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Autor:	Hay, William W. / Towe, Kenneth M.
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Electronmicroscopic Examination of some Coccoliths from Donzacq (France)

By William W. Hay and Kenneth M. Towe ¹⁾

With 10 plates (I-X) and 2 text-figures

I. INTRODUCTION

The Tuilerie de Donzacq is a classic source for nanofossils. The rich and varied assemblage has been studied by DEFLANDRE (1950), DEFLANDRE and FERT (1952, 1954), BRAMLETTE and RIEDEL (1954), MARTINI (1961), BRAMLETTE and SULLIVAN (1961) and HAY and TOWE (1962).

The first large scale application of electron microscopy to paleontology was made by DEFLANDRE and FERT (1952, 1953a, 1953b, 1954), who published a number of transmission micrographs of coccolithophorids, many of them from the Cuisian²⁾ marls of Donzacq. The transmission micrographs revealed that coccoliths are exceedingly complex, but carbon replicas have been needed to show the structural details clearly. Application of the carbon replica technique to coccoliths was developed in France by DEFLANDRE and DURRIEU (1957). Application of the carbon replica technique to fossil coccoliths has been developed by G. DEFLANDRE and L. DURRIEU (1957) in France, by MAURICE BLACK and BARBARA BARNES (1959, 1961) at the Sedgwick Museum, Cambridge, England, and by KENNETH M. TOWE at the Electron Microscope Laboratory of the University of Illinois.

The ultrastructure of coccoliths is so varied that much electronmicroscopic work will need to be done before an estimate of the variety of form and of the phylogenetic relationships of these abundant nanofossils can be made. Because so many species have been described from the Tuilerie de Donzacq, a sample from there was chosen for examination using the carbon replica technique. The braarudosphaerids have already been described (HAY and TOWE, 1962). This paper deals with some of the coccoliths and discoasters. The rhabdoliths are especially complex, and will be dealt with in a later paper (HAY and TOWE, in press).

¹⁾ Department of Geology and Electron Microscope Laboratory, University of Illinois, Urbana, Illinois.

²⁾ BURGER, CUVILLIER, and SCHOEFFLER (1945) considered the marls of Donzacq to be Lutetian. More recent studies indicate that they are Cuisian (HOTTINGER and SCHAUB, 1960).

II. TAXONOMY

Coccoliths and rhabdoliths are minute calcareous skeletal elements produced by microscopic chrysomonadinid flagellates. In the living organism, a number of coccoliths are arranged to form a coccospHERE. (See Pl. 3, fig. 2; Pl. 9, figs. 2, 4). The coccoliths may be all alike or there may be dimorphism, with the circum-flagellar cycle of coccoliths different from the others. The term coccolith is used loosely for all button-shaped skeletal elements having heliolithid structure, that is, the calcite elements are so arranged that a negative uniaxial pseudofigure is seen in polarized light. Rhabdoliths have an elongate rod attached to the basal disc. Braarudosphaerids construct skeletal elements made of five crystals of calcite, each having a different orientation. Discoasters are calcareous nanofossils the size of large coccoliths, but have ortholithid structure. They are constructed so that the c-axes of the calcite crystals are parallel and oriented perpendicular to the plane of the disc. There is but a single report of a living organism, a protist, bearing discoaster-like skeletal elements (LECAL, 1952).

III. TAXONOMIC PROBLEMS

Living species of coccolithophores are identified by the coccoliths they produce. PARKE and ADAMS (1960) have indicated that the life history of the coccolithophores may be complex, and that different coccoliths are produced during different phases of the life cycle. If a species produces only one kind of coccolith, nomenclatural problems need not arise. However, some coccolithophores produce different kinds of coccoliths within the same cell (DEFLANDRE, 1953), and multiple names inevitably arise. It is often impossible to assign a fossil coccolith to a Recent genus with certainty, so a number of paragenera have been proposed. Unfortunately, parageneric taxa have also been created for coccoliths of species readily assignable to Recent genera. Because the coccoliths are the basis for identification of modern coccolithophores, the proliferation of names for isolated coccoliths is unnecessary and is not followed here.

The suprageneric classification used here is that of KAMPTNER (1958).

IV. PREPARATION OF SAMPLES

The sample was first disaggregated in distilled water and the coccoliths separated by wet sedimentation. A dispersion of the coccolith concentration was then placed on a piece of Faxfilm and dried in air. The Faxfilm was next placed in a high vacuum evaporator and a thin film of carbon deposited at an angle of 60°. The Faxfilm was then placed on a piece of stainless steel 200 mesh screening and immersed in acetone. When the Faxfilm was thoroughly dissolved, dilute hydrochloric acid was added to dissolve the calcite coccoliths. The remaining carbon replica was then transferred into a bath of hydrofluoric acid to dissolve clay minerals and other silicates. The replicas were finally transferred for washing into distilled water and picked up on formvar coated electron microscope specimen support screens for viewing.

V. TERMINOLOGY

So few coccoliths have been studied in detail that few formal descriptive terms have been proposed. BLACK and BARNES (1959) introduced the term shield for the discs of the coccolith. The shields are constructed of a number of plates. The concave side of a coccolith is proximal and the convex side is distal. Most coccoliths consist of two or more shields connected by a central tube. Genera are distinguished on the basis of the relative size and development of the shield and tube units. A shield may consist of one or more cycles of plates. The plates of a cycle adjoin one another without overlap or may be imbricate. The imbrication is termed dextral if each plate overlaps the one to the right when viewed from the center of the cycle, or sinistral if each plate overlaps the one to the left. (See text-fig. 1.) The sutures between the plates are only rarely directed radially. More commonly they are inclined. The inclination is termed clockwise or counter-clockwise depending on the direction of peripheral deviation from the center. (See text-fig. 2.) The degree of inclination is termed slight when the sutures are nearly radially directed, strong when they are nearly tangentially directed, and moderate when they intersect a radius with an angle of about 45°.

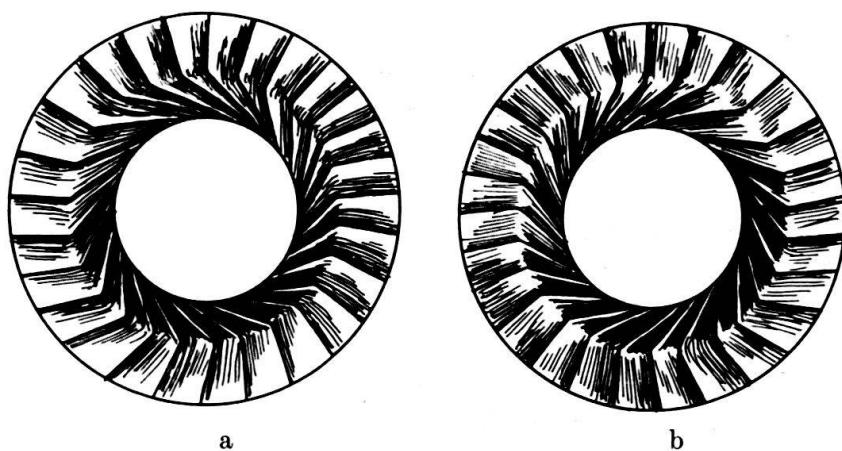


Fig. 1. Schematic diagram illustrating sinistral (a) and dextral (b) imbrication.

