15. COCCOLITH AGE DETERMINATIONS LEG 1, DEEP SEA DRILLING PROJECT

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This report combines the results of study of over 400 coccolith samples taken for shipboard and onshore investigation during Leg 1 of the Deep Sea Drilling Project, August-September 1968. Both electron-microscope and light-microscope techniques have been used to identify stratigraphically important coccoliths. Following a brief summary of the coccolith stratigraphy for each drilling site, the age-diagnostic species in selected samples are listed, and in Figures 1 through 3 the geologic ages determined from the assemblages at each site are summarized graphically.

For purposes of comparison, this volume contains another report on coccolith ages in a different set of samples from these same cores, prepared by W. W. Hay of the Institute of Marine Sciences, University of Miami. The samples in that report were taken from the upper part of each core section, whereas ours came from the middle of each section. Except for Hole 1, our material also includes many additional smear-slide samples prepared from other places in the cores during the shipboard operations.

The sample numbers, which identify the relative position of samples in the holes, consist of a series of numbered and lettered entries separated by hyphens in the following sequence: (cruise-leg number) – (drill-hole designation, consisting of site number plus a letter, if more than one hole) – (core-run number) – (core-section number). This series is followed by the interval below the top of each core section in centimeters. For example, 1-6A-1-1, 75-76 centimeters, means the sample came from Leg 1, Hole 6A (at Site 6), the first barrel of core recovered, the top section of that core, and from 75-76 centimeters below the top of the section. Most core runs were 9.1 meters long, but commonly the core liners were not full. In this report, recoveries are arbitrarily placed at the top of the core runs, and an approximate depth in meters below the sea floor follows each sample number.

[1]Publication authorized by the Director, U.S. Geological Survey.

HOLE 1
(lat 25°51.5'N., long 92°11.0'W., depth 2827 meters)

Summary of Coccolith Age Determinations

A thick sequence of Pleistocene sediment at the Hole 1 locality near the continental slope of the Gulf Coast contains a coccolith flora that has been greatly diluted by Mississippi River detritus that contains reworked late Cretaceous coccoliths. The indigenous Pleistocene coccoliths such as *Ceratolithus cristatus* Kamptner and *Gephyrocapsa oceanica* Kamptner occur in abundance

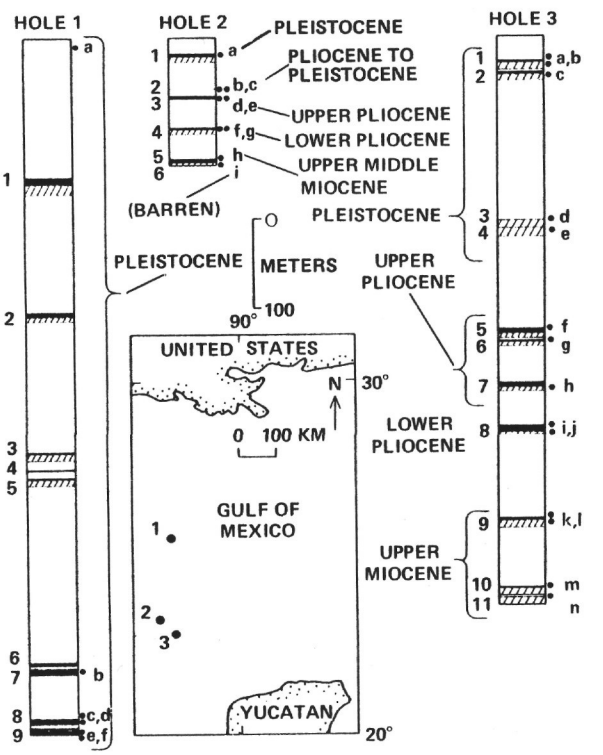


Figure 1. *Series represented in cores from the Gulf of Mexico based on coccolith assemblages. Core number to left of columns, sample to right.*

only near the top of the sediment section (sampled by piston core). Deeper cores are characterized by a sparse occurrence of all coccoliths and by a large proportion of reworked Cretaceous species such as *Eiffellithus turriseiffeli* (Deflandre), *Cribrosphaera ehrenbergi* Arkhangelsky, and *Micula decussata* Vekshina.

Age-diagnostic Coccoliths in Selected Samples, Hole 1

Pleistocene

Sample a (1-1P-1-3, 70 cm, depth 4 m):
Ceratolithus cristatus Kamptner; *Helicopontosphaera kamptneri* Hay and Mohler; *Cyclococcolithus leptoporus* (Murray and Blackman); *?Gephyrocapsa* sp. Reworked late Cretaceous taxa: *Eiffellithus turriseiffeli* (Deflandre); *Watznaueria barnesae* (Black); *Zygodiscus diplogrammus* (Deflandre).

Sample b (1-1-7-4, 3-4 cm, depth 699 m):
Reworked late Cretaceous taxa: *Eiffellithus turriseiffeli* (Deflandre); *Micula decussata* Vekshina; *Watznaueria barnesae* (Black); *Zygodiscus* sp.

Sample c (1-1-8-2, 77-78 cm, depth 753 m):
Reworked late Cretaceous taxa: *Eiffellithus turriseiffeli* (Deflandre); *Prediscosphaera cretacea* (Arkhangelsky); *Watznaueria barnesae* (Black); *Zygodiscus* sp.

Sample d (1-1-8-7, 76-77 cm, depth 761 m):
Gephyrocapsa oceanica Kamptner. Reworked late Cretaceous taxa: *Chiastozygus disgregatus* (Stover); *Eiffellithus turriseiffeli* (Deflandre); *Watznaueria barnesae* (Black).

Sample e (1-1-9-3, 73-74 cm, depth 764 m):
Reworked late Cretaceous taxa: *Arkhangelskiella concava* Gartner; *A. parca* Stradner, *Cribrosphaera ehrenbergi* Arkhangelsky; *Eiffellithus octoradiatus* (Gorka); *E. turriseiffeli* (Deflandre); *Markalius* sp.; *Microrhabdulus decoratus* Deflandre; *Micula decussata* Vekshina; *Prediscosphaera cretacea* (Arkhangelsky); *Watznaueria barnesae* (Black).

Sample f (1-1-9-4, 74-75 cm, depth 765 m):
Gephyrocapsa oceanica Kamptner; *Helicopontosphaera kamptneri* Hay and Mohler. Reworked late Cretaceous taxa: *Arkhangelskiella parca* Stradner; *Cribrosphaera ehrenbergi* Arkhangelsky; *Micula decussata* Vekshina.

HOLE 2
(lat 23°27.3′N., long 92°35.2′W., depth 3572 meters)

Summary of Coccolith Age Determinations

Coring operations on Challenger Knoll recovered sediment samples ranging in age from late Middle Miocene to Pleistocene. The first core contains a typical Pleistocene assemblage of coccoliths. Core 2 contains a transitional assemblage. Although it could be late Pliocene in age, it is probably early Pleistocene. This assignment is indicated by the rare occurrence of discoasters, by the occurrence of a variety of *Ceratolithus rugosus* Bukry and Bramlette with a concave arch that indicates the last occurrence of this species, and by the presence of a few specimens of the large form *Cyclococcolithus leptoporus* (Murray and Blackman), var. A of McIntyre, Bé, and Preikstas. Late Pliocene coccolith assemblages characterized by abundant three- and six-rayed specimens of *Discoaster brouweri* Tan are present in Core 3. In Core 4, a discoaster assemblage, the common occurrence of *Reticulofenestra pseudoumbilica* (Gartner) and *Sphenolithus* sp. aff. *S. abies* (Deflandre), along with *C. rugosus* indicate an early Pliocene age.

Probably because of salt-dome piercement the oldest sample recovered in this hole consists of a few chips of late Middle Miocene grey lutite at the top of the core barrel that contained oil and salt-dome cap rock. Identification of such species as *Discoaster bollii* Martini and Bramlette (common) and *Catinaster* sp. aff. *C. Coalitus* Martini and Bramlette (several specimens) indicates a late Middle Miocene age for the sediment above the cap rock. The coccolith assemblage is probably correlative to that of the upper part of Bolli's *Globorotalia menardii* Range Zone of foraminifera in Trinidad (see Bramlette and Wilcoxon, 1967). Black siltstone within the cap rock contains no calcareous microfossils.

Age-diagnostic Coccoliths in Selected Samples, Hole 2

Pleistocene

Sample a (1-2-1, core catcher, depth 23 m):
Ceratolithus cristatus Kamptner; *Gephyrocapsa oceanica* Kamptner; *Rhabdosphaera stylifera* Lohmann.

Early Pleistocene

Sample b (1-2-2-1, 76-77 cm, depth 58 m):
Ceratolithus cristatus Kamptner; *C. rugosus* Bukry and Bramlette; *Cyclococcolithus leptoporus* (Murray and Blackman), var. A of McIntyre, Bé, and Preikstas; *Discoaster brouweri* Tan; *D. pentaradiatus* Tan; *Rhabdosphaera clavigera* Murray and Blackman; *R. stylifera* Lohmann.

Sample c (1-2-2, core catcher, depth 59 m):
Ceratolithus rugosus Bukry and Bramlette; *Discoaster brouweri* Tan; *Helicopontosphaera kamptneri* Hay and Mohler; *Rhabdosphaera stylifera* Lohmann.

Late Pliocene

Sample d (1-2-3-1, 1 cm, depth 67 m):
Ceratolithus rugosus Bukry and Bramlette; *Cyclococcolithus leptoporus* (Murray and Blackman), var. A of McIntyre, Bé, and Preikstas; *Discoaster brouweri* Tan; *Helicopontosphaera kamptneri* Hay and Mohler; *Rhabdosphaera clavigera* Murray and Blackman.

