CALCAREOUS NANNOPLANKTON ZONATION OF THE CENOZOIC OF THE GULF COAST AND CARIBBEAN-ANTILLEAN AREA, AND TRANSOCEANIC CORRELATION

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A B S T R A C T

Calcereous nannoplankton organisms evolved rapidly during the Cenozoic, and are of great value as stratigraphic indicators. A large number of species exhibit world wide distribution, so that this group of fossils is very useful in transoceanic correlation. Calcereous nannofossils may often be recovered from relatively shallow water sediments, permitting the zonation established in pelagic sediments to be used in shelf deposits.

The event which ended the Cretaceous almost annihilated Mesozoic calcereous nannoplankton floras. Highly diversified assemblages of Maastrichtian coccoliths were replaced by early Danian assemblages having only a few genera and species. Species diversity increased rapidly during the Paleocene, and by the middle Paleocene had reached a level comparable to that in the late Mesozoic. Discoasters, which due to their large size are very easy to observe and use stratigraphically, first appeared in the middle Paleocene. Late Paleocene, early and middle Eocene pelagic sediments contain a remarkable succession of rapidly evolving calcereous nannoplankton assemblages, culminating in a diversity maximum in the early Lutetian. Later in the Lutetian, a sudden decline in the number of species occurred, and the late Eocene is characterized by relatively monotonous, slowly evolving calcarceous nannoplankton floras. Many species characteristic of the late Eocene became extinct in the latest Eocene or early Oligocene. Large calcereous nannofossils, particularly discoasters, are rare in the Oligocene, but forms bearing smaller coccoliths evolved rapidly. Early Miocene calcarceous nannofloral assemblages were dominated by an abundance of stout asteroliths belonging to the Discoaster deflandrei plexus. In the middle Miocene, these were replaced by rich asterolith assemblages with many delicate forms having long, thin arms. The number of species of asteroliths and coccoliths again reached a maximum in the early Pliocene. During the Pliocene a number of species, particularly discoasters, declined and became extinct. The last asterolith, Discoaster bruneri, became extinct at the Nebraskan-Aftonian boundary in the Gulf Coast region. During the Pleistocene, species bearing small coccoliths evolved rapidly, and modern assemblages are dominated by a species which first appeared in the Wisconsinan.

The zonation based on calcereous nannoplankton fossils, proposed here, approximates the stratigraphic resolution which can presently be achieved using planktonic foraminifera. However, monographic studies have been completed only for the Paleocene-lower Eocene, and uppermost Pliocene-Pleistocene-Recent intervals. Stratigraphic resolution should be considerably improved when detailed studies of the middle Eocene-upper Pliocene interval, now in progress, are completed.

INTRODUCTION

"Coccolith" is a general term applied to the minute calcereous skeletal elements secreted by microscopic chrysomonadinid flagellates. An elaborate terminology for different kinds of coccoliths has developed since

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7 The beginning of the century, and a glossary of terms has been presented by Hay, Mohler, & Wade (1966). In the living alga, the coccoliths are used to form a spherical, ellipsoidal, or spindle-shaped test, or are scattered loosely over the surface of the cell. The coccoliths on the surface of one cell may be all alike, or there may be dimorphism or polymorphism. A number of fossils of problematical origin, such as the star-shaped discoasters, commonly occur with coccoliths obviously related to modern species, and by reason of their association are thought to have also been produced by pelagic algae. Coccoliths, discoasters, and related minute calcereous fossils are referred to as calcereous nannofossils, or calcereous nannoplankton. Calcereous nannofossils have been known for over a century, but it is only within the last decade that
they have received wide attention as stratigraphic indicators. C. G. Ehrenberg (1836) first observed the common collar-button shaped coccoliths known as placoliths in a sample of chalk from Rugen. In his monumental work Mikrogeologie, he figured both discoasters and coccoliths but termed the coccoliths “Morpholite” and some of the discoasters “kalkerdige Crystalldrusen” or “Scheibensternchen”, indicating that he did not consider them to be of organic origin. The term “coccolith” was proposed by Huxley (in Dayman, 1858) in the description of sediments encountered in surveys for the first transatlantic telegraph cable. Wallich (1860) described coccoliths on the surface of minute spherical bodies, and suggested that these might be larval forms of the Globigerinae. Sorby (1861) discovered spheres made of coccoliths in the English chalk, and Wallich (1861) proposed the term “coccosphere” for such objects. It had become generally accepted that coccoliths were skeletal elements formed by some sort of organism, and Huxley became convinced that the coccoliths were produced by a protoplasmic slime which covered the floor of the oceans. In 1868, he named this extraordinary creature Bathybius haeckeli, and it was the subject of papers by Haeckel (1870) and Huxley (1871). Wallich (1875) discovered that the remarkable organism Bathybius was “little more than sulfite of lime, precipitated in a flocculent state from the sea water by the strong alcohol” (p. 325). Wallich established that coccospheres are the tests of free floating organisms.

Studies of living coccolithophores did not start until the early part of this century, but have expanded greatly in the past twenty years with the advent of electron microscopy as an aid in identification.

Discoasters, which had been figured by Ehrenberg (1854), by Murray & Renard (1891), and by Jukes-Browne & Harrison (1892), were first described in detail by Tan Sin Hok (1927a). Sjukowski (1951) and Parejas (1954) described discoasters (using the generic term Actinistes Ehrenberg) from rocks thought at the time to be Cretaceous, but which are apparently Eocene, and several other workers illustrated discoasters from Oligocene or Miocene sediments.

The modern era of investigation of calcareous nannofossils as biostratigraphic indicators was initiated by Bramlette & Riedel (1954). Since 1958 there have been a large number of papers, principally by European and American workers, on the stratigraphic distribution of fossil calcareous nannoplankton. Figure 1 presents a list of the papers dealing with Cenozoic calcareous nannofossils, indicating whether new species were described, the age of the assemblages studied, and the type of observational equipment from which illustrations were prepared.

Some of the techniques useful in studying calcareous nannofossils have been described by Hay (1965). Stereoscopic electron microscopy offers one of the best ways of determining the structure of complex nannofossils, and a selection of stereoscopic micrographs is presented on Plates 8-13. The electron micrographs show so much interesting detail that they must be printed on a large scale to be of maximum use. At a scale where the detailed structure becomes visible, the micrographs are too large to be viewed in their entirety with a pocket stereoscope. Accordingly, the stereo micrographs presented here are designed to be viewed using a larger air photo viewer equipped with mirrors. Perch-Nielsen (1967) has introduced a relatively simple technique for examination of the same coccolith in light and then in electron microscopy; this should permit solution of many nomenclatorial problems.

In the systematic section of this paper, only the new genera and species are described. References to the original descriptions of all other species, except those published since 1965, are to be found in the very useful “Annotated index and bibliography of the calcareous nannoplankton” by Loeblich & Tappan (1966).

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ZONATION BASED ON CALCAREOUS NANNOFOSILS

William W. Hay & Hans P. Mohler

Calcaneous nannofossils have several peculiarities which make them uniquely suitable for use as biostratigraphic indicators: 1) they are extremely abundant in many samples; 2) a large number of species have worldwide distribution; and 3) many groups have evolved very rapidly.

Because of their small size and common occurrence in pelagic and shelf marine sediments, calcaneous nannofossils in unlimited supply are available to the paleontologist. Oceanic oozes may contain 10⁵ specimens per cc, even with a considerable admixture of other pelagic fossils. Many shallower marine sediments contain 10⁴ specimens per cc, and even fine-sandy inner shelf sediments will commonly have thousands or tens of thousands of specimens per cc, so that with proper concentration good assemblages may be had for study. An assemblage slide with evenly spaced coccoliths and asterolaths usually has between 10³ and 10⁶ specimens. In terms of the size of the collection available for study, this is comparable to 1 to 10 liters of pure foraminiferal concentrate. A collection of such large size is obviously very valuable for biostratigraphy, as it permits detection of the presence or absence of a species with a much higher degree of certainty than is commonly possible (Shaw, 1964; Dennison & Hay, 1967).

Experience with samples from a wide variety of localities suggests that many species of calcaneous nannofossil have a very wide geographic distribution. In most instances it is possible to determine the age of an assemblage with great precision, but it is not possible to tell from which continent a sample came. The large late Eocene assemblages of North America are scarcely distinguishable from late Eocene assemblages from the Cauacus; early Pliocene assemblages from Italy and Algeria are identical, with each other and with assemblages from Indonesia.

Ecologic control also appears to be less important in this group than in many others, probably due at least in part to the length of time (weeks, months or years) required for calcaneous nannofossils to settle through the water column. Genera which appear to occupy more specialized ecologic niches include Coccolithus, which at present is restricted to temperate or cooler waters (McIntyre & Be, 1966b), and the members of the Family Braarudosphaeraceae, which are most abundant in shallow water sediments (Martini, 1965).

A number of groups of calcaneous nannofossils show rapid evolution. The evolutionary changes are gradual in some groups, but sudden and sharp in others. The sudden changes are understandable when it is recalled that the coccolithophores reproduce at least in great part asexually, and that a mutant might reproduce in sufficient numbers so that exchange of nuclear material with pre-mutant relatives need not occur.

The factors listed above contribute to the value of calcaneous nannofossils as biostratigraphic indicators. These fossils have two major disadvantages: 1) their small size, and 2) their propensity to be reworked into younger strata.

On account of their small size, it is necessary to have at least very high quality light optical equipment to study calcaneous nannofossils. An ordinary light microscope is satisfactory for investigations in the upper Paleocene and Eocene, and in the Miocene and Pliocene. However, phase optics are essential for study of lower Paleocene samples, and are a great aid in the study of other samples. Electron microscopy is essential for detailed work in the Oligocene and Pleistocene.

Calcaneous nannofossils are frequently reworked into younger strata, and most samples have a low background level of older nannofossils. A few samples consist entirely of nannofossils reworked from older strata, as was the case with the lacustrine Oligocene sediments described by Dangeard (1931, 1932; see also Delalandre, 1962). Reworked nannofossils have made the determinations of the tops of ranges more difficult, but the
ranges become clarified as more information becomes available.

Calcareous nanofossils are, then, uniquely suited for establishing a zonation for correlation over long distances, particularly between continents. In order for the zonation to be most useful, it is necessary to define exactly the nature of the zones proposed.

The American Commission on Stratigraphic Nomenclature (1961) has provided precise definitions and offered brief comments on the various kinds of biostratigraphic units. Shaw (1964), in his excellent discussion of biostratigraphic and chronostratigraphic methodology, has presented stimulating arguments for increasing objectivity in stratigraphic correlation. Essentially, there are three kinds of biostratigraphic zone recognized in the Code of Stratigraphic Nomenclature. These are, in order of increasing subjectivity (as noted by Shaw): 1) the range zone, defined as the body of strata comprising the total horizontal and vertical range of occurrence of a specified taxon; 2) the concurrent range zone, defined by the overlapping ranges of specified taxa, and 3) the assemblage zone, defined as the body of strata characterized by a certain assemblage of fossils without regard to their ranges.

The primary data available to the biostratigrapher are the occurrences of species in sampled sections. It is important to know whether the sections are continuous, or whether they have obvious breaks. In the range charts accompanying this paper, empty spaces are used to indicate barren intervals, intervals not sampled, unconformities, etc.

The zones defined here are concurrent range zones, usually based on a large number of species, although, following the practice of Bolli (1966), the appearance or disappearance of particular species is used to determine zone limits. Authorship of the zones is indicated, and in all cases, except one, a type locality or type section for the zone is designated. A list of common species indicates the nature of the assemblages, and a few remarks on correlation of the zones from area to area are offered. Because not all of the species used to define limits or considered characteristic of a zone occur in all sections, the composition of the whole assemblage must be carefully weighed when correlations are made. The large numbers in which calcareous nanoplankton fossils occur will permit a more extensive application of probability theory to biostratigraphic correlation, and in the near future it should be possible to express the probability of a correlation numerically.

ZONATION OF THE PALEOCENE-LOWER EOCENE INTERVAL

Hans P. Mohler & William W. Hay

The upper Paleocene and lower Eocene have been extensively investigated for calcareous nanoplankton fossils. Rich assemblages with highly distinctive discoasters have been described from a number of localities, and the only formal zone names already in common usage apply to this interval. Particularly useful range charts have been presented by Martini (1959a, 1961a), Stradner (1959; in Gohrbandt, 1963a), Bramlette & Sullivan (1961), Stradner & Papp (1961), Sullivan (1964, 1965), and Hay & Mohler (1965).

