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CALCAREOUS NANNOFOSSILS AND LATE PLIOCENE-EARLY PLEISTOCENE BIOSTRATIGRAPHY LOUISIANA CONTINENTAL SHELF

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ILLUSTRATIONS

[1]Names arranged alphabetically; no seniority implied.

ABSTRACT

The vertical distributions of calcareous nannofossils and pertinent planktonic foraminifers within the late Neogene strata of the Louisiana Continental Shelf were studied and compared with that in other areas including the type section of the Pleistocene in southern Italy. Thirty-two species of nannofossils from twenty genera are identified and illustrated from sidewall core samples taken from four wells drilled in the Ship Shoal Area, offshore Terrebonne Parish, Louisiana. Though the ranges of nine of these species are considered stratigraphically significant, only the extinction of *Discoaster brouweri* Tan Sin Hok and the approximate first appearance of *Gephyrocapsa caribbeanica* Boudreaux and Hay are recognized as useful stratigraphic criteria for delineating the Pliocene-Pleistocene boundary in this area. A new formation, the Terrebonne Shale, is described from the basal Pleistocene section on the Louisiana Continental Shelf. Other results include: 1) delineation of a phylogenetic series extending from *Coccolithus doronicoides* Black and Barnes in the middle Pliocene section to *Emiliania huxleyi* (Lohmann) in the Holocene; 2) recognition of the co-occurrence of *Ceratolithus cristatus* (Kamptner) and *Ceratolithus rugosus* Bukry and Bramlette in the earliest Pleistocene sediments; 3) extension of the geologic range of *Gephyrocapsa protohuxleyi* McIntyre and *Cricolithus jonesi* Cohen back to the early Pleistocene; 4) the first reported fossil record of *Homozygosphaera wettsteni* (Kamptner) and *Calyptrosphaera oblonga* Lohmann; and, 5) generic reassignment of *Coccolithus productus* (Kamptner), n. comb., and *Cristallolithus macroporus* (Deflandre), n. comb.

I. INTRODUCTION

The Pleistocene sedimentary deposits of the Louisiana Gulf Coast have been the subject of numerous investigations. Most of these studies, however, have dealt with non-marine alluvial terraces deposited during the interglacial stages. Relatively few studies pertain to the marine equivalents of the non-marine terraces. Although several investigators have referred to the base of the marine Pleistocene ("Upper Marine") beds, definitive paleontological studies of the Louisiana Continental Shelf sediments have been undertaken only by Akers and Holck (1957), Akers and Dorman (1964), Akers (1965), Wray and Ellis (1965), Sachs (1970), and Poag (1971, 1972).

In 1963, Ericson, Ewing, and Wollin postulated that the Pliocene-Pleistocene boundary can be recognized in deep-sea cores based on certain changes among the planktonic foraminifers and upon the extinction of discoasters. Since 1963, more than fifty papers, primarily concerned with planktonic foraminifers, have been written on the boundary problem with the authors taking positions for or against the hypothesis of Ericson *et al.* as well as employing other criteria for recognition of the Pliocene-Pleistocene boundary, namely paleomagnetism, radiolarians, and calcareous nannofossils.

More than eighteen years have elapsed since Bramlette and Riedel (1954) suggested that calcareous nannofossils could be used to determine stratigraphic horizons. In the interim, hundreds of investigations have been published; until quite recently, however, relatively few have dealt with late Neogene strata from the marine epicontinental environment.

The present study was undertaken to establish or recognize biostratigraphic zones within the lower marine Pleistocene section on the Louisiana Continental Shelf by comparing the distribution of calcareous nannofossils and pertinent planktonic foraminifers with their distributions in other areas including the type section of the Pleistocene in southern Italy. The objectives of this study, therefore, were as follows:

1) to describe the calcareous nannofossils from the late Neogene strata of the Louisiana Continental Shelf and to compare these assemblages with those from the type section of the Calabrian of Italy and with equivalent sections in other areas;

2) to establish stratigraphic divisions within the strata underlying the Louisiana Continental Shelf and to determine the position of the Pliocene-Pleistocene boundary in this area; and,
3) to review current opinions and the data from other recent studies and publications on the Pliocene-Pleistocene boundary problem and to evaluate these opinions and data in respect to the results of the present study.

II. RECOGNIZING THE PLIOCENE-PLEISTOCENE BOUNDARY

Ericson, Ewing, and Wollin (1963) suggested that quantitative analyses of temperature-sensitive microfossils in deep-sea cores could be used to measure the duration of the Pleistocene Epoch. Of the 3000 cores they examined, only eight contained an interface that was marked clearly by an abrupt change in the fossil assemblages. They concluded that this interface is the Pliocene-Pleistocene boundary and that it can be recognized in deep-sea cores on the basis of the following paleontological criteria:

1) change in the coiling direction of the *Globorotalia menardii* "complex" from 95 percent dextral below, to 95 percent sinistral above the interface;
2) extinction of the genus *Discoaster* at, or just above, this boundary;
3) the presence of forms resembling both "*Globorotalia menardii* var. *miocenica*" and *Globorotalia menardii multicamerata* below the interface, but only forms similar to the living *Globorotalia menardii menardii* present above the interface;
4) the larger average diameter of tests of *Globorotalia menardii* above the boundary, coupled with a reduction in the percentage represented by this species in the total foraminiferal assemblage;
5) the presence of abundant *Globorotalia truncatulinoides* only above the interface; and,
6) the occurrence of *Globigerinoides sacculifer fistulosus* which is present only below the suggested boundary.

Ericson *et al.* estimated the beginning of the Pleistocene at not less than 800,000 years ago.

Later in 1963, Bandy compared planktonic assemblages near the Miocene-Pliocene boundary in deep-sea cores from the Philippines with the material that Ericson, Ewing, and Wollin (1963) had examined from the Atlantic. He concluded that the planktonic foraminifers below the boundary of Ericson, Ewing, and Wollin were of late Miocene age and he attributed the absence of discoasters above the interface to the presence of a disconformity between the Miocene and Pleistocene sediments in the Atlantic cores.

Riedel, Bramlette, and Parker (1963) utilizing two cores taken by the Swedish Deep-Sea Expedition in the tropical Pacific, reported extinction patterns similar to those of Ericson *et al.* (1963) but they were reluctant to identify the Pliocene-Pleistocene boundary until more data became available. However, they believed that these faunal/floral changes could be used as a provisional basis for correlation.

In 1968, Ericson and Wollin revised the criteria for delineating the Pliocene-Pleistocene boundary as established previously by Ericson, Ewing, and Wollin (1963). This revision was based in part on paleomagnetic studies on Atlantic and Antarctic deep-sea cores by Opdyke *et al.* (1966) and Glass *et al.* (1967) who demonstrated that these cores represented continuous sedimentation. Of five Atlantic deep-sea cores examined, one barely missed the boundary of Ericson *et al.* but the remaining four did reach this level, and two cores extended several hundred centimeters below the datum. All five cores are from the South Atlantic and can be correlated with each other. Ericson and Wollin (1968) based their revised concept of the Plio-Pleistocene boundary on the following factors:

1) the presence of abundant *Globorotalia truncatulinoides,* considered the *principal* criterion for recognition of

the base of the Pleistocene section;

2) the extinction of discoasters above the first abundant appearance of *Globorotalia truncatulinoides,* which is within the Nebraskan Stage; and,
3) the extinction of *"Globorotalia* sp. 1" above the "extinction of discoasters" and during the early Aftonian. [This form is a variant of *Globorotalia inflata* and initially was discussed and figured by Phleger, Parker, and Peirson (1953) as *Globorotalia* sp.]

The change in direction of coiling in the *Globorotalia menardii* complex from predominantly dextral in the Pliocene to predominantly sinistral in the Pleistocene occurs in the section some two meters below the first abundant *Globorotalia truncatulinoides* and the equivalent of their Pliocene-Pleistocene boundary. Ericson and Wollin interpreted this coiling change as evidence that climatic deterioration began in late Pliocene.

Variations in the relative abundance of the *Globorotalia menardii* complex are used by Ericson and Wollin to infer glacial and interglacial stages in the Pleistocene section, with high percentage occurrences indicating interglacial stages and low percentages corresponding to glacial stages. These authors still recognized, as they did in their earlier studies (1963 and 1964), the effects of four glacial and three interglacial stages, and maintained that extensive continental glaciation began in the early Pleistocene. In 1968, with the aid of paleomagnetic data, Ericson and Wollin revised their date for the beginning of the Pleistocene Epoch to 2,000,000 years B. P.

With regard to the extinction of discoasters within the Nebraskan, Ericson and Wollin (1968) made no reference to individual species; however, *Discoaster brouweri, Discoaster pentaradiatus,* and *Discoaster challengeri* are cited in a previous study as becoming extinct at the base of the Pleistocene (Ericson, Ewing, and Wollin, 1963) with *Discoaster brouweri* indicated as the last asterolith to become extinct.

The first data on the occurrence of Neogene discoasters in the Gulf Coast were published by Wray and Ellis (1965). They utilized cuttings from ten wells in the Ship Shoal and South Timbalier areas south of the central Louisiana Coast. Although cuttings are much less desirable than cores, they can permit recognition of extinction levels. Two levels of extinction were recognized which in the ten wells examined by Wray and Ellis are separated by 150 to 500 feet of section. The lower horizon is delineated by the last occurrence of *Discoaster exilis, Discoaster hamatus, Discoaster pentaradiatus, Discoaster surculus,* and *Discoaster variabilis,* in addition to a marked reduction in the abundance of *Discoaster brouweri.* The authors considered this horizon to be the top of the Pliocene interval. The upper level is marked by the extinction of *Discoaster brouweri.* Wray and Ellis were reluctant to state the precise age of this upper horizon as planktonic foraminiferal zones were not determined in their study.

The distribution of *Globorotalia truncatulinoides* on the Louisiana Continental Shelf has been studied by Akers and Dorman (1964), Akers (1965), and Poag and Akers (1967). They reported that the first appearance of this species is below the base of the marine Pleistocene sediments and that the first abundant appearance is at the base of the marine section. In addition, Akers (1965) recorded the distribution of discoasters in this area similar to that reported by Wray and Ellis, with *Discoaster brouweri* becoming extinct in the basal marine Pleistocene bed, which Akers interpreted as representing the first interglacial or the Aftonian Stage. Poag (1971) re-examined Akers's cores and postulated that several unconformities are present in this well. Nevertheless, the first abundant occurrence of *Globorotalia truncatulinoides* and the disappearance of *Discoaster brouweri* coincide at the base of the shale which Poag interprets as the base of the Pleistocene section.

In a short paper, Banner and Blow (1965) described twenty-three foraminiferal zones that have been widely cited in making intercontinental correlations. One of these, N.22, is marked by the first appearance of *Globorotalia truncatulinoides* which they interpret as the immediate descendant of *Globorotalia tosaensis,* a relationship first noted by these authors in cores from the Philippines. They stated that zone N.22 is that "which we have recognized to occur in the lower part of the stratotype Calabrian of Santa Maria di Catanzaro, the agreed earliest Quaternary." This statement by Banner and Blow is the basis for most of the subsequent interpretation of this interface in deep-sea cores by various authors. Hays and Berggren (1971) maintained that the evolutionary transition from one species to another occurs only once and that extinctions and the non-evolutionary transition from *Globorotalia tosaensis* to *Globorotalia truncatulinoides* are the best paleontological criteria for recognizing the Pliocene-Pleistocene boundary.

The first definitive study of the Pliocene-Pleistocene interface utilizing calcareous nannofossils was by McIntyre, Bé, and Preikstas (1967) who selected for their study seven of the Atlantic deep-sea cores used by Ericson, Ewing, and Wollin (1963) in which the Pliocene-Pleistocene boundary was recognized. Not one of these seven cores, however, was used by Ericson and Wollin in 1968 in making their revised interpretation. In these seven cores, discoasters were present throughout the length of the section examined. Though the abundance of discoasters decreased markedly at the Ericson and Wollin boundary, all of the species persisted throughout the section studied. After detailed analysis of their results, McIntyre *et al.* concluded that the discoasters present above the boundary were reworked, as they are corroded, fragmented, and occur in clumps with clay acting as a binding agent. The discoasters occurring below this level are intact and are not worn. Furthermore, if discoasters were gradually becoming extinct, the sequential disappearance of various species could be expected.

In reviewing the distribution of coccoliths, McIntyre *et al.* recorded the extinction of *Cyclococcolithus leptoporus* var. A [now *Cyclococcolithina macintyrei* (Bukry and Bramlette)] and the disappearance of *Coccolithus pelagicus* at the boundary. They reported that the first species to appear in the basal Pleistocene is *Gephyrocapsa oceanica* [this variable taxon was later subdivided; *Gephyrocapsa caribbeanica* Boudreaux and Hay was erected for the early Pleistocene form].

Below the Pliocene-Pleistocene boundary the dominant species according to McIntyre, Bé, and Preikstas (1967) is *Coccolithus doronicoides* which constitutes 60 percent of the assemblage. Above this interface both *Coccolithus doronicoides* and *Gephyrocapsa caribbeanica* are present; *Gephyrocapsa caribbeanica* progressively replaces *Coccolithus doronicoides;* and, the two species together constitute 60 percent of the assemblage. The writers agree (see discussion of *Gephyrocapsa caribbeanica)* with McIntyre *et al.* that *Coccolithus doronicoides* is the progenitor of *Gephyrocapsa caribbeanica* and that it is replaced in part by the latter species as a constituent of the assemblage.

From their earlier studies, McIntyre, Bé, and Preikstas (1967) made the following pertinent observations about the ecology of coccolithophores:

1) *Gephyrocapsa oceanica* has preference for warmer waters;
2) *Coccolithus pelagicus* is restricted to areas north of the 14 degree isotherm in the North Atlantic Ocean; and,
3) *Cyclococcolithina macintyrei* is present in sub-antarctic waters.

These statements indicate that the assemblages in the strata above the boundary of Ericson, Ewing, and Wollin (1963) represent warmer waters than the assemblages below this interface.

McIntyre, Bé, and Preikstas (1967) concluded that:

1) the appearance of one new species following the disappearance of two other species, together with minor changes in the abundance of five species, represents sufficient change in the assemblage to justify the term "boundary"; and,

2) ecologically the assemblage below this interface represents colder conditions than the assemblage above; therefore, this horizon is the Nebraskan-Aftonian boundary instead of the Pliocene-Nebraskan boundary.

The present writers are in basic agreement with McIntyre, Bé, and Preikstas but cannot substantiate the distribution of *Coccolithus pelagicus* which is represented by extremely low percentages in the late Pliocene and the early Pleistocene of the Louisiana Gulf Coast. It is difficult to compare the statistical data of McIntyre *et al.* (1967) with that of other workers. Most workers combine light microscopy with electron microscopy, using the information obtained under the light microscope to compile statistical data; McIntyre *et al.* relied solely on the electron microscope for the statistical studies. Their interpretation of the first appearance of *Gephyrocapsa caribbeanica* in the early Pleistocene, agrees with the distribution of this species on the Louisiana Continental Shelf and in most other areas.

In June, 1964, the personnel of the Texas A & M University research vessel *Alaminos* obtained a 550 cm long core (No. 64-A-9-5E) from the largest of the Sigsbee knolls. In a preliminary paper, Bryant and Pyle (1965) reported *Discoaster brouweri* and *Discoaster pentaradiatus* as the dominant species throughout the core. In 1966, Pyle published the stratigraphic distribution of calcareous nannofossils from this core. He recorded nineteen species, of which six are discoasters. Unfortunately, the sediments above 150 cm in his core were disturbed and mixed with older sediments during extrusion from the core barrel which had been bent during the coring operation. The sediments above this level have been assigned by Pyle to the post-Pliocene.

James L. Lamb (1969) examined the planktonic foraminifers from the upper portion of this same *Alaminos* core and dated his sample at 150 to 153 cm as post-Pliocene, and the sediments at 200 to 203 cm as late Pliocene in age. Pyle (1966) stated that because discoasters were present in considerable abundance above the 150 cm level in his core, the genus *Discoaster* did not become extinct at the end of the Tertiary. The distribution of the twelve heliolithid species as interpreted by Pyle (1966) needs little explanation. All are long-ranging and are characteristic of Neogene strata. One modification in the reported distribution was made by Pyle in 1968 when *Emiliania huxleyi* was noted in Pliocene and Pleistocene sediments. This change in interpretation is questionable, however, as the species first appears elsewhere in upper Pleistocene strata (Boudreaux, 1968; Gartner, 1969; and McIntyre and Bé, 1967).

Beard and Lamb (1968), in a controversial paper on the Pliocene-Pleistocene boundary in the Caribbean and the Gulf of Mexico, recognized the horizon at 192 cm in this same core. This level coincides with the extinction of *Globoquadrina altispira*, at the point which corresponds closely with the disappearance of other warm-water species, such as *Globoquadrina venezuelana* and *Globorotalia menardii*, and the appearance of the cold-water indicator *Globorotalia inflata*. The Aftonian-Nebraskan boundary was placed at 160 cm in the core based on the disappearance of *Globorotalia menardii multicamerata* and *Globorotalia menardii miocenica* and the appearance of *Globoquadrina dutertrei* and sinistrally coiled *Globorotalia menardii menardii*.

Beard and Lamb (1968), Beard (1969), and Lamb (1969), reporting on the same *Alaminos* core and on a 1000 foot long section cored by the Chevron, Gulf, Humble, and Mobil oil companies on the northwest Florida shelf, record a similar distribution of *Globorotalia truncatulinoides* to that of Akers (1965). Because of the controversial placement of the Pliocene-Pleistocene boundary by Beard and Lamb in core No. 64-A-9-5E, Pyle (1968) re-examined the core and reaffirmed his belief that the stratigraphic ranges of the discoasters agree with the interpretation of Akers (1965) and Wray and Ellis (1965) in that discoasters became extinct within the early Pleistocene.

