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CALCAREOUS NANNOFOSSILS FROM THE *JOIDES* BLAKE PLATEAU CORES, AND REVISION OF PALEOGENE NANNOFOSSIL ZONATION

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ABSTRACT

The calcareous nannofossil zonation for the Paleocene-Eocene interval has been refined by study of samples previously dated with planktonic foraminifers and of samples from continuous sections. In the middle Paleocene one additional distinctive zone, the *Cyclococcolithina robusta* Zone, is recognizable. The middle and upper Eocene interval, formerly divided into two zones, the *Discoaster tani nodifer* Zone (≅ *Coronulus germanicus* Zone) and the *Isthmolithus recurvus* Zone, can be divided into nine zones:

1. the *Discoaster tani* s.l.—*Sphenolithus radians* Zone;
2. the *Reticulofenestra umbilica*—*Sphenolithus furcatolithoides* Zone;
3. the *Pemma papillatum* Zone;
4. the *Bramletteius serraculoides* Zone;
5. the *Helicopontosphaera compacta*—*Chiasmolithus grandis* Zone;
6. the *Hayella situliformis* Zone;
7. the *Isthmolithus recurvus* Zone (emended);
8. the *Sphenolithus predistentus*—*Discoaster barbadiensis* Zone;
9. the *Helicopontosphaera reticulata* Zone.

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The lower Tertiary sediments penetrated in JOIDES Blake Plateau cores J–3, J–4, and J–6B can be zoned effectively with calcareous nannofossils. J–3 contains lower, middle and upper Eocene sediments, but the section is discontinuous and contains numerous gaps. J–4 contains an upper Paleocene section from the *Discoaster gemmeus* Zone through the *Discoaster multiradiatus* Zone. J–6B contains a discontinuous record of lower and middle Eocene sediments and a continuous upper Eocene section, from the *Hayella situliformis* Zone on up. The Eocene-Oligocene boundary is contained in cores J–3 and J–6B, but because of the inadequacy of the definition of this boundary in terms of biostratigraphic criteria, its exact level remains undetermined.

I. Introduction

In April and May of 1965 the drilling ship MV *Caldrill* I, under the auspices of JOIDES and the sponsorship of the National Science Foundation, drilled six sites off the east coast of Florida, east and southeast of Jacksonville. Two of the sites (nos. 1 & 2) are on the continental shelf, and one site (no. 5) is on the continental slope. The remaining three sites are on Blake Plateau, a broad platform bounded to the west by the foot of the continental slope, and to the east by a steep escarpment which drops off to the ocean basin. At sites 3, 4 and 6 a more or less complete Tertiary section was penetrated down to the upper Paleocene. Because of operational difficulties, however, not all of the section was recovered in the cores.

The sediments consist largely of calcareous pelagic ooze, except that in the Eocene interval significant amounts of chert were encountered, interbedded with the calcareous sediments. The calcareous sediments are made up chiefly of the skeletal remains of planktonic organisms—coccolithophores and planktonic foraminifers—along with some minor amounts of fine detrital constituents. A preliminary report of the drilling operation and of the sediments recovered was published by JOIDES in *Science*, **150**, (3697): 709–716, 1965. A cruise report and preliminary core log were prepared on behalf of the JOIDES Blake Panel by John Schlee and Robert Gerard. The latter report is unpublished.

Calcareous nannofossils have proven particularly useful for dating of calcareous deep sea sediments, of which they commonly constitute a considerable fraction. This has been demonstrated with numerous samples recovered with conventional coring equipment in various parts of the world oceans. The JOIDES Blake Plateau cores, however, offer the first opportunity to study nannofossils in substantial sections of Paleogene pelagic sediments from the deep ocean basin.

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II. Purpose and Scope

The purpose of this study is to identify the calcareous nannofossils—coccoliths, discoasters and associated forms—in the Paleocene-Eocene sediments recovered at JOIDES sites 3, 4 and 6 on Blake Plateau; to determine the stratigraphic distribution of the various taxa within the above interval; to date this interval on the basis of presently available nannofossil zonation; and, finally, to determine what further refinements can be made on the current nannofossil zonation scheme.

III. Methods and Techniques

Techniques for the preparation of nannofossil samples have been described in numerous publications, as also have been methods of study both with light and electron microscopes. In addition to optical techniques widely used for studying calcareous nannofossils (phase contrast, cross-polarized light, oblique illumination), interference contrast optics were found particularly useful in the examination of certain types of coccoliths with the light microscope. Electron microscope studies were made on single stage carbon replicas with a Phillips 100 transmission type electron microscope.

IV. Previous Work

The first use of calcareous nannofossils as a means for biostratigraphic correlation of early Tertiary deposits was the study of Bramlette (1957) in which the Eocene and Oligocene deposits of Saipan were correlated on the basis of coccoliths and discoasters. The first formal nannofossil zones were proposed by Brönnimann and Stradner (1960) for the Paleocene to Oligocene deposits in Cuba, where these authors recognized six distinct discoaster zones for this interval. In 1961 Bramlette and Sullivan presented a nannofossil zonation of the upper Paleocene to middle Eocene deposits of the Lodo Formation of California in which they proposed six biostratigraphic units for this interval. Sullivan (1964, 1965) expanded this work to include other lower Tertiary deposits from various localities in central and southern California. In the process, he compressed the six "biostratigraphic units" into four "faunizones."

Gohrbandt and Stradner proposed a zonation of the Paleocene and basal Eocene of Austria (Gohrbandt, 1963) based on the occurrence of planktonic foraminifers, nummulitids and calcareous nannofossils; and Hay (1964) worked out a zonational scheme for the middle part of the Paleocene to middle Eocene based on the discoasters of the Schlierenflysch of Switzerland. Hay's zones subsequently were correlated with planktonic foraminifer zones, nummulitid zones, alveolinid zones, and the standard European stages for the Paleocene-lower Eocene by Luterbacher and Premoli Silva (1964). Additional information on the distribution of calcareous nannofossils in lower Tertiary sediments was given by Martini (1961), Lezaud (1964), Locker (1965, 1968), Sales (1966), Levin and Joerger (1967), Reinhardt (1967), and Hay, *et al.* (1967). Hay and Mohler (1967) presented a detailed nannofossil zonation of the Paleocene based on a surface section at Pont Labau in SW France. Similarly detailed information has been presented by Radomski (1967, 1968) for the Paleogene calcareous nannoplankton of the western Polish Carpathians, and by Bystrická (1969) for the Paleogene discoasters of the western Carpathians in Slovakia.

V. Biostratigraphic Zonation

Several detailed and more or less comprehensive nannofossil zonations have been presented for the Paleogene (Hay, *et al.*, 1967; Radomski, 1967, 1968). These schemes essentially are very similar, as they are, in large part, successive expansions of the same zonations. In all of them the data of earlier investigators, especially that of species range relations indicated by Bramlette and Sullivan (1961), are utilized to supplement the new data.

There are, however, differences in the emphasis placed on one species or another as stratigraphic markers. These differences appear to reflect local or regional differences in the composition of the nannofossil assemblages, which in turn were probably caused by differences in the environments prevailing in the various regions. One such difference is noted in the abundance of fossil holococcoliths, which may be common or abundant in certain hemipelagic sediments, but often are completely lacking in age equivalent open ocean pelagic oozes (Gartner and Bukry, 1969). Similarly, various species of pentaliths may constitute a significant portion of the nannofossil assemblage in sediments deposited relatively closer to a continental area, while in the open ocean they are only very sparsely represented (see for example Bukry, 1970). The latter group is represented by a variety of ornate and unusual species in middle and upper Eocene sediments deposited in marginal pelagic environments (Bouché, 1962; Chang, 1969; Bukry and Bramlette, 1969).

The calcareous nannofossil zonation used for this study is a modified version of that devised by Hay and others during the past five years, and which was correlated with the planktonic foraminiferal zonation scheme during the working session of the Colloque sur l'Éocène in Paris in May 1968 (Cita, 1969). The present modification was first presented at the 1969 Eocene Colloquium in Hungary. The planktonic foraminiferal zonation is that of Blow (1969) except for the *Globigerina eugubina* Zone which is not included in Blow's zonation (fig. 1).

The modifications in the nannofossil zonation scheme have been prompted by the recognition of several additional nannofossil datums, one in the middle Paleocene, and several more in the middle and upper Eocene. These have been recognized chiefly through the study of nannofossils from samples which were previously dated by means of planktonic foraminifers. Because these samples were obtained from widely separated geographic localities, and represent different lithologies—in many instances probably reflecting different environments—the zonation scheme may have some inherent weaknesses. As was pointed out above the holococcoliths and pentaliths are most commonly found in hemipelagic sediments. In addition, the Tertiary rhabdoliths commonly constitute a much larger proportion of the assemblage in sediments deposited near a continental area than in truly pelagic sediments. The same generalization appears to be true, although to a lesser extent, for the genus *Helicopontosphaera* and for the species *Isthmolithus recurvus* Deflandre, *Hayella situliformis* Gartner, *Chiasmolithus titus* Gartner, and *Corannulus germanicus* Stradner. The opposite effect is noted for the species *Bramletteius serraculoides* Gartner, which is encountered in large numbers in truly pelagic sediments but is rare or lacking in clayey sediments or sediments deposited under strong continental influences. Most placolith species (*Coccolithus, Cyclococcolithina,* etc.) and asteroliths (*Discoaster*) appear to be more cosmopolitan in their distribution in sediments of the same age.