A resume of the history of zonal terminology for the middle Paleocene-middle Eocene interval is presented in Figure 2. The first formal names were proposed by Bronnimann & Stradner (1960), but no definitions of the zones were given. The assemblages intended to represent the zones were first listed in Bronnimann & Rigassi (1963) under the descriptions of samples; no precise definitions were given. Bramlette & Sullivan (1961) subdivided the Lodo Formation at Lodo Gulch in California into three units, giving these tentative formal names; zone limits were not defined, but an elaborate range chart was presented along with comments on species that might be of particular stratigraphic significance. Hay (1964) presented a composite zonation based primarily on observations in the Schlierenflussh of Switzerland. Two figures accompanied the published paper, but these were prepared during the meetings of the Colloque sur le Paleogene in Bordeaux in 1962, and it was not known that they would be printed. The text presented a subzonal subdivision of the Schlierenflussh sequence not given on the figures, and the figures introduced a new term, "Discoaster gemmeus Zone". The relation of the Discoaster gemmeus Zone and the Discoaster delicatus Zone (= Heliolithus riedeli Zone) was not known with certainty in 1962, as the two had not been found superposed in the same section, and the figure indicated that the Discoaster delicatus Zone was probably older. This has since proven to be wrong, and the order has been corrected in Figure 2. Hay & Mohler (1965) proposed two new subzonal terms for their Martasterites tribrachiatius Zone to accord with the terms of Bronnimann & Rigassi (1963).

In the scheme of zonation proposed here, the rule of priority has been applied whenever possible, so that the term Martasterites tribrachiatius Zone is now used to refer to strata bearing the assemblage characterizing the concurrent range of Martasterites tribrachiatius and Discoaster lodoensis, as originally intended by Bronnimann & Stradner (1960). The complex double and triple names which have been proposed are replaced by simpler terms containing the name of a single fossil.

Assemblages from the lower Paleocene have been described by Stradner (in Gohrbandt, 1963a, 1963b), Bramlette & Martini (1964), Martini (1964b), and Edwards (1966). In a paper scheduled to appear shortly, Hay & Mohler describe well preserved, rich assemblages of calcareous nanofossils from a lower Paleocene section at Pont Labau, south of Pau, Basses Pyrenees, France. A simplified range chart from this study is presented in Figure 3, and several new zones having their type localities at Pont Labau are described below.

The lower part of the Paleocene, prior to the appearance of the first species of Discoaster, contains assemblages of coccoliths indicating rapid diversification after the near annihilation which marked the end of the Cretaceous. Four zones can be recognized in strata below the first occurrence of Discoaster gemmeus Strad-
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Figure 2. Correlation of zonations based on calcareous nannoplankton fossils for the middle Paleocene-middle Eocene.
CRUCIPLACOLITHUS TENUIS ZONE

Definition: Interval from the first occurrence of Cruciplacolithus tenuis (Stradner) to the first occurrence of Fasciculithus tympaniformis Hay & Mohler, n. sp.

Authors: Mohler & Hay, this paper.

Type locality: Upper part of the Carrières de la Roque, on the west bank of the River Neez, 30-250 meters southwest of Pont Labau, 3 kilometers south of Gan along Route Nationale 134bis, Basses Pyrenees, France (GAN 780-790 of Hay & Mohler, 1967; most representative sample GAN 782; see Figure 3.)

Common species: Those of the Markalius astroporus Zone plus: Cruciplacolithus tenuis (Stradner) and Coccolithus danicus (Broten); and several new species described in Hay & Mohler (1967).

Remarks: This zone is relatively thinner than the underlying Markalius astroporus Zone at all of the localities thus far studied. Most of the type Danian of Denmark belongs to the Cruciplacolithus tenuis Zone. In the Gulf Coast, the remainder of the Pine Barren Member of the Clayton Formation, and the Kincaid Formation of Texas can be assigned to this zone. Samples from the Globorotalia uncinata Zone in Mexico (Velasco Shale) and Trinidad (Lizard Springs Formation) belong to the Cruciplacolithus tenuis Zone. The lower limit of the Cruciplacolithus tenuis Zone probably lies within the Globigerinoides daubjergensis Zone although it might be as high as the Globorotalia trinidadensis Zone.

FASCICULITHUS TYMPANIFORMIS ZONE

Definition: Interval from the first occurrence of Fasciculithus tympaniformis Hay & Mohler, n. sp., to the first occurrence of Heliothrus kleinpellii Sullivan.

Authors: Mohler & Hay, this paper.

Type locality: Exposure along the upper part of the road leading to Cottage Bellevue (Guillemau), 200-300 meters west of Pont Labau, 3 kilometers south of Gan, just off Route Nationale 134bis, Basses Pyrenees, France (GAN 791-808 of Hay & Mohler, 1967; most representative sample GAN 795; see Figure 3.)

Common species: Those of the Cruciplacolithus tenuis Zone plus: Fasciculithus tympaniformis Hay & Mohler, n. sp.; Zygolithus concinnus Martini; Coccolithus con-suetus Bramlette & Sullivan; and Coccolithus bidens Bramlette & Sullivan.

Remarks: Fasciculithus tympaniformis has not yet been found in the Gulf Coast, but it does occur in Trinidad, in the Globorotalia pusilla pusilla Zone. It seems possible that sample A-7612, from the “Martinez” of the Simi Valley, of Sullivan (1965) might belong to this zone and contain the same species, although Fasciculithus involutus Bramlette & Sullivan was cited by Sullivan (see Figure 4). Assemblages lacking the name species, but typical for the Fasciculithus tympaniformis Zone are found in the McBryde limestone Mem-

MARKALIUS ASTROPORUS ZONE

Definition: Interval from the first occurrence of Markalius astroporus (Stradner) to the first occurrence of Cruciplacolithus tenuis (Stradner).

Authors: Mohler & Hay, this paper.

Type locality: Lower part of the Carrières de la Roque, on the west bank of the River Neez, 250 meters southwest of Pont Labau, 3 kilometers south of Gan along Route Nationale 134bis, Basses Pyrenees, France (GAN 775-779 of Hay & Mohler, 1967; most representative sample GAN 778; see Figure 3.)

Common species: Markalius astroporus (Stradner) [=Cyclococcolithus astroporus Stradner, in Gohrbandt, 1963a, p. 75, pl. 9, figs. 5-7, text-figs. 3 (2a, b)]; Braarudosphaera bigelovii (Gran & Braarud); Braarudosphaera discors Bramlette & Riedel; Bitholithus sparsus Bramlette & Martini.

Remarks: A detailed account of the significance and correlation of this zone is presented in Hay & Mohler (1967). This unit can be recognized in the base of the Danian in Denmark and at several other localities in Europe. In the Gulf Coast, the basal few feet of the Pine Barren Member of the Clayton Formation in Wilcox and Dallas Counties, Alabama, belong to this zone.
ber of the Clayton Formation in Wilcox County, Alabama, and in the Wills Point Formation in Texas. The lower limit of the *Fasciculithus tympaniformis* Zone probably lies within the *Globorotalia uncinata* Zone.

**HELIOLITHUS KLEINPELLI ZONE**

Definition: Interval from the first occurrence of *Heliolithus kleinpelli* Sullivan to the first occurrence of *Discoaster gemmeus* Stradner.

Authors: Mohler & Hay, this paper.

Type locality: Exposures along the lower part of the road to Cottage Bellevue (Guillemopau) and along Route Nationale 134bis 200 meters northwest of Pont Labau, 3 kilometers south of Gan, Basses Pyrenees, France (GAN 809-819 of Hay & Mohler, 1967; most representative sample GAN 811; see Figure 3).

Common species: Those of the *Fasciculithus tympaniformis* Zone, less *Markalius astroporus* (Stradner) and *Cruciplacolithus tenuis* (Stradner) which probably became extinct prior to the beginning of deposition of the *Heliolithus kleinpelli* Zone, plus: *Heliolithus kleinpelli* Sullivan.

Remarks: This zone has not yet been recognized in the United States Gulf Coast, but is known in Mexico in samples from the Velasco Shale assignable to the *Globorotalia pusilla pusilla* Zone. The *Heliolithus kleinpelli* Zone can be readily recognized in the range charts presented by Sullivan (1965), particularly that for the Simi Valley (see Figure 4).

The first discoaster to appear in Paleocene strata is *Discoaster gemmeus* Stradner. A number of distinctive sunflower-like discoasters rapidly evolved. It is possible to make stratigraphic determination in the upper Paleocene using a simple high-quality optical microscope, but phase contrast and polarizing optics are helpful.

**DISCOASTER GEMMEUS ZONE**

Definition: Interval from the first occurrence of *Discoaster gemmeus* Stradner to the first occurrence of *Heliolithus riedeli* Bramlette & Sullivan.

Author: Hay, 1964

Type locality: Along Route Nationale 134bis, 200-300 meters north-northwest of Pont Labau, 3 kilometers south of Gan, Basses Pyrenees, France (GAN 820-826 of Hay & Mohler, 1967; most representative sample GAN 822; see Figure 3).

Common species: Those of the *Heliolithus kleinpelli* Zone, less *Heliolithus kleinpelli* Sullivan, plus: *Discoaster gemmeus* Stradner; *Discoaster helianthus* Bramlette & Sullivan; and *Discoaster sp. aff. aster* Bramlette & Riedel.

Remarks: This zone is not yet known from North America, but should be found within the Velasco Shale in Mexico.

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**HELIOLITHUS RIEDELI ZONE**

Definition: Interval from the first occurrence of *Heliolithus riedeli* Bramlette & Sullivan to the first occurrence of *Discoaster multiradiatus* Bramlette & Riedel.

Authors: Bramlette & Sullivan, 1961.

Type locality: Lodo Gulch, side gully, lower part of the Lodo Formation, Fresno County, California (Samples 6+1 and 7 of Bramlette & Sullivan, 1961; most representative sample 6+1; see Figure 5).

Common species: Those of the *Discoaster gemmeus* Zone, plus: *Heliolithus riedeli* Bramlette & Sullivan; *Ellipsoolithus distichus* (Bramlette & Sullivan); *Fasciculithus involutus* Bramlette & Sullivan; *Discoaster delicatus* Bramlette & Sullivan; and *Discoaster nobilis Martini (=*Discoaster julipus* Bramlette & Sullivan); *Discoaster limbatus* Bramlette & Sullivan; and *Zygodiscus plectopons* Bramlette & Sullivan.

Remarks: At the type locality, the Lodo Formation rests unconformably on the Moreno Shale, so that it is not possible to study the assemblages immediately beneath the *Heliolithus riedeli* Zone. A barren interval of almost 100 feet intervenes between samples 7 and 19 of Bramlette & Sullivan, so that the nature of the transition from the *Heliolithus riedeli* Zone to the overlying *Discoaster multiradiatus* Zone is also unknown at Lodo Gulch. The Simi Valley section described by Sullivan (1965) has a more continuous record of the *Heliolithus riedeli* Zone - *Discoaster multiradiatus* Zone.
Figure 5. Distribution of important species of calcareous nannoplankton fossils in the Lodo Formation at Lodo Gulch, Fresno County, California (after Bramlette & Sullivan, 1961). Only samples marking bases or tops of zones, or in which stratigraphically important species have their first occurrence, are plotted.

1. To be transferred to another genus by Hay & Mohler (1967).
3. Not recorded by Bramlette & Sullivan, but found in abundance in a cut of sample 6+1 provided by Bramlette.

boundary (see Figure 4). Bramlette & Sullivan noted that the Helolithus riedeli Zone assemblage is found in the Nanafalia Formation in the Gulf Coast, in the Velasco Shale of Mexico, and in samples from the Globorotalia pseudomenardii Zone in Trinidad. They also recorded the presence of Helolithus riedeli and Discoaster delicatus in the Thanet Sand of England, type Thanetian.

DISCOASTER MULTIRADIATUS ZONE

Definition: Interval from the first occurrence of Discoaster multiradiatus, Bramlette & Riedel to the first occurrence of Marnotherites bramlettei Bronnmann & Stradner.

