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THE CALCAREOUS NANNOPLANKTON OF THE MIDWAY GROUP (PALEOCENE) OF ALABAMA

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ILLUSTRATIONS

I. ABSTRACT

The calcareous nannoplankton in samples from the Paleocene Midway group of Alabama were examined and photographed using both a light misroscope and a scanning electron miscroscope. Twenty-seven species were identified, two of which are described as new. The nannoplankton distribution was used to correlate the Alabama Midway Group with standard Paleocene nannoplankton zonations resulting in the Pine Barren and McBryde members of the Clayton Formation being assigned to the *Cruciplacolithus tenuis* zone, and the Porters Creek Clay and the Matthews Landing Member being assigned to the *Cyclococcolithina robusta* zone. The nannoplankton distribution and abundances are related to the lithology and depositional environments of the Midway units. The Clayton and Porters Creek units contain certain species that are confined to or are more abundant in, particular lithologic facies. The very shallow-water deposits of the Naheola Formation are barren of nannoplankton.

II. INTRODUCTION

The Midway Group of Alabama consists of three formations (figure 1). These are, in order of stratigraphic sequence: (1) the Clayton Formation, which in central Alabama is divided into the lower Pine Barren Member and the upper McBryde Limestone Member; (2) the Porters Creek Clay, present only in western Alabama, with the Matthews Landing Marl Member at the top; and (3) the Naheola Formation, present only in central and western Alabama, divided into the lower Oak Hill Member and the upper Coal Bluff Marl Member.

Smith (1886) first used the term "Midway" in describing the strata exposed at Midway Landing on the Alabama River in Wilcox County, Alabama (figures 2, 3 and 4). This section at Midway Landing was described by Smith as having a few feet of black clay, which seemed equivalent to that at Black Bluff on the Tombigbee River (Porters Creek Clay), overlying about ten feet of gray, argillaceous limestone (the McBryde Limestone) with the nautiloid

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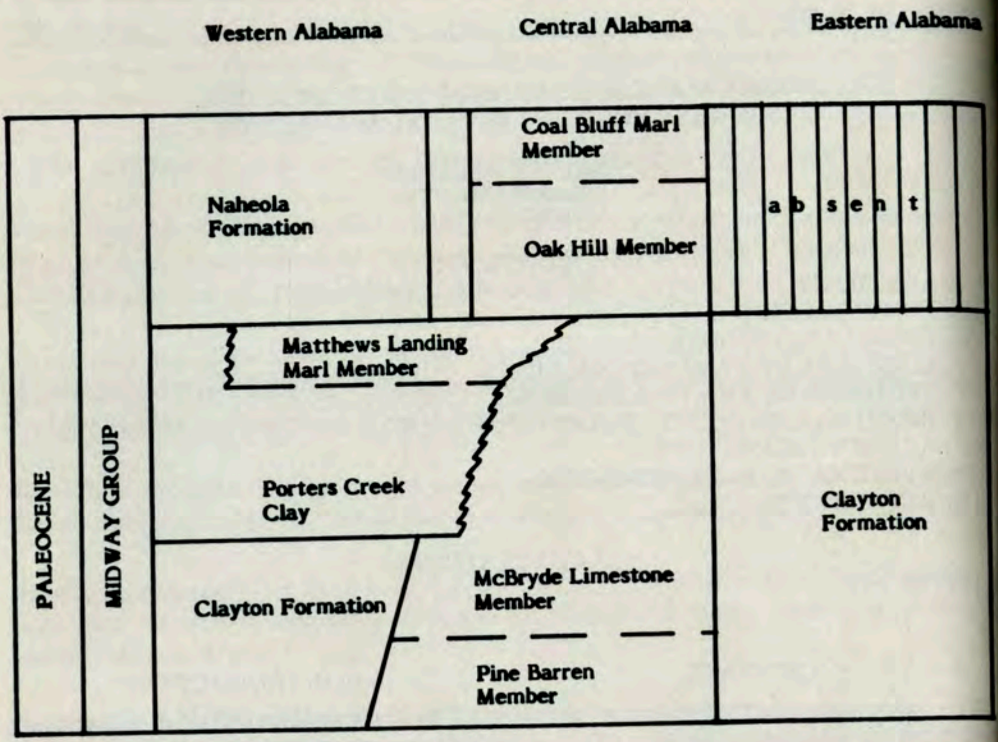

Figure 1 - Formations and Members of the Midway Group in Alabama

Enclimatoceras. LaMoreaux and Toulmin (1953) described this Midway section as part of the McBryde Limestone Member of the Clayton Formation, consisting of four hard calcareous claystone ledges interbedded with gray marl. Since the Alabama River has been dammed, only the uppermost claystone ledge is exposed.

The Clayton Formation was named for exposures near Clayton, Barbour County, Alabama by Smith (1892). Exposures at the type locality, in a Central of Georgia Railroad-cut one mile east of Clayton, consist of approximately 12 feet of dense, crystalline, gray limestone underlain by a tan, clayey sand (figures 2 and 5). LaMoreaux and Toulmin (1953) described the Clayton in Wilcox County, Alabama, as consisting of about 140 feet of massive limestone with some basal sand. In extreme western Alabama the Clayton Formation consists of less than 20 feet of limestone.

The Pine Barren Member of the Clayton Formation was named by MacNeil (1946) for strata exposed in roadcuts on the south side of Pine Barren Creek, along Alabama Highway 21 in Wilcox County (figures 2 and 4). In the upper part of this member is the "*Turritella* rock" of Smith (1894), which consists of a sandy yellow, crystalline limestone containing *Turritella alabamensis*. The lower part of the member is a gray calcareous silt with indurated ledges. In Wilcox County the Pine Barren Member has an estimated thickness of 125 feet (LaMoreaux and Toulmin, 1953).

The McBryde Limestone Member was named by MacNeil (1946) for exposures in roadcuts along Alabama Highway 21 in Wilcox County, approximately three miles west of McBryde Station. The station no longer exists but exposures can be found along Highway 21 at a locality 0.2 mile south of the intersection of Highway 21 and Highway 28 in Wilcox County (figures 2 and 4). At this locality the strata consist of approximately ten feet of light gray limestone, lying directly on the "*Turritella* rock" of the Pine Barren Member. The McBryde Limestone thickens to about 30 feet in eastern Wilcox County and Butler County (LaMoreaux and Toulmin, 1953).

Farther west it becomes more clayey and intertongues with the lower part of the Porters Creek Clay.

The Porter's Creek Clay was named by Safford (1864) for exposures west of Middleton, Tennessee. The equivalent deposits in Alabama were originally called the Sucarnoochee Clay by Smith (*in* Smith and Johnson, 1887) from exposures along Sucarnoochee Creek in Sumter County, Alabama. The type locality of the Sucarnoochee Clay is Black Bluff on the Tombigbee River below its confluence with Sucarnoochee Creek (figures 2 and 6). In western Alabama, the Porters Creek Clay consists of 350 feet of black, jointed clay with some limonitic concretions. Approximately 5 feet of glauconitic sand is present

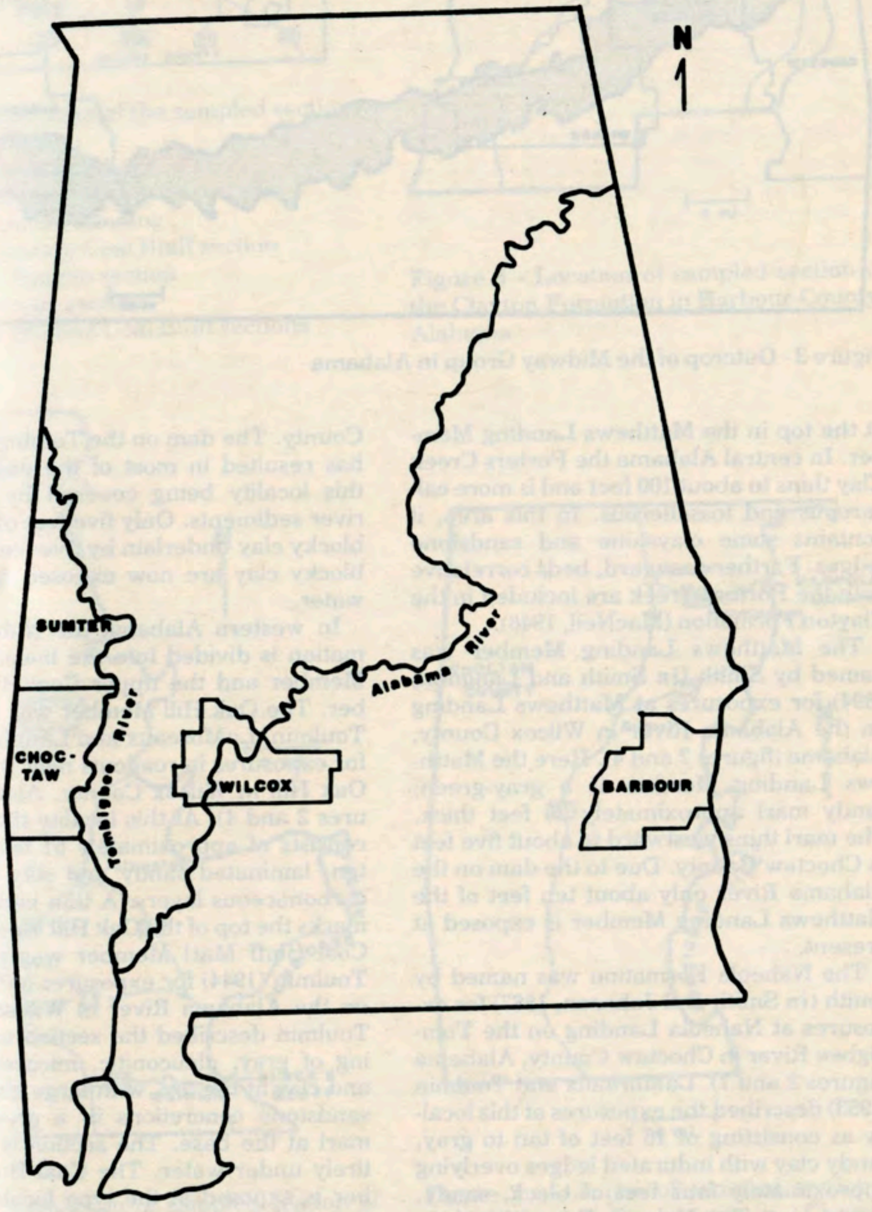

Figure 2 - Counties containing type sections of the Midway Group in Alabama

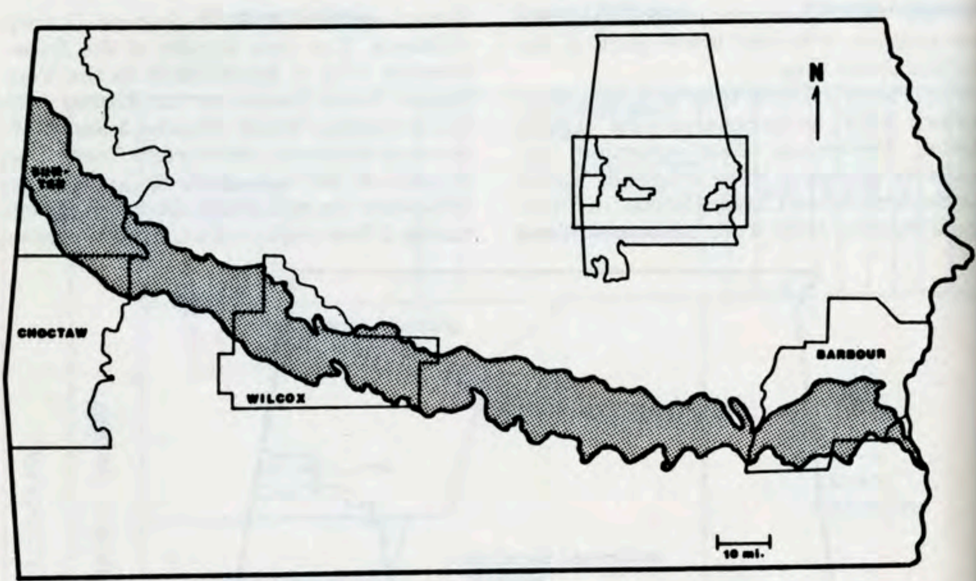

Figure 3 - Outcrop of the Midway Group in Alabama

at the top in the Matthews Landing Member. In central Alabama the Porters Creek Clay thins to about 100 feet and is more calcareous and fossiliferous. In this area, it contains some claystone and sandstone ledges. Farther eastward, beds correlative with the Porters Creek are included in the Clayton Formation (MacNeil, 1946).

The Matthews Landing Member was named by Smith (*in* Smith and Langdon, 1894) for exposures at Matthews Landing on the Alabama River in Wilcox County, Alabama (figures 2 and 4). Here the Matthews Landing Member is a gray-green, sandy marl approximately 20 feet thick. The marl thins westward to about five feet in Choctaw County. Due to the dam on the Alabama River only about ten feet of the Matthews Landing Member is exposed at present.

The Naheola Formation was named by Smith (*in* Smith and Johnson, 1887) for exposures at Naheola Landing on the Tombigbee River in Choctaw County, Alabama (figures 2 and 7). LaMoreaux and Toulmin (1953) described the exposures at this locality as consisting of 16 feet of tan to gray, sandy clay with indurated ledges overlying approximately four feet of black, sandy, blocky clay. The Naheola Formation thins eastward until it disappears east of Wilcox County. The dam on the Tombigbee River has resulted in most of the exposures at this locality being covered by water or river sediments. Only five feet of tan-gray, blocky clay underlain by five feet of black, blocky clay are now exposed during low water.

In western Alabama the Naheola Formation is divided into the lower Oak Hill Member and the upper Coal Bluff Member. The Oak Hill Member was named by Toulmin, LaMoreaux and Lanphere (1951) for exposures in roadcuts near the town of Oak Hill in Wilcox County, Alabama (figures 2 and 4). At this locality the Oak Hill consists of approximately 51 feet of gray-tan, laminated sandy and silty clay with carbonaceous layers. A thin bed of lignite marks the top of the Oak Hill Member. The Coal Bluff Marl Member was named by Toulmin (1944) for exposures at Coal Bluff on the Alabama River in Wilcox County. Toulmin described the section as consisting of gray, glauconitic, micaceous sand and clay at the top, with large glauconitic, sandstone concretions in a green sandy marl at the base. The section is now entirely under water. The Coal Bluff Member is exposed at the type locality of the Oak Hill Member and at Shoal Creek in Wilcox County (figures 2 and 4).

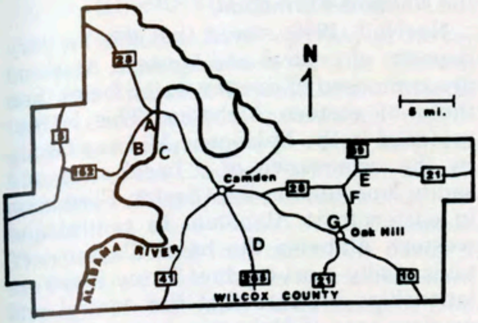

Figure 4 - Location of the sampled sections in Wilcox County.
A - Midway Landing
B - Secondary McBryde section
C - Matthews Landing
D - Secondary Coal Bluff section
E - Pine Barren section
F - McBryde section
G - Oak Hill and Coal Bluff sections

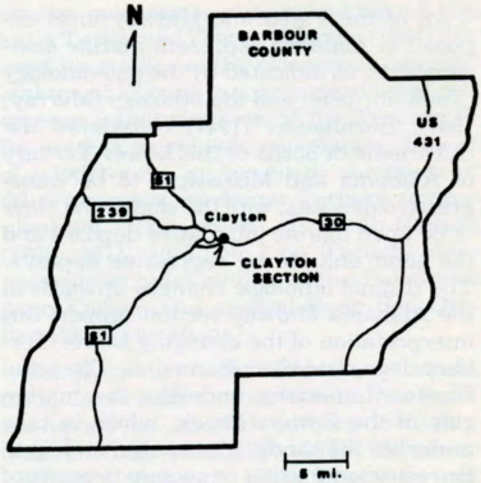

Figure 5 - Location of sampled section of the Clayton Formation in Barbour County, Alabama

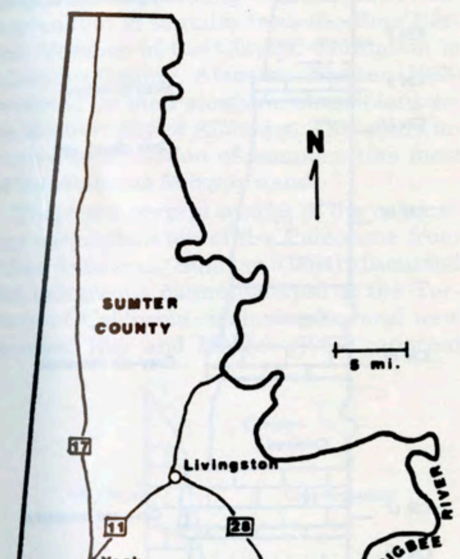

Figure 6 - Location of sampled section of the Porters Creek Formation in Sumter County, Alabama

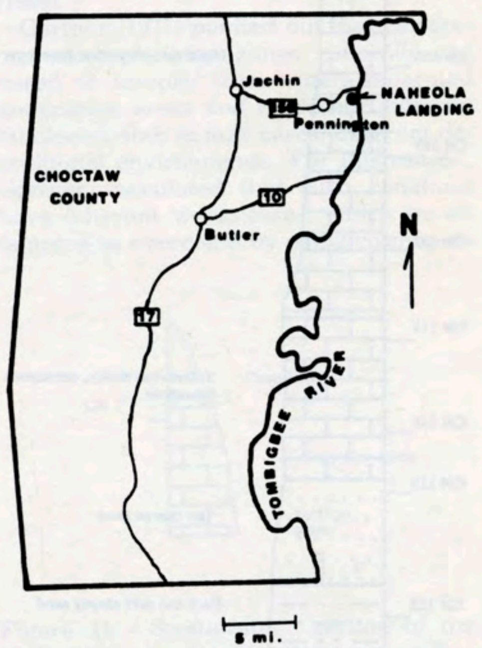

Figure 7 - Location of sampled section of the Naheola Formation in Choctaw County, Alabama

All of the Paleocene Midway units exposed in Alabama represent marine environments, as indicated by the paleontology (Toulmin, 1946) and the lithology (Murray, 1947). Bornhauser (1947) considered the calcareous deposits of the Lower Tertiary of Alabama and Mississippi to be transgressive deposits; with the shales and clays to be open marine inundative deposits and the sand units to be regressive deposits. The distinct lithologic changes upwards in the Alabama Midway section support this interpretation of the changing Lower Tertiary depositional environments. The basal Clayton Limestone underlies the marine clay of the Porters Creek, which in turn underlies the sandy, glauconitic, and lignitic restricted marine or swamp deposits of the Naheola Formation.

NacNeil (1946) stated that the Tertiary deposits of central and western Alabama are composed of deeper water facies than those of eastern Alabama. This is represented in the Paleocene Midway Group by the occurrence of a basal sand and sandy limestone in the Clayton Formation in easternmost Alabama. In central and western Alabama the basal Clayton contains a silty marl or clay. These facies relationships indicate that the central and western area of Alabama was more remote from the source of sediments than the areas on either side, and that the Tertiary shoreline extended from eastern Georgia to northern Mississippi (Toulmin, 1946).