In the present study, core samples from the Louisiana Continental Shelf were compared with material from the *Alaminos* core using both the electron and light microscopes. It is concluded that the early Pleistocene beds on the Louisiana Continental Shelf are younger than the 150 to 160 cm interval that is called "Aftonian" by Beard and Lamb (1968) and "early Aftonian" by Lamb (1969). The bases on which the section from the Louisiana Continental Shelf is judged to be younger are as follows:

1) in the 150 to 160 cm segment in the *Alaminos* core from the Sigsbee knolls, discoasters are abundant; but discoasters are very rare in the Pleistocene strata on the Louisiana Continental Shelf;
2) five species of discoasters are identified in the 150 to 160 cm segment; but only rare specimens of one species, *Discoaster brouweri*, are present in the basal marine shale of the Louisiana Gulf Coast. The presence of rare specimens of [reworked] *Discoaster brouweri* in the early Pleistocene of the Gulf Coast section is substantiated by the work of Akers (1965) and of Wray and Ellis (1965). It may be argued that the Calabrian stratotype in Italy contains abundant and diverse discoasters; however, considerable reworking exists in this section (Smith, 1969). Thus, the evidence is insufficient to substantiate the presence of discoasters throughout the section in the type area;
3) no species of *Gephyrocapsa* were found in the 150 to 160 cm segment in the Sigsbee knolls core in either light or electron microscope examination. *Gephyrocapsa caribbeanica* occurs in the marine shale on the Louisiana Continental Shelf;
4) *Sphenolithus abies* is present in the 150 to 160 cm segment of the *Alaminos* core, but is unknown in Pleistocene and late Pliocene sediments elsewhere.

In 1963, twenty miles off the southwest coast of Jamaica, a long core taken by the drilling vessel *Submarex* penetrated 56.4 meters of sediment. Unfavorable weather hampered the drilling operations and only 20.7 meters (37%) of the core was recovered. Hay and Boudreaux (1968) reported that the preservation of the nannofossils was not good and that secondary overgrowths made identification of species difficult. Asteroliths are rare even in the lower portion of the recovered section. *Discoaster surculus*, *Discoaster variabilis*, and *Discoaster pentaradiatus* are extremely rare and are present only in the basal portion of the core. A few reworked older discoasters such as *Discoaster tani* and *Discoaster deflandrei*, were also recorded. According to Hay and Boudreaux, "the only obvious change in the nannoplankton of the core is the ultimate extinction of *Discoaster brouweri* and the disappearance of *Coccolithus pelagicus* at 23.5 meters." Boudreaux (1968) placed the Pliocene-Pleistocene boundary at this level in the core. *Gephyrocapsa caribbeanica* is reported common down to 29 meters in this core (Boudreaux, 1968) and "sparse" down to the base of the core at 56.4 meters.

The *Coccolithus doronicides* complex, which Gartner (1969), McIntyre *et al.* (1967), and Sachs (1970) report as abundant in lower Pleistocene and upper Pliocene sediments was not recorded initially from this core. Re-examination of the samples, however, revealed its presence as a minor constituent of the assemblage.

Bolli, Boudreaux, Emiliani, Hay, Hurley, and Jones (1968), reported on the planktonic foraminifers in the same *Submarex* core. they noted that *Globorotalia truncatulinodes* is present throughout the entire interval, but attributed the occurrence of *Globorotalia truncatulinoides* to environmental conditions. According to these authors, the lower portion of the core at 4753 to5634 cm correlates with the Manchioneal Formation of Jamaica based on the joint occurrence of *Globoquadrina altispira* and *Globorotalia truncatulinoides*. Such combined occurrence of these two species was not recognized in the studies by Parker (1967); Banner and Blow (1967); Blow (1969); Beard and Lamb (1968); Hays, Saito, Opdyke, and Burckle (1969); Beard (1969); and others. In addition, Robinson (1968) and Lamb (1969) do not report the presence of *Globoquadrina altispira* in the Manchioneal Formation and both authors consider this formation to be early Pleistocene in age. Bolli *et al.* (1968), in reviewing the distribution of planktonic foraminifers in this core, state that the "upper portion of the *Submarex* core (from 549 to 4174 centimeters) cannot yet be correlated with known marine epicontinental deposits."

Poag (1971) and other workers, have recently demonstrated that the extinction of *Globoquadrina altispira* occurs below the first appearance of *Globorotalia truncatulinoides* in the northern Gulf of Mexico. This interpretation agrees with the work of Beard (1969) and Lamb(1969). the distribution in the *Submarex* core, namely the rare occurrence of *Discoaster brouweri*, the "extremely rare" occurrence of other discoasters, and the presence of both *Gephyrocapsa caribbeanica* and *Globorotalia truncatulinoides* throughout its length, lead to the suggestion that the core is Pleistocene in age and that the presence in this core of *Globoquadrina altispira, Sphenolithus abies*, and older discoasters represent reworking. Considering the proximity of the *Submarex* core to the present coast of Jamaica, it is quite possible that the lowering of sea level during the early Pleistocene intensified reworking of the section.

III. THE JOIDES PROGRAM

Gartner (1969) published a calcareous nannofossil zonation of the Neogene strata utilizing samples from Leg 2 of the JOIDES program and piston cores from the Atlantic and Pacific oceans. He used the planktonic foraminiferal zonation of Blow (1969) because the samples had been dated previously according to Blow's zonation. The base of zone N.22, the first appearance of *Globorotalia truncatulinoides*, and the Tertiary-Quaternary boundary coincide with the base of Gartner's *Pseudoemiliania* zone. The base of his *Pseudoemiliania* zone is marked by the extinction of *Discoaster brouweri* and near the base of this zone the genus *Gephyrocapsa* first appears. The *Pseudoemiliania* zone replaces, in part, the *Gephyrocapsa caribbeanica* zone which Hay *et al.* (1967) had proposed earlier. Gartner maintains that the different species of *Gephyrocapsa* are not readily discernible with the light microscope and that the *Pseudoemiliania* zone is more suitable and recognizable for practical stratigraphic work.

From Leg 7, Martini and Worsley (1970, 1971) published another Neogene zonation of calcareous nannofossils. The portion for the upper Pliocene and Quaternary is almost identical with that of Gartner (1969). However, they reported that one sample from the *Discoaster brouweri* zone contained rare occurrences (less than one specimen per ten fields of view) of *Gephyrocapsa*. Hay, reporting on Leg 4, also noted that in a few samples rare specimens of *Gephyrocapsa caribbeanica* were found in the *Discoaster brouweri* zone. Bukry also worked extensively on the JOIDES cores, publishing on samples from Legs 1 through 8. Bukry and Bramlette (1970), and Bukry (1971a, 1971b) proposed a nannofossil zonation which included numerous subzones. Of particular interest is their subdivision of the late Pliocene and early Pleistocene into subzones.

Bukry (1971a) in an exemplary discussion of biostratigraphic zones, stated that his basis for subdivision of zones is "that advocated by M. N. Bramlette, which utilizes the specific character of an assemblage bounded by closely spaced multiple first and last occurrences." In this manner the whole assemblage is not affected by the presence or absence of any one species.

The top of the *Discoaster brouweri* zone of Bukry and Bramlette (1970) differs from that of other authors in that it is defined not on the last occurrence of *Discoaster brouweri* but on the marked reduction in numbers of *Discoaster brouweri, Discoaster pentaradiatus, Cylococcolithina macintyrei*, and *Ceratolithus rugosus*. In a similar vein the base of the *Coccolithus doronicoides* zone is characterized by abundance of *Coccolithus doronicoides, Cyclococcolithina leptora*, and *Emiliania annula;* and, when present, the paucity of *Discoaster brouweri, Gephyrocapsa caribbeanica, Cyclococcolithina macintyrei*, and *Ceratolithus rugosus*.

IV. THE CALABRIAN SECTION

At the Eighteenth International Geological Congress in 1948, it was recommended that the Calabrian Formation should be considered as the lowest member of the lower Pleistocene Epoch (type locality, Santa Maria di Catanzaro in Calabria). The Calabrian originally had been considered as the youngest stage of the upper Pliocene by Gignoux (1910, 1913). The basis for this recommendation was the "reported" occurrence of two boreal forms, the bivalve *Arctica islandica* and the benthonic foraminifer *Hyalinea balthica*. These occurrences were believed to coincide with climatic deterioration in the Mediterranean area. Subsequent efforts at international meetings have failed to resolve the problem of selecting a type area for delineating the Pliocene-Pleistocene boundary. Therefore, at present, the Calabrian section of Santa Maria di Catanzaro remains the sole standard for recognition of this boundary.

Calabrian Bivalvia and Foraminiferida

As previously stated, Banner and Blow (1965) reported that the evolutionary transition from *Globorotalia tosaensis* to *Globorotalia truncatulinoides* was "recognized to occur in the lower part of the stratotype Calabrian." This brief statement was the only evidence offered to substantiate their position that the Pliocene-Pleistocene boundary should be recognized on the first appearance of *Globorotalia truncatulinoides*. Neither the stratigraphic distribution of species, location of the samples, frequency distributions, nor any other evidence was offered to justify or explain their position. It is upon this statement by Banner and Blow that *most* workers base their delineation of this horizon.

Bayliss (1969) in a study of the distribution of *Hyalinea balthica* and *Globorotalia truncatulinoides* in three sections in the Santa Maria di Catanzaro area, including the type locality, reports the presence in "undiminished numbers" of *Hyalinea balthica* 76 meters below the first appearance of *Arctica islandica*, the species that marks the base of the type Calabrian as defined by Gignoux (1910, 1913). *Globorotalia truncatulinoides* is rare in occurrence in all three of his sections and makes its first appearance at Santa Maria di Catanzaro at a point 50 meters above the base of Gignoux's Calabrian. One "questionable" specimen of *Globorotalia tosaensis* was identified in the underlying Pliocene beds. The ranges of both species were variable in all three sections and to Bayliss this "suggests that environmental controls other than the nature of the bottom deposits, viz. water depth affected the composition of the fauna."

Bayliss (1969) doubted the value of *Hyalinea balthica* and *Globorotalia truncatulinoides* as markers for the base of the Pleistocene, although he stated "they appear to be the best available and give a broad outline of the distribution of the Calabrian on a regional scale." Furthermore, he stated that

TABLE I

PLIOCENE-PLEISTOCENE ZONATION (after Bukry, 1971b)

	ZONE	SUBZONE
MIDDLE and LOWER PLEISTOCENE	Gephyrocapsa oceanica	
	Coccolithus doronicoides	Gephyrocapsa caribbeanica Emiliania annula
UPPER PLIOCENE	Discoaster brouweri	Cyclococcolithina macintyrei Discoaster pentaradiatus Discoaster tamalis

"if it is accepted that the first appearance of any one of the three species *Hyalinea balthica, Arctica islandica,* or *Globorotalia truncatulinoides* indicates the base of the Pleistocene, then the Pliocene-Pleistocene boundary has to be drawn below the lowest exposed beds in the Santa Maria di Catanzaro section, in which case it cannot coincide with Gignoux's horizon."

Lamb (1969) examined samples from the Calabrian stratotype and supported the interpretation of Bayliss (1969), although he reported the first appearance of *Globorotalia truncatulinoides* somewhat lower. Bandy and Wilcoxon (1970) examined samples from the Calabrian at Santa Maria di Cantanzaro and from a nearby section at Le Castella. At the type locality they restricted their sampling to the Calabrian as defined by Gignoux (1910, 1913) except for a single sample analyzed from just below the base of Gignoux's type Calabrian in the upper Pliocene sediments. They record once again that *Globorotalia truncatulinoides* makes its first appearance near the upper limit of the Calabrian, some 76 meters above the base of Gignoux's section. *Hyalinea balthica* was noted throughout the type section but was not recorded from the one sample in the upper Pliocene beds.

At Le Castella, Bandy and Wilcoxon sampled the entire section, taking one sample every meter for a total of 26 samples. Only one specimen of *Globorotalia truncatulinoides* was identified from all of their samples. *Hyalinea balthica* was recorded above what Bandy and Wilcoxon considered to be the Pliocene-Pleistocene boundary but was not recorded from the upper Pliocene strata. *Globorotalia tosaensis* was not reported by these authors from either the Calabrian stratotype or from Le Castella.

Calcareous Nannofossils

Hay and Boudreaux (1968) reported on three samples from the section at Le Castella. Two of these samples were located near Gignoux's Pliocene-Pleistocene boundary, one just above and the other just below the interface. The authors stated that, in addition to *Discoaster brouweri* both samples contained reworked assemblages of older discoasters. The third sample, located some 90 meters below the boundary, contained an "indigenous assemblage" which included *Discoaster surculus, Discoaster pentaradiatus, Discoaster brouweri,* and *Discoaster variabilis.* Hay and Boudreaux (1968) concluded that the extinction of discoasters occurs within the Pliocene, but that the level at which *Discoaster brouweri* becomes extinct cannot be determined precisely.

Smith (1969) published a study of calcareous nannofossils from the type Calabrian at Santa Maria Di Catanzaro and examined the Quaternary section at Le Castella. Lamb (1969), quoting Smith from a personal communication, stated that the sections in both areas are difficult to interpret as considerable reworking has occurred, and that "reworked floras are evident throughout the Pliocene and Early Pleistocene strata." Smith's reported distribution of discoasters at the stratotype reveals that, of the fifteen samples he examined (including four from the Pliocene), only *Discoaster brouweri* and *Discoaster variabilis* are found in every sample; *Discoaster exilis* occurs in the majority of the samples; *Discoaster surculus* is present intermittently through the section; and *Discoaster hamatus* was found in only a few of the samples.

Among the other calcareous nannofossils, Smith reports that "*Coccolithus* is the dominant form in the samples in the middle part of the section, whereas *Cyclococcolithus [Cyclococcolithina]* dominates the assemblage from Pliocene samples" as well as in the upper portion of the section. At Le Castella, Smith reported the presence of *Discoaster brouweri* in all 22 samples, *Discoaster surculus* in 16 samples, and *Discoaster exilis* in 15 of the samples. The distribution of coccoliths was reported as similar to that in the Calabrian section with three important exceptions. Smith noted the initial appearance of *Gephyrocapsa caribbeanica* in the upper portion of the section, and reported the presence of *Coccolithus lacunosus [Pseudoemiliania lacunosa]* and *Coccolithus exsectus [Coccolithus doronicoides]* intermittently through the section. From his study Smith (1969) draws the following conclusions:

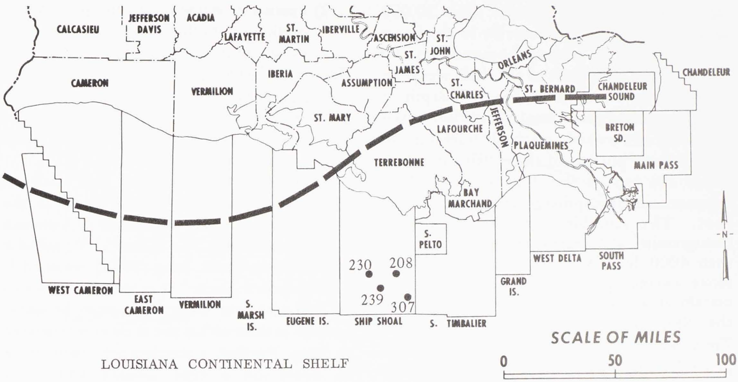

Figure 1. Location of cored wells on the Louisiana Continental Shelf. The dashed line indicates the approximate northern limit of the Terrebonne Shale.

1) discoasters do not become extinct at the Pliocene-Pleistocene boundary as they occur in younger sediments;
2) the Calabrian section at Santa Maria di Catanzaro contains the Pliocene-Pleistocene boundary, is equivalent to the American marine Nebraskan based on the presence of *Globorotalia truncatulinoides* and *Discoaster brouweri*, and this section represents cool-water deposition;
3) at Le Castella, the strata are younger than the Calabrian at Santa Maria di Catanzaro based on the presence of *Discoaster brouweri* and *Gephyrocapsa caribbeanica*, and this section represents warm-water deposition.

Bandy and Wilcoxon (1970) supported Hay and Boudreaux's (1968) contention that discoasters became extinct at or near the Pliocene-Pleistocene boundary at Le Castella. Furthermore, they corroborated this extinction from their studies at Santa Maria di Catanzaro, the stratotype. At both localities they reported the presence of *Pseudoemiliania lacunosa* and *Gephyrocapsa caribbeanica* in both the Pleistocene and the Pliocene beds. Based on their study of the distribution of planktonic foraminifers and calcareous nannofossils at the type locality, Bandy and Wilcoxon concluded that the presence of three species, *Globorotalia truncatulinoides, Pseudoemiliania lacunosa,* and *Gephyrocapsa caribbeanica,* together with the absence of *Discoaster brouweri* and other discoasters, is sufficient to define the Pliocene-Pleistocene boundary. However, from the foregoing discussion of the many stratigraphic problems, it is obvious that clear definition of the Pliocene-Pleistocene boundary at the stratotype and at nearby exposed sections has not yet been accomplished and that controversy on this subject is certain to continue.

V. BIOSTRATIGRAPHY OF THE LATE PLIOCENE AND EARLY PLEISTOCENE, LOUISIANA CONTINENTAL SHELF

The Terrebonne Shale

The early Pleistocene deposits of southeastern Louisiana and the Louisiana Continental Shelf consist of basal regressive sandstones overlain by a thick marine transgressive shale unit, here named the Terrebonne Shale. This early Pleistocene shale which is overlain by later Pleistocene regressive sandstones is recognized only in the subsurface section south of the line indicated in Figure 1. The areal extent of the Terrebonne Shale and the underlying regressive sandstones is more than 20,000 square miles. The shale varies in thickness from 100 feet to several thousand feet and near the northern limit of the shale wedge in southeastern Louisiana it lies at a depth of 1700 feet below sea level. The Pleistocene strata dip southward and thicken seaward to the southern portion of the continental shelf where the top of the Terrebonne Shale is encountered at depths greater than 10,000 feet. The combined thickness of the transgressive and regressive phases is more than 4000 feet, with the Terrebonne Shale alone exceeding 3000 feet in thickness in certain areas. In the southeastern portion of the Ship Shoal Area and in the South Timbalier Area the underlying regressive phase becomes predominantly shale so that the Terrebonne Shale expands to include both the transgressive and regressive phases in the downdip stratigraphic section.

