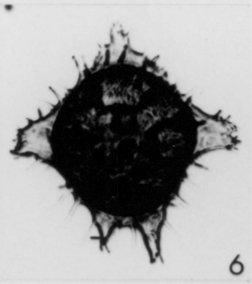
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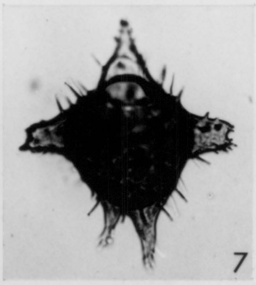
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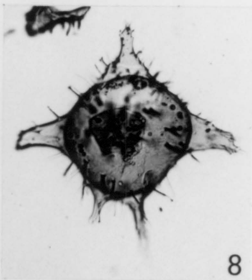
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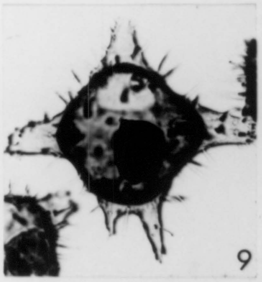
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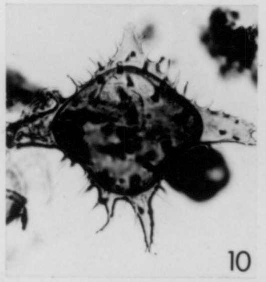
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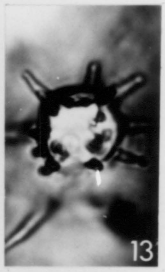
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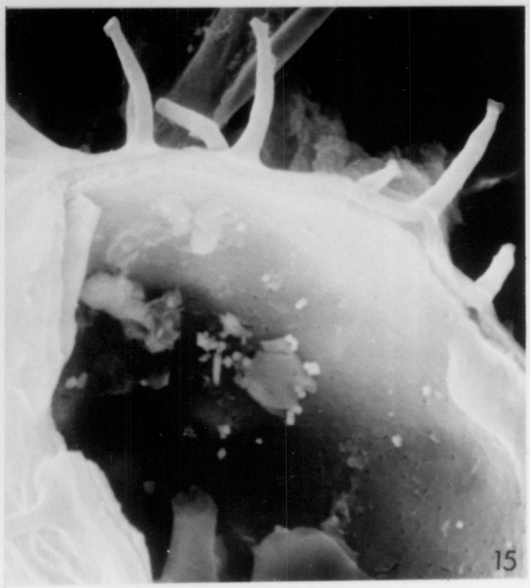
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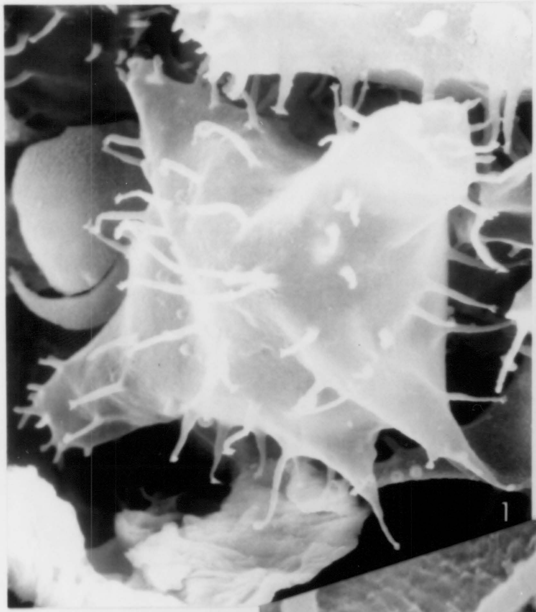
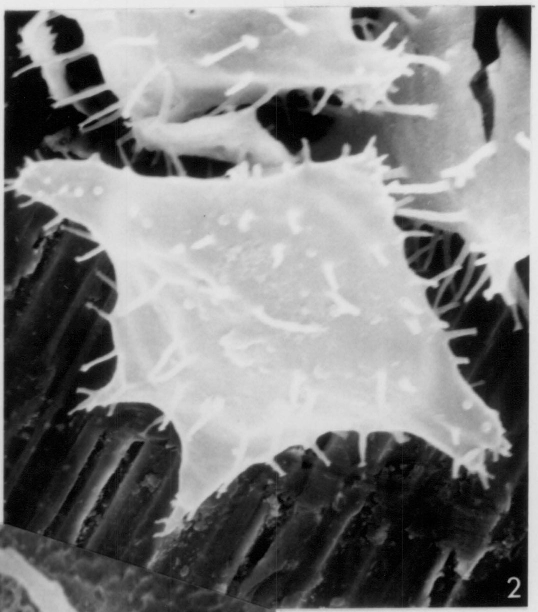
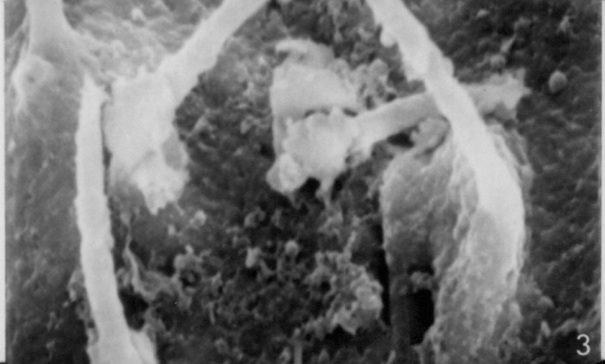
PLATE 29

Figs. 1-5: *Wetzeliella samlandica* Eisenack 1954. Figs. 1, 2, 4, 5: Scanning electron micrographs of specimens from a single population (VPISUPL Sample 332) showing cyst variability. Fig. 1: Approximate pericyst L X W: 120um X 100um. Fig. 2: Approximate pericyst L X W: 125um X 95um. Fig. 4: Approximate pericyst L X W: 115um X 100um. Fig. 5: Approximate pericyst L X W: 135um X 120um. Fig. 3: Scanning electron micrograph of processes and periphragm outer surface. Process to extreme left approximately 10um long. VPISUPL Sample 332.

PLATE 29







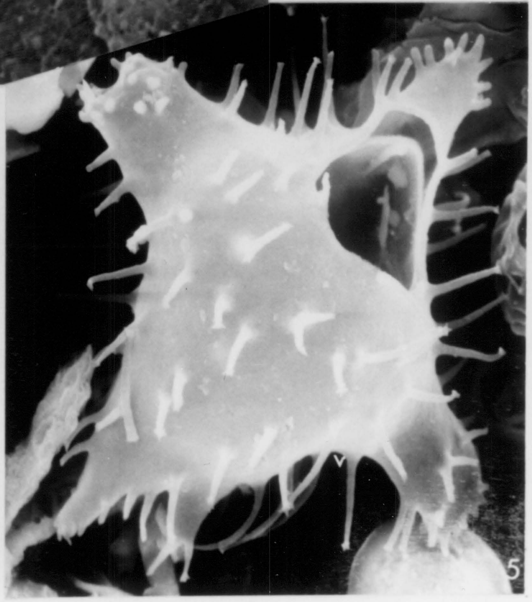


PLATE 30

Figs. 1-5: *Wilsonidium tabulatum* (Wilson 1967) Lentin and Williams 1976. Figs. 1-3: Three focal levels of specimen; note paratabulation reflected by spines. Fig. 1: Dorsal view (focused through specimen) showing intercalary archeopyle. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Pericyst L X W: 162um X 134um; spines up to 4um long. VPISUPL Sample 326, Slide AO-57, Coords. R12.1;+11.7. Figs. 4-5: Two specimens from the same population (Sample 326, Slide AO-57) demonstrating extremes in spine lengths. Fig. 4: Pericyst L X W: 150um X 144um; spines up to 1um long. Coords. R6.0;+11.4. Fig. 5: Pericyst L X W: 132um X 134um; spines up to 3um long. Coords. R16.6;+4.9.

Figs. 6-12: *Wetzeliella varielongituda* Williams and Downie 1966. Figs. 6-8: Three focal levels of specimen. Fig. 6: Dorsal view (focused through specimen) exhibiting intercalary archeopyle. Fig. 7: Optical cross-sectional view. Fig. 8: Ventral view. Pericyst L X W: 110um X 100um; processes up to 10um long. VPISUPL Sample 331, Slide AO-71, Coords. R18.1;+4.0. Figs. 9-12: Specimens from a population (Sample 331, Slide AO-72) showing variability in cyst shape. Fig. 9: Pericyst L X W: 120um X 106um; processes up to 10um long. Coords. R15.5;+18.1. Fig. 10: Pericyst L X W: 118um X 100um; processes up to 9um long. Coords. R13.1;+4.9. Fig. 11: Pericyst L X W: 130um X 128um; processes up to 14um long. Coords. R9.3;+4.4. Fig. 12:

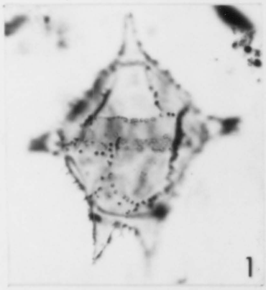
Pericyst L X W: 136um X 124um; processes up to 15um long. Coords. R9.6;+10.8.

Figs. 13-16: *Apectodinium homomorphum* complex. Figs. 13-14: Two focal levels of specimen. Fig. 13: Dorsal view (focused through specimen) showing intercalary archeopyle with operculum in place. Fig. 14: Optical cross-sectional view. Pericyst L X W: 74um X 72um; processes up to 18um long. VPISUPL Sample 324, Slide AO-48, Coords. R17.6;+5.0. Figs. 15-16: Two specimens with distinctly pentagonally-shaped pericysts and varying process development. Fig. 15: Dorsal view (focused through specimen). Pericyst L X W: 80um X 80um; processes up to 20um long. VPISUPL Sample 324, Slide AO-48, Coords. R1.0;+9.0. Fig. 16: Optical cross-sectional view. Pericyst L X W: 68um X 67um; processes up to 18um long. VPISUPL Sample 318, Slide AO-41, Coords. R12.4;+4.7.

Figs. 17-20: *Apectodinium* sp. A. Figs. 17-18: Two views of specimen exhibiting only slight incipient process development. Fig. 17: Dorsal view showing intercalary archeopyle with operculum in place. Fig. 18: Ventral view (focused through specimen). Pericyst L X W: 66um X 68um. VPISUPL 322, Slide AO-45, Coords. R2.3;+6.5. Figs. 19-20: Two additional specimens from the same population (Sample 322, Slide AO-45) displaying varying cyst shapes and process development. Fig. 19: Ventral view. Pericyst L X W: 60um X 58um. Coords.

R3.1;+4.4. Fig. 20: Dorsal view. Pericyst L X W: 60um X 60um. Coords. R15.9;7.7.

PLATE 30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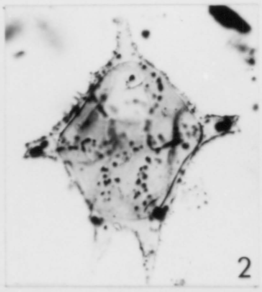
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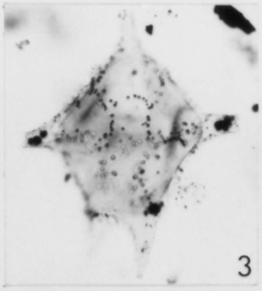
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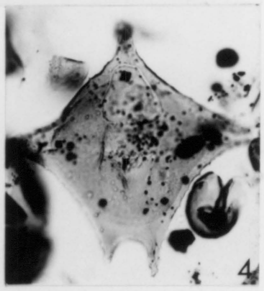
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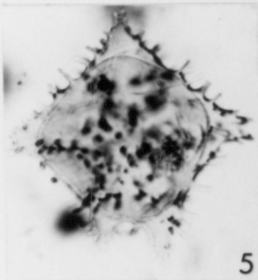
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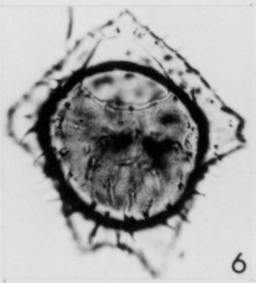
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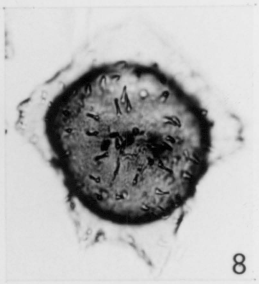
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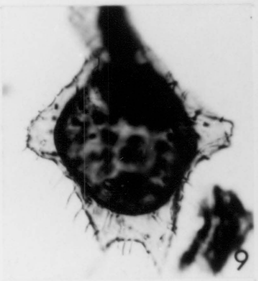
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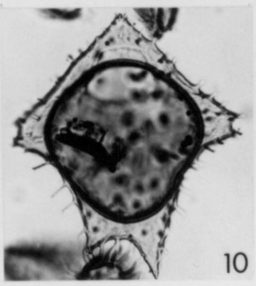
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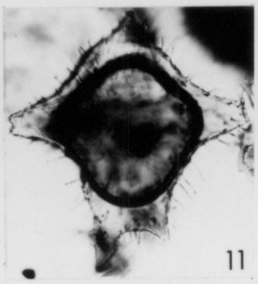
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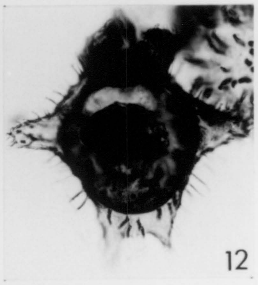
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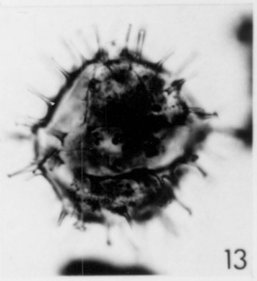
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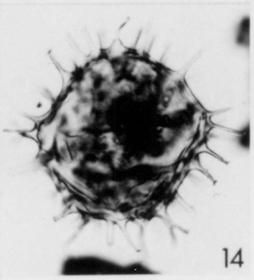
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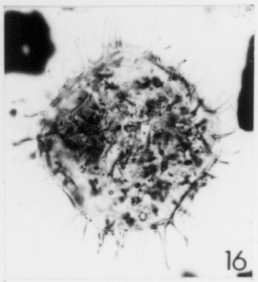
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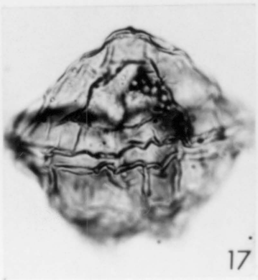
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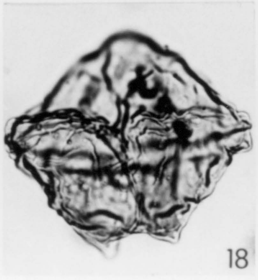
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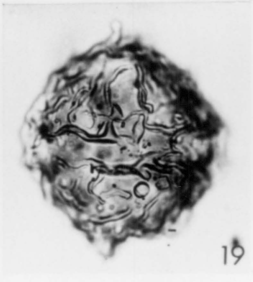
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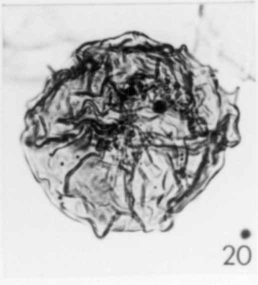
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PLATE 31

Fig. 1: *Ascostomocystis hydria* Drugg and Loeblich 1967. Specimen showing peripheral flange (up to 7um wide) and aperture (possible apical archeopyle). Main body L X W: 60um X 45um. VPISUPL Sample 305, Slide AO-9, Coords. R3.7;+16.1.

Figs. 2-3: *Caligodinium amiculum* Drugg 1970. Two focal levels of specimen with typical kalyptra surrounding main body; note attached operculum. Overall L X W: 100um X 70um; main body L X W: 74um X 40um. VPISUPL Sample 306, Slide AO-10, Coords. R15.0;+17.0.

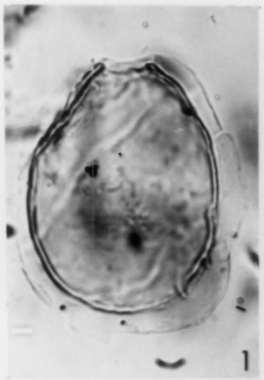
Fig. 4: *Cyclopsiella elliptica* Drugg and Loeblich 1967. Specimen displaying granulate ornamentation. Overall L X W: 80um X 66um. VPISUPL Sample 348, Slide AP-23, Coords. R13.7;+18.9.

Figs. 5-6: *Cyclopsiella vieta* Drugg and Loeblich 1967. Fig. 5: Specimen with plug in aperture (10um diameter). Overall L X W: 88um X 80um. VPISUPL Sample 312, Slide AO-24, Coords. R16.7;+5.2. Fig. 6: Specimen exhibiting fold around equatorial region. Overall L X W: 60um X 50um. VPISUPL Sample 339, Slide AO-93, Coords. R8.3;+17.6.