Sample e (1-2-3, core catcher, depth 71 m): *Ceratolithus rugosus* Bukry and Bramlette; *Cyclococcolithus leptoporus* (Murray and Blackman), var. A of McIntyre, Bé, and Preikstas; *Discoaster brouweri* Tan; *D. pentaradiatus* Tan; *D. surculus* Martini and Bramlette.

Early Pliocene

Sample f (1-2-4-1, 41-42 cm, depth 102 m): *Ceratolithus rugosus* Bukry and Bramlette; *Discoaster brouweri* Tan; *D. challengeri* Bramlette and Riedel; *D. pentaradiatus* Tan; *D. surculus* Martini and Bramlette; *Reticulofenestra pseudoumbilica* (Gartner); *Sphenolithus* sp. aff. *S. abies* (Deflandre).

Sample g (1-2-4-2, 100 cm, depth 104 m): *Ceratolithus rugosus* Bukry and Bramlette; *Cyclococcolithus leptoporus* (Murray and Blackman); *Discoaster brouweri* Tan; *D. challengeri* Bramlette and Riedel; *D. surculus* Martini and Bramlette; *D.* sp.; *Reticulofenestra pseudoumbilica* (Gartner).

Late Middle Miocene

Sample h (1-2-5, top of recovery, depth 136 m): *Catinaster* sp. aff. *C. coalitus* Martini and Bramlette; *Coccolithus pelagicus* (Wallich); *Discoaster bollii* Martini and Bramlette; *D. brouweri* Tan; *D. variabilis* Martini and Bramlette; *D.* sp.; *Reticulofenestra pseudoumbilica* (Gartner).

Sample i (1-2-6, core catcher, depth 141 m): Barren.

HOLE 3
(lat 23°01.0′N., long 92°01.4′W., depth 3746 meters)

Summary of Coccolith Age Determinations

The first four cores recovered from this hole contain coccolith assemblages of Pleistocene age. The upper two cores contain an admixture of reworked late Cretaceous coccoliths, as do most of the Pleistocene cores from Hole 1. Cores 5, 6, and 7 are characterized by late Pliocene coccolith assemblages containing *Ceratolithus rugosus* Bukry and Bramlette, *Discoaster brouweri* Tan, *D. pentaradiatus* Tan, and abundant small coccoliths probably related to *Coccolithus doronicoides* Black and Barnes. Core 8, the level which was selected on the basis of shipboard predictions of the position of the Miocene-Pliocene boundary by W. Berggren and D. Bukry (based on sedimentation rates calculated from the upper 7 cores), contains a coccolith assemblage indicating the earliest Pliocene. Of particular interest in it is the overlap of *C. rugosus* with *Ceratolithus tricorniculatus* Gartner, emended, which occurs only in sediment of latest Miocene or early Pliocene age (Bukry and Bramlette, 1968). This core is considered to be earliest Pliocene because of the numerical dominance of *C. tricorniculatus* among the ceratoliths and because of the presence of small numbers of an undescribed discoaster species that is abundant in late Miocene assemblages.

The discoaster assemblage in Cores 9, 10, and 11 are dominated by such species as *Discoaster calcaris* Gartner, *D. challengeri* Bramlette and Riedel, *D. variabilis* Martini and Bramlette, and *D.* sp. (undescribed), which indicate a late Miocene age. Calcareous detritus and reworked coccoliths of Middle Miocene, Eocene, and late Cretaceous age are present in most samples from these lower three cores.

Age-diagnostic Coccoliths in Selected Samples, Hole 3

Pleistocene

Sample a (1-3-1-1, 112 cm, depth 26 m): *Ceratolithus cristatus* Kamptner; *Gephyrocapsa oceanica* Kamptner; *Helicopontosphaera kamptneri* Hay and Mohler; *Thoracosphaera* sp.

Sample b (1-3-1, core catcher, depth 28 m): *Gephyrocapsa oceanica* Kamptner; *Helicopontosphaera kamptneri* Hay and Mohler. Reworked late Cretaceous taxa: *Arkhangelskiella parca* Stradner; *Eiffellithus turriseiffeli* (Deflandre); *E. octoradiatus* (Gorka); *Watznaueria barnesae* (Black).

Sample c (1-3-2-3, 75 cm, depth 39 m): *Cyclococcolithus leptoporus* (Murray and Blackman); *Gephyrocapsa oceanica* Kamptner; *Rhabdosphaera clavigera* Murray and Blackman. Reworked late Cretaceous taxa: *Arkhangelskiella parca* Stradner; *Micula decussata* Vekshina; *Watznaueria barnesae* (Black).

Sample d (1-3-3, core catcher, depth 202 m): *Cyclococcolithus leptoporus* (Murray and Blackman); *Gephyrocapsa oceanica* Kamptner.

Sample e (1-3-4-1, 90 cm, depth 210 m): *Ceratolithus cristatus* Kamptner; *Gephyrocapsa oceanica* Kamptner; *Helicopontosphaera kamptneri* Hay and Mohler; *Thoracosphaera* sp.

Late Pliocene

Sample f (1-3-5, top of recovery, depth 320 m): *Ceratolithus rugosus* Bukry and Bramlette; *Discoaster brouweri* Tan; *D. pentaradiatus* Tan; *Helicopontosphaera kamptneri* Hay and Mohler; *Rhabdosphaera clavigera* Murray and Blackman.

Sample g (1-3-6, top of recovery, depth 330 m): *Ceratolithus rugosus* Bukry and Bramlette; *Discoaster brouweri* Tan; *D. pentaradiatus* Tan.

Sample h (1-3-7, core catcher, depth 387 m): *Cyclococcolithus leptoporus* (Murray and Blackman);

Discoaster brouweri Tan; *D. pentaradiatus* Tan; *D. surculus* Martini and Bramlette.

Early Pliocene

Sample i (1-3-8, top of recovery, depth 430 m): *Ceratolithus rugosus* Bukry and Bramlette; *Discoaster brouweri* Tan; *D. pentaradiatus* Tan; *D. surculus* Martini and Bramlette; *Reticulofenestra pseudoumbilica* (Gartner); *Sphenolithus* sp. aff. *S. abies* Deflandre.

Sample j (1-3-8, core catcher, depth 438 m): *Ceratolithus rugosus* Bukry and Bramlette; *C. tricorniculatus* Gartner, emended; *Discoaster brouweri* Tan; *D. surculus* Martini and Bramlette; *D.* sp.; *Reticulofenestra pseudoumbilica* (Gartner); *Sphenolithus* sp. aff. *S. abies* Deflandre.

Late Miocene

Sample k (1-3-9, top of recovery, depth 534 m): *Discoaster brouweri* Tan; *D. challengeri* Bramlette and Riedel; *D. variabilis* Martini and Bramlette; *D.* sp.; *Helicopontosphaera kamptneri* Hay and Mohler; *Sphenolithus abies* Deflandre.

Sample l (1-3-9, core catcher, depth 543 m): *Catinaster* sp.; *Discoaster brouweri* Tan; *D. calcaris* Gartner; *D. surculus* Martini and Bramlette; *D. variabilis* Martini and Bramlette; *D.* sp.

Sample m (1-3-10-1, 150 cm, depth 611 m): *Discoaster brouweri* Tan; *D. calcaris* Gartner; *D. challengeri* Bramlette and Riedel; *D. variabilis* Martini and Bramlette; *Reticulofenestra pseudoumbilica* (Gartner). Reworked specimens: *Discoaster barbadiensis* Tan; *D. bollii* Martini and Bramlette; *Zygodiscus diplogrammus* (Deflandre).

Sample n (1-3-11-1, composite, depth 620 m to 621 m): *Cyclococcolithus leptoporus* (Murray and Blackman); *Discoaster brouweri* Tan; *D. calcaris* Gartner; *D. challengeri* Bramlette and Riedel; *D. calcaris* Gartner and Bramlette; *Reticulofenestra pseudoumbilica* (Gartner). Reworked specimens: *Catinaster coalitus* Martini and Bramlette; *Watznaueria barnesae* (Black); *Zygodiscus diplogrammus* (Deflandre).

HOLES 4 AND 4A
(lat 24°28.7'N., long 73°47.5'W., depth 5319 meters)

Summary of Coccolith Age Determinations

Core 1 extends from the surface to a depth of 9.1 meters. The upper 6 meters contain a mixture of coccoliths of Cretaceous, Eocene, Oligocene, Miocene, and Pliocene age. Although the Miocene specimens are numerically dominant, the youngest coccoliths present are Pliocene in age. Samples from the bottom of this core

