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COCCOLITHS AND RELATED CALCAREOUS NANNOFOSSILS FROM THE YAZOO FORMATION (JACKSON, LATE EOCENE) OF LOUISIANA

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ABSTRACT

Coccoliths, discoasters, and related calcareous nannofossils have been studied commonly using light microscopes and electron microscopes, but the results from the two techniques often have been impossible to relate. In order to test the feasibility of combining the best features of both, an assemblage from a late Eocene sample was studied intensively using a light microscope together with an electron microscope. Of 15 species in the assemblage, 3 are described as new. In addition, different pseudointerference figures of placoliths are considered to be a reliable basis for specific distinctions, whereas size of the placoliths and the degree of development of some rhabdoliths are not considered taxonomically important.

INTRODUCTION

Coccoliths, discoasters, and associated calcareous nannofossils have received considerable attention recently, partly because of their application to biostratigraphic problems. To the paleontologist, these minute fossils are particularly interesting and useful because the planktonic mode of life and wide distribution of the parent organisms make them well suited for regional and worldwide correlations and their minute size makes possible recovery of large assemblages from small samples, such as are obtained from well cuttings.

Coccoliths, discoasters, and related forms are the calcareous remains of minute calcareous algae that inhabit tropical, temperate, and subarctic oceans. The coccoliths and discoliths are embedded in the surface of the organism and form a sort of armor around it. The discoasters, on the other hand, appear to be completely enclosed within the organism (Bursa, 1965); the function of these calcareous parts is not well understood.

Coccoliths and discoasters have been known for more than a century, but only recently has their value in biostratigraphy been recognized, owing largely to the efforts of M. N. Bramlette. One reason why paleontologists have generally ignored these fossils is that their small size—about 10 μ—makes it difficult to differentiate the many similar forms even with the best light microscope. Consequently, when electron microscopes were introduced, coccoliths were one of the first fossils to be examined with this new tool. The earliest electron micrographs indicated a complexity of structure that could only be inferred from the most sophisticated light-microscopic study. With improvement in techniques, electron micrographs showed vast amounts of detail, much of which is beyond the limit of resolution of light optics (Pl. 1, fig. 3,4). The two methods of study, however, yield rather different results. In light microscopic study, structural detail must be interpreted largely from what happens to a beam of polarized light when it passes through one of these minute fossils. With the electron microscope, on the other hand, even the most minute structural detail of the surface can be resolved, but it is impossible to obtain a polarized-light image. As a result of these differences in the two methods of study, two bodies of literature have come into being, and the results often are difficult to interrelate.

In this study, both electron microscopy and light microscopy were used on the same sample. Specimens are illustrated with light micrographs made with phase-contrast optics, plain transmitted light, and polarized light. In addition, every species (except one) also is illustrated with electron micrographs so that the light optical image can be related to the electron optical image of the same species.

The forms identified in the assemblage are recorded in the following section on Systematic Paleontology. Previously named species are not redescribed in detail, but pertinent features that supplement earlier descriptions are cited.

The assemblage used in this study was obtained from a composite sample of gray, soft mudstone from the basal 9 feet of the Yazoo Formation, lower Jackson (5 to 14 feet above the base), upper Eocene. The sample was collected by E. J. Reynolds and C. H. Stevens from the east bank of Red River at Montgomery Landing on Creole Bluff, in West Montgomery, Grant Parish, Louisiana.

For study with the electron microscope, single-stage, self-shadowed carbon replicas were used. The micrographs were made with a Phillips 75-electron microscope on 35-mm. film and were printed at $\times$10,000. For light microscopic study, fixed and mobile mounts were used. The former can be prepared with any of several mounting materials such as Canada balsam, cedax, or an epoxi resin; the mobile mounts were prepared using a nondrying silicone fluid that has a viscosity of 30,000 centistoke. The mobile mount permits moving and turning the specimen so that the observer may study it from all sides.

NATURE OF ASSEMBLAGE AND CONCLUSIONS

The sample yielded a total of 15 species of which three are new. Fourteen of the species are illustrated with both light and electron micrographs; *Pemma angulatum* Martini is illustrated only by an electron micrograph. The three new species (*Coccolithus falcatus, Cyclococcolithus orbis,* and *Cyclococcolithus reticulatus*) are superficially similar in the light microscope, but electron micrographs show them to be quite different in construction; this is borne out by the distinctive pseudointerference figures in cross-polarized light.

Specimens of *Coccolithus eopalagicus* (Bramlette & Riedel) tend to differ greatly both in size and in the manner in which shield elements are terminated at the periphery, but this variation appears to be superficial. *Zygrhablithus bijugatus* (Deflandre) similarly has great variability within the species, but this variation is confined primarily to the degree of development of the stem.

In comparing results from the two methods of study, it was found that some subtle differences seen in the light microscope, such as the pseudointerference figure of a placolith seen in cross-polarized light, may serve as the basis for specific distinction between similar forms. Caution is indicated, however, because rather obvious differences in the size of a placolith, for example *Coccolithus eopalagicus* (Bramlette & Riedel), or in the degree of development of the stem of a rhabdolith, as in *Zygrhablithus bijugatus* (Deflandre), may have no taxonomic significance.

In comparing this upper Eocene assemblage with several Upper Cretaceous assemblages studied in the same manner, vast differences are seen. Not one of nearly 100 Upper Cretaceous species survived to late Eocene time, and the only genus that is found consistently in Upper Cretaceous and upper Eocene deposits is *Coccolithus.* This change in the nature of the calcareous nannoplankton has been discussed extensively by Bramlette & Martini (1964) and by Bramlette (1965).

SYSTEMATIC PALEONTOLOGY

Genus COCCOLITHUS Schwarz, 1894

Type species.—Coccolithus oceanicus Schwarz, 1894 (=*Coccosphaera palagica* Wallich, 1877).

Elliptical placoliths consisting of a smaller proximal and a larger distal shield; shields connected at centers of a tube. *U.Cret.-Rec.*

COCCOLITHUS UMBILICUS Levin, 1965

Coccolithus umbilicus LEVIN, 1965, p. 265, pl. 41, fig. 2.

The elements that make up the proximal and distal shields of this placolith are about 0.25 μ wide and, therefore, are just beyond the resolution limit of the light microscope. As seen in electron micrographs, the distal shield is constructed of up to 100 radial elements which come to a point at the periphery. The proximal shield is made of an equal number of elements; these also are pointed at the periphery. Sutures on both shields curve and incline slightly clockwise when viewed proximally, and the elements imbricate sinistrally. The collar or central tube is robust and continuous with the elements of the proximal shield but is attached along a distinct suture to the distal shield. The opening of the central tube is obstructed by a lacy network at the level of the proximal shield. Holes in the network are slitlike and are arranged radially.

Illustrations.—Plate 1, figures 3, 4. Illustrations showing difference in resolution of morphologic features in photographs obtained using a light microscope (3) and an electron microscope (4), ×4,300.——Plate 2, figures 1-3. Electron and light micrographs; 1,2, electron micrographs, ×8,600, proximal (1) and distal (2) views; 3, proximal views using light microscope, ×3,400, phase contrast (3a) and cross-polarized light (3b). [This species is the largest in the Yazoo Formation and is also very abundant. Note the lacy network across the central area in Plate 2, figure 1; this is never visible with the light microscope.]

COCCOLITHUS EOPALAGICUS (Bramlette & Riedel), 1954

Tremalithus eopalagicus BRAMLETTE & RIEDEL, 1954, p. 392, pl. 38, fig. 2.

Coccolithus aff. *C. eopalagicus* (BRAMLETTE & RIEDEL), LEVIN, 1965, p. 266, pl. 41, fig. 4 (not fig. 5).

The name of this species suggests similarity and relationship to the modern *Coccolithus palagicus* (WALLICH). The similarity is so very great that *Coccolithus eopalagicus* doubtlessly is ancestral to the modern form. Considerable variability is noted within the species, as is also the case with *C. palagicus*. In both instances this variability is expressed primarily in the range in size and to a lesser extent in the termination of the shield elements at the periphery. This termination may be at about 90° to the nearly radial sutures or may form a sharper angle with the suture. In the latter case the periphery of the placolith is serrate. The basic construction of the placolith, however, is the same, and the pseudointerference figure in cross-polarized light is identical. Although BRAMLETTE & RIEDEL (1954) restricted this species to the largest specimens only, the more abundant smaller specimens here are included as well.

Illustrations.—Plate 3, figures 1-5.——Fig. 1-3. Electron micrographs, ×8,600. 1,3, Proximal view; 2, distal view.——Fig. 4, 5. Light micrographs, ×3,400. 4,5a, Phase contract; 5b, cross-polarized light. [This is the most common species in this sample, and is easily recognized by the pseudo-inference figure in spite of the considerable range in size.]

COCCOLITHUS FALCATUS Gartner & Smith, n. sp.