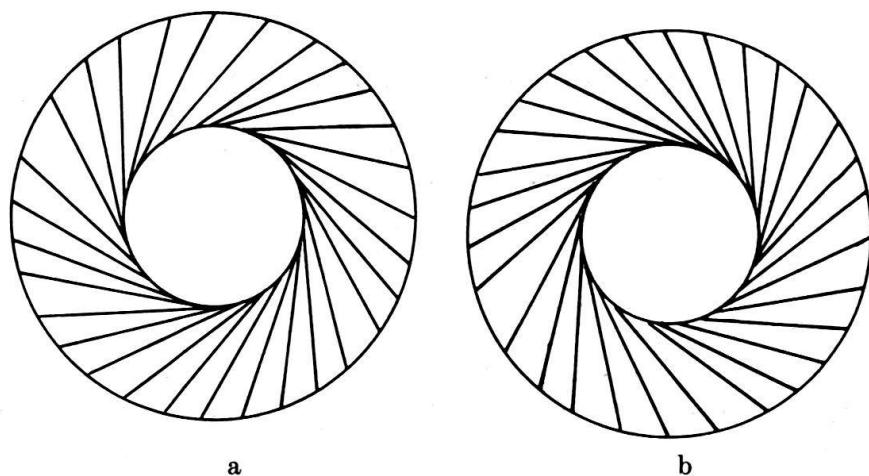


Fig. 2. Schematic diagram illustrating clockwise (a) and counterclockwise (b) inclination of the sutures between the plates.

VI. SYSTEMATICS

Family: Coccolithaceae

Subfamily: Coccolithoideae

TRIBE: SYRACOSPHAERAEAE

SUBTRIBE: TERGESTIELLINEAE

Genus *Cyclolithus* KAMPTNER 1948

Type species: Not designated.

KAMPTNER erected the genus *Cyclolithus* for three species of coccolith: *C. rotundatus* KAMPTNER, 1948, *C. ellipticus* KAMPTNER, 1948, and *C. inflexus* KAMPTNER, 1948, but did not designate a type species. Coccoliths of this genus are circular or elliptical, formed of one or two cycles of plates around a large central opening.

Cyclolithus bramletti HAY et TOWE, sp. nov.

Pl. V, fig. 6; Pl. VII, fig. 2

1962. *Cyclolithus* sp. TOWE and HAY, Science, vol. 135, p. 395, Cover photograph.

Name: In honor of M. N. BRAMLETTE, Scripps Institution of Oceanography, La Jolla, California.

Holotype: UI-EML-1910B.

Dimensions: Inside diameter of cyclolith 1.8μ ; outside diameter of cyclolith 3.2μ .

Locus typicus: Tuilerie de Donzacq, Landes, France.

Stratum typicum: Couches de Donzacq, Cuisian.

Diagnosis: A circular species of *Cyclolithus* with the width of the ring $\frac{1}{2}$ the radius of the cyclolith, composed of at least three cycles of plates stacked on top of one another.

Description: In top view circular, outer margin asymmetrically serrate; basal cycle widest, with about 40 petaloid plates, slightly sinistrally imbricate; middle cycle composed of an equal number of thick narrow plates moderately sinistrally imbricate, sutures on upper surface with strong clockwise inclination; upper cycle composed of an equal number of very thin plates not perceptibly imbricated, sutures with a moderate clockwise inclination, forming notches along inner margin.

Remarks: Coccoliths of this sort may be thought of as arising from those of the *Cyathosphaera* type through increase in size of the central perforate area and reduction in width of the upper and lower shields.

Of the species of *Cyclolithus* described to the present, only *C. rotundus* KAMPTNER from the Tortonian of the Vienna basin and *C. ? robustus* BRAMLETTE et SULLIVAN from the Paleocene of California have a circular outline. The width of the ring in proportion to the diameter of the cyclolith is much less in *C. rotundus* and much greater in *C. ? robustus* than in the new species.

The coccospores of this species must be very large as the fragment shown in Pl. V, fig. 6 displays little curvature.

Cyclolithus sp.

Pl. IX, fig. 4

Hypotype: UI-EML-2098A.

Dimensions: Diameter of coccospore, 5.3μ ; outside diameter of cyclolith 3.2μ .

Remarks: A spherical coccosphere of eight cycloliths is figured for purposes of comparison. Detailed structure of the cycloliths is obscured.

Cyclolithus ? sp.

Pl. IX, fig. 2

Hypotype: UI-EML-1624D.

Dimensions: Greatest diameter of coccosphere, 3μ ; diameter of cyclolith ? 1μ .

Remarks: An ellipsoidal coccosphere consisting of 8 cycloliths ? is figured for purposes of comparison. The cycloliths cannot be observed closely enough to permit detailed description.

SUBTRIBE: SYRACOSPHAERINAE

Genus *Discolithus* KAMPTNER, 1948

Type species: Not designated.

The taxon *Discolithus* was used by KAMPTNER (1948) but no type species was designated. A number of new species (*D. pulvinus* KAMPTNER, 1948; *D. multiporus* KAMPTNER, 1948; *D. vigintiforatus* KAMPTNER, 1948; *D. patera* KAMPTNER, 1948; *D. latus* KAMPTNER, 1948; *D. sparsiforatus* KAMPTNER, 1948; *D. circumcisus* KAMPTNER, 1948; and *D. staurophorus* KAMPTNER, 1948) were named, one of which must be the type species.

In 1958, KAMPTNER stated «Das Paragenus *Discolithus* enthält alle isolierten, generisch einstweilen unbestimmmbaren Funde an platten-, untartassen- und napfförmigen Kalkkörpern von elliptischem Umriss.» (p. 75.)

DEFLANDRE and FERT (1954) used the term in a very broad sense for a number of different cocoliths. BRAMLETTE and SULLIVAN (1961) used it in a sense which corresponds to that of KAMPTNER (1958).

Discolithus ocellatus BRAMLETTE et SULLIVAN, 1961

Pl. VIII

1961. *Discolithus ocellatus* BRAMLETTE et SULLIVAN, Micropaleontology, v. 7, p. 142, pl. 3, fig. 2a-c.

Hypotype: UI-EML-1614C.

Dimensions: Length 5.8μ ; width 4.1μ .