Studies of the benthonic Foraminiferida from the Terrebonne Shale reveal that its environment of deposition varied from the inner shelf near its present updip extremity to that of the upper slope along the southern portion of the present shelf. The underlying regressive phase varied from the nearshore deltaic environment in the north to normal marine outer shelf in the south. The change from deltaic deposits to outer shelf deposits takes place over a relatively short distance. This leads to the conclusion that the pre-Terrebonne shelf was rather narrow.

The Terrebonne Shale is so visually apparent on electrical logs that in the updip position it is the only shale significantly expressed on such logs in either the Pliocene or Pleistocene section. The shale overlaps a large portion of the Pliocene strata, a relationship which has led most Gulf Coast stratigraphers to conclude that this transgressive marine shale represents the first interglacial stage in the Pleistocene and it is so interpreted in this study.

The Terrebonne Shale is markedly thicker and more extensive than later Pleistocene transgressive shale deposits. Its great thickness is attributed to two factors:

1) lowered sea level during the first Pleistocene glacial stage; and,
2) extensive erosion of updip Neogene marine and fluvial deposits due to increased stream gradients.

These two factors permitted more extensive invasion by the sea when sea level rose at the end of the first glacial stage and permitted the accumulation of the thick Terrebonne Shale sequence (see Figure 2).

Akers (1964) interpreted this shale as Aftonian in age and referred to it as the "upper marine" beds with credit to Lowman (1949, p. 1992, fig. 32). Sachs (1970) called it the Aftonian Shale. Poag (1971) renamed it the "Brouweri Shale." It cannot be shown to be Aftonian nor does *Discoaster brouweri* become extinct within the shale as interpreted by Poag. Further, a stratigraphic name must be based on a type locality and on a geographic place name and not on a species-group designation. These earlier names, therefore, are invalid. (ACSN, Arts. 10 and 13). The formal name here proposed is the Terrebonne Shale, based on the area of its best development in southern Terrebonne Parish, Louisiana, and in the contiguous offshore areas of the Louisiana Continental Shelf. The type log depicting the shale in the downdip position (see figure 3) is the Gulf Oil Corporation No. A-1 OCS 0498, located in South Timbalier Area Block 128, offshore Terrebonne. The top of the shale in the type section is encountered at -5850 feet and the base at -6890 feet, a total thickness of 1040 feet.

VI. SAMPLES AND PROCEDURE

The samples used for this study are 23 sidewall cores from four wells drilled more than 60 miles offshore from the present coastline in the southern portion of the Ship Shoal Area, offshore Terrebonne Parish, Louisiana (figures 1 and 4). These four wells are located in the Ship Shoal Area blocks 208, 230, 239, and 307.

Three of the wells were correlated with each other by means of Induction-Electrical Logs to determine whether local facies changes occurred in this immediate area or whether the section penetrated in the Terrebonne Shale interval was faulted. The shale sequence is not interrupted by faulting

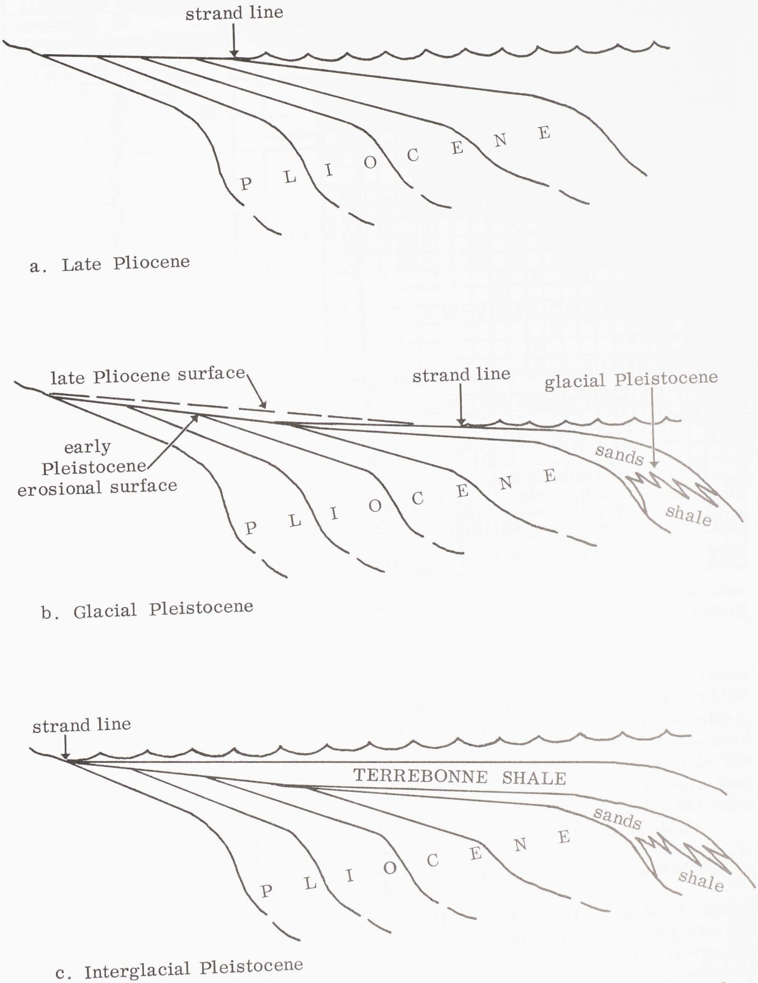

Figure 2. Hypothetical diagram illustrating three stages of depositional history in the formation of the Terrebonne Shale.

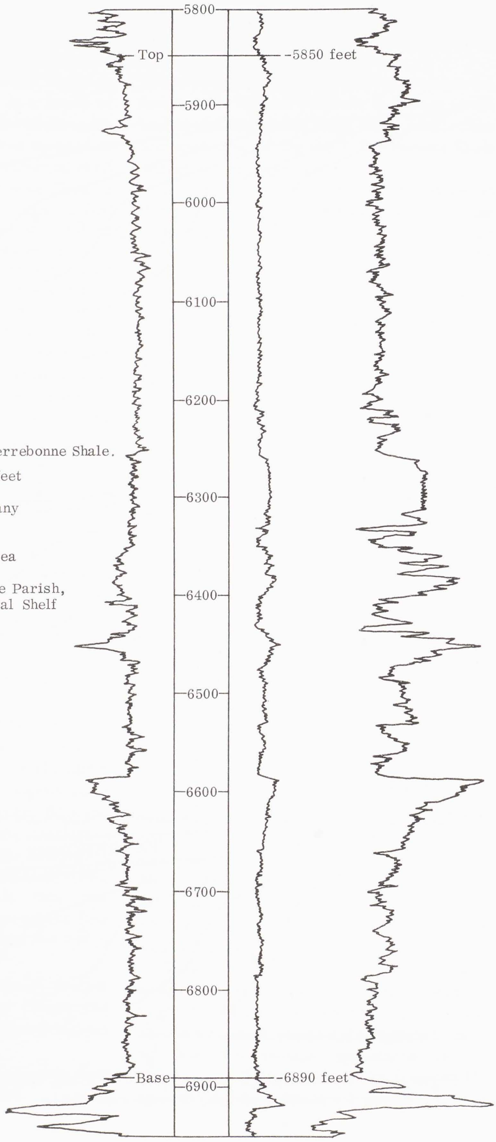

Figure 3. Type Log of the Terrebonne Shale.
-5850 to -6890 feet

Gulf Refining Company
#A-1 OCS 0498
Block 128
South Timbalier Area
(Block 135 Field)
Offshore Terrebonne Parish,
Louisiana Continental Shelf

AGE OF SAMPLES	LATE PLIOCENE			EARLY PLEISTOCENE Terrebonne Shale																			
LOCATION OF SIDEWALL CORES	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Acanthoica sp.													R										
Braarudosphaera bigelowi		R				R					R					R						R	
Calyptrosphaera oblonga										R													
Ceratolithus cristatus			R		R	R		R		R			R				S			S		R	R
Ceratolithus rugosus	S	R	R	R	R																		
Coccolithus doronicoides	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Coccolithus pelagicus	R		R		R	R								R									
Coccolithus productus		R	S		R	S		R			S					R			S			S	
Cricolithus jonesi	R					R			S				R						R				
Cristallolithus macroporus										R											R		
Cyclococcolithina leptopora	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Cyclococcolithina macintyrei	C	C	C	C	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Discoaster brouweri	C	C	S	R		S																	
Discolithina anisotrema	S	R	S	S	S	S			S		R			S	S		S		R			R	
Discolithina japonica		R			R	R			R		R						R					R	
Emiliania annula				R						R		R		S	S					S		S	S
Gephyrocapsa aperta										R						R							R
Gephyrocapsa caribbeanica						R	R	S	S	S	S	S	C	C	A	A	A	A	A	A	A	A	A
Gephyrocapsa protohuxleyi													R										
Helicopontosphaera cf. H. intermedia			R									R							R				
Helicopontosphaera kamptneri	S	S	S	S	S	S	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Homozygosphaera wettsteni	S	S	S	S					R								R						
Pseudoemiliania lacunosa	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Rhabdosphaera clavigera	S	S	S	S		S	C	C	S	C	S	S	C	C	S	S	S	S	S	S	S	S	S
Scapholithus fossilis	R		R		R	R		S			S		R			R		R		S		S	
Scyphosphaera apsteini	R		R		R				R								R						
Scyphosphaera pulcherrima		R		R			R							R		R					R		
Syracosphaera histrica			R									R					R	R					R
Syracosphaera pulchra		R			R			R					R							R		R	
Thoracosphaera saxea	C	S	S	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Thoracosphaera sp.							R							S									
Umbilocosphaera mirabilis	C	S	C	S	S	S	C	S	S	C	C	C	C	C	C	C	C	C	C	C	C	C	C

Figure 4. Distribution of calcareous nannofossils in late Pliocene-early Pleistocene sediments on the Louisiana Continental Shelf. A – Abundant (500+); C – Common (50-500); S – Scarce (5-50); R – Rare (1-5).

in the wells studied. The cores from the three wells selected were combined into a composite section. The spontaneous potential (SP) curve from one Induction-Electrical Log was selected to illustrate the configuration of the SP curve through the early Pleistocene sediments and the position of each core is marked adjacent to this curve on Figure 6. No log is available for the fourth well which is located in Ship Shoal Block 307.

In addition to the 23 sidewall cores from the Louisiana Continental Shelf, samples were examined from piston cores taken in the Atlantic and Pacific oceans and the distribution of pertinent calcareous nannofossils in these samples was compared with the studied section (see Figure 5). The samples examined from the Atlantic Ocean were from core V10-91 (Lamont), taken 1400 miles east-northeast of San Juan, Puerto Rico, and the JOIDES Blake Plateau cores, located offshore from the east coast of Florida. The samples from the Pacific Ocean were from CAP 38 BP (Scripps), cored 1300 miles east-southeast of the Marquesas Islands.

VII. CALCAREOUS NANNOFOSSILS

The Terrebonne Shale yielded 32 species of nannofossils assignable to 20 genera (see figure 4); the following 19 species are long-ranging forms which occur in sediments older and younger than the studied section or are so rare that they are considered to be of

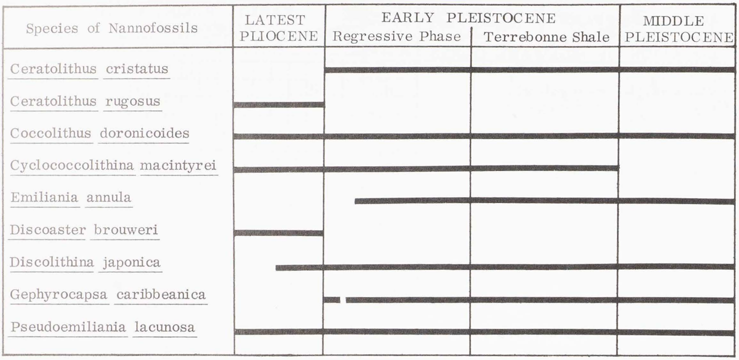

Figure 5. Composite range chart of stratigraphically significant calcareous nannofossils from the latest Pliocene-middle Pleistocene on the Louisiana Continental Shelf.

little value in determining the age of the studied section:

Acathoica sp.
Braarudosphaera bigelowi (Gran and Braarud)
Calyptrosphaera oblonga Lohmann
Cricolithus jonesi Cohen
Cristallolithus macroporus (Deflandre), n. comb.
Cyclococcolithina leptopora (Murray and Blackman)
Discolithina anisotrema (Kamptner)
Helicopontosphaera cf. *H. intermedia* Martini
Helicopontosphaera kamptneri Hay and Mohler
Homozygosphaera wettsteni (Kamptner)
Rhabdosphaera clavigera Murray and Blackman
Scapholithus fossilis Deflandre
Scyphosphaera apsteini Lohmann
Scyphosphaera pulcherrima Deflandre
Syracosphaera histrica Kamptner
Syracosphaera pulchra Lohmann
Thoracosphaera saxea Stradner
Thoracosphaera sp.
Umbilicosphaera mirabilis Lohmann

Two of the recorded species were reassigned to other existing genera:

Coccolithus productus (Kamptner), n. comb.
Cristallolithus macroporus (Deflandre), n. comb.

The following two species have not been reported previously from strata as old as early Pleistocene:

Gephyrocapsa protohuxleyi McIntyre
Cricolithus jonesi Cohen

Two living species are reported herein from the fossil record for the first time:

Homozygosphaera wettsteni (Kamptner)
Calyptrosphaera oblonga Lohmann

The Pleistocene species *Ceratolithus cristatus* (Kamptner) and the Pliocene species *Ceratolithus rugosus* Bukry and Bramlette occur together in the latest Pliocene sediments on the Louisiana Continental Shelf (see figures 4 and 5). However, both species were recorded as rare (less than five specimens per traverse) and cannot be used as definitive evidence for separating Pliocene from Pleistocene strata in this area.

Coccolithus pelagicus has been noted by several workers as temporarily disappearing at or slightly above the horizon that discoasters become extinct. This has been interpreted as indicating the onset of a warming trend. *Coccolithus pelagicus* is rare to scarce in the area studied and in all probability the waters of the Gulf were not cool enough to permit the species to flourish.

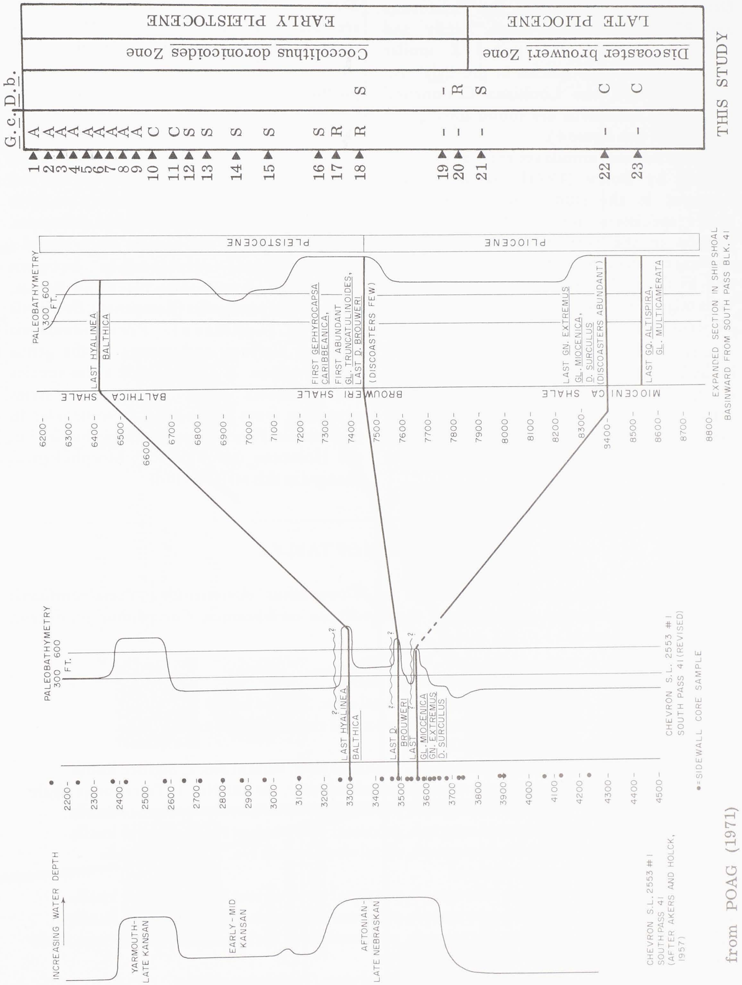

Figure 6. Pliocene-Pleistocene sequence in sediments on the Louisiana Continental Shelf. The frequency distributions of *Gephyrocapsa caribbeanica* and *Discoaster brouweri* are as reported in this study (light microscope). A – Abundant (500+); C – Common (50-500); S – Scarce (5-50); R – Rare (1-5).

Takayama (1967) first reported the species *Discolithina japonica* from the Pleistocene and Pliocene strata of Japan. Bandy and Wilcoxon (1970) also noted a similar distribution of this species in the Calabrian stratotype. On the Louisiana Continental Shelf, rare specimens are found throughout the section (see figure 4).

The *Emiliania annula* subzone (see table 1) erected by Bukry (1971b) is not readily apparent in the studied section although scarce specimens are found in the upper portion of the Terrebonne Shale and rare specimens occur in the lower part of the shale and in the underlying regressive Pleistocene beds (figure 5). None were encountered in the Pliocene section.