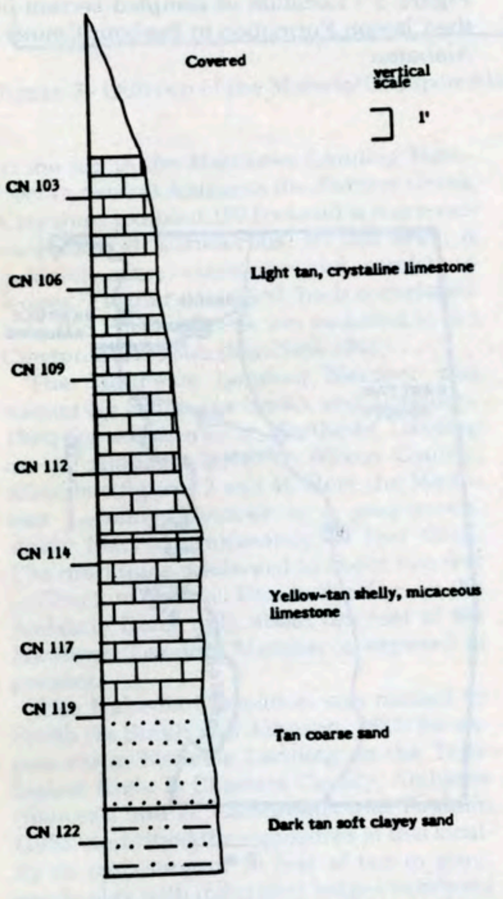

Figure 8 - Stratigraphic section of the Clayton Formation in Barbour County

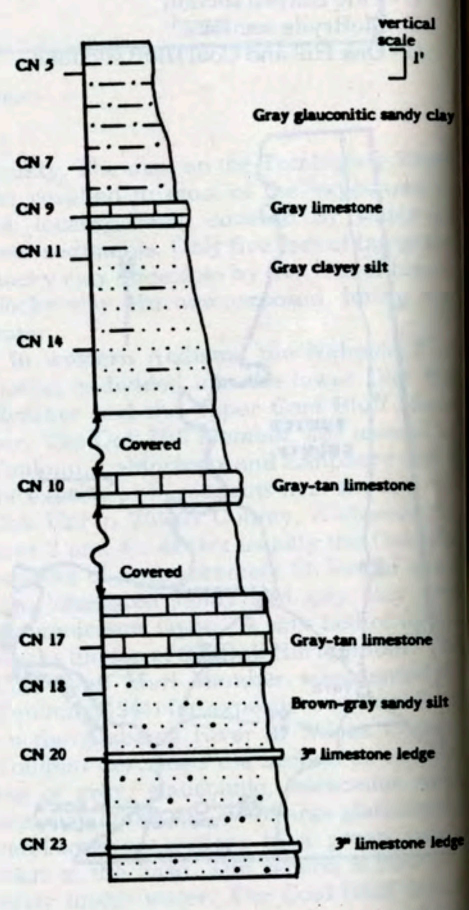

Figure 9 - Stratigraphic section of the Pine Barren Member in Wilcox County

III. PREVIOUS STUDIES

Several studies have reported on the calcareous nannoplankton of the Midway strata of Alabama. Bramlette and Martini (1964) described the calcareous nannoplankton in one sample from the McBryde Member of the Clayton Formation. Representatives of ten species of calcareous nannoplankton were found in that sample. They also stated that coccoliths occur in the Porters Creek Clay in sparse numbers. Hay and Mohler (1967) used samples from the McBryde and Pine Barren members of the Clayton Formation in their correlation of early Tertiary rocks from the U. S. Gulf Coast, France, and other worldwide locations. No list of the species found in the individual samples was included in that report. Ellis and Lohmann (1973) described a new species of coccolith, *Toweius petalosus*, in samples from the Clayton Formation and the Porters Creek Formation from Sumter County, Alabama. Cepek *et al.* (1968) reported finding no calcareous nannoplankton in samples from the Pine Barren Member of the Clayton Formation in Lowndes County, Alabama. Siesser (1983) reported on the Paleogene nannoplankton biostratigraphy of Alabama. This study included examination of samples from most of the Alabama Midway units.

There are several studies of the calcareous nannoplankton of the Paleocene from other locations. Sullivan (1964) discussed the calcareous nannoplankton of the Tertiary of California, including several new species. Hay and Mohler (1967) reported on the calcareous nannoplankton of the early Tertiary of France. Martini (1964) has used his studies of the calcareous nannoplankton of Europe to construct zones of calcareous nannoplankton of the Tertiary to be used in worldwide correlation. Hay *et al.* (1967) gave an excellent summary of other previous works on Tertiary nannoplankton. The work of Perch-Neilsen (1969, 1971, 1977, etc.) on Tertiary nannofossils includes studies of the Paleocene from Europe and several Deep Sea Drilling Project locations.

Subdivision of the Paleocene strata using calcareous nannoplankton has been attempted by several authors including Martini (1959, 1961, 1970, 1971), Stradner (1959; *in* Gohrbandt, 1963), Bramlette and Sullivan (1961), Hay and Mohler (1965, 1967), and Sullivan (1964). The more recent work of Hay *et al.* (1967) utilized previous studies to produce more useful zones based on continental and marine sediments. Gartner (1971) erected zones (see figure 18), modified from those of Hay, which he correlated with planktonic foraminiferal zones adapted from Blow (1969).

Gartner (1971) pointed out that calcareous nannoplankton zones generally are based on samples from widely separated geographic areas and represent different lithologies and, in may cases, different depositional environments. For this reason, Gartner speculated that such zonations have inherent weaknesses, which he attempted to overcome by using cosmopoli-

Figure 10 - Stratigraphic section of the McBryde Limestone Member at type locality in Wilcox County

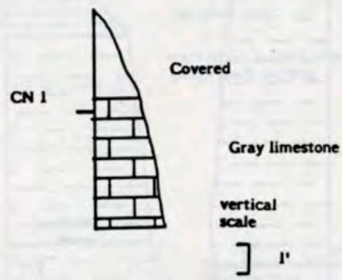

Figure 11 - Stratigraphic section of the McBryde Limestone Member at secondary location in Wilcox County (Sample CN 78 taken from 4 inch ledge of McBryde Limestone at Midway type locality)

tan species when possible as zonal indicators. His modification of the Hay *et al.* (1967) zonation consisted of recognizing one new mid-Paleocene zone, the *Cyclococcolithina robusta* zone, and defining the Paleocene-Eocene boundary, based on calcareous nannoplankton as falling within the *Marthasterites contortus* zone. Hay *et al.* did not base the Paleocene-Eocene boundary on the calcareous nannoplankton, but stated: "The Paleocene-Eocene boundary, as defined on the basis of evolutionary series of larger foraminifera in Europe, lies within the *Marthasterites tribrachiatus* zone."

The Paleocene calcareous nannoplankton zones of Gartner (1971) are based on the first or last occurrences of different calcareous nannoplankton species and are defined as follows:

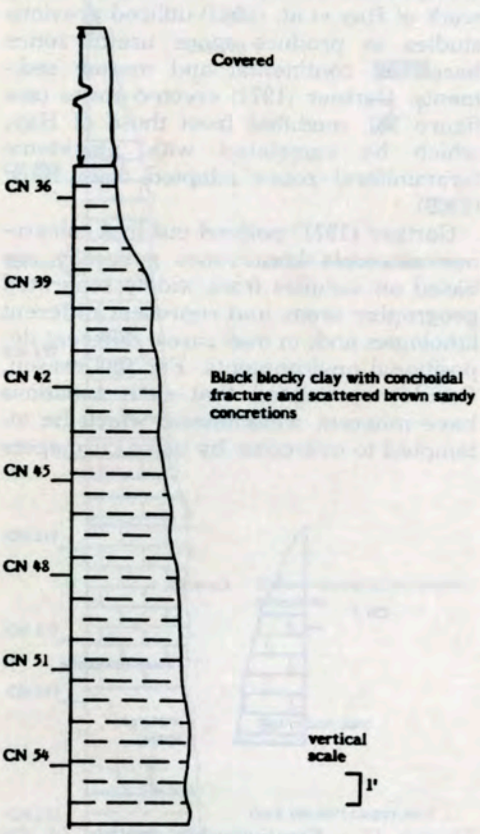

Figure 12 - Stratigraphic section of the Porters Creek Formation in Sumter County

MARKALIUS ASTROPORUS Zone - The interval from the first occurrence of *Markalius astroporus* to the first occurrence of *Cruciplacolithus tenius*. Other species common in this zone are;

Braarudosphaera bigelowi
Braarudosphaera discula
Biantholitus sparsus

CRUCIPLACOLITHUS TENUIS Zone - The interval from the first occurrence of *Cruciplacolithus tenuis* to the first occurrence of *Cyclococcolithina robusta*. The species of the *Markalius astroporus* zone are still present along with *Chiasmolithus danicus*.

CYCLOCOCCOLITHINA ROBUSTA Zone - The interval from the first occurrence of *Cyclococcolithina robusta* to the first occurrence of *Fasciculithus tympaniformis*. Other species common in this zone are:

Markalius astroporus
Cruciplacolithus tenuis
Ellipsolithus macellus
Toweius craticulus
Chiasmolithus bidens

FASCICULITHUS TYMPANIFORMIS Zone - The interval from the first occurrence of *Fasciculithus tympaniformis* to the first occurrence of *Heliolithus kleinpelli. The species of the Cruciplacolithus tenuis* and *Cyclococcolithina robusta* zones

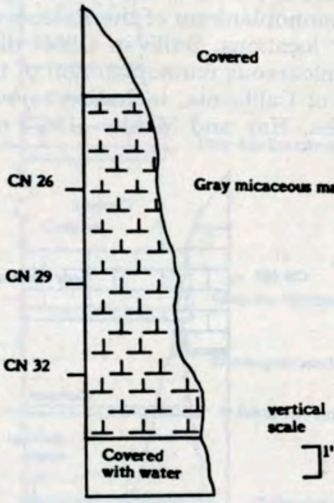

Figure 13 - Stratigraphic section of the Matthews Landing Member in Wilcox County

are still present. Other species common in this zone are:

Heliorthus concinnus
Chiasmolithus consuetus

HELIOLITHUS KLEINPELLI Zone - The interval from the first occurrence of *Heliolithus kleinpelli* to the first occurrence of *Discoaster gemmeus*. Other species common in this zone are:

Braarudosphaera bigelowi
Chiasmolithus danicus
Cyclococcolithina robusta
Fasciculithus tympaniformis
Chiasmolithus bidens
Heliorthus concinnus
Chiasmolithus consuetus

DISCOASTER GEMMEUS Zone - The interval from the first occurrence of *Discoaster gemmeus* to the first occurrence of *Heliolithus riedeli*. The species of the *Heliolithus kleinpelli* zone are still present except for *Heliolithus kleinpelli*. Also common in this zone is *Dicoaster helianthus*.

HELIOLITHUS RIEDELI Zone - The interval from the first occurrence of *Heliolithus riedeli* to the first occurrence of *Discoaster multiradiatus*. The species of the *Discoaster gemmeus* zone are still present. Other species common in this zone are:

Discoater delicatus
Discoaster nobilis
Discoaster limbatus
Zygodiscus plectopons

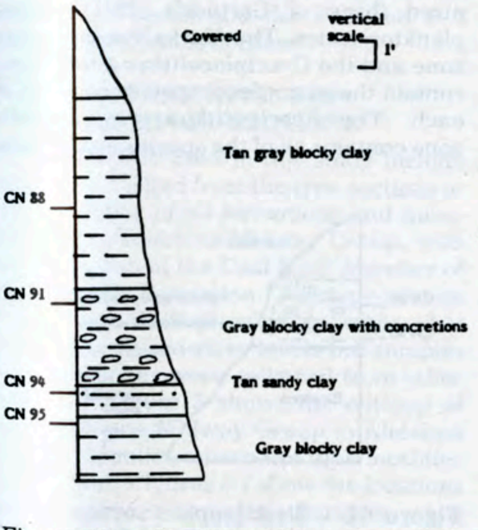

Figure 14 - Stratigraphic section of the Naheola Formation in Choctaw County

Ellipsolithus distichus
Fasciculithus involutus

DISCOASTER MULTIRADIATUS Zone - The interval from the first occurrence of *Discoaster multiradiatus* to the first occurrence of *Marthasterites bramletti*. Species common in this zone are:

Discoaster gemmeus
Discoaster perpolitus
Discoaster lenticularis
Discoaster mediosus
Discoaster delicatus
Discoaster nobilis
Discoaster limbatus
Zygodiscus plectopons
Clathrolithus ellipticus
Chiasmolithus danicus
Cyclococclithina robusta
Chiasmolithus consuetus
Fasciculithus tympaniformis

MARTHASTERITES CONTORTUS Zone - The interval from the first occurrence of *Marthasterites bramlettei* to the last occurrence of *Marthasterites contortus*. Species common in this zone are:

Discoaster binodosus
Discoaster diastypus

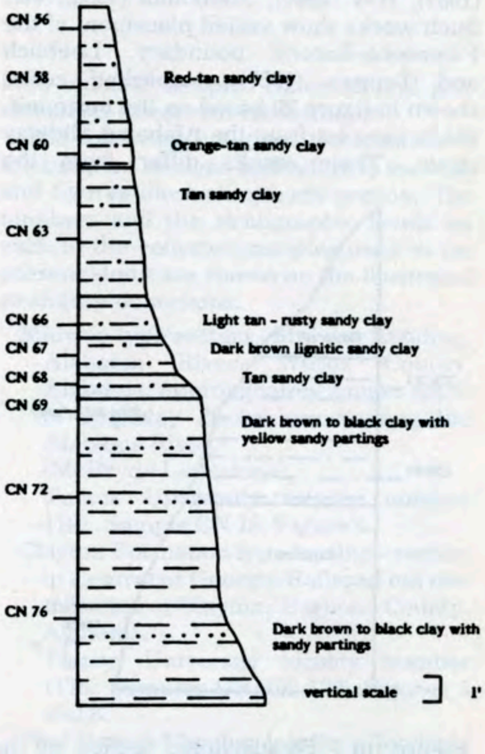

Figure 15 - Stratigraphic section of the Oak Hill Member in Wilcox County

Discoaster perpolitus
Discoaster multiradiatus
Discoaster gemmeus
Discoaster lenticularis
Discoaster nobilis
Zygodiscus plectopons
Chiasmolithus danicus
Fasciculithus tympaniformis
Cyclococcolithina robusta

The zonation of Martini (1970, 1971) has modified the previous zonations by erecting two zones between the *Cruciplacolithus tenuis* and *Fasciculithus tympaniformis* zones: 1) the *Chiasmolithus danicus* zone, and 2) the *Ellipsolithus macellus* zone. Martini assigned numbers (NP-1, etc.) to all of the nannoplankton zones (see figure 19) and correlated them to existing foraminiferal zones. Siesser (1983) assigned the following zones of Martini to the corresponding Alabama Midway units: Pine Barren, NP-1 and 2; McBryde, Porters Creek and Matthews Landing, NP-3 and 4; Naheola and Coal Bluff, NP-5.

Paleocene foraminiferal zonations have been published, based on studies by Bolli (1957), Hay (1960), Subbotina (1953), etc. Such works show varied placement of the Paleocene-Eocene boundary. Loeblich and Tappan (1957) established zones shown in figure 20 based on the foraminifers in samples from the Alabama Midway strata. Their results differ from the Paleocene zonation of other workers. Berggren (1965) used the results of previous workers to produce a correlation of the Alabama Midway Group with planktonic foraminiferal zones (see figures 20). Blow (1969), in his widely used foraminiferal zonations, divided the Paleocene into five planktonic zones (see figure 18).

Comparing the Gulf Coast Paleocene foraminiferal zonations of Loeblich and Tappan, and Berggren to the standard divisions of Blow and correlating these to the standard nannoplankton zones of Gartner (see figure 21), the following conclusions can be presented:

(1) The Clayton Formation is within the P1 zone of Blow, or the *Markalius astroporus* and *Cruciplacolithus tenuis* nannoplankton zones.

(2) According to Berggren's zonation, the lower section of the Porters Creek Clay correlates with zone P 2, or the *Cruciplacolithus tenuis* and *Cyclococcolithina robusta* nannoplankton zones.

(3) The Matthews Landing Member of the Porters Creek Clay, and the Naheola Formation correlate with the P 3 foraminiferal zone, or the *Cyclococcolithina robusta, Fasciculithus tympaniformis*, and *Heliolithus kleinpelli* nannoplankton zones.

Hay and Mohler (1967), examining samples from the McBryde and Pine Barren members of the Clayton Formation, recognized three of Gartner's (1971) nannoplankton zones. The *Markalius astroporus* zone and the *Cruciplacolithus tenuis* zone contain the nannofossil species common in each. The *Fasciculithus tympaniformis* zone contains all of the species characteris-

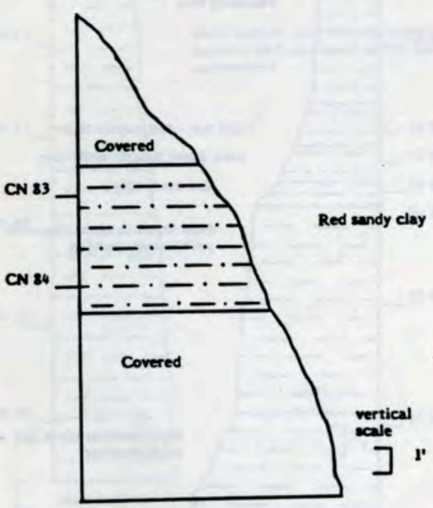

Figure 16 - Stratigraphic section of the Coal Bluff Member at Oak Hill locality in Wilcox County

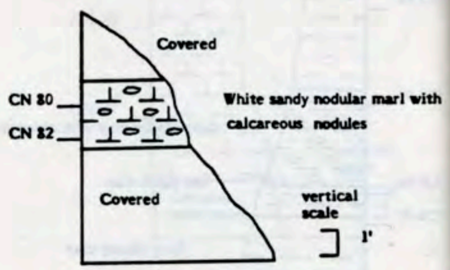

Figure 17 - Stratigraphic section of the Coal Bluff Member at Shoal Creek in Wilcox County

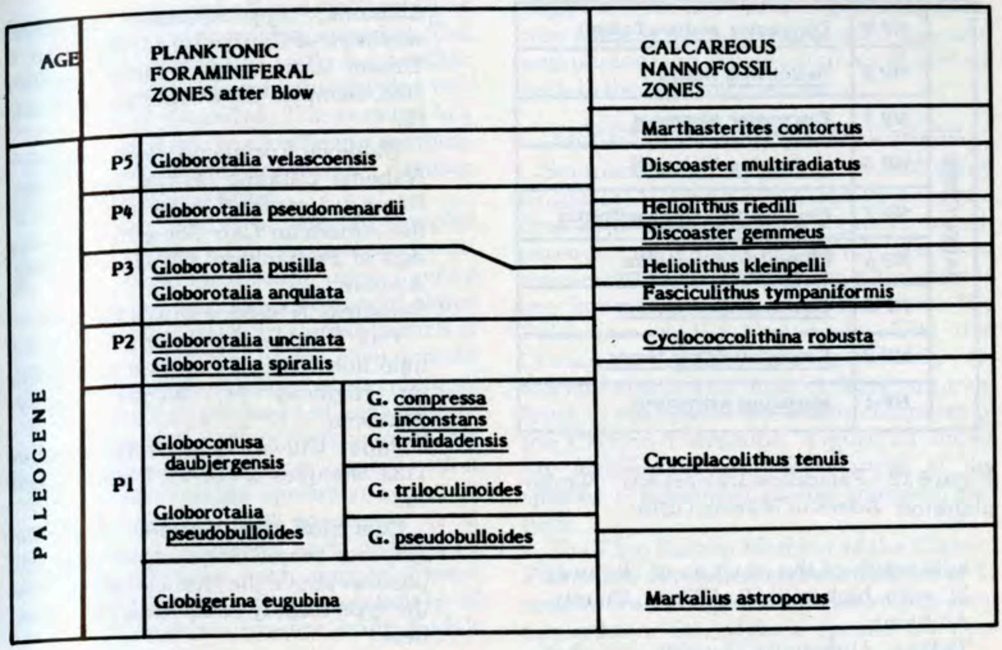

Figure 18 - Paleocene Calcareous Nannoplankton Zonation and corresponding foraminiferal zonations (after Gartner 1971)

tic of Gartner's zone except for *Fasciculithus tympaniformis*. These occurrences are compared by the author with the standard foraminiferal zonations as shown in figure 22. The Clayton Formation is correlated with the aforementioned nannoplankton zones and the P 2 and P 3 foraminiferal zones of Blow.

IV. LOCATIONS OF SAMPLED SECTIONS

The samples used in this study include material collected from the type sections or type localities of all formations and members of the Alabama Midway Group, with the exception of the Coal Bluff Member of the Naheola Formation. The type section of the Coal Bluff Member is inaccessible because of raised river levels but samples of this member were collected from other locations. Figure 3 shows the outcrop of the Paleocene Midway Group in Alabama and the counties where the type localities are studied. Figures 5-7 show the locations of the sections sampled. Samples were taken at one foot intervals from each section. The letters CN before sample numbers indicate samples collected and processed for calcareous nannofossils.

The following list gives the location of the sampled sections and refers to the map and figures illustrating each section. The numbers and the stratigraphic levels for each of the collected samples used in the present study are shown on the illustrated stratigraphic sections.