Remarks: In top view elliptical, margin smooth, the shield composed of numerous thin adjoining plates, about 60 at center of shield, almost double that number around margin of shield. The sutures between the plates have a slight counterclockwise inclination and generally bifurcate before reaching margin. Two pores are present near the foci of the ellipse. They are about $1/2 \mu$ in the diameter and are connected by slit about 500 Å wide.

This species resembles *Discolithus planus* BRAMLETTE et SULLIVAN which they reported as occurring at Donzacq, but which lacks the two holes characteristic of the new species. *Discolithus ocellatus* BRAMLETTE et SULLIVAN from the Eocene of California, has two holes, which in the holotype are slightly elliptical and spaced more closely together than in the specimen figured here.

TRIBE: ZYGOSPHAERAEAE

SUBTRIBE: ZYGOSPHAERINAE

Genus *Zygrhablithus* DEFLANDRE, 1959

Type species: *Zygolithus bijugatus* DEFLANDRE, 1954.

This genus was proposed by DEFLANDRE for forms resembling a rhabdolith combined with a zyglith, having an elliptical or subcircular base, with an X-shaped structure in the center surmounted by a complex stem.

Zygrhablithus bijugatus (DEFLANDRE)

Pl. II, fig. 2

1954. *Zygolithus bijugatus* DEFLANDRE, Ann. Pal., v. 40, p. 148, pl. 11, figs. 20, 21, text-fig. 59.
 1954. *Rhabdolithus costatus* DEFLANDRE, Ann. Pal., v. 40, p. 157, pl. 11, figs. 8-11, text-figs. 41, 42, 77-79.
 1959. *Zygrhablithus bijugatus* (DEFLANDRE), DEFLANDRE, Rev. Micopal., v. 2, p. 135.

Hypotype: UI-EML-2096D.

Dimensions: Length 2.7 μ ; width 2.0 μ .

Remarks: Although DEFLANDRE's specimens were from the Oligocene diatomite of Oamaru, New Zealand, the specimen from Donzacq figured here resembles it so closely there can be no doubt that they are conspecific.

The electron micrograph fails to show any fine structure in the elliptical rim. Traces of the thin plates covering the proximal sides of the central pores (suggested by DEFLANDRE from the appearance of specimens in polarized light) can be seen. The cross bars appear to be massively constructed. The central stem bears four flanges directed between the cross bars. As will be shown in another publication, the ultrastructure of this species is quite different from that of *Zygrhablithus intercisis* (DEFLANDRE), 1954, from the Cretaceous of France.

TRIBE: COCCOLITHEAE

SUBTRIBE: COCCOLITHINAE

Genus *Cyclococcolithus* KAMPTNER, 1954; emend. KAMPTNER, 1958

Type species: *Coccospaera leptopora* MURRAY et BLACKMAN.

Remarks: This genus was erected by KAMPTNER, 1954, for «kreisrunde manschettenknopfformörnige Gehäuseelemente», and two species, *Coccospaera leptopora* MURRAY et BLACKMAN and *Umbilicosphaera mirabilis* LOHMANN, were transferred to it. Since *Umbilicosphaera mirabilis* LOHMANN is the type species of the genus *Umbilicosphaera* LOHMANN, it cannot be transferred into a new genus, and the species *Coccospaera leptopora* MURRAY et BLACKMAN must be the type species of the genus *Cyclococcolithus*. In 1954 KAMPTNER did not recognize the genus *Umbilicosphaera*, but in 1958 he stated that in *Umbilicosphaera* the basal shield is larger than the distal shield, while in the case of *Cyclococcolithus* the distal shield is larger.

BLACK and BARNES (1961) have published electron micrographs of the type species of the genus.

Cyclococcolithus dictyodus (DEFLANDRE et FERT)

Pl. V, figs. 4, (?) 5, Pl. VII, fig. 1

1954. *Discolithus dictyodus* DEFLANDRE et FERT, Ann. Pal., v. 40, p. 140, text-figs. 15, 16.

Hypotype: UI-EML-2097D, 1916B.

Dimensions: Diameter of upper shield $5-6 \mu$; diameter of lower shield $3-4 \mu$.

Remarks: This species can now be referred with certainty to the genus *Cyclococcolithus*. Electron micrographs of the type species (BLACK and BARNES, 1961) show that the upper shield bears a large pore. The replica figured here shows a bottom view of a specimen with a grilles central area in the basal shield. The shields consist of about 40 plates each. Sutures between the plates of the basal shield have a counterclockwise inclination (clockwise in the bottom views illustrated here). The peripheral margins of the plates are finely dentate. The perforate central disc is slightly recessed from the basal shield, and is made of about 40 anastamosing ribs which arise from the middle of each plate of the basal shield. The central area is broadly elliptical and the ribs are arranged to form four sets of V's with apices directed toward the center and the axes of the V's aligned along the major and minor axes of the ellipse.

The specimen figured on Pl. V, fig. 5 may be a corroded specimen of this species, the central grille having been destroyed and the upper tube damaged.

Genus *Umbilicosphaera* LOHMANN, 1902Type species: *Umbilicosphaera mirabilis* LOHMANN, 1902.

Remarks: This genus was erected by LOHMANN for forms with coccoliths having a basal disc and a very short tube which flares to form a thickened ring distally. The ultrastructure of the type species has been described by BLACK and BARNES (1961, p. 140, pl. 25, figs. 4, 5). They have shown the tube and upper shield to be made of a single cycle of rhombohedral calcite plates. The basal shield and the upper shield are almost equidimensional in the type species.

According to KAMPTNER, 1958, the difference between *Umbilicosphaera* LOHMANN, 1902, and *Cyclococcolithus* KAMPTNER, 1954, emend. KAMPTNER, 1958, lies in the relative size of the basal and upper shields. The basal shield is larger than the upper shield in *Umbilicosphaera* and smaller in *Cyclococcolithus*.

Umbilicosphaera arena HAY et TOWE, sp. nov.

Pl. II, figs. 3, 5

Holotype: UI-EML-2095C.

Dimensions of holotype: Length, 5.3μ ; width, 4.7μ .

Paratype: UI-EML-1922D.

Dimensions of Paratype: Length, 5.9μ ; width, 4.7μ .

Locus typicus: Tuilerie de Donzacq, Landes, France.

Stratum typicum: Couches de Donzacq, Cuisian.

Diagnosis: A species of *Umbilicosphaera* characterized by an elliptical outline, and wide elliptical central pore surrounded by a ring of rhomboidal nodes.

Description: In top view, upper shield made of about 42 stout rhomboidal plates surrounding central depression; rim of depression sharply angular; margin

of depression formed by edges of plates of upper shield; central elliptical pore surrounded by ring of 14 (?) rhomboidal nodes.