Authors: Bramlette & Sullivan, 1961.

Type locality: Lodo Gulch and side gulley, lower part of Lodo Formation, Fresno County, California

Figure 6. Distribution of important species of calcareous nannoplankton fossils in the Schlierenflysch, Gorge of the Grosse Schiere, Canton Obwalden, Switzerland (after Hay & Mohler, 1965). Only samples marking bases or tops of zones, or in which stratigraphically important species have their first occurrence, are plotted.

(Samples 19-22 from the side gully, and 30-32 from Lodo Gulch, of Bramlette & Sullivan, 1961; see Figure 5).


Remarks: At the type locality, the lower limit of this zone is probably within the barren interval between samples 7 and 19 of Bramlette & Sullivan. The upper limit of the zone is so abrupt at Lodo Gulch that Bramlette & Sullivan suggested that it must mark "some considerable discontinuity either in recorded time or facies" (p. 135). Sullivan (1965) has, as noted above, described a more continuous section from the Simi Valley (see Figure 4). The Schlierenflysch in Switzerland has an almost complete record of the transition to the overlying Marnotherites contortus Zone (see Figure 6). In the Gulf Coast, the Bashi Member of the Hatchetghie Formation belongs to the Discoaster multiradiatus Zone. The upper part of the Globorotalia pseudomenardii Zone and the lower part of the Globorotalia velascoensis Zone in the Velasco Shale, Mexico, also are assignable to the Discoaster multiradiatus Zone.
MARTHASTERITES CONTORTUS ZONE

Definition: Interval from the first occurrence of Marthasterites bramlettei Bronnimann & Stradner to the last occurrence of Marthasterites contortus Stradner.


Type locality: Immediately above the Gubersandstein, Schlierenflysch, Gorge of the Grosse Schilere, near Alpnach, Canton Obwalden, Switzerland (S 446b—S 430II of Hay & Mohler, 1965; most representative sample S 446d; see Figure 6).

Common species: Those of the Discaster multiradiatus Zone, less: Discaster delicatus Bramlette & Sullivan; plus: Marthasterites bramlettei Bronnimann & Stradner; Marthasterites contortus (Stradner); Discaster binodosus Martini; and Discaster diastypus Bramlette & Sullivan.

Remarks: Marthasterites bramlettei evolves into Marthasterites contortus at the base of this zone, and Marthasterites contortus evolves into Marthasterites tribrachiatus at the top. At the type locality in the Schlierenflysch, samples between S 432 and S 446b of Hay & Mohler (1965) carry impoverished assemblages, so that the record is not perfectly complete. However, very little development seems to have taken place between the samples with normal assemblages. Coccoliths are not well preserved in the Schlierenflysch, and the details of change in coccolith assemblages from the Discaster multiradiatus Zone through the Marthasterites contortus Zone into the base of the Marthasterites tribrachiatus Zone are not yet known. The Marthasterites contortus Zone is known in Cuba, in the Alkazar Formation (Discaster multiradiatus-Marthasterites bramlettei-Marthasterites contortus Zone of Bronnimann & Stradner, 1960). In Trinidad, the type locality of the Globorotalia rex Zone contains a nanofossil assemblage characteristic of the upper part of the Marthasterites contortus Zone.

DISCASTER BINODOSUS ZONE

Definition: Interval from the last occurrence of Marthasterites contortus (Stradner) to the first occurrence of Discaster lodoensis Bramlette & Riedel.

Authors: Mohler & Hay, this paper.

Type locality: Lower part of the Schonisandstein, Schlierenflysch, Gorge of the Grosse Schilere, near Alpnach, Canton Obwalden, Switzerland (S 454—S 475II of Hay & Mohler, 1965; most representative sample S 458II; see Figure 6).

Common species: Coccolithus consuetus Bramlette & Sullivan; Coccolithus grandis Bramlette & Sullivan; Lophodolithus nascens Bramlette & Sullivan; Discaster binodosus Martini; Discaster diastypus Bramlette & Sullivan; Discaster medius Bramlette & Sullivan; Sphenolithus radians Daffandres; and almost invariably most abundant, Marthasterites tribrachiatus (Bramlette & Riedel).

Remarks: This zone is readily recognized in California (see Figure 5), but has not yet been found in the Gulf Coast region.

MARTHASTERITES TRIBRACHIATUS ZONE

Definition: Interval from the first occurrence of Discaster lodoensis Bramlette & Riedel to the last occurrence of Marthasterites tribrachiatus (Bramlette & Riedel).


Type locality: Reparto Capri, on the west side of the Calzada de Bejucal between Arroyo Apolo and Arroyo Naranjo, La Habana, Cuba; Capdevila Formation, la Habana, Cuba (Samples BR 820 - BR 811 of Bronnimann & Rigassi, 1963; most representative sample: BR 811).

Common species: Those of the Discaster binodosus Zone plus: Discaster stradneri Martini; Discaster barbadiensis Tan Sin Hok; and Discaster deflandrei Bramlette & Riedel; and, usually abundant, Discaster lodoensis Bramlette & Riedel.

Remarks: This unit can be recognized in Cuba (Capdevila Formation) and in Trinidad, where the type locality of the Globorotalia aragonensis Zone has a typical Marthasterites tribrachiatus Zone nanofossil assemblage. It should be noted that the term Marthasterites tribrachiatus Zone is used here in the sense originally intended by Bronnimann & Stradner, 1960, for the concurrent range of Marthasterites tribrachiatus and Discaster lodoensis. The Paleocene-Eocene boundary, as defined on the basis of evolutionary series of larger foraminifera in Europe, lies within the Marthasterites tribrachiatus Zone (Hay & Mohler, 1967).

The two succeeding zones mark a time of particular flourishing of calcareous nanoplankton, and the assemblages show great diversity. There is considerable further development among the rayed discaster, and a large number of species have been recognized.

DISCASTER LODOENSIS ZONE

Definition: Interval from the last occurrence of Marthasterites tribrachiatus (Bramlette & Riedel) to the first occurrence of Discaster sublodoensis Bramlette & Sullivan.


Type locality: Tejar Andrade, east of La Lisa, about 500 meters southwest of the Autodromo de Mariana, Principe Member, Universidad Formation, La Habana, Cuba (Sample BR 858 of Bronnimann & Rigassi, 1963).

Common species: Those of the Marthasterites tribrachiatus Zone, less: Marthasterites tribrachiatus (Bramlette & Riedel); and Discaster diastypus Bramlette & Sullivan.

Remarks: Part of the Tallahatta Formation may belong to this zone. The Principe Member of the Universidad Formation of Cuba contains typical assemblages.
ZONATION OF THE MIDDLE-UPPER EOCENE INTERVAL

William W. Hay

The middle and upper Eocene have not been so intensively studied as the upper Paleocene and lower Eocene. Range charts dealing at least in part with this interval have been published by Bramlette (1957), Martini (1959, 1961), Bramlette & Sullivan (1961), Stradner & Papp (1961), Sullivan (1965), and Levin & Joerger (1967).

Only three formal zone names have been proposed for strata in this interval: *Discoaster barbadiensis* Zone, proposed by Bronnimann & Stradner (1960), and evidently intended to cover the entire upper Eocene; *Discoaster sublodoensis* Zone, proposed by Hay, 1964 (see Figure 2); and *Isthmolithus recurvus* Zone, proposed by Hay, Mohler, & Wade (1966).

In the early middle Eocene, calcareous nannoplankton reached a diversity maximum. Very rapidly the number of species dwindled, and in the upper Eocene the assemblages are relatively monotonous. The zonation proposed here reflects this history, the two lower zones lie wholly within the *Hantkenina aragonensis* Zone, and the next higher nannofossil zone has its base in that same planktonic foraminiferal zone. The species used in the zonation proposed here are readily recognized using high-quality phase contrast and polarizing optics.

DISCOASTER SUBLODOENSI S ZONE

Definition: Interval from the first occurrence of *Discoaster sublodoensis* Bramlette & Sullivan to the first occurrence of *Chipfragalithus quadratus* Bramlette & Sullivan.


Type locality: Upper Lodo Formation, Media Agua Creek area, Kern County, California (Samples A-7052-A-7038 of Sullivan, 1965; most representative sample, probably A-7047; see Figure 7).


Remarks: This zone corresponds to Unit 4 and most of Unit 5 of Bramlette & Sullivan, 1961. A more complete section has been described by Sullivan (1965), and has been selected here to serve as type locality for this and the succeeding zone. In the Gulf Coast, the Weches Formation in Texas may be assigned to this zone (see comments of Bramlette & Sullivan, 1961, p. 137). The assemblages of calcareous nannofossils found in type Lutetian strata by Bouche (1962a, 1962b) belong to the upper part of the *Discoaster sublodoensis* Zone.

CHIPFRAGMALITHUS QUADRATUS ZONE

Definition: Interval from the first occurrence of *Chipfragalithus quadratus* Bramlette & Sullivan to the first occurrence of *Discoaster tani nodifera* Bramlette & Riedel.

Author: Hay, this paper.

Type locality: Middle “Tejon” Formation, Media Agua Creek area, Kern County, California (Samples A-7009-A-7025 of Sullivan, 1965; most representative sample A-7023; see Figure 7).

Common species: *Chipfragalithus quadratus* Bramlette & Sullivan; *Chipfragalithus cristatus* (Martini); *Coccolithus gigas* Bramlette & Sullivan; *Coccolithus grandis* Bramlette & Riedel; *Apertepetra umbilica* (Levin); *Sphenolithus radians* Deflandre.

Remarks: A sample from the *Hantkenina aragonensis* Zone in Trinidad (JS 1412, close to K. 8914 in Fig. 25 in Bolli 1957c) contains a typical *Chipfragalithus quadratus* Zone assemblage.
DISCOASTER TANI NODIFERA ZONE

Definition: Interval from the first occurrence of Discoaster tani nodifera Bramlette & Riedel to the first occurrence of Isthmolithus recurvus Deflandre.

Author: Hay, this paper.

Type locality: To be designated later.

Common species: Discoaster tani nodifera Bramlette & Riedel; Apertapetra umbilica (Levin); Chiasmolithus oamaruensis (Deflandre); Coccotholithus grandis Bramlette & Riedel; Discoaster saipanensis Bramlette & Riedel; Clathrolithus spinosus Martini; Coronulus germanicus Stradner; and Coccotholithus pseudocarteri Hay, Mohler, & Wade.

Remarks: The lower part of the Oceanic Formation exposed on Mount Hillaby, Barbados, belongs to this zone (see Figure 8).

ISTHMOLITHUS RECURVUS ZONE

Definition: Interval from the first occurrence of Isthmolithus recurvus Deflandre to the last occurrence of Discoaster barbadiensis Tan Sin Hok.

Authors: Hay, Mohler, & Wade, 1966.

Type locality: Well drilled through the Alminsian Stage near Nal'chik, northwest Caucasus, U. S. S. R. (Samples Nal 4 - Nal 19 of Hay, Mohler, & Wade, 1966; most representative sample, Nal 11).

Common species: Those of the Discoaster tani nodifera Zone, plus: Reticulofenestra causasica Hay, Mohler, & Wade; Coroocyclocus serratus Hay, Mohler, & Wade; and Sujkowskia enigmatica Hay, Mohler, & Wade.

Remarks: The lower part of the Bath Cliff section of the Oceanic Formation (Barbados) belongs to the

Figure 8. Distribution of important species of calcareous nannoplankton fossils in the Oceanic Formation, Barbados. Sample numbers are those of John Saunders, Trinidad. Only samples marking the bases or tops of zones or exposures, or in which stratigraphically important species have their first occurrence, are plotted.

1 new species, described here.

Isthmolithus recurvus Zone (see Figure 8). In the Gulf Coast, the Cocoa Sand Member, the Pachuta Mari Member, and the Shubuta Mari Member of the Yazoo Formation, studied by Levin (1965) and Levin & Joerger (1967), belong to this zone (see Figure 9).