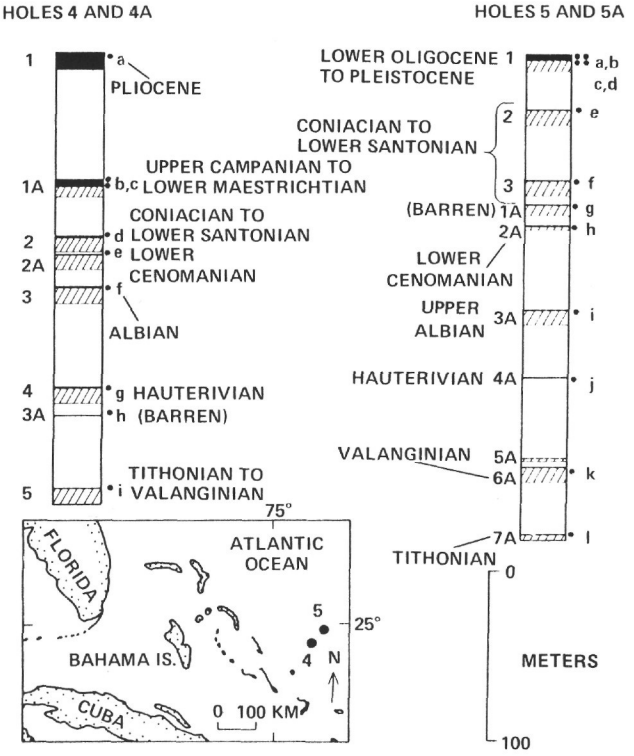


Figure 2. *Series and stages represented in cores from the Blake-Bahama Basin based on coccolith assemblages. Core number to left of columns, sample to right.*

are essentially barren. In superposable sequence, the next older core recovered is 1A, which contains Cretaceous coccolith assemblages of latest Campanian to early Maestrichtian age. As there is no evident change in species composition in the assemblages through this core, and since criteria for distinguishing late Campanian sediment from that of early Maestrichtian are not now available, further refinement of this age is impossible. The sparse assemblage of coccoliths in Core 2, including *Rucinolithus hayi* Stover and *Marthasterites furcatus* Deflandre, is Coniacian to early Santonian in age. Core 2A is assigned an early Cenomanian age based on the presence of *Prediscosphaera cretacea* (Arkhangelsky), *Zygodiscus ponticulus* (Deflandre), and *Z. xenotus* (Stover), in the absence of *Prediscosphaera columnatus* Stover and *Cretarhabdus decorus* (Deflandre). The coccolith assemblage in Core 3 correlates well to Albian coccolith assemblages described from European samples (Bukry, 1969; Reinhardt, 1966; Stradner, 1963; Stradner, Adamiker, and Maresch, 1968; Stover, 1966). Sediment in Core 4 has a characteristic early Cretaceous assemblage containing specimens of *Nannoconus steinmanni* Kamptner and vast numbers of *Braarudosphaera discula* Bramlette and Riedel of Stradner. Also present is the coccolith *Micrantholithus obtusus* Stradner,

which is diagnostic of Hauterivian age (Percival, S., personal communication, 1968; Reinhardt, 1966; Stradner, 1963). The final core containing coccoliths, Core 5, was taken at 250 meters below the sea floor. The coccolith assemblage is composed of fairly long-ranging species; and, a Tithonian to Valanginian age was assigned mainly because of the paucity of *B. discula* specimens, which usually are abundant in the few Barremian and Hauterivian sediments available for comparison.

Age-diagnostic Coccoliths from Selected Samples, Holes 4 and 4A

Pliocene

Sample a (1-4-1, top of recovery, depth 0 m): *Ceratolithus rugosus* Bukry and Bramlette, *Cyclococcolithus leptoporus* (Murray and Blackman); *Discoaster brouweri* Tan; *D. pentaradiatus* Tan; *D. surculus* Martini and Bramlette; *Reticulofenestra pseudoumbilica* (Gartner). Reworked Miocene taxa: *Cyclococcolithus neogammation* Bramlette and Wilcoxon; *Discoaster aulakos* Gartner; *Helicopontosphaera ampliaperta* (Bramlette and Wilcoxon); *Sphenolithus heteromorphus* Bramlette and Wilcoxon. Reworked Cretaceous taxa: *Cretarhabdus crenulatus* Bramlette and Martini; *Nannoconus steinmanni* Kamptner; *Watznaueria barnesae* (Black).

Late Cretaceous (Late Campanian to Early Maestrichtian)

Sample b (1-4A-1, top of recovery, depth 73 m): *Arkhangelskiella cymbiformis* Vekshina; *A. parca* Stradner; *Cribrosphaera* sp. cf. *C. pelta* (Gartner); *Marthasterites inconspicuus* Deflandre; *Prediscosphaera spinosa* (Bramlette and Martini); *Tetralithus aculeus* (Stradner); *T. nitidus trifidus* Stradner; *T. pyramidus* Gardet.

Sample c (1-4A-1, core catcher, depth 77 m): *Arkhangelskiella cymbiformis* Vekshina; *A. parca* Stradner; *A. specillata* Vekshina; *Biantholithus sparsus* Bramlette and Martini; *Tetralithus aculeus* (Stradner); *T. nitidus trifidus* (Stradner); *T. pyramidus* Gardet.

Late Cretaceous (Coniacian to Early Santonian)

Sample d (1-4-2-1, 4 cm, depth 104 m): *Cribosphaera ehrenbergi* Arkhangelsky, *Eiffellithus eximius* (Stover); *Marthasterites furcatus* (Deflandre); *Microrhabdulus decoratus* Deflandre; *Rucinolithus hayi* Stover; *Zygodiscus exiguus* (Stover); *Watznaueria actinosa* (Stover).

Late Cretaceous (Early Cenomanian)

Sample e (1-4A-2A, core catcher, depth 116 m): *Apertapetra gronosa* (Stover); *Eiffellithus turriseiffeli* (Deflandre); *Lithastrinus floralis* Stradner; *Parhabdolithus angustus* (Stradner); *Prediscosphaera cretacea* (Arkhangelsky); *Zygodiscus ponticulus* (Deflandre); *Z. xenotus* Stover.

Early Cretaceous (Albian)

Sample f (1-4-3-1, 0-32 cm, depth 134 m): *Apertapetra gronosa* (Stover); *Arkhangelskiella erratica* Stover; *A. striata* Stradner; *Corollithion signum* (Stradner); *Cretarhabdus decorus* (Deflandre); *Eiffellithus turriseiffeli* (Deflandre); *Parhabdolithus angustus* (Stradner); *P. granulatus* Stover; *P. embergi* Noël; *Zygodiscus erectus* (Deflandre); *Z. ponticulus* (Deflandre); *Watznaueria actinosa* (Stover).

Early Cretaceous (Hauterivian)

Sample g (1-4-4-1, 0-100 cm, depth 191 m): *Braarudosphaera discula* Bramlette and Riedel of Stradner; *Cruciplacolithus* sp.; *Discolithus asper* Stradner; *Lithraphidites carniolensis* Deflandre; *Micrantholithus obtusus* Stradner; *Parhabdolithus embergi* Noël; *Nannoconus steinmanni* Kamptner.

Sample h (1-4A-3, depth 207 m): Barren.

Late Jurassic (Tithonian) to Early Cretaceous (Valanginian)

Sample i (1-4-5, core catcher, depth 250 m): *Cruciplacolithus* sp.; *Discolithus asper* Stradner; *Lithraphidites carniolensis* Deflandre; *Parhabdolithus embergi* Noël; *Watznaueria barnesae* (Black).

HOLES 5 AND 5A
(lat 24°43.6′N., long 73°38.5′W., depth 5361 meters)

Summary of Coccolith Age Determinations

The upper 4 meters of Core 1 contain a chaotic succession of coccolith assemblages. This recovery presumably took place during oscillatory movement of the long drill pipe resulting in irregular sampling of various layers before enough penetration of firm strata was achieved to continue in a fixed hole. As a mixed sequence was also recovered in the first core at Hole 4, it would be desirable to take supplementary piston cores of the uppermost strata. In particular, the lower part of Core 1 of Hole 5 contains a mixed layer including Pliocene coccoliths beneath homogeneous early Miocene sediment. The recovery was as follows:

1-5-1-1, 31-32 cm:
Dark clay and silt, sparse Pleistocene coccoliths, with rare reworked Tertiary coccoliths.

1-5-1-1, 100 cm:
Same.

1-5-1-2, 70 cm:
Foraminiferal and coccolith ooze containing a mixture of Miocene, late Miocene, and Pliocene coccoliths.

1-5-1-2, 140 cm:
Foraminiferal and coccolith ooze with homogeneous early Miocene assemblage.

1-5-1-3, 3-4 cm:
Same.

1-5-1-3, 15-18 cm:
Same.

1-5-1-3, 21 cm:
Same.

1-5-1-3, 52-54 cm:
Sedimentary breccia with a mixture of coccoliths of all ages from Cretaceous to Pliocene.

1-5-1-3, 74 cm:
Same.

1-5-1-3, 93 cm:
Foraminiferal and coccolith ooze with homogeneous early Oligocene coccolith assemblage.

Cores 2 and 3 contain sparse late Cretaceous coccolith assemblages, including *Marthasterites furcatus* Deflandre and *Micula decussata* Vekshina, which aided in assigning a probable Coniacian to early Santonian age to these recoveries. The distribution and preservation of coccoliths in these two cores is unusual. The dominant coccolith species in most Cretaceous samples *Watznaueria barnesae* (Black) is missing, and only the coccolith rims of *?Watznaueria actinosa* (Stover) are present. The central structure of these coccoliths was removed by solution, and this solution also may have completely removed other taxa from these assemblages. Core 2A recovered sediment that contains few coccoliths. The presence of *Prediscosphaera cretacea* (Arkhangelsky), *Zygodiscus ponticulus* (Deflandre), and *Z. xenotus* (Stover) indicates a probable early Cenomanian age for this recovery. Examination of samples from Core 3A using electron microscopy shows the rich coccolith assemblage to be correlative to the Albian of Europe (Stradner and Adamiker, 1966; and Stradner, Adamiker, and Maresch, 1968). Characteristic species include: abundant *Apertapetra gronosa* (Stover); common *Prediscosphaera columnatus* (Stover); common *Cretarhabdus decorus* (Deflandre); few *Corollithion signum* Stradner; few *C. delftensis* (Stradner, Adamiker, and Maresch). A characteristic coccolith assemblage of early Cretaceous (Hauterivian) age is present in Core 4A including abundant *Braarudosphaera discula* Bramlette and Riedel of Stradner, common *Nannoconus globulus* Brönnimann, and few *Micrantholithus obtusus* Stradner. The coccoliths of *B. discula* and *M. obtusus* commonly disaggregate to produce a myriad of approximately triangular calcite fragments in the fine fraction of marine sediment of this age. Cores 5A and 6A are dated as Valanginian on the basis of the presence of *Nannoconus bermudezi* Brönnimann, *N. steinmanni* Kamptner, *N. globulus* Brönnimann, *Discolithus asper* Stradner, and because of the absence of coccoliths with Jurassic affinities. In Core 7A, electron microscopy has confirmed the presence of abundant *Diazomatolithus lehmani* Noël, common *Watznaueria britannica* (Stradner), few *Nannoconus dolomiticus* Cita and Pasquaré, and rare *Stephanolithion bigoti* Noël. This assemblage indicates a late Jurassic, Tithonian age for the core. Added indication of the late Jurassic aspect of the assemblage is seen in the presence of a transitional form intermediate between *S. bigoti* and *S. laffittei* Noël. Studies of Jurassic coccolith assemblages in Europe indicate that *S. bigoti* disappeared and *S. laffittei* appeared during the late Jurassic (Noël 1965; Stradner 1963).