This slightly elliptical placolith has the larger distal shield constructed of about 53 elements that terminated in a rounded point at the periphery of the shield. The central perforation is elliptical and in electron micrographs shows remnants of a lacy network. The collar or central tube is an elliptical cylinder having knoblike protrusions where it joins the remnants of the broken proximal shield. Viewed proximally, the sutures of the distal shield are slightly curved and incline clockwise. The elements imbricate sinistrally. Maximum diameter, 7.5 μ.

Discussion.—This species differs from *Coccolithus umbilicus* LEVIN (1965) in being much smaller, having only about half as many elements in the distal shield, and having these elements less sharply terminated at the periphery. It differs from *Coccolithus palagicus* (WALLICH) in having smaller shield elements and a thinner central tube. Both of these features contribute to giving this species a strikingly different pseudointerference figure in cross-polarized light.

Type specimen.—Plate 1, figure 3.

Illustrations.—Plate 1, figures 5, 6.——Fig. 5, Electron microgram, ×8,600, proximal view.——Fig. 6. Light micrographs, ×3,400, proximal view; 6a, bright field; 6b, phase contrast; 6c, cross-polarized light.

Genus CYCLOCOCCOLITHUS Kamptner, 1954

Type species.—*Coccosphaera leptopora* MURRAY & BLACKMAN, 1898.

Circular placoliths having a circular central perforation. *Eoc.-Rec.*

CYCLOCOCCOLITHUS ORBIS Gartner & Smith, n. sp.

Aff. *Coccolithus lusitanicus* BLACK, 1964, p. 308, pl. 50, fig. 1, 2.

This circular placolith has the larger distal shield constructed of about 50 elements with flat terminations giving the placolith a smooth circular outline. The central perforation is circular, in some views appearing crudely polygonal. The cylindrical collar is robust, extending up to half the radius of the distal shield, and the collar and shield elements are joined distally along a serrate line. The sutures of the distal shield incline counterclockwise and the elements appear to imbricate dextrally. In the proximal shield the elements have a pointed or rounded termination and form a serrate periphery. Sutures and imbrication are not clearly distinguishable. Diameter, 9 to 10.5 μ.

Discussion.—This species resembles the Miocene form from the experimental Mohole which was identified as *Cyclococcolithus leptoporus* (MURRAY & BLACKMAN) by MARTINI & BRAMLETTE (1963) but differs in having the sutures inclined in the opposite direction. *Cyclococcolithus orbis* closely resembles *Coccolithus lusitanicus* BLACK (1964), but the type of *C. lusitanicus* (BLACK, 1964, pl. 50, fig. 1) is elliptical. Intraspecific variation among placoliths from elliptical *(Coccolithus)* to circular *(Cyclococcolithus)* has not been demonstrated.

Type specimen.—Plate 4, figure 1.

Illustrations.—Plate 4, figures 1-3.——Fig. 1, 2. Electron micrographs, ×8,600. 1. Proximal view; 3, distal view.——Fig. 3. Light micrographs, ×3,400, proximal view; 3a, Phase contrast; 3b,c, cross-polarized light, high and low focus. This species has a sharp swastika-like presudointerference figure in cross-polarized light when the proximal shield is in focus.

CYCLOCOCCOLITHUS RETICULATUS Gartner & Smith, n. sp.

This circular placolith has the larger distal shield consisting of 50 to 70 elements that terminate in a point or are rounded at the periphery. The central perforation is covered by a network of radially disposed elements continuous with elements of the proximal shield. The sutures of the distal shield are nearly radial, inclining and curving slightly clockwise. The imbrication appears to be very slightly sinistral. The sutures of the proximal shield are irregular near the central perforation but become straight near the periphery of the shield. They incline slightly counterclockwise and the elements may imbricate dextrally. In the distal view, the central perforation commonly appears polygonal. Maximum diameter, 6 to 9.5 μ.

Discussion.—This species is similar to the form identified as *Cyclococcolithus dictyodus* (DEFLANDRE & FERT) by HAY & TOWE (1962) but differs in having a greater number of elements in the shield; these elements terminate in a point and have nearly radial sutures.

Type specimen.—Plate 5, figure 2.

Illustrations.—Plate 5, figures 1-4.——Fig. 1-3. Electron micrographs, ×8,600; 1, distal view; 2,3, proximal views.——Fig. 4. Light micrographs, ×3,400, proximal view; 4a,c, phase contrast, high and low focus; 4b,d, cross-polarized light, high and low focus. [The lacy network across the central opening of this species is commonly preserved, and yields a distinctive pseudointerference figure in cross-polarized light.]

Genus DISCOLITHINA Loeblich & Tappan, 1963

Type species.—*Discolithus vigintiforatus* KAMPTNER, 1948.

Elliptical disc having distinct rim that encloses a central area with multiple perforations. *Eoc.-Rec.*

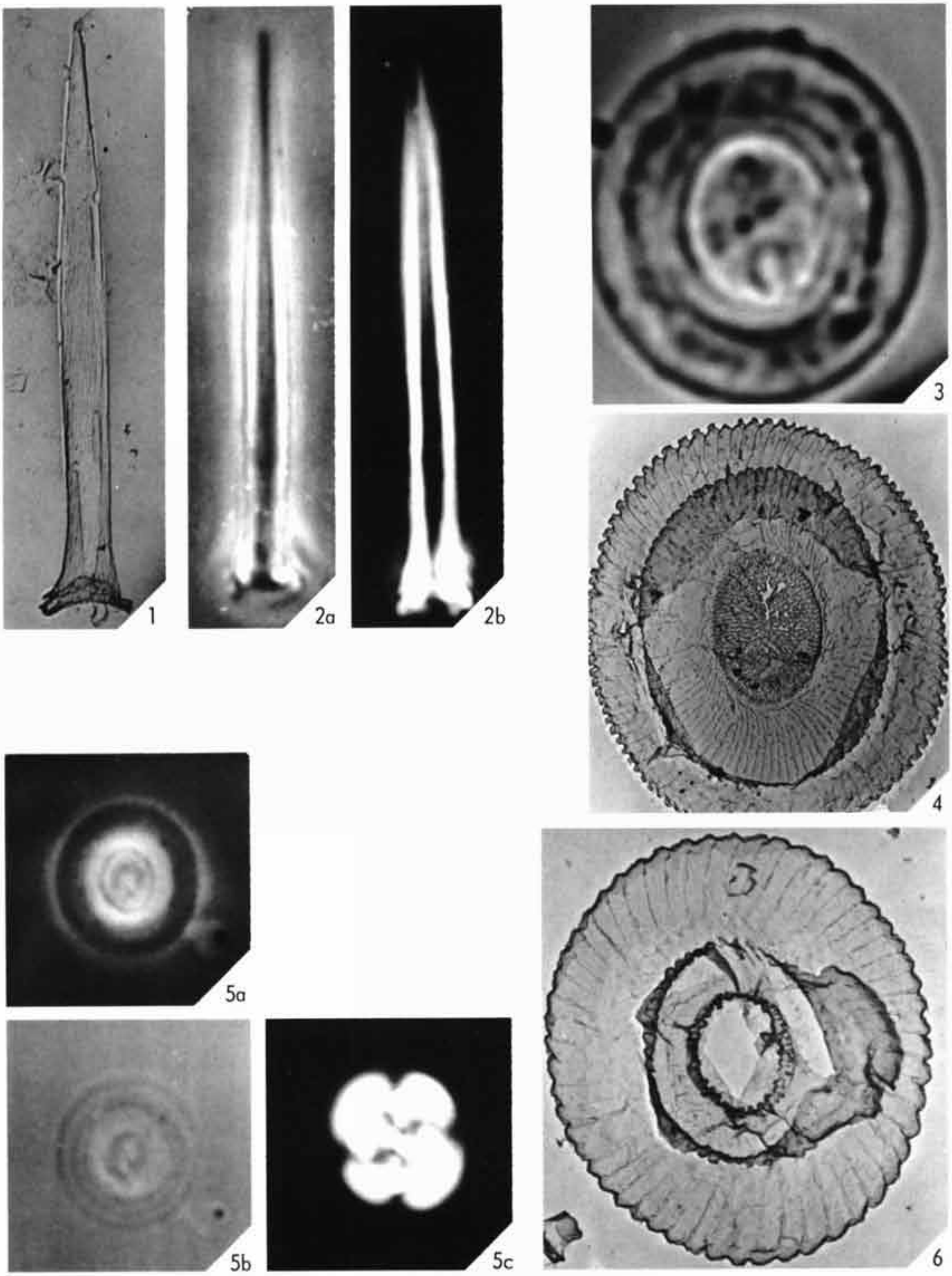
DISCOLITHINA sp. cf. D. PULCHEROIDES (Sullivan)

Cf. *Discolithina* aff. *D. pulcher* (DEFLANDRE). BRAMLETTE & SULLIVAN, 1961, p. 143, pl. 3, figs. 9, 10.

Cf. *Discolithus pulcheroides* SULLIVAN, 1964, p. 183, pl. 4, fig. 7.