Midway type section - Midway Landing, Alabama River, Wilcox County, Alabama; approximately 2 miles south of Highway 28 bridge crossing the Alabama River.
(McBryde Limestone)
Tulane University locality number 1181. Sample CN 78; Figure 4.

Clayton Formation type locality - section in Central of Georgia Railroad cut one mile east of Clayton, Barbour County, Alabama.
Tulane University locality number 1178. Samples CN 103-122; Figures 5 and 8.

Pine Barren Member locality - Roadcuts on the south side of Pine Barren Creek on Alabama Highway 21, one

PALEOCENE	NP 9	Discoaster multiradiatus
	NP 8	Heliolithus riedeli
	NP 7	Discoaster gemmeus
	NP 6	Heliolithus kleinpelli
	NP 5	Fasciculithus tympaniformis
	NP 4	Ellipsolithus macellus
	NP 3	Chiasmolithus danicus
	NP 2	Cruciplacolithus tenuis
	NP 1	Markalius astroporus

Figure 19 - Paleocene Calcareous Nannoplankton Zones of Martini (1970)

mile south of the junction of Highway 21 with highway 89, Wilcox County, Alabama.
Tulane University locality number 1179. Samples CN 5-23; Figures 4 and 9.

McBryde Member type locality - Roadcut on Alabama Highway 21, 0.2 mile south of the junction of Highway 21 with Highway 28, Wilcox County, Alabama.
Tulane University locality number 1180. Samples CN 96-102; Figures 4 and 10.

McBryde Member secondary locality - Creek bed just off of Alabama highway 162 one mile south of the junction of Highway 162 with Highway 28, Wilcox County, Alabama.
Tulane University locality number 1186. Samples CN 1-4; Figures 4 and 11.

Midway Landing type section (See Midway type section above).

Porters Creek Clay - type locality of Sucarnoochee Clay, Black Bluff on the Tombigbee River approximately 2.5 miles east of Whitfield, Sumter County, Alabama.
Tulane University locality number 1182. Samples CN 36-55; Figures 6 and 12.

Matthews Landing Marl Member type locality - Matthews Landing on the Alabama River, Wilcox County, Alabama; approximately 5 miles southeast of Canton Bend, Alabama.
Tulane University locality number 1183. Samples CN 24-35; Figures 4 and 13.

Naheola Formation type locality - Naheola Landing on the Tombigbee River just south of the pump house of the American Can Company, 2 miles east of Pennington, Choctaw County, Alabama.
Samples CN 85-95; Figures 7 and 14.

Oak Hill Member type locality - 0.5 mile northeast of Oak Hill post office on Highway 21, Wilcox County, Alabama.
Tulane University locality number 1185. Samples CN 56-77; Figures 4 and 15.

Coal Bluff Marl Member - (type locality not accessible) samples from exposures above the Oak Hill Member at the type locality of the Oak Hill Member.
Tulane University locality number 1185. Samples CN 83-84; Figures 4 and 16.

Coal Bluff Marl Member secondary locality - Roadcut on Highway 265 at Shoal Creek, 5.5 miles south of Camden, Wilcox County, Alabama.
Tulane University locality number 1187. Samples CN 79-82; Figures 4 and 17.

V. TECHNIQUES AND PROCEDURES

A portion of each of the samples collected from the Alabama Midway sections was processed to concentrate the coccolith-size fraction. This was accomplished by first removing the outer material from the rock fragment to ensure a non-contaminated portion. The cleaned sample was then crushed with a mortar and pestle. The powder was placed in a 50 ml beaker to which approximately 30 ml of buffering solution was added. An ultrasonic cleaner was then used to break up the sample and disperse the clay-size material. The beaker was allowed to stand for two minutes to settle the sand-size material. The remaining suspension was decanted into a second beaker and allowed to stand for two hours to concentrate the finer sized material. The remaining suspension was poured off and distilled water was added to the remaining sediment. The sample was allowed to settle for another two hours before the remaining water was decanted and discarded. This resulted in a sample free from any buffering solution, which could cause crystals to develop when the sample is dried.

Permanent mounts of selected samples were then prepared for examination with the Zeiss Photo microscope using Caedax as a mounting medium. Permanent slides were made of every third sample in each of the Midway sections, or for each sample where a change in lithology was evident. A second slide was prepared of each sample and examined to reduce the chance that a single slide could be of poor quality with a resulting unfavorable specimen count. A standard count of 150 specimens or 5 traverses was made on each of the two slides prepared for each sample. Photographs were taken of representatives of each of the species present using Kodak High Contrast Copy film. A Scanning Electron Microscope was also used to examine and photograph representatives of species seen in the light microscope.

VI. RESULTS AND CONCLUSIONS

Samples examined from the Midway Group of Alabama contained representatives of 27 species from 18 genera of calcareous nannoplankton. Two are new species described herein; the other species are forms previously described from the Paleocene or the Cretaceous. The five Cretaceous species are apparently reworked specimens; four of these are confined to the basal Pine Barren Member of the Clayton Formation. Figure 23 shows the distribution and abundances of the species represented in the sampled sections.

The Pine Barren Member of the Clayton Formation contained representatives of 21 species from 15 genera of calcareous nannoplankton. Ten of these species are con-

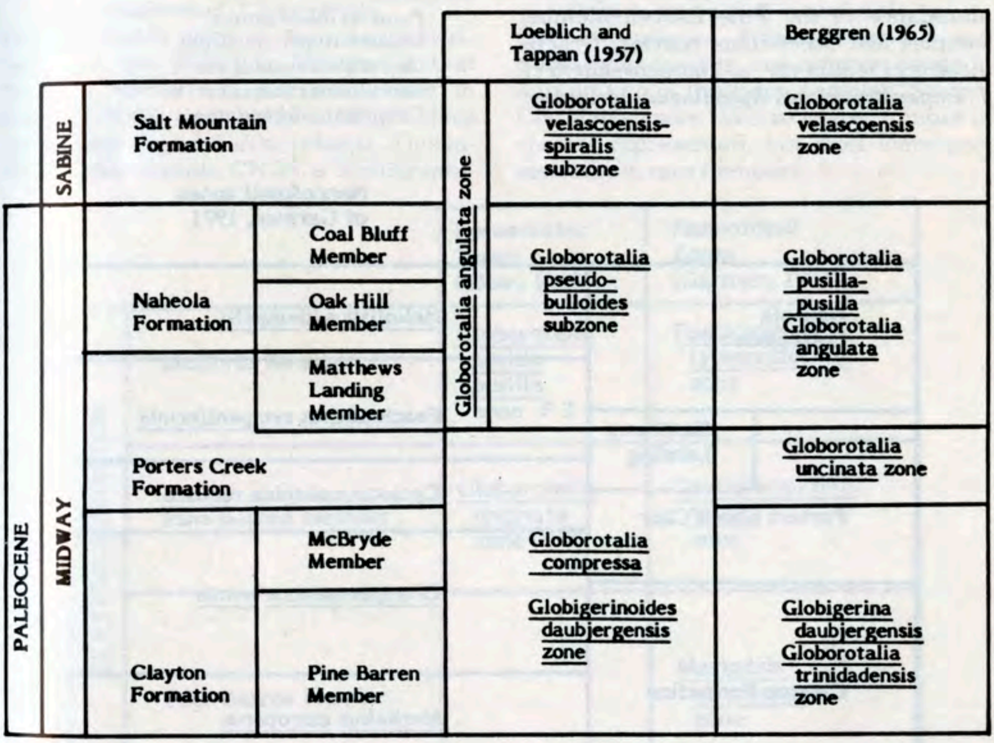

Figure 20 - Foraminiferal Zonation by Loeblich and Tappan, and Berggren of the Gulf Coast Paleocene

fined to the Pine Barren Member. These species are:

Braarudosphaera turbinea
Coccolithus species
Cribrosphaerella ehrenbergii
Cruciplacolithus tenuis var. c
Eiffelithus turriseiffeli
Heliorthus denticulatus
Markalius reinhardtii
Prediscosphaera cretacea
Toweius petalosus
Prinsius cf. *P. martinii*

Common species, or those appearing in more than fifty percent of the samples of the Pine Barren Member, are:

Chiasmolithus californicus
Coccolithus species
Cruciplacolithus tenuis var. a
Cruciplacolithus tenuis var. b
Markalius reinhardtii
Neococcolithes protenus
Thoracosphaera multiperforata
Tharacosphaera saxea
Thoracosphaera cf. *T. imperforata*
Zygodiscus sigmoides
Prinsius cf. *P. martinii*

Of these, the four that appear in greatest abundance in the Pine Barren Member samples are *Coccolithus* species, *Cruciplacolithus tenuis* var. a, *Thoracosphaera* cf. *T. imperforata*, and *Zygodiscus sigmoides*.

Three relationships are apparent in the Pine Barren Member:

1) The samples composed of sandy clay and silts generally yield more abundant counts of total specimens than the limestone samples;

(2) *Chiasmolithus californicus* is common in the Pine Barren Member and is confined to samples consisting of clayey silts, but is found in the overlying McBryde Limestone, indicating that no lithologic relationship between this species and associated sediments seems to exist;

(3) *Toweius petalosus* is present only in the lower half of the Pine Barren section and is more abundant near the bottom of the section. There is no apparent relation between the other species present or their abundances and the lithology of the samples.

The McBryde Member of the Clayton Formation contained representatives of 21 species from 10 genera of nannoplankton. Five species are confined to the McBryde Member:

Prinsius dimorphosus
Chiasmolithus consuetus
Coccolithus crassus var. a
Coccolithus crassus var. b
Coccolithus orbiculatus

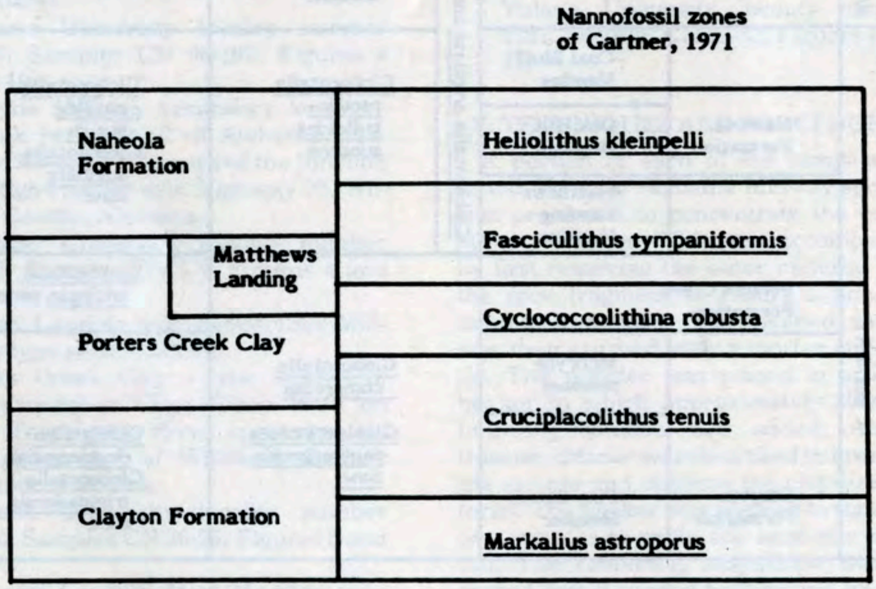

Figure 21 - Provisional Calcareous Nannoplankton zonation of the Alabama Midway based on foraminiferal zones of Blow

The samples examined are not from a single stratigraphic section, thus the primary relationship that can be determined is that of relative abundance and preservation. Sample CN-100 showed the poorest preservation with many specimens broken. Sample CN-78, from the type locality of the Midway, contained specimens in excellent condition. Species common to all three McBryde samples are:

Chiasmolithus californicus
Coccolithus cavus var. a
Coccolithus crassus var. b
Coccolithus orbiculatus
Cruciplacolithus tenuis var. b
Markalius astroporus
Neococcolithes protenus
Prinsius martinii
Thoracosphaera cf. *T. imperforata*
Zygodiscus sigmoides

The following species were common to abundant in at least two of the three McBryde Member samples:

Prinsius dimorphosus
Coccolithus cavus var. a
Thoracosphaera cf. *T. imperforata*

One noticeable point of nannofossil distribution in the McBryde Member is that *Prinsius martinii* is more abundant in sample CN-78, and that this sample does not contain *Prinsius dimorphosus*. This indicates that sample CN-78 is stratigraphically above the other two samples, as the stratigraphically higher Matthews Landing Mermber of the Porters Creek Clay also contains *Prinsius martinii* but not *Prinsius dimorphosus*.

The Porters Creek samples contained calcareous nannoplankton only in very small numbers. Only two species were present, *Cyclococcolithina robusta* and *Zygodiscus sigmoides*, both of which also occur in one sample of the Matthews Landing Member. The representatives of these species were only in fair condition, apparently due to partial solution.

The Matthews Landing Member contained 18 species of 12 genera of calcareous nannoplankton. Three species are confined to the Matthews Landing Member:

Braarudosphaera bigelowi
Cyclococcolithina cf. *C. robusta*
Discolithina versa

Four species appear in all three samples:

Prinsius martinii
Coccolithus species
Heliorthus concinnus
Thoracosphaera cf. *T. imperforata*

Only two species, *Prinsius martinii* and *Coccolithus* species, are common to abundant in two of the three samples. Sample CN-26 was more diverse in the number of species represented, but most were present only in rare numbers.

		Foraminifer Zones (Blow, 1969)	Nannofossil Zones (Gartner, 1971)
CLAYTON FORMATION	McBryde Member	Globorotalia pusilla pusilla zone P 3	Fasciculithus tympaniformis zone
	Pine Barren Member	Globorotalia uncinata zone P 2	Cruciplacolithus tenuis zone
	Pine Barren Member		Markalius astroporus zone

Figure 22 - Midway Calcareous Nannoplankton Zones after Hay and Mohler (1967)

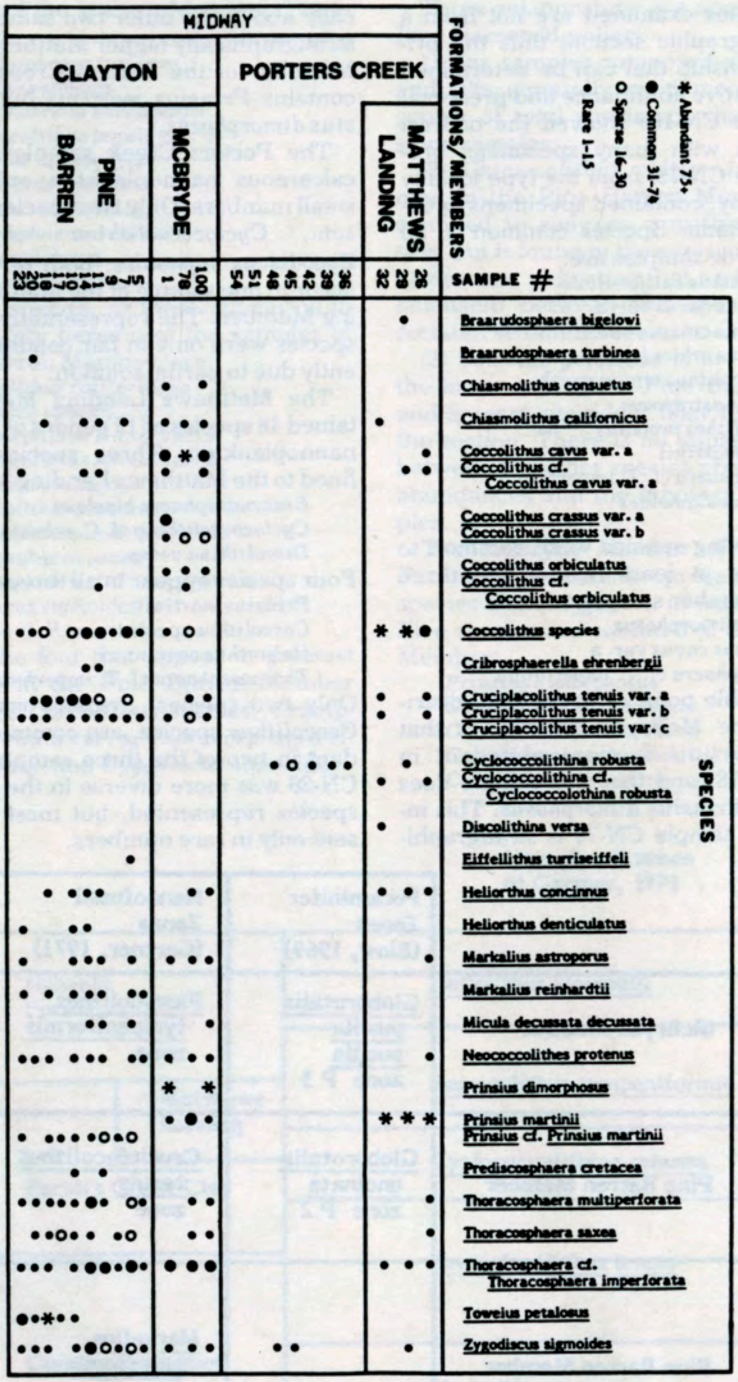

Figure 23 - Distribution and abundance of Calcareous Nannoplankton in the Alabama Midway Group. (Formations and Members not shown were barren of nannoplankton)

The samples from the Naheola Formation and the Oak Hill and Coal Bluff members of the Naheola were barren of calcareous nannoplankton. The samples from the type locality of the Clayton Formation were also barren of nannoplankton, apparently due to the recrystallization of the limestone.

The distribution and abundances of the calcareous nannoplankton are representative of the changing environmental conditions during the deposition of the Midway units. The calcareous deposits of the Clayton unit represent a shallow marine environment with an abundance of calcareous nannoplankton. The overlying Porters Creek Clay was deposited in a more open-marine environment (Bornhauser, 1947) but contains only two species of nannoplankton present in rare numbers. This indicates either that the environment was unfavorable for nannoplankton, possibly due to turbid water, or that preservation of the nannoplankton was poor as is evidenced by the poor conditions of the specimens seen in the samples. The two species present are more abundant in the Porters Creek Clay than in the Matthews Landing Member and may be indicators of the environmental conditions.

The Matthews Landing Member is calcareous and represents a more shallow-marine environment, similar to that represented by the Pine Barren and McBryde members of the Clayton Formation. This is evidenced by the fact that all three units contain some of the same species. But the environment of the Matthews Landing Member also must have been slightly different from that of the Clayton units as indicated by:

(1) The species common to the Clayton units and the Matthews Landing Member are generally present in more samples and/or greater numbers in individual samples in the two stratigraphically lower Clayton members;

(2) These two Clayton units also show a greater diversity in number of species;

(3) Some species appear and are confined to the Matthews Landing Member. This may be due to the restriction of these species to the environment present at the time of deposition of this unit, or to the evolution and extinction of certain forms.

The overlying Oak Hill and Coal Bluff members of the Naheola Formation are composed of sandy clays with lignitic, glauconitic, and micaceous layers indicative of very shallow marine or swamp conditions. Both of these units are barren of nannoplankton. The clays and sandy clays of the type locality of the Naheola Formation must have also been deposited in very shallow environments since no nannoplankton were found in the samples from this unit.

The examination of the samples from the Midway Group of Alabama results in the placement of;

(1) The Pine Barren and McBryde members of the Clayton Formation in the *Cruciplacolithus tenuis* zone of Cartner (1970), based on the presence of *Cruciplacolithus tenuis* and *Markalius astroporus* in samples from both members.

(2) The Porters Creek Clay and the Matthews Landing Member in the *Cyclococcolithina robusta* zone of Gartner (1970), based on the presence of *Cyclococcolithina robusta* in samples from both units, and on the presence of *Cruciplacolithus tenuis* and *Markalius astroporus* in the Matthews Landing samples.

Heliorthus concinnus and *Chiasmolithus consuetus*, indicators of the *Fasciculithus tympaniformis* zone, as defined by Hay *et al.* (1967), are present in the Pine Barren, McBryde, and/or Matthews Landing samples. These species are not indicators of the *Fasciculithus tympaniformis* zone in the Alabama Midway Group since they are restricted to the calcareous facies. If these two species were indicators of this zone most of the Alabama Midway section would have to be placed in the *Fasciculithus tympaniformis* zone, based only on the presence of these two species with *Fasciculithus tympaniformis* being absent. Thus the three lower Paleocene nannofossil zones would have to be contained in the lower part of the Pine Barren Member.