ZONATION OF THE OLIGOCENE INTERVAL

Peter H. Roth & William W. Hay

The Oligocene has received less study, as far as calcareous nannoplankton fossils are concerned, than any other part of the Tertiary. This is due primarily to the fact that the light microscope reveals only a few distinctive species, and these tend to range through the entire section. The Oligocene of Oamaru, New Zealand (Deflandre, in Deflandre & Fert, 1954) is now regarded as upper Eocene (Isthmolithus recurvus Zone) as suggested by Deflandre in the description of localities for the 1954 paper. The Oligocene of Limans (Dangeard, 1931; 1932) contains only reworked older nannofossils (Deflandre, 1962); and the Rupelian of the Mainz Basin described by Martini (1960a) appears to contain mostly reworked older forms. Range charts for some Oligocene species have been presented by Martini (1965) and Levin & Joerger (1967).

The only formal zone name proposed for the Oligocene is the term Discoaster woodrungi Zone, suggested by Bronnimann & Stradner, 1960. Levin &
Joeger (1967) established two "Biostratigraphic Units" in the Oligocene of Alabama; the Red Bluff Marl belongs to their Unit II; the Mint Springs Member and the Marianna Limestone Member of the Marianna Formation belong to their Unit III. Their Unit II may be defined as having its base at the level of disappearance of Discosaster barbadiensis Tan Sin Hok, Discosaster saipaiensis Bramlette & Riedel and Pemma papillatum Martini; and the upper limit is at the level of disappearance of Isthmolithus recurvus Deflandre and Micaenolithus basquensis Martini. Their Unit III is characterized by the presence of Braarudosphaera rosa Levin & Joeger.

A section of about 500 feet of Oligocene sediments in pelagic facies has been penetrated by JOIDES Hole 5, drilled about 100 miles off the east coast of Florida off Jacksonville. The following samples have been studied in detail in the electron microscope: J508, depth: 303' 8" below top. J507, depth: 337' 11" below top. J506, depth: 374' below top. J505, depth: 410' below top. J504, depth: 445' below top. J503, depth: 484' below top. J502, depth: 519' 2" below top. J501, depth: 554' 10" below top.

These samples fall into the interval characterized by the three planktic foraminifera Chiloupermellina cubensis, Gloganomalina micra, and Globorotalia postcresacea; (Bunce et al., 1964) these species have also been reported from the Marianna Limestone by Saito & Be (1964). Correlation of the zones described below with the biostratigraphic units of Levin & Joeger must remain uncertain until electron microscopic examination of the Alabama section has been completed. The presence of Braarudosphaera rosa in J501 and the absence of Isthmolithus recurvus above J502, together with the complete absence of Discosaster tani tani Bramlette & Riedel, Discosaster tani nodifera Bramlette & Riedel, and Micaenolithus basquensis Martini from all of the JOIDES samples listed above suggests that the zones proposed below correspond to the uppermost part of Unit II and to Unit III of Levin & Joeger, and to younger strata.

No attempt is made here to define the limits of the Oligocene in North America. The zones proposed below probably lie entirely between the Globorotalia ceraurozuleni Zone and the Globigerina ampliapertura Zone. Many of the stratigraphically important species can be recognized only using electron microscopy. In the light microscope, Oligocene assemblages in general are lacking in distinctive discoasters. Discosaster deflandrei Bramlette & Riedel and Discosaster aster Bramlette & Riedel are present throughout the Oligocene, but are never very abundant. Coccolithus eopelagicus (Bramlette & Riedel) and Sphenolithus pacificus Martini are abundant throughout, Isthmolithus recurvus Deflandre occurs in the lower part, and Reticulofenestra laevis Roth & Hay n. sp. can be recognized by light microscopy in the upper part of this interval.

**ELLIPSOLITHUS SUBDISTICHUS ZONE**

Definition: Interval from the last occurrence of Discosaster barbadiensis Tan Sin Hok to the first occurrence of Cyclococcolithus margaritae Roth & Hay n. sp.

Authors: Roth & Hay, this paper.

Type locality: JOIDES Hole 5, Lat. 30°23' N, Long. 80°08' W, Blake Plateau (J501; see Figure 10).

Common species: Ellipsolithus subdistichus Roth & Hay, n. sp.; Cruciplacolithus tarquinii Roth & Hay, n. sp.; Coccolithus joensuvi Roth & Hay, n. sp.; Coronocyclus serratus Hay, Mohler, & Wade; Sphenolithus pacificus Martini; Coccolithus floridanus Roth & Hay, n. sp.; Pyrocystus hermosus Roth & Hay, n. sp.; Coccolithus sarai Black; Coccolithus eopelagicus (Bramlette & Riedel); Blackites amplius Roth & Hay, n. sp.; Reticulofenestra gartneri Roth & Hay, n. sp.; and (rare) Isthmolithus recurvus Deflandre.

Remarks: The base of JOIDES Hole 5 touches the boundary with the Isthmolithus recurvus Zone.

**CYCLOCOCCOLITHUS MARGARITAE ZONE**

Definition: Interval from the first occurrence of Cyclococcolithus margaritae Roth & Hay, n. sp. to the first occurrence of Syracosphaera clathrata Roth & Hay, n. sp.

Authors: Roth & Hay, this paper.

Type locality: JOIDES Hole 5, Lat. 30°23' N, Long. 80°08' W, Blake Plateau (J502-J503; most representative sample: J502; see Figure 10).

Remarks: *Isthmolithus recurvus* has its last occurrence in the lower part of this zone, and *Coronocyclus serratus* disappears near the top.

SYRACOSPHAERA CLATHRATA ZONE

Definition: Interval from the first occurrence of *Syracosphaera clathrata* Roth & Hay, n. sp. to the first occurrence of *Reticulofenestra laevis* Roth & Hay, n. sp.

Authors: Roth & Hay, this paper.

Type locality: JOIDES Hole 5, Lat. 30°22' N, Long. 80°08' W, Blake Plateau (J504; see Figure 10).

Common species: Those of the *Cyclococcolithus margaritae* Zone, less: *Isthmolithus recurvus* Deflandre; *Coronocyclus serratus* Hay, Mohler, & Wade; and *Cyclococcolithus margaritae* Roth & Hay n. sp., plus: *Syracosphaera clathrata* Roth & Hay, n. sp.

Remarks: This appears to mark the first occurrence of typical *Syracosphaera*.

RETICULOFENESTRA LAEVIS ZONE

Definition: Interval from the first occurrence of *Reticulofenestra laevis* Roth & Hay, n. sp., to the first occurrence of *Discoaster saundersi* Hay, n. sp.

Authors: Roth & Hay, this paper.

Type locality: JOIDES Hole 5, Lat. 30°23' N, Long. 80°08' W, Blake Plateau (J505-J508; most representative sample: J507; see Figure 10).


Remarks: *Reticulofenestra insignita* seems to be restricted to this zone. Several species disappear in the upper part of the *Reticulofenestra laevis* Zone: *Blackites amplus*, *Reticulofenestra gartneri*, and *Coccolithus paralitos*.

ZONATION OF THE UPPER OLIGOCENE-UPPER MIocene INTERVAL

William W. Hay & Peter H. Roth

Next to the upper Paleocene-lower Eocene, this interval has received the most study. However, the assemblages are so rich, and the evolutionary changes so rapid, that a large number of species remain to be described. Information on the ranges of species is still sparse, and tends to be somewhat confusing because many of the species of *Discoaster*, in particular, have been rather loosely defined. Gradual evolution takes place in a number of phyla, increasing the difficulty of species definition. It has become evident that species must be narrowly and rigidly defined to be useful for biostratigraphy. Some information on the ranges of species in this interval has been presented by Bramlette & Riedel (1954), Bramlette (1957), Stradner & Papp (1961), Martini & Bramlette (1963), Martini (1965), and Gartner (1967).

The only formal zone names which have been proposed for this interval are those of Bronnimann & Stradner (1960). They suggested the term *Discoaster woodringi* Zone for strata equivalent to the *Globigerina amphiapertura*, *Globorotalia opima opima*, and *Globigerina ciperoensis* Zones, and the term *Discoaster deflandrei* Zone for strata equivalent to the *Globorotalia kugleri* Zone - *Globigerinatella insueta* Zone interval. Martini (1965) recognized three assemblages in the lower part of the interval considered here: Assemblage A was stated to be similar to that of the *Globigerina ciperoensis* Zone in Trinidad; Assemblage B was found to be similar with that of the *Globorotalia kugleri* Zone of Trinidad, and *Triquetorhabdulus carinatus* Martini was termed an index species; Assemblage C was stated to be comparable with that of the *Cataplydrax dimidiata* Zone of Trinidad.

The calcareous nannoplankton fossil assemblages of the Cipero and Lengua Formations of Trinidad are rich, diverse, and well preserved. Unfortunately, the penecontemporaneous slumping, later tectonic deformation, and general paucity of exposures makes it difficult to obtain continuous sections. Boll (1957b) has described the sequence of planktonic foraminifera in the Cipero and Lengua Formations, and established a zonation that is widely accepted. In sections in the Paleocene and Eocene, where both planktonic foraminifera and calcareous nannoplankton fossils have been described, the boundaries of zones of the two groups do not coincide. However, the limits of planktonic foraminifera and calcareous nannoplankton zones are not yet so well known in the upper Oligocene-upper Miocene, and it seems unnecessary at this time to establish and independent zonation for the calcareous nannoplankton. Figure 11 presents the distribution of calcareous nannoplankton fossils in samples from the type localities of the planktonic foraminifera zones proposed by Boll (1957b). The list is by no means exhaustive, but includes only a selection of species. A number of new species are described in this paper by Hay, and a large number of useful species still remain to be described.

In the preceding section on the Oligocene of JOIDES Hole 5 by Roth & Hay, the highest zone proposed, the *Reticulofenestra laevis* Zone, was stated to have its upper limit marked by the appearance of *Discoaster saundersi* Hay, n. sp. *Discoaster saundersi* is present in the *Globigerina amphiapertura* Zone in Trinidad, along with a number of small coccolith species resembling the flora of the *Reticulofenestra laevis* Zone. *Discoasters* become very abundant in the *Globorotalia opima opima* Zone, and the distinctive species *Discoaster lidi* Hay, n. sp. is not found in samples from the type localities
of higher or lower planktonic foraminiferal zones. *Discocoaster obtusus* Gartner appears in the *Globigerina ciperoensis ciperoensis* Zone, and *Triquetorhabdulus martinii* Gartner is not known from higher or lower zones. The *Globorotalia kugleri* Zone is characterized by a flood of *Discocoaster saundersi* Hay n. sp. and *Triquetorhabdulus carinatus* Martini appears to be restricted to it, not occurring in the type localities of higher or lower zones.

As already noted by Martini (1965), a major change in the calcareous nanoplankton assemblages occurs between the type localities of the *Globorotalia kugleri* and *Catapsydrax dissimilis* Zones. Many of the older species disappear, and a number of new species appear. The *Catapsydrax stainforthi* Zone is marked by a flood of *Discocoaster nephados* Hay, n. sp., and the first appearance of several other species. The *Globigerinatella insueta* Zone is the level of first appearance of *Discocoaster brouweri* Tan Sin Hok, and lacks *Discocoaster nephados* Hay, n. sp. and other species of the *Catapsydrax* Zones.

The assemblages of the *Globorotalia fohsi* barisanensis and higher zones are strikingly different from those of the lower part of the section, being completely dominated by discoasters with long, thin, delicate rays. *Discocoaster extilis* Martini & Bramlette first appears in the *Globorotalia fohsi* barisanensis Zone sample, and is very common in this and the succeeding zone. *Discocoaster kugleri* Martini & Bramlette first appears in the *Globorotalia fohsi* lobata Zone sample, and *Discocoaster sub-surculus* Gartner appears in the *Globorotalia fohsi* robusta Zone sample.

The assemblages of the Lengua Formation again differ markedly from those of the earlier zones. Typical *Discocoaster challengeri* Bramlette & Riedel, and *Discocoaster phylodous* Hay, n. sp. appear in the sample from the *Globorotalia mayerii* Zone. The *Globorotalia menardii* Zone contains a large number of new forms, including *Catinaster calyculus* Martini & Bramlette, *Discocoaster perclarius* Hay, n. sp., *Discocoaster calcarei* Gartner, *Discocoaster bullii* Martini & Bramlette, *Discocoaster stellulius* Gartner, and *Discocoaster hamatus* Martini & Bramlette.