Figs. 7-8: *Cassidium paleocenicum* n. sp. HOLOTYPE (Figs. 7-8): Two focal levels of specimen. Overall L X W: 80um X 74um. VPISUPL Sample 316, Slide AO-35, Coords. R4.2;+7.3.

Figs. 9-12: *Biconidinium longissimum* Islam 1983. Two focal levels of specimen. Fig. 9: Dorsal view (focused through specimen); note partially displaced operculum (apical archeopyle). Fig. 10: Ventral view. Overall L X W: 120um X 58um. VPISUPL Sample 332, Slide AO-74, Coords. R16.2;+6.0. Fig. 11: Another complete specimen from the same population (Sample 332, Slide AO-74). Overall L X W: 158um X 50um. Coords. R12.3;+6.1. Fig. 12: Specimen displaying apical archeopyle. Overall L X W: 98um X 50um. VPISUPL Sample 332, Slide AO-74, Coords. R6.0;+9.6.

PLATE 31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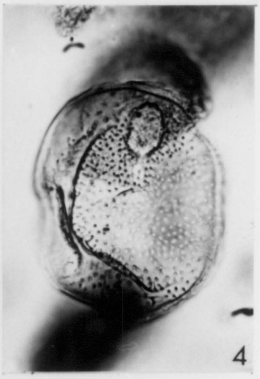
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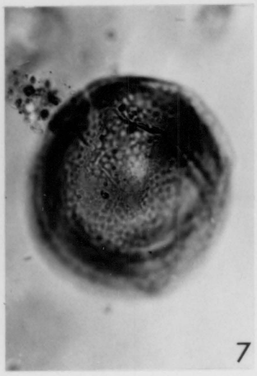
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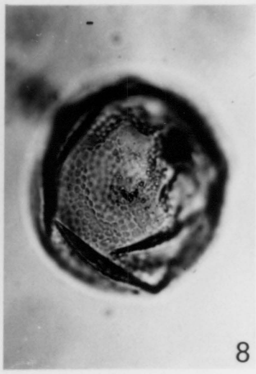
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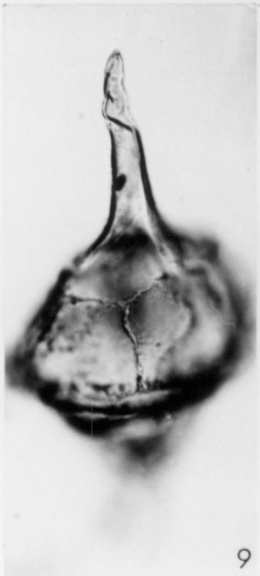
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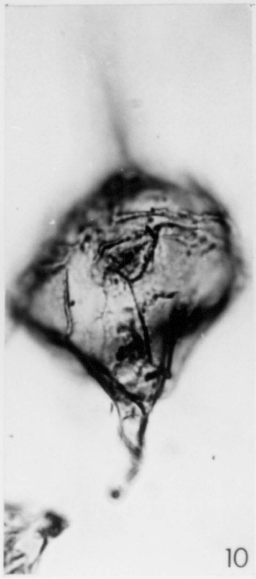
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PLATE 32

Figs. 1-4: *Chlamydophorella urna* Cookson and Eisenack 1960. Figs. 1-3: Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen). Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Overall L X W: 40um X 32um. VPISUPL Sample 303, Slide AO-1, Coords. R7.0;+17.9. Fig. 4: Optical cross-sectional view of form with longer bacula (up to 4um long). Overall L X W: 42um X 36um. VPISUPL Sample 307, Slide AO-15, Coords. R7.4;+13.8.

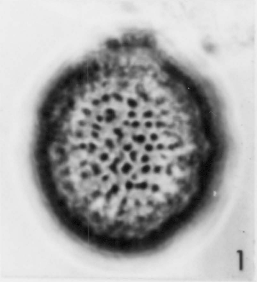
Figs. 5-8: *Cladopyxidium saeptum* (Morgenroth 1968) Stover and Evitt 1978. Figs. 5-7: Three focal levels of specimen. Fig. 5: Dorsal view (focused through specimen). Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view. Overall L X W: 34um X 33um. VPISUPL Sample 303, Slide AO-1, Coords. R14.9;+17.6. Fig. 8: Another specimen with attached operculum. Overall L X W: 37um X 34um. VPISUPL Sample 303, Slide AO-1, Coords. R9.0;+2.0.

Figs. 9-13: *Fibradinium annetorpense* Morgenroth 1968. Figs. 9-11: Three focal levels of specimen. Fig. 9: Dorsal view (focused through specimen). Fig. 10: Optical cross-sectional view. Fig. 11: Ventral view. Overall L X W: 45um X 42um. VPISUPL Sample 308, Slide AO-17, Coords. R9.6;+13.8. Figs. 12-13: Two focal levels of apex of another specimen. Fig. 12: View focused on outline of apical archeopyle (Type AI). Fig. 13: View focused on operculum; note small apical and anterior intercalary paraplates. Cyst width 38um. VPISUPL Sample 308, Slide AO-17, Coords. R9.7;+14.1.

Figs. 14-16: Forma A. Three focal levels of specimen. Fig. 14: Dorso-lateral view. Fig. 15: Optical cross-sectional view. Fig. 16: Ventro-lateral view (focused through specimen). Overall L X W: 42um X 38um. VPISUPL Sample 305, Slide AO-8, Coords. R16.0;+18.8.

Figs. 17-20: *Elytrocysta densobaculata* n. sp. HOLOTYPE (Figs. 17-18): Two focal levels of specimen. Fig. 17: Dorsal view showing densely distributed bacula and long accessory archeopyle parasutures. Fig. 18: Optical cross-sectional view. Overall L X W: 36um X 35um. VPISUPL Sample 317, Slide AO-39, Coords. R10.9;+3.9. Fig. 19: Apical view displaying apical archeopyle. Cyst width 32um. VPISUPL Sample 317, Slide AO-39, Coords. R17.0;+4.0. Fig. 20: Dorsal view of another specimen. Overall L X W: 36um X 32um. VPISUPL Sample AO-39, Coords. R9.7;+5.6.

PLATE 32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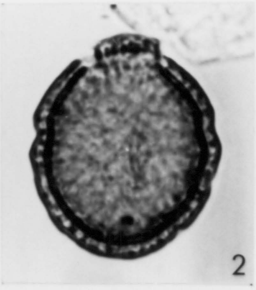
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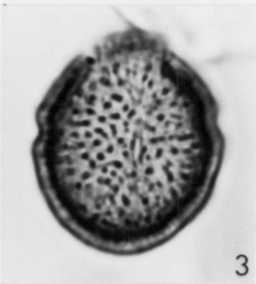
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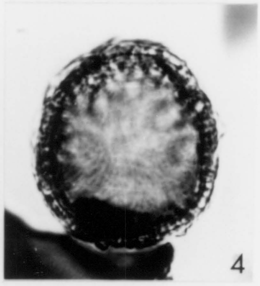
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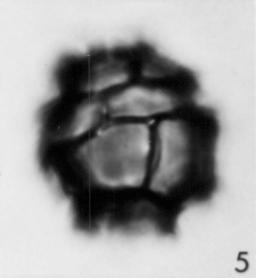
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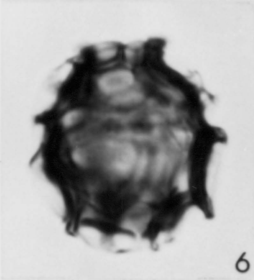
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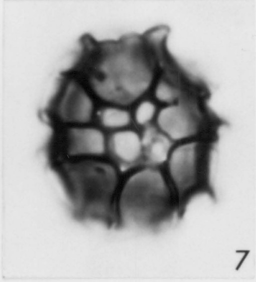
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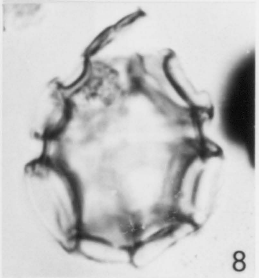
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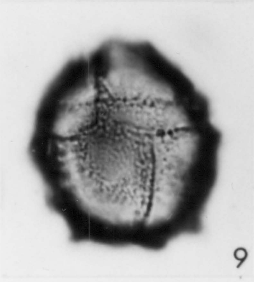
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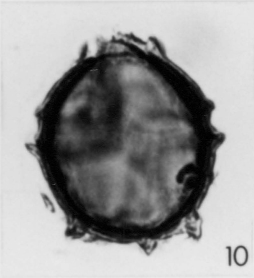
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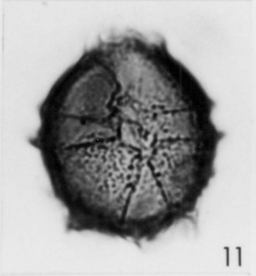
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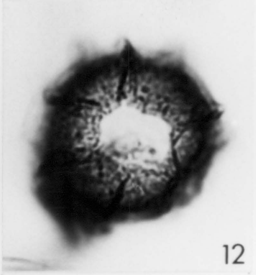
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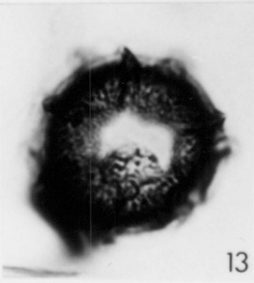
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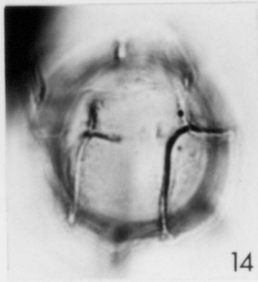
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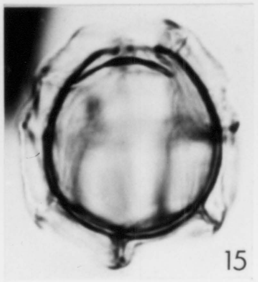
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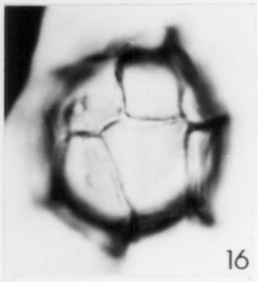
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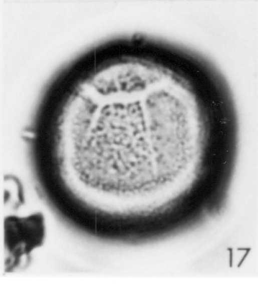
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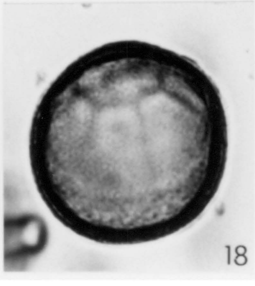
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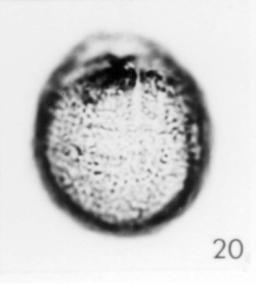
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PLATE 33

Figs. 1-5: *Elytrocysta obscurotabulata* n. sp. HOLOTYPE (Figs. 1-3): Three focal levels of specimen. Fig. 1: Dorsal view; note aligned bacula reflecting parasutures. Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view (focused through specimen); parasulcus is slightly to left of specimen midline. Overall L X W: 42um X 40um. VPISUPL Sample 330, Slide AO-68, Coords. R14.9;+9.7. Fig. 4: Lateral view of another specimen with attached operculum. Overall L X W: 32um X 27um. VPISUPL Sample 303, Slide AO-2, Coords. R5.6;+5.9. Fig. 5: Detailed view of attached operculum (about 8um wide) of another specimen. VPISUPL Sample 303, Slide AO-2, Coords. R5.4;+5.6.

Figs. 6-8: *Microdinium ornatum* Cookson and Eisenack 1960. Three focal levels of specimen. Fig. 6: Dorsal view (focused through specimen). Fig. 7: Optical cross-sectional view. Fig. 8: Ventral view. Overall L X W: 37um X 26um. VPISUPL Sample 307, Slide AO-15, Coords. R9.0;+17.0.

Figs. 9-12: Forma C. Figs. 9-10: Two focal levels of specimen with densely distributed spines. Main body diameter 86um; spines up to 18um long. VPISUPL Sample 331, Slide AO-72, Coords. R19.1;+2.7. Figs. 11-12: Two additional specimens from the same population (Sample 331). Fig. 11: Specimen revealing considerable loss of spines;

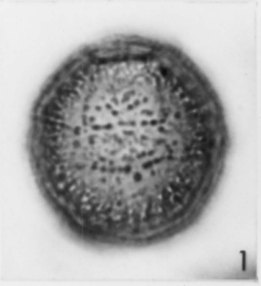
note paracingular paraplates. Maximum measurement 90um; spines up to 12um long. Slide AO-71, Coords. R14.2;+9.0. Fig. 12: Specimen exhibiting process sockets with almost all spines missing; note parasutures reflecting paracingular and postcingular paraplates. Main body diameter approximately 80um. Slide AO-71, Coords. R10.3;+9.7.

Fig. 13: *Dinopterygium cladoides* Deflandre 1935. Specimen exhibiting densely distributed small tubercles. Main body maximum diameter 82um; flange up to 14um wide. VPISUPL Sample 325, Slide AO-52, Coords. R17.3;+2.6.

Figs. 14-16: *Eocladopyxis peniculata* Morgenroth 1966. Figs. 14-15: Two focal levels of typically intact hypocyst showing paraplates. Main body diameter 67um; spines up to 13um long. VPISUPL Sample 316, Slide AO-35, Coords. R15.9;+2.7. Fig. 16: Specimen with a partial epicyst attached to hypocyst. Main body diameter 51um; spines up to 10um long. VPISUPL Sample 337, Slide AO-83, Coords. R7.9;+20.7.

Figs. 14-16: *Polysphaeridium zoharyi* (Rossignol 1962) Bujak, Downie, Eaton, and Williams 1980. Figs. 17-18: Two focal levels of specimen. Fig. 17: View (focused through specimen) of hypocyst. Fig. 18: Optical cross-sectional view. Main body diameter 42um; processes up to 10um long. Fig. 19: Detailed view of process (10um long). VPISUPL Sample 331, Slide AO-71, Coords. R15.0;+2.1. Fig. 20: Hypocyst of another specimen. Main body diameter 44um; processes up to 10um long. VPISUPL Sample 331, Slide AO-71, Coords. R13.8;+8.2.