The reason for these differences in the geographic distribution of various taxa is not entirely clear. It may reflect environmental preferences of the organisms that produced the coccoliths, or possibly, it may be a preservation artifact, *i.e.* some nannofossils are preserved readily in the clayey sediments deposited near continental areas, but commonly dissolve or disintegrate in the open oceanic environment where pelagic oozes accumulate.

These differences in distribution are taken into account in the present zonation, and whenever possible cosmopolitan species are used as zonal indicators. It should be noted that among the nannofossils which appear to be limited in geographic distribution are many distinctive and ornate species but because of their limited environmental range, their biostratigraphic usefulness is similarly limited.

The revisions in the Paleogene nannofossil zonation scheme prepared for the 1969 Eocene Colloquium will be reviewed briefly and updated here.

In the Paleocene the *Cruciplacolithus tenuis* Zone probably can be divided into several distinct subunits, but only one can be properly defined at this time. This is the *Cyclococcolithina robusta* Zone, which is the interval from the earliest occurrence of *Cyclococcolithina robusta* (Bramlette and Sullivan), n. comb. (= *Cyclolithus? robustus* Bramlette and Sullivan, 1961, p. 141, pl. 2, figs. 7 a–c) to the earliest occurrence of *Fasciculithus tympaniformis* Hay and Mohler. The *Cyclococcolithina robusta* Zone is within the upper part of the *Cruciplacolithus tenuis* Zone of Mohler and Hay (Hay, *et al.,* 1967), and in terms of Blow's planktonic foraminifer zones, extends from about the middle of zone P2 to the lower part of zone P3. The earliest occurrence of *Cyclococcolithina robusta* also corresponds approximately to the first occurrence of *Ellipsolithus macellus* (Bramlette and Sullivan), *Toweius craticulus* Hay and Mohler, and *Chiasmolithus bidens* (Bramlette and Sullivan). On figure 1 this is indicated as the *Chiasmolithus bidens* datum.

The remaining revisions concern the middle and upper Eocene interval which previously was divided into two zones, the *Discoaster tani nodifer* Zone (approximately Radomski's *Corannulus germanicus* Zone), roughly equivalent to the middle Eocene, and the *Isthmolithus recurvus* Zone, which is approximately equivalent to the upper Eocene. The base of the *Discoaster tani nodifer* Zone is defined by the earliest occurrence of the nominal species, and above this are several important datums which are indicated in figure 1. The lowest in the sequence is the *Reticulofenestra* datum, marked by the earliest occurrence of *Reticulofenestra umbilica* (Levin). Although the early representatives of this species are smaller than the typical forms encountered in the upper Eocene, the species is cosmopolitan in its distribution, common throughout its range, and hence a good stratigraphic indicator (see also systematic section on *Reticulofenestra umbilica*).

The next higher datum is the earliest occurrence of *Pemma papillatum* Martini, a distinctive pentalith, which, as most pentaliths, is common in marine sediments that show continental influences, but may be very scarce in pelagic ooze of this age. The *Bramletteius* datum succeeds this, marked by the earliest occurrence of *Bramletteius serraculoides.* It is easily recognized in pelagic oozes where it is common to abundant. This same species, however, may be only rarely encountered in hemipelagic sediments.

Next is the *Discoaster saipanensis* datum which corresponds closely to the earliest occurrence of three species: *Discoaster saipanensis* Bramlette and Riedel, *Pedinocyclus larvalis* (Bukry and Bramlette) and *Helicopontosphaera compacta* (Bramlette and Wilcoxon), n. comb. (= *Helicosphaera compacta* Bramlette and Wilcoxon, 1967, p. 105, pl. 6, figs. 5–8). The first occurrence of these three species probably does not coincide exactly, but seems to be fairly close in time.

Above this is the *Helicopontosphaera reticulata* datum, which is marked by the first occurrence of *Helicopontosphaera reticulata* (Bramlette and Wilcoxon), and which corresponds closely to the level of first occurrence of *Hayella situliformis* and *Chiasmolithus oamaruensis* (Deflandre), as well as the last occurrence of *Chiasmolithus grandis* (Bramlette and Riedel). This datum is near the top of the middle Eocene interval, somewhat below the top of the *Truncorotaloides rohri* Zone, and is the uppermost datum recognizable within the middle Eocene. Although each of the above three species is distinctive and easily recognized, this datum may be difficult to determine because in pelagic oozes all three species may be only sparsely represented or lacking entirely.

The next higher datum indicated is marked by the first occurrence of *Isthmolithus recurvus.* At the working session of the Colloque sur l'Éocène in Paris in 1968 (Cita, 1969) this datum was correlated approximately with the middle of the *Globigerapsis semiinvoluta* Zone (= *Globigerapsis mexicana* Zone of Blow's terminology). If this correlation is correct then the range of *Chiasmolithus grandis* may have to be extended into the upper Eocene interval, as this species occasionally may be found together with *Isthmolithus recurvus* (see for example Radomski, 1968, Table 3). The above two species commonly are not found together, nor has there been clearly established an overlapping of the ranges of *Chiasmolithus grandis* and *Chiasmolithus oamaruensis* (Gartner, in press). Nevertheless, it should be pointed out that the *Hayella situliformis* Zone indicated on the chart, may exist only locally or in environments from which *Isthmolithus recurvus* and/or *Chiasmolithus grandis* were excluded.

Next above is the datum marked by the first abundant occurrence of *Sphenolithus predistentus* Bramlette and Wilcoxon and *Sphenolithus pseudoradians* Bramlette and Wilcoxon. This datum also may be difficult to determine at times, because the two species marking it may be encountered sporadically at lower stratigraphic levels. However, all of these occurrences are very rare and contamination cannot be ruled out; additional sections through this interval must be studied before this datum can be fixed.

Finally, the youngest Eocene datum is marked by the last occurrence of *Discoaster barbadiensis* Tan, which also corresponds closely to the last occurrence of *Discoaster saipanensis* and *Cyclococcolithina reticulata* (Gartner and Smith), and to the first occurrence of *Quinquerhabdus colossicus* Bukry and Bramlette. This datum was considered to correspond to the Eocene-Oligocene boundary and is so indicated on the correlation chart compiled by the working session of the 1968 Eocene Colloquium in Paris (Cita, 1969). However, Blow (1969) has included in the planktonic foraminifer zone P17, the *Globigerina gortanii—Globorotalia centralis* Zone, strata which appear to be above the extinction level of *Discoaster barbadiensis.* The upper part of the type Shubuta Clay in Mississippi, traditionally included in the upper Eocene, is assigned by Blow to the foraminiferal zone P17, although *Discoaster barbadiensis* is lacking at the top of this unit. Similarly, *Discoaster barbadiensis* is not present in much of the section in JOIDES core 3 from Blake Plateau which Blow assigns to zone P17; however, Blow's age determination of this interval may require revision. Samples from the Marne di Brendola, from the uppermost Priabonian (upper Eocene) contain *Discoaster barbadiensis* in the interval assigned by Cita to the *Globigerina gortanii* Zone (= zone P17), which does not agree with the scheme proposed by Blow (1969) (see also Proto-Decima, 1969). The exact position of the Eocene-Oligocene boundary with respect to nannofossil datums is left open at this time, at least until some of the present contradictions can be resolved.

The various nannofossil datums listed above can be transformed into a zonation scheme such as is indicated on figure 1. The limits of the zones are indicated by the datums, and the zones are defined as follows:

Discoaster tani s.l.—*Sphenolithus radians*

Zone: Interval from the first occurrence of *Discoaster tani* s.l. to the first occurrence of *Reticulofenestra umbilica.* This zone corresponds to the lowermost portion of the *Discoaster tani nodifer* Zone of Hay (1967). *Chiasmolithus titus* first appears near the base of this zone. *Sphenolithus radians* Deflandre was earlier thought to occur no higher than this zone, however this may not be true, as *Sphenolithus radians* has been encountered sporadically in younger middle Eocene sediments.

Reticulofenestra umbilica—Sphenolithus furcatolithoides Zone: Interval from the first occurrence of *Reticulofenestra umbilica* to the first occurrence of *Pemma papillatum.* The holococcolith *Lanternithus minutus* Stradner first appears within this zone, and *Sphenolithus furcatolithoides* Locker and *Helicopontosphaera seminulum seminulum* (Bramlette and Sullivan), n. comb. (= *Helicosphaera seminulum seminulum* Bramlette and Sullivan, 1961, p. 144, pl. 4, figs. 1 a–c, 2) become extinct near the top of this zone.

Pemma papillatum Zone: Interval from the first occurrence of *Pemma papillatum* to the first occurrence of *Bramletteius serraculoides.* The holococcolith *Daktylethra punctulata* Gartner apparently is restricted to this zone. Also within this interval occur many varied pentalith species such as have been described by Bouché (1962), Chang (1969), and Bukry and Bramlette (1969). These pentaliths are unusually well developed in the upper part of the Lisbon Formation at Little Stave Creek in Alabama.