The nature of assemblages between the *Globorotalia menardii* Zone and the *Scyphosphaera amphora* Zone proposed by Hay & Schmidt in the next section of this paper, is still unclear. From the observations of Martini & Bramlette (1963) on the experimental Mohole drilled off Guadalupe Island near Baja California, it may be suggested that some impoverishment of the flora occurs (see Figure 12). The occurrence of *Discocoaster hamatus* Martini & Bramlette, *Discocoaster bullii* Martini & Bramlette, and *Catinaster calyculus* Martini & Bramlette in the lower part of segment EM 8-11 and upper part of EM 8-12 suggests that this may be the level of the *Globorotalia menardii* Zone. Segment EM 6-1 belongs to the *Discocoaster surculus* Zone (see next section).

Up to the present time, almost all of the work done on Miocene assemblages has been carried out with ordinary and phase contrast light microscopy. There are so many discoasters in samples from this part of the Cenozoic that the coccoliths have been largely overlooked. The work of Gartner (1967) suggests that combined electron and light microscopic studies may result in a much finer zonation than is now possible.

**ZONATION OF THE PLEISTOCENE INTERVAL**

William W. Hay & Ronald R. Schmidt

The Pliocene has received very little study thus far. Assemblages have been described by Tan Sin Hok (1927a, 1927b), Deflandre (1939; 1942a), Kampfner (1955, 1963), Stradier & Papp (1961), and Martini & Bramlette (1963). No extensive range charts have been published, and no formal names for zones proposed.

In the course of a study of the calcareous nanoplankton fossils in the Pliocene of Italy, it has become evident that two zones may be recognized in the lower and middle Pliocene. These have not been found in North America up to the present, but may be expected.
SCYPHOSPHAERA AMPHORA ZONE

Definition: From the first appearance of Discoaster surculus Martini & Bramlette to the last occurrence of Scyphosphaera amphora Deflandre.

Authors: Hay & Schmidt, this paper.

Type locality: Outcrop just above the road at Km. 3, on the road from Riace to Riace Marina, Calabria, Italy; white marl with Orbulina universa (Sample I-6 of Hay & Schmidt, 1968).


Remarks: This zone can be recognized in Italy, Algeria ("silex et marines sabelliennes" of El Medhi, near St. Denis-du-Sig, Oran) and Indonoea (Behalain, Rotti). Martini (1965) suggested that the assemblages dominated by Scyphosphaera might have been deposited in relatively shallow water, but the striking resemblance of the assemblages from Italy, Algeria, and Indonesia indicates that this zone can be recognized on a worldwide basis. Whether this unit belongs to the late Miocene or early Pliocene cannot be decided at present. It occurs in strata not definitely assigned to either.

DISCOASTER SURCULUS ZONE

Definition: From the last occurrence of Scyphosphaera amphora Deflandre to the last occurrence of Discoaster surculus Martini & Bramlette.

Authors: Hay & Schmidt, this paper.

Type locality: Type section of the Pleistocene, Castell'Arquato, near Piacenza, Lombardy, Italy [I-26-I-32 of Hay & Schmidt, 1968, most representative sample I-28 Lugagnano].


Remarks: This zone can be recognized in the base of the Submarex cores described in the next section.

Most of the work on the Pliocene has been carried out using light microscopy. There are a number of small coccoliths in most samples, however, and electron microscopic examination of representative assemblages may result in a finer zonation.

ZONATION OF THE LATEST PLIOCENE-RECENT INTERVAL

Joseph E. Boudreaux & William W. Hay

Little has been done with Pleistocene calcareous nanoplankton fossils until very recently. No formal zonation has been proposed until now, but Bramlette (1957) suggested that the extinction of Discoaster brouweri Tan Sin Hon might be used to mark the upper limit of the Pliocene in the Pacific region. Ericson, Ewing, & Wollin (1963) suggested that the extinction of Discoaster might be used to define the Pliocene-Pleistocene boundary in deep sea sediments, and their proposal has been discussed by Bandy (1963), Riedel, Bramlette, & Parker (1963), McIntryre, Be, & Kranxley (1964), McIntryre & Be (1965), and others. Wray & Ellis (1965) and Akers (1965) have shown that the discoasters do not all become extinct at the same time, but that one species in particular, Discoaster brouweri Tan Sin Hon, lingers to become extinct at a higher level.
DISCOASTER BROUWERI ZONE

Definition: From the last occurrence of Discoaster extensus Hay, n. sp. to the last occurrence of Discoaster brouweri Tan Sin Hok.

Authors: Boudreaux & Hay, this paper.

Type locality: Submarex Hole, Lat. 17°40' N, Long. 77°58' W, on the Nicaragua Rise; sections E4 and E3, from 2,354.5 cm. to 4,725 cm. (Samples E4, 1,312 cm. to E3, 574 cm.)

Common species: Those of the Discoaster extensus Zone, less: Discoaster pentaradiatus Tan Sin Hok and Discoaster brouweri Hay, n. sp.

Remarks: This zone corresponds to the “Nebraskan” of the Gulf Coast (see Akers, 1965).

GEPHYROCAPSA CARIBBEANICA ZONE

Definition: From the last occurrence of Discoaster brouweri Tan Sin Hok to the first occurrence of Gephyrocapsa oceanica Kampnert.

Authors: Boudreaux & Hay, this paper.

Type locality: Submarex Hole, Lat. 17°40' N, Long. 77°58' W, on the Nicaragua Rise; sections E3 and E1, from 613 cm. to 2,554 cm. (Samples E3, 545 cm. to E1, 434 cm.)

Common species: Those of the Discoaster brouweri Zone, less: Discoaster brouweri Tan Sin Hok, Scyphochaera campanula Deflandre, and Coccolithus pelagicus (Wallich); plus: Syracosphaera pulchra Lohmann.

Remarks: The base of this zone corresponds to the Nebraskan-Aftonian boundary in the Gulf Coast. Reasons for considering this to be the Pliocene-Pleistocene boundary are presented in Bolli et al. (1967), and Hay & Boudreaux (1968).

GEPHYROCAPSA OCEANICA ZONE

Definition: Interval from the first occurrence of Gephyrocapsa oceanica Kampnert to the first occurrence of Emiliania huxleyi (Lohmann).

Authors: Boudreaux & Hay, this paper.

Type locality: Submarex Hole, Lat. 17°40' N, Long. 77°58' W, on the Nicaragua Rise: top of section E1, above 613 cm., (Sample E1, 64 cm.), upper limit in the gap between the top of the drilled core and the piston cores (deepest penetration 220 cm.).

Common species: Those of the Gephyrocapsa caribbeana Zone, less: Gephyrocapsa caribbeana Boudreaux & Hay, n. sp. plus: Coccolithes annulus Cohen; and Gephyrocapsa oceanica Kampnert.

Remarks: Gephyrocapsa caribbeana evolves into Gephyrocapsa oceanica at the base of this zone.
EMILIANIA HUXLEYI ZONE

Definition: Interval above the first occurrence of Emiliania huxleyi (Lohmann).

Authors: Boudreaux & Hay, this paper.

Type locality: Submarex Piston Cores, P6407-9 and P6407-10, Lat. 17°40' N, Long. 77°58' W, on the Nicaragua rise; top to deepest penetration, 220 cm.

Common species: Those of the Geophycopora oceanica Zone plus: Emiliania huxleyi (Lohmann).

Remarks: The precise lower limit of this zone is being determined in other piston cores.

DESCRIPTIONS OF NEW GENERA AND SPECIES PLANT KINGDOM

Division PHAEOPHYTA Wettstein (1901) emend. Rothmaler, 1949
Class COCCOLITHOPHORACEAE Rothmaler, 1951
Order HELIOLITHAE Deflandre, 1952
Genus BLACKITES Hay & Towe, 1962
BLACKITES AMPLUS Roth & Hay, n. sp.
Pl. 7, Fig. 10

Blackites spinosus of BLACK, 1965, Endeavour, v. 14, n. 93, pp. 134-135, Fig. 17.

Diagnosis: A species of Blackites with a narrow ring of simple slits.

Description: The shield is composed of two cycles of elements; the outer cycle consists of 30-36 trapezoidal segments; the inner cycle has 44-48 wedge-shaped segments. The inner and outer cycles are joined by about 80 short, narrow struts, separated by slits. The central opening is about one fourth the diameter of the coccolith. The sutures of the distal cycle of elements are inclined counterclockwise; those of the inner cycle are inclined clockwise peripherally, but are sharply angled and inclined counterclockwise over the inner two-thirds of their length.

Remarks: This species is distinguished from Blackites spinosus (Deflandre & Fert) by the simple construction of the struts connecting the inner and outer cycles of the shield. In Blackites spinosus, each strut extending out from the inner cycle is received in a secondary slit in the segments of the outer cycle. It should be noted that the electron micrograph of Blackites spinosus of Hay & Towe (1962b, Pl. 4, Fig. 5), and that attributed to Blackites spinosus by Black (1965, Fig. 17) are mirror images of the specimens.


Diameter of holotype: 6.6 u.

Type locality: JOIDES Core 5, Lat. 30°23’ N, Long. 80°08’ W, Blake Plateau.

Type level: 554° 10” below top, Oligocene.

Distribution: Figured from Denmark by Black, this species ranges from the Ellipsolithus subdistichus Zone to near the top of the Reticulofenestra laevis Zone in JOIDES Core 5.

Genus COCCOLITHUS Schwarz, 1894

COCCOLITHUS FLORIDANUS Roth & Hay, n. sp.
Pl. 6, Figs. 1-4

Diagnosis: A broadly elliptical species of Coccolithus with a small subcircular central opening.

Description: The placoliths are broadly convex. The distal shield has 40-41 segments, separated by sutures having a slight clockwise inclination on the distal surface, but which are straight on the proximal surface. The proximal shield has an equal number of segments; the sutures on the proximal surface are radial except near the central hole, where they bend sharply to become inclined counterclockwise. The central hole is subcircular, and is about one fifth the shorter dimension of the coccolith. A broken coccosphere (Pl. 6, Fig. 1) shows the tube to be short, and demonstrates the interlocking of the coccoliths to form the rigid sphere. The complete coccosphere of this species apparently has eight coccoliths.

Remarks: This species most closely resembles Coccolithus marismontium Black, but in Coccolithus floridanus, the coccoliths are more strongly elliptical and have a much smaller central hole.

Holotype: IMS-J501-164 (Pl. 6, Fig. 1).

Diameter of holotype: Coccosphere, 5 u.; coccoliths, 3.6 u.

Paratypes: IMS-J503-646; -J503-706; -J501-381.

Diameter of paratypes: Coccosphere, 8 u.; coccoliths, 4.1-5.5 u.

Type locality: JOIDES Core 5, Lat. 30°23’ N, Long. 80°08’ W, Blake Plateau.

Type level: 554° 10” below top, Oligocene.

Distribution: Ranges through the Oligocene in JOIDES Core 5.

COCCOLITHUS JOENSUUI Roth & Hay, n. sp.
Pl. 6, Fig. 5

Diagnosis: A species of Coccolithus with a narrowly elliptical central area plugged by stout blocks.

Description: The outline of the coccolith is smoothly elliptical. The distal shield is composed of an outer cycle of 22 tabular segments. The central depression is more narrowly elliptical, and is lined by a narrow cycle of granules; it is plugged by a series of stout blocks radiating from the long axis of the ellipse. These blocks arch upward along the mid-line of the central area to form a low mound. The coccosphere of this species has 10-12 coccoliths.

Remarks: These species is distinguished from others assigned to the genus Coccolithus by the peculiar construction of the central area. In other forms encountered in the Oligocene, the central area is a simple crater-like depression. The peculiar construction of Coccolithus joensuui may warrant its assignment to a new genus later.

Holotype: IMS-J501-311.
Diameter of holotype: Cocosphere 4.7 u; coccolith, 2.8 u.

Type locality: JOIDES Core 5, Lat. 30°23' N, Long. 80°08' W, Blake Plateau.

Type level: 554' 10" below top, Oligocene.

Distribution: Not found above the top of the Ellipsolithus subdistichus Zone in JOIDES Core 5.

**COCCOLITHUS PARALITOS** Roth & Hay, n. sp.  
Pl. 6, Fig. 6

Diagnosis: A species of Coccolithus with 25 segments, distinguished by its small size.

Description: The distal shield of this species is constructed of 25 tabular, dextrally imbricate segments. The sutures of the distal shield are radial on the distal surface. The central area is a large crater-like depression, half the diameter of the coccolith, and is surrounded by a cycle of small granules.