PLATE 33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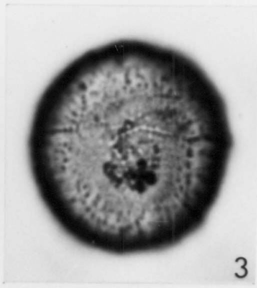
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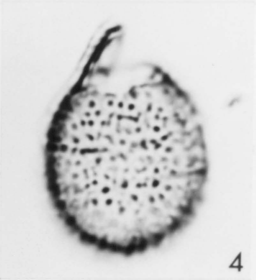
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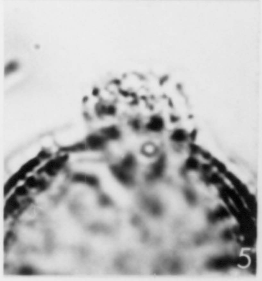
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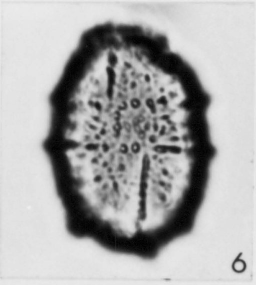
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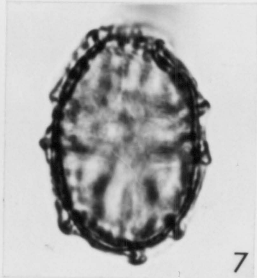
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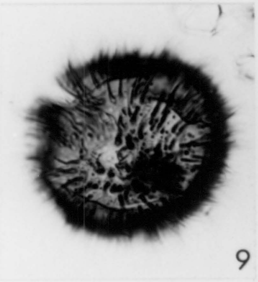
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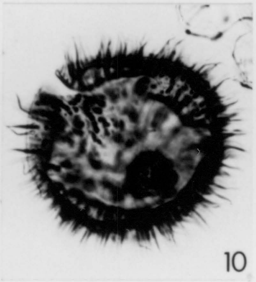
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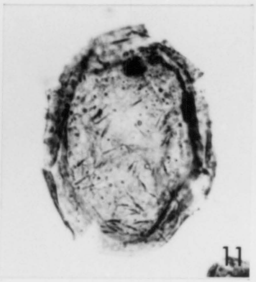
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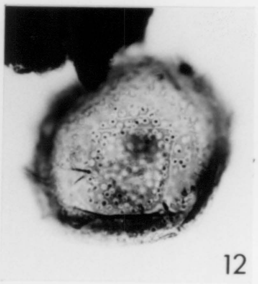
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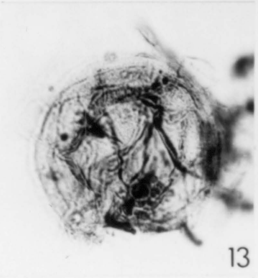
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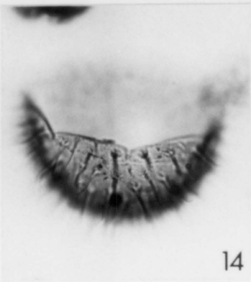
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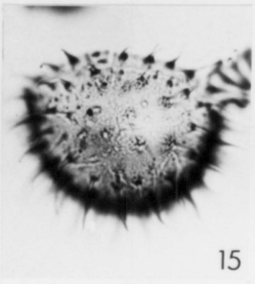
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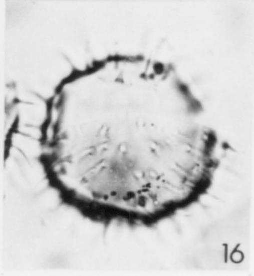
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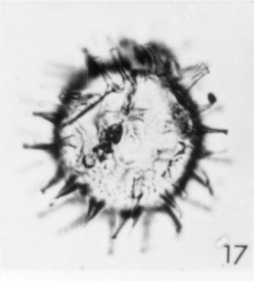
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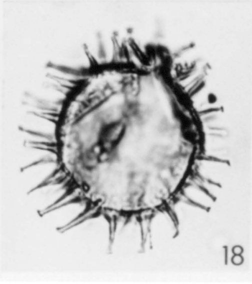
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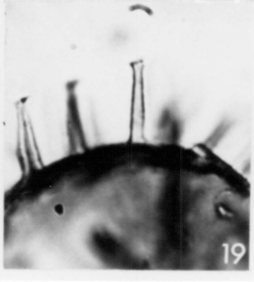
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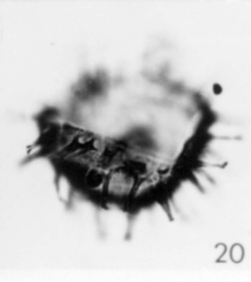
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PLATE 34

Figs. 1-2: *Polysphaeridium* cf. *P. zoharyi* (Rossignol 1962) Bujak, Downie, Eaton, and Williams 1980. Fig. 1: Broken specimen bearing processes with aculeate tips. Main body diamter approximately 48um; processes up to 16um long. Fig. 2: Detailed view of process (15um long) with aculeae up to 1um long. VPISUPL Sample 329, Slide AO-64, Coords. R14.2;+14.6.

Figs. 3-4: Forma B. Two focal levels of specimen. Fig. 3: Dorsal? view showing probable archeopyle (possibly precingular Type 2P or 3P) with operculum in place. Fig. 4: Optical cross-sectional view. Overall diameter 80um. VPISUPL Sample 330, Slide AO-68, Coords.R20.0;+8.6.

Figs. 5-7: *Heteraulacacysta campanula* Drugg and Loeblich 1967. Three focal levels of specimen. Fig. 5: Dorsal view. Fig. 6: Optical cross-sectional view. Fig. 7: Ventral view (focused through specimen). Overall L X W: 48um X 56um. VPISUPL Sample 334, Slide AO-77, Coords. R9.7.;+21.8 (all figures Interference Contrast).

Figs. 8-10: *Dinopterygium fehmarnense* (Morgenroth 1966) Stover and Evitt 1978. Three focal levels of specimen. Fig. 8: Dorsal view (focused through specimen). Fig. 9: Optical cross-sectional view. Fig. 10: Ventral view. Overall L X W: 66um X 70um. VPISUPL Sample

338, Slide AO-89, Coords. R6.0;+15.8 (all figures Interference Contrast).

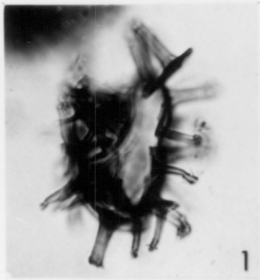
Figs. 11-13: *Homotryblium caliculum* Bujak 1980. Two focal levels of specimen bearing mushroom-shaped processes. Main body diameter approximately 45um; processes up to 18um long. VPISUPL Sample 338, Slide AO-87, Coords. R13.6;+7.4. Fig. 13: Another specimen from the same population (Sample 338) with processes of slightly different shape. Main body diameter 44um; processes up to 13um long. Slide AO-87, Coords. R14.5;+19.5.

Figs. 14-16: *Homotryblium pallidum-tenuispinosum* complex. Figs. 14-15: Two focal levels of specimen. Fig. 14: Dorsal view of complete specimen; note apical and precingular paraplates making up attached operculum (archeopyle is epicystal). Main body diameter 46um; processes up to 25um long. VPISUPL Sample 338, Slide AO-87, Coords. R10.6;+7.0. Fig. 16: Hypocyst of a specimen. Main body diameter 43um; processes up to 20um long. VPISUPL Sample 338, Slide AO-87, Coords. R9.7;+16.2.

Figs. 17-18: *Homotryblium tasmaniense* Cookson and Eisenack 1967. Two focal levels of specimen. Fig. 17: Antapical view; note relatively short, broad processes. Fig. 18: Optical cross-sectional view. Main body diameter 50um; processes up to 12um long and 11um wide. VPISUPL Sample 329, Slide AO-64, Coords. R11.8;+4.3.

Figs. 19-20: *Impletosphaeridium rugosum* Morgenroth 1966. Two focal levels of specimen. Fig. 19: Apical view (focused through specimen) showing faintly visible apical archeopyle. Fig. 20: Optical cross-sectional view. Main body diameter 20um; processes up to 9um long. VPISUPL Sample 316, Slide AO-35, Coords. R11.0;+16.2.

PLATE 34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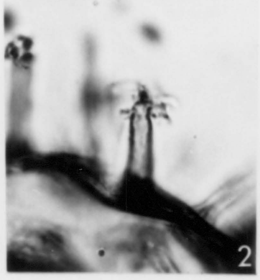
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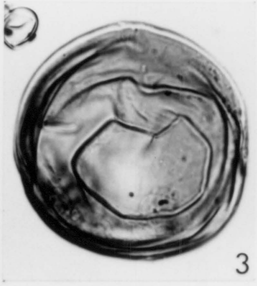
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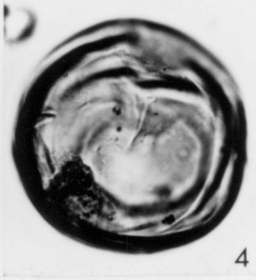
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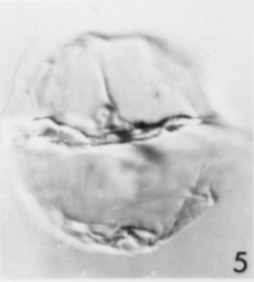
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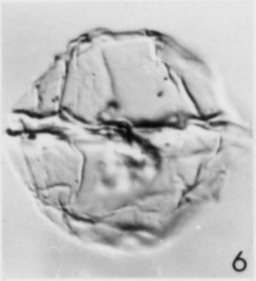
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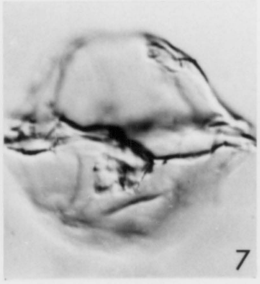
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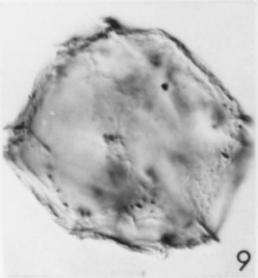
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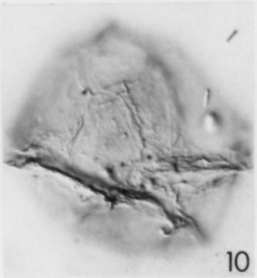
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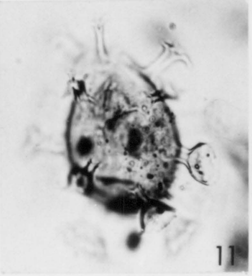
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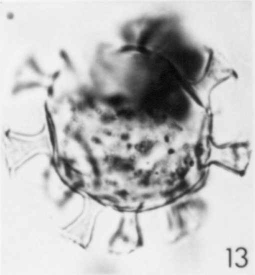
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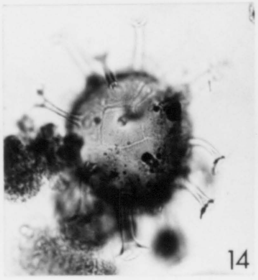
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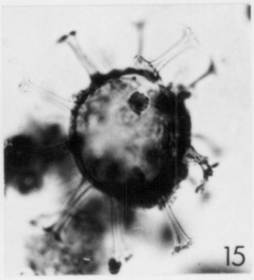
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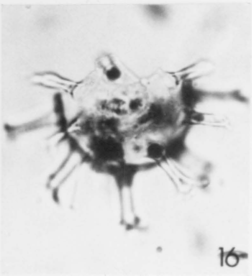
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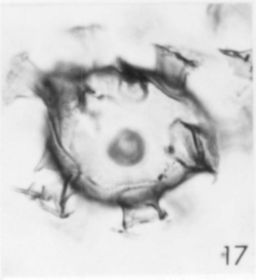
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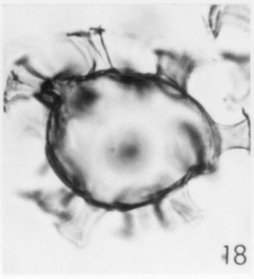
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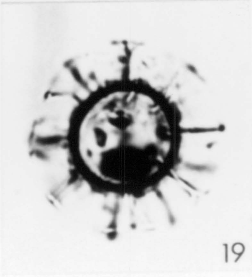
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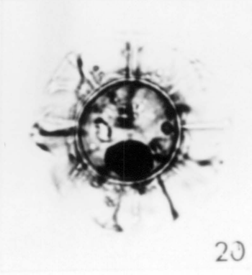
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PLATE 35

Fig. 1: *Impletosphaeridium kroemmelbeini* Morgenroth 1966. Specimen bearing rod-like and blade-like processes (up to 16um long). Main body diameter 34um. VPISUPL Sample 338, Slide AO-89, Coords. R9.5.;+3.6.

Figs. 2-4: *Impletosphaeridium?* sp. A. Three focal levels of specimen. Fig. 2: Dorsal view showing ventrally-attached operculum. Fig. 3: Optical cross-sectional view. Fig. 4: Ventral view (focused through specimen). Main body diameter 38um; processes up to 9um long. VPISUPL Sample 347, Slide AP-19, Coords. R17.8;+7.8.

Figs. 5-7: *Paucisphaeridium inversibuccinum* (Davey and Williams 1966) Bujak, Downie, Eaton, and Williams 1980. Fig. 5: Lateral view. Fig. 6: Optical cross-sectional view. Fig. 7: Lateral view (focused through specimen). Main body diameter 20um; processes up to 10um long. VPISUPL Sample 334, Slide AO-77, Coords. R13.7;+18.0.

Fig. 8: *Horologinella apiculata* Cookson and Eisenack 1962. Note small protuberance at one end on this small hourglass-shaped cyst. Overall L X W: 16um X 18um. VPISUPL Sample 317, Slide AO-39, Coords. R17.5;+18.1 (Interference Contrast).

Figs. 9-12: Forma D. Figs. 9-11: Three focal levels of specimen. Fig. 9: Apical view (focused through specimen). Fig. 10: Optical cross-sectional view. Fig. 11: Ventral view. Main body diameter 24um; overall diameter 40um. VPISUPL Sample 336, Slide AO-82, Coords. R18.0;+18.0. Fig. 12: Optical cross-sectional view of another specimen. Main body diameter 24um; overall diameter 42um. VPISUPL Sample 334, Slide AO-77, Coords. R9.7;+19.2.

Figs. 13-14: *Tuberculodinium?* sp. A. Two focal levels of specimen. Main body diameter 100um; processes up to 14um long. VPISUPL Sample 348, Slide AP-23, Coords. R19.0;+11.4.

Figs. 15-16: *Tuberculodinium vancampoae* (Rossignol 1962) Wall 1967. Two focal levels of specimen. Fig. 15: Apical view (focused through specimen) showing apical archeopyle. Fig. 16: Optical cross-sectional view. Main body diameter 96um; processes up to 20um long. VPISUPL Sample 348, Slide AP-21, Coords. R5.9;+17.8.

Figs. 17-20: *Tubidermodinium sulcatum* Morgenroth 1966. Figs. 17-19: Three focal levels of folded specimen. Fig. 17: Dorsal view (focused through specimen). Fig. 18: Optical cross-sectional view. Fig. 19: Ventral view. Main body L X W: 64um X 56um; bacula up to 7um long. Fig. 20: Detailed view of bacula supporting ectophragm. Bacula about 7um long. VPISUPL Sample 335, Slide AO-79, Coords. R12.4;+4.1.

PLATE 35


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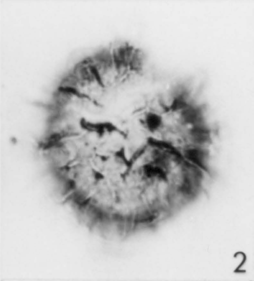
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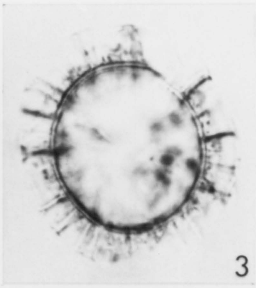
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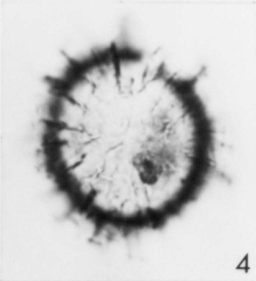
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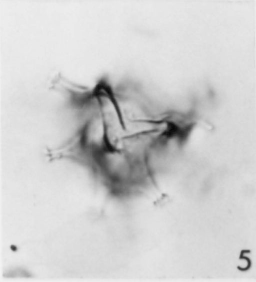
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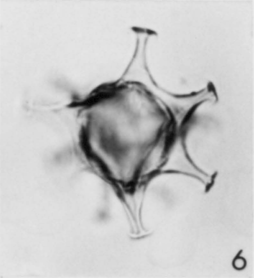
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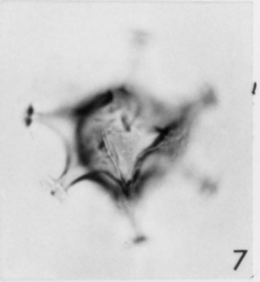
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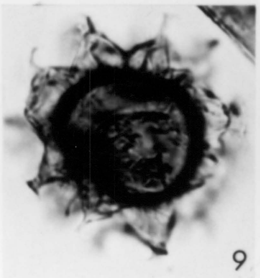
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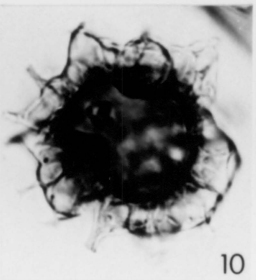
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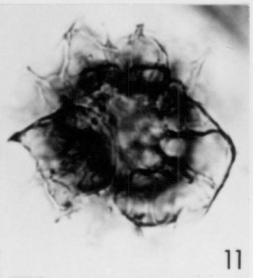
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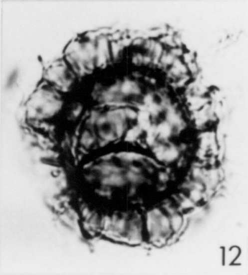
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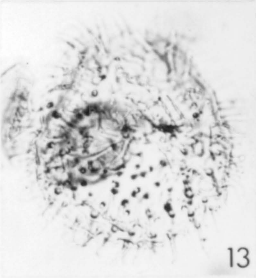
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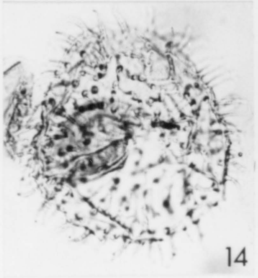
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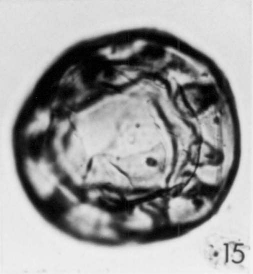
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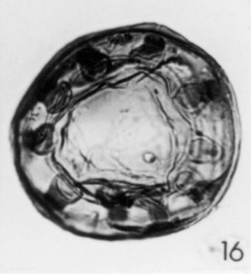
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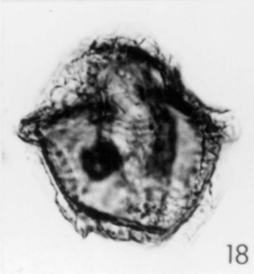
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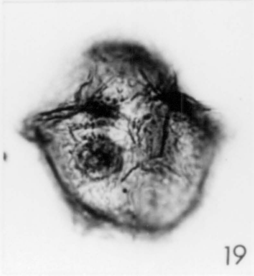
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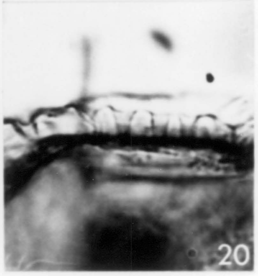
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PLATE 36

Figs. 1-3: *Inversidinium exilimurum* McLean 1973. Three focal levels of specimen. Fig. 1: Dorsal view (focused through specimen). Fig. 2: Optical cross-sectional view. Fig. 3: Ventral view. Overall L X W: 58um X 37um. VPISUPL Sample 308, Slide AO-17, Coords. R4.2;+2.9 (all figures Interference Contrast).