Remarks: The general appearance of this species is much closer to that of *Umbilicosphaera mirabilis* than that of *Cyclococcolithus leptoporus*, and the species is placed in the genus *Umbilicosphaera*. The basal shield is either smaller than the upper shield or is missing from the specimen.

Genus *Tiarolithus* KAMPTNER, 1958

Type species: *Calcidiscus medusoides* KAMPTNER, 1954.

Remarks: This genus was erected to include circular coccoliths with a central pore. The coccoliths have a single shield, concave proximally, and a short tube surrounding the central pore.

Tiarolithus sp.

Pl. IX, fig 5

Hypotype: UI-EML-1909C.

Dimensions: 2.2μ .

Remarks: A coccolith bearing some resemblance to *Calcidiscus medusoides* KAMPTNER (1954, p. 26, ff, text-figs. 24-34) is figured for purposes of comparison. It has about 30 plates in the marginal cycle. The plates extend upward to form a short stem about the central opening. Bits of calcite visible in the central opening may indicate that it was originally plugged.

Tiarolithus obscurus (DEFLANDRE et FERT)

Pl. IX, fig. 3

- 1952. *Calcidiscus obscurus* DEFLANDRE et FERT, C. R. Acad. Sci., v. 234, p. 2101, text-fig. 7 (*nomen nudum*).
- 1954. *Calcidiscus obscurus* (DEFLANDRE et FERT), Ann. Pal., v. 40, p. 145, text-figs. 3, 4.
- 1962. *Coccolithites gammation* BRAMLETTE et SULLIVAN; of TOWE et HAY, Amer. Assoc. Petrol. Geol., Bull. v. 46, p. 282.

Hypotype: UI-EML-1926B.

Dimensions: Diameter 2.5μ .

Remarks: The transmission micrographs published by DEFLANDRE and FERT show only a dark disc slightly over 1μ in diameter. The dimensions of the carbon replica agree closely with those of the specimen of DEFLANDRE and FERT, which was also from Donzacq. *Coccolithites gammation*, BRAMLETTE and SULLIVAN, 1961, is larger, $5-9 \mu$ in diameter. The coccolith consists of a marginal cycle of 10 large plates. Sutures between the plates are slightly depressed and have a curving counterclockwise inclination (clockwise when viewed from the bottom as in Pl. IX, fig. 3). The periphery of plates of the marginal cycle is finely dentate, with about 18 denticles per plate. Medially there is a cycle of raised modular plates surrounding the central opening. The central opening is often clogged.

Genus *Rhabdosphaera* HAECKEL, 1894

Type species: *Rhabdosphaera claviger*, MURRAY et BLACKMAN, 1898.

The skeletal elements of *Rhabdosphaera* ('rhabdoliths') consist of a basal disc surmounted by a long stem. A collar may be present next to the basal disc.

Rhabdoliths from Donzacq have proven to be exceedingly complex and interesting and are the subject of another paper by HAY and TOWE (in press).

Rhabdosphaera sp.

Pl. IX fig. 1

Hypotype: UI-EML-2098B.

Dimensions: Diameter, 3 μ .

Remarks: A single fragment of rhabdolith is figured here because it bears resemblance to a coccolith. The fragment figured consists of the inner cycle of the basal disc and the collar of the rhabdolith. The outer cycles of the basal disc and the stem are broken off.

Genus *Blackites* HAY et TOWE, gen. nov.

Type species: *Discolithus spinosus* DEFLANDRE et FERT.

Name: In honour of MAURICE BLACK, Sedgwick Museum, Cambridge, England.

Diagnosis: Coccoliths belonging to this genus are characterized by a single circular shield with a perforate ring spanned by interlocking ribs near the periphery.

Remarks: The structure may be unique among coccoliths and the genus is monotypical.

Blackites spinosus (DEFLANDRE et FERT)

Pl. IV, fig. 5

1952. *Discolithus spinosus* DEFLANDRE et FERT, C. R. Acad. Sci., v. 234, p. 2101, text-fig. 4 (nomen nudum).

1954. *Discolithus spinosus* DEFLANDRE et FERT, Ann. Pal., v. 40, p. 143, pl. 14, figs. 13, 14, 15.

Hypotype: UI-EML-2091C.

Dimensions: Diameter, 4.7 μ .

Remarks: The electron micrograph of a carbon replica figured there shows several features not visible on the transmission micrographs of DEFLANDRE and FERT. The plates of the outer cycle are about 30 in number, thick, and sinistrally imbricate. The overlapping margins have a slight clockwise inclination. The inner margins of the plates bear 1-3 deep slits which receive thin vertical plates crossing the perforate ring. Immediately inside the perforate ring is a cycle of about 30 or more thinner dextrally imbricate overlapping plates. The sutures of these plates are inclined counterclockwise peripherally and clockwise centrally. The central area is circular, depressed, and apparently occupied by a solid disc of calcite. The central disc may apparently be easily lost, as DEFLANDRE and FERT's micrographs show openings of various sizes and shapes in the central area. The species was reported by DEFLANDRE and FERT from Donzacq, the holotype being a specimen lacking the outer cycle of plates. Two other specimens, both with part of the outer cycle of plates intact, from Donzacq and from the Oligocene of New Zealand, were referred questionably to this species by DEFLANDRE and FERT, but there is no longer any uncertainty as to their position.

Genus *Heliolithus* BRAMLETTE et SULLIVAN, 1961

Type species: *Heliolithus riedeli* BRAMLETTE et SULLIVAN, 1961.

Remarks: This genus was erected for forms consisting of two partial cones joined at truncate apices and having concave basal ends. The larger of the conical

parts is more appressed or flaring and shows more distinctly the many thin radiate elements of construction (BRAMLETTE and SULLIVAN, 1961, p. 164).

For convenience of description, the larger cone is here regarded as the base of the heliolith. How the helioliths were oriented in the living organism is unknown.

Heliolithus helianthus HAY et TOWE, sp. nov.

Pl. V, figs. 1-3

Holotype: UI-EML-1907E.

Dimensions of Holotype: Greatest diameter, 4.3 μ .

Paratypes: UI-EML-1904E, 1905A.

Dimension of Paratypes: Greatest diameter, 2.8 μ .

Locus typicus: Tuilerie de Donzacq, Landes, France.

Stratum typicum: Couches de Donzacq, Cuisian.

Diagnosis: A species of *Heliolithus* characterized by its central area, with a ring of crescent slits surrounding a perforate disc.

Description: In top view circular; margin of basal cone slitted, plates petaloid, about 40 in number, sutures straight, radial; margin of upper cone asymmetrically serrate, plates about 40 in number, with slight counterclockwise inclination; sutures between plates of upper cone arise from outer tips of crescent shaped slits of central area; central area with peripheral ring of about 40 crescent slits, concave clockwise, surrounding perforate central disc.