Remarks: This species resembles Coccolithus litos Hay, Mohler, & Wade, but is distinguished by its much smaller size and relatively larger central depression.

Holotype: IMS-J505-012.

Maximum diameter of holotype: 3.4 u.

Type locality: JOIDES Core 5, Lat. 30°23' N, Long. 80°08' W, Blake Plateau.

Type level: 410' below top, Oligocene.

Distribution: Ranges through the Cyclococcolithus margaritae, Syracosphaera clathrata, and lower part of the Reticulofenestra laevis Zones in JOIDES Core 5.

Genus CRUCIPLACOLITHUS Hay & Mohler, n. gen.

Diagnosis: Evenly concave elliptical placoliths with a central cross having arms oriented in the major and minor axes of the ellipse.

Type species: Cruciplacolithus tenuis (Stradner) Hay & Mohler [=Heliorthus tenuis Stradner, 1961, p. 84, text-figs. 64-65; junior synonym: Coccolithus helis Stradner, 1963 (nom. subst. pro Coccolithus (Heliorthus) tenuis Stradner, non Coccolithus tenuis Kampneter, 1937) in Gohrbandt, 1963a, p. 74, pl. 8, fig. 16, pl. 9, figs. 1-2].

**CRUCIPLACOLITHUS TARQUINII**  
Roth & Hay, n. sp.  
Pl. 6, Fig. 8

Diagnosis: A species of Cruciplacolithus distinguished by a prominent cycle of tabular elements lining the central opening.

Description: The distal shield is composed of two cycles of elements, the outer cycle being constructed of about 31 wedge-shaped segments having dextral imbrication and separated by sutures having a clockwise inclination centrally and a counterclockwise inclination peripherally. The inner cycle displays a serrate outer margin. It consists of an equal number of segments, which are very slightly imbricate dextrally; the sutures are inclined counterclockwise except at the innermost margin of the central area, where they run sharply clockwise. The central opening is about half the diameter of the coccolith, and is spanned by a cruciform structure aligned in the long and short axes of the ellipse, as is typical of the genus.

Remarks: This species is distinguished from Cruciplacolithus tenuis by the much larger openings bordering the central cross.

Holotype: IMS-J501-449.

Length of holotype: 5.4 u.

Type locality: JOIDES Core 5, Lat. 30°23' N, Long. 80°08' W, Blake Plateau.

Type level: 554' 10" below top, Oligocene.

Distribution: Probably restricted to the Ellipsolithus subdistichus Zone in JOIDES Core 5.

Genus CYCLOCOCCOLITHUS Kampneter, 1954

CYCLOCOCCOLITHUS MARGARITAE  
Roth & Hay, n. sp.  
Pl. 6, Fig. 9

Diagnosis: A small species of Cyclococcolithus distinguished by having a distal shield constructed of only about 15 segments.

Description: The outline is smooth and circular. The distal shield is composed of 15 dextrally imbricate, wedge-shaped segments. The sutures are radial centrally, but curve counterclockwise peripherally. The central depression is large, about one-third the diameter of the coccolith.

Remarks: The similarity of this species to Cyclococcolithus leptoporus (Murray & Blackman) in basic construction is striking (compare with Pls. 12, 13, Fig. 3). Cyclococcolithus margaritae differs in being extremely small, and in having only about half as many segments in the distal shield.

Holotype: IMS-J502-194.

Diameter of holotype: 2.4 u.

Type locality: JOIDES Core 5, Lat 30°23' N, Long. 80°08' W, Blake Plateau.

Type level: 519' 2", Oligocene.

Distribution: Restricted to the Cyclococcolithus margaritae Zone in JOIDES Core 5.

Genus ELLIPSOLITHUS Sullivan, 1964

ELLIPSOLITHUS SUBDISTICHUS  
Roth & Hay, n. sp.  
Pl. 6, Fig. 7

Diagnosis: A species of Ellipsolithus with four pair of perforations on either side of the long axis, and one hole at each end of the central area.

Description: The shield is broadly elliptical, and is composed of about 30 subtrapezoidal segments which are dextrally imbricate. The sutures have a slight counterclockwise inclination over most of the surface, but curve more strongly in the same direction peripher-
ally. The central area has a longitudinal ridge flanked by four pair of pores; two additional pores lying in the long axis delimit the ends of the ridge.

Remarks: This species bears a strong resemblance to *Ellipsolithus distichus* (Bramlette & Sullivan), but differs in being much smaller, more broadly elliptical in outline, and in having a different arrangement of the pores. In *Ellipsolithus distichus*, all of the pores are in pairs about the longitudinal ridge, while in *Ellipsolithus subdistichus* two isolated pores mark the termination of the central ridge, and the pore pairs produce a more broadly elliptical pattern.

Holotype: IMS-J501-451

Length of holotype: 4.3 u.

Type locality: JOIDES Core 5, Lat. 30°23' N, Long. 80°08' W, Blake Plateau.

Type level: 554' 10" below top, Oligocene.

Genus **EMILIANIA** Hay & Mohler, n. gen.

Diagnosis: Cocco lithophor, placolithos ferens, cum circumacto scuto ex I-forma membris facto; fistula cum inclinatis et imbricatis membris; interior scutum ex I-forma vel petaloid membris factum; centrum vel cum reticula. [Coccolithophores having placoliths having a distal shield constructed of I-shaped segments and a proximal shield constructed of I-shaped or petaloid elements; center solid or with reticule.]

Type species: **Emiliania huxleyi** (Lohmann), 1902 [= Pontosphaera huxleyi Lohmann, 1902, pp. 129-130, pl. 4, Figs. 1-9, pl. 6, Fig. 69; = Hymenomonas huxleyi (Lohmann) Kampfner, 1930, pp. 155-156, 159-160; = Coccolithus huxleyi (Lohmann) Kampfner, 1943, p. 44].

Remarks: The coccoliths of *Emiliania* differ markedly from those of *Coccolithus* in their optical behaviour. In *Coccolithus pelagicus* (Wallich), the distal shield produces no interference figure between crossed polarizers when viewed perpendicular to the plane of the disc. In *Emiliania*, the distal shield is illuminated between crossed nicols. Another major difference lies in manner in which the segments of the shield adjoin; in *Coccolithus* they are strongly imbricate while in *Emiliania* they are not imbricate. *Pontosphaera* has a wholly different form and mode of construction (see Pls. 10, 11; Fig. 6). Stereoscopic electron micrographs of *Emiliania huxleyi* are presented on Pls. 10, 11; Figs. 1 and 2.

Genus **FASCICULITHUS** Bramlette & Sullivan, 1961

**FASCICULITHUS TYPMANIFORMIS**

Hay & Mohler, n. sp.

Pls. 8, 9, Figs. 1-5

Diagnosis: A smooth species of *Fasciculithus* composed of about 16 wedge-shaped units.

Description: A short sub-cylindrical object with one end slightly pointed, the other end concave. The cylinder is constructed of about 16 wedges, so arranged that their thin edges meet at the center and the thick ends form the outer surface of the cylinder. The surface of the cylinder is smooth, lacking ornamentation. In some specimens, a few tabular plates are present on the pointed end.

Remarks: This species is readily distinguished from *Fasiculithus involutus* Bramlette & Sullivan by its smoothly finished outer surface.

Holotype: UI-H-3731 (Pls. 8, 9; Fig. 1).

Diameter of holotype: About 4 u.

Paratypes: UI-H-3732-3735

Length of paratypes: 5-6 u.

Type locality: Exposure along Route Nationale 134bis, about 250 meters northwest of Pont Labau, 3 kilometers south of Gan, Basses Pyrenees, France (GAN 822 of Hay & Mohler, 1967).

Distribution: Found commonly throughout the Fasciculithus typmaniformis, Helolithus kleinpellii, and Discaster gemmeus Zones at Pont Labau; also known in Trinidad.

Genus **GEPHYROCAPSA** Kampfner, 1943

**GEPHYROCAPSA CARIBBEANICA**

Boudreaux & Hay, n. sp.

Pls. 12, 13, Figs. 1-4

Diagnosis: A species of *Gephyrocapsa* with 38-48 elements in the distal shield, and a bridge formed by two offset plates making an angle of about 30-35° with the long axis of the ellipse.

Description: The distal shield is composed of 38-48 petaloid elements, the proximal shield of an equal number of petaloid elements; central area partially or completely plugged by an extension of the elements of the proximal shield or tube. The bridge is formed by two offset plates which do not overlap, but merely touch one another. The bridge makes an angle of 30-35° with the long axis of the ellipse. A distinct interference figure is produced between crossed polarizers.

Remarks: This species is believed to be the ancestor of *Gephyrocapsa oceanica* Kampfner. In the Submarex cores, it is replaced by *Gephyrocapsa oceanica* at about 613 cm. from the top. It is distinguished from *Gephyrocapsa oceanica* by the distinctly jogged bridge, by the filling of the central area, and by the steeper angle between the bridge and the long axis (in *Gephyrocapsa oceanica*, the angle made by the bridge and the long axis is 75-80°). *Gephyrocapsa aperta* Kampfner has a much larger central opening.

Holotype: UI-H-3736 (Pls. 12 & 13, Fig. 4)

Length of holotype: 4 u.

Paratypes: UI-H-3737-3739

Length of paratypes: 4-4.5 u.

Type locality: Core A240-M1, Lat. 15°26' N, Long. 65°45' W, eastern Caribbean Sea.

Type level: 540 cm. below top.

Distribution: Found throughout the Submarex cores, but rare above 613 cm.; lower limit not known.
Genus HELICOPONTOSPHAERA
Hay & Mohler, n. gen.

Diagnosis: Coccolithophor, lopadolithus ferens, cum muricatim introto muro. [Coccolithophores bearing lopadoliths having a spiral wall].

Type species: Helicopontosphaera kamptneri Hay & Mohler, n. sp.

HELICOPONTOSPHAERA KAMPTNERI
Hay & Mohler, n. sp.
Pls. 10, 11, Fig. 5

Coccolithus carteri (Wallich) of KAMPTNER, 1954, Arch. Protistenk., v. 100, n. 1, p. 21, text-figs. 17-19.

Diagnosis: Coccolithophor, lopadolithus ferens, cum muricatim introto muro, murus paulum expansus versus parietem extremum, imperforatus vel cum duis parvis fissuris. [Coccolithophores bearing lopadoliths having a spiral wall; wall flaring somewhat at one end; imperforate or with two small slits].

Description: An excellent account of the structure of the coccoliths of this species has been presented by Black & Barnes (1961; cited in synonymy above). It should be noted that the electron micrographs of Black & Barnes are mirror images of the actual coccoliths. Both perforate and imperforate specimens occur in the same samples. The floor of the lopadolith is concave when viewed from the convex side of the lopadolith, suggesting that the coccoliths are probably arranged as typical (though shallow) lopadoliths opening to the outside when attached to the surface of the living coccolithophore.

Remarks: Coccolithus carteri (Wallich) was described and figured in such a way as to leave no doubt of its construction. Wallich stated that it differed from Coccosphaera palagica [=Coccolithus palagicus (Wallich)] only in possessing two central perforations instead of one, and his illustration of the side view indicates two distinct shields. The species which in recent years has been referred to as Helicophsphaera carteri is not that described by Wallich, and since Coccosphaera carteri was designated type species of the genus Helicophsphaera Kamptner, 1954, a new generic name as well as a new species name has been needed (Hay, Mohler, & Wade, 1966; p. 386). The similarity of construction with that of Pontosphaera (Pls. 10, 11; Fig. 6) is evident when the stereoscopic electron micrographs are compared. The lopadoliths of Pontosphaera are, of course, much deeper; those of Helicopontosphaera kamptneri are shallow to almost flat. The only named species with which Helicopontosphaera kamptneri might be confused is Helicopontosphaera intermedia (Martini) [=Helicophsphaera intermedia Martini, 1965, p. 404, pl. 35, figs. 1-2].

Holotype: UI-H-3730.

Length of holotype: 10 u.

Type locality: Core CG-9, Lat. 17°12' N, Long. 65°45' W, eastern Venezuelan Basin.

Type level: Top of core, Recent.

Distribution: Probably ranges back to the early Pliocene or late Miocene.