Fig. 4: *Fromea laevigata* (Drugg 1967) Stover and Evitt 1978. Optical cross-sectional view of specimen; note slightly folded inner body. Overall L X W: 80um X 24um. VPISUPL Sample 313, Slide AO-28, Coords. R9.0;+15.3 (Interference Contrast).

Figs. 5-6: *Fromea fragilis* (Cookson and Eisenack 1962) Stover and Evitt 1978. Two focal levels of specimen. Fig. 5: Dorsal? view. Fig. 6: Ventral? view showing longitudinal fold. Overall L X W: 80um X 48um. VPISUPL Sample 303, Slide AO-2, Coords. R3.2;+9.5 (both figures Interference Contrast).

Figs. 7-8: *Xenikoon australis* Cookson and Eisenack 1960. Fig. 7: Optical cross-sectional view of specimen. Overall L X W: 74um X 60um. VPISUPL Sample 309, Slide AO-19, Coords. R19.1;+7.5. Fig. 8: Cluster of three specimens which seem to be attached to one another. Overall L X W of lowermost cyst: 70um X 44um. VPISUPL Sample 309, Slide AO-19, Coords. R18.6;+3.0.

Figs. 9-10: *Paralecaniella indentata* (Deflandre and Cookson 1955) Elsik 1977. Fig. 9: Relatively large specimen with equatorial indentations (paracingulum?). Overall L X W: 127um X 116um. VPISUPL Sample 308, Slide AO-17, Coords. R17.8;+9.8. Fig. 10: Cluster of three specimens which appear to be connected; note aperture on flattened (bottom?) side of cysts. Overall L X W of lower right cyst: 54um X 50um. VPISUPL Sample 314, Slide AO-29, Coords. R8.7;+10.5 (Interference Contrast).

Figs. 11-14: Forma E. Fig. 11: Dorsal? view of specimen with rounded (precingular type?) archeopyle; ectophragm shows evidence of incipient process formation. Overall L X W: 100um X 114um; main body L X W: 56um X 56um. VPISUPL Sample 343, Slide AP-6, Coords. R4.3;+6.5. Figs. 12-14: Three focal levels of another specimen. Fig. 12: Oblique dorsal? view (focused through specimen). Fig. 13: Optical cross-sectional view. Fig. 14: Oblique ventral? view. Overall L X W: 130um X 122um; main body L X W: 60um X 60um. VPISUPL Sample 341, Slide AP-1, Coords. R14.0;+10.0.

PLATE 36


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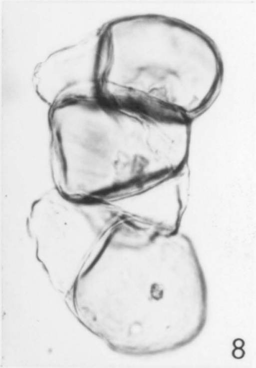
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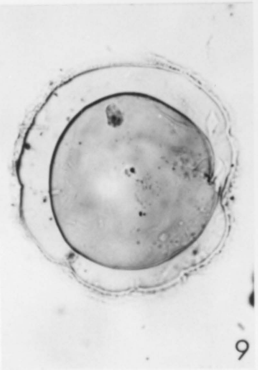
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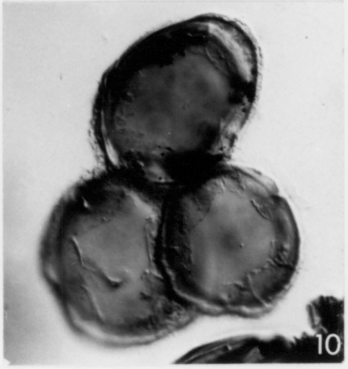
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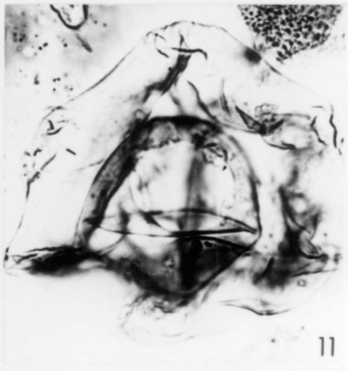
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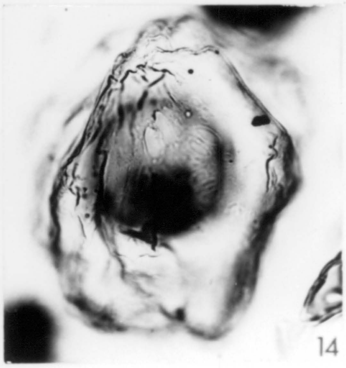
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PLATE 37

Fig. 1: *Micrhystridium* cf. *M. fragilis* Deflandre 1947. Main body diameter 23um; spines up to 28um long. VPISUPL Sample 315, Slide AO-34, Coords. R15.0;+9.3.

Fig. 2: *Micrhystridium* cf. *M. variabile* Valensi 1953. Main body diameter 26um long; spines up to 8um long. VPISUPL Sample 303, Slide AO-1, Coords. R2.3;+12.1.

Figs. 3-4: *Micrhystridium* spp. Fig. 3: Main body diameter 21um. VPISUPL Sample 319, Slide AO-42, Coords. R15.2;+19.7. Fig. 4: Main body diameter 13um; spines up to 4um long. VPISUPL Sample 319, Slide AO-42, Coords. R4.8;+21.0.

Figs. 5-6: *Cymatiosphaera* spp. Fig. 5: Main body diameter 17um; septa up to 4um high. VPISUPL Sample 319, Slide AO-42, Coords. R10.8;+2.5. Fig. 6: Main body diameter 18um; septa up to 3um high. VPISUPL Sample 323, Slide AO-47, Coords. R4.4;+20.1.

Figs. 7-8: *Pterospermopsis* spp. Fig. 7: Overall diameter 86um; central body diameter 54um. VPISUPL Sample 330, Slide AO-68, Coords. R10.1;+11.3. Fig. 8: Overall diameter 48um; central body diameter 32um. VPISUPL Sample 326, Slide AO-58, Coords. R11.5;+9.7.

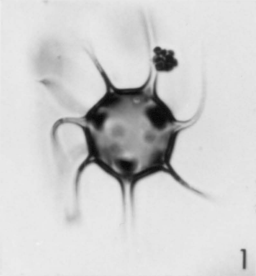
Figs. 9-10: *Trigonopyxidia ginella* (Cookson and Eisenack 1960) Cookson and Eisenack 1961. Fig. 9: Optical cross-sectional view of specimen. Overall L X W: 67um X 88um. Fig. 10: Detailed view of one vertex (possibly apical) with broken tip; note partial break on inner body (both broken tip on outer body and break on inner body may represent excystment features). Vertex width approximately 14um. VPISUPL Sample 307, Slide AO-16, Coords. R12.1;+13.8 (both figures Interference Contrast).

Figs. 11-12: *Palambages* sp. A. Fig. 11: Cluster of cells (diameters up to 50um). Fig. 12: Detailed view showing grana and cell openings. Maximum measurement of aperture in central cell approximately 20um. VPISUPL Sample 306, Slide AO-10, Coords. R16.7;+1.4.

Figs. 13-14: *Palambages* sp. B. Fig. 13: Cluster of cells (diameters up to 25um). Fig. 14: Detailed view showing small, faintly visible, strands (up to 3um long) which apparently hold cells together. VPISUPL Sample 309, Slide AO-19, Coords. R12.4;+14.2.

Figs. 15-16: *Palambages* sp. C. Fig. 15: Cluster of cells (diameters up to 22um). Fig. 16: Detailed view showing hair-like projections (up to 4um long). VPISUPL Sample 334, Slide AO-77, Coords. R5.5;+6.0.

PLATE 37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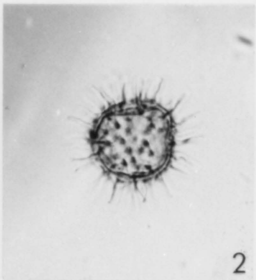
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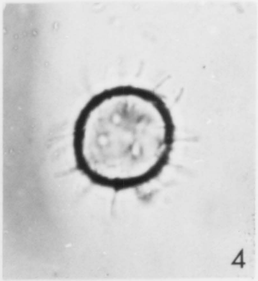
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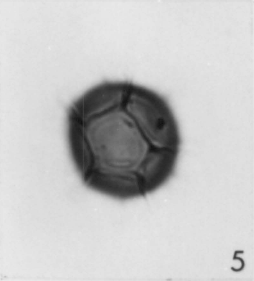
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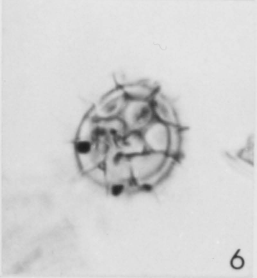
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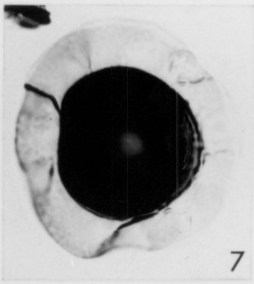
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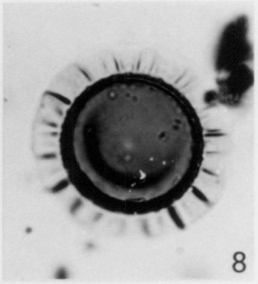
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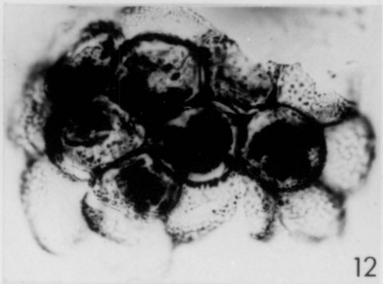
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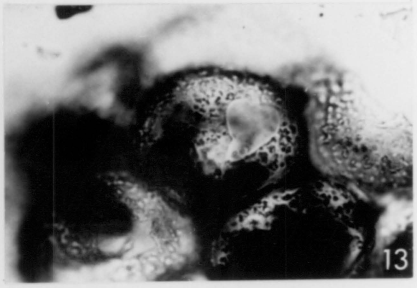
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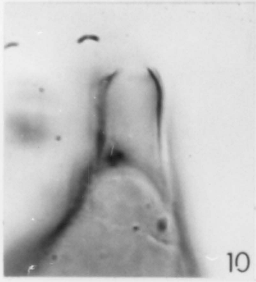
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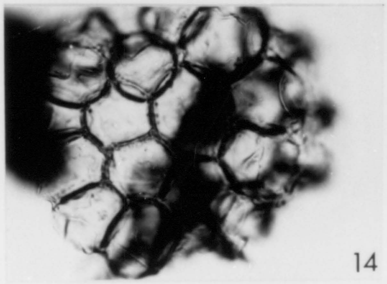
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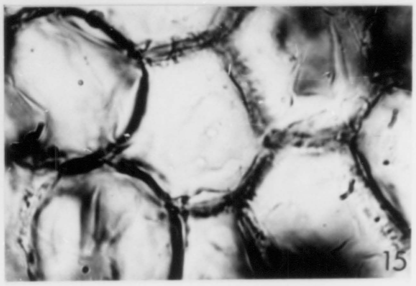
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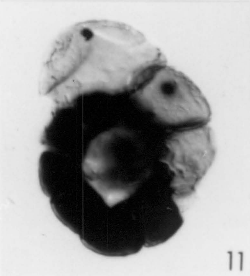
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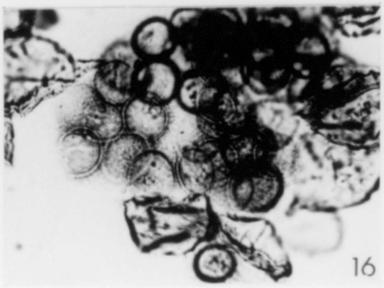
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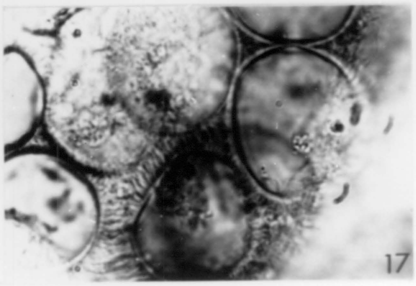
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PLATE 38

Fig. 1: *Sphagnumsporites* sp. (Brightseat equivalent-basal Aquia? strata); maximum measurement 32um. VPISUPL Sample 308, Slide AO-17, Coords. R6.0;+4.9.

Fig. 2: *Gleicheniidites* sp. (Aquia strata); maximum measurement 54um. VPISUPL Sample 318, Slide AO-41, Coords. R4.8;+9.4.

Fig. 3: *Sphagnumsporites* sp. (Nanjemoy strata); maximum measurement 100um. VPISUPL Sample 334, Slide AO-77, Coords. R3.5;+19.2.

Fig. 4: *Deltoidospora* sp. (Nanjemoy strata); maximum measurement 60um. VPISUPL Sample 336, Slide AO-82, Coords. R7.1;+15.6.

Fig. 5: *Nudopollis thiergartii* (Thompson and Pflug) Pflug 1953 (Brightseat equivalent-basal Aquia? strata); maximum measurement 40um. VPISUPL SAmple 307, Slide AO-16, Coords. R19.0;+4.8.

Fig. 6: *Caryapollenites* sp. (Aquia strata); maximum measurement 38um. VPISUPL Sample 312, Slide AO-26, Coords. R5.5;+7.5.

Fig. 7: *Pinus* sp. (Aquia strata); maximum measurement 92um. VPISUPL Sample 313, Slide AO-28, Coords. R8.0;+18.6.

Fig. 8: *Triatriopollenites subtriangulus* (Stanley) Frederiksen 1979 (Aquia strata); maximum measurement 36um. VPISUPL Sample 318, Slide AO-41, Coords. R15.4;+11.2.

Fig. 9: *Tricolpites* cf. *T. variabilis* Stanley 1965 (Marlboro Clay strata); maximum measurement 30um. VPISUPL Sample 319, Slide AO-42, Coords. R20.2;+13.2.

Fig. 10: *Intratriporopollenites reticulatus* (Groot and Groot) Frederiksen 1979 (Marlboro Clay strata); maximum measurement 42um. VPISUPL Sample 319, Slide AO-42, Coords. R18.6;+19.1.

Fig. 11: *Cupuliferoipollenites* sp. (Nanjemoy strata); maximum measurement 25um. VPISUPL Sample 330, Slide AO-68, Coords. R18.7;+8.9.

Fig. 12: *Verrutricolporites* sp. (Nanjemoy strata); maximum measurement 36um. VPISUPL Sample 333, Slide AO-76, Coords. R12.8;+10.7.

Fig. 13: *Tricolpites* sp. (Nanjemoy strata); maximum measurement 28um. VPISUPL Sample 333, Slide AO-76, Coords. R14.3;+5.0.

Fig. 14: *Polyatriopollenites stellatus* (Potonie) Pflug 1953 (Nanjemoy strata); maximum measurement 32um. VPISUPL Sample 333, Slide AO-76, Coords. R12.8;+11.5.

Fig. 15: *Triporopollenites* sp. (Nanjemoy strata); maximum measurement 36um. VPISUPL Sample 334, Slide AO-77, Coords. R10.7;+1.2.

Fig. 16: *Gleicheniidites* sp. (Nanjemoy strata); maximum measurement 40um. VPISUPL Sample 334, Slide AO-77, Coords. R15.5;+21.2.

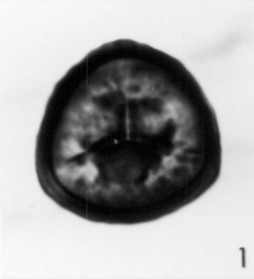
Fig. 17: *Picea* sp. (Nanjemoy strata); maximum measurement 66um. VPISUPL Sample 334, Slide AO-77, Coords. R12.9;+16.2.

Fig. 18: *Caryapollenites* sp. (Calvert strata); maximum measurement 60um. VPISUPL Sample 348, Slide AP-23, Coords. R7.5;+3.4.

Fig. 19: Periporate pollen (Choptank strata); maximum measurement 61um. VPISUPL Sample 349, Slide AP-26, Coords. R5.8;+9.7.