The absence of the key species *Fasciculithus tympaniformis* agrees with the findings of Hay and Mohler (1967), who assigned a section of the McBryde Member of the Clayton Formation to the *Fasciculithus tympaniformis* zone, but stated that this species was absent. Hay and Mohler (1967) assigned two sections of the

Pine Barren Member to the *Markalius astroporus* and *Cruciplacolithus tenuis* zones. The Pine Barren samples used in the present study are apparently from the higher stratigraphic portions of the Pine Barren section and represent only the *Cruciplacolithus tenuis* zone.

The zonation resulting from the present study of the nannoplankton in the Alabama Midway Group agrees more with the provisional nannoplankton zonation based on correlation of standard nannoplankton zones with Gulf Coast Paleocene foraminiferal zones (see figure 21), than with the Midway nannoplankton zonation of Hay and Mohler (1967).

VII. ACKNOWLEDGMENTS

The author wishes to thank Hubert C. Skinner, Harold Vokes, and Stefan Gartner for their assistance and advice during the course of this study.

VIII. SYSTEMATIC PALEONTOLOGY

The classification followed in the present study is that of the *Code of Botanical Nomenclature*.

Kingdom PLANTAE
Subkingdom PROTOBIONTA
Rothmaler, 1948
Division PHAEOPHYTA Wettstein, *emend.*, Rothmaler, 1949
Subdivision CHRYSOPHYTINA
Rothmaler, 1949
Class COCCOLITHOPHYCEAE
Rothmaler, 1949
Subclass COCCOLITHOPHYCIDAE
Rothmaler, 1949
Order PYRMNESIALES
Christensen, 1962
Family COCCOLITHACEAE
Kamptner, 1928
Subfamily COCCOLITHOIDEAE
Kamptner, 1928
Genus COCCOLITHUS Schwarz, 1894

Type species: Coccolithus oceanicus Schwarz, 1894

Definition: Elliptical placoliths with the distal shield larger than the proximal shield and joined to the proximal shield by a hollow tube. Both shields concave on the proximal side.

COCCOLITHUS CAVUS var. a
Plate 1, figures 1 and 2

Coccolithus cavus HAY and MOHLER, 1967, p. 1524, pl. 196, figs. 1-3; pl. 197, figs. 5, 7, 10, 12. PERCH-NEILSEN, 1969b, p. 322, pl. 33, figs. 3-6.

Ericsonia cava (HAY and MOHLER), PERCH-NIELSEN, 1969a, p. 61, pl. 4, figs. 13, 14.

Description: This large elliptical placolith has a distal shield composed of approximately 48 elements which show a slight dextral imbrication. The central area forms a depression that is partially filled by a cycle of elongate trapezoidal elements. The small central opening makes up approximately one-fifth of the total width of the placolith. The proximal shield is composed of the same number of elements as the distal shield but has a serrate margin.

Size: Maximum length 10 microns.

Occurrence: This species was reported from the Paleocene of France and Austria and was found in the Pine Barren and

PLATE 1

Figures 1, 2. *Coccolithus cavus* var. a; Sample CN-78
1a. Cross-polarized light, x3250
1b. Transmitted light, x3250
2. Electron micrograph, x9500, distal view

Figure 3. *Coccolithus* cf. *C. cavus* var. a; Sample CN-26
3a. Cross-polarized light, x3250, 70° to polarizer
3b. Transmitted light, x3250
3c. Phase-contrast, x3250

Figure 4. *Coccolithus* species; Sample CN-5
4a. Cross-polarized light, x3250, 70° to polarizer
4b. Transmitted light, x3250

*The cross-polarized light photographs were taken with the long axes of the specimen parallel to the polarizer unless stated otherwise.

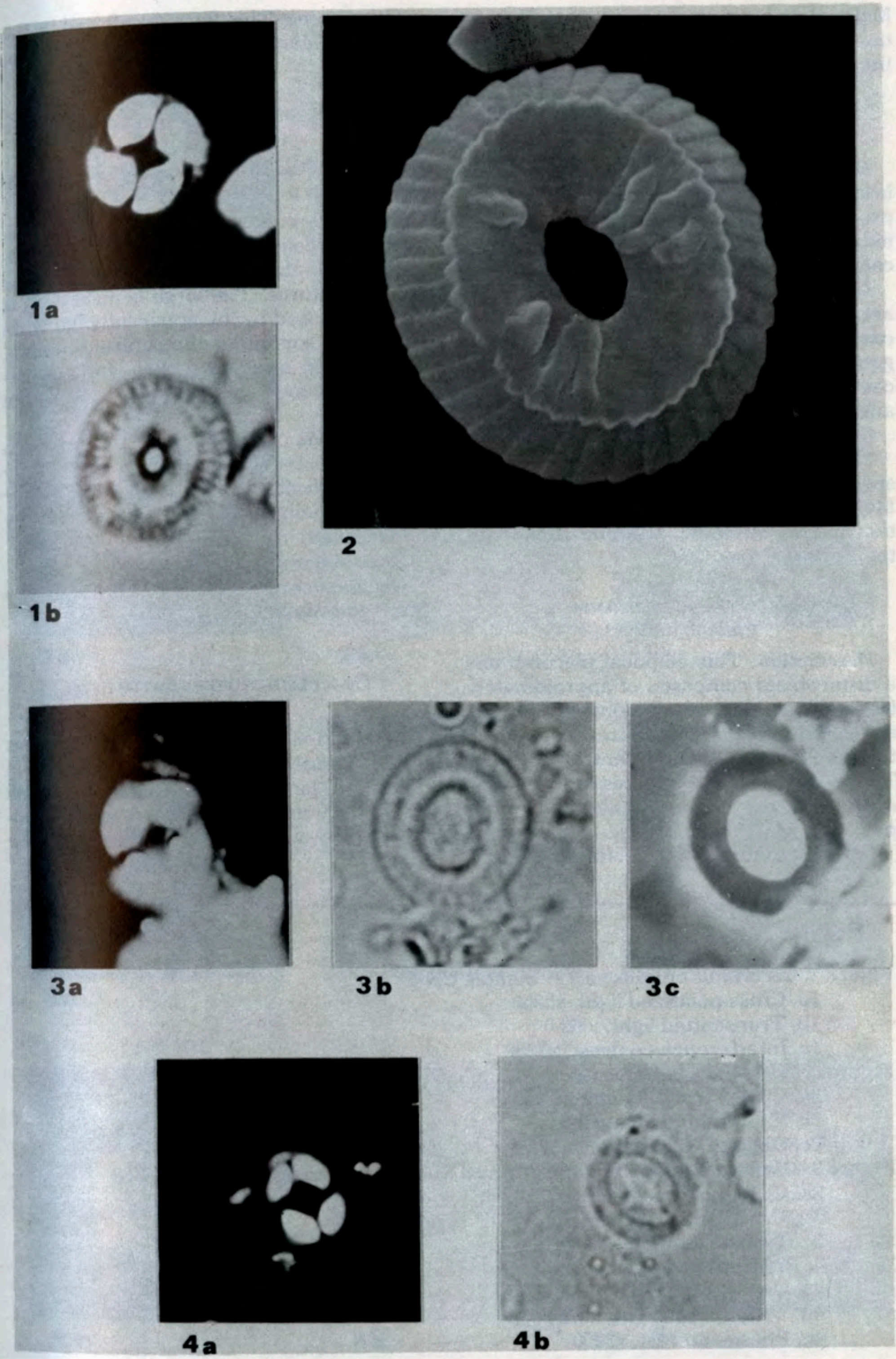

PLATE 1

McBryde members of the Clayton Formation and the Matthews Landing Member of the Porters Creek Clay.

COCCOLITHUS cf. COCCOLITHUS CAVUS var. a
Plate 1, figure 3

Description: The distal shield of this large elliptical placolith is composed of approximately 50 elements surrounding an indistinct central area. No central opening can be seen.

Discussion: Specimens included here are similar but not identical to *Coccolithus cavus* var. a. These forms have the same general size and structure of *Coccolithus cavus* var. a but have an indistinct central area.

Size: Maximum length 10 microns.

Occurrence: Representatives of this species were found in the Pine Barren and McBryde members of the Clayton Formation and the Matthews Landing Member of the Porters Creek Clay.

COCCOLITHUS CRASSUS var. a
Plate 2, figure 1

Description: This elliptical placolith has a distal shield composed of approximately 60 elements which meet along straight sutures. The large central area contains a thick collar and a wide central opening. The central opening makes up approximately one-third of the total width of the placolith.

Size: Maximum length 8 microns.

Occurrence: This form was found in the McBryde Member of the Clayton Formation.

COCCOLITHUS CRASSUS var. b
Plate 2, figure 2

Coccolithus crassus BRAMLETTE and SULLIVAN, 1961, p. 139, pl. 1, figs. 4a-d.

Description: The distal shield of this elliptical placolith is composed of approximately 60 elements which meet along straight sutures. The large central area is partially closed by the apparently flat wide collar that surrounds the central opening. The central opening makes up approximately one-fourth of the total width of the placolith.

Discussion: This species differs from *Coccolithus crassus* var. a in being slightly more elliptical, having a slightly smaller central opening, and having an apparently flatter collar.

Size: Maximum length 8 microns.

Occurrence: This form was found in the McBryde Member of the Clayton Formation.

COCCOLITHUS ORBICULATUS n. sp.
Plate 8, figure 5

Description: This circular placolith has approximately 45 elements in the distal field. The large central area has a small central opening, which makes up approximately one-sixth of the total width of the placolith.

PLATE 2

Figure 1. *Cocclithus crassus* var. a; Sample CN-1
1a. Cross-polarized light, x3250
1b. Transmitted light, x3250
1c. Interference-contrast, x3250

Figure 2. *Coccolithus crassus* var. b; Sample CN-1
2a. Cross-polarized light, x3250
2b. Transmitted light, x3250
2c. Oblique illumination, x3250

Figure 3. *Discolithina versa* (Bramlette and Sullivan), n. comb.; Sample CN-32
3a. Cross-polarized light, x3250, 90° to polarizer
3b. Cross-polarized light, x3250, 45° to polarizer
3c. Transmitted light, x3250

Figure 4. *Braarudosphaera bigelowii* (Gran and Braarud) Deflandre; Sample CN-29
4a. Cross-polarized light, x3250
4b. Transmitted light, x3250
4c. Phase-contrast, x3250

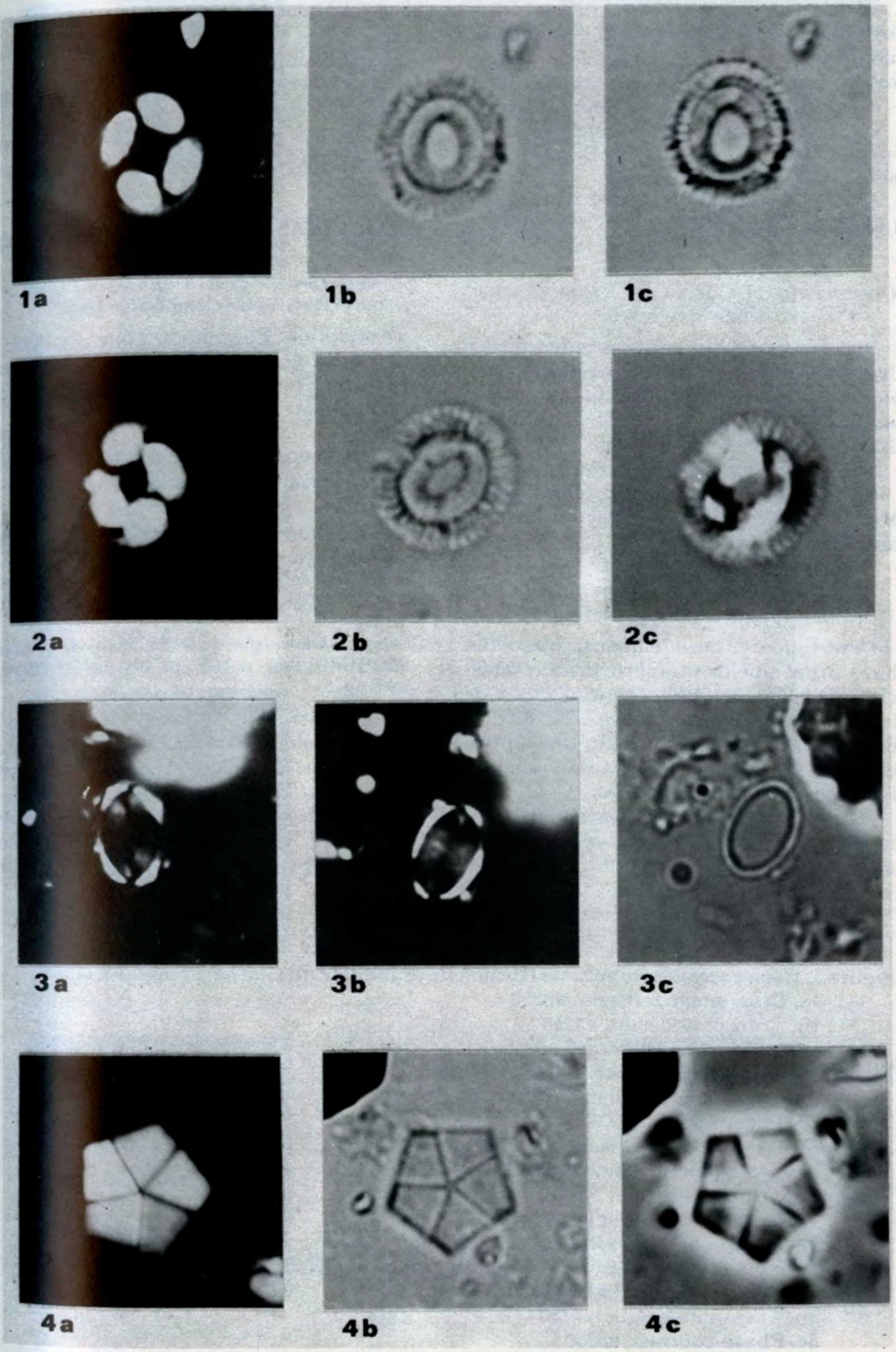

PLATE 2

Discussion: This species differs from forms of *Coccolithus cavus* in being circular. It differs from certain species of *Markalius* in that the central area is open.

Size: Maximum diameter 6 microns.

Occurrence: Representative of this species were found in the McBryde Member of the Clayton Formation.

Holotype: USNM 388226-CN-1-19 (11.2 x 1.6) (Plate 8, figure 5).

COCCOLITHUS cf. COCCOLITHUS ORBICULATUS
Plate 8, figure 6

Discussion: This group includes forms that are identical to *Coccolithus orbiculatus* except for being slightly larger and showing a slight dextral imbrication of the elements of the distal shield.

Size: Maximum diameter 6 microns.

Occurrence: This form was found in the McBryde Member of the Clayton Formation.

COCCOLITHUS species
Plate 1, figure 4; Plate 13, figure 1

Description: These elliptical placoliths have distal shields of approximately 30-60 elements. The size of the central area varies. The interference pattern consists of a dark rim with a dark cross in the central area, which separates into two V-shaped lines when rotated 45 degrees.

Discussion: Included here are two different coccolith species not assignable to others noted, which showed a high variability and occurred only in very low numbers.

Size: Maximum length 8 microns.

Occurrence: These forms were found in the Matthews Landing Member of the Porters Creek Clay, and in the Pine Barren and McBryde members of the Clayton Formation.

Genus CHIASMOLITHUS Hay, Mohler, and Wade, 1966

Type species: Chiasmolithus oamaruensis (Deflandre) Hay, Mohler, and Wade, 1966.

Description: Placoliths with a large central opening spanned by an X-shaped structure. The distal rim is larger than the proximal rim.

CHIASMOLITHUS CALIFORNICUS
(Sullivan) Hay and Mohler
Plate 5, figure 3

Coccolithus aff. *C. gigas* BRAMLETTE and SULLIVAN, 1961, p. 140, pl. 1, fig. 7 a-d.

Coccolithus californicus SULLIVAN, 1964, p. 180, pl. 2, figs. 3 a, b; 4 a-b; SULLIVAN, 1965, p. 31.

Chiasmolithus californicus (Sullivan). HAY and MOHLER, 1967, p. 1527, pl. 196, figs. 18-20; pl. 198, fig. 5.

Description: This elliptical placolith has a distal shield composed of approximately 60 elements, which show a slight dextral imbrication. The large central area is spanned by an X-shaped structure. Both of the bars of the X have a sigmoid shape, one bar being longer than the other. The X is

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PLATE 3

Figure 1. *Cyclococcolithina robusta* (Bramlette and Sullivan) Gartner; Sample CN-39
- 1a. Cross-polarized light, x3250
- 1b. Transmitted light, x3250
- 1c. Interference-contrast, x3250

Figure 2. *Cyclococcolithina* cf. *C. robusta*; Sample CN-26
- 2a. Cross-polarized light, x3250
- 2b. Phase-contrast, x3250

Figures 3, 4. *Prinsius* cf. *P. martinii*; Sample CN-11
- 3a. Cross-polarized light, x3250
- 3b. Transmitted light, x3250
- 4a. Cross-polarized light, x3250
- 4b. Phase-contrast, x3250

Figure 5. *Braarudosphaera turbinea* Stradner; Sample CN-20
- 5a. Cross-polarized light, x3250
- 5b. Transmitted light, x3250
- 5c. Phase-contrast, x3250

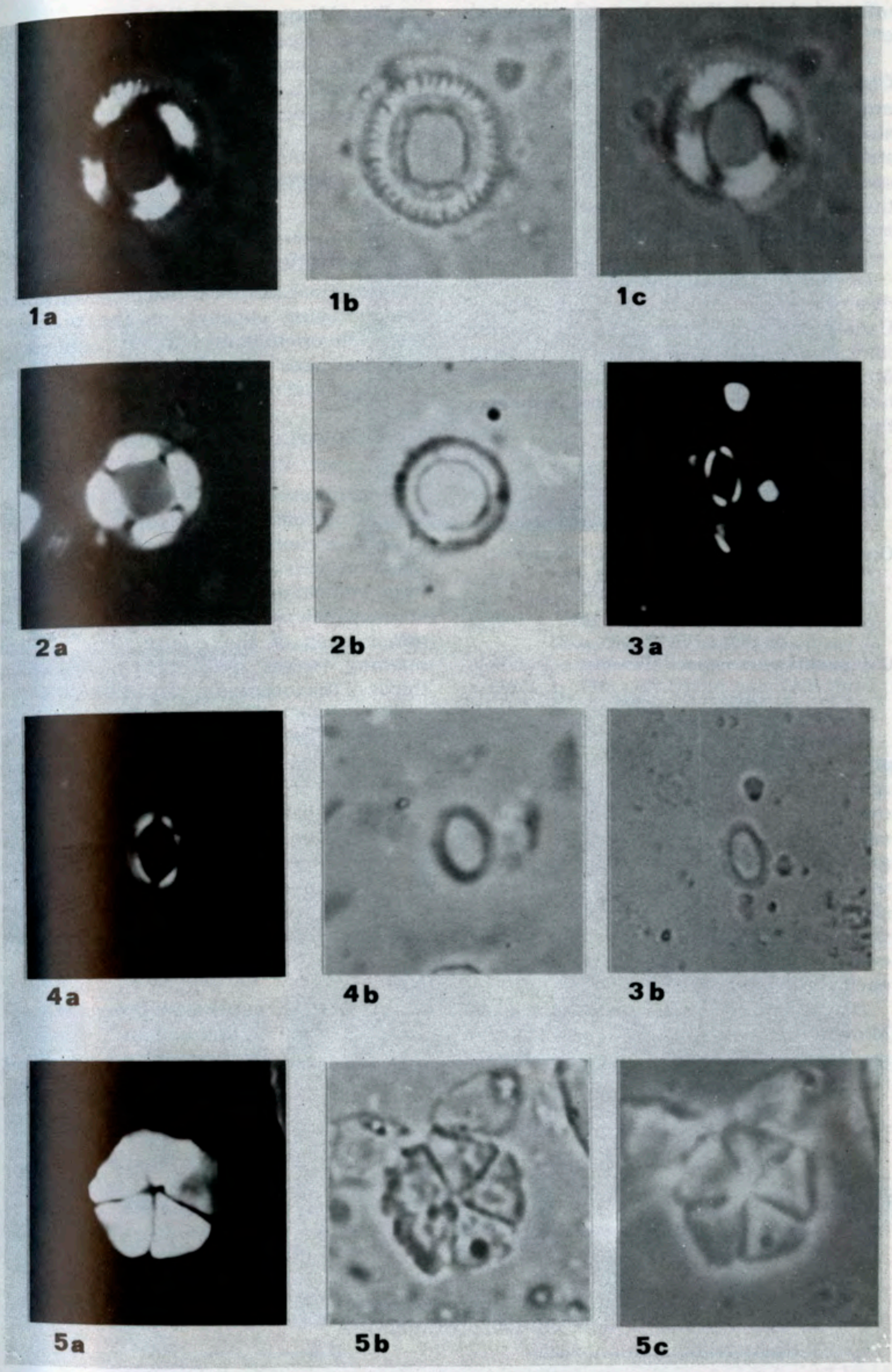


PLATE 3

offset slightly to the major and minor axis of the ellipse.