Cyclococcolithina macintyrei is common in the late Pliocene sediments of the Louisiana Continental Shelf and scarce throughout the early Pleistocene section. The common occurrence coincides with Bukry's uppermost Pliocene subzone *Cyclococcolithina macintyrei*.

Coccolithus doronicoides Black and Barnes and *Pseudoemiliania lacunosa* Gartner are the most abundant coccoliths in the studied section, together constituting more than one-half of the assemblage. In the upper portion of the Terrebonne Shale, both species decrease in abundance as *Gephyrocapsa caribbeanica* increases (see figures 4 and 5). This relationship was observed first by McIntyre, Bé, and Preikstas (1967) and has since been noted by other workers on cores from both temperate and tropical sediments.

The results of the present study reveal a morphological relationship between *Coccolithus doronicoides* Black and Barnes, *Coccolithus productus* (Kamptner), *Emiliania huxleyi* (Lohmann), *Pseudoemiliania lacunosa* Gartner, and species of the genus *Gephyrocapsa*. It appears that these species are members of a phylogenetic series extending from *Coccolithus doronicoides* in the middle Pliocene to *Emiliania huxleyi* in the Holocene (see Table 2). Morphological changes in this series include:

DESCRIPTION OF TABLE 2

Suggested phylogenetic relationships of *Coccolithus doronicoides, Pseudoemiliania lacunosa, Gephyrocapsa protohuxleyi, Gephyrocapsa caribbeanica, Coccolithus productus,* and *Emiliania huxleyi.*

Figure

1, 2 *Coccolithus doronicoides* Black and Barnes
- 1. Electron micrograph, distal view, Sigsbee knolls
- 2. Electron micrograph, proximal view, Sigsbee knolls

3–7 *Pseudoemiliania lacunosa* Gartner
- 3. Electron micrograph, proximal view, variant No. 1, Sigsbee knolls
- 4. Electron micrograph, pronimal view, variant No. 1, Terrebonne Shale
- 5. Electron micrograph, proximal view, variant No. 1, Sigsbee knolls
- 6. Electron micrograph, proximal view, variant No. 2, Sigsbee knolls
- 7. Electron micrograph, distal view, variant No. 2, Sigsbee knolls

8–10 *Emiliania* sp. not designated
- 8. Electron micrograph, proximal view, variant No. 3, Sigsbee knolls
- 9. Electron micrograph, proximal view, variant No. 3, Sigsbee knolls
- 10. Electron micrograph, proximal view, variant No. 3, Terrebonne Shale

11 *Gephyrocapsa protohuxleyi* McIntyre
- 11. Electron micrograph, distal view, Terrebonne Shale

12 *Gephyrocapsa caribbeanica* Boudreaux and Hay
- 12. Electron micrograph, proximal view, Terrebonne Shale

13 *Coccolithus productus* (Kamptner), new combination
- 13. Electron micrograph, proximal view, Sigsbee knolls

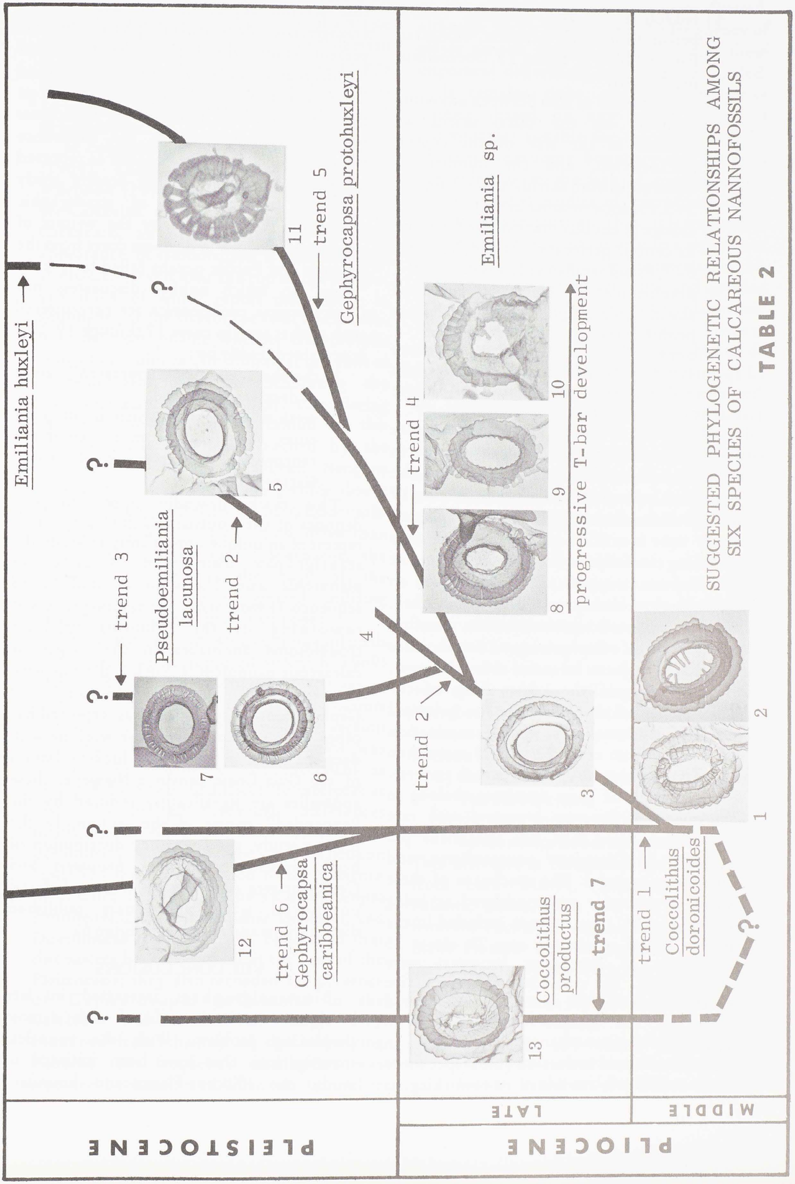

TABLE 2

SUGGESTED PHYLOGENETIC RELATIONSHIPS AMONG SIX SPECIES OF CALCAREOUS NANNOFOSSILS

1) reduction of the elliptical central perforation to an irregular, elongated fissure (table 2, figure 13, *Coccolithus productus);*
2) development of slits between adjoining elements on the distal shield, an increase in the size of the central perforation, and the number of elements in both shields (table 2, figures 3–5, *Pseudoemiliania lacunosa);*
3) change to circular shape of the form and its central perforation (table 2, figures 6–7, *Pseudoemiliania lacunosa);* and,
4) development of T-bars on the distal shield (table 2, figure 11, *Gephyrocapsa protohuxleyi).*

Members of this series constitute approximately 60 per cent of the placoliths recovered from the upper Pliocene and lower Pleistocene sediments.

The results of Poag (1971) and those from this study agree with reference to *Gephyrocapsa caribbeanica* (see figure 6). The specimens belonging to this species in cores 17 and 18 were diminutive and in the present study were identified only because we were searching carefully for the first appearance of this important species. Ordinarily, such an occurrence probably would be overlooked. From a pragmatic point of view, the first appearance of *Gephyrocapsa caribbeanica* does take place in core 16. However, interpretation of the upper limit of the distribution of discoasters is the principal point of difference. During the examination of samples from cores 22 and 23 more than 100 discoasters were counted in each traverse. Practically all of these specimens belong to the species *Discoaster brouweri* with rare occurrences (less than five specimens per traverse) of *Discoaster pentaradiatus,* and *Discoaster surculus.* The specimens of these latter two species are considered as being reworked and, thus, are not included in the master list of species. In core 21, about 35 specimens of *Discoaster brouweri* were encountered; in core 20, less than five specimens; in core 19, none were encountered although the sample does contain an abundant flora. The slight increase in discoasters noted in core 18 [most specimens were broken] is attributed to reworking, as this section represents the base of the transgressive depositional phase. In the present study, the top of the *Discoaster brouweri* zone is placed between cores 20 and 21 (which are spaced 40 feet apart) based on the reduction in number of *Discoaster brouweri* recorded. Thus, the difference between the top of the Pliocene as reported by Poag (1971) and in the present study amounts to 500 feet of stratigraphic separation. Examination by the writers of equivalent sections in deep-sea cores from the Atlantic and Pacific oceans failed to reveal a "zone" in which neither discoasters nor *Gephyrocapsa caribbeanica* are encountered such as that seen in cores 17 through 19. This is explained readily by:

1) the characteristic "compressed" nature of deep-sea cores; and,
2) vertical reworking which in deep-sea cores may range from ten to thirty centimeters (McIntyre *et al.,* 1967; Gartner, 1972).

The thick, downdip upper Neogene deposits of the Louisiana Gulf Coast section represent an unique opportunity to study the stratigraphic distribution of calcareous planktonic assemblages in an undistorted sequence. In most areas, the natural process of reworking of the sediments produces troublesome anomalies in the ranges of calcareous nannofossils. Such is the case with the ranges of *Discoaster brouweri* and *Gephyrocapsa caribbeanica* as reported by other authors, especially those working with deep-sea cores. In the greatly thickened strata of the Gulf Coast province Neogene, these anomalies are significantly reduced by the "expanded" nature of the section. In the present study, the frequency distribution of both species, *Discoaster brouweri* and *Gephyrocapsa caribbeanica,* is emended and compared with previously published distributions and ranges (see figure 6).

VIII. CONCLUSIONS

Biostratigraphers interested in late Neogene zonation are faced with a most perplexing problem. With the countless investigations that have been initiated to study the Pliocene-Pleistocene boundary problem, it seems incredible that there is no single definitive, illustrated study of a major micropaleontologic group from the Calabrian at Santa Maria di Catanzaro, the stratotype section, or the purported equivalent section at Le Castella, some twenty-five miles to the east of Catanzaro.

In consideration of the studies by Bayliss (1969), Lamb (1969), and Bandy and Wilcoxon (1970) of the type Calabrian and pre-Calabrian sediments at Santa Maria di Catanzaro, all of which report the first appearance of *Globorotalia truncatulinoides* at different levels near the top of the section, and none of which report this species in abundance at the stratotype or at Le Castella, it seems questionable whether *Globorotalia truncatulinoides* can be utilized at this time as a meaningful basis for delineating the Pliocene-Pleistocene boundary. Considering that no consensus on definition of this boundary has yet been reached by the Committee on Mediterranean Neogene Stratigraphy, and that considerable doubt remains on the usefulness of *Globorotalia truncatulinoides* for any purpose other than as a guide to the early Pleistocene, the question of whether the base of the Pleistocene can be recognized utilizing planktonic Foraminiferida is still open.

The distribution of calcareous nannofossils at the stratotype as reported by Smith (1969) and by Bandy and Wilcoxon (1970) are in direct conflict. Smith reported discoasters extending throughout the Calabrian section and that *Gephyrocapsa caribbeanica* was absent. The distribution of coccoliths as reported by Smith is difficult to interpret as resolution of the taxonomic differences involving late Neogene forms was then in a preliminary stage. Bandy and Wilcoxon restricted their investigation to the presence or absence of the discoasters *Gephyrocapsa caribbeanica, Pseudoemiliania lacunosa,* and *Discolithina japonica* and concluded that discoasters became extinct at the base of the Pleistocene; they also recorded the presence of *Gephyrocapsa caribbeanica* in the Calabrian and in the one sample they examined from the top of the underlying Pliocene. No frequency distribution was reported by Bandy and Wilcoxon. In neither of the studies were any specimens figured, although Smith reported on the frequency of major generic groups. It appears that these important differences cannot be reconciled.

It remains quite clear that definitive criteria (based on any major group of microfossils) suitable for recognition of the Pliocene-Pleistocene boundary are not now available due to the lack of comprehensive and illustrated studies of microfossils from the stratotype section. Thus, it is impossible to propose criteria acceptable to a significant number of biostratigraphers interested in this problem. Until proper definitive and detailed studies are made of both planktonic Foraminiferida and calcareous nannofossils at the stratotype section at Santa Maria de Catanzaro and of the Calabrian section at Le Castella this problem cannot be resolved. Therefore, lacking alternatives, the customary procedure of delineating the Pliocene-Pleistocene boundary based on the extinction of *Discoaster brouweri* and on the approximate first appearance of *Gephyrocapsa caribbeanica* is followed in this study.

Thirty-two species of calcareous nannofossils from 20 genera were identified from the late Pliocene and early Pleistocene strata of the Louisiana Continental Shelf. Of these 32 species, two are sufficiently restricted to be useful stratigraphically. These two species aid in defining the base of the Terrebonne Shale which is named herein. The calcareous nannofossils which define this horizon are:

1) the extinction of *Discoaster brouweri* Tan Sin Hok; and,
2) the first appearance of *Gephyrocapsa caribbeanica* Boudreaux and Hay.

This interface is recognized also in samples from core V10-91 (Lamont) from the Atlantic Ocean, from CAP 38 BP (Scripps) from the Pacific Ocean, and in cores from the Blake Plateau. This stratigraphic level is of major correlative importance.

The following additional results were obtained from this study:

1) A phylogenetic series extending from *Coccolithus doronicoides* Black and Barnes, in the middle Pliocene section

to *Emiliania huxleyi* (Lohmann) in the Holocene has been recognized and delineated;

2) this series reveals a morphological relationship among the following species:

Coccolithus doronicoides Black and Barnes
Coccolithus productus (Kamptner)
Emiliania huxleyi (Lohmann)
Pseudoemiliania lacunosa Gartner
Gephyrocapsa caribbeanica Boudreaux and Hay
Gephyrocapsa protohuxleyi McIntyre;

3) *Ceratolithus cristatus* Kamptner) and *Ceratholithus rugosus* Bukry and Bramlette occur together in the earliest Pleistocene sediments, confirming the distribution of these species as reported by other authors;
4) the geologic ranges of two species, *Gephyrocapsa protohuxleyi* McIntyre and *Cricolithus jonesi* Cohen, are extended back to the early Pleistocene;
5) two species, *Homozygosphaera wettsteni* (Kamptner) and *Calyptrosphaera oblonga* Lohmann, are first reported from the fossil record; and,
6) two species, *Coccolithus productus* (Kamptner), n. comb., and *Cristallolithus macroporus* (Deflandre), n. comb., are reassigned to other existing genera.

IX. ACKNOWLEDGMENTS

The writers are deeply indebted to several colleagues who have contributed substantially to the research reported here. Among these are W. H. Akers, who provided counsel and encouragement throughout the study; Stefan Gartner, Jr., who provided extensive technical advice, counsel, and help throughout the work; and Harold E. Vokes who assisted with stratigraphic problems. These three men also served as members of the editorial committee. We are grateful to Cesare Emiliani, W. W. Hay, C. Wylie Poag, and Ruth Trencher for technical advice, assistance, and making available much needed equipment and facilities.

This work was supported by the National Science Foundation (Grant No. GA 4293); this essential funding is gratefully acknowledged. T. C. Pyle and W. R. Bryant kindly gave permission to publish data from the Texas A & M University Sigsbee knolls core No. 64-A-9-5E.

X. SYSTEMATIC PALEONTOLOGY

Kingdom PROTISTA
Phylum CHRYSOPHYTA
Class COCCOLITHOPHYCEAE Rothmaler
Order COCCOLITHALES
Family COCCOLITHACEAE Kamptner, 1928

Genus COCCOLITHUS Schwarz, 1894

Type species: *Coccolithus oceanicus* Schwarz, 1894.

Definition: Elliptical placoliths, the smaller or proximal shield and the larger or distal shield are connected by a central tube or collar. Both shields are curved, with the concave surface on the proximal side and the convex surface on the distal side.

COCCOLITHUS DORONICOIDES
Black and Barnes
Table 2, figs. 1, 2;
Plate 1, figs. 1, 2, 6–8

Coccolithus doronicoides BLACK and BARNES, 1961, Roy. Micros. Soc., Jour., ser. 3, Vol. 80, pt. 2, p. 142, pl. 25, fig. 3.
Ellipsoplacolithus galenis KAMPTNER, 1967, Naturh. Mus. Wien, Ann., vol. 71, p. 140, pl. 6, fig. 41.
Coccolithus doronicoides Black and Barnes. McINTYRE, BÉ, and PREIKSTAS, 1967, Progress in Oceanography, vol. 4, p. 8, pl. 2, figs. A, B.
Coccolithus doronicoides Black and Barnes. COHEN and REINHARDT, 1968, Neues Jahrb. Geologie Paläontologie, Abh., vol. 131, no. 3, p. 239, pl. 20, fig. 4.

Description: "Coccoliths consisting of two broadly elliptical or almost circular shields, nearly equal in size, with a large central opening approximately one-third the diameter of the smaller shield. Rays of the two shields are equal in number, narrow, gently curved and bluntly pointed; adjacent rays are separated by a suture at right angles to the surface of the shield and are never overlapping." (Black and Barnes, 1961)

Discussion: Commenting on their original description, Black and Barnes (1961) state that in all observed specimens the central pore is either obscured or damaged and that they are uncertain if the pore is in fact large, with the possibility that the pore of a complete undamaged specimen would possess a fine grill.

The holotype contains 37 elements in each shield but, as the authors state, the other 8 specimens they examined are constructed of from 28 to 48 elements and it is probable that more than one species is included among their material.

McIntyre, Bé, and Preikstas (1967) redescribed *Coccolithus doronicoides,* and broadened the definition of this species, differing on several points from Black and Barnes. McIntyre *et al.* (1967) state that the distal shield possesses a strongly developed ring surrounding the central pore (Table 2, fig. 1) and that "this ring of elements is sinistrally imbricate and is separated by a channel from the dextrally imbricated outer elements, which are occasionally incomplete. The elements of the proximal shield are sinistrally imbricate. The suture lines are radial throughout most of the shield width, both distally and proximally." The element count reported by McIntyre *et al.* also differs in that they recognized an elliptical form of 40 to 50 elements with a mean of 48, and a circular variant with an element count of 50 to 68, and a mean of 63 elements. Thus, they agree with Black and Barnes that more than one species is involved.