Fig. 20: *Pinus* sp. (Choptank strata); maximum measurement 110um. VPISUPL Sample 349, Slide AP-46, Coords. R14.3;+6.8.

PLATE 38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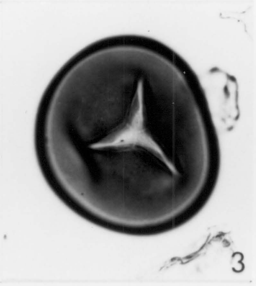
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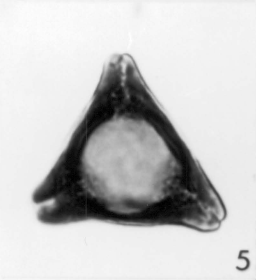
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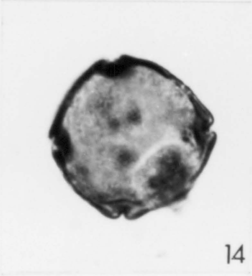
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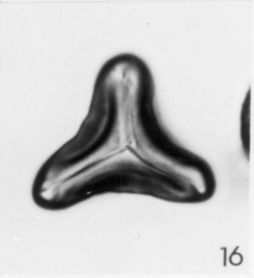
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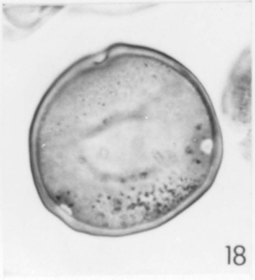
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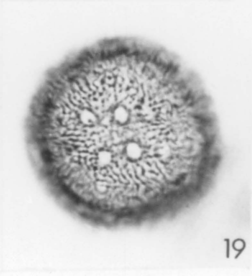
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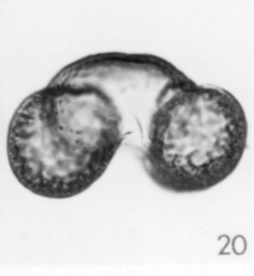
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APPENDIX

Appendix I (A-H)

This section includes various tabulations of numbers and percentages of dinoflagellate, acritarch, and chlorophyte species and specimens counted and computed in the assemblages recovered from the Tertiary strata of the Oak Grove core. These data form the basis upon which the curves in Text-figures 9, 12, 13, 14, 15, and Chart 7 are plotted.

Appendix I(A). Numbers of species in common and computed Otsuka coefficients for adjacent samples throughout the Tertiary strata of the Oak Grove core. Numerical data for Text-fig. 10.

	Smpl. No.	Species in Common	Otsuka Coefficient
Choptank Fm.	351	12	77.5
	350	14	68.6
	349	22	84.6
Calvert Fm.	348	25	88.1
	347	29	92.1
	346	23	83.0
	345	16	68.1
	344	13	60.6
	343	15	73.2
	342	17	72.7
	341	20	80.1
	340	9	29.1
Nanjemoy Fm.	339	26	67.6
	338	25	58.7
	337	30	68.6
	336	26	69.4
	335	28	61.8
	334	46	79.3
	333	32	58.9
	332	36	66.3
	331	39	69.1
	330	40	65.5
	329	45	75.8
	328	34	70.2
	327	29	68.5
	326	20	51.3
	325	33	77.9
	324	8	35.9
Marlboro Clay	323	9	75.2
	322	6	60.3
	321	4	59.6
	320	4	51.6
	319	10	39.6
Aquia Fm.	318	31	63.5
	317	34	73.9
	316	39	79.6
	315	28	60.5
	314	28	69.2
	313	31	80.5
	312	28	70.1
	311	27	63.5
	310	28	63.6
	309	32	72.7
	308	37	80.6
	307	38	76.0
?	306	38	73.8
	305	38	74.5
	304	46	88.5
	303		

Appendix I(B). Numbers of dinoflagellate, acritarch, and chlorophyte species, and numbers and percentages of species with respect to the relative abundances throughout the Tertiary strata of the Oak Grove core. Numerical data used in Text-figs. 13-16.

	Smpl. No.	No. of Dino. species	No. of Acrit. species	Total No. of species	No. of species (by relative abundance*)					% of species (by relative abundance*)				
					E	R	S	C	A	E	R	S	C	A
Choptank Fm.	351	14	1	15	7	5	2	0	1	47	33	13	0	7
	350	15	1	16	9	5	1	0	1	56	32	6	0	6
	349	25	1	26	10	8	7	0	1	38	31	27	0	4
Calvert Fm.	348	26	0	26	5	17	2	2	0	19	65	8	8	0
	347	29	2	31	14	11	5	1	0	45	35	17	3	0
	346	29	3	32	12	12	7	1	0	38	38	21	3	0
	345	22	2	24	13	7	2	0	2	55	29	8	0	8
	344	20	3	23	17	3	1	1	1	74	14	4	4	4
	343	18	2	20	5	10	2	2	1	25	50	10	10	5
	342	20	1	21	14	4	2	0	1	66	19	10	0	5
	341	26	0	26	15	6	2	3	0	58	23	8	11	0
	340	23	1	24	10	9	3	1	1	42	38	12	4	4
Nanjemoy Fm.	339	36	4	40	29	6	2	2	1	72	15	5	5	3
	338	36	1	37	24	6	5	1	1	65	16	13	3	3
	337	46	3	49	28	18	1	2	0	57	37	2	4	0
	336	37	2	39	32	5	0	1	1	81	13	0	3	3
	335	33	3	36	23	9	1	2	1	64	25	3	5	3
	334	56	1	57	40	14	1	1	1	70	24	2	2	2
	333	58	1	59	44	12	1	1	1	74	20	2	2	2
	332	46	4	50	38	8	2	1	1	76	16	4	2	2
	331	57	2	59	43	11	4	1	0	72	19	7	2	0
	330	49	5	54	43	7	1	2	1	79	13	2	4	2
	329	68	1	69	43	20	5	1	0	63	29	7	1	0
	328	49	2	51	41	7	1	0	2	80	14	2	0	4
	327	43	3	46	30	14	1	0	1	65	30	2	0	2
	326	36	3	39	27	10	0	0	2	69	26	0	0	5
	325	36	3	39	25	10	1	2	1	63	26	3	5	3
	324	35	3	38	26	9	0	2	1	68	24	0	5	3
Marlboro Clay	323	10	3	13	8	4	0	0	1	62	30	0	0	8
	322	8	3	11	6	4	0	0	1	55	36	0	0	9
	321	7	2	9	8	1	0	0	0	89	11	0	0	0
	320	4	1	5	3	2	0	0	0	60	40	0	0	0
	319	9	3	12	10	2	0	0	0	83	17	0	0	0
Aquia Fm.	318	50	3	53	35	16	0	0	2	67	29	0	0	4
	317	39	6	45	29	11	3	1	1	65	24	7	2	2
	316	43	4	47	29	16	0	1	1	62	34	0	2	2
	315	48	3	51	35	13	2	0	1	69	25	4	0	2
	314	36	6	42	31	8	1	0	2	74	19	2	0	5
	313	35	4	39	22	13	3	0	1	56	33	8	0	3
	312	34	4	38	29	7	1	0	1	76	18	3	0	3
	311	37	5	42	35	5	0	1	1	83	13	0	2	2
	310	41	2	43	28	12	1	1	1	65	29	2	2	2
	309	40	5	45	35	7	1	1	1	78	16	2	2	2
	308	39	4	43	25	14	2	2	0	58	32	5	5	0
	307	44	5	49	27	18	2	2	0	55	37	4	4	0
?	306	48	3	51	31	15	4	1	0	61	29	8	2	0
	305	47	5	52	32	16	2	2	0	62	30	4	4	0
	304	44	6	50	36	10	2	1	1	72	20	4	2	2
	303	47	7	54	36	12	5	0	1	67	22	9	0	2

* See the section "Methods of Study: Analytical Procedures" for definition of categories E (Extremely rare), R (Rare), S (Sparse), C (Common), and A (Abundant).

Appendix I(C). Percentages of dinoflagellate species and specimens with respect to general generic groups for the Tertiary strata of the Oak Grove core. Numerical data for Text-fig. 15.

	Smpl. No.	% of Species		% of Specimens	
		W/Ap/D	A/G + S/H/C	W/Ap/D	A/G + S/H/C
Chop-tank Fm.	351	0	33	0	14
	350	0	25	0	6
	349	0	27	0	17
Calvert Fm.	348	0	31	0	36
	347	0	26	0	37
	346	0	31	0	40
	345	0	33	0	12
	344	0	26	0	5
	343	0	25	0	15
	342	0	29	0	5
	341	0	27	0	8
	340	0	33	0	33
Nanjemoy Fm.	339	5	17	1	36
	338	11	13	5	23
	337	16	16	16	6
	336	23	10	87	5
	335	19	9	47	22
	334	18	16	42	6
	333	15	19	50	3
	332	12	14	53	4
	331	8	24	16	10
	330	17	17	39	5
	329	10	29	9	27
	328	14	30	43	17
	327	13	24	7	13
	326	15	18	79	4
	325	10	34	38	14
	324	13	32	41	10
Marl-boro Clay	323	23	15	94	1
	322	27	9	92	1
	321	44	0	90	0
	320	40	0	60	0
	319	25	17	70	20
Aquia Fm.	318	15	25	36	8
	317	16	17	13	29
	316	9	27	5	48
	315	16	24	15	44
	314	7	29	3	41
	313	10	26	12	19
	312	11	26	6	78
	311	10	22	4	62
	310	10	28	4	30
	309	11	20	3	53
	308	5	24	3	24
	307	6	31	7	44
?	306	12	26	4	48
	305	12	27	9	31
	304	10	24	12	38
	303	7	24	9	46

W:	*Wetzeliella* species
Ap:	*Apectodinium* species
D:	*Deflandrea* species
A:	*Areoligera* species
G:	*Glaphyrocysta* species
S:	*Spiniferites* species
H:	*Hystrichosphaeridium* species
C:	*Cordosphaeridium* species

Appendix I(D). Numbers of gonyaulacacean (G) and peridiniacean (P) dinoflagellate species and computed G/P ratios for the Tertiary strata of the Oak Grove core. Numerical data for Text-fig. 15.

	Smpl. No.	G	P	G/P
Choptank Fm.	351	12	1	12.00
	350	11	1	11.00
	349	18	1	18.00
Calvert Fm.	348	20	1	20.00
	347	21	1	21.00
	346	20	1	20.00
	345	17	1	17.00
	344	13	1	13.00
	343	15	1	15.00
	342	17	1	17.00
	341	21	1	21.00
	340	20	1	20.00
Nanjemoy Fm.	339	23	4	5.75
	338	18	6	3.00
	337	24	13	1.85
	336	20	11	1.82
	335	14	9	1.56
	334	29	11	2.64
	333	28	12	2.33
	332	33	8	2.88
	331	23	6	3.83
	330	25	11	2.27
	329	46	8	5.75
	328	34	8	4.25
	327	27	8	3.38
	326	22	6	3.67
	325	27	4	6.75
	324	26	5	5.20
Marlboro Clay	323	2	5	.40
	322	3	4	.75
	321	1	5	.20
	320	1	1	1.00
	319	3	4	.75
Aquia Fm.	318	28	9	3.11
	317	19	8	2.38
	316	28	5	5.60
	315	28	9	3.11
	314	21	3	7.00
	313	15	5	3.00
	312	18	5	3.60
	311	17	5	3.40
	310	25	5	5.00
	309	22	5	4.40
	308	22	4	5.50
	307	28	4	7.00
?	306	27	7	3.86
	305	27	7	3.86
	304	24	6	4.00
	303	26	5	5.20

G: Gonyaulacacean species
P: Peridiniacean species

Appendix I(E). Numbers and percentages of dinoflagellate species and specimens with respect to cyst type for the Tertiary strata of the Oak Grove core. Numerical data for Text-fig. 16.

	Smpl. No.	No. of Species/Specimens				% of Species/Specimens			
		Ch	P	C	O	Ch	P	C	O
Chop-tank Fm.	351	10/295	2/4	2/2	0/0	72/98	14/1	14/1	0/0
	350	10/276	2/22	3/3	0/0	67/92	13/7	20/1	0/0
	349	21/253	2/45	2/3	0/0	84/84	8/15	8/1	0/0
Calvert Fm.	348	12/248	3/39	2/14	0/0	80/82	12/13	8/5	0/0
	347	23/249	3/47	3/4	0/0	79/83	11/16	10/1	0/0
	346	24/252	2/24	3/20	0/0	83/85	7/8	10/7	0/0
	345	16/206	3/84	3/6	0/0	72/70	14/28	14/2	0/0
	344	14/224	2/71	3/4	1/1	70/75	10/24	15/1	5/<1
	343	10/180	5/102	2/6	1/9	55/61	28/34	11/2	6/3
	342	16/72	3/228	1/3	0/0	80/24	15/75	5/1	0/0
	341	20/157	4/90	1/2	1/51	77/52	15/30	4/1	4/17
	340	15/203	6/84	2/13	0/0	65/68	26/28	9/4	0/0
Nanjemoy Fm.	339	27/266	2/6	6/33	1/3	74/86	6/2	17/11	3/1
	338	23/228	3/21	8/53	2/4	64/75	8/7	22/17	6/1
	337	26/219	5/20	13/59	2/8	57/71	11/7	28/19	4/3
	336	20/31	1/1	14/267	2/8	54/10	3/<1	38/87	5/3
	335	19/155	2/2	11/132	1/11	58/52	6/<1	33/44	3/4
	334	33/128	5/5	17/138	1/9	59/46	9/2	30/49	2/3
	333	35/116	4/6	17/162	2/4	60/40	7/2	30/57	3/1
	332	26/73	5/22	13/217	2/5	57/23	11/7	28/68	4/2
	331	38/214	4/7	13/80	2/6	66/70	7/2	23/26	4/2
	330	27/45	4/54	16/173	2/42	55/15	8/17	33/55	4/13
	329	52/232	3/8	12/46	1/20	76/76	4/3	19/15	1/6
	328	33/171	3/4	12/136	1/1	68/55	6/1	24/44	2/<1
	327	27/229	3/26	13/51	0/0	63/75	7/8	30/17	0/0
	326	21/46	2/11	12/247	1/1	58/15	6/4	33/81	3/<1
	325	28/180	2/2	5/119	1/1	77/60	6/<1	14/40	3/<1
	324	26/167	2/4	6/130	1/2	74/55	6/1	17/43	3/1
Marl-boro Clay	323	2/3	0/0	8/293	0/0	20/1	0/0	80/99	0/0
	322	3/3	0/0	5/290	0/0	38/1	0/0	62/99	0/0
	321	1/1	0/0	6/11	0/0	14/8	0/0	86/92	0/0
	320	0/0	0/0	4/10	0/0	0/0	0/0	100/100	0/0
	319	3/3	0/0	6/10	0/0	33/23	0/0	67/77	0/0
Aquia Fm.	318	30/65	3/6	17/233	0/0	60/21	6/2	34/77	0/0
	317	18/171	5/31	16/100	0/0	46/56	13/10	41/34	0/0
	316	28/262	5/12	10/30	0/0	65/86	12/4	23/10	0/0
	315	25/207	4/30	19/66	0/0	52/68	8/10	40/22	0/0
	314	22/150	2/2	11/66	1/79	61/51	6/1	31/22	2/26
	313	16/184	0/0	18/108	1/12	46/60	0/0	51/36	3/4
	312	16/259	2/2	15/48	1/1	47/84	6/1	44/15	3/<1
	311	15/217	2/2	19/93	1/1	40/69	5/1	52/30	3/<1
	310	25/114	0/0	15/184	1/1	61/38	0/0	37/62	2/<1
	309	21/171	1/2	17/128	1/1	52/56	3/1	43/43	2/<1
	308	21/109	2/3	15/179	1/1	55/37	5/1	38/62	2/<1
	307	28/166	1/1	14/123	1/2	64/57	2/<1	32/42	2/1
?	306	27/177	1/2	18/108	2/2	56/61	2/1	38/37	4/1
	305	24/124	3/5	20/162	0/0	51/43	6/2	43/55	0/0
	304	25/134	0/0	18/161	1/2	57/45	0/0	41/54	2/1
	303	27/163	1/1	17/129	2/3	58/55	2/<1	36/43	4/1

Ch: Chorate--bear tubular or spine-like processes (varying tips) that may or may not reflect paratabulation (e.g., Cordosphaeridium, Hystrichosphaeridium, Spiniferites, Cleistosphaeridium); includes trabeculate (e.g., Adnatosphaeridium) and marginate (e.g., Areoligera, Glaphyrocysta) types.

P: Proximate--approximate size and morphology of parent theca; paratabulation generally reflected by parasutural septa, ridges, etc. (e.g., Impagidinium, Gonyaulacysta).

C: Cavate--constructed of periphragm and endophragm not generally in contact resulting in cavities (pericoels); paratabulation typically reflected by parasutural or intratabular ornament (e.g., Deflandrea, Spinidinium); includes holocavate types (e.g., Chlamydophorella).