BRAMLETTE & SULLIVAN have indicated that this species grades into *Discolithina pulcher* in the development of the spikelike denticulate ornamentation of the inner rim. This is suggested also by the electron micrographs (Pl. 6, fig. 1, 2), which show an outer (peripheral) half of tangentially arranged elements and an inner half of concentrically arranged elements in the rim. The concentric elements generally are less than 1 μ long and are joined by very irregular radial sutures. These sutures probably cause the scalloped appearance of the inner rim, or they may be sites at which the spikelike denticulations develop.

Illustrations.—Plate 6, figures 1-3.——Fig. 1, 2. Electron micrographs, ×8,600.——Fig. 3. Light micrographs, ×3,400; 3a, bright field; 3b, phase contrast, 3c, cross-polarized light.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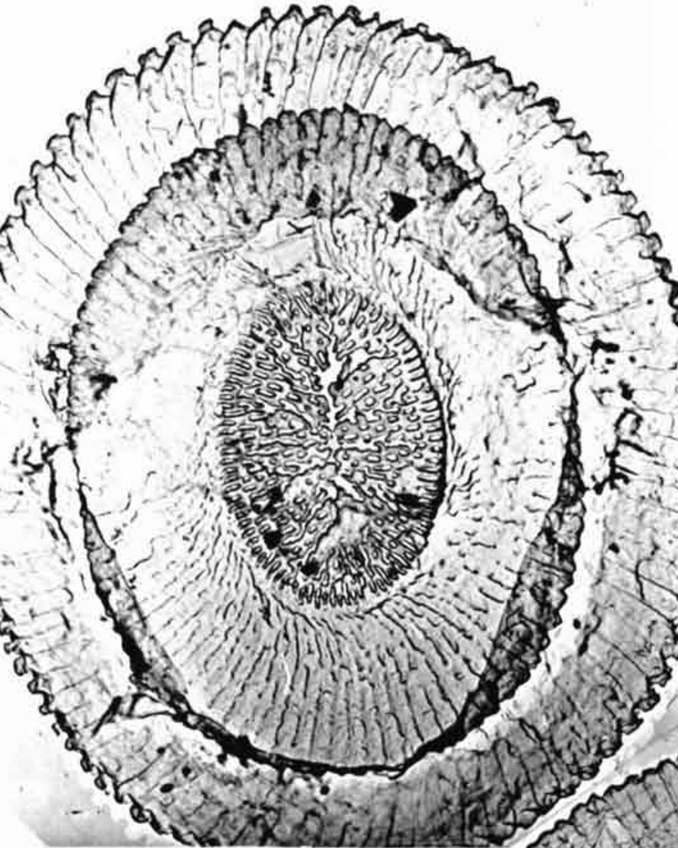

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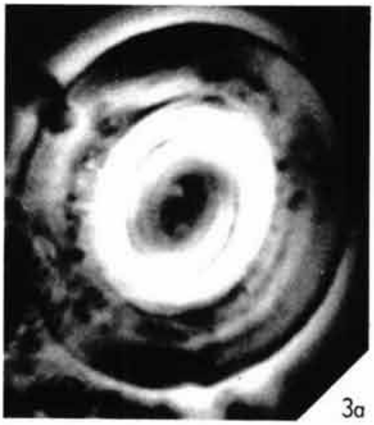

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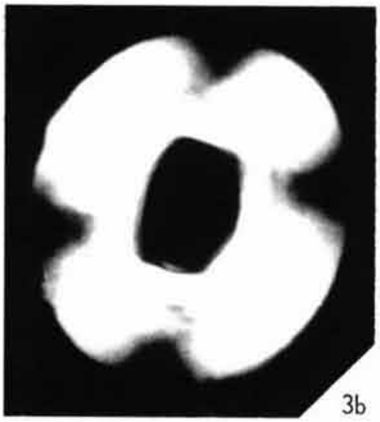

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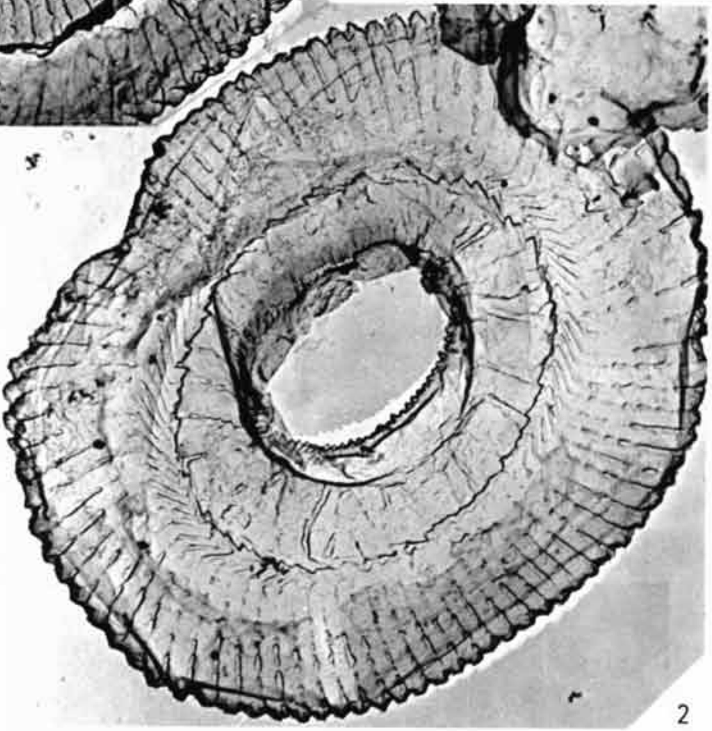

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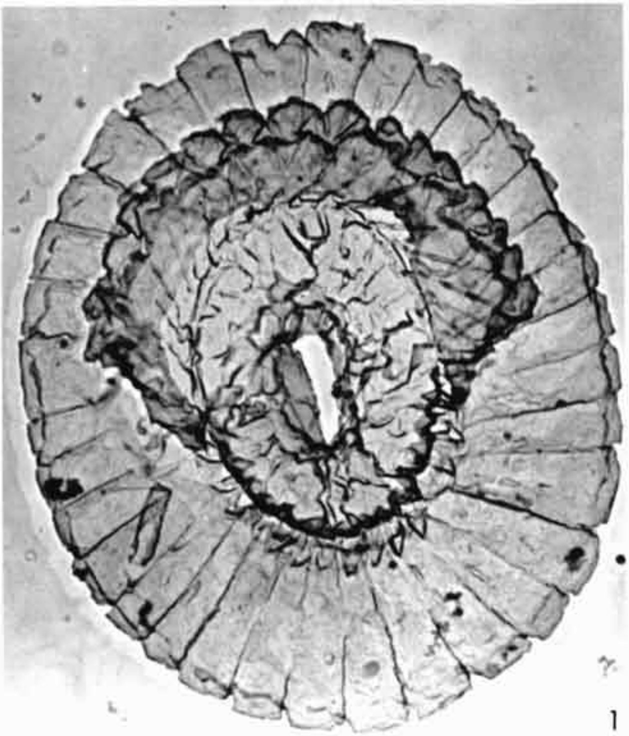

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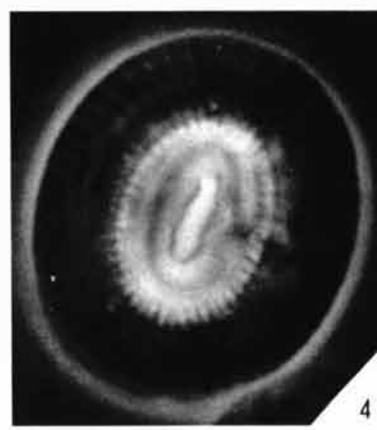

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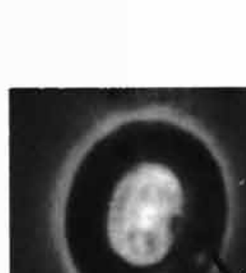

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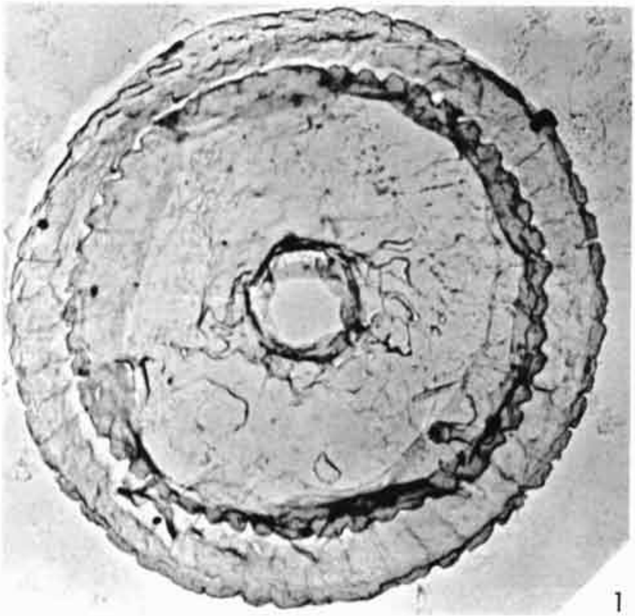