Remarks: There is some indication that the upper cone may actually consist of two superimposed cycles of plates (see upper left quadrant of Pl. V, fig. 3).

Relationship: The species *Heliolithus riedeli* has not been observed in the electron microscope, but shows a strong uniaxial pseudofigure in polarized light. Inspection of a number of samples indicates that *H. riedeli* is stratigraphically restricted to the middle Paleocene, and does not occur at Donzacq. Heliolithid forms present at Donzacq have lower interference colors than *H. riedeli*. The new species also has about twice as many plates in the basal cone as *H. riedeli*.

SUBTRIBE: COCCOLITHINAE

Genus *Coccolithus* SCHWARZ, 1894

Type species: *Coccolithus oceanicus* SCHWARZ, 1894.

SCHWARZ (1894) proposed 'for all the forms hitherto described, recent and fossil, the one name *Coccolithus oceanicus*' (p. 346). However only two of the specimens he illustrated (figs. 8, 9) were designated *Coccolithus oceanicus*. The illustrated specimens were apparently from the Lias of the Dorset Coast (*Schlotheimia angulata* zone). They show an elliptical rim surrounding a central knob which is 'usually slightly, but frequently also markedly, raised above the surface . . . when seen from the side' (p. 342). Reexamination of the type species of the genus may show that many of the Cenozoic and recent forms placed in this genus belong elsewhere. No species are placed in the genus *Coccolithus* here, and the taxon *Cyathosphaera* HAECKEL, 1894, is used as a general term for coccoliths with two shields connected by a tube.

Genus *Cyathosphaera* HAECKEL, 1894

Type species: *Coccospaera pelagica* WALLICH, 1877.

The first coccolithophores to be given latin binomial names were *Coccospaera pelagica* and *Coccospaera carteri*, both proposed along with the generic term *Coccospaera* by WALLICH in 1877. However, the taxon *Coccospaera* had already been used by PERTY in 1852 for another genus of algae. In 1894, HAECKEL suggested that the generic name *Coccospaera* be used for forms bearing simple imperforate coccoliths consisting of a single disc and the name *Cyathosphaera* for those forms with perforate coccoliths consisting of two discs connected by a short tube. The name *Coccospaera* was used by HAECKEL in a totally different sense from that of WALLICH, whereas HAECKEL's *Cyathosphaera* corresponds to WALLICH's *Coccospaera*. LOHmann (1902) realizing that the name *Coccospaera* was not available, proposed the name *Coccolithophora* to replace it even though he pointed out that HAECKEL's definition of the term *Cyathosphaera* corresponded to WALLICH's *Coccospaera*. Since *Coccospaera* is preoccupied, the next valid name is *Cyathosphaera*, and it has preference over *Coccolithophora*.

Cyathosphaera sp.

Pl. II, fig. 4

Hypotype: UI-ELM-1935A.

Dimensions: Length, 0.2 μ .

Remarks: This is the smallest coccolith found in the course of the present investigation. The basal shield is composed of about 20 plates and the upper shield has an equal number of plates. The sutures of the upper shield do not coincide with those of the basal shield but are slightly displaced. The sutures of the basal shield are poorly developed. The central opening is an irregular slit.

This coccolith may belong to a new species or may represent an incipient growth stage of some larger coccolith. Almost nothing is known about the manner in which coccoliths are produced; nor is it known whether they start as small skeletal elements and grow, or whether they are produced full sized by the coccolithophore.

Cyathosphaera crux (DEFLANDRE et FERT)

Pl. II, fig. 1

1952. *Discolithus crux* DEFLANDRE et FERT, C. R. Acad. Sci., v. 234, p. 2101, fig. 8 (nomen nudum).

1954. DEFLANDRE et FERT, Ann. Pal., v. 40, p. 143, pl. 14, fig. 4, text-fig. 55.

Hypotype: UI-ELM-1922B.

Dimensions: Length, 10 μ ; width, 7 μ .

Remarks: The electron micrograph figured here shows a number of features which could not be observed on the transmission micrographs of DEFLANDRE and FERT. The shields can be seen to consist of at two cycles of about 60 plates each. The sutures of the outer cycles are nearly radially directed, while those of the inner cycles have moderate clockwise inclination. The central area is bordered by an ellipse made of about the same number of plates as in each cycle of the shields,

but the sutures have a strong counterclockwise inclination. The cross bars are made of small overlapping platelets having the same orientation.

This species is easily distinguished from *Cyathosphaera cruciformis* HAY et TOWE, sp. nov. by the greater number of plates in the shields and by the entire margin.

Cyathosphaera lacrima HAY et TOWE, sp. nov.

Pl. IV, fig. 1

Holotype: UI-ELM-1910C.

Dimensions: Length, 2.2 μ ; width, 1.7 μ .

Locus typicus: Tuilerie de Donzacq, Landes, France.

Stratum typicum: Couches de Douzacq, Cuisian.

Diagnosis: A species of *Cyathosphaera* characterized by its subelliptical shape, being more sharply rounded at one end, and by the large strongly imbricate plates of the upper shield.

Description: In top view subelliptical, one end more sharply rounded than the other; upper shield made of about 20 stout strongly imbricate plates; basal shield slightly smaller than upper; central area perforated by an irregular, elongate, lengthwise slit.

Remarks: This unusual teardrop-shaped species resembles no other previously described form closely and is somewhat atypical for the genus *Cyathosphaera*. It seems intermediate between typical *Cyathosphaera* and *Umbilicosphaera* species. The basal shield can be seen through the replicated surface of the upper shield on the electron micrograph, but its ultrastructure is obscured.

Cyathosphaera cruciformis HAY et TOWE, sp. nov.

Pl. II, fig. 6

Holotype: UI-ELM-1907A.

Dimensions: Length, 3 μ ; width, 2.7 μ .

Locus typicus: Tuilerie de Donzacq, Landes, France.

Stratum typicum: Couches de Donzacq, Cuisian.

Diagnosis: A species of *Cyathosphaera* characterized by having about 30 large plates in the elliptical upper shield, by its notched margin and by having 2 cross bars in the axes of the ellipse.

Description: In top view, elliptical, upper shield composed of about 30 large flat plates, lower shield composed of an equal number of thicker, shorter plates; tube short, apparently continuous with lower shield; sutures of lower shield offset about $1/4$ plate-width from those of upper shield; sutures of upper shield expand marginally to form indentations; central area with two bars, one in major axis, other in minor axis of the ellipse.

Remarks: In the light microscope, this species would be difficult to distinguish from *Cyatholithus crux* (DEFLANDRE et FERT). However, electron micrographs reveal that the two bear only a superficial resemblance. The smaller number of plates in the shields and the serrate outer margin of C. distinguish it from *Cyatholithus crux*.