Age-diagnostic Coccoliths in Selected Samples, Holes 5 and 5A

Pleistocene

Sample a (1-5-1-1, 1 cm, depth 0 m):
Ceratolithus cristatus Kamptner; *Cyclococcolithus leptoporus* (Murray and Blackman); *Gephyrocapsa oceanica* Kamptner; *Helicopontosphaera kamptneri* Hay and Mohler; *Rhabdosphaera clavigera* (Murray and Blackman).

Early Miocene

Sample b (1-5-1-2, 139-142 cm, depth 3 m):
Coccolithus sp. aff. *C. bisectus* Hay, Mohler, and Wade; *Cyclococcolithus neogammation* Bramlette and Wilcoxon; *Discoaster deflandrei* Bramlette and Riedel; *Helicopontosphaera intermedia* (Martini); *H. kamptneri* Hay and Mohler; *H. truncata* (Bramlette and Wilcoxon); *Sphenolithus* sp. aff. *S. belemnos* Bramlette and Wilcoxon.

Pliocene with Chaotic Mixing

Sample c (1-5-1-3, 74 cm, depth 4 m):
Ceratolithus rugosus Bukry and Bramlette; *Discoaster pentaradiatus* Tan; *D. surculus* Martini and Bramlette. Reworked taxa: *Arkhangelskiella parca* Stradner; *Braarudosphaera discula* Bramlette and Riedel; *B. rosa* Levin and Joerger; *Cruciplacolithus* sp.; *Cyclococcolithus neogammation* Bramlette and Wilcoxon; *Discoaster barbadiensis* Tan; *D. brouweri rutellus* Gartner; *D. multiradiatus* Bramlette and Sullivan; *Nannoconus steinmanni* Kamptner; *Peritrachelina joidesa* Bukry and Bramlette; *Sphenolithus belemnos* Bramlette and Wilcoxon; *Stephanolithion laffittei* Noël; *Watznaueria barnesae* (Black).

Early Oligocene

Sample d (1-5-1, core catcher, depth 4 m):
Braarudosphaera rosa Levin and Joerger; *Peritrachelina joidesa* Bukry and Bramlette; *Coccolithus bisectus* Hay,

Mohler, and Wade; *Cyclococcolithus neogammation* Bramlette and Wilcoxon; *Discoaster tani tani* Bramlette and Riedel; *Helicopontosphaera compacta* (Bramlette and Wilcoxon); *Sphenolithus predistentus* Bramlette and Wilcoxon. Reworked taxon: *Marthasterites tribrachiatus* Bramlette and Riedel.

Late Cretaceous (Coniacian to Early Santonian)

Sample e (1-5-2-1, 89-90 cm, depth 32 m): *Cribrosphaera ehrenbergi* Arkhangelsky; *Eiffellithus turriseiffeli* (Deflandre); *Lithastrinus floralis* Stradner; *Micula decussata* Vekshina; *Prediscosphaera cretacea* (Arkhangelsky); *Watznaueria actinosa* (Stover); *W. barnesae* (Black).

Sample f (1-5-3-1, 4-7 cm, depth 71 m): *Lithastrinus floralis* Stradner; *Marthasterites furcatus* Deflandre; *Micula decussata* Vekshina; *Watznaueria actinosa* (Stover).

Age Unknown

Sample g (1-5A-1, depth 85 m): Barren.

Late Cretaceous (Early Cenomanian)

Sample h (1-5A-2, core catcher, depth 98 m): *Lithastrinus floralis* Stradner; *Prediscosphaera cretacea* (Arkhangelsky); *Watznaueria barnesae* (Black); *Zygodiscus ponticulus* (Deflandre); *Z. xenotus* (Stover).

Early Cretaceous (Late Albian)

Sample i (1-5A-3, core catcher, depth 145 m): *Apertapetra gronosa* (Stover); *Arkhangelskiella striata* Stradner; *Corollithion delftensis* (Stradner, Adamiker, and Maresch); *C. signum* Stradner; *Cretarhabdus decorus* (Deflandre); *Parhabdolithus angustus* (Stradner); *P. embergi* Noël; *Prediscosphaera columnatus* (Stover); *Zygodiscus erectus* (Deflandre); *Z. ponticulus* (Deflandre).

Early Cretaceous (Hauterivian)

Sample j (1-5A-4-1, 24 cm, depth 185 m): *Braarudosphaera discula* Bramlette and Riedel of Stradner; *Cruciplacolithus* sp.; *Discolithus rugosus* Noël; *Lithraphidites carniolensis* Deflandre; *Micrantholithus obtusus* Stradner; *Nannoconus globulus* Brönnimann; *Parhabdolithus embergi* (Noël); *Stephanolithion laffittei* Noël; *Watznaueria barnesae* (Black).

Early Cretaceous (Valanginian)

Sample k (1-5A-6, core catcher, depth 236 m): *Braarudosphaera discula* Bramlette and Riedel of Stradner; *Cruciplacolithus* sp.; *Cyclagelosphaera margereli* Noel; *Discolithus asper* Stradner; *Lithraphidites carniolensis* Deflandre; *Nannoconus bermudezi* Bronnimann; *N. globulus* Bronnimann; *N. steinmanni* Kamptner; *Parhabdolithus embergi* Noel; *Rhabdosphaera* sp.; *Stephanolithion laffittei* Noël; *Watznaueria barnesae* (Black).

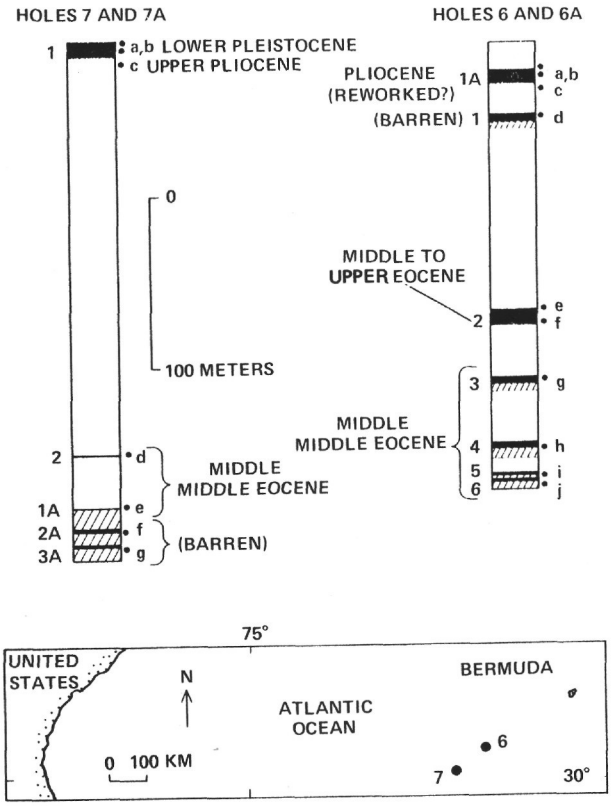


Figure 3. *Series represented in cores from the Bermuda Rise based on coccolith assemblages. Core number to left of columns, sample to right.*

Late Jurassic (Tithonian)

Sample l (1-5A-7, core catcher, depth 274 m): *Braarudosphaera discula* Bramlette and Riedel of Stradner; *Cruciplacolithus* sp.; *Cyclagelosphaera margereli* Noël; *Diazomatolithus lehmani* Noël; *Discolithus rugosus* Noël; *Nannoconus dolomiticus* Cita and Pasquaré; *N. steinmanni* Kamptner; *Parhabdolithus embergi* Noël; *P.* sp. cf. *P. marthe* Noël; *Rhabdosphaera* sp.; *Stephanolithion bigoti* Noël; *S. laffittei* Noël; *Watznaueria barnesae* (Black); *W. britannica* (Stradner).

HOLES 6 AND 6A
(lat 30°50.4'N., long 67°38.9'W., depth 5125 meters)

Summary of Coccolith Age Determinations

Cores recovered from Holes 6 and 6A contain coccolith assemblages ranging in age from early Tertiary to late Tertiary or Quaternary. The upper two cores are virtually barren of calcareous microfossils, however, in one interval (1-6A-1A-1, 64-75 cm) coccoliths and discoasters are present. The species present indicate an

assemblage of Pliocene age. Occurrence of this assemblage within a sequence of deep marine red clay, that is otherwise barren, suggests that the assemblage may have been redeposited from older and shallower beds. Diatoms present in 1-6-2, top of recovery, are distinctive of Middle or Upper Eocene assemblages throughout the world. For instance, the assemblages from Hole 6 are similar to those present at Mt. Diablo, California (Kanaya, 1957), in the Scripps Institution of Oceanography Middle Eocene DWBG #23B core-catcher sample from the Pacific Ocean (16-42S. and 145-48W.), and in the Upper Eocene Oamaru Diatomite of New Zealand. No calcareous microfossils are present. The remaining samples in this hole contain rich microfossil assemblages of both coccoliths and diatoms. The coccolith species indicate that the assemblages are middle Middle Eocene in age in all cases. The best correlation to the biostratigraphic reference sections in Trinidad is to the coccolith assemblage of the *Globigerapsis kugleri* Range Zone of Bolli (1966). There appears to be little difference in the age of the coccolith assemblages recovered between the subbottom depths of 191 meters and 267 meters.