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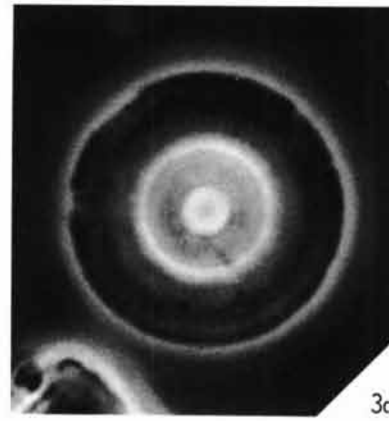

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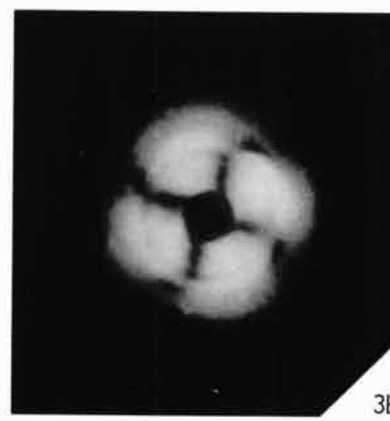

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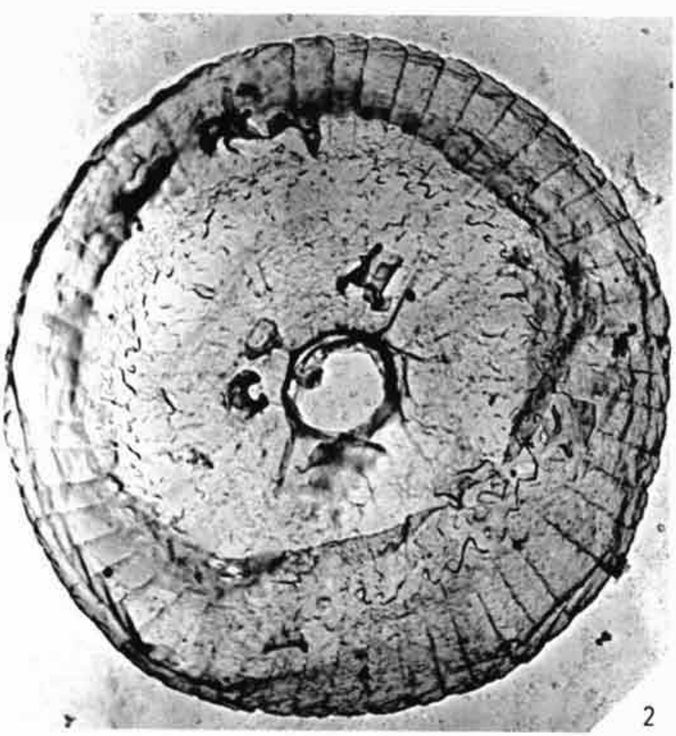

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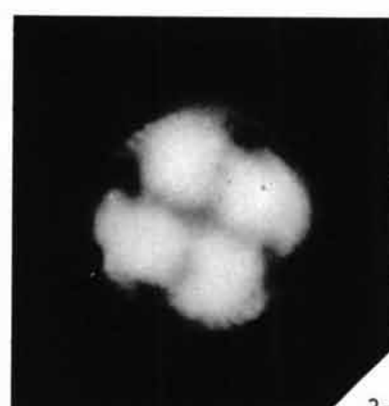

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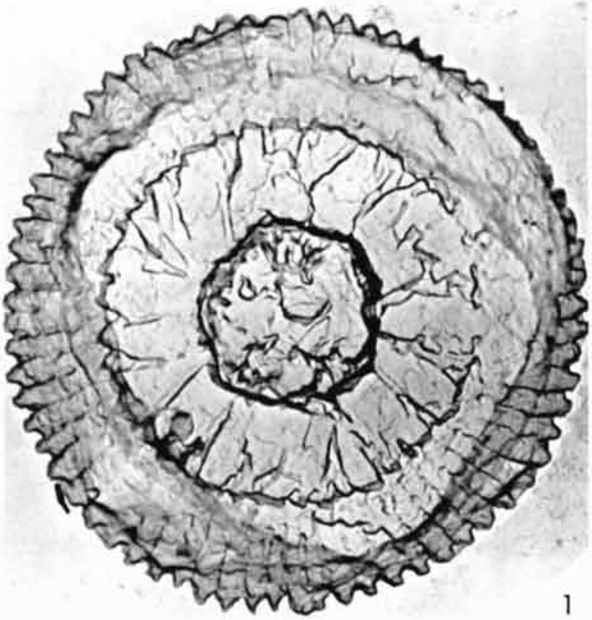
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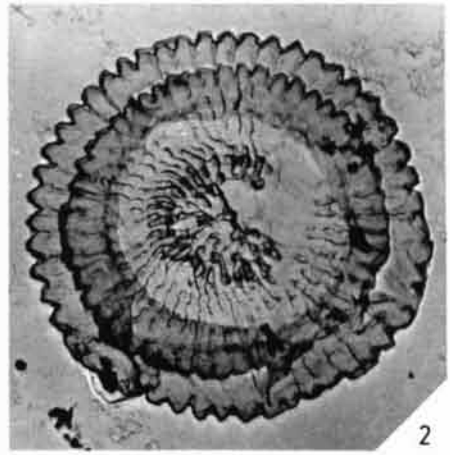
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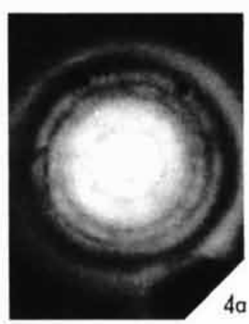
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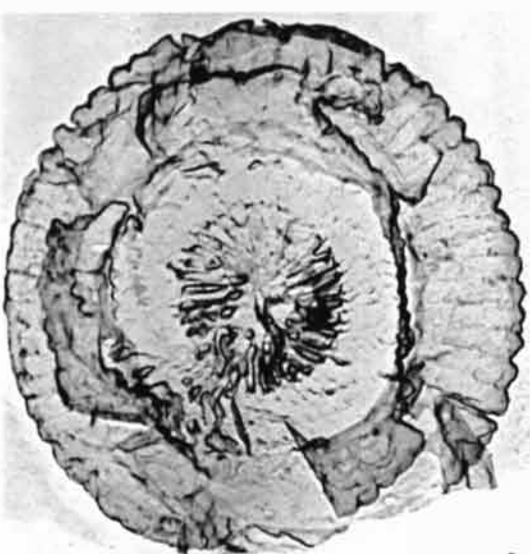
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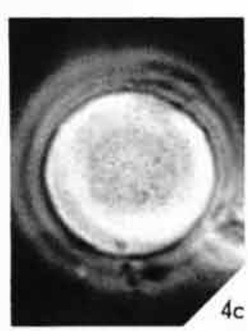
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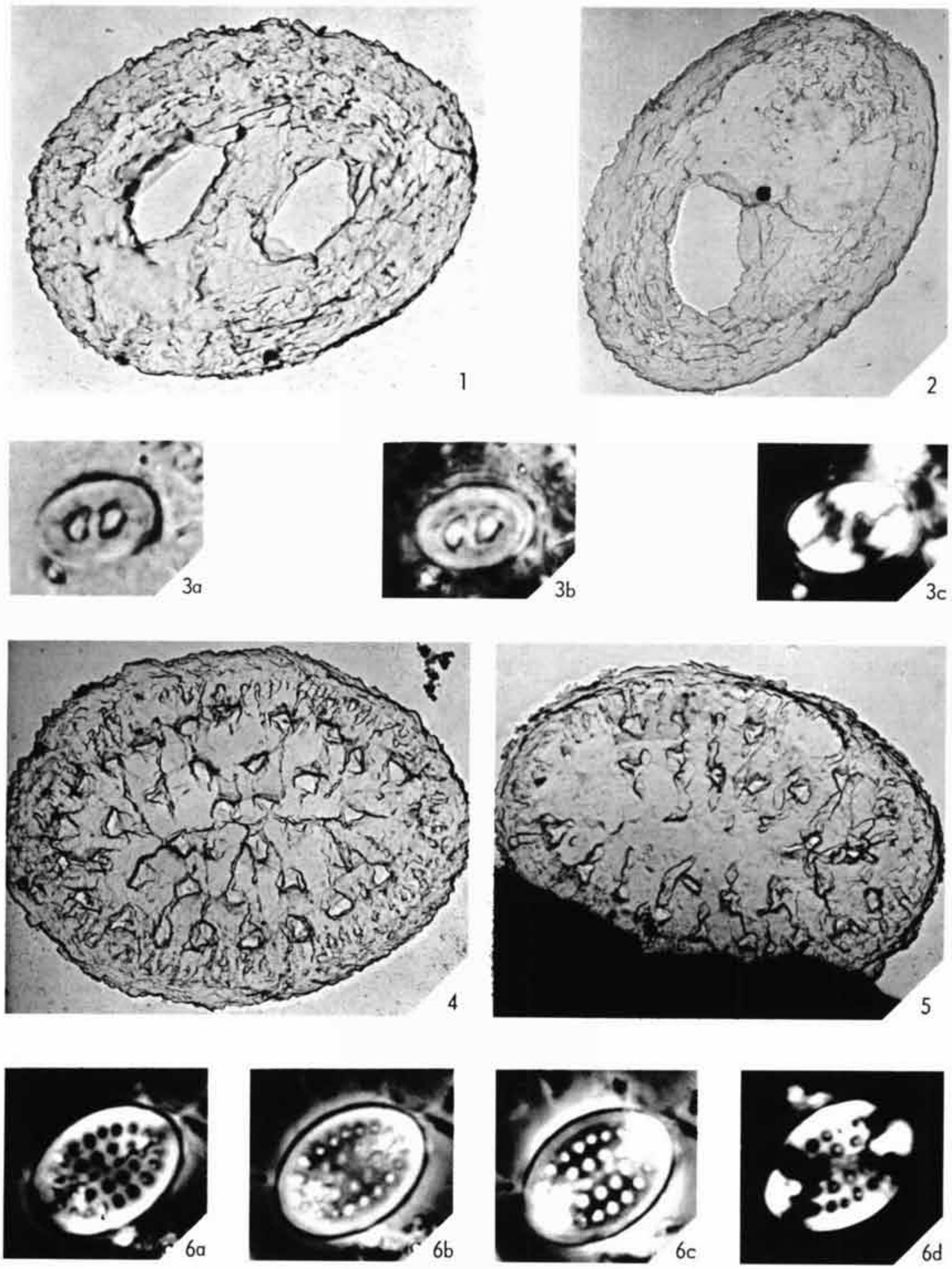
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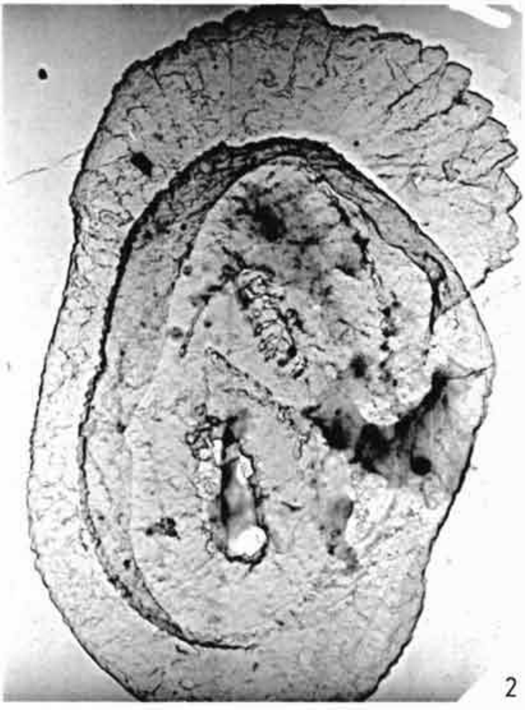