Bramletteius serraculoides Zone: Interval from the first occurrence of *Bramletteius serraculoides* to the first occurrence of *Helicopontosphaera compacta. Chiasmolithus consuetus* (Bramlette and Sullivan) has its last occurrence within this zone, and *Coccolithus floridanus* Roth and Hay first appears within this zone.

Helicopontosphaera compacta—Chiasmolithus grandis Zone: Interval from the first occurrence of *Helicopontosphaera compacta* to the first occurrence of *Hayella situliformis. Discoaster saipanensis* and *Pedinocyclus larvalis* first appear near the base of this zone, and *Chiasmolithus grandis* apparently ranges no higher than the top of this zone. *Coronocyclus serratus* Hay, Mohler and Wade also first appears within this zone.

Hayella situliformis Zone: Interval from the first occurrence of *Hayella situliformis* to the first occurrence of *Isthmolithus recurvus. Chiasmolithus oamaruensis, Helicopontosphaera reticulata* and *Helicopontosphaera wilcoxonii* Gartner, n. sp., first appear near the base of this zone. The only record of *Corannulus germanicus* in the Blake Plateau cores is from this zone.

Isthmolithus recurvus Zone (emended): Interval from the first occurrence of *Isthmolithus recurvus* to the first abundant occurrence of *Sphenolithus predistentus.* Rare specimens of *Sphenolithus predistentus* and *Sphenolithus radians* have been recorded somewhat lower than the top of this zone, but these occurrences appear to be due to contamination.

Sphenolithus predistentus—Discoaster barbadiensis Zone: Interval from the first abundant occurrence of *Sphenolithus predistentus* to the last occurrence of *Discoaster barbadiensis.* The top of this zone is marked also by the last occurrence of *Discoaster saipanensis* and *Cyclococcolithina reticulata.*

The late middle Eocene and early part of the late Eocene interval are characterized by the development of many new species of nannofossils other than discoasters, which appear to have declined in prominence throughout most of the middle and upper Eocene. During the interval of the *Discoaster barbadiensis—Sphenolithus predistentus* Zone a balance seems to have been reached and few or no new species appeared. This is followed by an accelerating decline of diversity in the nannofossil assemblages and the successive extinction of many species during early Oligocene time.

The interval immediately above the extinction of *Discoaster barbadiensis* has been designated by Roth and Hay (*in* Hay, *et al.*, 1967) as the *Ellipsolithus subdistichus* Zone (= *Ericsonia subdisticha* Zone of Baumann and Roth, 1969), and was defined as the interval from the last occurrence of *Discoaster barbadiensis* to the first occurrence of *Cyclococcolithina margaritae* (Roth and Hay). The base of this zone is readily recognized, as *Discoaster barbadiensis* is easily distinguished from all other upper Eocene discoasters. The top of the *Ellipsolithus subdistichus* Zone, however, is difficult to determine because *Cyclococcolithina margaritae* is a very small species and is not readily identifiable with a light microscope even at its type level in JOIDES Blake Plateau core J–5.

An alternative zonal designation has been suggested by Bramlette and Wilcoxon (1967), who propose the name *Helicosphaera reticulata* (= *Helicopontosphaera reticulata*) Zone and indicate this zone as the interval from the top of the *Isthmolithus recurvus* Zone (of Hay, Mohler and Wade, 1965) to the last occurrence of *Helicopontosphaera reticulata.* According to Bramlette and Wilcoxon (1967) *Reticulofenestra umbilica* and *Cyclococcolithina formosa* (= *Cyclococcolithina lusitanica*) also become extinct at the top of the *Helicopontosphaera reticulata* Zone. (Hay, *et al.*, 1967, lowered the upper limit of the *Isthmolithus recurvus* Zone by defining it as the interval from the first occurrence of *Isthmolithus recurvus* to the last occurrence of *Discoaster barbadiensis.* This resulted in a downward expansion of the *Helicopontosphaera reticulata* Zone because the range of *Isthmolithus recurvus* extends above the extinction level of *Discoaster barbadiensis.*) The designation of Bramlette and Wilcoxon (1967) seems preferable for practical reasons; *Cyclococcolithina margaritae* is difficult or impossible to identify with a light microscope, as also is the next higher marker, *Reticulofenestra laevis* Roth and Hay, indicated by Roth (1968). The upper limit of the *Helicopontosphaera reticulata* Zone, on the other hand, corresponds closely to the extinction level of three easily identified species: *Helicopontosphaera reticulata, Reticulofenestra umbilica,* and *Cyclococcolithina formosa* (Kamptner), the last two being cosmopolitan species. Further modification of the zonation scheme of the uppermost Eocene-lower Oligocene interval should be expected, however, as a number of distinctive species become extinct in rapid succession during early Oligocene time (see also Hay, 1969).

In a recent study Martini (1969) has correlated the lower Oligocene, the type Lattorfian, with the *Ellipsolithus subdistichus* Zone, and the presence of *Cyclococcolithina formosa* and absence of *Discoaster barbadiensis* suggests that the Lattorfian correlates also with the *Helicopontosphaera reticulata* Zone. It is not clear, however, that the top of the Eocene corresponds to the extinction level of *Discoaster barbadiensis* because in all of Martini's sections the critical interval is lacking—represented by a hiatus, a sandy facies without nannofossils or not sampled. In any case, the problem of fixing the exact position of the Eocene-Oligocene boundary may be more imaginary than real because Eocene sediments which presumably overlie the extinction level of *Discoaster barbadiensis* are developed in only few localities and seem to represent a very short interval of time.

VI. Biostratigraphic correlation of JOIDES cores J–3, J–4, and J–6B

On figure 2 the three Blake Plateau cores J–3, J–4 and J–6B are represented on a scheme of calcareous nannoplankton zones. It is clear that not the entire Paleocene-Eocene interval is represented. Much of the Paleocene section was not reached by coring, and only a small part of the upper Paleocene is represented by the 300′+of Paleocene sediment recovered at site J–4.

No cores were recovered from the lowermost Eocene interval, which may be related directly to the presence of extensive cherty layers in the lower Eocene and in the lower part of the middle Eocene. It is worth noting that lower and middle Eocene cherts have been recovered from several locations in the North Atlantic during legs 1 and 2 of the Deep Sea Drilling Project, and that these cherts have been correlated with the prominent reflector Horizon A (see for example M.N.A. Peterson, *et al.*, 1970). Although Horizon A has not been identified seismically on Blake Plateau, Emery and Zarudzki (1967) noted that the top of the Paleocene can be correlated by a good reflecting horizon there. The presence of lower and middle Eocene cherts thus indicate that the conditions leading to the widespread silica deposition in the North Atlantic Ocean at this time were not confined to the deepest parts of the ocean basin.

The middle and upper Eocene intervals are represented in cores J–3 and J–6B in a more or less complete section. Some notable gaps are present, however, some of them clearly due to core loss, but the more significant gaps in the section are recognizable where cores were recovered continuously, as in cores J–3, between 504′ 11″ and 505′ 4″.

J–4 (37° 02′N, 77° 43′W)

At site J–4 Paleogene sediments were

penetrated from about 270′ below the sediment surface down to about 585′. The sediments consist mostly of slightly lithified clayey limestone. Although more than 300′ of Paleogene section was penetrated, only a relatively short interval of time is represented, all within the late Paleocene (figure 3). The core recovery throughout this interval was sporadic, and there may be appreciable gaps between adjacent samples.

From 271′5″ down to about 470′ the *Discoaster multiradiatus* Zone is represented. Apparently the upper limit of this zone was not cored; however, within the section represented here two subzones can be distinguished. The lower subzone is marked by the presence of an unusual sphenolith, *Fasciculithus mitreus* Gartner, n. sp., and the upper subzone is marked by the presence of the distinctive species *Rhomboaster calcitrapa* Gartner, n. sp. These two subzones may be significant only locally, and there is as yet no evidence that such a subdivision is recognizable elsewhere. These two subzones were not recognized by Hay and Mohler (1967) in the same interval at Pont Labau in southern France.

From 480′ to 540′11″ the *Heliolithus riedeli* Zone is represented. *Sphenolithus anarrhopus* Bukry and Bramlette is characteristic of this zone, although not entirely restricted to it.

Below 540′11″ *Heliolithus riedeli* Bramlette and Sullivan is lacking and the remaining section is assigned to the *Discoaster gemmeus* Zone.

J–3 (28°30′N, 77°31′W)

At site J–3 Paleogene sediments were recovered from about 500′ below the sediment surface down to the bottom of the borehole at about 585′. Blow (1969) places the Eocene-Oligocene boundary between 484 and 493′. Bramlette and Wilcoxon (1967) place the boundary slightly lower between 496 and 505′. According to the distribution chart (fig. 4) the interval above 504′11″ correlates with the *Helicopontosphaera reticulata* Zone, and from 504′11″ on down the interval is older.