Coccolithus doronicoides and *Pseudoemiliania lacunosa* are the dominant coccoliths in the section studied where they constitute more than one-half of the assemblage. *Coccolithus doronicoides* is believed to be a progenitor of *Emiliania huxleyi* (Lohmann), the most ubiquitous coccolith in the modern oceans, and to be ancestral to the genus *Gephyrocapsa,* another major group of placoliths.

Studies of the late Pliocene and early Pleistocene sediments from the Louisiana Continental Shelf with the aid of light and electron microscopes have revealed several evolutionary trends among placoliths from this area which are discussed below and figured in Table 2.

Trend No. 1: The elliptical form known as *Coccolithus doronicoides* first appears in middle Pliocene beds and continues to be present higher in the section, increasing in abundance until it constitutes a significant percentage of the placoliths in late Pliocene and early Pleistocene sediments (see Table 2, figs. 1, 2; Plate 1, figs. 1, 2, 6–8). It is this elliptical form that Black and Barnes (1961) designated as the type of *Coccolithus doronicoides.*

In 1967, Kamptner proposed a new species *Ellipsoplacolithus galenis* for a form very similar to *Coccolithus doronicoides* but with 30 elements as compared to 37 in the holotype of *Coccolithus doronicoides.* However, this is well within the range of variation noted by Black and Barnes, and *Ellipsoplacolithus galenis* is considered a junior synonym of *Coccolithus doronicoides.*

Trend No. 2: In middle Pliocene, certain forms derived from *Coccolithus doronicoides* developed slits between the adjoining elements on the distal shield with an increase in the number of elements in both shields and the distal collar. This new form, which retains the elliptical shape of its ancestor, has been designated *Pseudoemiliania lacunosa* by Gartner (1969). *Pseudoemiliania lacunosa* became extinct within the middle Pleistocene (see Table 2, figs. 3–7; Plate 1, figs. 3–5, 9–13).

Trend No. 3: From trend No. 2 another variation developed in the middle or late Pliocene. The form and the central perforation are circular and the latter increases in size at the expense of the width of the shields (see Table 2, figs. 6, 7; Plate 1, figs. 12, 13). As this variant became extinct at approximately the same level as *Pseudoemiliania lacunosa,* it is assigned provisionally to this species.

Trend No. 4: Another distinctive elliptical variant is produced when the slits on the distal shield become enlarged and the remaining elements develop into distinctive T-bars (see Table 2, figs. 8, 9, 10; Plate 2, fig. 10). The results of the present study reveal that this form may be ancestral to both *Gephyrocapsa* *protohuxleyi* and *Emiliania huxleyi*, although a gap in the known geologic record exists between this variant and the first appearance of *Emiliania huxleyi*. *Gephyrocapsa protohuxleyi* may be derived from the T-bar variant form by addition of the characteristic *Gephyrocapsa* bridge, and *Emiliania huxleyi* may have been derived from this same variant by addition of a second series of T-bars on the proximal shield. The T-bar variant form from trend No. 4 is here placed in the genus *Emiliania* but is not assigned to a nominal species pending further study of more definitive material.

Trend No. 5: Specimens in trend No. 5 differ from those in trend No. 4 by the addition of a bridge across the central pore (see Table 2, fig. 5; Plate 2, fig. 11). This form has been designated *Gephyrocapsa protohuxleyi* by McIntyre (1970), and is, according to its author, the ancestor of *Emiliania huxleyi*. If McIntyre is correct, this represents a reversal in evolution as *Emiliania huxleyi* does not possess a bridge. It appears much more logical that *Emiliania huxleyi* developed from the T-bar variant (see discussion above) without the necessity of first developing and then losing a bridge.

PLATE 1

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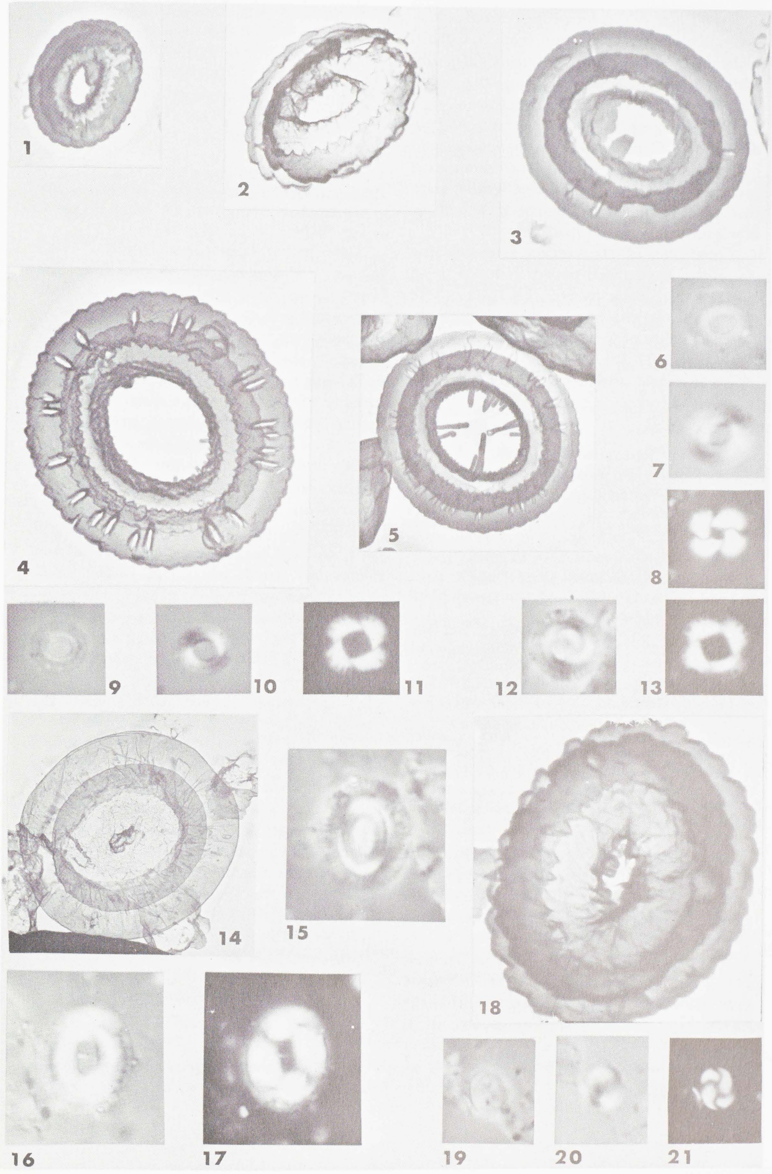

PLATE 1

Trend No. 6: Gephyrocapsa caribbeanica, a small placolith, is derived from the small, elliptical *Coccolithus doronicoides* by addition of a bridge during the early Pleistocene (see Table 2, fig. 12; Plate 2, figs. 1–8). McIntyre, Bé, and Preikstas (1967) in discussing *Coccolithus doronicoides* and comparing this species to diminutive specimens of the genus *Gephyrocapsa,* state that "if the bridge were lost it would be impossible to tell them apart."

Trend No. 7: In certain late Pliocene placoliths, the central pore is reduced to an elongated, irregular fissure; this form is here designated *Coccolithus productus,* n. comb. (see discussion of *Coccolithus productus* and Table 2, fig. 13).

Reported occurrences: Middle Pliocene to middle Pleistocene.

COCCOLITHUS PELAGICUS (Wallich)
Plate 1, figs. 14–17

Coccosphaera pelagica WALLICH, 1877, Ann. Mag. Nat. Hist., ser. 4, vol. 19, p. 348, pl. 17, figs. 1, 2, 5, 11, 12.

Coccolithus pelagicus (Wallich). SCHILLER, 1930, *in* L. RABENHORST, Kryptogamen-Flora, Leipzig, vol. 10, p. 246.

Coccolithus pelagicus (Wallich) Schiller. KAMPTNER, 1954. Archiv. Protistenk., vol. 100, p. 20, 21, figs. 14, 15.

Coccolithus pelagicus (Wallich). COHEN, 1965, Leidsche Geologische Mededelingen, vol. 35, p. 11, pl. 1, figs. a–c.

Coccolithus pelagicus (Wallich) Schiller. McINTYRE, BÉ, and PREIKSTAS, 1967, Progress in Oceanography, vol. 4, p. 11, figs. A, B.

Coccolithus pelagicus (Wallich) Schiller. McINTYRE and BÉ, 1967, Deep-Sea Research, vol. 14, p. 569, pl. 8, figs. A–C.

Discussion: This large oval placolith, one of the first described coccoliths, is very rare in the Terrebonne Shale. Its scarcity is attributed to its preference for colder waters (McIntyre and Bé, 1967).

Hay and Boudreaux (1968) drew a similar conclusion in their report on the *Submarex* core from the Nicaragua Rise stating that the extinction of *Coccolithus pelagicus* is coincident with the onset of warmer temperatures as determined by Bolli *et al.* (1968).

Reported occurrences: Oligocene to Holocene.

COCCOLITHUS PRODUCTUS (Kamptner), new combination
Table 2, fig. 13;
Plate 1, figs. 18–21

Ellipsoplacolithus productus KAMPTNER, 1963, Naturh. Mus. Wien, Ann., vol. 66, p. 172, pl. 8, figs. 42, 44.

Description: Elliptical placolith, 2.7–2.9 microns long and 2.0–2.3 microns wide. The larger convex distal shield consists of 30 to 40 elements which are inclined in one direction; the periphery of the shield is serrated. The proximal shield, which also has a serrated periphery, is concave and contains the same number of elements as the distal shield. The central perforation is narrow, irregular, and elongated (modified from Kamptner, 1963).

Discussion: The character of the central perforation distinguishes this species from *Coccolithus doronicoides,* to which it is probably related (see Table 2, fig. 13) and with which it may be confused. In electron microscope study, where clay or other fine debris may cover portions of the central pore, or if the micrograph is of poor quality (as is Plate 1, fig. 18), the form could be misidentified as *Coccolithus doronicoides.* In cross-polarized light (see Plate 1, fig. 21) the elliptical pore is not visible and the pseudointerference figure is distinctive.

The International Code of Botanical Nomenclature provides that provisional or conditional generic names are invalid (Art. 34, par. i). Thus, *Ellipsoplacolithus* is invalid, but the species-group name *productus* is valid when used in combination with a valid generic name. As the form is similar to *Coccolithus doronicoides,* the species is here reassigned to the genus *Coccolithus.*

Reported occurrences: Pliocene and Pleistocene.

Genus GEPHYROCAPSA Kamptner, 1943

Type species: *Gephyrocapsa oceanica* Kamptner, 1943.

Definition: Elliptical placoliths with a central pore spanned by a bridge not aligned with the major or minor axes of the ellipse.

GEPHYROCAPSA APERTA
Kamptner
Plate 2, fig. 9

Gephyrocapsa aperta KAMPTNER, 1963, Naturh. Mus. Wien, Ann., 66, p. 173, pl. 6, figs. 32, 35.

Discussion: The large elliptical central perforation and the narrow shields are characteristic of this species. The figured specimen is identical with that of Kamptner (1963). Only one specimen was encountered in the electron microscope work. Because of its diminutive size and rarity, this form is not readily identified with the light microscope.

Reported occurrences: Pleistocene.

GEPHYROCAPSA CARIBBEANICA
Boudreaux and Hay
Table 2, fig. 12;
Plate 2, figs. 1–8

Gephyrocapsa caribbeanica BOUDREAUX and HAY, 1967, *in* HAY *et al.,* Gulf Coast Assoc. Geol. Soc., Trans., vol. XVII, p. 447, pl. 12, figs. 1–4; pl. 13, figs. 1–4.

Gephyrocapsa caribbeanica Boudreaux and Hay. SMITH, 1969, Gulf Coast Assoc. Geol. Soc., Trans., vol. XIX, p. 579–583, figs. 1–3.

Gephyrocapsa caribbeanica Boudreaux and Hay. GARTNER, 1969, Gulf Coast Assoc. Geol. Soc., Trans., vol. XIX, p. 585–599, figs. 1–7.

Discussion: This placolith is rare at the base of the studied section but becomes increasingly abundant in the upper portion of the Terrebonne Shale where it constitutes about 20 per cent of the calcareous nannofossils. This increase in abundance is at the expense of *Coccolithus doronicoides* and *Pseudoemiliania lacunosa.*

Satisfactory phase and interference contrast pictures are not obtained due to the diminutive size of this form, but the pseudointerference image is distinctive. [The origin of *Gephyrocapsa* has been discussed under *Coccolithus doronicoides.*]

Reported occurrences: An important but unresolved conflict exists in the distribution of this species as reported by Smith (1969), and Bandy and Wilcoxon (1970). In both papers, *Gephyrocapsa caribbeanica* was reported from Le Castella, but only Bandy and Wilcoxon recorded the species at the Calabrian stratotype section. Until this difference is reconciled, the problem of the first appearance of *Gephyrocapsa caribbeanica* cannot be resolved. (?) Pliocene to middle Pleistocene.

GEPHYROCAPSA PROTOHUXLEYI
McIntyre
Table 2, fig. 11;
Plate 2, fig. 11

Gephyrocapsa protohuxleyi McINTYRE, 1970, Deep-Sea Research, vol. 17, p. 187–190, fig. 1.

Description: "Placolith, oval in plan view, convex proximally with a large elliptical central pore and a bridge crossing the pore on the distal surface." (McIntyre, 1970). The larger distal shield is constructed of T-bars as in *Emiliania huxleyi;* the smaller proximal shield is constructed of tabular elements, similar to those of *Coccolithus doronicoides.*

Discussion: According to McIntyre,(1970) this species varies considerably with ecologic conditions. In specimens from lower latitudes the T-bars on the distal shield are thickened and fused together at the margin, but the elements on the smaller proximal shield are rounded and partially fused, at a stage of development intermediate between a solid shield and that of the distal shield. In addition, forms from the lower latitudes have a thickened bridge. Identification of this species in the Louisiana Shelf area, with both T-bars and bridge, extends its lower range into the early Pleistocene strata.

Rare forms similar to *Gephyrocapsa protohuxleyi,* but lacking a bridge are also encountered (see Table 2, figs. 9–11) but the data were insufficient to ascertain whether these represent a new species; they are provisionally assigned to *Emiliania* sp.

Reported occurrences: Early Pleistocene to late Pleistocene, Atlantic Ocean and Gulf of Mexico.

Genus PSEUDOEMILIANIA
Gartner, 1969

Type Species: *Ellipsoplacolithus lacunosa* Kamptner, 1963.

Definition: Elliptical to circular placoliths. Shields solid or with radial slits located between adjacent elements. Center open or with grillwork.

PSEUDOEMILIANIA LACUNOSA
(Kamptner)
Table 2, figs. 3–7;
Plate 1, figs. 3–5, 9–13

Ellipsoplacolithus exsectus KAMPTNER, 1963, Naturh. Mus. Wien, Ann., vol. 66, p. 171, pl. 9, figs. 51, 52 [figure 52 is incorrectly labelled].
Ellipsoplacolithus lacunosus KAMPTNER, 1963, Naturh. Mus. Wien, Ann., vol. 66, p. 172, pl. 9, fig. 50.
Coccolithus doronicoides Black (partim). McINTYRE, BÉ, and PREIKSTAS, 1967, Progress in Oceanography, vol. 4, p. 8, pl. 3, fig. A.
Umbilicosphaera cricota (Gartner). COHEN and REINHARDT, 1968, Neues Jahrb. Geologie Paläontologie, Abh., vol. 131, p. 296, pl. 21, fig. 3.
Pseudoemiliania lacunosa (Kamptner). GARTNER, 1969, Gulf Coast Assoc. Geol. Soc., Trans., vol. XIX, p. 598, pl. 2, figs. 9, 10.

Discussion: As previously stated, development of slits between adjoining elements on the larger distal shield and increase in the number of elements of both shields differentiates this species from *Coccolithus doronicoides* from which it was derived (see discussion of *Coccolithus*

PLATE 2

Figures		Page
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	1. Electron photomicrograph, distal view, X 8700	
	2. Electron photomicrograph, distal view, X 11,000	
	3. Phase contrast, X 2250	
	4. Interference contrast, X 2250	
	5. Crossed nicols, X 2250	
	6. Phase contrast, X 2250	
	7. Interference contrast, X 2250	
	8. Crossed nicols, X 2250	
9	*Gephyrocapsa aperta* Kamptner	139
	9. Electron photomicrograph, proximal view, X 15,500	
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	10. Electron photomicrograph, proximal view, X 16,500	
11	*Gephyrocapsa protohuxleyi* McIntyre	139
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16, 17	*Cyclococcolithina leptopora* (Murray and Blackman)	142
	16. Electron photomicrograph, proximal view isolated distal shield, var. "B", X 5950	
	17. Electron photomicrograph, proximal view, var. "B", X 5950	

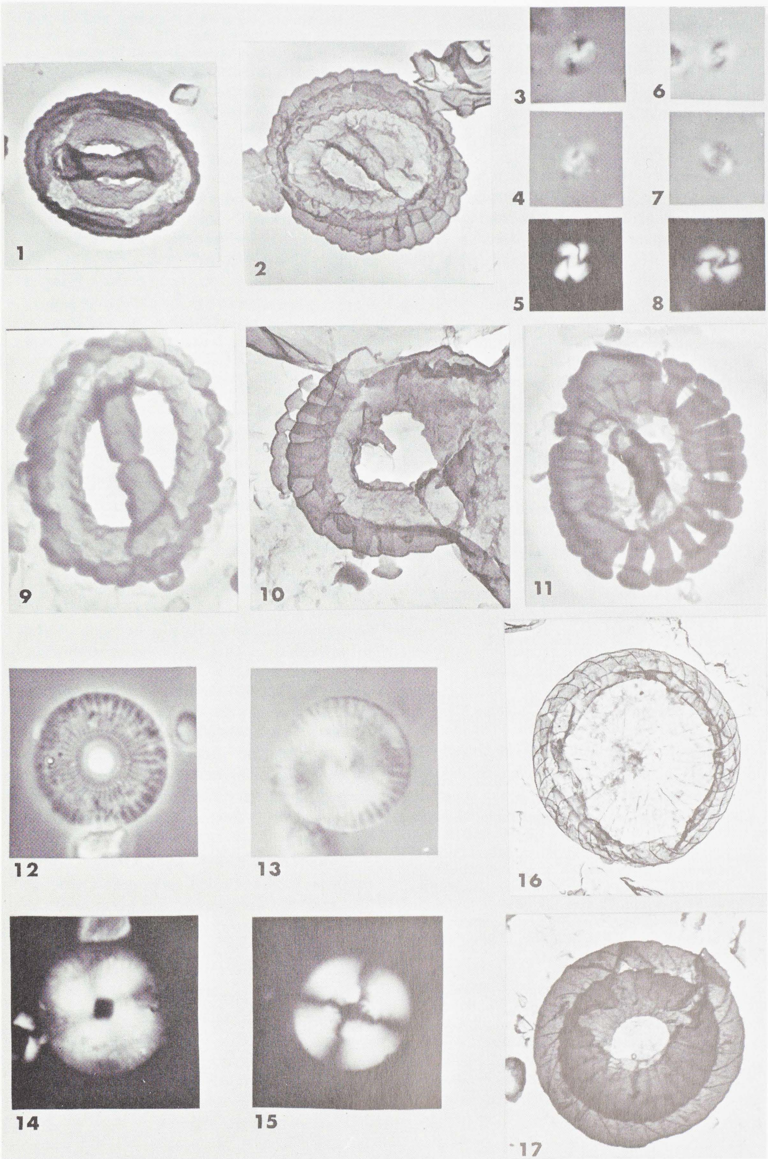

PLATE 2

doronicoides).