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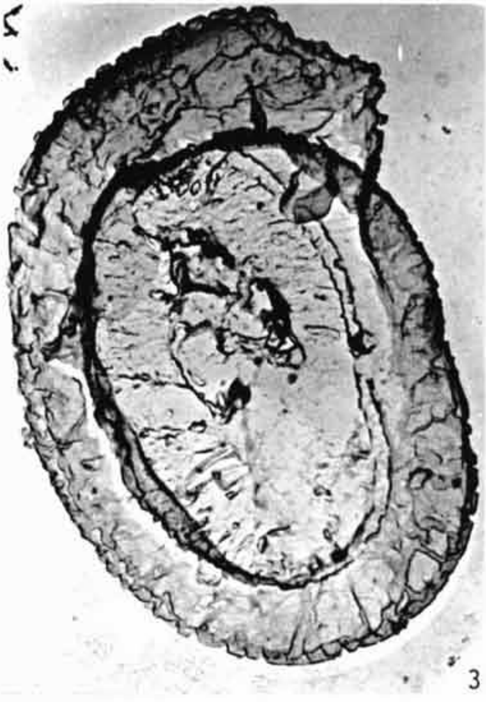

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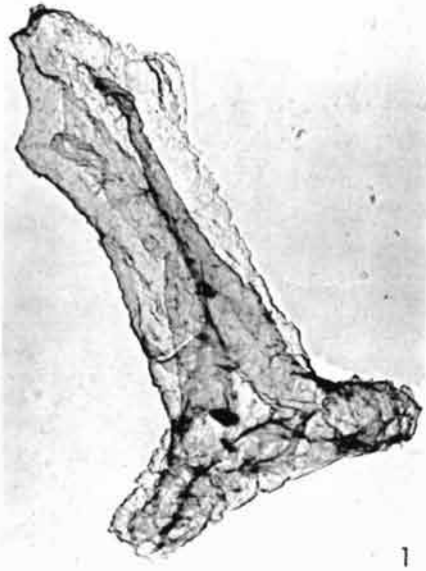
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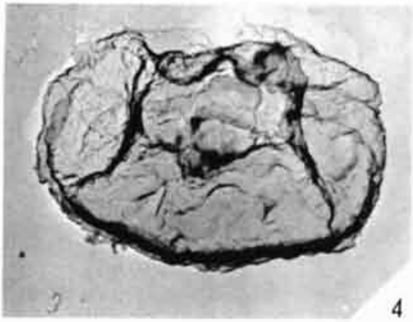
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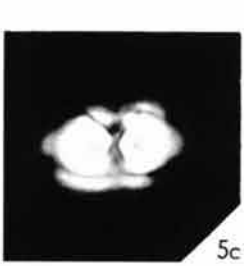
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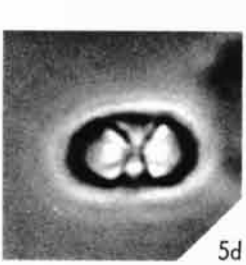
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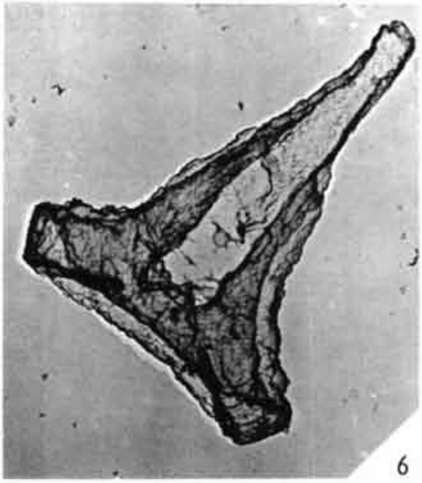
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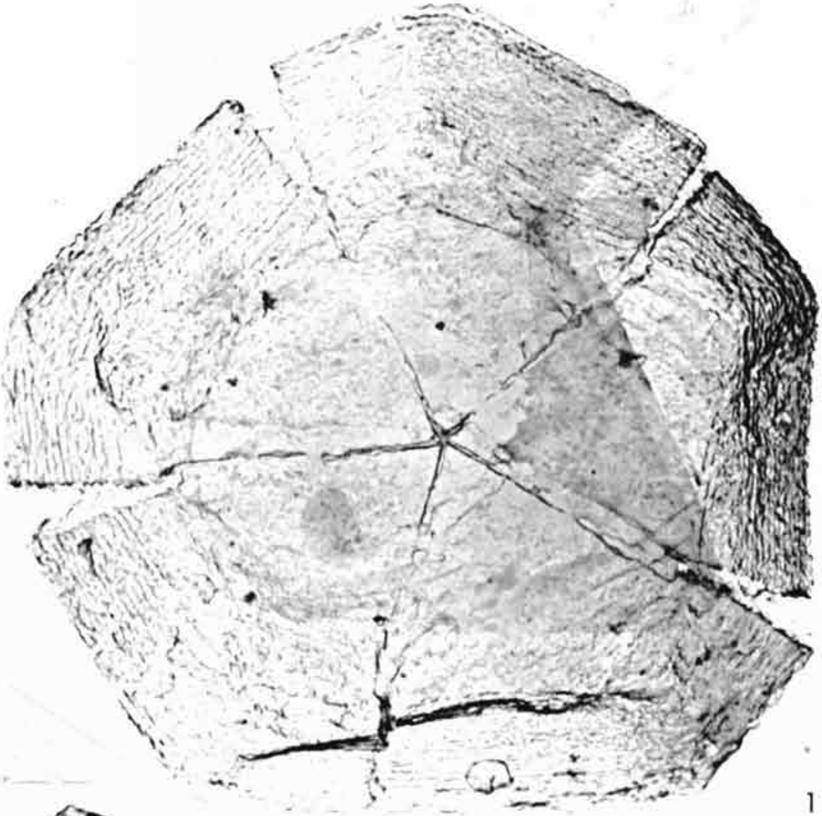