The zonal succession appears somewhat disjointed and contains appreciable gaps. This may be because the sediments consist of interbedded chert, limestone, and calcareous ooze. Recovery was sporadic in this interval and contamination is probably not uncommon. Nevertheless several datums can be determined, although not every zone within the interval is recognizable. Between 503′5″ and 504′11″ the *Sphenolithus predistentus–Discoaster barbadiensis* Zone is represented. Between 504′11″ and 505′4″ there appears to be a significant hiatus because the interval from 505′4″ to 507′3″ represents the *Helicopontosphaera compacta–Chiasmolithus grandis* Zone. From 508′8″ to 515′3″ the *Bramletteius serraculoides* Zone is recognized, and the interval from 516′6″ to 517′6″ belongs to the *Reticulofenestra umbilica–Sphenolithus furcatolithoides* Zone. The *Discoaster tani* s.l.–*Sphenolithus radians* Zone is not recognizable in this core as *Discoaster tani* is present only higher in the section.

The *Chiphragmalithus quadratus* Zone extends from 519′6″ down to 538′2″, below which level about 15′ of core is missing. From 553′3″ to 555′ the *Discoaster sublodoensis* Zone is well developed, and the interval from 561′5″ to 569′10″ belongs to the *Discoaster lodoensis* Zone. No samples are available below 569′10″. The lowermost sample in this interval may have some older contaminants, but it is not clear whether actual penetration was below the *Discoaster lodoensis* Zone.

J–6 (30°05′N, 79°15′W)

At site J–6 Paleogene sediments were cored from about 150′ below the sediment surface down to about 394′ where drilling was terminated. Saito and Lidz (*in* JOIDES, 1965, and *in* Schlee & Gerard, 1965) place the Eocene-Oligocene boundary at about 185′ below the sediment surface. This seems to be slightly in error, however, and the boundary is here placed between 151′6″ and 152′6″. Also, coring appears to have terminated within the lower Eocene without reaching Paleocene sediments.

The cored interval consists of calcareous ooze, fine grained limestone and chert. Core recovery below 200′ was sporadic, and there are several long intervals in which no samples were recovered.

The interval from 152′6″ through 157′8″ (fig. 5) is equivalent to the lower part of the *Helicopontosphaera reticulata* Zone, *i.e.* the uppermost upper Eocene. This zone extends up beyond 152′6″, and it is possible that the Eocene-Oligocene boundary may be even higher than indicated here.

The *Sphenolithus predistentus–Discoaster barbadiensis* Zone extends from 159′ down through 224′, and is well represented in this core. The interval from 230′1″ through 251′ is assignable to the *Isthmolithus recurvus* Zone.

The *Hayella situliformis* Zone is represented from 254′ through 264′. Between 264′ and 325′6″ no core was recovered, but the interval from 325′6″ to about 329′ is still assignable to the *Helicopontosphaera compacta–Chiasmolithus grandis* Zone, the zone immediately below the *Hayella situliformis* Zone. Between 332′ and about 360′ the calcareous nannofossils are of mixed ages. The interval is cherty and recovery was poor. Much of the middle and some of the lower Eocene section probably is missing. The remaining section is assignable to the *Discoaster lodoensis* Zone from about 360′ through 381′9″ and below this level the *Marthasterites tribrachiatus* Zone is recognizable.

VII. Systematic Paleontology

Genus Cruciplacolithus Hay & Mohler, 1967

Cruciplacolithus staurion (Bramlette & Sullivan), n. comb.

Coccolithus staurion Bramlette & Sullivan, 1961, p. 141, pl. 2, fig. 5a–b, 6a–c; Sullivan, 1964, p. 181, pl. 3, fig. 2a–b, 3a–b; Sullivan, 1965, p. 32, pl. 3, fig. 7a–b.

Remarks: Hay & Mohler (*in* Hay, *et al.*, 1967) did not specifically assign this species to the genus *Cruciplacolithus,* but the definition of that genus must include this species. Some doubt remains about the phylogenetic accuracy of this assignment however, as the assignment is based purely on morphological criteria. Furthermore, the delicate crossbars in the center of this species may be broken out readily, and such a specimen would be placed in the genus *Coccolithus.*

Genus Cyclococcolithina Wilcoxon, 1970

Cyclococcolithina formosa (Kamptner)

Cyclococcolithus formosus Kamptner, 1963, p. 163, pl. 2, fig. 8, text fig. 20.

Coccolithus lusitanicus Black, 1964, p. 308, pl. 50, fig. 1, 2.

Cyclococcolithus lusitanicus (Black). Hay, Mohler & Wade, 1966, p. 390, pl. 7, fig. 3–6.

Cyclococcolithus orbis Gartner & Smith, 1967, p. 4, pl. 4.

Cyclococcolithus lusitanicus (Black). Bramlette & Wilcoxon, 1967, p. 103, pl. 3, fig. 16, 17.

Cyclococcolithus formosus Kamptner. Martini, 1969, p. 132, pl. 1, fig. 1, 2.

Cyclococcolithina formosa (Kamptner). Wilcoxon, 1970, p. 82.

Remarks: This species of *Cyclococcolithina* is easily recognized with the light microscope because of its distinctive interference figure in cross-polarized light.

Occurrence: *Cyclococcolithina formosa* first appears in lower Eocene sediments and persists throughout the middle and upper Eocene and into the lower Oligocene.

Cyclococcolithina protoannula Gartner, n. sp.

Pl. 5, figs. 1a–c, 2

Description: Small to medium size species of *Cyclococcolithina* with large open center, narrow collar, and subequal narrow shields. The shields are constructed of about 45 slightly dextrally inclined elements. In cross-polarized light the collar of this species gives a strong interference figure, but the shield is less distinct. The proximal shield is slightly smaller than or the same size as the distal shield, and the periphery of the shields is nearly smooth.

Remarks: This species is similar to *Cyclolithella annula* (Cohen), but the latter lacks a distinct interference figure on the collar, and in electron micrographs the shield elements are more clearly visible.

Type specimen: Pl. 5, figs. 1a–c.

Type level: JOIDES core J–6B, 251′.

Occurrence: *Cyclococcolithina protoannula* may be found in abundance throughout the middle and upper Eocene, although its areal distribution may be environmentally controlled. In the Blake Plateau core J–6B it is common in the upper Eocene, but in core J–3 it may be scarce or lacking in the same interval.

Genus Fasciculithus Bramlette & Sullivan, 1961

Fasciculithus mitreus Gartner, n. sp.

Pl. 3; Pl. 4, fig. 1

Description: A mitre-shaped species of *Fasciculithus* with stellate or crudely polygonal cross section, concave base, and distally expanding body surmounted and terminated by a broad cone. The body is constructed of radially arranged tabular calcite crystallites which are separated by furrows at the periphery.

Remarks: *Fasciculithus mitreus* is similar to *Fasciculithus tympaniformis* but differs from that species in that it is commonly larger, expands distally, and has a distinct conical "top." *Fasciculithus schaubi* Hay and Mohler also is similar, but this latter species has a regularly pitted surface and a short stem.

Type specimen: Pl. 3, fig. 4.

Type level: JOIDES core J–4, 432′.

Occurrence: *Fasciculithus mitreus* occurs only in the lower part of the *Discoaster multiradiatus* Zone within the upper Paleocene interval.

Genus HELICOPONTOSPHAERA Hay & Mohler, 1967

HELICOPONTOSPHAERA RETICULATA (Bramlette & Wilcoxon), n. comb.

Pl. 1

Helicosphaera reticulata BRAMLETTE & WILCOXON, 1967, p. 106, pl. 6, fig. 15.

Remarks: *Helicopontosphaera reticulata* is broadly elliptical to rhomboidal in shape, the side opposite from the flaring rim commonly being nearly straight, although the remainder of the periphery may be more or less gently curved. The central disc, to which the flaring rim is attached, is also subrhomboidal with a pronounced two-part oblique bar across the center, on either side of which is a single, or, more often, double row of circular or elliptical pits. Although these pits may not be obvious in the light microscope to the casual observer, they can be seen readily in cross-polarized light and with interference contrast optics. The termination of the flaring rim may be broadly rounded or abrupt and pointed.

Occurrence: *Helicopontosphaera reticulata* first appears near the boundary between the middle and upper Eocene, and persists into the lower Oligocene. The species is not cosmopolitan and is not found in pelagic sediment from the deep ocean basins.

HELICOPONTOSPHAERA WILCOXONII Gartner, n. sp.

Pl. 2

?*Helicosphaera* aff. *H. seminulum* Bramlette & Sullivan. BRAMLETTE & WILCOXON, 1967, p. 106, pl. 5, fig. 11, 12.

Description: Broadly elliptical species of *Helicopontosphaera* with relatively uniform peripheral flange which broadens rapidly at one end of the ellipse then terminates sharply. The central plate is regularly elliptical with two large openings in the center separated by a transverse bar, which may be aligned with the short axis of the ellipse, or may be inclined slightly to the axis. The crossbar is constructed of several discreet particles all of which have the same crystallographic orientation, but the crossbar is not continuous crystallographically with the shield.

Remarks: *Helicopontosphaera wilcoxonii* is similar to *Helicopontosphaera seminulum seminulum* but differs from that species in having the expanded flange terminated sharply rather than smoothly rounded as in the latter. *Helicopontosphaera* aff. *H. seminulum* of Bramlette & Wilcoxon (1967) also is similar but in that form too the flaring flange is more smoothly rounded. Very probably *Helicopontosphaera wilcoxonii* is a closely related form.

Type specimen: Pl. 2, fig. 2a, b.

Type level: JOIDES core J–6B, 233′ 1″.