O: Others--for those that could not be accomodated by types mentioned above; includes membranate (e.g., membranate, etc. types).

Note: Numbers and percentages of specimens are based on counts of 300 per sample, except for very sparse Samples 319, 320, and 321 where counts of 10 were made. Sample specimen totals may not add up to 300 (or 10) because of those specimens observed in routine study but not in the 300 (or 10) numerical count.

Appendix I(F). Numbers and percentages of dinoflagellate species with respect to archeopyle types for the Tertiary strata of the Oak Grove core. Numerical data for Text-fig. 16.

	Smpl.	No. of species						% of species					
	No.	A	P	E	I	O	Total	A	P	E	I	O	Total
Choptank Fm.	351	3	9	0	2	0	14	21	65	0	14	0	100
	350	3	8	0	2	2	15	20	54	0	13	13	100
	349	8	12	1	1	3	25	32	48	4	4	12	100
Calvert Fm.	348	8	14	0	1	3	26	31	54	0	4	11	100
	347	8	15	1	1	4	29	28	52	3	3	14	100
	346	8	15	1	1	4	29	28	52	3	3	14	100
	345	7	11	0	1	3	22	32	50	0	4	14	100
	344	5	9	1	1	4	20	25	45	5	5	20	100
	343	5	11	0	1	1	18	28	62	0	5	5	100
	342	5	12	0	1	2	20	25	60	0	5	10	100
	341	8	15	1	1	1	26	30	58	4	4	4	100
	340	5	15	0	1	2	23	22	65	0	4	9	100
Nanjemoy Fm.	339	12	13	4	4	3	36	33	37	11	11	8	100
	338	10	12	6	6	3	36	26	32	17	17	8	100
	337	11	14	6	12	3	46	24	30	13	26	7	100
	336	10	12	2	11	2	37	27	33	5	30	5	100
	335	8	8	6	9	2	33	24	24	18	28	6	100
	334	10	18	9	12	6	56	18	33	16	22	11	100
	333	11	20	9	12	6	58	19	34	16	21	10	100
	332	14	15	6	8	3	46	30	33	13	17	7	100
	331	16	23	7	7	4	57	28	41	12	12	7	100
	330	13	17	4	11	4	49	27	35	8	22	8	100
	329	15	34	6	8	4	68	22	50	9	12	7	100
	328	15	20	3	8	3	49	31	41	6	16	6	100
	327	9	21	1	8	4	43	21	49	2	19	9	100
	326	13	12	1	6	4	36	36	33	3	17	11	100
	325	7	22	2	4	1	36	19	61	6	11	3	100
	324	7	20	1	5	2	35	20	57	3	14	6	100
Marlboro Clay	323	1	2	0	5	2	10	10	20	0	50	20	100
	322	1	1	0	4	2	8	13	13	0	50	25	100
	321	2	0	0	5	0	7	29	0	0	71	0	100
	320	1	0	0	2	1	4	25	0	0	50	25	100
	319	4	1	0	4	0	9	44	12	0	44	0	100
Aquia Fm.	318	15	19	1	9	6	50	30	38	2	18	12	100
	317	12	13	1	8	5	39	31	34	3	21	13	100
	316	14	19	1	5	4	43	33	44	2	12	9	100
	315	16	17	1	9	5	48	33	36	2	19	10	100
	314	13	14	0	3	6	36	36	39	0	8	17	100
	313	13	11	0	5	6	35	37	32	0	14	17	100
	312	13	12	0	5	4	34	38	35	0	15	12	100
	311	14	11	0	4	8	37	38	31	0	11	20	100
	310	13	17	0	5	6	41	32	41	0	12	15	100
	309	14	18	0	4	4	40	35	45	0	10	10	100
	308	14	17	0	4	4	39	36	44	0	10	10	100
	307	17	21	0	4	2	44	39	48	0	9	4	100
?	306	16	22	0	6	4	48	34	46	0	12	8	100
	305	15	21	0	6	5	47	32	45	0	13	11	100
	304	14	19	0	6	5	44	32	43	0	14	11	100
	303	17	20	0	5	5	47	36	42	0	11	11	100

Appendix I(G). Numbers and percentages of pollen and spores in general for the Tertiary strata of the Oak Grove core. Numerical data for Text-fig. 14.

		[Pollen/Spores as a group]				
	Smpl. No.	No. of specimens (300 count)	% of total palynomorphs (300 count)	% spores in pollen/spore fraction	% bissacate pollen in pollen/spore fraction	% other pollen in pollen/spore fraction
Chop-tank Fm.	351	113	38	< 1	16	22
	350	221	74	< 1	21	52
	349	190	63	< 1	31	33
Calvert Fm.	348	190	63	1	29	34
	347	148	49	< 1	23	27
	346	143	48	< 1	27	21
	345	221	74	< 1	29	45
	344	243	81	< 1	30	51
	343	229	76	< 1	24	52
	342	260	87	< 1	31	56
	341	170	57	< 1	23	34
	340	168	56	< 1	25	31
Nanjemoy Fm.	339	11	4	< 1	2	2
	338	12	4	< 1	2	2
	337	9	3	1	1	1
	336	86	29	1	4	24
	335	29	10	1	3	6
	334	86	29	2	2	25
	333	92	31	2	2	27
	332	15	6	1	3	2
	331	6	2	< 1	1	1
	330	52	17	1	6	10
	329	9	3	< 1	2	1
	328	18	6	1	2	4
	327	18	6	< 1	2	4
	326	51	17	1	3	13
	325	16	5	< 1	1	4
	324	18	6	1	2	3
Marl-boro Clay	323	211	70	12	2	56
	322	169	56	10	1	45
	321	281	94	18	1	75
	320	293	98	13	1	84
	319	257	86	24	4	58
Aquia Fm.	318	86	28	3	4	21
	317	57	20	1	12	7
	316	30	10	< 1	9	1
	315	44	15	< 1	13	2
	314	53	18	< 1	15	3
	313	47	16	1	13	2
	312	41	14	< 1	11	3
	311	38	13	< 1	10	3
	310	76	25	< 1	15	10
	309	39	13	< 1	7	6
	308	74	25	1	13	12
	307	48	16	< 1	10	6
?	306	58	19	< 1	12	7
	305	79	26	< 1	17	9
	304	61	20	< 1	13	7
	303	59	20	1	12	7

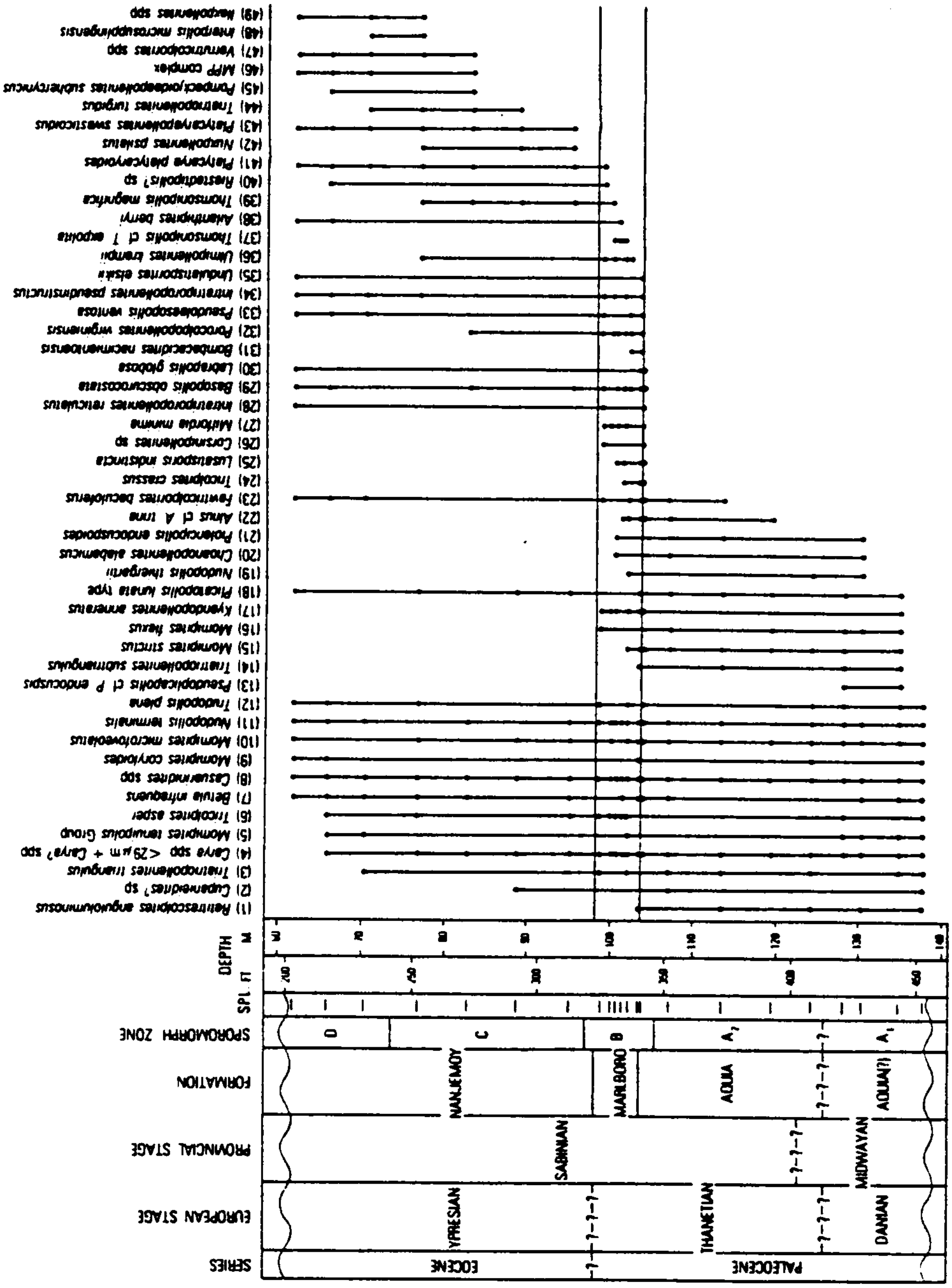
Appendix I(H). Tabulation of the five most abundant dinoflagellate species (Ranks 1-5) for each of the samples in the Tertiary strata of the Oak Grove core. Species' percentage in total sample assemblage shown in parentheses following name. Column at extreme right indicates what total percentage the first five ranked species in sample represent. (See Chart 6 (in back pocket) for diagrammatic representation.)

Smpl No.	SPECIES' RANK IN SAMPLE					1-5 Ranks Total %
	First	Second	Third	Fourth	Fifth	
351	O.centrocarpum(73)	L.machaerophorum(10)	S.crassipellis-C(7)	S.ramosus ramosus(3)	O.paradoxum(2)	95
350	O.centrocarpum(82)	Impagidinium sp.B(6)	L.machaerophorum(3)	S.ramosus ramosus(2)	S.crassipellis-C(2)	95
349	H.rigaudiae(32)	B.microreticulata(10)	Impletosp. sp.A(8)	O.centrocarpum(7)	L.machaerophorum(6)	63
348	O.centrocarpum(24)	S.crassipellis-C(21)	B.microreticulata(9)	S.ramosus ramosus(7)	L.machaerophorum(5)	66
347	S.crassipellis-C(21)	B.microreticulata(13)	Impletosp. sp.A(12)	O.centrocarpum(10)	L.machaerophorum(7)	63
346	S.crassipellis-C(19)	O.centrocarpum(13)	S.ramosus ramosus(7)	O.paradoxum(7)	C.diversispinosum(6)	52
345	C.diversispinosum(40)	B.microreticulata(27)	L.machaerophorum(7)	S.ramosus ramosus(5)	S.crassipellis-C(5)	84
344	C.diversispinosum(54)	B.microreticulata(23)	L.machaerophorum(13)	S.ramosus ramosus(2)	O.centrocarpum(1)	93
343	C.diversispinosum(27)	B.microreticulata(23)	L.machaerophorum(12)	S.crassipellis-C(8)	M.giuseppei(7)	77
342	B.microreticulata(76)	L.machaerophorum(9)	C.diversispinosum(6)	Tuberculodinium sp.(2)	S.ramosus ramosus(2)	95
341	C.diversispinosum(25)	A.labyrinthum(22)	Forma E(17)	L.machaerophorum(8)	B.microreticulata(7)	79
340	C.amputatospinosum(26)	M.giuseppei(18)	C.diversispinosum(15)	B.microreticulata(8)	L.machaerophorum(6)	73
339	G.ordinata(32)	H.pallidum/tenuisp.(21)	C.diversispinosum(19)	W.lunaris(6)	L.machaerophorum(6)	84
338	G.ordinata(20)	A.biformoides(8)	W.lunaris(7)	L.machaerophorum(6)	E.peniculata(6)	47
337	E.peniculata(25)	C.diversispinosum(20)	S.paratabulatum(9)	A.biformoides(4)	H.tasmaniense(4)	62
336	D.phosphoritica(58)	W.hampdenensis(24)	Areoligera spp.(3)	T.pelagica(2)	S.paratabulatum(2)	89
335	D.phosphoritica(38)	Areoligera spp.(25)	C.diversispinosum(7)	W.hampdenensis(6)	T.pelagica(4)	80
334	S.macmurdoense(33)	Forma C(21)	T.pelagica(3)	D.phosphoritica(3)	Areoligera spp.(2)	62
333	S.macmurdoense(41)	Forma C(20)	E.peniculata(3)	W.hampdenensis(2)	D.phosphoritica(2)	68
332	W.samlandica(51)	B.longissimum(17)	A.multisp./vittatum(8)	A.australiense(5)	A.biformoides(3)	84
331	A.multisp./vittatum(17)	E.peniculata(14)	Forma C(13)	W.varielongituda(10)	A.robustum(6)	60
330	W.samlandica(32)	Forma B(17)	E.densobaculata(15)	T.pelagica(14)	W.hampdenensis(2)	80
329	A.multisp./vittatum(18)	T.pelagica(7)	C.inodes(6)	H.tasmaniense(5)	Glaphyrocysta sp.B(5)	41
328	W.hampdenensis(38)	A.multisp./vittatum(31)	Areoligera spp.(9)	S.placacantha(2)	S.ramosus ramosus(2)	82
327	S.placacantha(48)	Forma B(7)	P.indentata(6)	S.ramosus ramosus(5)	H.tubiferum(4)	70
326	W.tabulatum(44)	D.phosphoritica(41)	M.giuseppei(3)	M.fimbriatum(3)	A.multisp./vittatum(2)	93
325	A.multisp./vittatum(28)	A.homomorphum cplx.(21)	S.dilwynense(15)	M.fimbriatum(6)	O.israelianum(3)	73
324	A.multisp./vittatum(32)	A.homomorphum cplx.(23)	S.dilwynense(19)	O.israelianum(5)	M.fimbriatum(3)	82
323	S.dilwynense(92)	A.homomorphum cplx.(2)	E.obscurotabulata(2)	Micrhystridium spp.(1)	S.obscurum(1)	98
322	S.dilwynense(90)	Apectodinium sp.A(4)	A.homomorphum cplx.(2)	Micrhystridium spp.(1)	S.obscurum(1)	98
321	S.dilwynense(50)	A.homomophum cplx.(20)	E.obscurotabulata(10)	Apectodinium sp. A(10)	K.brevibarbatum(10)	-100
320	S.dilwynense(50)	E.obscurotabulata(30)	A.homomorphum cplx.(10)	H.apiculata(10)	-----	-100
319	S.dilwynense(40)	E.obscurotabulata(30)	A.homomorphum cplx.(20)	P.golzowense(10)	-----	-100
318	A.homomophum cplx.(31)	E.obscurotabulata(29)	T.paratabulata(5)	A.hydria(3)	K.brevibarbatum(2)	70
317	Glaphyrocysta sp.A(25)	A.robustum(19)	E.obscurotabulata(11)	I.speciosum(6)	D.phosphoritica(5)	66
316	Glaphyrocysta sp.A(37)	E.peniculata(21)	A.robustum(6)	D.phosphoritica(3)	E.obscurotabulata(3)	70
315	Glaphyrocysta sp.A(38)	E.peniculata(14)	I.cf.I.speciosum(8)	D.dartmooria(6)	L.ruginosa(5)	71
314	Glaphyrocysta sp.A(35)	T.delicata(26)	P.indentata(15)	T.filosa(3)	D.dartmooria(2)	81
313	T.filosa(39)	Glaphyrocysta sp.A(10)	D.dartmooria(9)	X.australis(7)	G.exuberans cplx.(5)	70
312	G.exuberans cplx.(69)	T.filosa(8)	D.dartmooria(5)	X.australis(3)	Glaphyrocysta sp.A(3)	88
311	G.exuberans cplx.(55)	F.annetorpense(18)	E.obscurotabulata(6)	Glaphyrocysta sp.A(3)	D.dartmooria(2)	84
310	F.annetorpense(33)	G.exuberans cplx.(21)	X.australis(15)	E.obscurotabulata(4)	Glaphyrocysta sp.A(3)	76
309	G.exuberans cplx.(43)	X.australis(20)	F.annetorpense(11)	E.obscurotabulata(4)	Glaphyrocysta sp.A(3)	81
308	F.annetorpense(24)	E.obscurotabulata(16)	C.giganteum(12)	G.exuberans cplx.(6)	X.australis(5)	63
307	C.giganteum(18)	E.obscurotabulata(17)	G.exuberans cplx.(10)	F.annetorpense(5)	C.amiculum(4)	54
306	G.exuberans(22)	C.giganteum(11)	E.obscurotabulata(10)	F.annetorpense(6)	P.indentata(5)	54
305	F.annetorpense(21)	C.giganteum(17)	E.obscurotabulata(9)	D.dartmooria(7)	G.exuberans cplx.(5)	59
304	G.exuberans cplx.(26)	F.annetorpense(20)	X.australis(8)	E.obscurotabulata(7)	P.pyrophorum(6)	67
303	G.exuberans cplx.(28)	F.annetorpense(14)	E.obscurotabulata(7)	X.australis(6)	C.giganteum(6)	61