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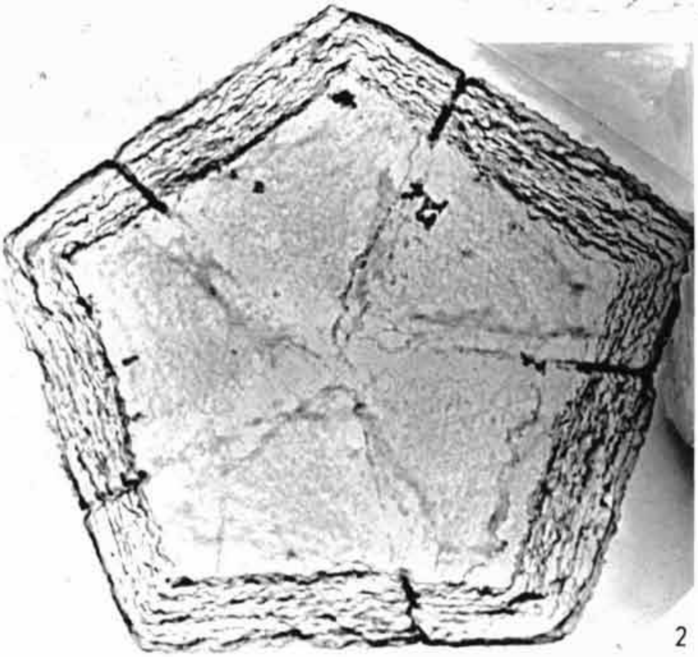

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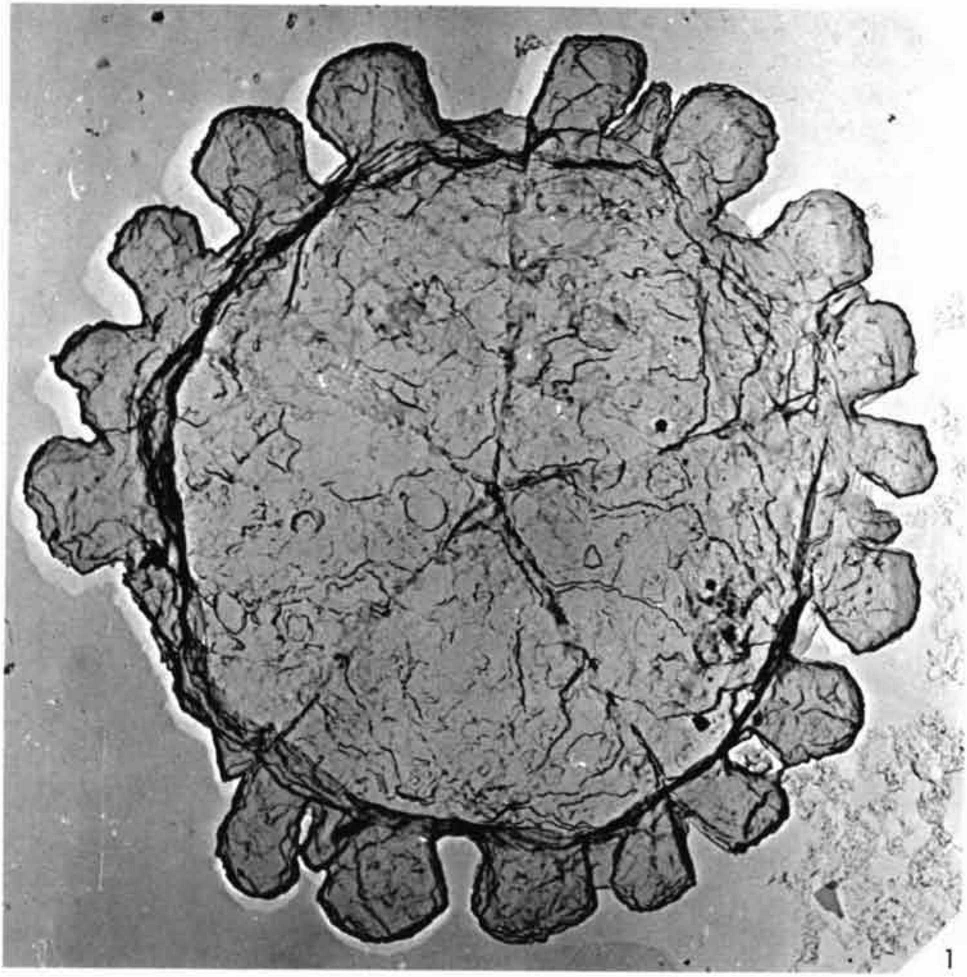
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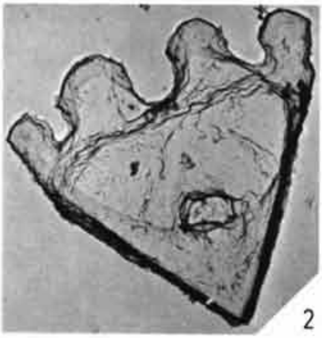
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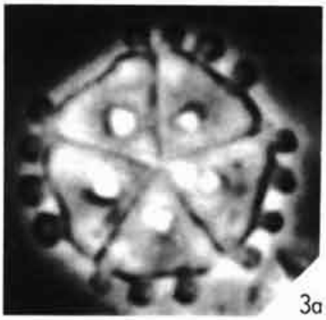
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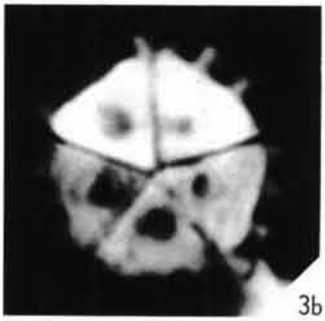
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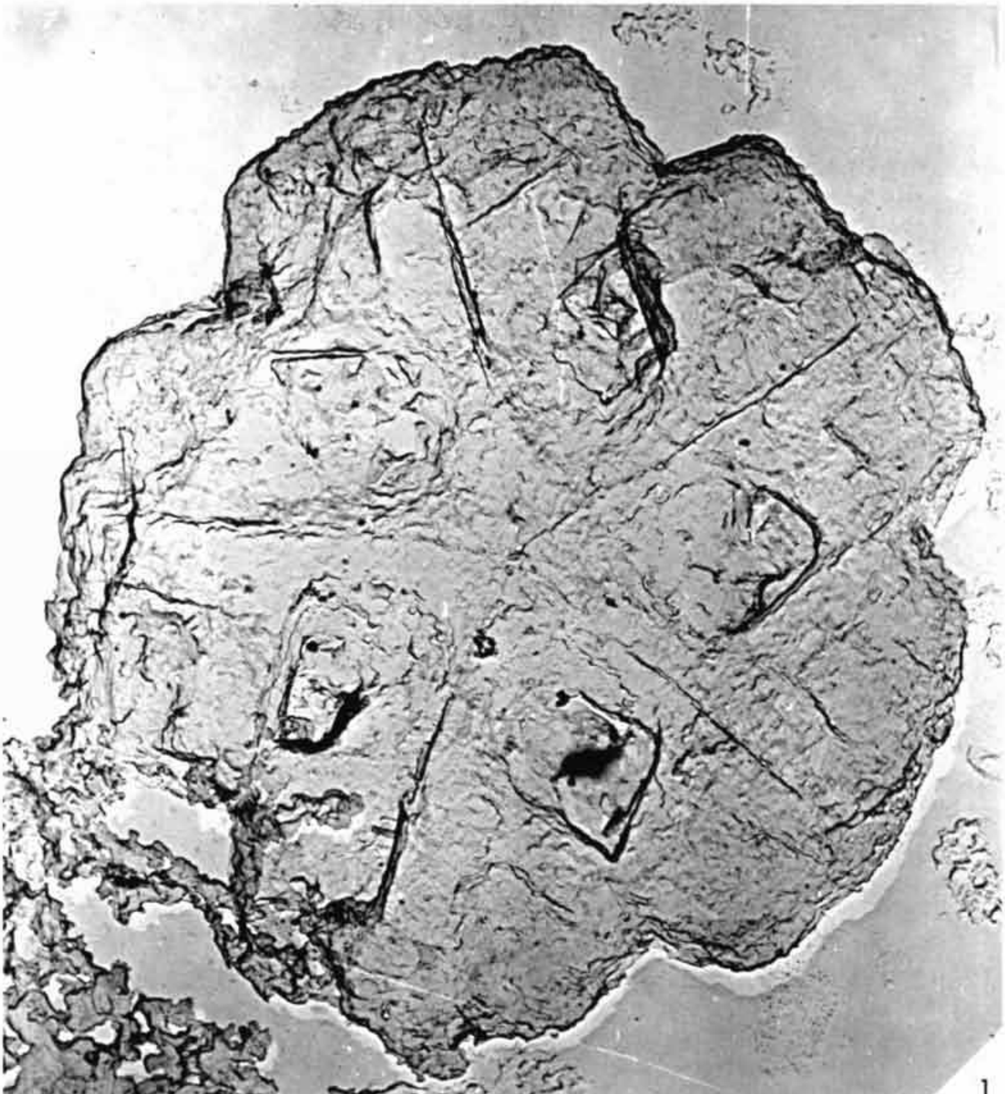