Occurrence: *Helicopontosphaera wilcoxonii* first appears near the base of the upper Eocene within the *Hayella situliformis* Zone, and persists throughout the upper Eocene interval. It is best developed in Blake Plateau core, J–6B, but may be found rarely in core J–3 also.

Genus MARKALIUS Bramlette & Martini, 1964

MARKALIUS ASTROPORUS (Stradner)

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

Markalius inversus (Deflandre) of BRAMLETTE & MARTINI, 1964, p. 302, pl. 2, fig. 4–9 (*not* pl. 7, fig. 2a, b); MARTINI, 1964, p. 49, pl. 6, fig. 9, 10.

Markalius astroporus (Stradner). HAY & MOHLER, 1967, p. 1528, pl. 196, fig. 32–35; pl. 198, fig. 2(?), 6.

Markalius inversus (Deflandre) of PERCH-

NIELSEN, 1968, p. 72, pl. 24, fig. 1–8; pl. 25, fig. 1, text-fig. 35.
Cyclococcolithus astroporus Stradner. RADOMSKI, 1968, p. 568, pl. 44, fig. 7, 8.
Markalius inversus (Deflandre) of PERCH-NIELSEN, 1969a, p. 326, text-fig. 5; PERCH-NIELSEN, 1969b, p. 63, pl. 3, fig. 5, 6.

Remarks: This medium to large size species has 33 to 36 elements per shield. With the light microscope a star may or may not be visible in the center of this species but with the electron microscope no stellate pore is visible. On some specimens radial ribs can be seen in the center, but on most a thin plate seemingly covers this structure (see also *Markalius inversus* (Deflandre)).

Occurrence: *Markalius astroporus* is most common in early Paleocene sediments, but has been recorded in reduced numbers from late Cretaceous, and middle and late Paleocene sediments as well.

MARKALIUS INVERSUS (Deflandre)

Cyclococcolithus leptoporus var. *inversus* DEFLANDRE *in* DEFLANDRE & FERT, 1954, p. 150, pl. 9, fig. 4, 5.
Cyclococcolithus inversus (Deflandre). HAY, MOHLER & WADE, 1966, p. 389, pl. 7, fig. 2.
Cyclococcolithus sp., LEVIN & JOERGER, 1967, p. 166, pl. 1, fig. 10, 11.
Cyclococcolithus inversus (Deflandre). HAQ, 1968, p. 24, pl. 8, fig. 1; MARTINI, 1969, p. 134, pl. 1, fig. 3, 4.

Remarks: The specimens which have been assigned to the species *Markalius inversus* (Deflandre) by various authors are readily divisible into three apparently natural groups on the basis of the number of shield elements. One group of specimens has between 33 and 36 elements per shield. These specimens all are from Paleocene (early and middle) and youngest Cretaceous samples, and very probably are conspecific with *Markalius astroporus (*Stradner). A second group of specimens has 27 or 28 elements per shield. This group includes the type specimen of *Markalius inversus,* and has been recorded from middle (?) and late Eocene deposits. The third group is characterized by relatively small specimens which have 19 to 21 elements per shield. This third group, as yet unnamed, has been reported only from late Eocene deposits. The specimens illustrated by Stradner & Edwards (1968), pl. 26, fig. 2, pl. 27, fig. 3–6 belong to this last group. Of the other specimens illustrated by Stradner & Edwards (1968) the specimen on pl. 26, fig. 1 probably belongs to the species *Pedinocyclus larvalis* (Bukry & Bramlette); that specimen on pl. 27, figs. 1, 2 cannot be assigned definitely because the number of shield elements is not discernible.

Occurrence: Although *Markalius inversus* has been reported from middle and late Eocene strata, all illustrations of this species are from late Eocene samples. As three distinct species probably have been grouped under this name, it is not possible to establish the range of the species at this time. Data gathered by the author indicate that *Markalius inversus* may be found sporadically as early as the late middle Eocene, but is encountered regularly, though sparsely, only in late Eocene strata.

Genus RETICULOFENESTRA Hay, Mohler & Wade, 1966

RETICULOFENESTRA UMBILICA (Levin)

Coccolithus? sp., BOUCHÉ, 1962, p. 84, pl. 1, fig. 17(?), 21a, b, 22(?).
Coccolithus placomorphus (Kamptner) of STRADNER, 1964, p. 135, text-fig. 10.
?*Ellipsoplacolithus* sp., BACHMAYER, 1964, p. 184, pl. 2, fig. 10.
Coccolithus? sp., COHEN, 1965, p. 13, pl. 1, fig. h, i.
Coccolithus umbilicus LEVIN, 1965, p. 265, pl. 41, fig. 2.
Reticulofenestra caucasica HAY, MOHLER & WADE, 1966, p. 386, pl. 2, fig. 5 (*not* fig. 6–8); pl. 3, fig. 1, 2; pl. 4, fig. 1, 2.
Apertapetra samodurovi HAY, MOHLER & WADE, 1966, p. 387, pl. 6, fig. 1–3 (*not* fig. 4–7).
Coccolithus pelicomorphus REINHARDT, 1967, p. 206, pl. 1, fig. 10, 11, 14; pl. 5, fig. 10; pl. 7, fig. 4, text-fig. 6.
Apertapetra umbilicus (Levin). LEVIN & JOERGER, 1967, p. 166, pl. 1, fig. 9a–c; BRAMLETTE & WILCOXON, 1967, p. 101, pl. 5, fig. 1, 2.
Reticulofenestra placomorpha (Kamptner) of STRADNER & EDWARDS, 1968, p. 22, pl. 19?; 20 (*not* pl. 21, probably *not* pl. 22, fig. 1, 2, 3); pl. 23?; 24; 25, fig. 1?, 2; HAQ, 1968, p. 29, pl. 5, fig. 1–5; pl. 3, fig. 3.

Remarks: Stradner & Edwards (1968) synonymize this form with *Tremalithus placomorphus* Kamptner from the Tortonian (Miocene) of the Vienna basin. However, there are significant differences between the two species. *Reticulofenestra umbilica* has approximately 100 elements per shield whereas *Tremalithus placomorphus* has only about 70 elements. The large number of elements in the former species and the consequent small size of the elements makes them unresolvable with light optics. Similarly the delicate laths and grillwork in the center of *Reticulofenestra umbilica* are not visible with light optics. It is very unlikely, therefore, that Kamptner's specimen of *Tremalithus placomorphus* is identical with *Reticulofenestra umbilica.* In addition *Reticulofenestra umbilica* has been reported only from middle Eocene to early Oligocene deposits, and is notably absent from post early Oligocene sediments (see for example Bramlette & Wilcoxon, 1967). Kamptner's specimens, therefore, would have to be reworked and although reworking of calcareous nannofossils is not uncommon, it seems imprudent to select as the nomenclatural type of a species a specimen which is, at best, atypical and reworked.

Stradner & Edwards' concept of this species also seems broader than is necessary or desirable. The specimens illustrated on pl. 21, figs. 1 & 2 are readily assignable to *Reticulofenestra scissura* Hay, Mohler and Wade, a species easily identified in both light and electron microscope.

Reticulofenestra umbilica very probably developed from the middle Eocene species *Coccolithus marismontium* Black from which species it differs primarily by its larger size and relatively larger central opening. This last feature, however, is highly variable in *Reticulofenestra umbilica* and probably not a reliable criterion. *Coccolithus marismontium* apparently also is the ancestor of *Coccolithus floridanus* Roth & Hay (= *Cyclococcolithus neogammation* Bramlette & Wilcoxon), which ranges from the upper part of the middle Eocene well into the Miocene.

Occurrence: *Reticulofenestra umbilica* first appears in middle Eocene sediments and is a common element of the assemblage through most of the middle and upper Eocene interval. The species is also present in earliest Oligocene sediments, but its numbers diminish as it becomes extinct.

RETICULOFENESTRA SCISSURA Hay, Mohler & Wade

Reticulofenestra scissura HAY, MOHLER & WADE, 1966, p. 387, pl. 5, fig. 1, 5, 6? (*not* fig. 2, 3, 4).

Syracosphaera bisecta HAY, MOHLER & WADE, 1966, p. 393, pl. 10, fig. 1–6.

Coccolithus cf. *C. scissurus* (Hay, Mohler & Wade). BRAMLETTE & WILCOXON, 1967, pl. 102, pl. 4, fig. 1, 2.

Coccolithus bisectus (Hay, Mohler & Wade). BRAMLETTE & WILCOXON, 1967, pl. 102, pl. 4, fig. 11–13.

Reticulofenestra dictyoda (Deflandre & Fert) of STRADNER & EDWARDS, 1968, p. 19, pl. 12, fig. 3? only; pl. 13, pl. 22, fig. 4.

Reticulofenestra placomorpha (Kamptner) of STRADNER & EDWARDS, 1968, p. 22 (in part), pl. 21.

Stradnerius dictyodus (Deflandre & Fert) of HAQ, 1968, p. 31, pl. 2, fig. 5–8.