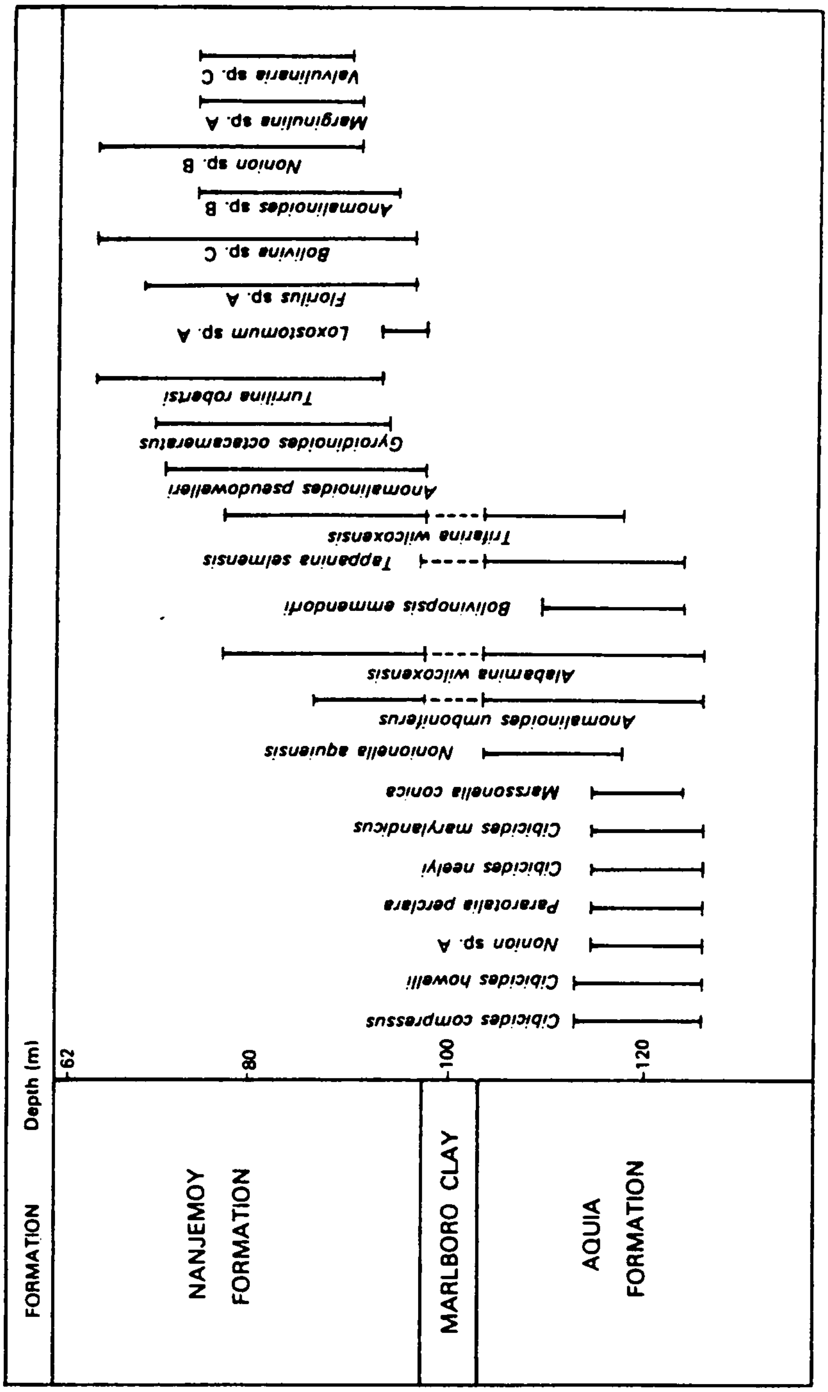
Appendix II (A-D)

Included in this section are biostratigraphic range charts of pollen and spores, benthonic foraminifera, calcareous nannofossils, and mollusks for the Tertiary strata of the Oak Grove core. These fossil groups were studied by various paleontologists as indicated in the section "Palynological Biostratigraphy: Ages of the Formations" (see Table 2) and Gibson et al. (1980).

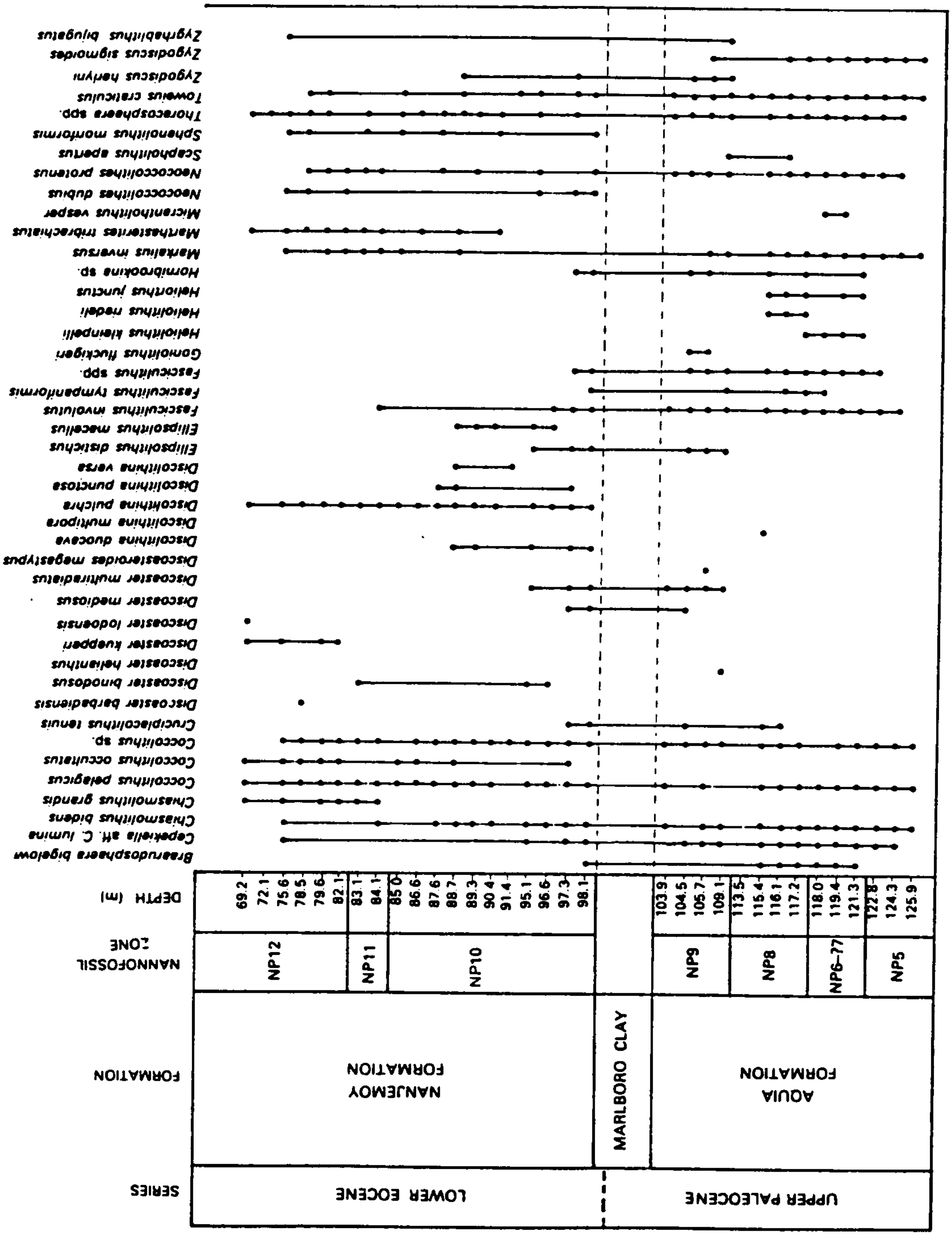
Appendix II(A). Biostratigraphic range chart of pollen and spores species in the Aquia(?), Aquia, Marlboro Clay, and Nanjemoy strata of the Oak Grove core. (Taken from Gibson et al., 1980.)



Appendix II(B). Biostratigraphic range chart of key benthonic foraminifers in the Aquia, Marlboro Clay, and Nanjemoy strata of the Oak Grove core. (Taken from Gibson et al., 1980.)



Appendix II(C). Biostratigraphic range chart of calcareous nannofossils in the Aquia, Marlboro Clay, and Nanjemoy strata of the Oak Grove core. (Taken from Gibson et al., 1980.)



Appendix II(D). Biostratigraphic range chart of mollusks in the Nanjemoy strata of the Oak Grove core. (Taken from Gibson et al., 1980.)

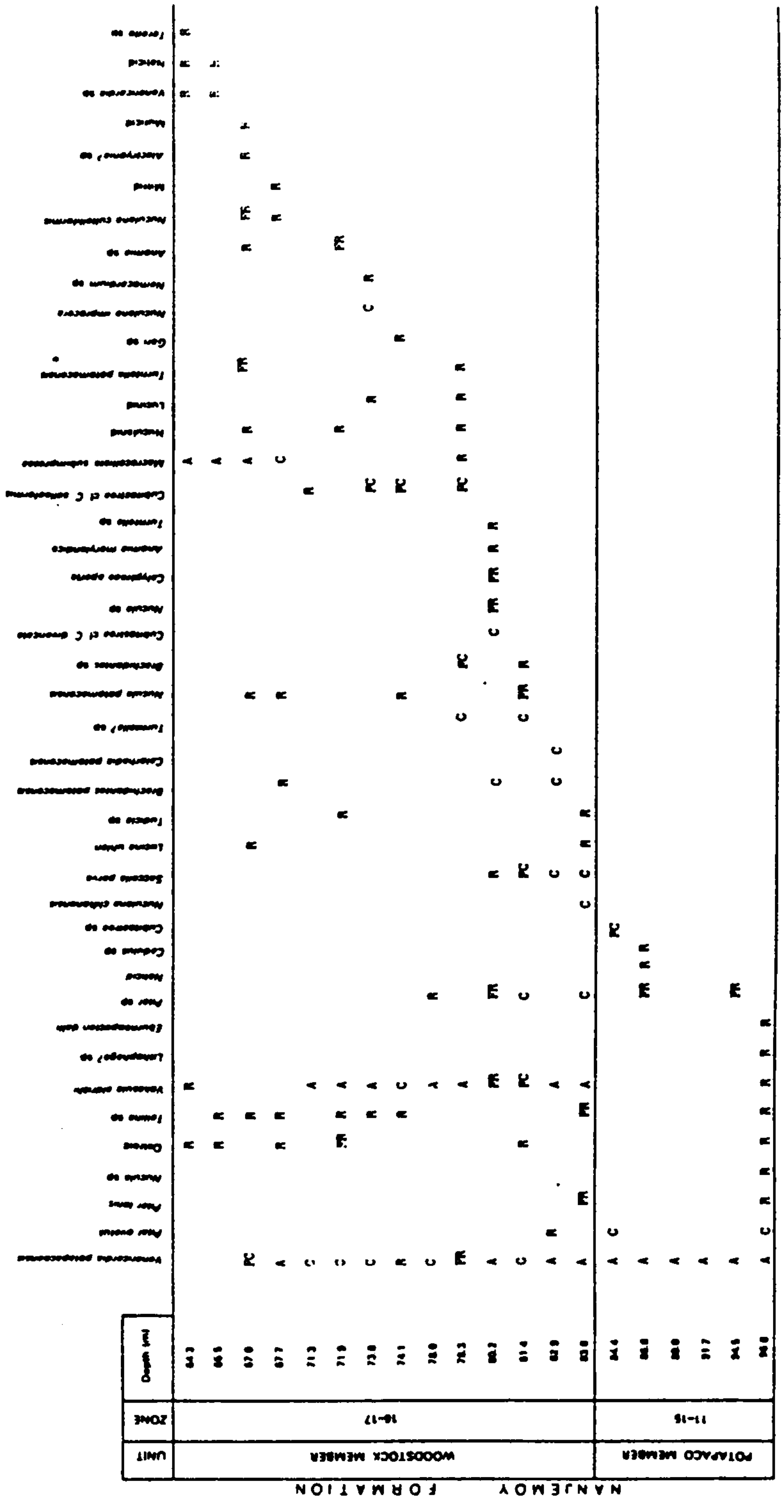


CHART 1. BIOSTRATIGRAPHIC RANGE CHART OF DINOFLAGELLATE, ACRITARCH, AND CHLOROPHYTE SPECIES FROM TERTIARY STRATA OF OAK GROVE CORE; ARRANGED WITH RANGE BASES IN ASCENDING ORDER

CHART 2. BIOSTRATIGRAPHIC RANGE CHART OF DINOFLAGELLATE, ACRITARCH, AND CHLOROPHYTE SPECIES FROM TERTIARY STRATA OF OAK GROVE CORE; ARRANGED WITH RANGE TOPS IN DESCENDING ORDER

CHART 3. BIOSTRATIGRAPHIC RANGE CHART OF DINOFLAGELLATE, ACRITARCH, AND CHLOROPHYTE SPECIES FROM TERTIARY STRATA OF OAK GROVE CORE; ARRANGED ALPHABETICALLY

NOTE: NUMBERS BASED ON 300 COUNT PER SAMPLE, EXCEPT 10 COUNT FOR SAMPLES 319-321; SYMBOL (+) DENOTES OBSERVATION DURING COURSE OF STUDY BUT NOT DURING COUNT.