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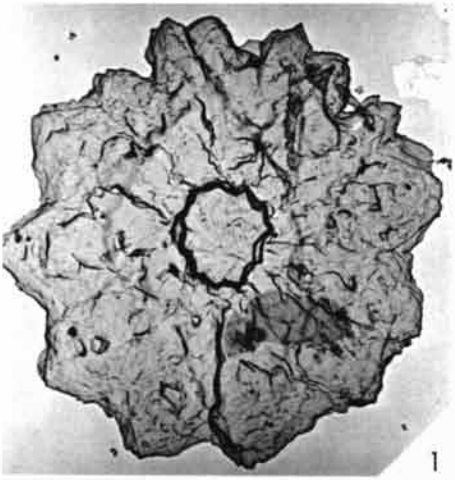
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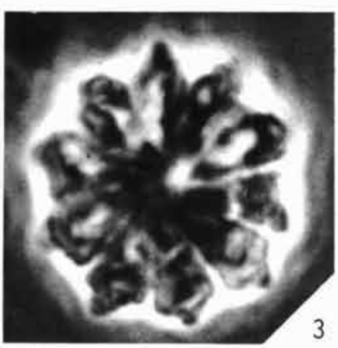
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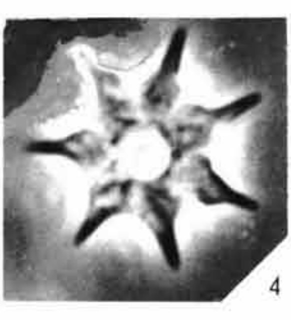
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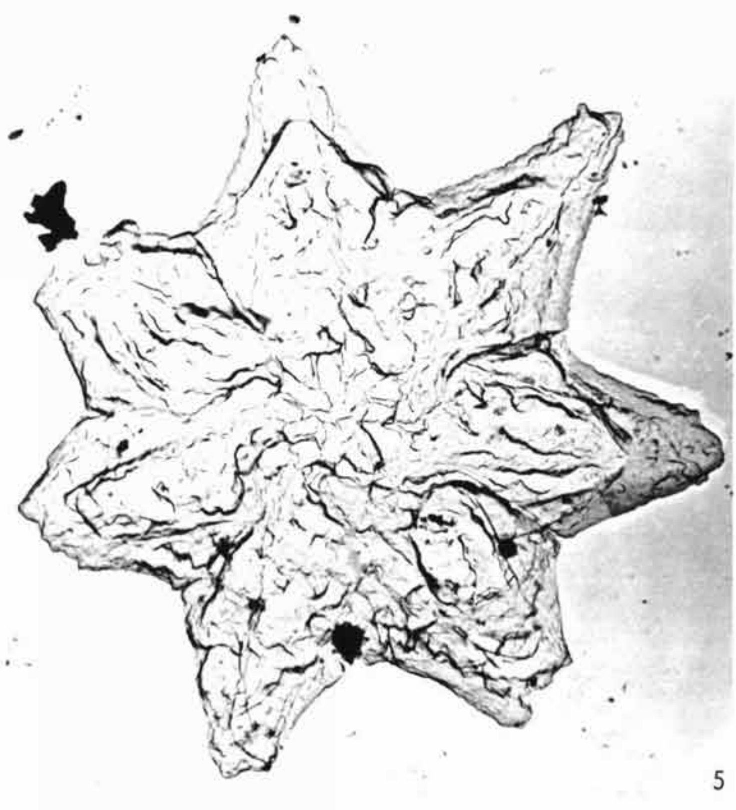
5

DISCOLITHINA sp. aff. D. DISTINCTA (Bramlette & Sullivan)

Aff. *Discolithus distinctus* BRAMLETTE & SULLIVAN, 1961, p. 141, pl. 2, fig. 9 (?fig. 8).

Discolithus distinctus Bramlette & Sullivan, SULLIVAN, 1965, p. 33, pl. 4, figs. 1-6.

Specimens figured here closely resemble the middle Eocene species, *Discolithina distincta* (BRAMLETTE & SULLIVAN), but the central area of the Yazoo form is relatively larger, the outline is not as elongated, and the perforations appear to be more distinctly developed. One specimen illustrated by SULLIVAN (1965, pl. 4, fig. 1) appears to be identical to specimens figured here, but it is possible that SULLIVAN has included more than one species in this group.

Illustrations.—Plate 6, figures 4-6.——Fig. 4, 5. Electron micrographs, ×8,600.——Fig. 6. Light micrographs, ×3,400; 6a,c, phase contract with lower polarizer inserted; 6b, phase contrast; 6d, cross-polarized light.

Genus HELICOSPHAERA Kamptner, 1954

Type species.—?*Coccosphaera carteri* WALLICH, 1877.

Elliptical disc with an open or closed central area; the helicoid outer rim overlaps when fully developed to simulate two shields in optical side view. *Eoc.-Rec.*

HELICOSPHAERA SEMINULUM Bramlette & Sullivan, 1961

Aff. *Helicosphaera seminulum lophota* BRAMLETTE & SULLIVAN, 1961, p. 144, pl. 4, fig. 3, 4.

Electron micrographs reveal that the oblique bar has a complex structure. The openings on either side of the bar may be partially covered on the proximal side by an irregular grillwork. The angle of the oblique bar is intermediate between that of *Helicosphaera seminulum seminulum* BRAMLETTE & SULLIVAN and *Helicosphaera seminulum lophota* BRAMLETTE & SULLIVAN. The specimens figured here have a more elongate elliptical outline and are not as wide as specimens figured by BRAMLETTE & SULLIVAN.

Illustrations.—Plate 7, figures 1-4.——Fig. 1-3. Electron micrographs, ×6,800; 1, distal view; 2,3, proximal views.——Fig. 4. Light micrographs, ×3,400; proximal view; 4a,d, phase contrast, high focus and low focus; 4b, bright field; 4c, cross-polarized light. [Note the many small bars that extend partially across the two slits of 1 and 2.]

Genus RHABDOSPHAERA Haeckel, 1894

Type species.—*Rhabdosphaera claviger* MURRAY & BLACKMAN, 1898.

Circular or elliptical discs surmounted by a stem. *Eoc.-Rec.*

RHABDOSPHAERA SPINULA Levin

Rhabdosphaera spinula LEVIN, 1965, p. 267, pl. 42, fig. 3.

This form is similar to *Rhabdosphaera tenuis* BRAMLETTE & SULLIVAN (1961) but has a distinctly curved basal disc and a groove at the broad base of the stem which optically makes it appear that the base is double. The long stem is made up of minute longitudinally aligned laths. Specimens from the Yazoo do not taper uniformly nor are they rugose as is the specimen of *R. tenuis* figured by BRAMLETTE & SULLIVAN (1961, pl. 5, fig. 14).

Illustrations.—Plate 1, figures 1, 2.——Fig. 1. Electron micrograph, ×4,300, side view.——Fig. 2. Light micrographs, ×3,400, side view; 2a, cross-polarized light; 2b, bright field.

Genus ZYGRHABLITHUS Deflandre, 1959

Type species.—*Zygolithus bijugatus* DEFLANDRE in DEFLANDRE & FERT, 1954.

Elliptical zygolith-like base apparently continuous with crossbars and stem and of simple massive construction. *Eoc.-Rec.*

ZYGRHABLITHUS BIJUGATUS (Deflandre)

Zygolithus bijugatus DEFLANDRE in DEFLANDRE & FERT, 1954, p. 148, fig. 54, pl. 11, fig. 20, 21.

This form consists of a single, open, elliptical disc, crossbars, and stem. The disc lacks distinct elements and seems to be continuous with the 4 arms of the crossbars that merge to form the 4-bladed stem. In some specimens blades of the stem flare near the distal end and, above the flare, taper to a point. In other specimens the blades and the stem are only partially developed.

Illustrations.—Plate 8, figures 1-6.——Fig. 1-4, 6. Electron micrographs, ×8,600; 1, 6, Side views; 2, 3, distal views; 4, oblique view.——Fig. 5. Light micrographs, ×3,400; 5a, side view, phase contrast; 5b-d, distal view; 5b, bright field; 5c, cross-polarized light; 5d, phase contrast. [The basal disc is constructed of large, barely distinguishable elements; the stem is massive.]

Genus BRAARUDOSPHAERA Deflandre, 1947

Type species.—Pontosphaera bigelowi GRAN & BRAARUD, 1935.

Imperforate pentaliths. *Eoc.-Rec.*

BRAARUDOSPHAERA BIGELOWI (Gran & Braarud)

Pontosphaera bigelowi GRAN & BRAARUD, 1935, p. 389, fig. 67.
Braarudosphaera bigelowi (GRAN & BRAARUD), DEFLANDRE, 1947, p. 439, figs. 1-5.
Braarudosphaera bigelowi parvula STRADNER, 1960, p. 431, fig. 2.
Eodiscoaster danicus MARTINI, 1961, p. 9, pl. 2, figs. 17, 18; pl. 5, figs. 48, 49.

In both proximal and distal views the pentalith is seen to be constructed of a series of laminae that build up the thickness of the pentalith. The individual laminae appear to be continuous across the segment boundaries. As each segment of the pentalith has a different crystallographic orientation, however, the laminae cannot be continuous over the entire pentalith. The periphery of the pentalith is wedge-shaped; in cross section, the slope of the wedge is longer on the proximal surface. This cross section is the result of the laying down on the surface of successively smaller laminae with more laminae being laid down on the proximal surface.