Remarks: Hay, Mohler & Wade illustrated *Reticulofenestra scissura* with electron micrographs only in proximal view, and their light micrographs represent either an aberrant specimen or an entirely different species. On the other hand, they illustrated *Syracosphaera bisecta* only in distal view, and the light micrographs of this species probably are quite accurate. The illustrations of Haq demonstrate convincingly the true nature of the proximal and distal surface of this placolith, *i.e.* the irregular reticulate network in the proximal surface of the central pore, and the large, roughly radial plates on the distal surface of the central pore. It is surprising, therefore, that Stradner & Edwards, and Haq identify the above species with *Discolithus dictyodus* Deflandre & Fert which species clearly does not have the large radial plates on the distal surface of the central pore. The two different forms illustrated

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PLATE 1

Helicopontosphaera reticulata (Bramlette & Wilcoxon). Gartner, n. comb.

Figure 1, 3. Electron micrographs, × 10,000. 1—J–6B, 251′; 3—Shubuta Clay, Clark Co., Mississippi.

Figure 2a–c. Light micrographs, × 2500, J–6B, 182′1″. 2a—phase contrast; 2b—interference contrast; 2c—cross-polarized light.

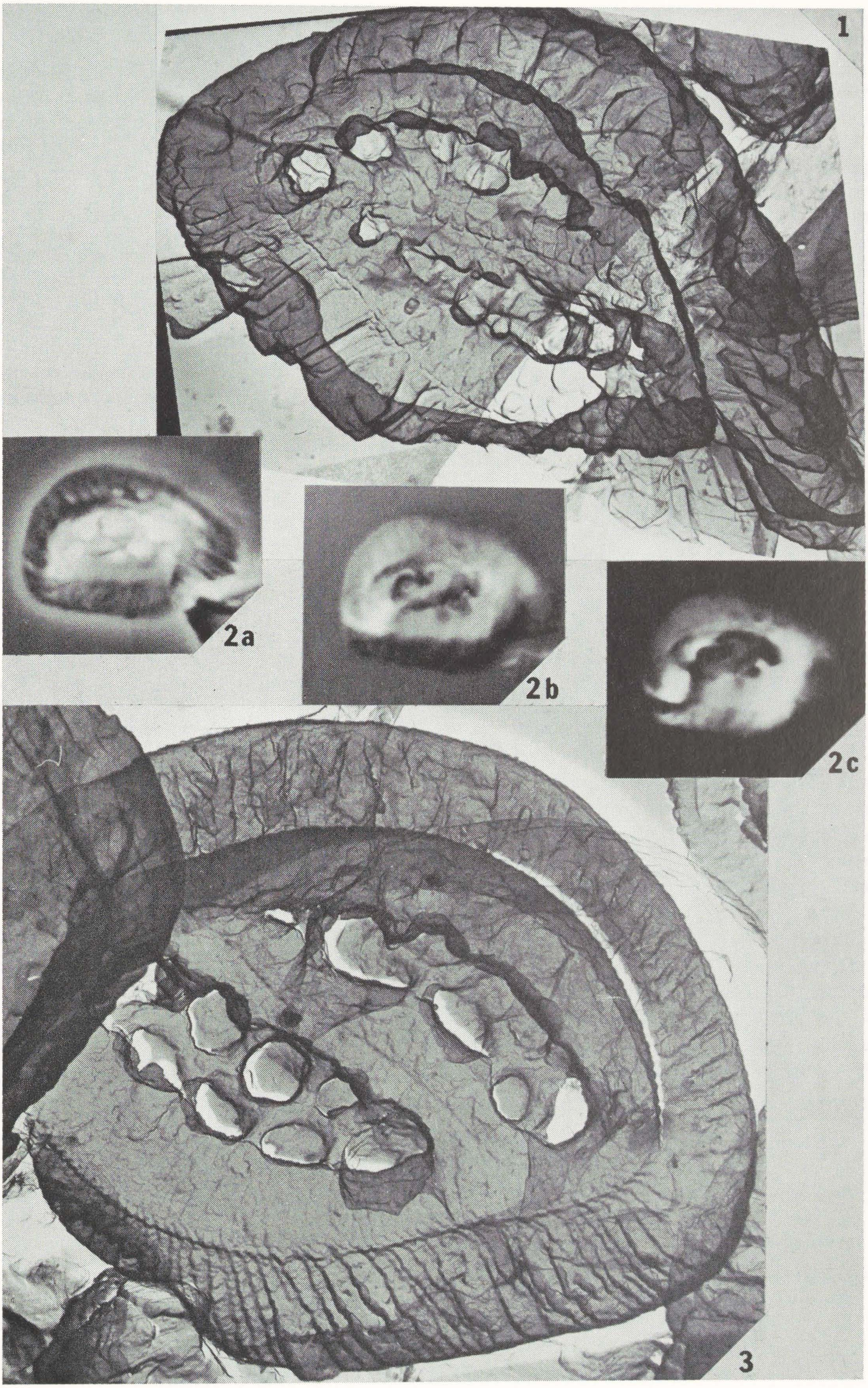

PLATE 1

by Bramlette & Wilcoxon, and assigned by them to different species appear to fall within the range of variation of *Reticulofenestra scissura,* a conclusion supported by their similar stratigraphic range.

Occurrence: *Reticulofenestra scissura* first appears in the middle Eocene and persists as a significant constituent of the assemblage into the Oligocene, finally becoming extinct within the *Sphenolithus ciperoensis* Zone (see Bramlette & Wilcoxon, 1967).

Genus RHOMBOASTER Bramlette & Sullivan, 1961

RHOMBOASTER CALCITRAPA Gartner, n. sp.
Pl. 4, figs. 2–6

Description: *Rhomboaster* on which some or all of the eight corners have long spines developed which extend roughly radially and taper to a point. The spines commonly are slightly curved and somewhat irregular in their orientation, so that they may extend at an unusual angle from the corner of the rhomb. In ultrastructure *Rhomboaster calcitrapa* resembles most closely certain asteroliths in that no discrete crystallographic units can be recognized and the entire object appears to be built up by the deposition of successive layers of calcite.

Remarks: *Rhomboaster calcitrapa* differs from *Rhomboaster cuspis* Bramlette & Sullivan in having long irregularly oriented spines developed on its corners. The Cretaceous genus *Micula* is similar but probably unrelated to this form.

Type specimen: Pl. 2, fig. 3.

Type level: JOIDES core J–4, 300′4″.

Occurrence: *Rhomboaster calcitrapa* is a conspicuous constituent of the assemblage in the upper part of the *Discoaster multiradiatus* Zone in the JOIDES Blake Plateau core J–4.

Genus SPHENOLITHUS Deflandre, 1952

SPHENOLITHUS STELLATUS Gartner, n. sp.
Pl. 5, figs. 3a, b

Description: Sphenolith with stellate outline, consisting of six segments arranged radially each segment having a different crystallographic orientation. Adjacent segments are joined along a radial suture, and the length of each segment is at least twice the length of the sutures. At the periphery the segments are evenly tapered and pointed.

Remarks: *Sphenolithus stellatus* superficially resembles small asteroliths but is readily distinguished from them in cross-polarized light. It differs from all species of *Sphenolithus* by the regular stellate outline and by the small number of radially arranged segments.

Type specimen: Pl. 5, figs. 3a, b.

Type level: JOIDES core J–6B, 251′.

Occurrence: *Sphenolithus stellatus* was recorded only from the middle Eocene interval of the JOIDES Blake Plateau core J–3.

Genus TOWEIUS Hay & Mohler, 1967

TOWEIUS EMINENS (Bramlette & Sullivan), n. comb.

Coccolithus eminens BRAMLETTE & SULLIVAN, 1961, p. 139, pl. 1, fig. 3a–d; SULLIVAN, 1964, p. 181, pl. 1, fig. 11a, b; SULLIVAN, 1965, p. 31.

Cruciplacolithus eminens (Bramlette & Sullivan). HAY & MOHLER, 1967, p. 1527, pl. 196, fig. 26–28 (*not* p. 198, fig. 9, 10).

Coccolithus eminens Bramlette & Sullivan. RADOMSKI, 1968, p. 564, pl. 45, fig. 7, 8.

Remarks: This species resembles *Toweius craticulus* Hay & Mohler in both optical properties (interference figure in cross-polarized light) and in ultrastructure, except in one distinguishing characteristic: *Toweius eminens* has only four pores in the center. These pores are larger than the 8 to 12 pores in *Toweius craticulus* and are symmetrically arranged in the center of the placolith. The bars separating these four pores, although

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PLATE 2

Helicopontosphaera wilcoxonii Gartner, n. sp
Figure 1, 4. Electron micrographs, × 10,000, J–6B, 251′.
Figure 2a, b, 3. Light micrographs, × 2500. 2a, b—J–6B, 233′1″; 2a—interference contrast; 2b—cross-polarized light. 3—J–6B, 251′, interference contrast.