Genus PYROCYCLUS Hay & Towe, 1962

PYROCYCLUS HERMOSUS Roth & Hay
Pl. 6, Figs. 10-12

Diagnosis: A species of Pyrocyclus with a large, open central area.

Description: The side shown in the view of the holotype (side A) is constructed of about 41 wedge-shaped elements which are strongly imbricate sinistrally. The sutures are straight, having a slight counter-clockwise inclination over most of the surface of the shield, but curve sharply near the periphery to become inclined steeply clockwise. The other side (side B, shown in Pl. 6, Fig. 10) shows an almost identical construction. The sutures run slightly counterclockwise, but are interrupted by a furrow not far from the margin of the central opening; near the periphery, the sutures again change direction abruptly to become inclined clockwise.

Remarks: Assignment of this species to the genus Pyrocyclus seems appropriate, as Pyrocyclus hermosus is more closely allied to Pyrocyclus inversus Hay & Towe than to any other described species. It differs from Pyrocyclus inversus in having a large, open central area. The structure of coccoliths of this sort is still not well understood, and must await stereoscopic examination.

Holotype: IMS-J501-226 (Pl. 6, Fig. 11).

Length of holotype: 2.9 u.

Paratypes: IMS-J501-320, -J503-662

Length of Paratypes: 2.9-3.5 u.

Type locality: JOIDES Hole 5, Lat. 30°32' N, Long. 80°08' W, Blake Plateau.

Type level: 554' 10" below top, Oligocene.

Distribution: This species ranges through the Oligocene of JOIDES Hole 5.
Genus **Reticulofenestra**
Hay, Mohler, & Wade, 1966

**Reticulofenestra gartneri**
Roth & Hay, n. sp.
Pl. 7, Fig. 1

**Description:** A broadly elliptical species of *Reticulofenestra* with a central grille perforated by about 120 small holes.

**Remarks:** In *Reticulofenestra caucasia* Hay, Mohler, & Wade and *Reticulofenestra insignita* Roth & Hay, n. sp., the margin of the central area is marked by a series of slits. *Reticulofenestra insignita* has a narrower outline and fewer perforations in the relatively larger central area.

**Holotype:** IMS-J501-453
Length of holotype: 5.8 u.

**Type locality:** JOIDES Hole 5, Lat. 30°23' N, Long. 80°08' W, Blake Plateau.

**Type level:** 554' 10''

**Distribution:** Ranges through the Oligocene to near the top of the *Reticulofenestra laevis* Zone in JOIDES Hole 5.

**Reticulofenestra laevis**
Roth & Hay, n. sp.
Pl. 7, Fig. 11

**Diagnosis:** A subcircular species of *Reticulofenestra* with a small round central opening spanned by a grille with 30-40 small round perforations.

**Remarks:** This is the most nearly circular species of *Reticulofenestra* yet described, and its nearly circular outline serves to distinguish it from *Reticulofenestra gartneri* Roth & Hay, n. sp., and other members of the genus.

**Holotype:** IMS-J507-091
Greatest diameter of holotype: 6.4 u.

**Type locality:** JOIDES Hole 5, Lat. 20°23' N, Long. 80°08' W, Blake Plateau.

**Type level:** 337° 11''

**Distribution:** This species first appears at the base of the *Reticulofenestra laevis* Zone; its upper limit has not yet been determined.

Genus **Syracosphaera** Lohmann, 1902

**Syracosphaeraclathrata**
Roth & Hay, n. sp.
Pl. 7, Fig. 9

**Diagnosis:** A species of *Syracosphaera* with a narrow rim and a central area spanned by elongate bars separated by slits.

**Description:** The outline of the coccolith is narrowly elliptical. The rim is very narrow, composed of about 80 segments. The central opening is spanned by a series of laths radiating from the rim to fuse along the long axis of the ellipse. The laths are of equal width near the margin and in the center, so that the slit-like openings separating them become narrower and finally close toward the center.
Remarks: In basic construction, this species resembles *Syracosphaera pulchra* Lohmann, but has a narrower rim and less complex central area. In *Syracosphaera pulchra* the laths are narrower, and thin toward the center.

Holotype: IMS-J504-127
Length of holotype: 4.9 u.
Type locality: JOIDES Hole 5, Lat. 30°23' N, Long. 80°08' W, Blake Plateau.
Type level: 445°
Distribution: Restricted to the *Syracosphaera clathrata* Zone in JOIDES Hole 5.

Genus TRANSVERSOPONTIS
Hay, Mohler, & Wade, 1966
TRANSVERSOPONTIS ZIGZAG Roth & Hay, n. sp.
Pl. 7, Figs. 4-6

Diagnosis: A species of *Transversopontis* with an irregularly coarsely perforate grille filling the two holes.

Description: The rim is narrowly elliptical, composed of 100 or more imbricate elements, as is common in pontospheirid lopadoliths. The base of the lopadolith is built by about 100 segments peripherally, but about half of these wedge out before reaching the holes in the central part of the base. The transverse bridge is inclined to the long axis of the ellipse at an angle of 30°, and is broadly Z-shaped. The opening usually found in members of this genus are filled by a coarse grille with about six perforations around the periphery and five crude holes in the center.

Remarks: This species most closely resembles *Transversopontis obliquipons* Deflandre, but differs in the zig-zag bridge and in having the grille filling the holes in the ends of the base.
Holotype: IMS-J503-696 (Pl. 7, Fig. 4)
Length of holotype: 4.7 u.
Length of paratypes: 6.0 u.
Type level: 48°
Distribution: From the upper part of the *Cyclococcolithus margaritae* Zone to the top of the *Reticulo-fenestra laevis* Zone in JOIDES Hole 5.

Order ORTHOLITHAE Deflandre, 1952
Genus DISCOASTER Tan Sin Hok, 1927
DISCOASTER ARGUTUS Hay, n. sp.
Pl. 5, Fig. 8

Discoaster sp. (ciperoensis-group) MARTINI, 1965,
37, figs. 10-11.

Diagnosis: Asteroliths with six bluntly pointed rays, separated along slightly more than half their length; rays separated by straight sutures extending across the central disc.

Description: The rays are of moderate length and breadth; the tips are rounded to ogival; adjacent rays meet at an angle of 60° at a point slightly more than half way from the tips to the center. Prominent straight sutures extend across the central area of the asterolith, joining opposite interray notches.

Remarks: This species is distinguished from *Discoaster aster* Bramlette & Riedel by the nature of the tips of the rays, and from *Discoaster incomptus* Hay, n. sp., by the sutures in the central disc, which join opposite interray spaces.
Holotype: UI-H-3740
Diameter of holotype: 11 u.

Type locality: Hermitage Quarry, on the west side of the road leading from Hermitage Village to Ally's Creek about 1,200 feet northwest from the road junction in the village, south Trinidad (N: 208100 links; E: 351800 links; Locality Bo 202 of Bolli, 1957b).

Type level: *Globorotalia fohsi barisanensis* Zone (Type locality).
Distribution: Ranges from the *Catapsydrax dissimilis* Zone through the *Globorotalia fohsi barisanensis* Zone.

DISCOASTER DILATUS Hay, n. sp.
Pl. 4, Figs. 3-4

Discoaster molengraaffi Tan Sin Hok of STRADNER (part) in STRADNER & PAPP, 1961, Jb. Geol. Bundesanst., Sdrbd. 7, pp. 80-81, pl. 14, fig. 6a-b.

Diagnosis: Asteroliths with six (rarely seven) slightly to broadly flaring, flatly terminated rays.

Description: The rays are of moderate length, and are broad, becoming wider peripherally. Ends of the rays are flat or slightly concave. Intercalary notches are deep, extending well over half way to the center. This species tends to be rather variable in appearance, and the margins of the rays are not smooth, but show slight irregularities. No sutures are visible in the central area.

Remarks: According to Bramlette & Riedel, *Discoaster molengraaffii* Tan Sin Hok is merely a variant of *Discoaster broweri* Tan Sin Hok. *Discoaster dilatus* differs from *Discoaster broweri* by having much shorter, wider rays which thicken toward the tips. In *Discoaster argutus* Hay, n. sp., and in *Discoaster aster* Bramlette & Riedel, the tips of the rays are rounded or ogival.

Holotype: UI-H-3741 (Pl. 4, Fig. 3)
Diameter of holotype: 10 u.
Paratype: UI-H-3742
Diameter of paratype: 13 u.

Type locality: Hermitage Quarry, on the west side of the road leading from Hermitage Village to Ally's Creek about 1,200 feet northwest from the road junction in the village, south Trinidad. N: 208100 links; E: 351800 links. (Bo 202 of Bolli, 1957b).

Type level: *Globorotalia fohsi barisanensis* Zone (Type locality).
Distribution: Rare from the Globigerina ampliapertura Zone through the Globigerinatella insueta Zone, abundant in the Globorotalia fohsi barisanensis and Globorotalia fohsi fohsi Zones.

DISCOASTER DIVARICATUS Hay, n. sp.
Pl. 3, Figs. 7-9

*Discoaster challenger* Bramlette & Riedel var. BRAMLETTE, 1957, U. S. G. S. Prof. Pap. 280, pp. 248-249, pl. 6, fig. 3.

Diagnosis: Six-rayed asteroliths with broad, bifurcating ray tips displaying a distinct notch; interray spaces angulated.

Description: The rays are of moderate length; the sides of the rays are parallel to the point of bifurcation. Each limb of the bifurcate ray has the same width as the ray below the point of bifurcation. The angle of bifurcation is 120°. The ends of the bifurcate segments are flat. The central disc is formed solely by fusion of the rays. The interray spaces are sharply angular to subangular.

Remarks: This species is distinguished from *Discoaster deflandrei* Bramlette & Riedel by the angular to subangular interray spaces. It is distinguished from *Discoaster aulakos* Gartner by the notched ray tips.

Holotype: UI-H-3743 (Pl. 3, Fig. 8)
Diameter of holotype: 13 u.
Paratypes: UI-H-3744-3745
Diameter of paratypes: 10 u.

Type locality: Hermitage quarry, on the west side of the road leading from Hermitage Village to Ally's Creek about 1.200 feet northwest from the road junction in the village, south Trinidad. N: 208100 links; E: 351800 links (Bo 202 of Bolli, 1957b).

Type level: *Globorotalia fohsi barisanensis* Zone.

Distribution: Ranges from the Globigerinatella insueta through Globorotalia fohsi lobata Zones.

DISCOASTER EXTENSUS Hay, n. sp.
Pl. 3, Figs. 10, 12; Pl. 4, Figs. 1-2

Diagnosis: Six-rayed asteroliths with peripherally flaring rays which expand slightly, bifurcate, and curve sharply downward at the tips.

Description: The rays are of moderate length and breadth. They expand slightly peripherally, and curve sharply downward at the point of bifurcation, giving the impression that the limbs of the bifurcation become vanishingly thin when seen in top view. The central disc is small, less than half the diameter of the asterolith, and lacks sculpture.

Remarks: This species is most closely related to *Discoaster variabilis* Martini & Bramlette, but differs in having more strongly recurved ray tips, and in lacking the sculpture of the central disc characteristic of that species.

Holotype: UI-H-3746 (Pl. 3, Fig. 10)
Diameter of holotype: 13 u.
Paratypes: UI-H-3747-3749
Diameter of paratypes: 11-13 u.

Type locality: Ditch on the east side of the Cunjal Road, about 150 feet from its junction with the Realize Road, about 2 1/2 miles south southeast of Lenguag Settlement, south Trinidad. N: 205000 links; E: 419600 links. (KR 23422 of Bolli, 1957b).

Type level: *Globorotalia meyeri* Zone (Type locality).

Distribution: This species is common to abundant in the Globorotalia fohsi robusta through Globorotalia menardii Zones.

DISCOASTER INCOMPTUS Hay, n. sp.
Pl. 1, Fig. 3

Diagnosis: Asterolith with six rays arranged in two sets of three; rays bluntly tipped, separate for about half their length.

Description: The rays are moderately long and broad, with broadly rounded to subgival tips. Sutures in the central area extend from one interray angle to the center, turn abruptly 120°, and extend out to the next interray angle.

Remarks: This species conforms to the description of the subgenus *Hemidiscoaster* Tan Sin Hok. It is distinguished from *Discoaster argutus* Hay, n. sp., by the sutures in the central area, which in that species extend directly across the central disc to join opposite rather than adjacent interray areas.