Discussion: The species differs from *Chiasmolithus consuetus* in being large and having more elements in the distal shield. The bars of the central X-shaped structure are sigmoidally shaped in both species but are more nearly aligned with the equal axis of the ellipse in *Chiasmolithus consuetus*.

Size: Maximum length 9 microns.

Occurrence: This species was originally described from the Lodo Formation of California and at Pont Labau in France, and was found in the Pine Barren and McBryde members of the Clayton Formation and the Matthews Landing Member of the Porters Creek Clay.

CHIASMOLITHUS CONSUETUS
(Bramlette and Sullivan) Hay and Mohler
Plate 5, figures 1 and 2

Coccolithus consuetus BRAMLETTE and SULLIVAN, 1961, p. 139, pl. 1, figs. 2 a-c. STRADNER *in* GOHRBANDT, 1963, p. 74, pl. 8, figs. 10-12. SULLIVAN, 1964, p. 180, pl. 3, figs. 1 a-b; SULLIVAN, 1965, p. 31.

Chiasmolithus consuetus (Bramlette and Sullivan). HAY and MOHLER, 1967, p. 1526, pl. 196, figs. 23-25; pl. 198, fig. 16.

Description: This regularly elliptical placolith has a distal shield composed of approximately 60 slightly trapezoidal elements, which show a slight dextral imbrication. The central opening is spanned by an X-shaped cross bar more or less aligned with the axes of the ellipse. This central structure is composed of overlapping rhombs of calcite. Each of the bars of the X curve slightly in opposite directions giving each bar a sigmoid shape.

Discussion: The specimens seen in the Midway samples differ from previously described forms in having more elements in the distal shield.

Size: Maximum length 11 microns.

Occurrence: This species was reported from the Lodo Formation of California and from Pont Labau in France and occurs in the McBryde Member of the Clayton Formation.

Genus CRUCIPLACOLITHUS Hay and Mohler, 1967

Type species: *Cruciplacolithus tenuis* (Stradner) Hay and Mohler, 1967

Definition: Elliptical placolith with both shields being concave on the proximal side. The open central area is spanned by a central cross whose bars are aligned with the major and minor axes of the coccolith.

CRUCIPLACOLITHUS TENUIS var. a
Plate 11, figure 4

Description: The distal shield of this elliptical placolith is composed of approximately 45 elements and has a central depression with a sloping margin. The very large central opening is spanned by a thin cross, which is aligned with the major and minor axes of the ellipse. The central opening makes up approximately two-thirds of the total width of the placolith.

Discussion: This form differs from *Cruciplacolithus tenuis* var. b in having a larger central opening and a narrower rim, and differs from var. c in having a larger central opening and a thinner collar.

Size: Maximum length 7 microns.

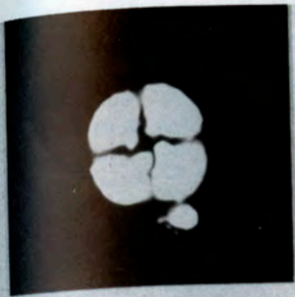
Occurrence: This form was found in the Pine Barren and McBryde members of the Clayton Formation and the Matthews Landing Member of the Porters Creek Clay.

CRUCIPLACOLITHUS TENUIS var. b
Plate 11, figures 1 and 2

Heliorthus tenuis STRADNER, 1961, p. 84, text figs. 64, 65.

PLATE 4

Figures 1-3. *Markalius astroporus* (Stradner) Hay and Mohler; Sample CN-78
1a. Cross-polarized light, x3250
1b. Transmitted light, x3250
1c. Interference-contrast, x3250
2a. Electron micrograph, x4800, proximal view
2b. Electron micrograph, x19,100, proximal view
3. Oblique illumination, x3250



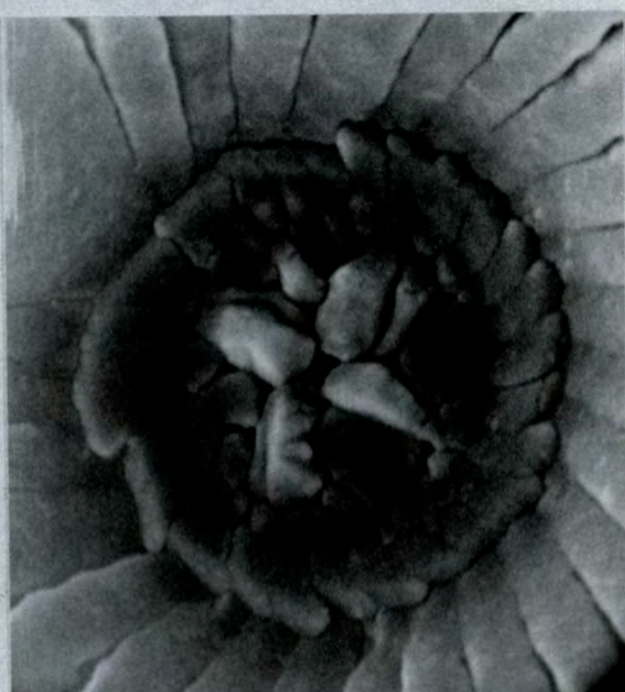
1a

1b

1c

3

2a



2b

PLATE 4

Coccolithus helis STRADNER *in* GOHRBANDT, 1963, p. 74, pl. 8, fig. 16; pl. 9, figs. 1. 2. BRAMLETTE and MARTINI, 1964, p. 298-299, pl. 1, figs. 10-12; *non* pl. 7, figs. 5 a, b, 6.
Cruciplacolithus tenuis (Stradner). HAY and MOHLER, 1967, p. 1527, pl. 198, figs. 1, 17; *non* pl. 196, figs. 29-31. PERCH-NIELSEN, 1969a, p. 59, pl. 1, figs. 7, 8; PERCH-NIELSEN, 1969b, p. 323, pl. 34, figs. 1-7.

Description: This elliptical placolith has a distal shield composed of a broad rim of approximately 40 to 55 elements, and has a central depression with a sloping margin. The moderate-sized central opening may be almost entirely closed by the broad cross-shaped central structure that spans the central opening. The cross is aligned with the major and minor axes of the ellipse. Scanning electron micrographs show the bars of the cross to be composed of two rows of flat rhombs that overlap. The central depression may be covered by a cycle of small short elements.

Discussion: This variety of *Cruciplacolithus tenuis* is larger than variety a and has a broader rim and a much smaller central opening. *Cruciplacolithus tenuis* var. c is smaller and has a thinner collar and a larger central opening than this variety.

Size: Maximum length 10 microns.

Occurrence: This form was found in the Pine Barren and McBryde members of the Clayton Formation and in the Matthews Landing Member of the Porters Creek Clay.

CRUCIPLACOLITHUS TENUIS var. c
Plate 11, figure 3

Description: The distal shield of this elliptical placolith is composed of approximately 55 elements. The broad rim surrounds a central area with a thin collar and a large central opening. The central opening is spanned by a thin cross, which is aligned with the major and minor axes of the ellipse.

Discussion: This form differs from *Cruciplacolithus tenuis* var. a in having a broader rim, a thicker collar, and a smaller central opening; and from *Cruciplacolithus tenuis* var. b in being slightly smaller, having a more open central area, and having a thinner collar.

Size: Maximum length 8 microns.

Occurrence: This form was found in the Pine Barren Member of the Clayton Formation.

Subfamily CYCLOCCOLITHOIDEAE
Hay and Mohler, 1967
Genus CYCLOCOCCOLITHINA
(Kamptner) Wilcoxon, 1970

Type species: *Cyclococcolithina leptopora* (Murray and Blackman) Wilcoxon, 1970.

Definition: Circular placoliths having a circular central perforation.

CYCLOCOCCOLITHINA ROBUSTA
(Bramlette and Sullivan) Gartner
Plate 3, figure 1

Cyclolithus? robustus BRAMLETTE and SULLIVAN, 1961, p. 141, pl. 2, figs. 7 a-c.
Cyclococcolithina robusta (Bramlette and Sullivan). GARTNER, 1967, p. 104.

Description: This circular placolith has a large central opening with approximately 55 elements in both the distal and proximal shields. The distal shield is larger than the proximal shield. The large central opening is bordered by a narrower collar.

Discussion: The forms examined in the present study have two shields of elements forming a placolith instead of a single grooved ring as reported by Bramlette and Sullivan. No electron micrographs were taken of this species so the actual structure

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PLATE 5

Figures 1, 2. *Chiasmolithus consuetus* (Bramlette and Sullivan) Hay and Mohler; Sample CN-1
1a. Cross-polarized light, x3250
1b. Transmitted light, x3250
2. Electron micrograph, x4800, distal view
Figure 3. *Chiasmolithus californicus* (Sullivan) Hay and Mohler; Sample CN-1
3a. Cross-polarized light, x3250
3b. Transmitted light, x3250

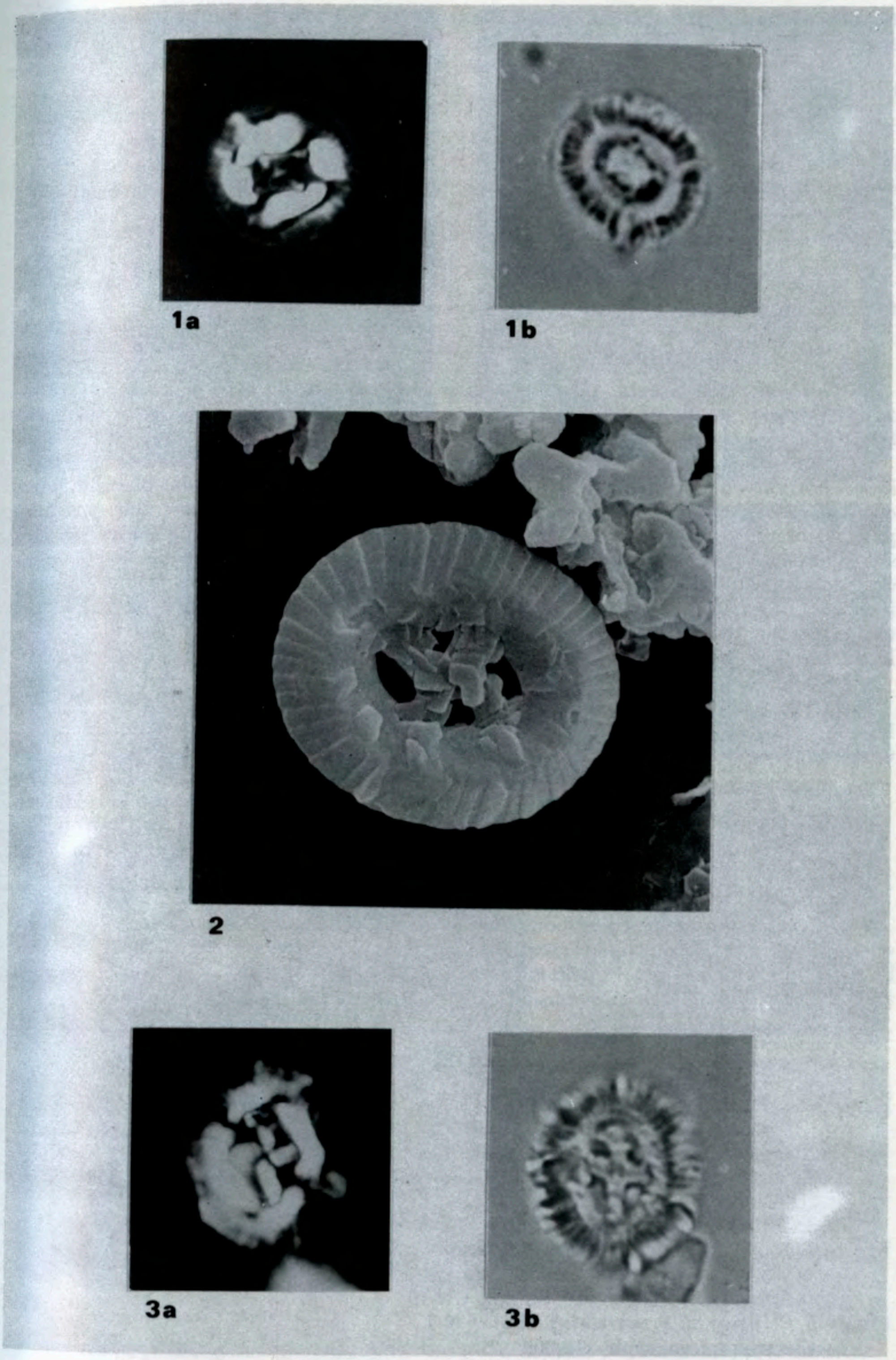

PLATE 5

of these forms is not known. All of the specimens of this species seen in the Alabama Midway samples appear to have been partially dissolved.

Size: Maximum diameter 9 microns.

Occurrence: This species was reported from the Paleocene of California and in samples from the Blake Plateau, and was found in the Porters Creek Clay and the Matthews Landing Member of the Porters Creek.

CYCLOCOCCOLITHINA cf. CYCLOCOCCOLITHINA ROBUSTA
Plate 3, figure 2

Description: This circular placolith has approximately 40 elements and a very large central opening.

Discussion: These forms seem to be the inner portion of specimens of *Cyclococcolithina robusta*, which have undergone partial solution. The size, and shape is similar to *Cyclococcolithina robusta*. They occur stratigraphically higher than the level of common *Cyclococcolithina robusta* and may represent reworked forms of the latter.

Size: Maximum diameter 6 microns.

Occurrence: This form was found in the Matthews Landing Member of the Porters Creek Clay.

Genus MARKALIUS
Bramlette and Martini, 1964

Type species: *Markalius inversus* (Deflandre) Bramlette and Martini, 1964

Definition: Circular placolith composed of two closely appressed shields connected by a hollow tube. The distal shield is larger and shows counterclockwise curved sutures. The interference pattern shows a dark cross in the central area with the rim being black.

MARKALIUS ASTROPORUS (Stradner)
Hay and Mohler
Plate 4, figures 1-3

Cycloccocolithus astroporus STRADNER *in* GOHRBANDT, 1963, p. 75, pl. 9, figs. 5-7; text figs. 3-2 a, b.

Markalius inversus (Deflandre). BRAMLETTE and MARTINI, 1964, p. 302, pl. 2, figs. 4-9; *non* pl. 8, figs. 2 a-b. MARTINI, 1964, p. 49, pl. 6, figs. 9, 10. PERCH-NIELSEN, 1968, p. 72, pl. 24, figs. 1-8; pl. 25, fig. 1; text fig. 35; PERCH-NIELSEN, 1969a, p. 326; text fig. 5; PERCH-NIELSEN, 1969b, p. 63, pl. 3, figs. 5-6.

Markalius astroporus (Stradner). HAY and MOHLER, 1967, p. 1528, pl. 196, figs. 32-35; pl. 198, figs. 2, 6. GARTNER, 1967, p. 110.

Description: This circular placolith has a distal shield larger than the proximal shield showing a slight sinistral imbrication of the elements. Both shields are composed of 32 to 36 elements. In the scanning electron microscope the proximal shield shows a four-rayed primary structure plus auxiliary elements in the central area surrounded by a thin cycle of counterclockwise curving elements.

Size: Maximum diameter 9 microns.

Occurrence: This species has been reported from Cretaceous and Paleocene localities and was found in the Pine Barren and McBryde members of the Clayton Formation, and in the Matthews Landing Member of the Porters Creek Clay.

MARKALIUS REINHARDTII Perch-Nielsen
Plate 10, figure 5

Tergestiella barnesae part (Black). REINHARDT, 1966, pl. 1, figs. 1-2; text fig. 2.

PLATE 6

Figures 1-3. *Prinsius dimorphosus* Perch-Nielsen
1. Electron micrograph, x20,300, Sample CN-100
2. Electron micrograph, x30,400, Sample CN-100
3a. Cross-polarized light, x3250; Sample CN-1
3b. Transmitted light, x3250; Sample CN-1
3c. Phase-contrast, x3250; Sample CN-1

Figure 4. *Toweius petalosus* Ellis and Lohman
4a. Cross-polarized light, x4050; Sample CN-10
4b. Phase-contrast, x4050; Sample CN-10

Figure 5. *Prinsius* cf. *P. martini*; Sample CN-7
Electron micrograph, x18,300

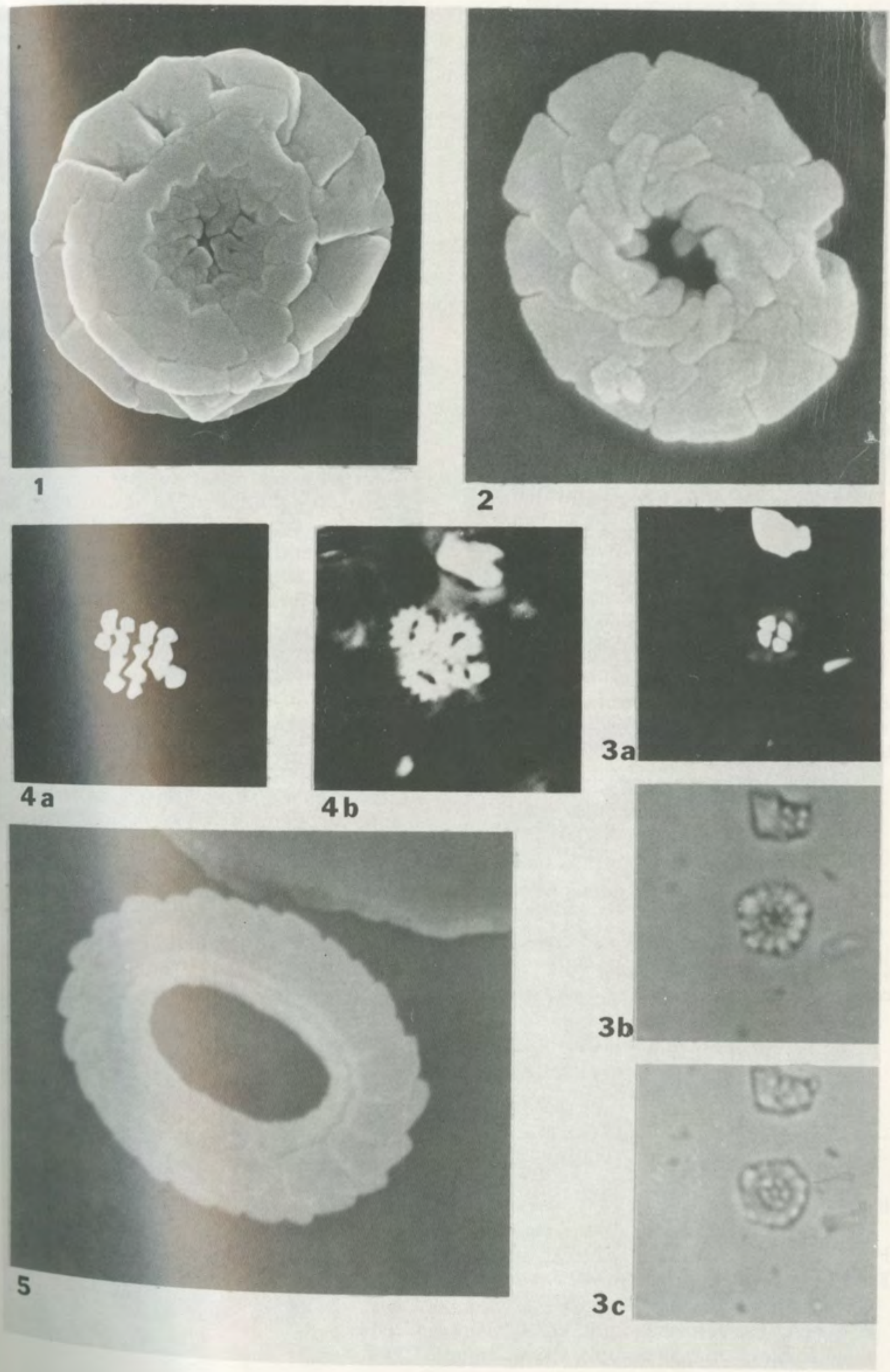

PLATE 6

Markalius reinhardtii PERCH-NIELSEN, 1968, p. 76, pl. 23, figs. 6-8, text figs. 34c, 38; PERCH-NIELSEN, 1969a, p. 63-64, pl. 3, figs. 2-4; pl. 7, figs. 13, 14; PERCH-NIELSEN, 1969b, p. 327, pl. 34, fig. 8.