Cyathosphaera oculus-electrae (DEFLANDRE et FERT)

Pl. III, figs. 5, 6

1952. *Discolithus oculus-electrae* DEFLANDRE et FERT, C. R. Acad. Sci., v. 234, p. 2101, text-fig. 2 (nomen nudum).

1954. *Discolithus oculus-electrae* DEFLANDRE et FERT, Ann. Pal., v. 40, p. 142, pl. 14, fig. 2, (?) 11, text-figs. 21, 22.

1957. *Cribrosphaerella oculuselectrae* (DEFLANDRE et FERT), DEFLANDRE et DURRIEU, C. R. Acad. Sci., v. 244, p. 2950, text-fig. 2.

Hypotypes: UI-EML-1909B, D.

Dimensions: Greatest diameter, 3.2–3.6 μ .

Remarks: The upper and lower shields consist of about 30 large petaloid plates. The plates do not overlap and are usually separated toward the margin. Pl. III, fig. 6 shows a specimen which possesses only the bottom shield. Between the marginal cycle of plates and the cycle forming the tube a deep broad suture can be seen indicating that the plates of the marginal cycle are only loosely attached. The lower cycle of tube plates seen in Pl. III, fig. 6 has a 90° clockwise inclination while the upper cycle, seen in Pl. III, fig. 5, has a 70° counterclockwise inclination. The central grille has about 40 perforations.

This species is distinguished from *C. dupouyi* (DEFLANDRE et FERT), 1954, by its more nearly circular outline.

Cyathosphaera dupouyi (DEFLANDRE et FERT)

Pl. III, figs. 1–4

1952. *Discolithus dupouyi* DEFLANDRE et FERT, C. R. Acad. Sci., v. 234, p. 2101, text-fig. 1 (nomen nudum).

1954. *Discolithus dupouyi* DEFLANDRE et FERT, Ann. Pal., v. 40, p. 142, pl. 14, figs. 1, 9 (?), 10, 12.

1957. *Cribrosphaerella dupouyi* (DEFLANDRE et FERT), DEFLANDRE et DURRIEU, C. R. Acad. Sci., v. 244, p. 2950, text-fig. 1.

Hypotypes: UI-EML-1670B, 1904E, 2092A, 2098C.

Dimensions: Length, 1.8–2.6 μ ; width, 1.3–2.0 μ ; diameter of coccospaere, 3.1 μ .

Remarks: The upper shield is broad, overlapping the lower shield. Both are made of about 24 large, petaloid, well-separated plates. The tube consists of a cycle of wedge-shaped overlapping plates. Pl. III, fig. 3, shows a specimen with additional cycles of overlapping plates having a very strong alternating sinistral and dextral imbrication surrounding the central area. It is thought that this is an extension of the tube which has broken off and is not present on the specimens figured in Pl. III, figs. 1, 4. The central area is occupied by a complex grille with 18–20 perforations. The bars of the grille may be incomplete so that the perforations are not complete. A coccospaere of this species, consisting of eight coccoliths, is figured on Pl. IX, fig. 6.

This species is distinguished from *C. oculus-electrae* (DEFLANDRE et FERT), 1954, by its strongly elliptical outline.

Cyathosphaera parvula (DEFLANDRE et FERT)

Pl. IX, fig. 6

1954. *Tremalithus parvulus* DEFLANDRE et FERT, Ann. Pal., v. 40, p. 154, pl. 14, fig. 6.

Hypotype: UI-EML-2096A.

Dimensions: Length, 2.9 μ ; width, 2.3 μ .

Remarks: The original figure given by DEFLANDRE and FERT is a transmission micrograph showing an oblique view of a partially obscured specimen. In the examination of the material from Donzacq only one sort of coccolith was found which has a central structure and outline resembling DEFLANDRE and FERT's picture. The two shields are apparently both present in the specimen figured here, but have almost exactly the same dimensions. It is not certain whether the figure is a top or a bottom view. The outer cycle has about 25 large plates. The sutures between the plates of the outer cycle have a moderate clockwise (?) inclination. The tube plates are also large and have a strong counterclockwise imbrication. The central area has a number of overlapping subrhomboidal plates equal to those of the outer cycle.

Cyathosphaera martinii HAY et TOWE, sp. nov.

Pl. IV, fig. (?) 2, 3, 4

Name: In honour of E. MARTINI, Frankfurt am Main, Germany.

Holotype: UI-EML-2093E.

Dimensions of Holotype: Length 2.2 μ ; width 1.5 μ .

Paratypes: UI-EML-2093C (?), 2097C.

Dimensions of Paratypes: Length 1.9–2.9 μ ; width 1.3–2.4 μ .

Locus typicus: Tuilerie de Donzacq, Landes, France.

Stratum typicum: Couches de Donzacq, Cuisian.

Diagnosis: A species of *Cyathosphaera* distinguished by its narrow shield plates, stout wedge-shaped tube plates, and asymmetrical ribbed central area.

Description: In top view elliptical, shields narrow, tube cycle consisting of about 25 thick wedge-shaped plates; sutures on top of tube cycle radial on inner edges with strong clockwise inclination; margins of lower cycles of tube plates serrate, plates with strong counterclockwise imbrication; central area with ribs equal in number to the plates of the tube cycles, extending inward to major axis of ellipse to form an asymmetrical grille, ribs may or may not anastomose along axis; axis represented by bar or slit.

Relations: The overall structure of these coccoliths resembles that of several recent species of *Syracosphaera* figured by HALLDAL and MARKALI (1954), DEFLANDRE and FERT (1954), and BLACK and BARNES (1961). However, none of the details of structure match. The central grille resembles that of *Coccolithus huxley* (LOHMAN), 1902, figured by DEFLANDRE and FERT (1954, esp. Pl. 2, fig. 9), but the other parts of the coccolith differ markedly. *Discolithus simillimus* DEFLANDRE et FERT (1954, p. 138, pl. 10, fig. 21) resembles specimens of *Cyathosphaera* which possess only the tube cycles and central grille, but has about $1\frac{1}{2}$ times as many plates in the tube cycles.

Cyathosphaera diaphragma HAY et TOWE, sp. nov.

Pl. VI, figs. 2, 3, (?) 4, 5, (?) 6

Holotype: UI-EML-2090A.

Dimensions of Holotype: Length 2.7 μ ; width 2.4 μ .

Paratypes: UI-EML-1905C, 1907D (?), 1010A, 1922D (?).

Dimensions of Paratypes: Length 3.4–4.5 μ , 3.5–4.0 μ .

Locus typicus: Tuilerie de Donzacq, Landes, France.

Stratum typicum: Couches de Donzacq, Cuisian.