In examining outcrop and deep-sea piston core samples, M. N. Bramlette notes that Middle and Upper Eocene samples commonly contain abundant siliceous microfossils, such as diatoms and radiolarians, in association with volcanic ash beds. In addition to promoting growth of diatoms and radiolarians, the ash concentrations probably contribute to the sediment chemistry state that favors preservation of siliceous microfossils. Recoveries from this site on the Bermuda Rise attest further to the great bloom and preservation of microplankton-bearing siliceous skeletons from the Eocene oceans.

Age-diagnostic Coccoliths in Selected Samples, Holes 6 and 6A

Pliocene or Reworked Pliocene

Sample a (1-6A-1-1, 1 cm, depth 15 m):
Barren.

Sample b (1-6A-1-1, 64-75 cm, depth 16 m):
Coccolithus doronicoides Black and Barnes; *Cyclococcolithus leptoporus* (Murray and Blackman), var. A of McIntyre, Bé, and Preikstas; *Discoaster brouweri* Tan; *D. surculus* Martini and Bramlette; *Helicopontosphaera kamptneri* Hay and Mohler.

Sample c (1-6A-1A, core catcher, depth 24 m):
Barren.

Age Unknown

Sample d (1-6-1, depth 41 m to 46 m):
Barren.

Middle or Upper Eocene (dating based on diatoms only)

Sample e (1-6-2, top of recovery, depth 152 m):
Hemiaulus polycystinorum Ehrenberg, var. *Mesolepta* Grunow; *H. polymorphus* Grunow; *Pyxilla (Pterotheca) aculeifera* (Grunow ex Van Heurck); *?P. (Pyxilla) intermedia* Tempère and Forti; *Stephanopyxis turris* (Greville and Arnott) Ralfs, var. *intermedia* Grunow; *Triceratium barbadense* Greville.

Sample f (1-6-2, core catcher, depth 161 m):
Barren.

Middle Middle Eocene

Sample g (1-6-3-2, 49-52 cm, depth 193 m):
Chiasmolithus expansus (Bramlette and Sullivan); *C. grandis* (Bramlette and Riedel); *Chiphragmalithus quadratus* Bramlette and Sullivan; *Cyclococcolithus luminis* Sullivan; *C. lusitanicus* (Black); *Discoaster barbadiensis* Tan; *D. saipanensis* Bramlette and Riedel; *Reticulofenestra umbilica* (Levin).

Sample h (1-6-4, core catcher, depth 234 m):
Chiasmolithus grandis (Bramlette and Riedel); *Cyclococcolithus gammation* Bramlette and Sullivan; *C. luminis* Sullivan; *C. lusitanicus* (Black); *Discoaster barbadiensis* Tan; *D. saipanensis* Bramlette and Riedel; *Reticulofenestra umbilica* (Levin); *Sphenolithus furcatolithoides* Locker.

Sample i (1-6-5, core catcher, depth 249 m):
Chiasmolithus expansus (Bramlette and Sullivan); *C. grandis* (Bramlette and Riedel); *Cyclococcolithus gammation* Bramlette and Sullivan; *C. lusitanicus* (Black); *Discoaster barbadiensis* Tan; *D. saipanensis* Bramlette and Riedel; *Helicopontosphaera seminulum seminulum* (Bramlette and Sullivan); *Lanternithus minutus* Stradner; *Reticulofenestra umbilica* (Levin).

Sample j (1-6-6-1, 146-149 cm, depth 251 m):
Chiasmolithus expansus (Bramlette and Sullivan); *C. gigas* (Bramlette and Sullivan); *C. grandis* (Bramlette and Riedel); *C. solitus* (Bramlette and Sullivan); *C. staurion* (Bramlette and Sullivan); *Discoaster barbadiensis* Tan; *D. saipanensis* Bramlette and Riedel; *Lophodolithus* sp. aff. *L. mochlophorus* Deflandre; *Reticulofenestra* sp. aff. *R. umbilica* (Levin); *Sphenolithus furcatolithoides* Locker. Reworked taxa: *Discoaster sublodoensis* Bramlette and Sullivan; *Micula decussata* Vekshina; *Rhabdosphaera inflata* Bramlette and Sullivan.

HOLES 7 AND 7A
(lat 30°08.0'N., long 68°17.8'W., depth 5185 meters)

Summary of Coccolith Age Determinations

A 9.1-meter surface core, from 0.0 to 9.1 meters below the ocean floor, recovered a sequence of coccolith assemblages indicating that the boundary between the

Tertiary and Quaternary is present near the top of this recovery. Coccoliths indicating an early Quaternary age are present at the top of the core. There are no *Gephyrocapsa oceanica* Kamptner recorded in the upper 90 centimeters of the core, and only rare reworked specimens of *Discoaster brouweri* Tan are present. A sample at 95 centimeters below the top of the core contains abundant specimens of *D. brouweri.* There are approximately equal proportions of six-rayed and three-rayed varieties. The relative abundance of the three-rayed specimens indicates a late Pliocene age. Coccoliths and discoasters become less abundant lower in the core; however, in a sample 208 centimeters below the surface, both *D. brouweri* and *D. pentaradiatus* Tan are present. These were the two dominant discoasters of Pliocene time, and they—the last of the discoasters—became extinct at about the time generally assigned to the Pliocene-Quaternary boundary. Coccoliths are quite rare in a sample at 276 centimeters below the surface, and the remaining samples consist of barren deep-sea clay.

Core 2 recovered middle Middle Eocene coccolith- and diatom-rich sediment and correlates with similar cores described from Hole 6.

In redrilling Site 7, the first coring was not attempted until after 267 meters of subbottom penetration. The core barrel was apparently empty when it was retrieved, but when the core-catcher assembly, which was unused before this coring, was dismantled, three specks of sediment totalling less than 1 cubic millimeter were recovered. Three smear slides were made to examine the contained coccoliths. All three coccolith assemblages proved to be middle Middle Eocene. On the basis of this information, the decision was made to continue drilling instead of attempting another core at this level. The next two core recoveries, the last of this leg, retrieved deep-sea silty clay that contained neither coccoliths nor diatoms, and its age is unknown.

Age-diagnostic Coccoliths in Selected Samples, Holes 7 and 7A

Early Pleistocene

Sample a (1-7-1-1, 80 cm, depth 1 m): *Ceratolithus rugosus* Bukry and Bramlette; *Coccolithus doronicoides* Black and Barnes; *Cyclococcolithus leptoporus* Murray and Blackman.

Late Pliocene

Sample b (1-7-1-1, 95 cm, depth 1 m): *Ceratolithus rugosus* Bukry and Bramlette; *Coccolithus doronicoides* Black and Barnes; *Cyclococcolithus leptoporus* Murray and Blackman; *Discoaster brouweri* Tan.

Sample c (1-7-1, core catcher, depth 9 m): Barren.

Middle Middle Eocene

Sample d (1-7-2, core catcher, depth 236 m): *Chiasmolithus expansus* (Bramlette and Sullivan); *C. gigas* (Bramlette and Sullivan); *C. grandis* (Bramlette and Riedel); *Chiphragmalithus cristatus* (Martini); *Discoaster elegans* Bramlette and Sullivan; *Helicopontosphaera seminulum lophota* (Bramlette and Sullivan); *Reticulofenestra umbilica* (Levin).

Sample e (1-7A-1, core catcher, depth 267 m): *Chiasmolithus solitus* (Bramlette and Sullivan); *Cyclococcolithus gammation* Bramlette and Sullivan; *C. lusitanicus* (Black); *Discoaster barbadiensis* Tan; *Reticulofenestra* sp. aff. *R. umbilica* (Levin); *Rhabdosphaera spinula* Levin.

Age Unknown

Sample f (1-7A-2, composite, depth 278 m to 290 m): Barren.

Sample g (1-7A-3, composite, depth 287 m to 290 m): Barren.

PLATE 1

Coccolith replica electronmicrographs (magnifications: 10,000 X, unless stated). Hole 5A, Core 3A, core catcher (145 meters subbottom)

A *Apertapetra gronosa* (Stover) magnification: 5,000 X

B *Arkhangelskiella erratica* Stover

C *Costacentrum horticum* (Stradner, Adamiker, and Maresch)

D *Cretarhabdus crenulatus* Bramlette and Martini

E *Cretarhabdus decorus* (Deflandre) magnification: 9,000 X

F *Cretarhabdus decussatus* (Manivit)

PLATE 2

Coccolith replica electronmicrographs (magnifications: 10,000 X, unless stated). Hole 5A, Core 3A, core catcher (145 meters subbottom)

A *Eiffellithus turriseiffeli* (Deflandre) magnification: 8,000 X

B-C *Parhabdolithus* sp.