Illustrations.—Plate 9, figures 1-3.——Fig. 1, 2. Electron micrographs, ×8,600; 1, proximal view; 2, distal view.——Fig. 3. Light micrograph, ×3,400, proximal view in cross-polarized light. [In proximal view of this species a greater number of laminae are visible than in distal view.]

Genus PEMMA Klumpp, 1953

Type species.—Pemma rotundum KLUMPP, 1953.

Pseudoperforate pentaliths. *U.Eoc.-Rec.*

PEMMA PAPILLATUM Martini

Pemma papillatum MARTINI, 1959a, p. 139, fig. 1.

The ornamentation near the center of each segment of the pentalith has been interpreted as either a perforation or a knob. The electron micrographs show that it is a depression on the distal surface which does not penetrate the segment.

Illustrations.—Plate 10, figures 1-3.——Fig. 1, 2. Electron micrographs, ×8,600; 1, proximal view; 2, distal view of one segment.——Fig. 3. Light micrographs, ×3,400; 3a, phase contrast with lower polarizer inserted; 3b, cross-polarized light.

PEMMA ANGULATUM Martini

Pemma angulatum MARTINI, 1959b, p. 416, pl. 1, fig. 1,2,4.

Each segment appears to have one pair of thickened ridges along the sutures and another pair nearly normal to the suture with the pairs meeting at the peripheral notch of the segment. This results in a diamond-shaped depression near the center of the segment and a triangular-shaped thin area on either side of the peripheral notch.

Illustrations.—Plate 11.——Fig. 1. Electron micrograph, ×8,600. [Much of the surface of this pentalith is covered with fine clay particles. The sutures are nevertheless clearly visible, as also are the diamond-shaped depressions in the center of each segment.]

Genus DISCOASTER Tan Sin Hok, 1927

Type species.—Discoaster pentaradiatus TAN SIN HOK, 1927.

Ortholithid asteroliths. *Eoc.-Rec.*

DISCOASTER BARBADIENSIS Tan Sin Hok

Discoaster barbadiensis TAN SIN HOK, 1927, p. 119 (part); HAY & TOWE, 1962, p. 515, pl. 10, fig. 3,5.

The two electron micrographs represent small specimens, but specimens with a diameter more than twice as large were also encountered. The radial sutures are more strongly developed on one side of the asterolith than on the other.

Illustrations.—Plate 12, figures 1-3.——Fig. 1, 2. Electron micrographs, ×8,600.——Fig. 3. Light micrograph, ×3,400, phase contrast.

Although radial sutures are developed on both sides of the asteroliths, they are not constructed of radial elements as are the shields of placoliths; instead, the asteroliths are made of a series of laminae laid down parallel to the plane of the asterolith.

DISCOASTER SAIPANENSIS Bramlette & Riedel

Discoaster saipanensis BRAMLETTE & RIEDEL, 1954, p. 398, pl. 39, fig. 4.

Although the tips of the rays of the specimen represented in the electron micrograph are damaged, the species is sufficiently distinct to be easily identified.

Illustrations.—Plate 12, figures 4, 5.——Fig. 4. Light micrograph, ×3,400, phase contrast.——Fig. 5. Electron micrograph, ×8,600.

REFERENCES

Black, Maurice, 1964, *Cretaceous and Tertiary coccoliths from Atlantic seamounts:* Palaeontology, v. 7, p. 306-316, pl. 50-53.

Bramlette, M. N., 1965, *Massive extinctions in biota at the end of Mesozoic time:* Science, v. 148, p. 1696-1699.

———, & Martini, Erlend, 1964, *The great change in calcareous nannoplankton fossils between the Maastrichtian and Danian:* Micropaleontology, v. 10, p. 291-322, pl. 1-7.

———, & Reidel, W. R., 1954, *Stratigraphic value of discoasters and some other microfossils related to Recent coccolithophores:* Jour. Paleontology, v. 28, p. 385-403, 26 fig., pl. 38-39.

———, & Sullivan, F. R., 1961, *Coccolithophorids and related nannoplankton of the early Tertiary in California:* Micropaleontology, v. 7, p. 129-188, fig. 1, pl. 1-14.

Bursa, A. S., 1965, *Discoasteromonas calciferus, n. sp., an Arctic relict secreting Discoaster Tan Sin Hok 1927:* Grana Palynologica, v. 6, p. 147-165, fig. 1-22, pl. 1-4.

Deflandre, Georges, 1947, *Braarudosphaera nov. gen., type d'une famille nouvelle de coccolithophorides actuels à éléments composites:* Acad. Sci. Paris Comptes Rendus, v. 225, p. 439-441, fig. 1-5.

———, 1959, *Sur les nannofossiles calcaires et leur systématique:* Rev. Micropaléontologie, v. 2, p. 127-152, pl. 1-4.

———, & Fert, Charles, 1954, *Observations sur les coccolithophorides actuels et fossiles en microscopie ordinaire et électronique:* Annales Paléontologie, v. 40, p. 115-176, fig. 1-127, pl. 1-15.

Gran, H. H., & Braarud, Trygve, 1935, *A qualitative study of the phytoplankton in the Bay of Funday and the Gulf of Maine:* Biol. Board Canada Jour., v. 1, p. 279-467, fig. 67.

Haeckel, Ernst, 1894, *Systematische Phylogenie der Protisten und Pflanzen:* Berlin, Georg Reimer, v. 1, 400 p.

Hay, W. W., & Towe, K. M., 1962 (1963), *Electron microscopic examination of some coccoliths from Donzacq (France):* Eclogae Geol. Helvetiae, v. 55, p. 497-518, fig. 1-2, pl. 1-10.

Kamptner, Erwin, 1948, *Coccolithen aus dem Torton des inneralpiner Wiener Beckens:* Oesterreichische Akad. Wiss. Sitzungsber., Math.-Naturw. Kl., Abt. 1, v. 157, p. 1-16, pl. 1-2.

———, 1954, *Untersuchungen ueber den Feinbau der Coccolithen:* Archiv Protistenkunde, v. 100, p. 1-90, fig. 1-50.

Klumpp, Barbara, 1953, *Beitrag zur Kenntnis der Mikrofossilien des mittleren und oberen Eozaen:* Paleontographica, Abt. A, v. 103, p. 377-406, pl. 16-20.

Levin, H. L., 1965, *Coccolithophoridae and related microfossils from the Yazoo Formation (Eocene) of Mississippi:* Jour. Paleontology, v. 39, p. 265-272, pl. 41-43.

Loeblich, A. R., Jr., & Tappan, Helen, 1963, *Type fixation and validation of certain calcareous nannoplankton genera:* Biol. Soc. Washington Proc., v. 76, p. 191-196.

Martini, Erlend, 1959a, *Der stratigraphische Wert von Nanno-fossilien im nordwestdeutschen Tertiaer:* Erdoel u. Kohle, v. 12, no. 3, p. 137-140, fig. 1.

———, 1959b, *Pemma angulatum und Micrantholithus basquensis, zwei neue Coccolithophoriden-Arten aus dem Eozaen:* Senckenbergiana Lethaea, v. 40, p. 415-421, pl. 1.

———, 1961, *Nannoplankton aus dem Tertiaer und der obersten Kreide von SW-Frankreich:* Same, v. 42, p. 1-41, fig. 1-3, pl. 1-5.

———, & Bramlette, M. N., 1963, *Calcareous nannoplankton from the experimental Mohole drilling:* Jour. Paleontology, v. 37, p. 845-856, fig. 1-2, pl. 102-105.

Murray, George, & Blackman, V. H., 1898, *On the nature of the coccospheres and rhabdospheres:* Royal Soc. (London) Philos. Trans., ser. B, v. 190, p. 427-441, pl. 15-16.

Schwarz, E. H. L., 1894, *Coccoliths:* Annals and Mag. Nat. History, ser. 6, v. 14, p. 341-346, fig. 1-27.

Stradner, Herbert, 1960, *Ueber Nannoplankton-invasionen im Sarmat des Wiener Becken:* Erdoel Zeitschr., v. 76, p. 430-432, fig. 1-2.

Sullivan, F. R., 1964, *Lower Tertiary nannoplankton from the California Coast Ranges; I. Paleocene:* California Univ. Pub. Geol. Sci., v. 44, p. 163-228, fig. 1-2, pl. 1-12.

———, 1965, *Lower Tertiary nannoplankton from the California Coast Ranges; II. Eocene:* California Univ. Pub. Geol. Sci., v. 53, p. 1-52, pl. 1-11.

Tan Sin Hok, 1927, *Discoasteridae incertae sedis:* Koninkl. Nederlandse Akad. Wetensch. Proc., Sec. Sci., v. 30, p. 411-419.

Wallich, G. C., 1877, *Observations on the coccosphere:* Annals and Mag. Nat. History, ser. 4, v. 19, p. 342-350, pl. 17.