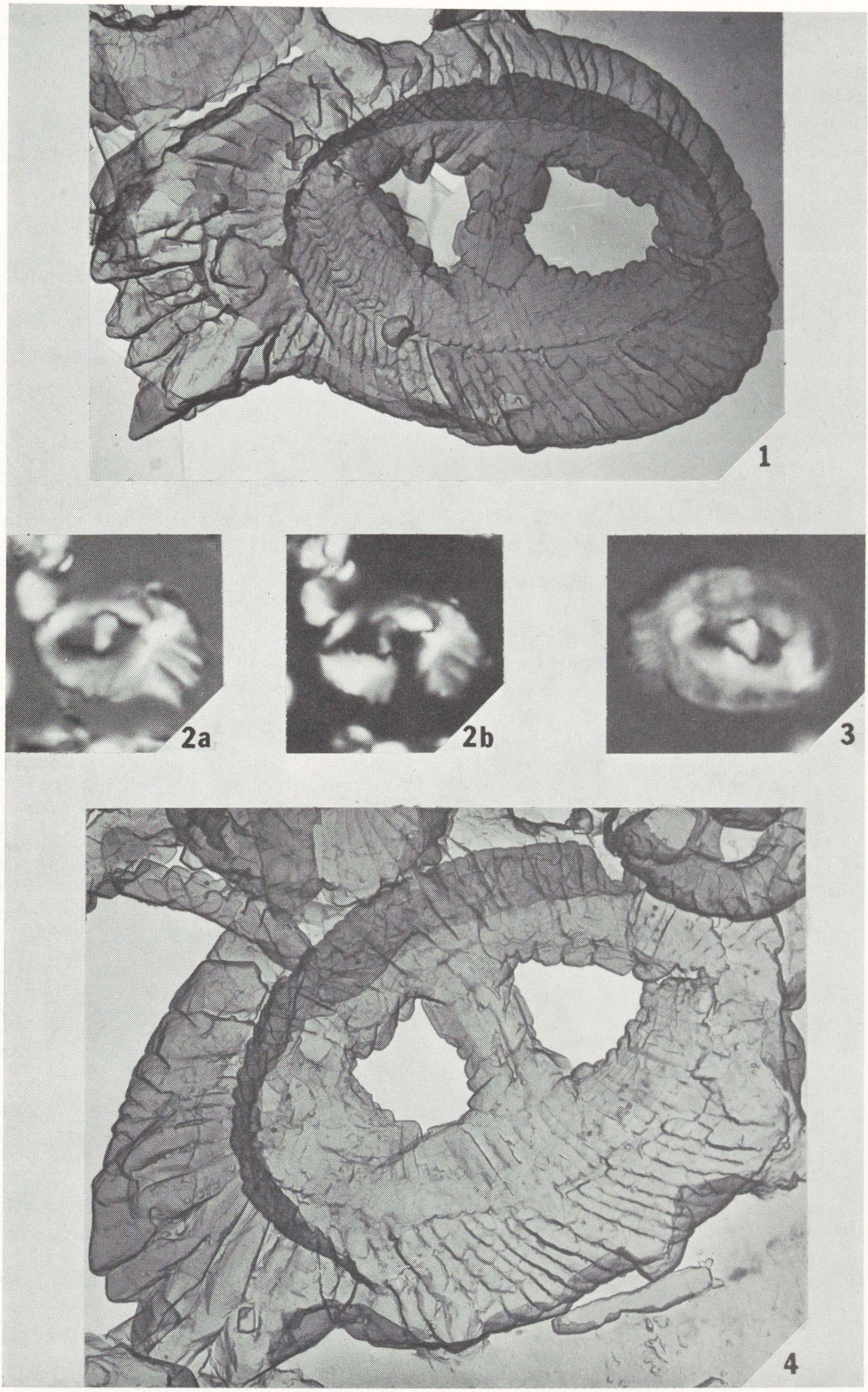

PLATE 2

analogous to the crossbars in *Cruciplacolithus,* are not homologous in a biological sense because in *Toweius eminens* the crossbars developed from the central plug and radiating bars of *Toweius craticulus,* whereas the crossbars of *Cruciplacolithus* (i.e. *Cruciplacolithus tenuis* (Stradner)) developed from the peculiar grillwork exhibited by the Cretaceous genus *Sollasites.*

Occurrence: *Toweius eminens* first appears near the top of the *Discoaster gemmeus* Zone and persists into the basal Eocene *Marthasterites contortus* Zone.

Nomenclatural Note

The following names, used on the accompanying charts but not mentioned in the text, are new combinations not used validly in previous publications. One name is newly proposed as a substitute for a homonym.

Cyclolithella bramletti (Hay & Towe), n. comb. = *Cyclolithus bramlettei* Hay & Towe, 1962, p. 500, pl. 5, fig. 6, pl. 7, fig. 2.

Discolithina ocellata (Bramlette & Sullivan), n. comb. = *Discolithus ocellatus* Bramlette & Sullivan, 1961, p. 142, pl. 3, figs. 2a–c.

Helicopontosphaera parallela (Bramlette & Wilcoxon), n. comb. = *Helicosphaera parallela* Bramlette & Wilcoxon, 1967, p. 106, pl. 5, figs. 9, 10.

Helicopontosphaera seminulum lophota (Bramlette & Sullivan), n. comb. = *Helicosphaera seminulum lophota* Bramlette & Sullivan, 1961, p. 144, pl. 4, figs. 3a, b, 4.

Transversopontis exilis (Bramlette & Sullivan), n. comb. = *Discolithus exilis* Bramlette & Sullivan, 1961, p. 142, pl. 2, figs. 10 a–c.

Marthasterites nunnii, nom. nov., substitute name for *Marthasterites bramlettei* Brönnimann & Stradner, 160, p. 366, figs. 17–20, 23, 24 (junior homonym; see Loeblich & Tappan, 1966, p. 148).

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Plate 3

Fasciculithus mitreus Gartner, n. sp.

Figure 1, 2. Electron micrographs, × 10,000, J–4, 432′. 1—side view; 2—proximal view (concave side).

Figure 3a, b; 4a–c. Light micrographs, × 2500. 3a, b—J–4, 321′, side view. 3a—interference contrast; 3b—cross-polarized light. 4a–c—J–4, 392′; 4a—side view, interference contrast; 4b—distal view (convex side), phase contrast; 4c—distal view (convex side), cross-polarized light.

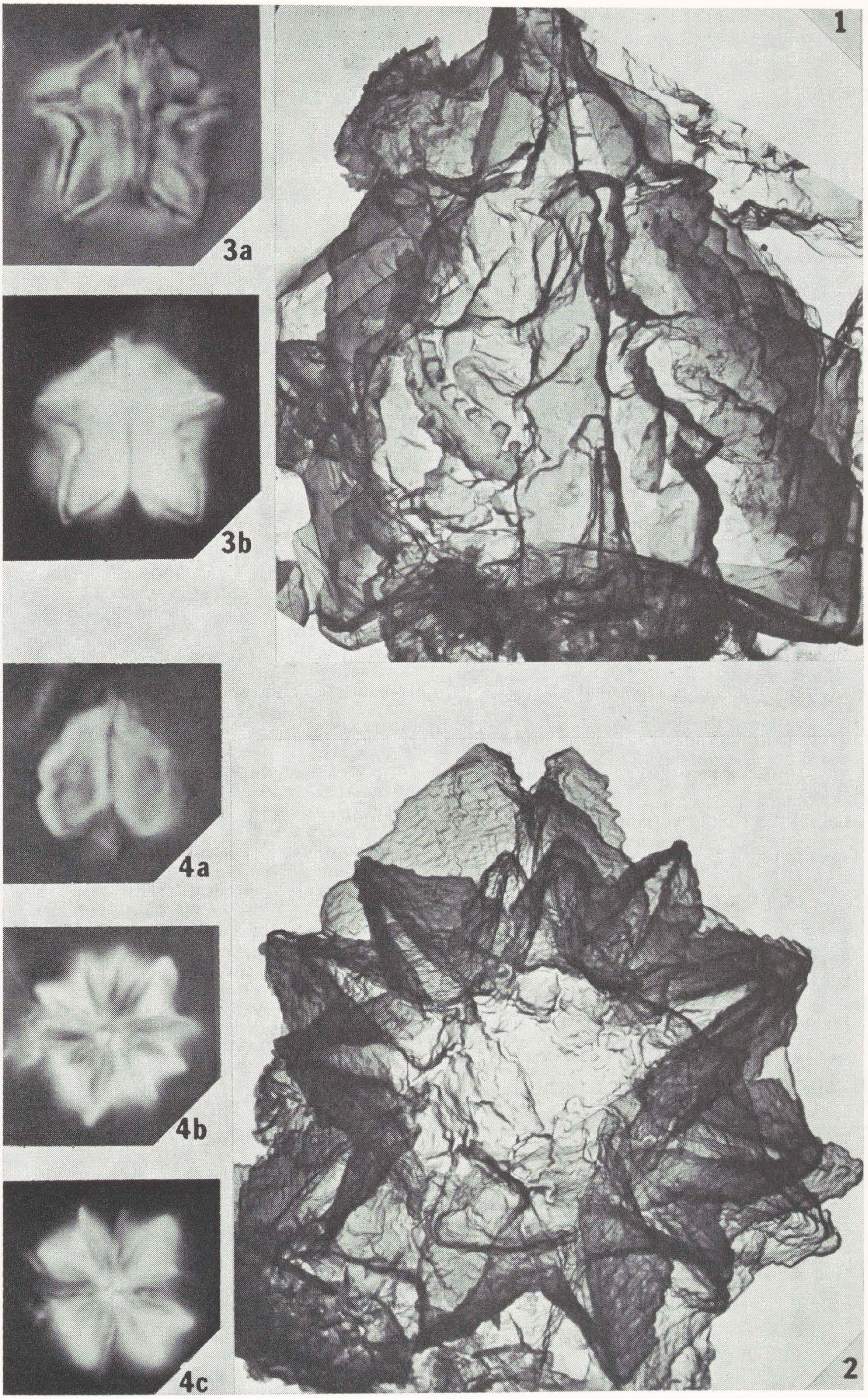

PLATE 3

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PLATE 4

Figure 1. *Fasciculithus mitreus* Gartner, n. sp. Electron micrograph, × 10,000, J–4, 432′. Distal view (convex side).