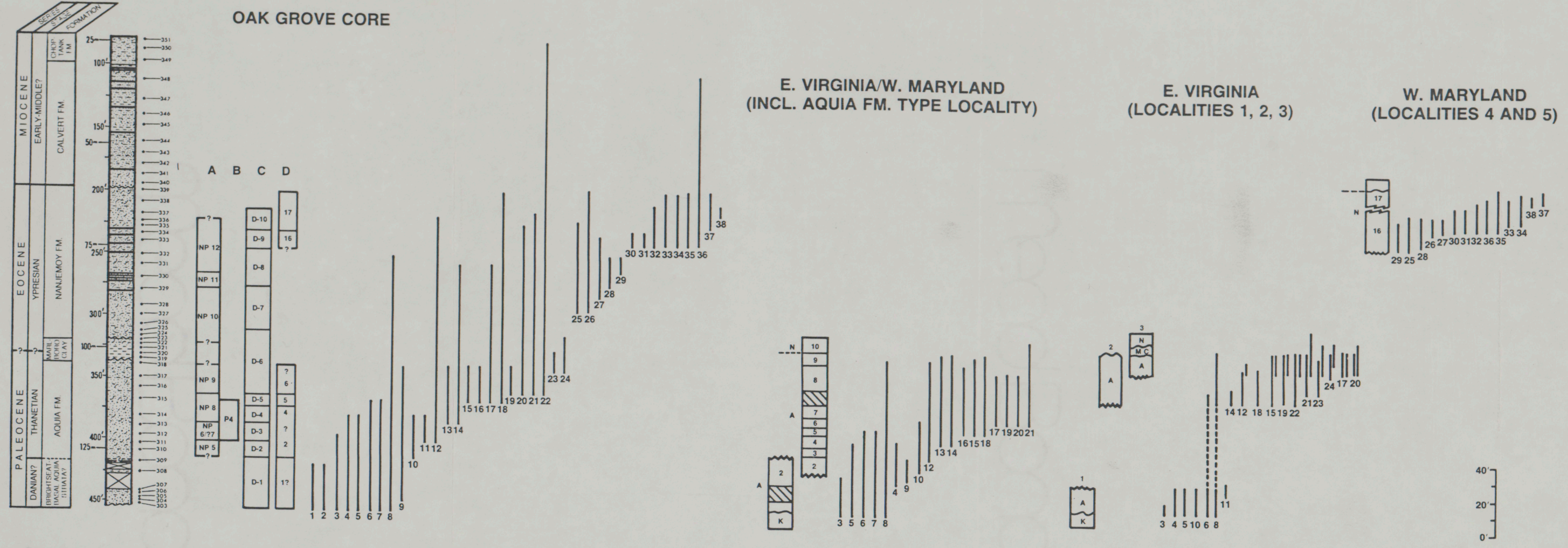


CHART 4. BIOSTRATIGRAPHIC CORRELATION OF THE PALEOCENE AND EOCENE STRATA OF THE OAK GROVE CORE WITH OUTCROP SECTIONS FROM THE COASTAL PLAIN OF VIRGINIA AND MARYLAND

KEY TO SPECIES:

1. *Danea?* sp.
2. *Palaeoperidinium pyrophorum*
3. *Fibradinium annetorpense* (=*Microdinium microreticulatum;* McLean, 1971)
4. *Thalassiphora delicata*
5. *Xenikoon australis*
6. *Deflandrea dartmooria*
7. *Nematosphaeropsis pertusa* n. sp. (=*N. robusta;* McLean, 1971)
8. *Microdinium ornatum*
9. *Ascostomocystis hydria*
10. *Turbiosphaera filosa* (=*Cordosphaeridium* cf. *C. filosum;* McLean, 1971)
11. *Alisocysta* cf. *A. margarita* (=*Aquiasphaeridium simulatum ;* Witmer, 1975)
12. *Deflandrea phosphoritica*
13. *Cassidium paleocenicum* n. sp. (=*C. foveatum;* McLean, 1971)
14. *Adnatosphaeridium robustum*
15. *Turbiosphaera paratabulata* n. sp. (=*L. tabulatum;* McLean, 1971)
16. *Turbiosphaera rotunda* n. sp. (=*L. ornatum;* McLean, 1971)
17. *Hystrichokolpoma tumescens* (=*H. bulbosa;* McLean, 1971)
18. *Eocladopyxis peniculata* (=*Hemicystodinium fragmentum;* McLean, 1971)
19. *Apteodinium retiolum* n. sp. (=*A. baculatum;* McLean, 1971)
20. *Fibrocysta bipolare* (=*Cordosphaeridium bipolare;* McLean, 1971)
21. *Apectodinium homomorphum* complex
22. *Lingulodinium machaerophorum*
23. *Wetzeliella* cf. *W. irtyschensis*
24. *Hystrichokolpoma unispinum*
25. *Wetzeliella samlandica*
26. *Polysphaeridium zoharyi*
27. *Polysphaeridium* cf. *P. zoharyi* (=*H. aculeatum;* Goodman, 1975)
28. *Wetzeliella varielongituda* (=*W. articulata?;* Goodman, 1975)
29. *Biconidinium longissimum* (=*Fusidinium tabulatum;* Goodman, 1975)
30. *Senagalinium? asymmetricum*
31. *Spinidinium macmurdoense*
32. *Kisselovia coleothrypta*
33. *Homotryblium caliculum* (=*H. alisum;* Goodman, 1975)
34. *Homotryblium pallidum-tenuispinosum* complex
35. *Wetzeliella lunaris*
36. *Operculodinium multispinosum* n. sp. (=*O. potomacense;* Goodman, 1975)
37. *Spinidinium paratabulatum* n. sp. (=*S. bilineatum;* Goodman, 1975)
38. *Wetzeliella* sp. A (=*W. coalita;* Goodman, 1975)

KEY TO ABBREVIATIONS:

Oak Grove Core:

Column A—Calcareous Nannoplankton NP Zones of Martini (1971)
Column B—Planktonic Foraminifera Zones of Blow (1969)
Column C—Dinoflagellate Zones of the Present Study
Column D—Zones (Units, Present Study) of Clark and Martin (1901)

E. Virginia/W. Maryland Outcrop Localities:

K —Cretaceous strata
A —Aquia Formation strata
MC —Marlboro Clay strata
N —Nanjemoy Formation strata

4 / 3 Zones (Units, Present Study) of Clark and Martin (1901)

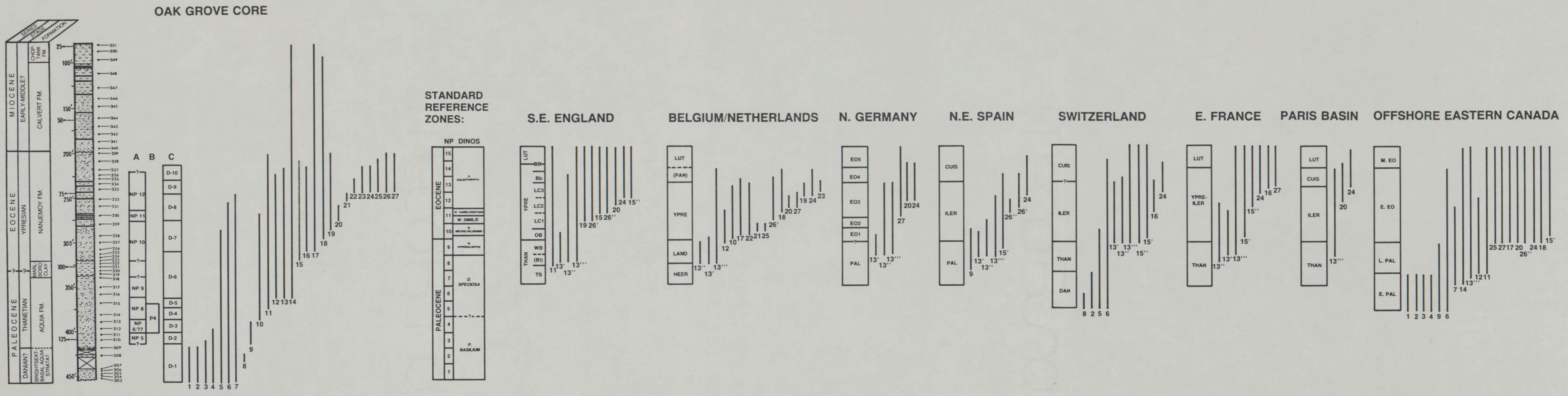


CHART 5. BIOSTRATIGRAPHIC CORRELATION OF THE PALEOCENE AND EOCENE STRATA OF THE OAK GROVE CORE WITH OUTCROP AND CORE SECTIONS FROM EUROPE AND OFFSHORE EASTERN CANADA

KEY TO SPECIES:

1— *Danea*? sp. (? = *Danea mutabilis*)
2— *Palaeoperidinium pyrophorum* (= *P. basilium*)
3— *Tanyosphaeridium variecalamum*
4— *Fibradinium annetorpense*
5— *Glaphyrocysta exuberans* complex
6— *Hystrichosphaeridium tubiferum*
7— *Hafniasphaera septata*
8— *Isabelidinium cooksoniae*
9— *Turbiosphaera filosa*
10— *Adnatosphaeridium robustum*
11— *Eocladopyxis peniculata*
12— *Fibrocysta bipolare*
13— *Apectodinium homomorphum* complex
13′— *Apectodinium hyperacanthum*
13″— *Apectodinium quinquelatum*
13‴— *Apectodinium homomorphum*
14— *Lingulodinium machaerophorum*
15— *Adnatosphaeridium multispinosum-vittatum* complex
15′— *Adnatosphaeridium multispinosum*
15″— *Adnatosphaeridium vittatum*
16— *Wilsonidium tabulatum*
17— *Melitasphaeridium pseudorecurvatum*
18— *Polysphaeridium zoharyi*
19— *Achilleodinium biformoides*
20— *Wetzeliella varielongituda*
21— *Apteodinium australiense*
22— *Paucisphaeridium inversibuccinum*
23— *Samlandia chlamydophora*
24— *Kisselovia coleothrypta*
25— *Deflandrea wardenensis*
26— *Homotryblium pallidum-tenuispinosum* complex
26′— *Homotryblium pallidum*
26″— *Homotryblium tenuispinosum*
27— *Hystrichokolpoma eisenackii*

KEY TO ABBREVIATIONS:

Oak Grove Core:

Column A—Calcareous Nannoplankton NP Zones of Martini (1971)
Column B—Planktonic Foraminifera Zones of Blow (1969)
Column C—Dinoflagellate Zones of the Present Study

S.E. England:

Than—Thanetian
Ypre—Ypresian
Lut —Lutetian

TS —Thanet Sands
Bt —Bottom Beds
WB —Woolwich Beds
OB —Oldhaven Beds

LC —London Clay
Bb —Bagshot Beds
BB —Bracklesham Beds

Belgium/Netherlands:

Heer—Heersian
Land—Landenian
Ypre—Ypresian

Pan —Paniselian
Lut —Lutetian

N. Germany:

Pal —Palaozan (Paleocene)
Eo 1-3 —Untereozan 1-3 (Early Eocene or Ypresian 1-3)
Eo 4-5 —Eozan (Eocene 4-5)

N.E. Spain/Switzerland/E. France/Paris Basin:

Pal —Paleocene
Dan —Danian
Than—Thanetian

Iler —Ilerdian
Ypre—Ypresian

Cuis—Cuisian
Lut —Lutetian

Offshore Eastern Canada:

E/L Pal—Early/Late Paleocene
E/M Eo—Early/Middle Eocene

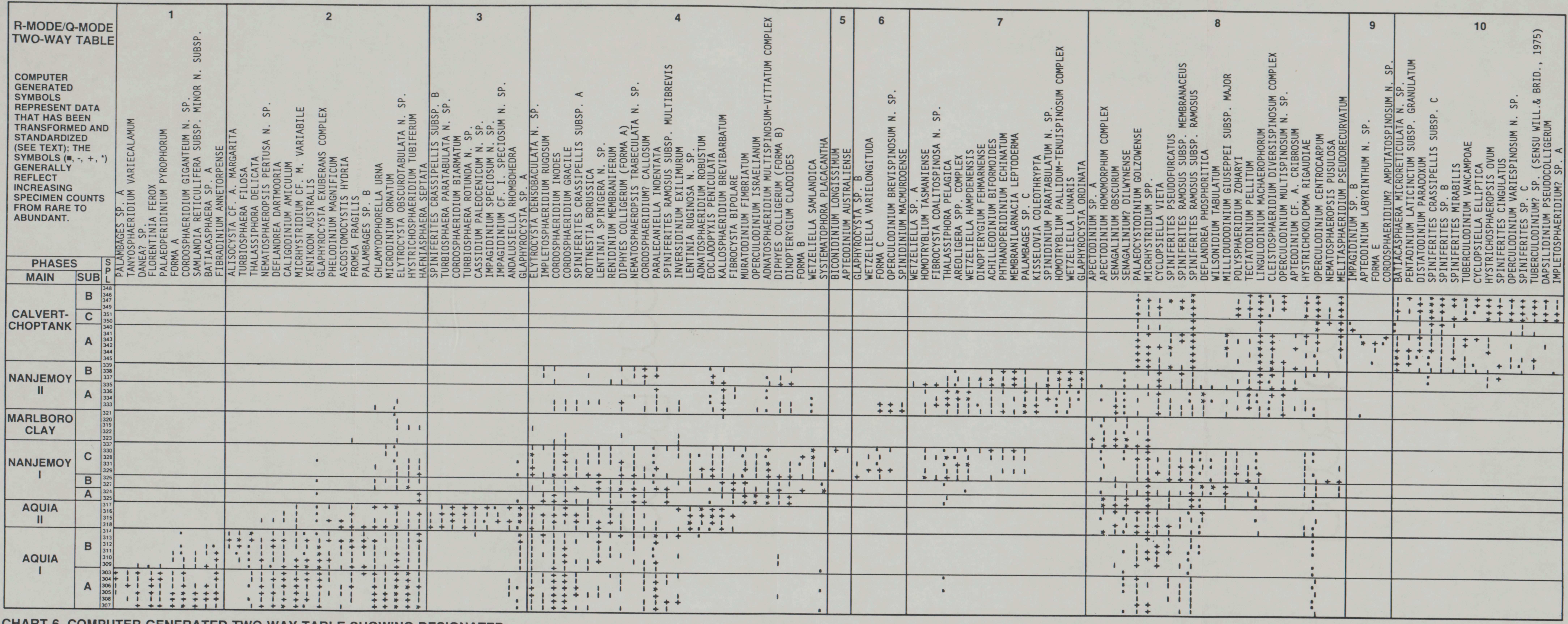
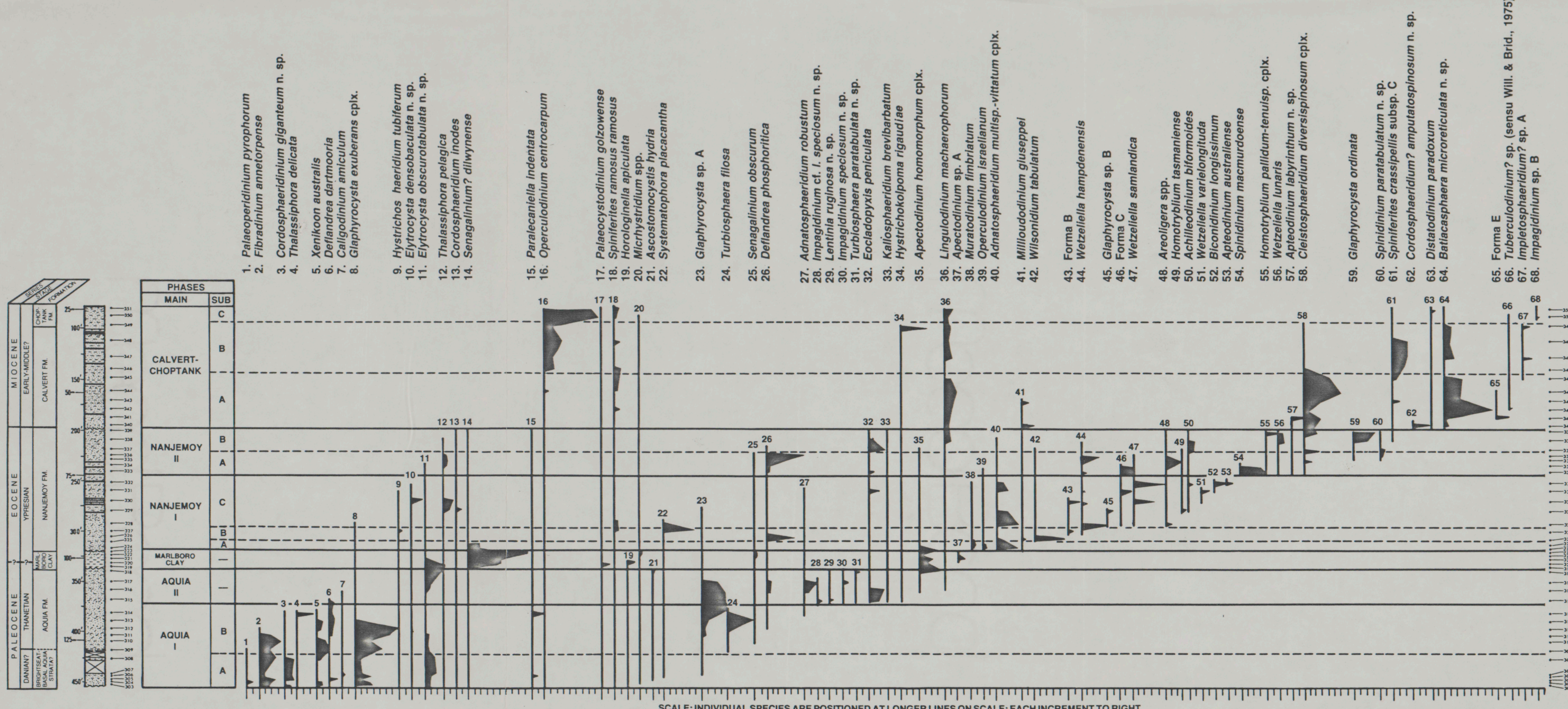


CHART 6. COMPUTER-GENERATED TWO-WAY TABLE SHOWING DESIGNATED Q-MODE CLUSTERS (PHASES) AND R-MODE CLUSTERS (SPECIES) FOR THE TERTIARY STRATA OF THE OAK GROVE CORE.

SEE TEXT FOR DISCUSSION.



SCALE: INDIVIDUAL SPECIES ARE POSITIONED AT LONGER LINES ON SCALE; EACH INCREMENT TO RIGHT EQUALS 10% OF TOTAL SAMPLE ASSEMBLAGE (BASED ON 300 COUNT)

CHART 7. BIOSTRATIGRAPHIC RANGE CHART BASED ON FIVE MOST ABUNDANT DINOFLAGELLATE AND ACRITARCH SPECIES PER SAMPLE FOR THE TERTIARY STRATA OF THE OAK GROVE CORE.

VERTICAL BARS SHOW SPECIES' TOTAL STRATIGRAPHIC RANGE; SHADED PEAKS REPRESENT PERCENT ABUNDANCE WHEN SPECIES IN TOP FIVE RANKS.