Description: This circular placolith has a strongly sloping distal shield composed of approximately 40 overlapping elements. The overlapping edge of the elements is inclined counterclockwise near the center, changing direction near the middle of the rim and extending to the outer edge. The wide central area contains two sets of elements. The outer set consists of straight elements, which are inclined at the same angle as the elements of the outer rim. The inner set of central elements consists of at least three elements making a tall stem-like structure. Reinhardt's illustrations show this structure to have three sides.

Discussion: The forms seen in the Midway samples show a distinctive interference pattern consisting of two dark crosses, one on the outer rim and one in the center. The raised central structure is very distinctive in the light microscope.

Size: Maximum diameter 5 microns.

Occurrence: This species was reported from the Maastrichtian and Danian of Denmark and was found in the Pine Barren Member of the Clayton Formation.

Family ZYGODISCACEAE
Hay and Mohler, 1967
Genus HELIORTHUS
Bronnimann and Stradner, 1960

Type species: Heliorthus fallax Bronniman and Stradner, 1960

Definition: An elliptical ring with an X-shaped structure spanning the central opening.

HELIORTHUS CONCINNUS (Martin)
Hay and Mohler
Plate 12, figures 3 and 4

Zygolithus concinnus MARTINI, 1961, p. 18, pl. 3, fig.35; pl. 5, fig. 54. BRAMLETTE and MARTINI, 1964, p. 304, pl. 4, figs. 13, 14; *non* pl. 7, figs. 3 a, b. SULLIVAN, 1965, p. 38.

Zygolithus chiastus BRAMLETTE and SULLIVAN, 1961, p. 149, pl. 6, figs. 1 a-d; 2 a, b; 3 a, b. STRADNER *in* GOHRBANDT, 1963, pl. 10, figs. 1-3. SULLIVAN, 1964, p. 187, pl. 7, fig. 12.

Heliorthus concinnus (Martin). HAY and MOHLER, 1967, p. 1533, pl. 199, figs. 16-18; pl. 201, figs. 6, 7, 10. PERCH-NIELSEN, 1969a, p. 62, pl. 5, figs. 6-8.

Description: This elliptical coccolith has a distal rim of stongly imbricate triangular elements surrounding an inner cycle of broader triangular elements that show no imbrication. The open central area is spanned by an X-shaped structure that is formed of elongate laths. One of the bars of the structure is offset so that it does not form a straight bar. The amount of the offset varies as is shown in the figures of Bramlette and Sullivan (1961).

Discussion: The offset bar and thicker rim of this form distinguishes it from *Neococcolithes protenus*. The laths of the central structure are wider than those of *N. protenus*. Martini's (1961) original figure shows the offset nature of the central structure and makes this a distinctive feature to be used in the identification of this species.

Size: Maximum length 7 microns.

Occurrence: This species was reported from Paleocene strata in various parts of the world and was found in the samples from the Pine Barren Member and the McBryde Member of the Clayton Formation, and the Matthews Landing Member of the Porters Creek Clay.

HELIORTHUS DENTICULATUS Perch-Nielsen
Plate 13, figures 2-5

Heliorthus denticulatus PERCH-NIELSEN 1969a, p. 62, pl. 5, fig 5.

PLATE 7

Figure 1. *Thoracosphaera* cf. *T. imperforata* Kamptner; Sample CN-14, Cross-polarized light, x3250

Figure 2. *Thoracosphaera saxea* Stradner: Sample CN-18, Cross-polarized light, x3250

Figures 3-5. *Thoracosphaera multiperforata* n. sp.
3. Cross-polarized light, x3250; Sample CN-7
4. Cross-polarized light, x3250; Sample CN-14
5. Electron micrograph, x9300; Sample CN-7

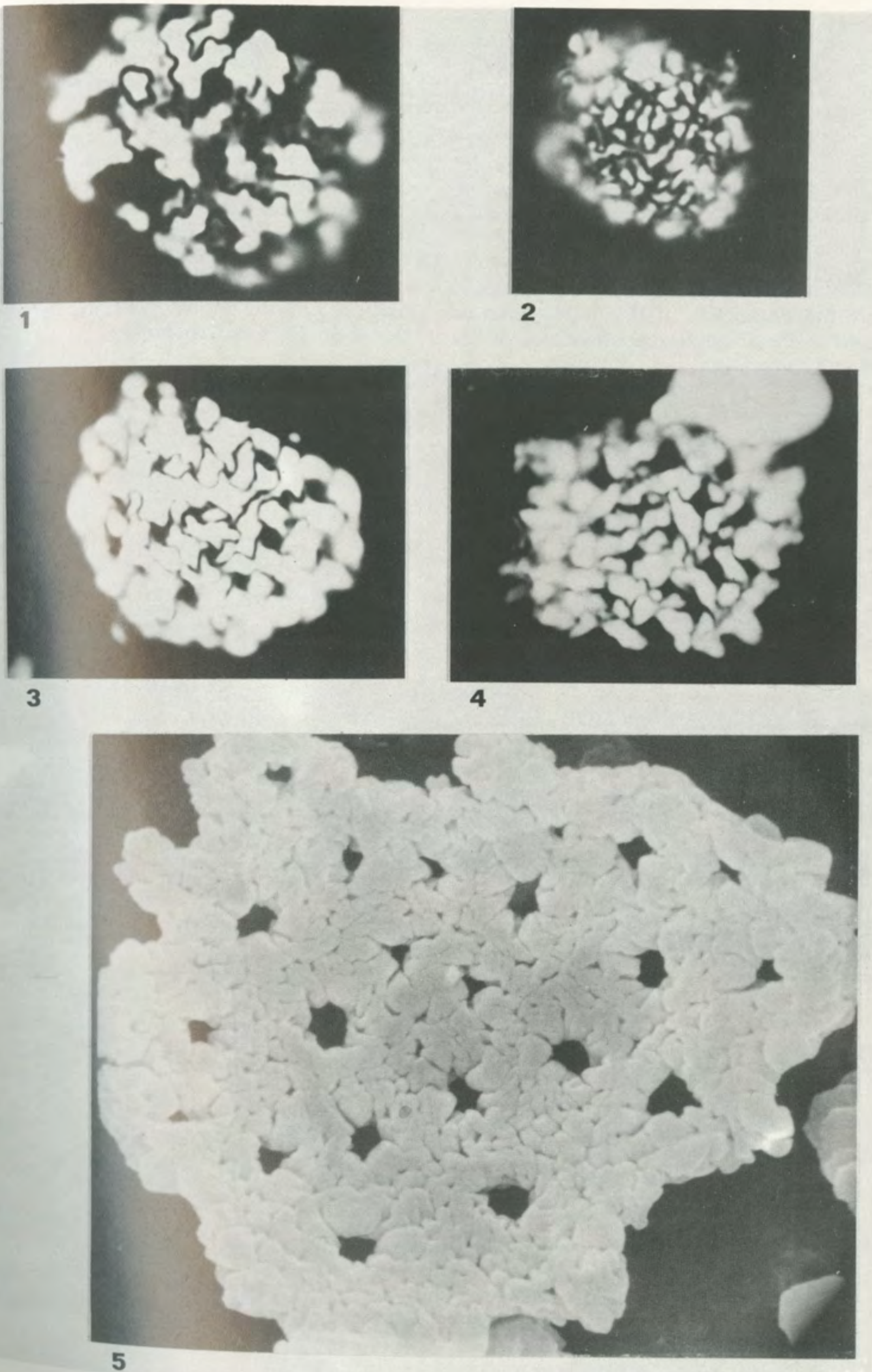

PLATE 7

Description: This elliptical coccolith is formed of a tall elliptical outer rim made of steeply inclined, overlapping flat elements. These overlay a cycle of irregular basal elements, which may fill part of the large central area. The central area is spanned by a thin cross made of bars that are not aligned with the axes of the ellipse and lie at angles to each other. The bars are made of elongate laths.

Size: Maximum length 6 microns.

Occurrence: This species was reported from the Paleocene of Denmark and was found in the Pine Barren Member of the Clayton Formation.

Genus NEOCOCCOLITHES
Sujkowski, 1931

Type species: Neococcolithes lososnensis Sujkowski, 1931

Definition: Thin elliptical rim with a large central opening spanned by an H-shaped structure.

NEOCOCCOLITHES PROTENUS
(Bramlette and Sullivan) Hay and Mohler
Plate 12, figures 1, 2

Zygolithus protenus BRAMLETTE and SULLIVAN, 1961, p. 150, pl. 6, figs. 15 a, b.
Chiphragmalithus protenus (Bramlette and Sullivan). SULLIVAN, 1964, p. 179, pl. 1, fig. 1.
Neococcolithes protenus (Bramlette and Sullivan). HAY and MOHLER, 1967, p. 1533, pl. 199, figs. 19-21; pl. 201, fig. 9. PERCH-NIELSEN, 1969, p. 64, pl. 5, fig. 4.

Description: This form has an elliptical rim constructed of strongly imbricate elements surrounding an inner cycle of more irregular elements. The central opening is spanned by an X-shaped structure that is made of elongate laths. The bars of the X are arranged so that they form a smaller angle with the short axis of the ellipse and a larger angle with the long axis.

Size: Maximum length 7 microns.

Occurrence: This species was reported from various worldwide Paleocene localities and was found in the Pine Barren and McBryde members of the Clayton Formation, and the Matthews Landing Member of the Porters Creek Clay.

Genus ZYGODISCUS
Bramlette and Sullivan, 1961

Type species: Zygodiscus adamas Bramlette and Sullivan, 1961

Definition: Coccoliths with an elliptical rim surrounding a central area with a vestige of a basal plate and a central opening spanned by a transverse bar. The bar has more than one segment of different calcite orientation.

ZYGODISCUS SIGMOIDES
Bramlette and Sullivan
Plate 14, figures 1-5

Zygodiscus sigmoides BRAMLETTE and SULLIVAN, 1961, p. 149, pl. 4, figs. 11 a-e. SULLIVAN, 1964, p. 187, pl. 5, figs. 7 a-c. BRAMLETTE and MARTINI, 1964, p. 303, pl. 4, figs. 4, 5. SULLIVAN, 1965, p. 38, pl. 6, figs. 8a, b, 9a, b. HAY and MOHLER, 1967, p. 1532, pl. 199, figs. 12-14. PERCH-NIELSEN, 1969a, p. 65, pl. 5, figs. 1-3; PERCH-NIELSEN, 1969b, p. 327, pl. 35, figs. 1-6.

PLATE 8

Figures 1, 2. *Thoracosphaera multiperforata* n. sp.
- 1a. Cross-polarized light, x3250; Sample CN-14
- 1b. Transmitted light, x3250; Sample CN-14
- 2. Electron micrograph, x18,800, Sample CN-7

Figure 3. *Thoracosphaera* cf. *T. imperforata* Kamptner; Sample CN-1
Cross-polarized light, x3250

Figure 4. *Micula decussata decussata* Vekshina; Sample CN-100
Phase-contrast, x3250

Figure 5. *Coccolithus orbiculatus* n. sp.; Sample CN-1
- 5a. Cross-polarized light, x3250
- 5b. Transmitted light, x3250

Figure 6. *Coccolithus* cf. *C. orbiculatus*; Sample CN-78
- 6a. Cross-polarized light, x3250
- 6b. Transmitted light, x3250

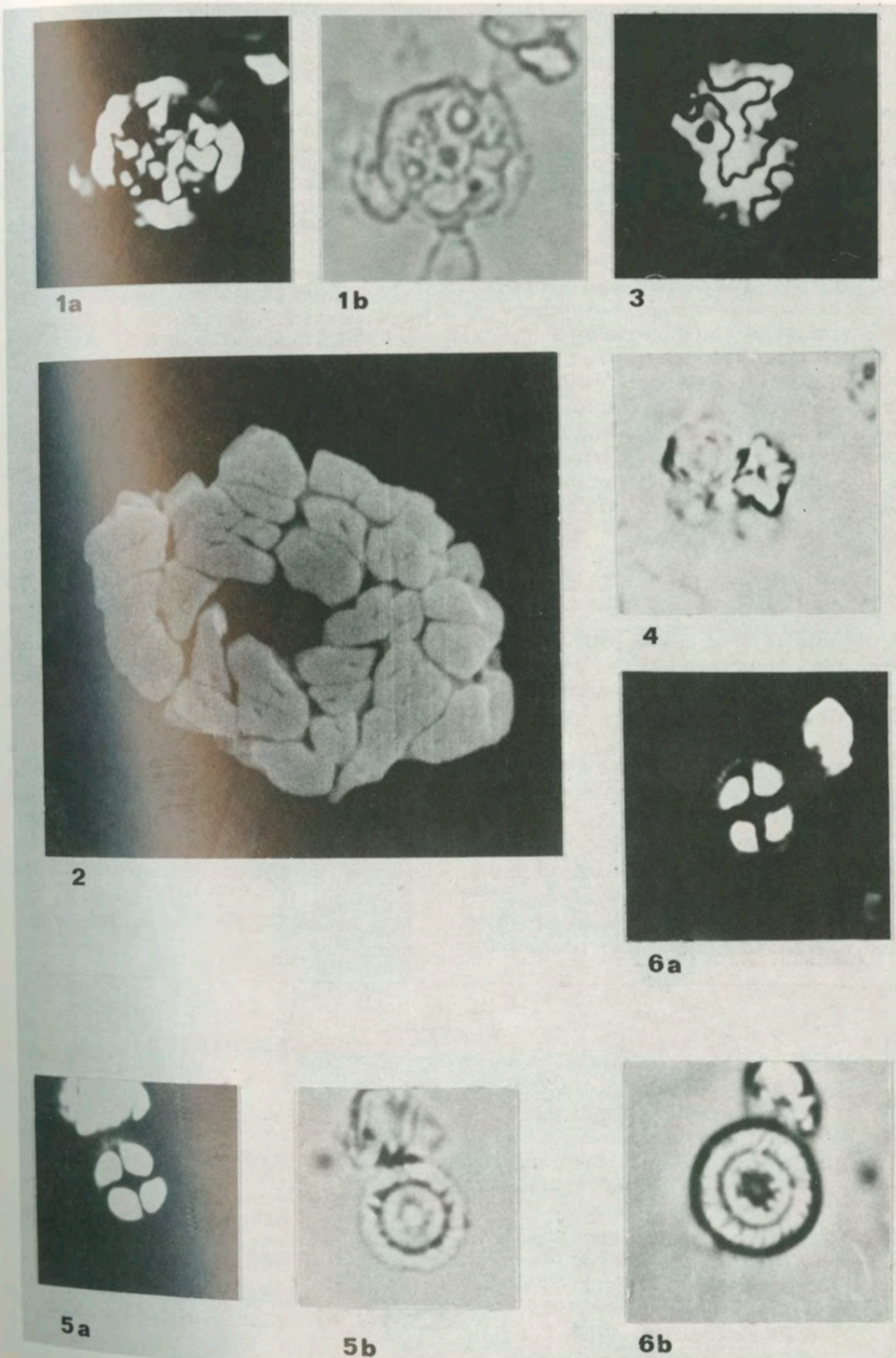

PLATE 8

Description: This elliptical coccolith has a low rim composed of a distal set of 30 to 35 elements, which show a strong dextral imbrication. Underlying these elements is a set of approximately 45 rectangular basal elements, which may partially close the large central opening. The central opening is spanned by a transverse bar composed of elongate laths that meet and form a short stem. The bar is highly arched and rises above the distal rim when viewed from the side. In the light microscope the crossbar may appear sigmoidal in shape.

Size: Maximum length 8 microns.

Occurrence: This species has been reported from the Paleocene of California, Alabama, Denmark, and France and was found in the Pine Barren and McBryde members of the Clayton Formation, the Matthews Landing Member of the Porters Creek Clay, and in the Porters Creek.

Family RHABDOSPHAERACEAE Lemmerman, 1903

Definition: Rhabdoliths with a circular basal plate composed of three or more cycles of radial elements, and a distally tapering stem.

Genus EIFFELLITHUS Reinhardt, 1965

Type species: *Zygolithus turriseiffeli* (Deflandre) Reinhardt, 1965

Definition: Rhabdolith with the basal disc constructed of a single cycle of imbricate elements that form a distally expanding rim. The central area is usually open and is spanned by two intersecting cross bars, which are symmetrical with the axes of the basal disc.

EIFFELLITHUS TURRISEIFFELI (Deflandre) Reinhardt
Plate 9, figure 3

Zygolithus turriseiffeli DEFLANDRE *in* DEFLANDRE and FERT, 1954, p. 149, fig. 65; pl. 13, figs. 15, 16.

Rhabdosphaera elliptica VERKSHINA, 1959, p. 74, pl. 1, fig. 10; pl. 2, figs, 14 a, b.

Zygrhablithus turriseiffeli DEFLANDRE, 1959, p. 135. MANIVIT, 1969, p. 191, pl. 1, fig. 1.

Zygrahablithus? turriseiffeli (Deflandre). BRAMLETTE and MARTINI, 1964, p. 304, pl. 3, figs. 18-21; pl. 4, figs. 1, 2.

Eiffellithus turriseiffeli (Deflandre). REINHARDT, 1965, p. 32. GARTNER, 1968, p. 26, pl. 2, figs. 22-23; pl. 3, fig. 13. THIERSTEIN, 1971, p. 475, pl. 7, figs. 9-11.

Clinorhabdus turriseiffeli (Deflandre). STOVER, 1966, p. 138, pl. 3, fig. 9.

Description: This rhabdolith has the elliptical disc composed of 60 to 80 dextrally imbricate elements. The rim is extended distally. The central area may be partly or completely covered. The X-shaped cross bars span the central area and may be symmetrical but not aligned with the axes of the basal disc. A hollow stem surmounts the centers of the cross bars.

Size: Maximum length 8 microns.

Occurrence: This species is common in the Cretaceous and was found in the Pine Barren Member of the Clayton Formation.