Holotype: UI-H-3750
Diameter of holotype: 16 u.

Type locality: East slope of Mount Hillaby, Barbados; Oceanic Formation about 54° above the contact with the Joes River Formation (JS 1871).

Type level: *Isthmolithus recurvus* Zone.

Distribution: Common in the upper part of the Discoaster tani nodifera Zone, ranges well into the Isthmolithus recurvus Zone.

DISCOASTER LAUTUS Hay, n. sp.
Pl. 5, Fig. 7

*Discoaster molengraaffi* Tan Sin Hok of STRADNER (part) in STRADNER & PAPP, 1961, Jb. Geol. Bundesanst., Sdrbd. 7, pp. 80-81, pl. 14, fig. 5a-b.

Diagnosis: Asterolith with six rays arranged in two sets of three; rays short, rhomboidal, with pointed tips; rays free for half their length.

Description: The rays are short, and each has a rhomboidal outline. The tips of the rays are angular to sharply pointed. Arrangement of the rays is as in *Hemidiscoaster* Tan Sin Hok.

Remarks: The interray areas are shallower than in *Discoaster incomptus* Hay, n. sp., or *Discoaster argutus* Hay, n. sp. The appearance of the asterolith is sharp...
and crisp, the sutures of the central disc are well defined.

Holotype: UI-H-3751
Diameter of holotype: 7 u.
Type locality: “Cipero Nose”, Cipero coast, south Trinidad. N:229450 links; E:354250 links (Rz 108 of Bolli, 1957b).
Type level: Globigerinatella insueta Zone (Type locality).
Distribution: This species may be restricted to the Globigerinatella insueta Zone.

DISCOASTER LEVINI Hay, n. sp.
Pl. 1, Figs. 7-8

Diagnosis: Six to seven (rarely eight or five) rayed asteroliths with long, thin, cylindrical, sharply pointed rays.

Description: The rays are long, thin, cylindrical, and sharply pointed. The interray spaces are broadly rounded where they meet the central disc. The rays do not adjoin each other at the central disc, but are distinctly separated. Vague sutures extend from the interray spaces to the center, and there is a short stem in the center of the disc.

Remarks: This species closely resembles, and is apparently descended from, Discoaster saipanensis Bramlette & Riedel. It differs from that species in having longer, more cylindrical rays, and in being larger. Typical specimens of Discoaster saipanensis occur together with Discoaster levinii, but transitional forms appear to be rare.

Holotype: UI-H-3752 (Pl. 1, Fig. 7.)
Diameter of holotype: 22 u.
Paratype: UI-H-3753
Diameter of paratype: 14 u.
Type locality: Top of the lower section at Bath Cliff, Barbados, Oceanic Formation (JS 1077).
Type level: Upper part of the Isthmolithus recurvus Zone.
Distribution: Occurs only in the upper part of the Isthmolithus recurvus Zone.

DISCOASTER LIDZI Hay, n. sp.
Pl. 2, Figs. 1-3

Diagnosis: Asteroliths with a very large disc and four to six very broad, short, bifurcate rays.

Description: The rays of this species are very broad and short; interray areas extend only about one fourth of the way in toward the center of the asterolith. The bifurcation in the end of each ray is broad, and almost as deep as the interray area. The central part of the disc is thickened, but featureless.

Remarks: This species most closely resembles Discoaster nephostis Hay, n. sp., but is distinguished by having much shallower interray areas.

Holotype: UI-H-3754 (Pl. 2, Fig. 1)
Diameter of holotype: 14 u.
Paratypes: UI-H-3755-3756
Diameter of paratypes: 12-13 u.
Type locality: Cipero coast, north end, at locality 10 on Fig. 19 in Bolli, 1957b, south Trinidad. (JS 20 of Bolli 1957b).
Type level: Globorotalia opima opima Zone (Type locality).
Distribution: Discoaster lidzi appears to have a very short range; it is not found at the type localities of the Globigerina ampliapertura Zone or Globigerina ciperoensis Zone.

DISCOASTER NEPHADOS Hay, n. sp.
Pl. 2, Figs. 4-5


Diagnosis: Asteroliths with six broad, gently bifurcate rays separated by shallow interray areas.

Description: The rays are broad and short; they expand slightly distally, and the terminations are slightly indented, producing the effect of a shallow bifurcation. The interray areas are narrow and shallow, extending less than half way in to the center. Sutures in the central area are weakly developed.

Remarks: This species is related to Discoaster woodringi Bramlette & Riedel, but differs in having ray tips slightly concave. The interray spaces are deeper than in Discoaster lidzi Hay, n. sp.

Holotype: UI-H-3757 (Pl. 2, Fig. 4)
Diameter of holotype: 12 u.
Paratype: UI-H-3758
Diameter of paratype: 13 u.
Type locality: Cipero type section, near south end; south Trinidad. N:227300 links; E:352900 links. (JS 1840 = K.9397 of Bolli, 1957b).
Type level: Catapsydrax stainforthi Zone (Type locality).
Distribution: Found in the Catapsydrax dissimilis and Catapsydrax stainforthi Zones.

DISCOASTER PERCLARUS Hay n. sp.
Pl. 4, Figs. 11-12

Diagnosis: Asterolith with six thin, delicate rays; rays bifurcating into thin terminal segments subequal in length to the inner part of the ray; central disc hexagonal, sculptured.

Description: The rays of this species are exceedingly thin and delicate; they bifurcate peripherally at an angle of 120° into two segments each almost as long as the inner part of the ray. The central disc has a hexagonal outline, the sides of the hexagon distinctly separating the bases of the rays. The central disc is
sculptured so that a six rayed star-like pattern is seen within it in phase contrast illumination.

Remarks: This species is most closely related to Discoaster challengeri, Bramlette & Riedel, from which it appears to have arisen. It differs from Discoaster challengeri in having thinner, more delicate rays, with longer terminal bifurcations, and in possessing a distinct, sculptured central disc.

Holotype: UI-H-3759 (Pl. 4, Fig. 11)
Diameter of holotype: 15 u.
Paratype: UI-H-3760
Diameter of paratype: 11 u.

Type locality: Ditch on the east side of the road leading from Lengua Settlement to Cipero-Ste. Croix, about 150 feet from the road junction in Lengua Settlement, about one mile south of Princes Town, south Trinidad. N:208900 links; E:413600 links (KR 23425 of Bolli, 1957b).

Type level: Globorotalia menardii Zone (Type locality).

Distribution: This species is found only in the Globorotalia menardii Zone in Trinidad. It also occurs in abundance in the San San Clay of Jamaica.

DISCOASTER PHYLLODUS Hay, n. sp.
Pl. 4, Figs. 5-6

Diagnosis: Asterolith with six broadly flaring, lightly bifurcate rays; interray areas ogival, deep; rays well separated.

Description: The rays are narrow where they leave the central disc, but expand peripherally to become broad at the ends. The ends of the rays are gently concave. The interray spaces are ogival, widest slightly over half way from the center; they extend in two-thirds of the way to the center. The central disc is featureless.

Remarks: This species resembles flaring specimens of Discoaster dilatus, but differs in its more delicate construction, and in the shape of the interray spaces.

Holotype: UI-H-3762 (Pl. 4, Fig. 6)
Diameter of holotype: 12 u.
Paratype: UI-H-3761
Diameter of paratype: 11 u.

Type locality: Ditch on the east side of the Gunjal Road, about 150 feet from its junction with the Realize Road, about 2 1/2 miles south southeast of Lengua Settlement, south Trinidad. N:205000 links; E:419600 links. (KR 23422 of Bolli, 1957b).

Type level: Globorotalia menardii Zone (Type locality).

Distribution: This species occurs in the Globorotalia menardii Zone and Globorotalia menardii Zones in Trinidad.

DISCOASTER SAUNDERSI Hay, n. sp.
Pl. 3, Figs. 2-6

Diagnosis: Asteroliths with six or seven rays having bifurcate tips; each tip bearing two small lateral nodes at the point of bifurcation.

Description: The rays are short, of moderate breadth, bifurcating distally into two short segments. At the inner corner of each bifurcate segment is a small node. The notch in the end of each ray is moderately deep, extending down to the level of the nodes, and is sharply angled. The interray spaces are rounded. The central disc is featureless.

Remarks: This species is closely related to Discoaster deflandrei Bramlette & Riedel, but is distinguished by the characteristic nodes bordering the terminal bifurcation of the rays.

Holotype: UI-H-3763 (Pl. 3, Fig. 2)
Diameter of holotype: 14 u.
Paratypes: UI-H-3764-3767
Diameter of paratypes: 10-13 u.

Type locality: About 300 feet southwest of the mouth of Ally's Creek on the coast, south Trinidad. N:224280 links; E:352000 links (JS 845).

Type level: Globorotalia kugleri Zone.

Distribution: This species is rare to common from the Globigerina ampliapertura Zone to the Globigerina ciperoensis csiperoensis Zone, abundant in the Globorotalia kugleri Zone.

DISCOASTER TRINIDADENSIS Hay, n. sp.
Pl. 2, Figs. 10-12

Diagnosis: Asteroliths with six subpentagonal rays having flat or slightly concave terminations.

Description: The rays of this species are closely joined throughout two-thirds of their length; the interray areas are shallow notches with the two sides making an angle of about 120°. The ends of the rays are flat or slightly concave. The rays are apparently joined in two sets of three, in the manner typical for Hemidiscaster Tan Sin Hok.

Remarks: This species is related to Discoaster nephados, but differs in having the rays joined throughout most of their length, and in having flatter terminations.

Holotype: UI-H-3768 (Pl. 2, Fig. 11)
Diameter of holotype: 9 u.
Paratypes: UI-H-3769-3770
Diameter of paratypes: 12-14 u.

Type locality: Cipero type section, near south end; south Trinidad. N:227300 links; E:352900 links. (JS 1840 = K.9397 of Bolli, 1957b).

Type level: Catapsydax stainforthi Zone (Type locality).

Remarks: Common in the Catapsydax stainforthi Zone, rare in the Catapsydax dissimilis Zone.
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EDITORIAL NOTE: Foreign language accents have not been used in this book because they were not available to the printers. The authors are in no way responsible for their omission. The Editor regrets this unavoidable circumstance.
EXPLANATION OF PLATE 1

Light micrographs, phase contrast illumination, 2000X
Oceanic Formation, Barbados

Figure 1. Discoaster tani tani Bramlette & Riedel. Hypotype UI-H-3771, JS 1880, near summit of Mount Hillaby.

Figure 2. Discoaster tani nodifera Bramlette & Riedel. Hypotype UI-H-3772, JS 1871, about 54' above contact with Joes River Formation, Mount Hillaby.

Figure 3. Discoaster incomptus Hay, n. sp. Holotype UI-H-3750, JS 1871, about 54' above contact with Joes River Formation, Mount Hillaby.


Figure 12. Isthmolithus recurvus Deflandre. Hypotype UI-H-3779, JS 1880, near summit of Mount Hillaby.
Plate 1.
EXPLANATION OF PLATE 2

Light micrographs, phase contrast illumination, 2000X

Cipero Formation, Trinidad; Oceanic Formation, Barbados


Figures 4-5. Discoaster nephados Hay, n. sp. 4. Holotype UI-H-3757, JS 1840 (= K.9397 of Bolli, 1957b; type locality of the Catapsydrax stainforthi Zone), Trinidad; 5. Paratype UI-H-3758, JS 1842, about 300 feet northeast of JS 1840, Catapsydrax stainforthi Zone.


EXPLANATION OF PLATE 3

Light micrographs, phase contrast illumination, 2000X

Cipero and Lengua Formations, Trinidad;
San San Clay Jamaica

Figure 1. Discoaster aulakos Gartner. Hypotype UI-H-3784, Rz 108 (Type locality of the Globigerinatella insueta Zone), Trinidad.


Figure 11. Discoaster variabilis Martini & Bramlette. Hypotype UI-H-3785, KR 23425 (Type locality of the Globorotalia menardii Zone), Trinidad.
EXPLANATION OF PLATE 4

Light micrographs, phase contrast illumination, 2000X

Cipero and Lengua Formations, Trinidad;
San San Clay, Jamaica.


Plate 4.