Two varieties occur within the species:

a) an elliptical form (see Table 2, figs. 3–5: Plate 1, figs. 3–5, 9–11); and,

b) a circular form (see Table 2, figs. 6, 7; Plate 1, figs. 12, 13).

In this study the circular form appears to occur first in late Pliocene. Other workers have recorded both forms as becoming extinct at approximately the same horizon in the middle Pleistocene strata. Considering that the extinctions appear to coincide, it does not seem prudent to subdivide or "split" the species.

Reported occurrences: Middle Pliocene to middle Pleistocene.

Genus CYCLOCOCCOLITHINA
Wilcoxon, 1970

Type species: *Coccosphaera leptopora* Murray and Blackman, 1898.

Definition: Circular placolith with a larger distal shield and a smaller proximal shield. The shields are attached to each other by a collar or tube.

CYCLOCOCCOLITHINA LEPTOPORA
(Murray and Blackman)
Plate 2, figs. 16, 17;
Plate 3, figs. 1–9

Coccosphaera leptopora MURRAY and BLACKMAN, 1898, Roy. Soc. London, Phil. Trans., ser. B., vol. 190, p. 430, pl. 15, figs. 1–7.

Coccolithosphora leptopora (Murray and Blackman). LOHMANN, 1902, Archiv. Protistenk., vol. 1, p. 138, pl. 5, figs. 52, 61–64.

Coccolithus leptoporus (Murray and Blackman). SCHILLER, 1930, *in* L. RABENHORST, Kryptogamen-Flora, vol. 10, p. 245, text-fig. 10.

Coccolithus leptoporus (Murray and Blackman). KAMPTNER, 1941, Naturh. Mus. Wien, Ann., vol. 51, p. 94, pl. 13, figs. 137–139.

Cyclococcolithus leptoporus (Murray and Blackman). KAMPTNER, 1954, Archiv. Protistenk., vol. 100, p. 23, fig. 20.

Coccolithus leptoporus (Murray and Blackman). GARDET, 1955, Publ. Service Carte Géol. Algérie, N.S., Bull. 5, p. 513, pl. 6, fig. 50.

Coccolithus leptoporus (Murray and Blackman). BLACK and BARNES, 1961, Roy. Micros. Soc., Jour., ser. 3, vol. 80, pl. 2, p. 143, pl. 24, figs. 3, 4.

Cyclococcolithus leptoporus (Murray and Blackman). MARTINI and BRAMLETTE, 1963, Jour. Paleontology, vol. 37, no. 4, p. 850, pl. 102, figs. 4, 5.

Cyclococcolithus leptoporus (Murray and Blackman). COHEN, 1964, Micropaleontology, vol. 10, no. 2, p. 237, pl. 1, figs. 6 a–e, pl. 2, figs. h, i; pl. 18, figs. a–e; pl. 19, figs. a, b.

Cyclococcolithus leptoporus (Murray and Blackman) Kamptner. PYLE, 1966, Texas A & M Univ., Dept. Oceanography Tech. Rept. 66–13T, p. 21, pl. 2, fig. 3.

Coccolithus leptoporus (Murray and Blackman). McINTYRE, BÉ, and PREIKSTAS, 1967, Progress in Oceanography, vol. 4, p. 9 (partim), pl. 4, figs. C, D; pl. 5, figs. A, C, D [*not* pl. 2, figs. A, B = *Cyclococcolithina macintyrei*].

Cyclococcolithus leptoporus (Murray and Blackman). McINTYRE and BÉ, 1967, Deep-Sea Research, vol. 14, p. 569, pl. 7, figs. A–C.

Cyclococcolithus leptoporus (Murray and Blackman). GARTNER, 1967a, Univ. Kansas Paleont. Contr., paper 28, p. 1–3, pl. 1, figs. 1–4, pl. 2, figs. 1–4.

Cyclococcolithina leptopora (Murray and Blackman). WILCOXON, 1970, Tulane Stud. Geol. Paleont., vol. 8, no. 2, p. 82.

Discussion: In an investigation of the Pliocene-Pleistocene boundary, McIntyre *et al.* (1967) examined two hundred and thirty-three specimens of *Cyclococcolithina leptopora* and came to the conclusion that three varieties were present (see Table 3).

They stated that nearly three per cent of the specimens do not correspond to the varieties described (see table 3), but because of the polymorphic nature of coccolithophorids, these could not be designated as separate species. However, as indicated by McIntyre *et al.*, the stratigraphic distribution across the Pliocene-Pleistocene boundary shows that their variety "A" [now *Cyclococcolithina macintyrei* (Bukry and Bramlette)] becomes extinct, variety "B" decreases significantly, and variety "C" increases considerably at the boundary.

Cyclococcolithina leptopora is quite common in the studied section and varieties "B" and "C" are present, but because of the terrigenous nature of the sediment the material cannot be analyzed meaningfully in the same way as deep-sea sediments.

Reported occurrences: Miocene to Holocene.

CYCLOCOCCOLITHINA MACINTYREI
(Bukry and Bramlette)
Plate 2, figs. 12–15

Coccolithus leptoporus (Murray and Blackman). McINTYRE, BÉ, and PREIKSTAS, 1967, Progress in Oceanography, vol. 4, p. 9 (partim), pl. 2, figs. A, B [not pl. 4, figs. C, D; pl. 5, figs. A, C, D = *Cyclococcolithina leptopora*].

Cyclococcolithus macintyrei BUKRY and BRAMLETTE, 1969, Tulane Stud. Geol. Paleont., vol. 7, no. 3, p. 132, pl. 1, figs. 1–3.

Cyclococcolithina macintyrei. GARTNER, 1973, Geol. Soc. America, Bull., vol. 84, no. 6, p. 2021.

Discussion: This species is distinguished from *Cyclococcolithina leptopora* by its larger size, 11 microns compared with 6 microns, and by the consistently larger number of elements in either shield.

Bukry (1971a) noted that in some areas it is possible to subdivide the late Pliocene *Discoaster brouweri* zone into several subzones; the latest of these is the *Cyclococcolithina macintyrei* subzone. Distribution of this species in late Pliocene and early Pleistocene sediments on the Louisiana Continental Shelf coincides approximately with this subzone. Common occurrences (50 to 500 per traverse) are found in late Pliocene beds, and scarce (5 to 50 specimens per traverse) are reported from early Pleistocene strata.

Reported occurrences: Miocene to Pleistocene.

Genus UMBILICOSPHAERA
Lohmann, 1902

Type species: *Umbilicosphaera mirabilis* Lohmann, 1902.

Definition: Circular placoliths possessing a short tube connecting the shields, the proximal shield is equal to, or smaller than the distal shield. The central perforation is large in most species.

UMBILICOSPHAERA MIRABILIS
Lohmann
Plate 3, figs. 10–13

Umbilicosphaera mirabilis LOHMANN, 1902, Archiv. Protistenk., vol. 1, p. 139, pl. 5, figs. 66, 66a.

Umbilicosphaera mirabilis Lohmann. BLACK and BARNES, 1961, Roy. Micros. Soc., Jour., ser. 3, vol. 80, p. 140, pl. 25, figs. 4, 5.

Cyclococcolithus mirabilis (Lohmann). KAMPTNER, 1954, Archiv. Protistenk., vol. 100, p. 24, text-figs. 21–23.

Umbilicosphaera mirabilis Lohmann. McINTYRE, BÉ, and PREIKSTAS, 1967, Progress in Oceanography, vol. 4, p. 13, pl. 2, figs. C, D.

Umbilicosphaera mirabilis Lohmann. McINTYRE and BÉ, 1967, Deep-Sea Research, vol. 14, p. 571, 572, pl. 11, figs. B, C; pl. 11, fig. A.

Discussion: McIntyre and Bé (1967) noted that in modern specimens the ultrastructure of this species varies with environmental conditions. In colder waters the placoliths are heavier, the distal shield is larger, and the central perforation is smaller than in warm water specimens.

In the Terrebonne Shale the warm water form is common. Specimens when viewed in cross-polarized light produce a distinct black interference cross.

Reported occurrences: Pliocene to Holocene.

Genus EMILIANIA
Hay and Mohler, 1967

Type Species: *Pontosphaera huxleyi* Lohmann, 1902.

Definition: Placoliths with the distal shield constructed of I-shaped segments and the proximal shield constructed of I-shaped or petaloid elements.

TABLE 3

VARIETIES OF *CYCLOCOCCOLITHINA LEPTOPORA* (Murray and Blackman)
(After McIntyre, Bé, and Preikstas, 1967).

Variety	Diameter of Distal Shield	Diameter of Proximal Shield	Number of Elements
"A"	7.4–11.8 microns	6.8–8.7 microns	40 ± 2
"B"	4.4–8.5 microns	4.0–6.5 microns	31 ± 2
"C"	4.1–7.5 microns	3.1–5.6 microns	19 ± 2

EMILIANIA ANNULA
(Cohen)
Plate 4, figs. 6–8

Coccolithites annulus COHEN, 1964, Micropaleontology, vol. 10, no. 2, p. 243, pl. 3, figs. 1a–e.
Cyclolithella annulus (Cohen). McINTYRE and BÉ, 1967, Deep-Sea Research, vol. 14, p. 568, pl. 5, figs. A–C.
Emiliania annula (Cohen). BUKRY, 1971, *in* WINTERER *et al.*, 1971, Initial Rpts., Deep Sea Drilling Project, vol. VII, p. 1514.

Discussion: Cohen (1964) described and figured four light micrographs and one drawing of a new species, *Coccolithites annulus.* His first three figures (Plate 3, figs. 1a, 1b, 1c) are plan views taken with phase contrast. It is obvious that the three figures represent different specimens but they appear to be conspecific. The fourth micrograph (fig. 1d), taken in cross-polarized light, may represent a fourth specimen. Unfortunately, no holotype was designated.

After Loeblich and Tappan (1963) showed that the generic name *Coccolithites* is invalid, McIntyre and Bé (1967) placed this species in the genus *Cyclolithella* because of its cricolith

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PLATE 3

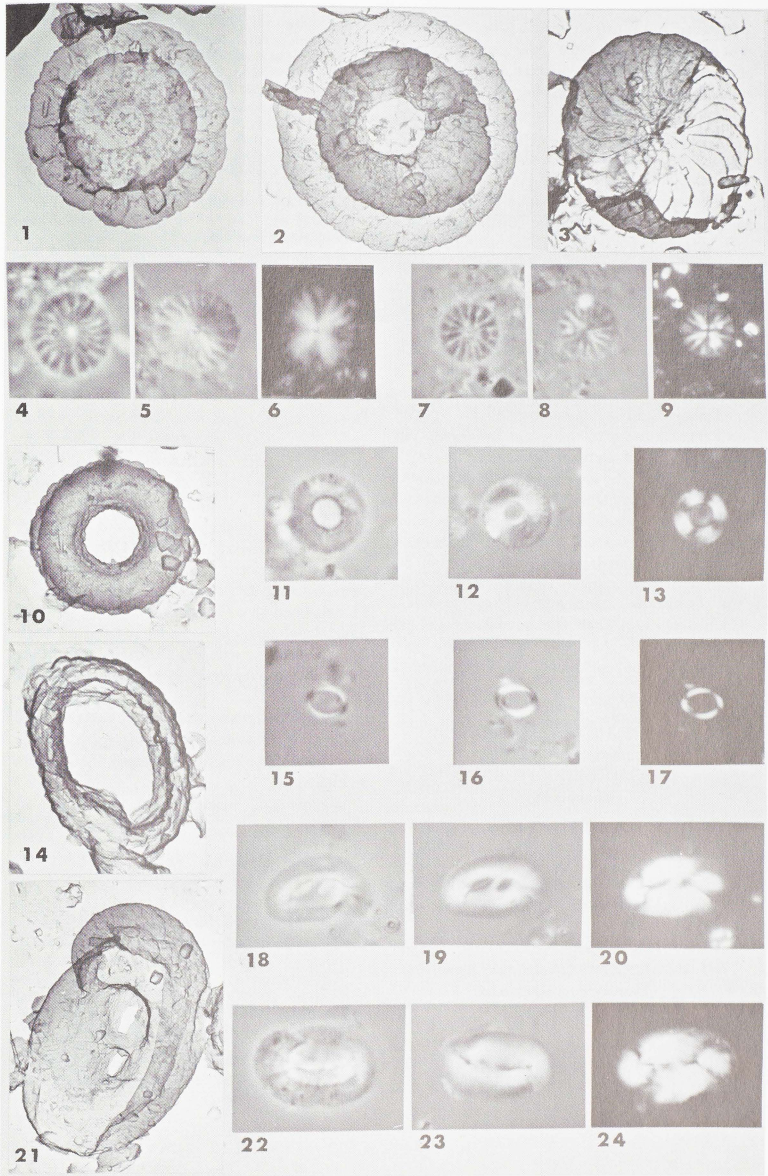

PLATE 3

structure, but illustrated their paper only with transmission electron photomicrographs. Boudreaux (1968) presented both electron and light photomicrographs of this species. One of the electron photomicrographs, however, shows a subcircular placolith, which does not agree with the definition of this species by McIntyre and Bé (1967).

The specimen figured here (Plate 4, figs. 6–8) is similar to the phase contrast pictures of Cohen (1964) and Boudreaux (1968) but Boudreaux's cross-polarized light figure does not resemble Cohen's illustration. After examining numerous specimens in both phase contrast and cross-polarized light, the conclusion is reached that Cohen's cross-polarized light figure probably is a different species.

Bukry (1971a) re-evaluated this species and transferred it to the genus *Emiliania.* His study included detailed stratigraphic work which revealed abundance of *Emiliania annula* in earliest Pleistocene sediments, and he erected a subzone based on this species in the basal Pleistocene. His results are not supported by the present study as less than 50 specimens per traverse were encountered in the Louisiana Continental Shelf samples; therefore, his subzone cannot be recognized in this area.

Reported occurrences: Pleistocene and Holocene.

Family RHABDOSPHAERACEAE
Lemmermann, 1908
Genus RHABDOSPHAERA
Haeckel, 1894

Type species: *Rhabdosphaera clavigera* Murray and Blackman, 1898.

Definition: A rod or stem extending from the central portion of an elliptical disc on the distal side.

RHABDOSPHAERA CLAVIGERA
Murray and Blackman
Plate 5, figs. 5–9

Rhabdosphaera clavigera MURRAY and BLACKMAN, 1898, Roy. Soc. London, Phil. Trans., ser. B, vol. 190, p. 438, pl. 15, figs. 13–15.

Rhabdosphaera stylifera LOHMANN, 1902, Archiv. Protistenk., vol. 1, p. 143, pl. 5, fig. 65.

Discolithus phaseolus BLACK and BARNES, 1961, Roy. Micros. Soc., Jour, ser. 3, vol. 80, p. 144, pl. 26, figs. 1–4.

Ahmuellerella phaseolus (Black and Barnes). REINHARDT, 1964, Deutsch. Akad. Wiss., Monatsber., vol. 6, p. 751.

Rhabdosphaera stylifera Lohmann. McINTYRE and BÉ, 1967, Deep-Sea Research, vol. 14, p. 567, pl. 4, figs. A–C.

Rhabdosphaera clavigera Murray and Blackman. COHEN and REINHARDT, 1968, Neues Jahrb. Geologie Paläontologie, Abh., vol. 131, no. 3, p. 292, pl. 19, figs. 18, 22; pl. 20, figs. 6, 7; pl. 21, fig. 4.

Aspidorhabdus stylifer (Lohmann). BOUDREAUX and HAY, 1969, Rev. Española Micropaleontologia, vol. I, num. 3, p. 269, pl. IV, figs. 11–15.

Discussion: In view of the research by McIntyre and Bé (1967) on modern Coccolithophoridae, *Rhabdosphaera stylifera* and *Discolithus phaseolus* are placed in synonomy with *Rhabdosphaera clavigera.* They demonstrated that *Rhabdosphaera clavigera* and *Rhabdosphaera stylifera* intergrade in both plankton and sediment samples. Furthermore, they state that no zoogeographic differences can be demonstrated between them. Unfortunately, these authors mistakenly placed *Rhabdosphaera clavigera* in synonomy with *Rhabdosphaera stylifera* although the former has priority over *Rhabdosphaera stylifera* by four years.