D *Podorhabdus dietzmanni* (Reinhardt)

E *Prediscosphaera columnatus* (Stover)

F *Scapholithus fossilis* Deflandre

PLATE 3

Coccolith replica electronmicrographs Hole 5A, Core 7A, core catcher (274 meters subbottom)

A *Bidiscus* sp. magnification: 14,000 X

B *Cretarhabdus* sp. cf. *C. crenulatus* Bramlette & Martini

C-D *?Cruciplacolithus* sp. magnifications: 7,000 X

E *Diazomatolithus lehmani* Noël magnification: 10,000 X

F *Parhabdolithus embergi* Noël magnification: 7,000 X

PLATE 4

Coccolith replica electronmicrographs Hole 5A, Core 7A, core catcher (274 meters subbottom)

A *Rucinolithus* sp. aff. *R. hayi* Stover magnification: 10,000 X

B *Stephanolithion* sp. magnification: 14,000 X

C *Watznaueria barnesae* (Black) magnification: 10,000 X

D-E *Watznaueria britannica* (Stradner) magnifications: 7,000 X

F *Zygodiscus* sp. cff *Z theta* (Black) magnification: 7,000 X

PLATE 5

Coccolith replica electronmicrographs (magnifications: 10,000 X, unless stated). Hole 5A, Core 4A, Section 1, 24 cm (185 meters subbottom)

A *Biscutum blacki* Gartner magnification: 15,000 X

B *Corollithion* sp.

C *?Cruciplacolithus* sp. magnification: 6,000 X

D *Micrantholithus obtusus* Stradner

E *Stephanolithion laffittei* Noël

F *Zygodiscus erectus* (Deflandre)

PLATE 6

Coccolith replica electronmicrographs (magnifications: 10,000 X, unless stated). Hole 3, Core 9, Section 3, 75 cm (537 meters subbottom)

A-B *Discoaster* sp.
A magnification: 9,000 X
B magnification: 6,000 X

C *Discoaster* sp. aff. *D. brouweri* Tan

D *Discolithina* sp. magnification: 6,000 X

E *Helicopontosphaera kamptneri* Hay and Mohler

F *Sphenolithus abies* Deflandre magnification: 16,000 X

PLATE 7

Coccolith replica electronmicrographs (magnifications: 5,000 X, unless stated). Hole 3, Core 8, Section 6, 72 cm (438 meters subbottom)

A *Ceratolithus tricorniculatus* Gartner magnification: 8,000 X

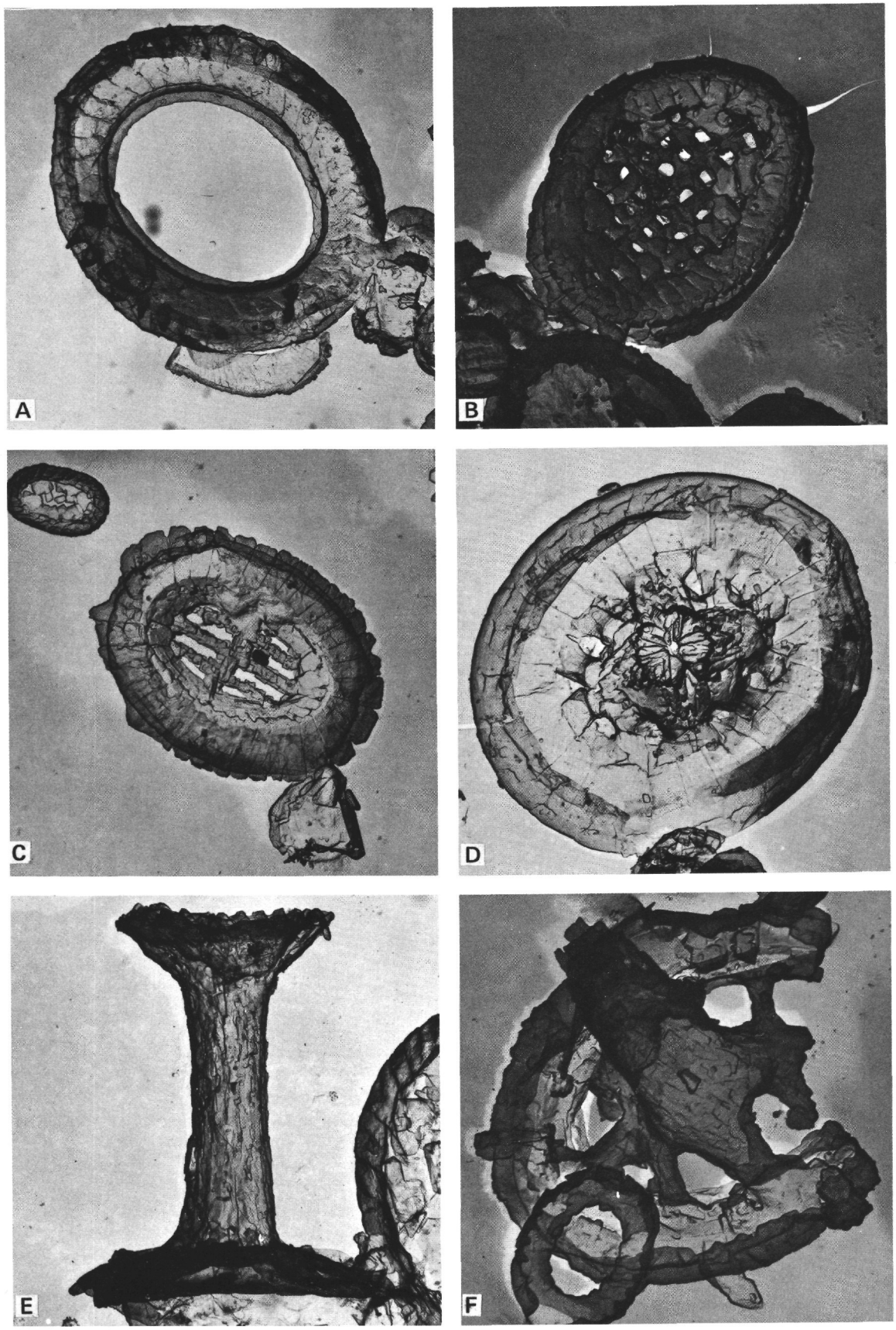
B *Scyphosphaera pulcherrima* Deflandre

C *Discoaster brouweri* Tan

D *Discoaster surculus* Martini and Bramlette

E-F *Reticulofenestra pseudoumbilica* (Gartner) magnification: 10,000 X

PLATE 1.



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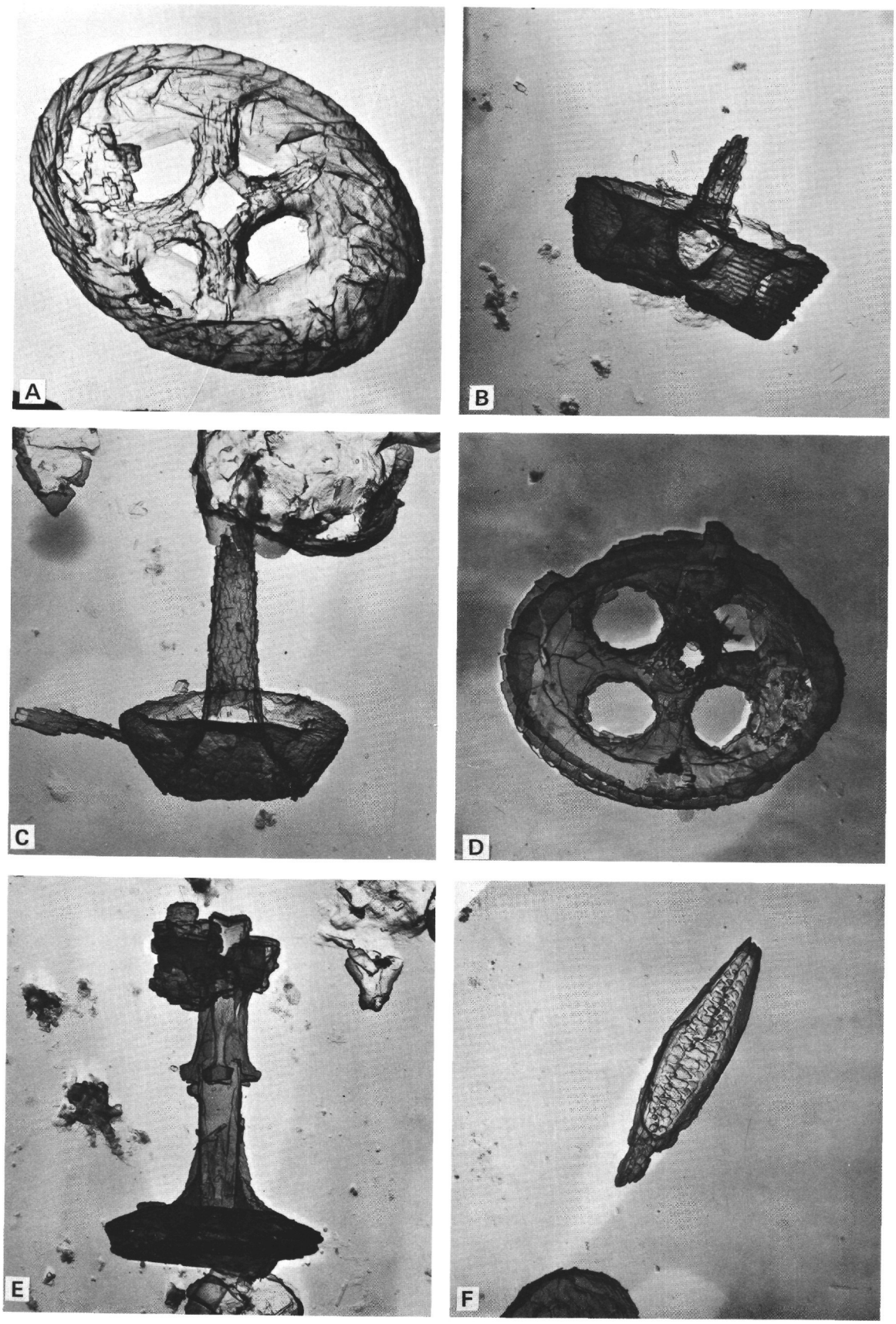