Diagnosis: A species of *Cyathosphaera* distinguished by its smooth margin, straight sutures between the plates of the shield, by the complex tube wall built up of cycles of overlapping plates, by the elliptical tube opening, distally, circular and open basally.

Description: In top view elliptical, margin entire, upper and lower shields composed of about 40 flat plates; sutures of upper shield directly above those of lower shield, with moderate clockwise inclination, tube wall composed of numerous cycles of thin overlapping plates, one cycle being strongly sinistrally imbricate, the next being strongly dextrally imbricate, tube opening elliptical distally, circular proximally, apparently covered by porous plate slightly below level of upper shield.

Remarks: The holotype (Pl. VI, fig. 3) is the most complete specimen, although it is the smallest. It shows two alternating cycles of tube plates above the upper shield and what appears to be a somewhat obscured porous plate covering the central opening. Pl. VI, fig. 2, illustrates a similar specimen, and shows that the tube opening is elliptical at its top and circular at its base. A number of cycles of tube wall plates can be seen. Pl. VI, fig. 5, probably represents a basal shield with attached tube wall cycle, because the central opening is circular and the tube wall thick. The tube wall apparently thickens toward the base of the coccilith to restrict the size of the central opening. Pl. VI, figs. 4 and 6, may represent single cycles of tube wall plates near the base of the coccilith, as they agree generally in dimensions and degree of sutural inclination with the tube wall cycle attached to the basal shield in Pl. VI, fig. 5.

Relationships: The outer series of tube cycles with the perforate central plate bear some resemblance to *Cyathosphaera dupouyi* (DEFLANDRE et FERT), 1954, but the more rounded outline and smooth margin of the coccilith distinguish the new species. *Cyathosphaera oculus-electrae* (DEFLANDRE et FERT), 1954, has a much larger central area.

Cyathosphaera cf. *diaphragma* HAY et TOWE, sp. nov.

Pl. VI, fig. 1

Hypotype: UI-EML-1934D.

Dimensions: Length 5.0 μ ; width 4.5 μ .

Remarks: A specimen is figured which has a certain resemblance of *Cyathosphaera diaphragma* HAY et TOWE, n. sp., but which has a ragged margin not found in other specimens. It may be a corroded specimen.

Genus *Helicosphaera* KAMPTNER, 1952, ex Deflandre, 1954

Typs species: *Coccospaera carteri* WALLICH, 1877.

The name *Helicosphaera* was originally published by KAMPTNER, 1954, as a new combination: *Helicosphaera carteri* (WALLICH). However, according to Article 42 of the International Code of Botanical Nomenclature, a monotypic generic

name unaccompanied by a description is valid only if published with the name of a new species. The first description of the genus was given by DEFLANDRE (in DEFLANDRE and FERT, 1954).

Coccoliths belonging to this genus have a central, elliptical, doubly perforate shield surrounded by a spiral flange made of numerous plates.

The ultrastructure of the type species of the genus has been described in detail by BLACK and BARNES (1961, p. 139), who have introduced terminology for the features of the coccoliths. A few Eocene forms have been referred to this genus by BRAMLETTE and SULLIVAN (1961).

Helicosphaera seminulum BRAMLETTE et SULLIVAN *seminulum* BRAMLETTE et SULLIVAN
Pl. I, figs. 1, 2, 3, 5

1961. *Helicosphaera seminulum seminulum* BRAMLETTE et SULLIVAN, Micropaleontology, v. 7, p. 144, pl. 4, figs. 1a-c, 2.

Hypotypes: UI-EML-1906E, 2093A, 2097E.

Dimensions: Length 8-13 μ ; width 6-10 μ .

Remarks: The ultrastructure of the flange of this species corresponds closely to that of *H. carteri* (WALLICH), 1877, as described by BLACK and BARNES (1961, p. 139). The general features are best shown in top view Pl. I, fig. 2. The flange appears to arise at the narrow end of the coccolith (the end opposite the wing) and run along as a vertical wall until it reaches the wing end. There the flange suddenly bends upward to become horizontal, becoming wide and prominent. It passes around the narrow end of the coccolith spiralling gently downward and forms a wing after having made $1\frac{1}{2}$ volutions. Pl. I, fig. 2, is a bottom view of a replica of the same species. Part of the replica has been folded back on itself, so that the general features are not so clear. The indentation in the outer margin of the coccolith in the lower left portion of the fig. 1 (Pl. I) indicates that the wing becomes fused with the previous volution of the spiral flange instead of remaining free as in *H. carteri*. Pl. I, fig. 3, shows a top view of a coccolith of *H. seminulum seminulum* in which the central shield has been destroyed along with the first volution of the spiral flange. Again, the last volution of the flange appears continuous although an indentation in the outline is visible in the upper right corner of the picture.

The central shield differs strongly from that of *H. carteri*, the perforations of the shield being much larger. The individual plates of the shield could not be seen, nor could any central suture be found joining the pores.

Helicosphaera sp.

Pl. II, figs. 4, 6

Hypotype: UI-EML-2090B.

Dimensions: Length, 2 μ ; width 9 μ .

Remarks: A specimen showing a stronger inclination of the sutures between narrower plates of the flange may belong to a species of *Helicosphaera*, but the incompleteness of the electron micrographs do not allow detailed description.

Genus *Aspidorhabdus* HAY et TOWE, gen. nov.

Diagnosis: Coccoliths made of a numerous cycle of plates, the central cycles being circular and raised as a central prominence, the outer cycles being strongly elliptical. The direction of inclination of the sutures usually alternates from one cycle to the next.

Type species: *Aspidorhabdus ovalis* HAY et TOWE, sp. nov.

Aspidorhabdus ovalis HAY et TOWE, sp. nov.

Pl. II, fig. 7

Holotype: UI-EML-1909E.

Dimensions: Length, 6 μ ; width, 4.5 μ .

Locus typicus: Tuilerie de Donzacq, Landes, France.

Stratum typicum: Couches de Donzacq, Cuisian.

Diagnosis: A species of coccolith characterized by having several cycles of plates, the outer cycle being elliptical and the inner cycle circular and raised.

Description: In top view outline strongly elliptical, ends evenly rounded, sides almost straight; margin entire or slightly lobate, outer cycle of plates elliptical with little or no imbrication, plates large, subtrapezoidal, about 35 in number; second cycle of plates circular, sutures with strong clockwise inclination, plates wedge-shaped, equal in number to those of outer cycle; inner cycles circular, composed of numerous small overlapping plates, raised above the level of first two cycles as a prominence.

Relationships: *Discolithus phasolus* BLACK et BARNES, 1961, has an outline similar to that of the new species, but has a wholly different ultrastructure. The new species may be most closely related to some rhabdoliths, as the general ultrastructural plan is similar to that of rhabdoliths (HAY and TOWE, in press). However true rhabdoliths are always circular or very nearly so when seen in top view.