Discolithus phaseolus is the separated basal plate of *Rhabdosphaera clavigera.* It is common in late Pliocene and early Pleistocene sediments.

Reported occurrences: Miocene to Holocene

Family THORACOSPHAERACEAE
Deflandre, 1952

Genus THORACOSPHAERA
Kamptner, 1927

Type species: *Thoracosphaera pelagica* Kamptner, 1927.

Definition: Coccolithophores with a spherical to subspherical test constructed of regularly or irregularly shaped polygonal elements of calcite.

THORACOSPHAERA SAXEA Stradner
Plate 5, figs. 10–12

Thoracosphaera sp. BRAMLETTE and RIEDEL, 1954, Jour. Paleontology, vol. 28, no. 4, p. 393, pl. 38, fig. 5.

Thoracosphaera saxea STRADNER, 1961, Erdöl–Zeitschr., vol. 77, p. 84, text-fig. 71.

Thoracosphaera saxea Stradner. COHEN, 1964, Micropaleontology, vol. 10, no. 2, p. 248, pl. 5, figs. 6a–e; pl. 6, fig. 6.

Description: Small, irregular, imperforate polygonal elements, forming a spherical test. Contacts between plates appear crenulated.

Reported occurrences: Cretaceous to Holocene.

THORACOSPHAERA sp.
Plate 5, figs. 13–15

Description: Polygonal elements which are neither perforate or crenulated. Numerous species have been described by Kamptner (1967), but specific identification is difficult.

Family BRAARUDOSPHAERACEAE Deflandre, 1947

Genus BRAARUDOSPHAERA Deflandre, 1947

Type species: *Pontosphaera bigelowi* Gran and Braarud, 1935.

Definition: Pentagonal plates constructed of five calcite crystal units.

BRAARUDOSPHAERA BIGELOWI (Gran and Braarud)
Plate 6, figs. 1–3

Pontosphaera bigelowi GRAN and BRAARUD, 1935, Jour. Biol. Board Canada, vol. 1, p. 389, text-fig. 67.

Braarudosphaera bigelowi (Gran and Braarud). DEFLANDRE, 1947, Comptes Rendus Acad. Sci., Paris, vol. 225, p. 439, text-figs. 1–5.

Braarudosphaera bigelowi (Gran and Braarud). BRAMLETTE and RIEDEL, 1954, Jour. Paleontology, vol. 28, no. 4, p. 393, pl. 38, figs. 6a, b.

Braarudosphaera bigelowi (Gran and Braarud). BRAMLETTE and SULLIVAN, 1961, Micropaleontology, vol. 7, no. 2, p. 153, pl. 8, figs. 1a, b, 2–5.

Braarudosphaera bigelowi (Gran and Braarud). HAY and TOWE, 1962, Science, vol. 137, no. 3528, p. 426, fig. 1.

Braarudosphaera bigelowi (Gran and Braarud). COHEN, 1965, Leidsche Geologische Mededelingen, vol. 35, p. 31, pl. 6, figs. a–d.

Discussion: Pentaliths composed of five elements. This long ranging species is of no stratigraphic value.

Reported occurrences: Cretaceous to Holocene.

Family PONTOSPHAERACEAE Lemmermann, 1908

Genus HELICOPONTOSPHAERA Hay and Mohler, 1967

Type species: *Helicopontosphaera kamptneri* Hay and Mohler, 1967.

Definition: Shallow lopadolith with a spirally expanding wall.

HELICOPONTOSPHAERA sp. cf. HELICOPONTOSPHAERA INTERMEDIA Martini
Plate 3, figs. 18–20

Helicosphaera intermedia MARTINI, 1965, Submarine Geology and Geophysics, Proc. 17th Symp. Colston Res. Soc., London, p. 404, pl. 35, figs. 1, 2.

Helicosphaera intermedia Martini. BRAMLETTE and WILCOXON, 1967, Tulane Stud. Geol., vol. 5, no. 3, p. 105, pl. 6, figs. 11, 12.

Helicopontosphaera intermedia (Martini). HAY, 1970, *in* BADER *et al.,* 1970, Initial Rpts., Deep Sea Drilling Project, vol. IV, p. 458.

Discussion: This species is distinguished from *Helicopontosphaera kamptneri* by a bar extending diagonally across the center, and the wing-like extension of the last spiral (see *Helicopontosphaera kamptneri.*)

Reported occurrences: Oligocene to Holocene.

HELICOPONTOSPHAERA KAMPTNERI Hay and Mohler
Plate 3, figs. 21–24

Coccolithus carteri (Wallich). KAMPTNER, 1941, Naturh. Mus. Wien, Ann., vol. 51, p. 93, 111, pl. 13, fig. 136 [not *Coccosphaera carteri* Wallich, 1877, Ann. Mag. Nat. Hist., ser. 4, vol. 19, p. 348, pl. 17, figs. 3, 4, 6, 7, 17].

Helicosphaera carteri (Wallich). KAMPTNER, 1954, Archiv. Protistenk., vol. 100, no. 1, p. 21, text-figs. 17–19.

Helicosphaera carteri (Wallich). BLACK and BARNES, 1961, Roy. Micros. Soc., Jour., ser. 3, vol. 80, p. 139, pls. 22, 23.

Helicosphaera carteri (Wallich). COHEN, 1964, Micropaleontology, vol. 10, no. 2, p. 238, pl. 3, figs. 2a–f; pl. 4, figs. 1a–c.

Helicosphaera carteri (Wallich). COHEN, 1965, Leidsche Geologische Mededelingen, vol. 35, p. 21, pl. 3, figs. o–q; pl. 17, figs. a–d.

Helicosphaera carteri (Wallich) Kamptner. PYLE, 1966, Texas A & M Univ., Dept. Oceanography, Tech. Rept. 66–13T, p. 20, pl. 2, figs. 1, 2.

Helicosphaera carteri (Wallich) Kamptner. McINTYRE, BÉ, and PREIKSTAS, 1967, Progress in Oceanography, vol. 4, p. 12, pl. 6, figs. A, B.

Helicosphaera carteri (Wallich) Kamptner. McINTYRE and BÉ, 1967, Deep-Sea Research, vol. 14, p. 571, pl. 11, fig. A.

PLATE 4

Figures		Page
1–3	*Scyphosphaera apsteini* Lohmann	150
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	2. Crossed nicols, X 2250	
	3. Interference contrast, X 2250	
4, 5	*Scyphosphaera pulcherrima* Deflandre	150
	4. Phase contrast, X 2250	
	5. Crossed nicols, X 2250	
6–8	*Emiliania annula* (Cohen)	144
	6. Phase contrast, X 2250	
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	8. Crossed nicols, X 2250	
9–11	*Syracosphaera histrica* Kamptner	152
	9. Phase contrast, X 2250	
	10. Interference contrast, X 2250	
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12–15	*Syracosphaera pulchra* Lohmann	151
	12. Electron photomicrograph, X 5000	
	13. Electron photomicrograph, X 6400	
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16–18	*Discolithina anisotrema* (Kamptner)	150
	16. Electron photomicrograph, X 3650	
	17. Phase contrast, X 2250	
	18. Crossed nicols, X 2250	
19–21	*Acanthoica* sp.	154
	19. Electron photomicrograph, X 6750	
	20. Phase contrast, X 2250	
	21. Crossed nicols, X 2250	
22–24	*Discolithina japonica* Takayama	151
	22. Electron photomicrograph, X 5000	
	23. Phase contrast, X 2250	
	24. Crossed nicols, X 2250	

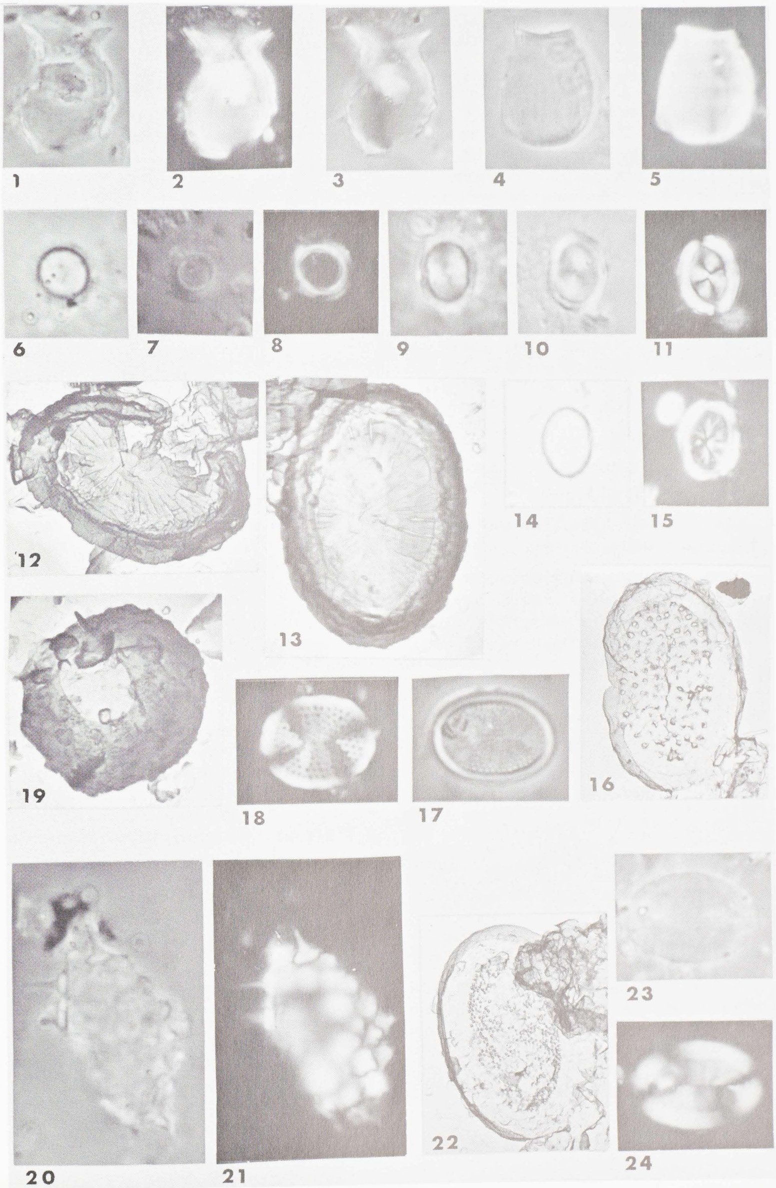

PLATE 4

Helicopontosphaera kamptneri HAY and MOHLER, 1967, Gulf Coast Assoc. Geol. Soc., Trans., vol. XVII, p. 448, pls. 10, 11, fig. 5.

Helicopontosphaera kamptneri Hay and Mohler. HAY, 1970, *in* BADER *et al.*, 1970, Initial Rpts., Deep Sea Drilling Project, vol. IV, p. 458.

Discussion: This spirally coiled coccolith was described in detail by Black and Barnes (1961), but their electron micrographs are mirror images resulting in reversal of imbrication and suture directions.

The species may be confused with *Helicopontosphaera intermedia* (see above) which Martini (1965) separated on the basis of the bar that extends diagonally rather than directly across the center. Numerous workers have questioned this separation as there are morphological graduations between the two forms.

Reported occurrences: Miocene to Holocene.

Genus SCYPHOSPHAERA
Lohmann, 1902

Type species: *Scyphosphaera apsteini* Lohmann, 1902.

Definition: Dimorphic coccolithophores bearing basket-like coccoliths called lopadoliths which are arranged in a circle along the equator of the outer cell wall.

SCYPHOSPHAERA APSTEINI
Lohmann
Plate 4, figs. 1–3

Scyphosphaera apsteini LOHMANN, 1902, Archiv. Protistenk., vol. 1, p. 132, pl. 4, figs. 26–30.

Scyphosphaera apsteini Lohmann, 1902. DEFLANDRE, 1942, Bull. Soc. Hist. Nat. Toulouse, vol. 77, p. 130, figs. 10–15.

Scyphosphaera apsteini Lohmann. KAMPTNER, 1955, Kon. Nederl. Akad. Wetensch. Afd. Natuurkunde, Verh., ser. 2, vol. 50, no. 2, p. 22, text-figs. 109–112.

Scyphosphaera apsteini Lohmann. KAMPTNER, 1967, Naturh. Mus. Wien, Ann., vol. 71, p. 148, pl. 9, figs. 64–67; pl. 10, figs. 69–71.

Discussion: The lopadolith bears parallel ribs and furrows arranged vertically along the outer surface. The figured specimen closely resembles those of Kamptner (1955, 1967) and Boudreaux (1968).

The species is rare in the section studied.

Reported occurrences: Pliocene to Holocene.

SCYPHOSPHAERA PULCHERRIMA
Deflandre
Plate 4, figs. 4, 5

Scyphosphaera pulcherrima DEFLANDRE, 1942, Bull. Soc. Hist. Nat. Toulouse, vol. 77, p. 133, figs. 28–31.

Syphosphaera pulcherrima Deflandre. BRAMLETTE and WILCOXON, 1967, Tulane Stud. Geol., vol. 5, no. 3, p. 107, pl. 10, fig. 5.

Discussion: This lopadolith is more robust in shape in the early Pleistocene sediments than the Miocene holotype. The more robust form is characteristic of late Neogene examples of this species. The main body is as wide or wider than the distal rim, the latter being slightly concave; the specimen depicted by Bramlette and Wilcoxon (1967) from the upper Cipero Formation lacks these two features.

Although this species is rare in the late Pliocene and early Pleistocene beds, this lopadolith is more common than *Scyphosphaera apsteini.*

Reported occurrences: Miocene to Pleistocene.

Genus DISCOLITHINA
Loeblich and Tappan, 1963

Type species: *Discolithus vigintiforatus* Kamptner, 1948.

Definition: A single elliptical disc, generally perforated, with or without a rim.

DISCOLITHINA ANISOTREMA
(Kamptner)
Plate 4, figs. 16–18

Coccolithites anisotrema KAMPTNER, 1955, Kon. Nederl. Akad. Wetensch. Afd. Natuurkunde, Verh., ser. 2, vol. 50, p. 16, 91, figs. 22a, b.

Discolithus anisotrema KAMPTNER, 1956, Anz. Österr. Akad. Wiss., Math.-Naturw. Kl., vol. 93, p. 9 [validated by reference to description and figure previously published under invalid name].

Discolithina cf. *D. anisotrema* (Kamptner). BRAMLETTE and WILCOXON, 1967, Tulane Stud. Geol., vol. 5, no. 3, p. 104, pl. 5, figs. 5, 6.

Discolithina anisotrema (Kamptner). HAY, 1970, *in* BADER *et al.*, 1970, Initial Rpts., Deep Sea Drilling Project, vol. IV, p. 458.

Discussion: The figured specimens are similar to those of Kamptner (1956). Immediately inside the rim, within the central area, is a circle of perforations that is developed in all forms. In most specimens additional perforations are present and arranged roughly in cycles; the total number of perforations varies between 75 and 100.

According to Bramlette and Wilcoxon (1967), "this taxon is one of a large number of inadequately described species which have been assigned to various genera." Unfortunately, many workers do not record such forms because of the questionable identifications and, thus, their stratigraphic distribution is uncertain.

Reported occurrences: Miocene to Pleistocene.

DISCOLITHINA JAPONICA
Takayama
Plate 4, figs. 22–24

Discolithina japonica TAKAYAMA, 1967, Jahrb. Geol. Wein, vol. 110, p. 177, 181.
Discolithina millepuncta GARTNER, 1967b, Univ. Kansas Paleont. Contr., paper 29, p. 5, pl. 8, fig. 4.

Description: A thin elliptical disc with numerous central perforations too small to be seen with the light microscope. The imperforate rim is broad, about one-fourth of the shorter diameter of the plate.

The central area is traversed by a longitudinal fissure visible in both electron and light micrographs, although this feature is obscured by clay in the electron micrograph figured here (fig. 22). The perforations in the central area are aligned diagonally, accounting for the radial appearance in the light photographs.

Reported occurrences: Pliocene and Pleistocene.

Family CALCIOSOLENIACEAE
Kamptner, 1937

Genus SCAPHOLITHUS
Deflandre, 1954

Type species: *Scapholithus fossilis* Deflandre, 1954.

Definition: An elongated rhomboidal rim with flat parallel lamellae extending from the sides of the rim to the middle of the central area.

SCAPHOLITHUS FOSSILIS
Deflandre
Plate 5, figs. 16–18

Scapholithus fossilis DEFLANDRE, 1954, *in* DEFLANDRE and FERT, Ann. Paléontologie, vol. 40, p. 165, pl. 8, figs. 12, 16, 17.
Scapholithus fossilis Deflandre. COHEN, 1964, Micropaleontology, vol. 10, no. 2, p. 244, pl. 3, figs. 4a–f; pl. 4, figs. 2a–c.
Scapholithus fossilis Deflandre. COHEN, 1965, Leidsche Geologisch Mededelingen, vol. 35, p. 24, pl. 3, figs. j–l; pl. 25, figs. a–d.

Discussion: Only the rhombic form is observable in the light microscope. In the electron micrograph, laths traversing the rhombic outline can be seen.

Reported occurrences: Cretaceous to Holocene.

Family SYRACOSPHAERACEAE
Lemmermann, 1908

Genus SYRACOSPHAERA
Lohmann, 1902

Type species: *Syracosphaera pulchra* Lohmann, 1902.

Definition: Dimorphic coccolithophores bearing caneoliths, those from the circumflagellar cycle bearing a central spine, others lacking spines.