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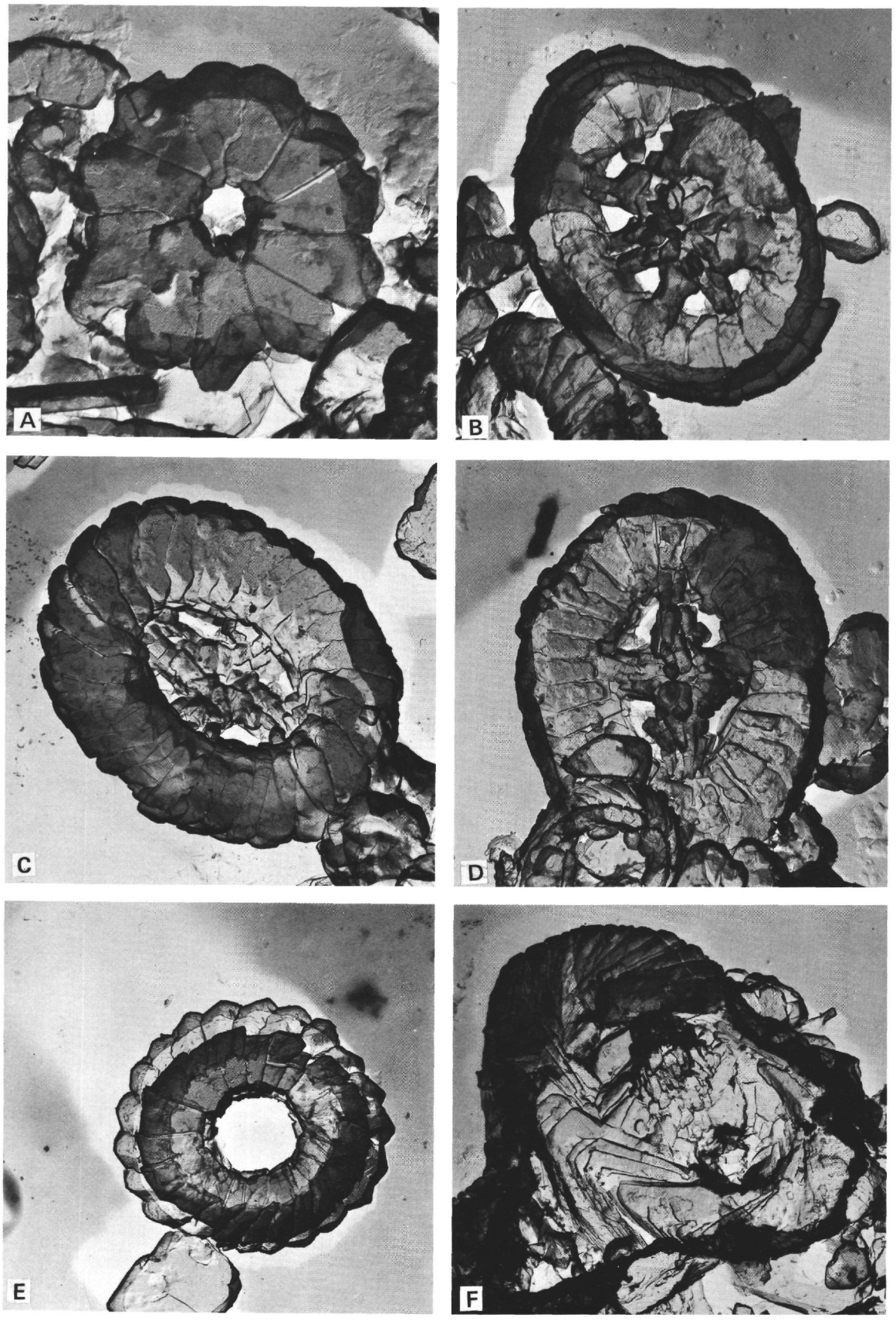

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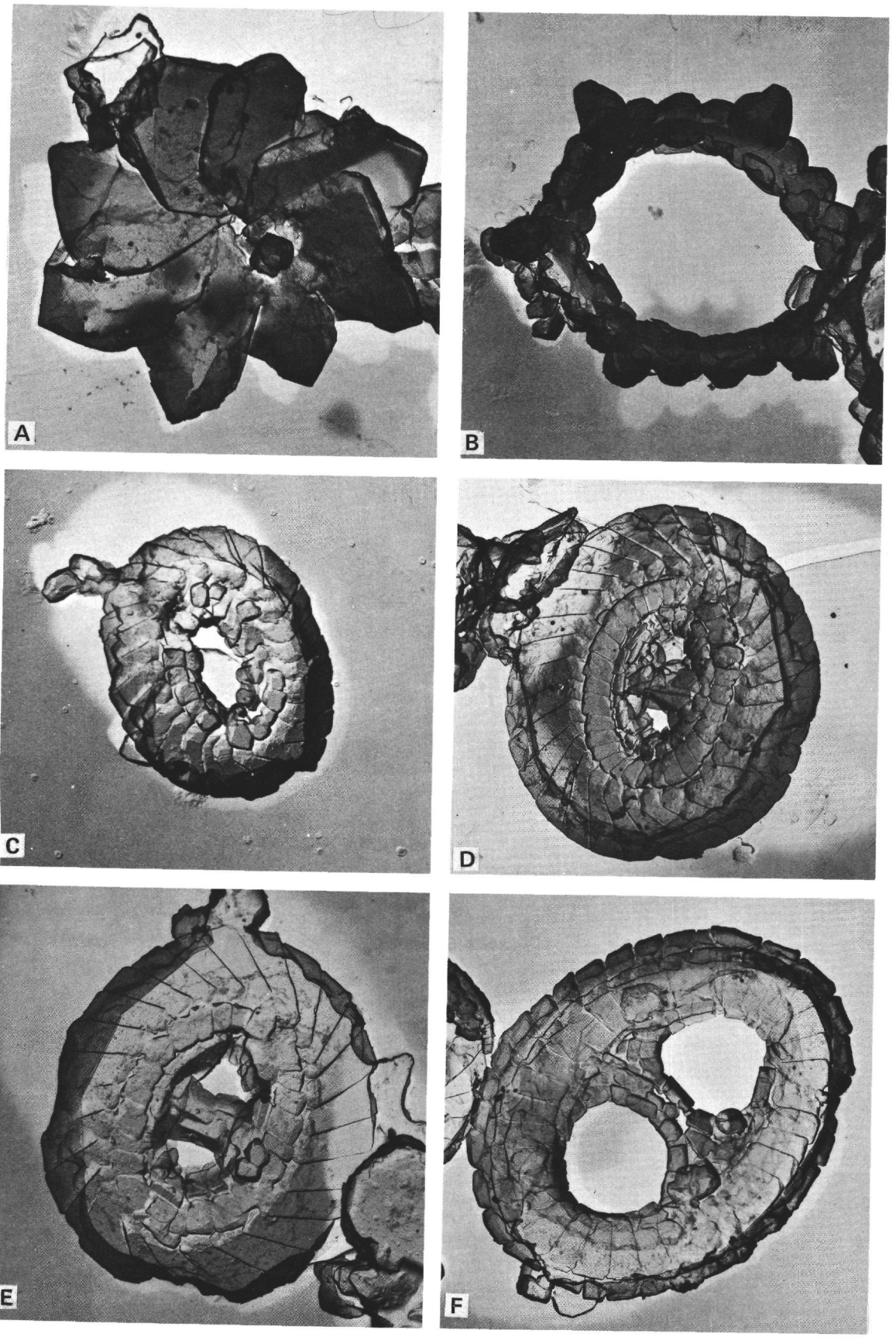