Genus PREDISCOSPHAERA Vekshina, 1959

Type species: *Prediscosphaera decorata* Vekshina, 1959

PLATE 9

Figure 1. *Cribrosphaerella ehrenbergii* Arkhangelsky; Sample CN-11
- 1a. Cross-polarized light, x3250
- 1b. Transmitted light, x3250
- 1c. Interference-contrast, x3250

Figure 2. *Prediscosphaera cretacea* (Arkhangelsky) Gartner; Sample CN-10
- 2a. Cross-polarized light, x3250, 45° to polarizer
- 2b. Transmitted light, x3250
- 2c. Interference-contrast, x3250

Figure 3. *Eiffellithus turriseiffeli* (Deflandre) Reinhardt; Sample CN-7
- 3a. Cross-polarized light, x3250
- 3b. Transmitted light, x3250
- 3c. Phase-contrast, x3250
- 3d. Interference-contrast, x3250

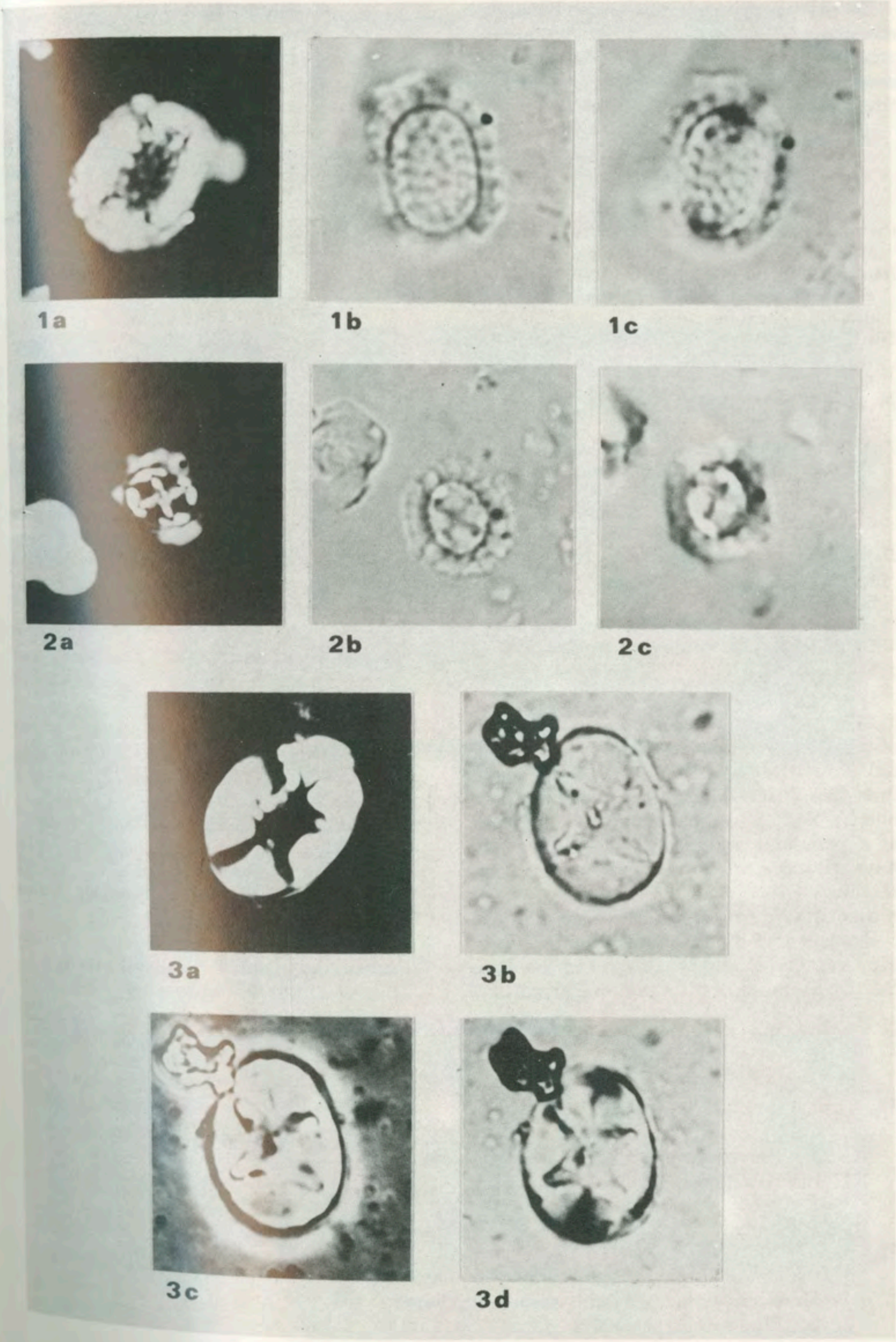

PLATE 9

Definition: Rhabdoliths with a basal disc constructed of two cycles of elements separated bya groove. The open central area is spanned by two cross bars that intersect at the center and are surmounted by a stem.

PREDISCOSPHAERA CRETACEA
(Arkhangelsky) Gartner
Plate 9, figure 2

Coccolithophora cretacea ARKHANGELSKY, 1912, p. 410, pl. 6, figs. 12, 13.
Rhabdolithus intercisus DEFLANDRE *in* DEFLANDRE and FERT, 1954, p. 159, p. 13, figs. 12, 13; text figs. 91-92.
Discolithus cretaceus (Arkhangelsky). GORKA, 1957, p. 251, pl. 2, fig. 11. BLACK and BARNES, 1959, p. 326, pl. 11, figs. 1, 2.
Prediscosphaera decorata VEKSHINA, 1959, p. 73, p. 1, figs. 8, 9; pl. 2, figs. 13a.
Zygrhablithus intercisus (Deflandre). DEFLANDRE, 1959, p. 136, pl. 1, figs. 5-20.
Deflandrius cretaceus (Arkhangelsky). BRAMLETTE and MARTINI, 1964, p. 301, pl. 2, figs. 11, 12.
Deflandrius intercisus (Deflandre). BRAMLETTE and MARTINI, 1964, p. 301, pl. 2, figs. 13-16.
Prediscosphaera cretacea (Arkhangelsky). GARTNER, 1968, p. 19, pl. 2, figs. 10-14; pl. 3, fig. 8. THIERSTEIN, 1971, p. 479, pl. 7, fig. 7.

Description: This form has a broadly elliptical to subcircular basal disc consisting of two cycles of approximately 16 trapezoidal elements. The proximal cycle is smaller than the distal. The central area is spanned by X-shaped cross bars, which consist of a proximal and distal set of bars that have a square or rounded hole at the intersection.

Size: Maximum diameter 7 microns.

Occurrence: This species is common in the Cretaceous and was found in the Pine Barren Member of the Clayton Formation.

Family PRINSIACEAE
Hay and Mohler, 1967
Genus PRINSIUS Hay and Mohler, 1967

Type species: *Coccolithus bisulcus* Stradner, 1963

Definition: Elliptical placoliths, with simple, solidly constructed distal shield; interference figure between crossed polarizers dextrogyre; proximal shield bright, distal shield somewhat fainter.

PRINSIUS DIMORPHOSUS (Perch-Nielsen)
Plate 5, figure 1-3

Biscutum? dimorphosum PERCH-NIELSEN, 1969a, p. 57, pl. 4, figs. 6-12; PERCH-NIELSEN, 1969b, p. 318, pl. 32, figs. 1-3a.
Prinsius dimorphosus (Perch-Nielsen). PERCH-NIELSEN, 1977, p. 794, pl. 30, figs. 10-13.

Description: The distal shield of this small elliptical to rounded placolith is composed of 8-12 flattened trapezoidal elements. A second cycle of elements is present near the center. These are elongated and inclined dextrally. The central opening is small occupying only about one-tenth of the shield. The proximal shield is much smaller and is composed of a single cycle of elements equal in number to those in the distal shield.

Discussion: This species differs from *Prinsius martinii* in having few elements, in lacking the central granular elements, and in being less elliptical.

Size: Maximum diameter 4 microns.

Occurrence: Representatives of this species were found in samples CN-1 and CN-100 from the McBryde Member of the Clayton Formation.

PRINSIUS MARTINII (Perch-Nielsen) Haq
Plate 10, figures 1-4

PLATE 10

Figures 1-4. *Prinsius martinii* Perch-Nielsen
1a. Cross-polarized light, x3250, 40° to polarizer; Sample CN-26
1b. Phase-contrast, x3250; Sample CN-26
2. Cross-polarized light, x3250; Sample CN-26
3. Electron micrograph, x18,300, Sample CN-32, distal view
4. Electron micrograph, x18,300, Sample CN-32, distal view

Figure 5. *Markalius reinhardtii* Perch-Nielsen; Sample CN-14
5a. Cross-polarized light, x3250, low focus
5b. Cross-polarized light, x3250, high focus
5c. Phase-contrast, x3250

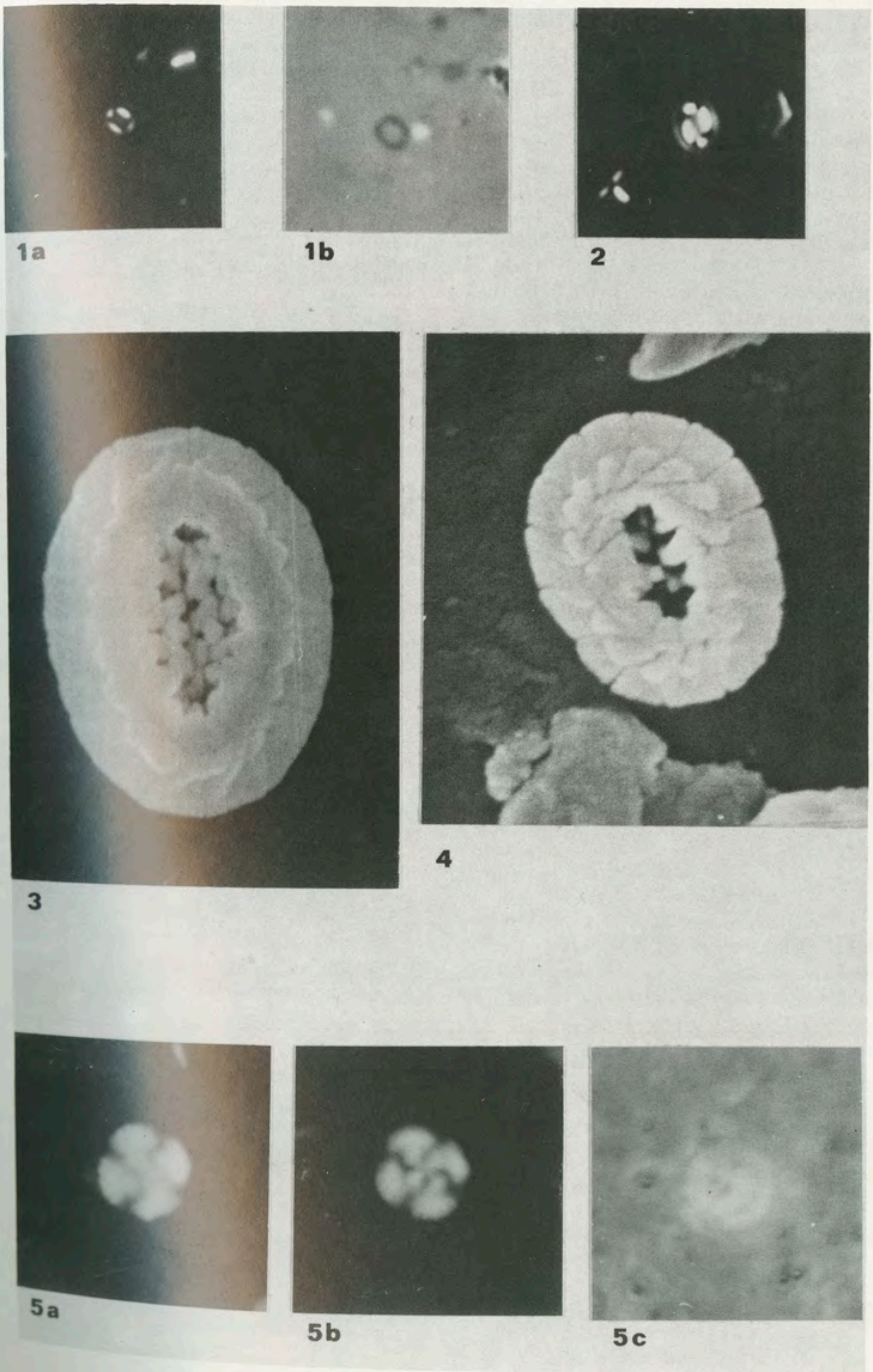

PLATE 10

Ericsonia? martinii PERCH-NIELSEN, 1969a, p. 61, pl. 4, figs. 13, 14; PERCH-NIELSEN, 1969b, p. 324, pl. 32, figs. 3b, 5, 6, 7. HAQ, 1971, p. 18, pl. 5, figs. 1, 5, 6, 7, 10.

Prinsius martinii (Perch-Nielsen). PERCH-NIELSEN, 1977, p. 794, pl. 30, fig. 3.

Description: The distal shield of this small elliptical placolith is composed of 15 to 25 flattened trapezoidal elements. A second cycle of elements is present near the center. These elements are triangular in shape and are inclined dextrally. Inside of and immediately adjacent to this second set of elements is a set of irregular elements that may overlay the second set and extend into the central opening. The central opening may be filled or partially filled with irregular granular elements, which may or may not be part of the previous irregular elements.

Discussion: Perch-Nielsen described this species as having columnar elements that meet in the middle along the major axis of the ellipse. Some of the specimens seen in the Alabama Midway do not have central elements meeting, probably due to partial solution.

Size: Maximum length 3 microns.

Occurrence: Representatives of this species were found in all three samples of the McBryde Member of the Clayton Formation, and in the Matthews Landing Member of the Porters Creek Clay.

PRINSIUS cf. PRINSIUS MARTINII
Plate 3, figures 3, 4
Plate 6, figure 5

Description: This elliptical placolith has a distal shield of 20 to 25 elements. The central area may be open or partially closed by elongate elements. Under the light microscope these forms appear mainly as elliptical rings.

Discussion: These forms are very similar in size, shape, and number of elements to *Prinsius martinii* and probably represent partially dissolved or poorly preserved specimens of that species.

Size: Maximum length 4 microns.

Occurrence: Representatives of this form were found in 8 of the 10 samples from the Pine Barren Member of the Clayton Formation.

Genus TOWEIUS Hay and Mohler, 1967

Type species: *Toweius craticulus* Hay and Mohler, 1967

Definition: Circular to subcircular placoliths whose shields are constructed of petaloid or trapezoidal elements, which are nonimbricate to slightly imbricate. The central area contains a reticulate grill.

TOWEIUS PETALOSUS Ellis and Lohman
Plate 6, figure 4

Toweius petalosus ELLIS and LOHMAN, 1973, p. 107, pl. 1, figs. 1-11.

Description: This small elliptical placolith has a distal shield composed of 9 to 17 petaloid plates or elements, which originate in the central area and extend outwards showing a slight sinistral imbrication. The petaloid plates expand in width towards the outer edge of the distal shield. These plates extend beyond the outer edge of the distal shield giving the palcolith a crown-like appearance. The proximal shield is smaller and is composed of what appear to be two cycles of relatively flat elements that are approximately the same in number as the distal shield.

PLATE 11

Figures 1, 2. *Cruciplacolithus tenuis* var. b; Sample CN-78
- 1a. Cross-polarized light, x3250, 70° to polarizer
- 1b. Transmitted light, x3250
- 1c. Interference-contrast, x3250
- 2. Electron micrograph, x9200, distal view

Figure 3. *Cruciplacolithus tenuis* var. c; Sample CN-18
- 3a. Cross-polarized light, x3250
- 3b. Transmitted light, x3250

Figure 4. *Cruciplacolithus tenuis* var. a; Sample CN-14
- 4a. Cross-polarized light, x3250
- 4b. Phase-contrast, x3250

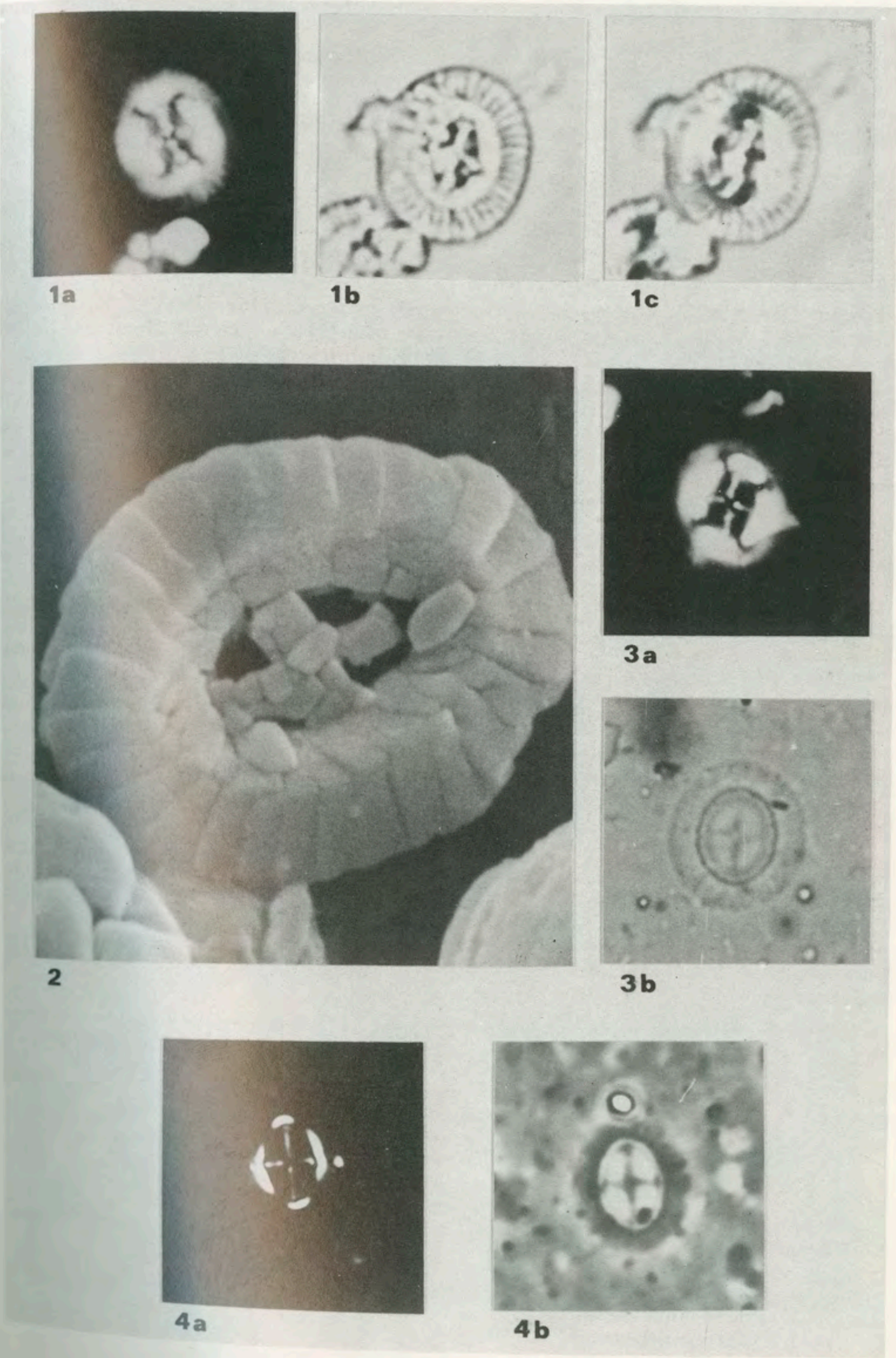

PLATE 11

Size: Maximum length 3 microns.

Occurrence: This species was reported from the Clayton Formation and Porters Creek Clay by Ellis and Lohman and was found in the Pine Barren Member of the Clayton Formation in the present study.

Family BRAARUDOSPHAERACEAE
Deflandre, 1947
Genus BRAARUDOSPHAERA
Deflandre, 1947

Type species: *Braarudosphaera bigelowi* (Gran and Braarud) Deflandre, 1947.

Definition: Pentaliths consisting of five quadrangular segments or elements whose outer edges are straight or slightly curved. The elements meet at straight sutures, which run from the center to the angles or the outer edges. The elements have no perforations or depressions.

BRAARUDOSPHAERA BIGELOWII
(Gran and Braarud) Deflandre
Plate 2, figure 4

Pontosphaera bigelowi GRAN and BRAARUD, 1935, p. 389, text fig. 67.

Braarudosphaera bigelowi (Gran and Braarud). DEFLANDRE, 1947, p. 439, figs. 1-5. DEFLANDRE, 1950, p. 1156, text figs. 1-4. BRAMLETTE and RIEDEL, 1954, p. 393, pl. 38, figs. 1a, b. BRAMLETTE and SULLIVAN, 1961, p. 153, pl. 8, figs. 1a, b, 2-5. SULLIVAN, 1964, p. 188, pl. 8, figs. 1a, b. HAY and MOHLER, 1967, p. 1535, pl. 202, figs. 12, 16, 20. PERCH-NIELSEN, 1971b, p. 942, fig. 1. BYBELL and GARTNER, 1972, p. 323, pl. 1, figs. 1, 2.

Description: These pentaliths are composed of five elements separated by distinctive sutures that run from the center to the outer edges. The periphery of the pentalith varies from slightly rounded to angular.

Size: Maximum diameter 7 microns.

Occurrence: This species is present in Cretaceous through Holocene sediments, and was found in the Matthews Landing Member of the Porters Creek Clay.

BRAARUDOSPHAERA TURBINEA Stradner
Plate 3, figure 5

Braarudosphaera turbinea STRADNER, 1963, p. 10, pl. 6, fig. 8.

Description: This pentalith consists of five triangular elements, which are sinistrally imbricate. The outer edge of the overlapping side tends to be slightly pointed.

Size: Maximum diameter 7 microns.

Occurrence: This species was originally reported from the Paleocene of Austria and was found in the Pine Barren Member of the Clayton Formation.