Figure 2–6. *Rhomboaster calcitrapa* Gartner, n. sp. J–4, 300′4″.
2–4. Electron micrographs, × 5000.
5, 6a, b. Light micrographs, × 2500. 5, 6b—dark field illuminations; 6a—transmitted light.

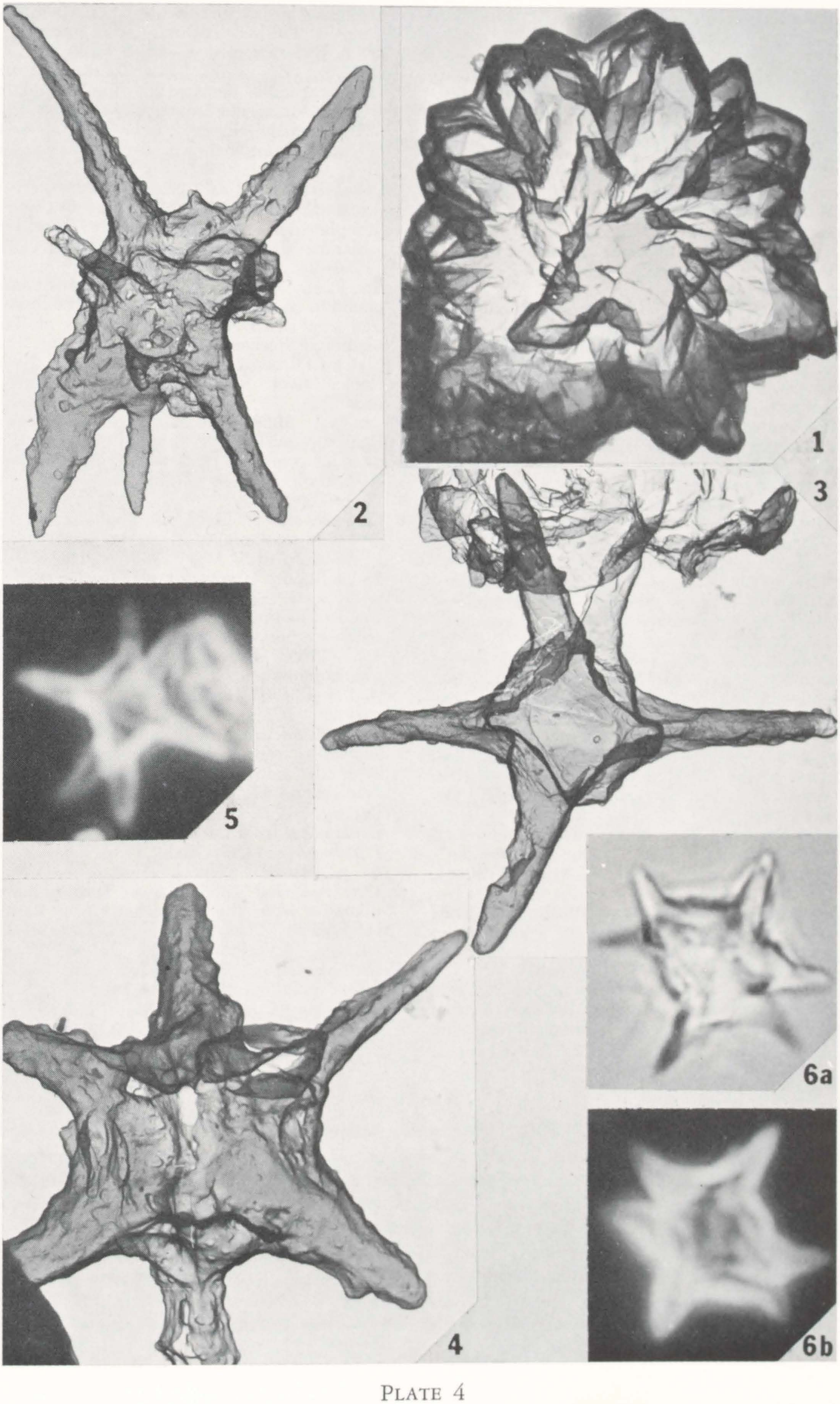

PLATE 4

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PLATE 5

Figure 1, 2. *Cyclococcolithina protoannula* Gartner, n. sp., J–6B, 251′. 1a–c. Light micrographs, × 2500. 1a—phase contrast; 1b—interference contrast; 1c—cross-polarized light. 2—Electron micrograph, × 10,000.

Figure 3a, b. *Sphenolithus stellatus* Gartner, n. sp., J–6B, 251′. 3a—Interference contrast; 3b—cross-polarized light.

Figure 4–6. *Toweius eminens* (Bramlette & Sullivan). Gartner, n. comb., J–4, 531′2″. 4a–c, 5. Light micrographs, × 2500. 4a—phase contrast; 4b—transmitted light; 4c, 5—cross-polarized light. 6—Electron micrograph, × 10,000. Distal view.

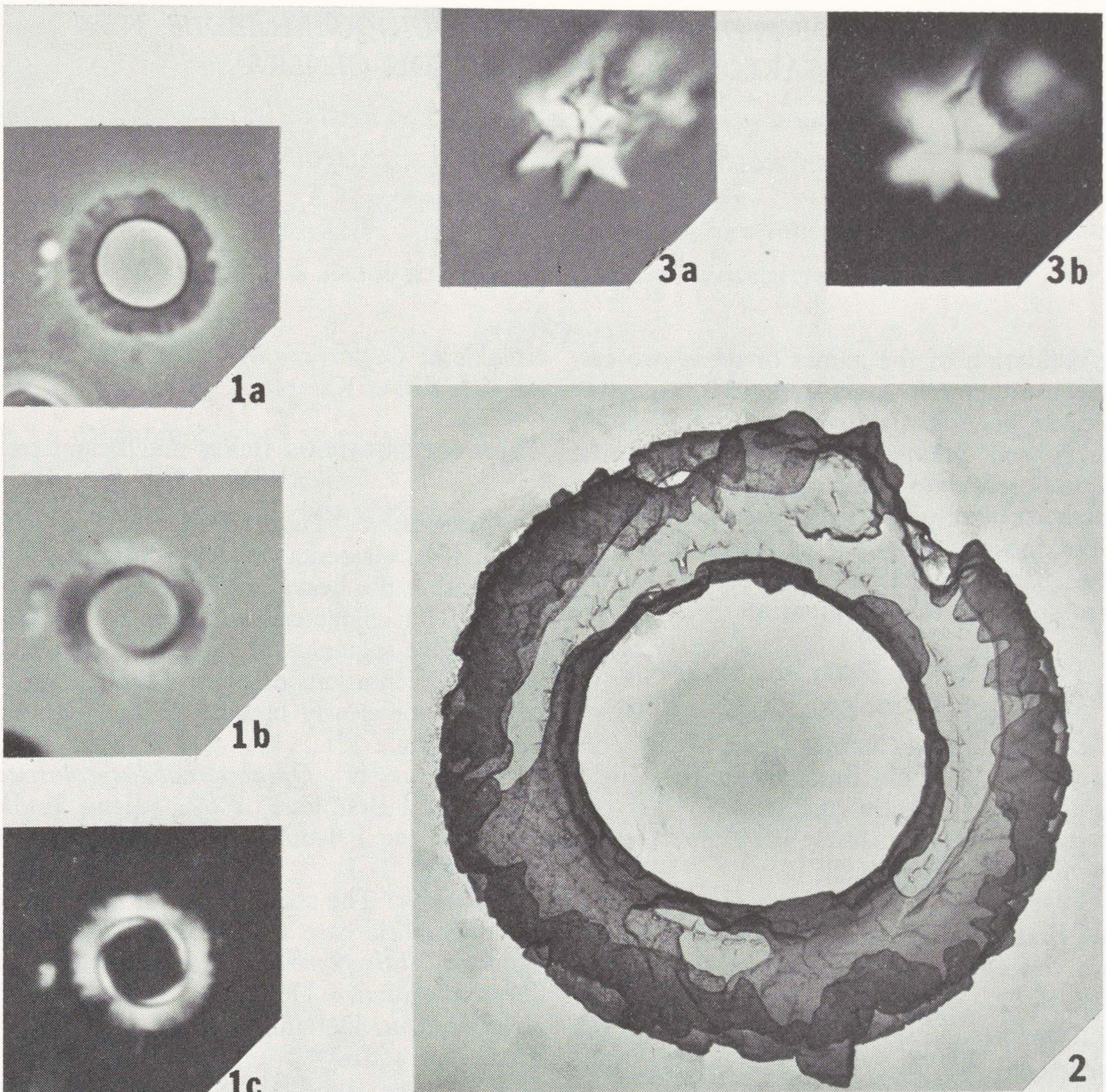

PLATE 5