SYRACOSPHAERA PULCHRA
Lohmann
Plate 4, figs. 12–15

Syracosphaera pulchra LOHMANN, 1902, Archiv. Protistenk., vol. 1, p. 124, pl. 4, figs. 33, 36, 37.
Syracosphaera pulchra Lohmann. SCHILLER, 1930, *in* L. RABENHORST, Kryptogamen-Flora, Leipzig, vol. 10, no. 2, p. 207, figs. 11, 30, 90a, b.
Syracosphaera pulchra Lohmann, 1902. DEFLANDRE and FERT, 1954, Ann. Paléontologie, vol. 40, figs. 1, 2 (?), 3, 4.
Syracosphaera pulchra Lohmann. BLACK and BARNES, 1961, Roy. Micros. Soc. Jour., ser. 3, vol. 80, p. 139, pl. 19, figs. 1, 2.
Syracosphaera pulchra Lohmann 1902. COHEN, 1965, Leidsche Geologische Mededelingen, vol. 35, p. 20, pl. 12, fig. d; pl. 14, figs. a, b.
Syracosphaera pulchra Lohmann 1902. COHEN and REINHARDT, 1968, Neues Jahrb. Geologie Paläontologie, Abh., vol. 131, no. 3, p. 292, pl. 20, fig. 3.

Description: The central area consists of radially arranged, lath-like elements which converge toward the center. These elements are not completely fused, and radial slits separate the adjacent laths. The outer margin or rim is constructed of about 50 imbricate elements.

Reported occurrences: Pliocene to Holocene.

SYRACOSPHAERA HISTRICA
Kamptner
Plate 4, figs. 9–11

Syracosphaera histrica KAMPTNER, 1941, Naturh. Mus. Wien, Ann., vol. 51, p. 84, pl. 6, figs. 65–68.
Discolithus histricus (Kamptner). COHEN, 1964, Micropaleontology, vol. 10, no. 2, p. 236, pl. 1, figs. 2a–g; pl. 2, fig. 1.
Discolithus aff. *histricus* (Kamptner). COHEN, 1965, Leidsche Geologische Mededelingen, vol. 35, p. 13, pl. 24, fig. a.

Discussion: This form produces a diagnostic interference figure in cross-polarized light. The central spine, formed by the fusion of slender elements radiating toward the center, is not seen in light micrographs.

Reported occurrences: Pliocene and Pleistocene.

Family ACANTHOIACEAE
Hay (in press)

Genus ACANTHOICA
Lohmann, 1903

Type species: *Acanthoica coronata* Lohmann, 1903.

PLATE 5

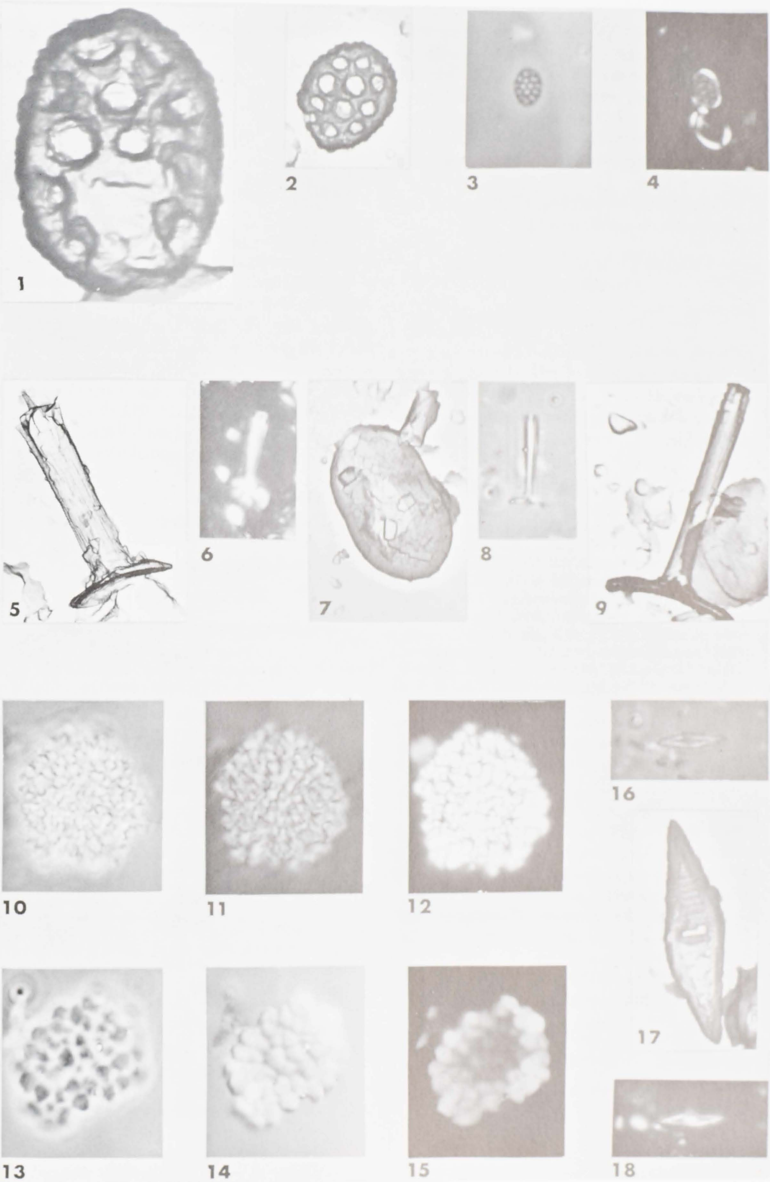

PLATE 5

Definition: Coccosphere without an aperture, constructed of calyptroliths, inverted discoliths which are convex exteriorly with a central outgrowth.

ACANTHOICA sp.
Plate 4, figs. 19–21

Coccosphere in which the structure of the calyptroliths is not discernible.

Family ZYGOSPHAERACEAE
Hay (in press)

Genus HOMOZYGOSPHAERA
Deflandre, 1952

Type species: *Corisphaera spinosa* Kamptner, 1941.

Definition: Zygoliths which are not dimorphic.

HOMOZYGOSPHAERA WETTSTENI
(Kamptner)
Plate 6, figs. 9–12

Zygosphaera wettsteni KAMPTNER, 1937, Archiv. Protistenk., vol. 89, p. 306, pl. 16, figs. 30–32.
Cavosphaera wettsteni (Kamptner). LECAL and BERNHEIM, 1960, Bull. Soc. Hist. Nat. Afr. Nord, vol. 51, p. 293, pl. 21, fig. 25.
Homozygosphaera wettsteni (Kamptner). HALLDAL and MARKALI, 1955, Norske Vid.–Akad. Oslo, Mat.-naturv. Kl., Avh., no. 1, p. 9, pl. 5.

Discussion: Identification of this holococcolith is difficult when a side view showing the arches is not available. The electron micrograph (fig. 9) shows six pores, but in the light micrograph only four can be discerned. Possibly both are misidentified and actually belong to the species *Homozygosphaera quadriperforata* (Kamptner) Gaarder.

Reported occurrences: Pleistocene and Holocene.

Family CALYPTROSPHAERACEAE
Boudreaux and Hay, 1969

Genus CALYPTROSPHAERA
Lohmann, 1902

Type species: *Calyptrosphaera globosa* Lohmann, 1902.

Definition: Like *Acanthoica* but with an aperture.

CALYPTROSPHAERA OBLONGA
Lohmann
Plate 6, fig. 13

Calyptrosphaera oblonga LOHMANN, 1902, Archiv. Protistenk., vol. 1, p. 135, pl. 5, figs. 43–46.
Calyptrosphaera oblonga Lohmann. HALLDAL and MARKALI, 1955, Norske Vid.-Akad. Oslo, Mat.-naturv. Kl., Avh., vol. 1, p. 8, pl. 1.

Discussion: This holococcolith is constructed of numerous hexagonal prisms of uniform size, regularly arranged in a lattice with hexagonal openings. The rim consists of several layers of closely packed prisms without openings. Although the electron micrograph is of insufficient quality to perceive the individual prisms that constitute the coccolith, the hexagonal openings are visible.

The one specimen encountered is the first fossil representative of this species reported.

Reported occurrences: Pleistocene and Holocene.

Family CRISTALLOLITHACEAE
Hay (in press)

Genus CRISTALLOLITHUS
Gaarder and Markali, 1956

Type species: *Cristallolithus hyalinus* Gaarder and Markali, 1956.

Definition: Coccoliths constructed of rhombohedral prisms.

CRISTALLOLITHUS MACROPORUS
(Deflandre), new combination

Plate 5, figs. 1–4

Discolithus macroporus DEFLANDRE, 1954, *in* DEFLANDRE and FERT, Ann. Paléontologie, vol. 40, p. 24, pl. 11, fig. 5.
Discolithus macroporus Deflandre. STRADNER, 1962, Verh. Geol. Bundesanst. (Wien), p. 363, pl. 3.
Discolithus macroporus Deflandre. COHEN, 1964, Micropaleontology, vol. 10, no. 2, p. 236, pl. 3, figs. 5a–c; pl. 4, figs. 6a, b.
Discolithus macroporus Deflandre. COHEN, 1965,

Leidsche Geologische Mededelingen, vol. 35, p. 15, pl. 3, fig. u.

Discolithina macroporus (Deflandre). LEVIN and JOERGER, 1967, Micropaleontology, vol. 13, p. 167, pl. 2, fig. 5.

Discolithina macropora (Deflandre). REINHARDT, 1968, *in* COHEN and REINHARDT, Neues Jahrb. Geologie Paläontologie, Abh., vol. 131, no. 3, p. 298, pl. 19, fig. 24; pl. 20, fig. 9.

Discolithina ? macropora (Deflandre). GARTNER and BUKRY, 1969, Jour. Paleontology, vol. 43, no. 5, p. 1215, pl. 140, figs. 1, 2; pl. 142, figs. 3, 4.

Discussion: Gartner and Bukry (1969) recently recognized this species as a holococcolith, stating: "this species is constructed entirely of closely packed calcite rhombs" . . . and "the crystallites are not modified to conform to the configuration of the large pores or to the periphery."

The discovery of this microstructure requires that the species be transferred to the genus *Crystallolithus.*

Reported occurrences: Eocene to Holocene.

Family DISCOASTERACEAE
Tan Sin Hok, 1927

Genus DISCOASTER
Tan Sin Hok, 1927

Type species: *Discoaster pentaradiatus* Tan Sin Hok, 1927.

Definition: Stellate calcareous plates with radial rays. Asteroliths.

DISCOASTER BROUWERI
Tan Sin Hok
Plate 6, fig. 8

Discoaster brouweri TAN SIN HOK, 1927, Jaarb. Mijnw. Nederl.-Indie, vol. 55, p. 120, text-figs. 2, 8a, b.

Discoaster brouweri Tan Sin Hok, sens. emend., BRAMLETTE and RIEDEL, 1954, Jour. Paleontology, vol. 28, p. 402, pl. 39, fig. 12, text-figs. 3a, b.

Discoaster brouweri (Tan Sin Hok). MARTINI and BRAMLETTE, 1963, Jour. Paleontology, vol. 37, no. 4, p. 851, pl. 102, figs. 9, 10.

Discoaster brouweri Tan Sin Hok. BRAMLETTE and WILCOXON, 1967, Tulane Stud. Geol., vol. 5, no. 3, p. 109, pl. 8, fig. 12.

Discoaster brouweri Tan Sin Hok. HAY, 1970, *in* BADER *et al.,* 1970, Initial Rpts., Deep Sea Drilling Project, vol. IV, p. 460.

Discussion: The marked reduction in the numbers of individuals of this species between cores 20 and 21 (see figure 6) marks the top of the *Discoaster brouweri* zone as defined by Bukry (1971b). Scarce specimens (5 to 50 per traverse) are recorded from core 18, but this small increase occurs at the base of the transgressive phase and is attributed to reworking in the lower Terrebonne Shale.

Family CERATOLITHACEAE
Norris, 1965

Genus CERATOLITHUS
Kamptner, 1950

Type species: *Ceratolithus cristatus* Kamptner, 1950.

Definition: Coccolithophores bearing horseshoe-shaped bodies or ceratoliths.

CERATOLITHUS CRISTATUS
(Kamptner)
Plate 6, figs. 4-5

Ceratolithus cristatus KAMPTNER, 1954, Archiv. Protistenk., vol. 100, p. 43, text-figs. 44–55.

Ceratolithus cf. *C. cristatus* (Kamptner). BRAMLETTE and RIEDEL, 1954, Jour. Paleontology, vol. 28, no. 4, p. 394, pl. 38, fig. 9.

Ceratolithus cristatus (Kamptner). COHEN, 1964, Micropaleontology, vol. 10, no. 2, p. 244, pl. 5, figs. 5a–d; pl. 6, fig. 5.

Ceratolithus cristatus (Kamptner). COHEN, 1965, Leidsche Geologische Mededelingen, vol. 35, p. 36, pl. 3, figs. m, n.

Ceratolithus cristatus (Kamptner). NORRIS, 1965, Archiv. Protistenk., vol. 108, p. 19–24, pls. 11–13.

Ceratolithus cristatus Kamptner, emended. BUKRY and BRAMLETTE, 1968, Tulane Stud. Geol., vol. 6, no. 4, p. 150, pl. 1, figs. 1–4.

Ceratolithus cristatus Kamptner. HAY, 1970, *in* BADER *et al.,* 1970, Initial Rpts., Deep Sea Drilling Project, vol. IV, p. 459.

Discussion: The revisions of *Ceratolithus* by Gartner (1967b) and Bukry and Bramlette (1968) are major contributions to the stratigraphic zonation of the Neogene. As originally defined, this species included all ceratoliths. Gartner named *Ceratolithus tricorniculatus,* a pre-Pleistocene form; Bukry and Bramlette (1968) emended both species and erected a third, *Ceratolithus rugosus,* for late Miocene to early Pleistocene forms. All three are readily distinguishable and morphological gradations between *Ceratolithus cristatus* and *Ceratolithus* *rugosus* occur only near the Pliocene-Pleistocene contact (Bukry and Bramlette, 1968).

Ceratolithus rugosus possesses the same crystallographic orientation as *Ceratolithus cristatus* but differs in its rugose surface and robust development. In *Ceratolithus cristatus* the arms are generally smooth but may be notched. Under cross-polarized light the form is dark when the axis of the horseshoe is parallel to the vibration direction of either nicol and uniformly bright when rotated 45 degrees.

Reported occurrences: latest Pliocene to Holocene.

"Family" INCERTAE SEDIS
Genus CRICOLITHUS
Kamptner, 1958

Type species: *Cricolithus multiradiatus* Kamptner, 1958.

Definition: Isolated ring of elliptical outline.

CRICOLITHUS JONESI Cohen

Plate 3, figs. 14–17

Cricolithus jonesi COHEN, 1965, Leidsche Geologische Mededelingen, vol. 35, p. 16, pl. 2, figs. j, k; pl. 16, figs. a–c.

Discussion: This simple elliptical ring of about 30 elements is distinctive in both the electron and light microscopes. The light micrograph is identical to the holotype but the electron micrograph (fig. 14) differs from Cohen's in that two rings appear to be present instead of one; however, this may be due to the poor quality of the micrograph.

Reported occurrences: Pleistocene and Holocene.

PLATE 6

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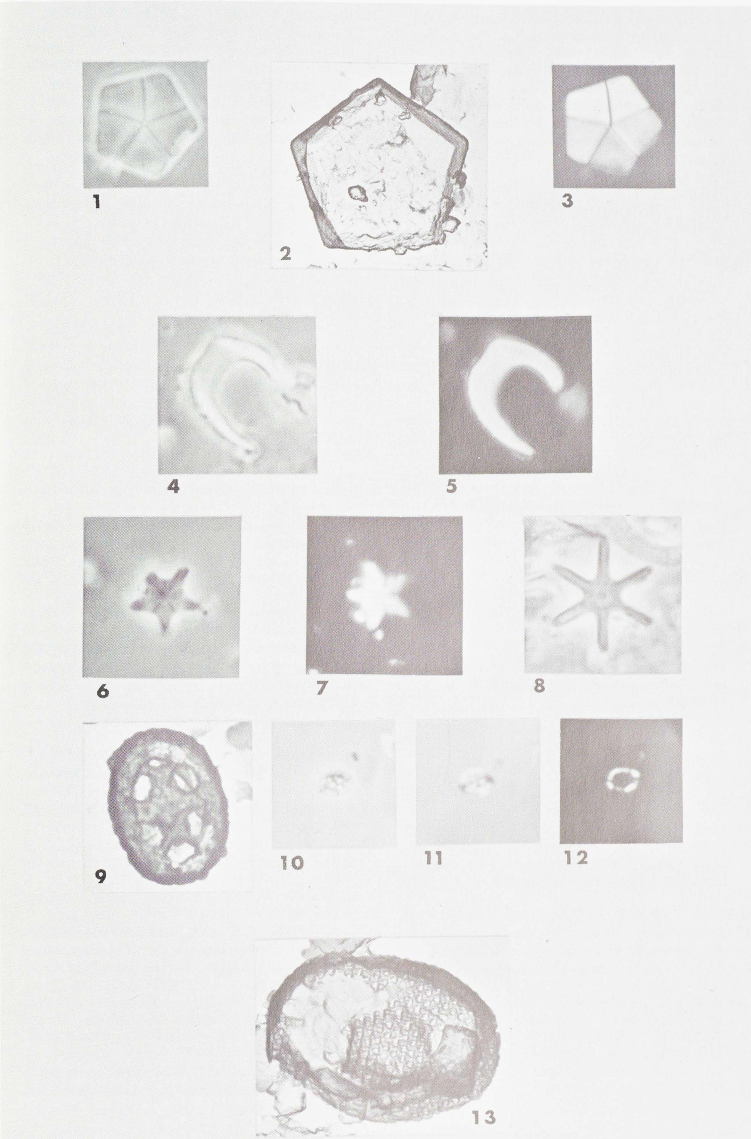

PLATE 6

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