Family PONTOSPHAERACEAE
Lemmermann, 1903
Genus DISCOLITHINA
Loeblich and Tappan, 1963

Type species: *Discolithus vigintiforatus* Kamptner, 1948.

Definition: Elliptical disc with or without distinct rim, generally perforated.

DISCOLITHINA VERSA
(Bramlette and Sullivan), n. comb.
Plate 2, figure 3

Discolithus versa BRAMLETTE and SULLIVAN, 1961, p. 144, pl. 3, fig. 16. SULLIVAN, 1964, p. 183, pl. 4, fig. 11. SULLIVAN, 1965, p. 35, pl. 5, figs. 8, 9.

Pontosphaera versa (Bramlette and Sullivan). SHERWOOD, 1974, p. 31, pl. 5, figs. 1, 2; pl. 4, fig. 10.

PLATE 12

Figures 1, 2. *Neococcolithes protenus* (Bramlette and Sullivan) Hay and Mohler; Sample CN-78
- 1a. Cross-polarized light, x3250
- 1b. Transmitted light, x3250
- 1c. Phase-contrast, x3250
- 2. Electron micrograph, x9500, distal view

Figures 3, 4. *Heliorthus concinnus* (Martini) Hay and Mohler; Sample CN-78
- 3a. Cross-polarized light, x3250
- 3b. Transmitted light, x3250
- 3c. Phase-contrast, x3250
- 4. Electron micrograph, x18,800

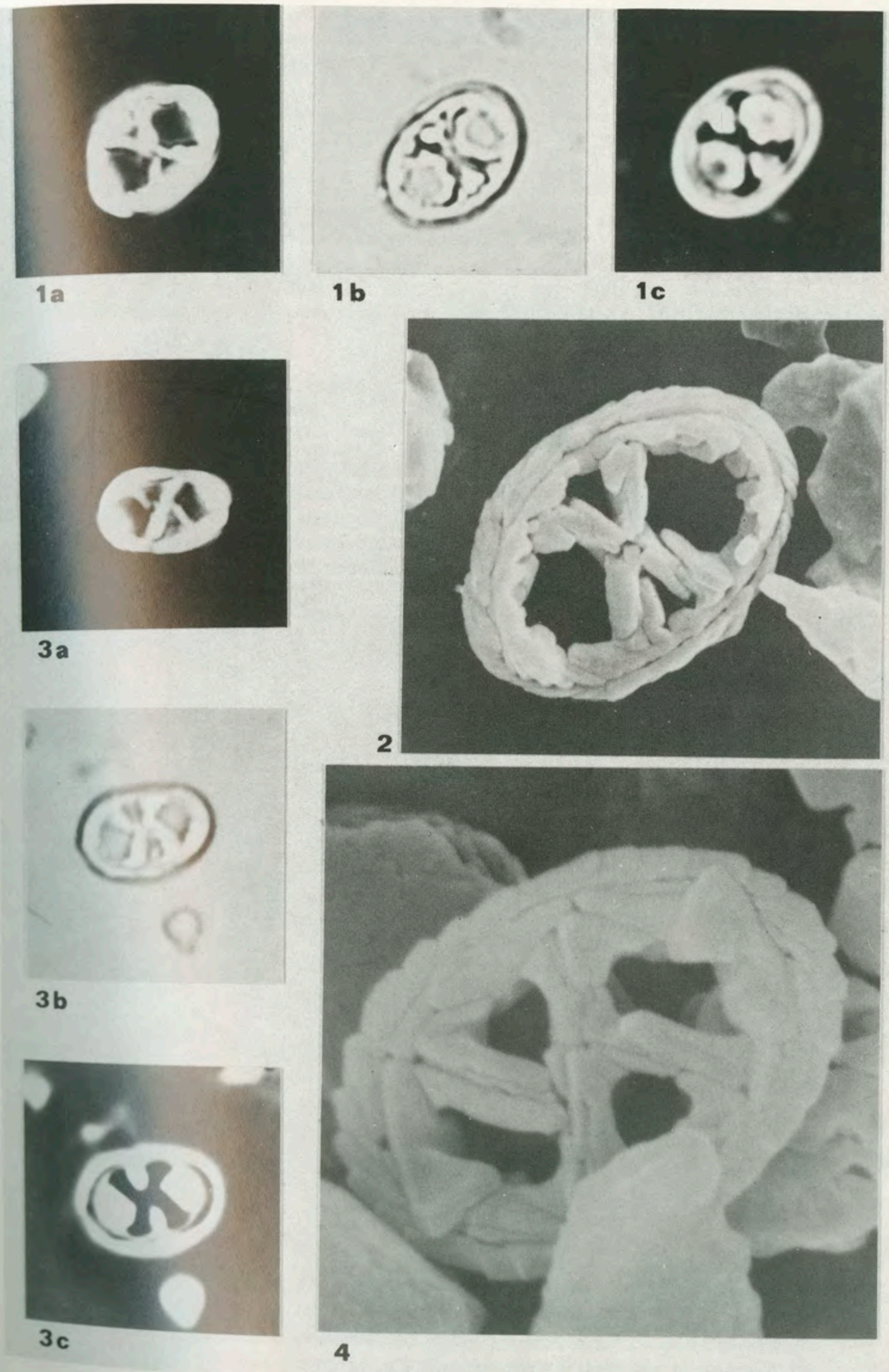

PLATE 12

Description: This elliptical discolith has a distinct rim that encloses the base plate. The base plate contains a sigmoidal slit, which appears widest at each end.

Size: Maximum length 7 microns.

Occurrence: This species is present from the Paleocene through the Oligocene and was found in the Matthews Landing Member of the Porters Creek Clay.

Family SYRACOSPHAERACEAE
Lemmermann, 1903
Genus CRIBROSPHAERELLA
Deflandre, 1952

Type species: *Cribosphaera ehrenbergi* Arkhangelsky, 1912.

Definition: Elliptical disc with a cribrate central plate and a rim of two or three tiers. Each tier is constructed of a single cycle of elements, which meet along irregular sutures. The central plate may or may not have perforations.

CRIBROSPHAERELLA EHRENBERGII
(Arkhangelsky) Deflandre
Plate 9, figure 1

Cribrosphaera ehrenbergi ARKHANGELSKY, 1912, p. 412, pl. 6, fig. 19.

Cribrosphaerella ehrenbergi (Arkhangelsky). DEFLANDRE, 1952, p. 111, text fig. 54a (*non* 54b). GORKA, 1957, p. 260, pl. 4, fig. 12. GARTNER, 1968, p. 40, pl. 1, figs. 14-15; pl. 3, fig. 2; pl. 6, fig. 7; pl. 12, fig. 2; pl.15, fig. 11. CEPEK, 1970, p. 239, pl. 22, figs. 1, 2; pl. 26, fig. 1.

Description: This form has an elliptical disc with a rim of two tiers, each constructed of a single cycle of elements. The central area is covered by a complex perforated plate.

Size: Maximum length 7 microns.

Occurrence: This species is common in the Cretaceous and was found in the Pine Barren Member of the Clayton Formation.

Family THORACOSPHAERACEA
Schiller, 1930
Genus THORACOSPHAERA
Kamptner, 1927

Type species: *Thoracosphaera pelagica* Kamptner, 1927.

Definition: Coccolithophorids with a spherical test composed of regular to irregularly-shaped polygonal elements of calcite.

THORACOSPHAERA MULTIPERFORATA, n. sp.
Plate 7, figures 3, 4, 5;
Plate 8, figures 1, 2

Description: These coccolithophorids are composed of small elongate but irregular elements which are arranged radially around small perforations. Smaller more equidimensional elements are present where the elongate elements meet. In cross polarized light the elements appear as four very elongate units framing the perforations.

Size: Maximum observed length of element - 1 micron.

Holotype: USNM 388225 - CN-7A 296 (1.5 x 9.4)(Plate 7, figure 3)

Paratypes: CN-14-31 (20.4 x 12.7)(Plate 7, figure 4). SEM CN-7-5 (Plate 7, figure 5)

Occurrence: Representatives of this species were found in the Pine Barren and McBryde members of the Clayton Formation, and the Matthews Landing Member of the Porters Creek Clay.

THORACOSPHAERA SAXEA Stradner
Plate 7, figure 2

PLATE 13

Figure 1. *Coccolithus* sp.; Sample CN-26
- 1a. Cross-polarized light, x3250
- 1b. Cross-polarized light, x3250, 45° to polarizer
- 1c. Phase-contrast, x3250

Figures 2-5. *Heliothus denticulatus* Perch-Nielsen
- 2a. Cross-polarized light, x3250; Sample CN-14
- 2b. Phase-contrast, x3250; SampleCN-14
- 3. Electron micrograph, x19,200, Sample CN-14, proximal view
- 4a. Cross-polarized light, x3250; Sample CN-10
- 4b. Phase-contrast, x3250; Sample CN-10
- 5. Electron micrograph, x8000, Sample CN-14, distal view

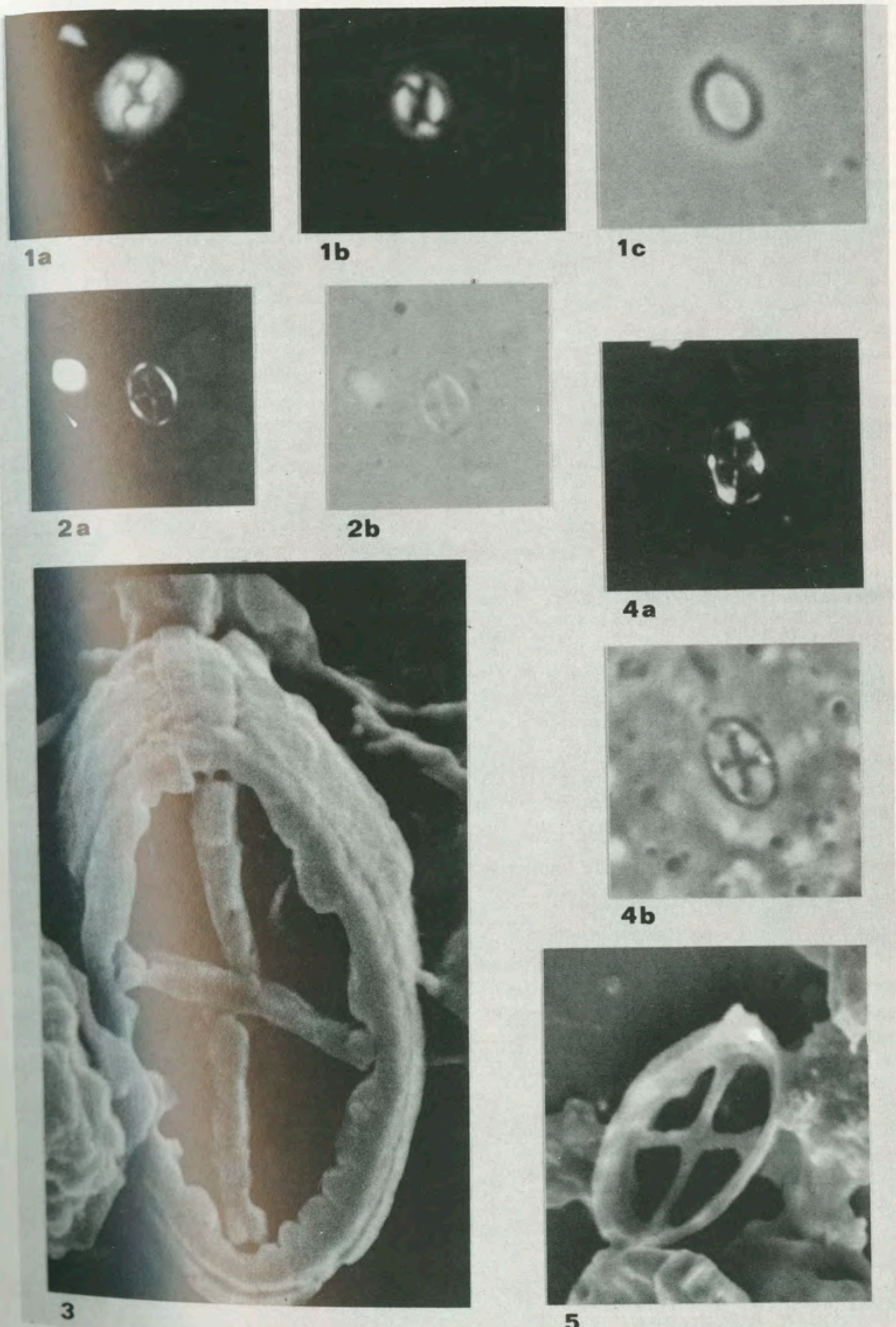

PLATE 13

Thoraosphaera sp. BRAMLETTE and RIEDEL, 1954, p. 393, pl. 38, fig. 5.

Thoracosphaera saxea STRADNER, 1961, p. 84, text fig. 71. COHEN, 1964, p. 248, pl. 5, figs 6 a-e; pl. 6, fig. 6. HAY and MOHLER, 1967, p. 1534, pl. 203, fig. 5. SACHS and SKINNER, 1973, p. 147, pl. 5, figs. 10-12.

Description: This form consists of small irregular imperforate elements that form a spherical test. The contacts between the elements may appear crenulated.

Size: Maximum observed length of element - 1 micron.

Occurrence: This species is found in Cretaceous to Holocene sediments and was found in the Pine Barren and McBryde members of the Clayton Formation, and the Matthews Landing Member of the Porters Creek Clay.

THORACOSPHAERA cf. THORACOSPHAERA IMPERFORATA Kamptner
Plate 7, figure 1; Plate 8, figure 3

cf. *Thoracosphaera imperforata* KAMPTNER, 1955, p. 37, pl. 8, fig. 98.

Thoracosphaera cf. *T. imperforata* Kamptner. BRAMLETTE and MARTINI, 1964, p. 305, pl. 5, figs. 1, 2.

Description: These large irregular elements form a mosaic of interlocking units. The size of the elements is fairly uniform and the edges appear smooth. Under cross-polarized light the elements appear as larger somewhat elongated units, surrounded by a dark line.

Discussion: The elements of this species are larger and seem to have smoother edges than those of *Thoacosphaera saxea*.

Size: Maximum width of element - 2 microns.

Occurrence: This species was described from the Cretaceous and Paleocene in various worldwide localities and was found in the Pine Barren and McBryde members of the Clayton Formation, and the Matthews Landing Member of the Porters Creek Clay.

Genera INCERTAE SEDIS
Genus MICULA Vekshina, 1959

Type species: *Micula decussata* Vekshina, 1959

Definition: Cube, with concave or plane faces and constructed of calcite laminae that are not crystallographically continuous.

MICULA DECUSSATA DECUSSATA Vekshina
Plate 8, figure 4

Micula decussata VEKSHINA, 1959, p. 71, pl. 1, fig. 6; pl. 2, fig. 11.

Discoaster staurophorus GARDET, 1955, p. 534, pl. 10, fig. 96.

Trochoaster staurophorus (Gardet). STRADNER, 1959, p. 480, figs. 49-50. MARTINI, 1960, p. 82, pl. 10, fig. 37.

Nannotetraster staurophorus (Gardet). MARTINI and STRADNER, 1960, p. 266, fig. 1. STRADNER and PAPP, 1961, p. 101, pl. 31, figs. 2-4.

Micula staurophora (Gardet) STRADNER. 1963, p. 179, pl. 4, fig. 12a. BRAMLETTE and MARTINI, 1964, p. 318, pl. 6, fig. 7-11.

Micula decussata Vekshina. GARTNER, 1968 (partim), p. 47, pl. 2, figs. 5-8; pl. 4, fig. 17; pl. 9, fig. 18; pl. 14, fig. 13; pl. 18, fig. 7; pl. 20, fig.15.

Micula decussata decussata Vekshina. BURKRY, 1969, p. 67, pl. 40, figs. 5, 6.

Description: This cube has concave faces and orthogonal or slightly extended corners. The concave faces make the form appear to be a four-rayed star under the light microscope.

Size: Maximum width 4 microns.

Occurrence: This species is common in the Cretaceous and was found in the Pine Barren and McBryde members of the Clayton Formation.

PLATE 14

Figures 1-5. *Zygodiscus sigmoides* Bramlette and Sullivan
1. Electron micrograph, x9500, Sample CN-7, distal view
2. Electron micrograph, x9300, Sample CN-7, distal view
3a. Cross-polarized light, x3250; Sample CN-78
3b. Transmitted light, x3250; Sample CN-78
4. Electron micrograph, x9200, Sample CN-7, proximal view
5a. Cross-polarized light, x3250; Sample CN-7
5b. Transmitted light, x3250; Sample CN-7

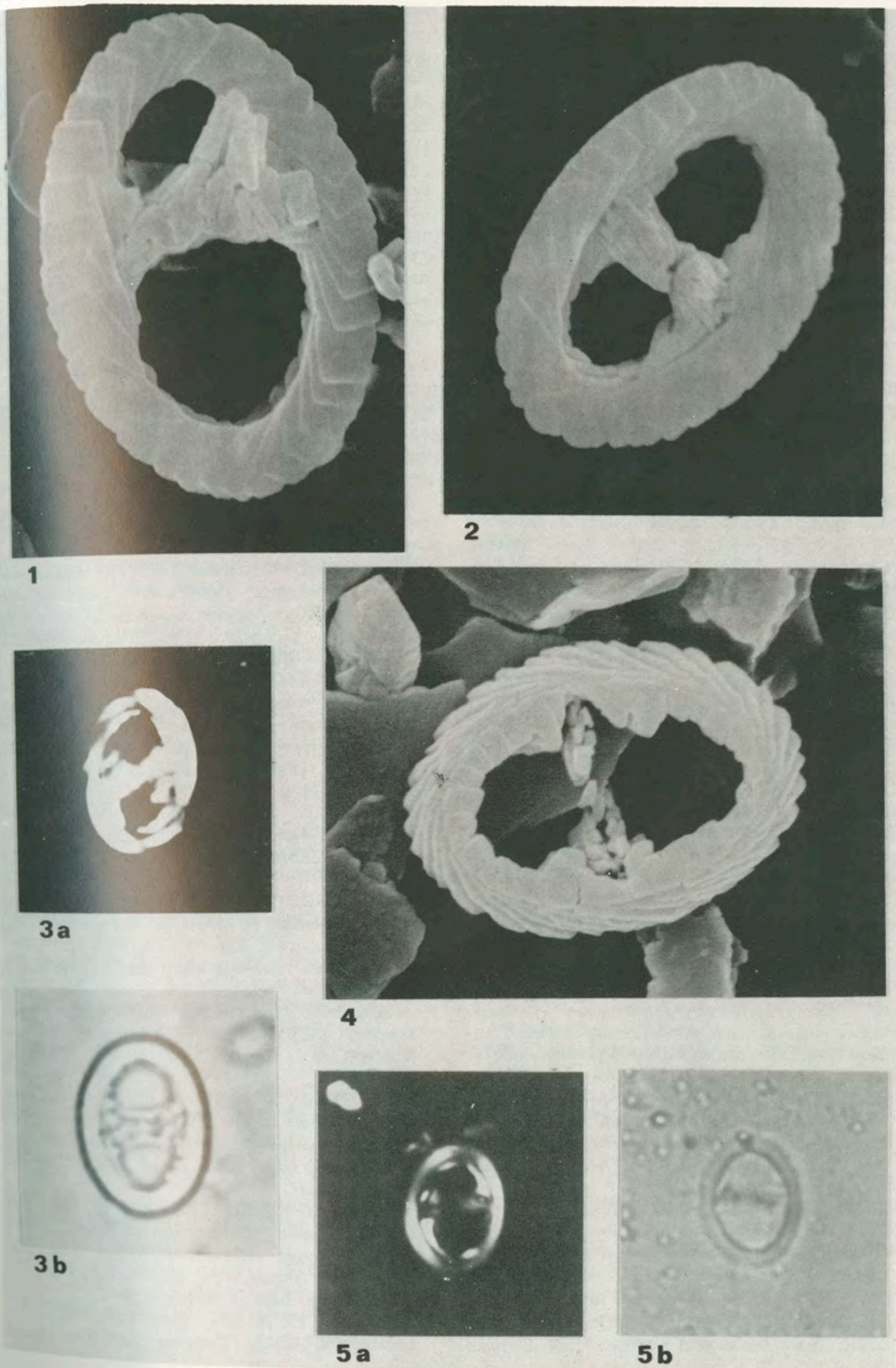

PLATE 14

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