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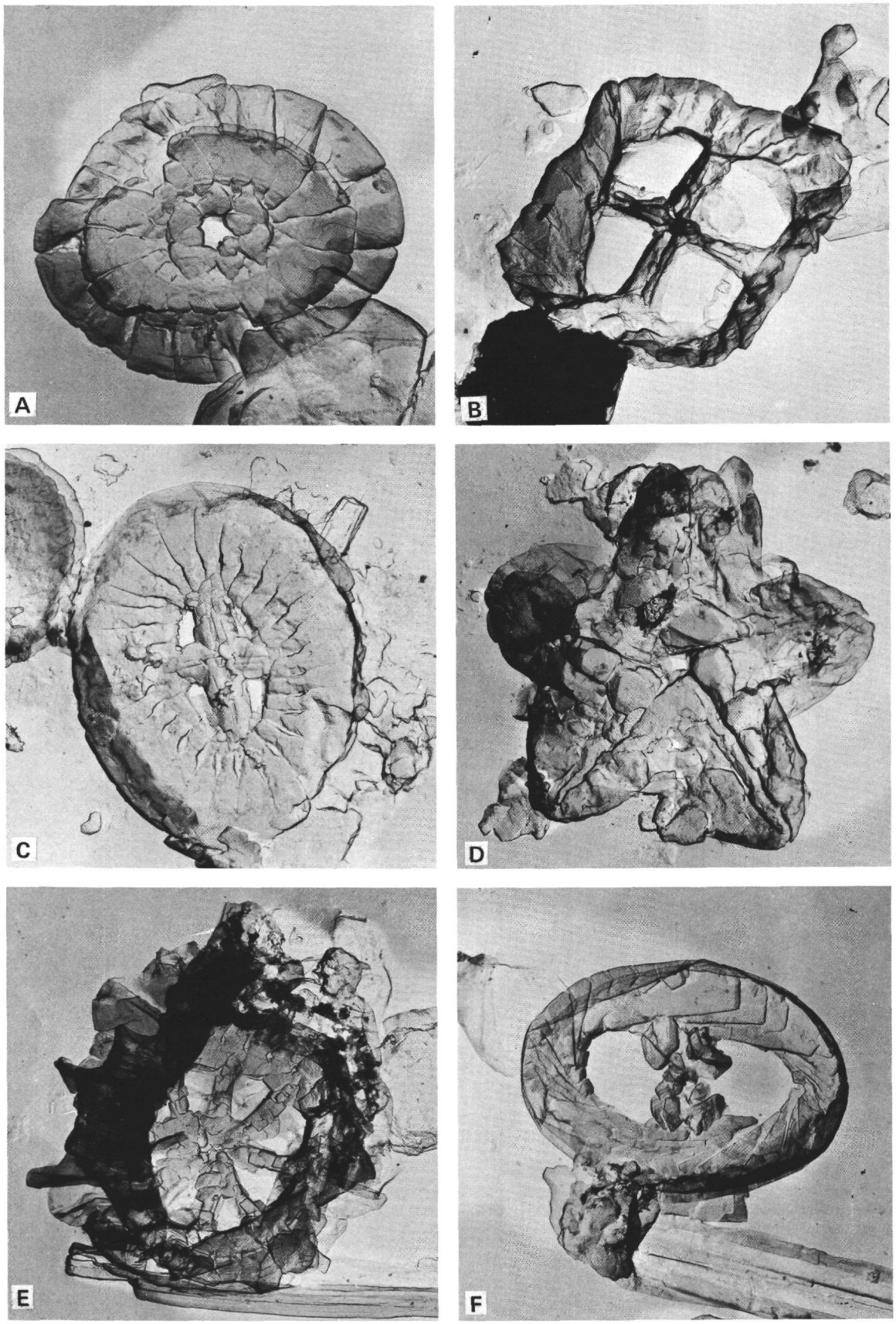

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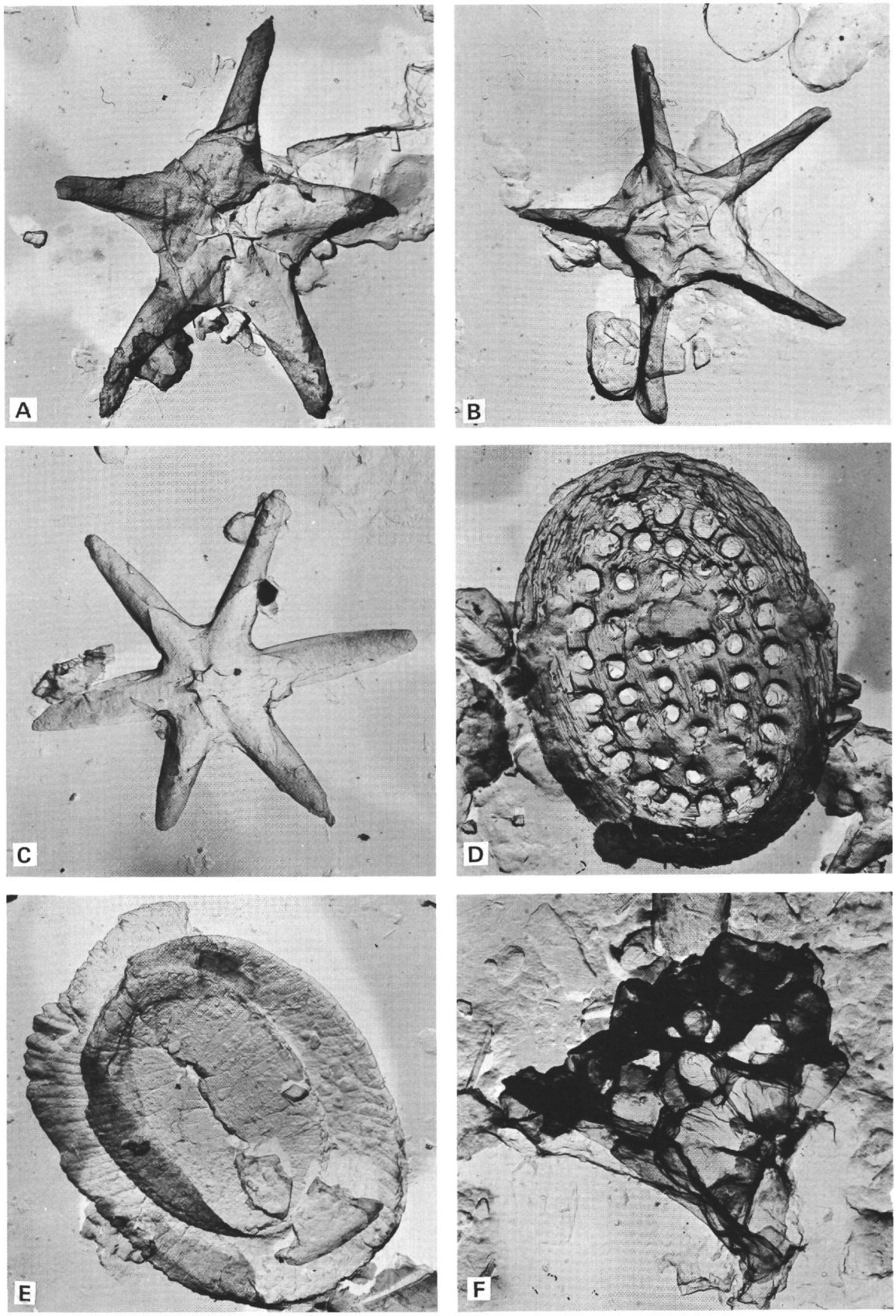
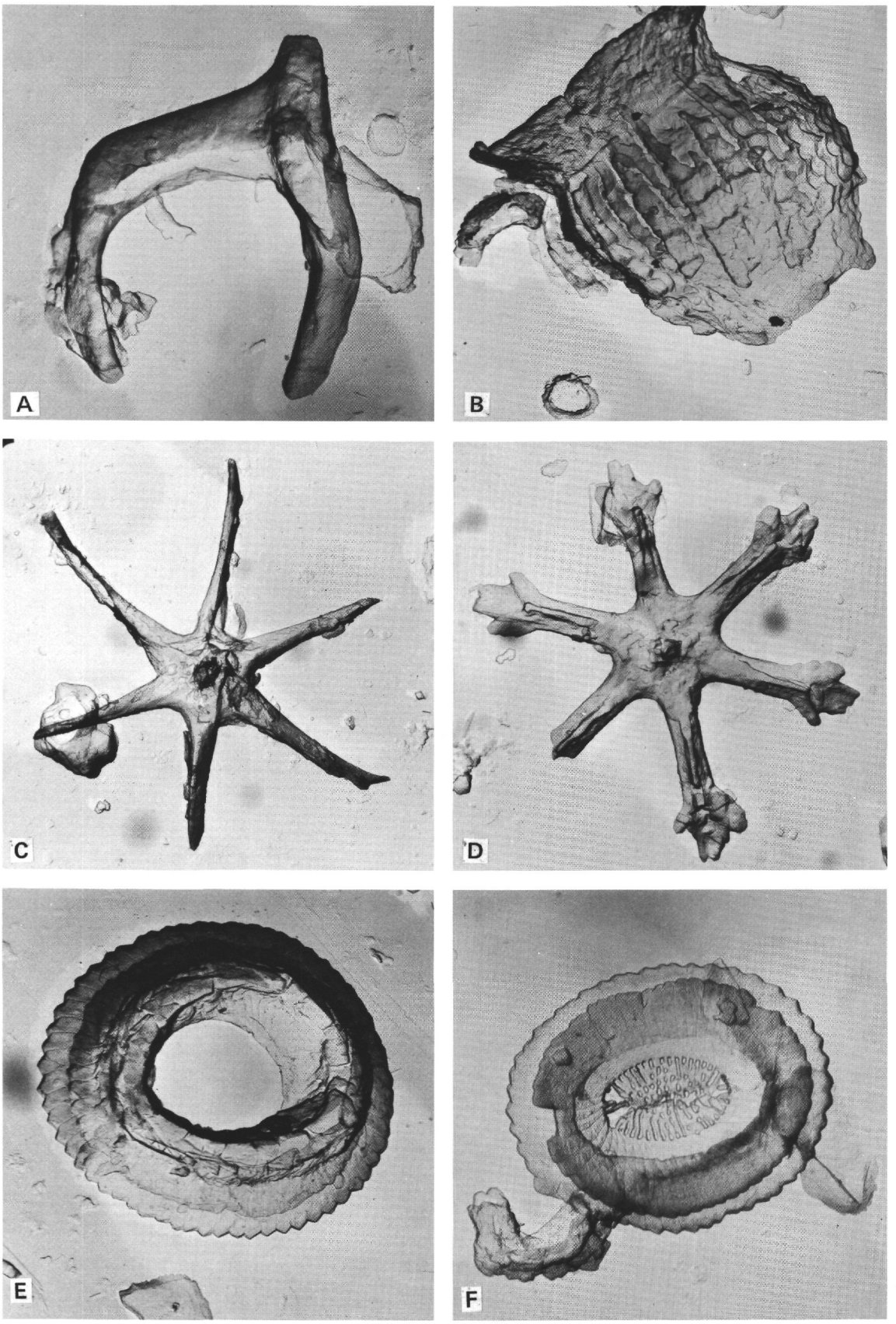


PLATE 7.



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