Genus *Pyrocyclus* HAY et TOWE, gen. nov.

Type species: *Pyrocyclus inversus* HAY et TOWE, sp. nov.

Coccoliths belonging to this genus apparently have a single elliptical shield, with an outer cycle of numerous wedge-shaped plates having a strong counter-clockwise inclination, a medial cycle of relatively few large overlapping plates with dextral imbrication, and a perforate central disc.

This genus differs from *Cyclolithus* KAMPTNER, 1948, in having elliptical cycles of plates surrounding a circular central area. The strong inclination of the outer cycle of plates is peculiar to this genus.

Pyrocyclus inversus HAY et TOWE, sp. nov.

Pl. IV, fig. 6

Holotype: UI-EML-2094C.

Dimensions: Greatest diameter 2.9 μ .

Locus typicus: Tuilerie de Donzacq, Landes, France.

Stratum typicum: Couches de Donzacq, Cuisian.

Diagnosis: A species of coccolith distinguished by its elliptical outline, outer cycle of plates with strongly inclined sutures and circular, depressed, perforate central area.

Description: In top view elliptical, margin serrate, outer cycle consisting of about 50 wedge-shaped plates with strong sinistral imbrication; medial cycle with about 20 ?? large overlapping flat plates, the sutures having a slight counter-clockwise inclination; central area depressed, a plate with irregular ramosc perforations.

Relationships: This species, with the strong inclination of the marginal cycle of plates, appears to be unique. No other coccolith observed in the electron microscope to the present shows this feature.

INCERTAE SEDIS

Genus *Discoaster* TAN SIN HOK, 1927

Type species: not designated.

Remarks: The taxon *Discoaster* is used as a general term for ortholithid asteroliths.

Discoaster lodoensis BRAMLETTE et RIEDEL, 1954

Pl. X, figs. 2, 4, 6

- 1954. *Discoaster lodoensis* BRAMLETTE et RIEDEL, Journ. Paleont., v. 28, p. 398, pl. 39, fig. 3a-b.
- 1958. *Discoaster lodoensis* BRAMLETTE et RIEDEL, STRADNER, Erdölzeitschr., v. 74, p. 182, text-fig. 8.
- 1958. *Discoaster lodoensis* BRAMLETTE et RIEDEL, MARTINI, Senck. leth., v. 39, p. 366, pl. 6, fig. 28a-d.
- 1959. *Discoaster lodoensis* BRAMLETTE et RIEDEL, STRADNER, Erdölzeitschr., v. 75, p. 478, text-figs. 14-16, 20.
- 1960. *Discoaster lodoensis* BRAMLETTE et RIEDEL, MARTINI, Notizbl. hess. L.-Amt Bodenforsch., v. 88, p. 76, pl. 8, fig. 11.
- 1961. *Discoaster lodoensis* BRAMLETTE et RIEDEL, MARTINI, Senck. leth., v. 42, p. 11.
- 1961. *Discoaster lodoensis* BRAMLETTE et RIEDEL, BRAMLETTE and SULLIVAN, Micropaleontology, v. 7, p. 161, pl. 12, figs. 4-5.
- 1961. *Discoaster lodoensis* BRAMLETTE et RIEDEL, STRADNER and PAPP, Jb. geol. Bundesanst., Sdrb. 7, p. 92, pl. 25, figs. 1-10, pl. 26, figs. 1-6, text-figs. 912, 9/3, 24/9.

Hypotypes: UI-EML-1922C, 2091A, 2095B.

Dimensions: Diameter about 20 μ .

Remarks: The sides of this discoasterid are distinguished by Stradner into a facies dextrogyra, from which side the rays curves to the right, and a facies laevogyra from which side the rays appear to curve to the left. The three electronmicrographs of replicated specimens reproduced here show a number of features which cannot be seen clearly in the light microscope.

The view of the facies laevogyra (Pl. X, fig. 2) shows no raised margin along the edges of the rays. In the center of the asterolith is a short stem forming an hexagonal prism with concave sides. In side view (Pl. X, fig. 4) the stem on the facies laevogyra can be seen to have a depressed center. The asterolith can be seen to be slightly concave toward the facies dextrogyra. Pl. X, fig. 6, shows that discrete ridges arise from the stem and extend along the left margin of each ray.

The rays cannot be seen clearly to extend upward to the top of the stem although the side view would indicate this to be the case.

If the asteroliths are oriented in the living organism so that the concave side of the disc is directed inwards (as in the case of most coccoliths), the facies dextrogyra would be the proximal side of the *D. lodoensis*.

Discoaster barbadiensis TAN SIN HOK, 1927

Pl. X, figs. 3, 5

- 1927. *Discoaster barbadiensis* TAN SIN HOK (pro parte), Jaarb. Mijnwezen Ned. Oost-Indie, p. 119.
- 1954. *Discoaster barbadiensis* TAN SIN HOK, BRAMLETTE and RIEDEL, Journ. Paleont., v. 28, p. 398, pl. 39, fig. 5a-b.
- 1958. *Discoaster barbadiensis* TAN SIN HOK, STRADNER, Erdölzeitschr., v. 74, p. 183, text-fig. 11.
- 1958. *Discoaster barbadiensis* TAN SIN HOK, MARTINI, Senck. leth., v. 39, p. 366, pl. 5, fig. 25a-c.
- 1960. *Discoaster barbadiensis* TAN SIN HOK, MARTINI, Notizbl. hess. L.-Amt. Bodenforsch., v. 88, p. 76, pl. 8, fig. 10.
- 1961. *Discoaster barbadiensis* TAN SIN HOK, MARTINI, Senck. leth., v. 42, p. 10.
- 1961. *Discoaster barbadiensis* TAN SIN HOK, BRAMLETTE and SULLIVAN, Micropaleontology, v. 7, p. 158, pl. 11, fig. 2.
- 1961. *Discoaster barbadiensis* TAN SIN HOK, STRADNER and PAPP, Jb. geol. B.A., Sdrd. 7, p. 95, pl. 28, figs. 1, 2, text-figs. 9/7, 18/6, 24/3.

Hypotype: UI-EML-1904D, 2093D.

Dimensions: Diameter about 16 μ .

Remarks: Two replicas of specimens of *D. barbadiensis* are figured here. Relative to the coccoliths, discoasterids of this sort are massively built and best studied in the light microscope.

Genus *Discoasteroides* BRAMLETTE et SULLIVAN, 1961

Type species: *Discoaster kuepperi* STRADNER, 1959.

This genus was erected for asteroliths which have an ortholithid disc and a heliolithid stem.

Discoasteroides kuepperi (STRADNER)

Pl. X, fig. 1

- 1959. *Discoaster kuepperi* STRADNER Erdöl-Zeitschr., v. 75, p. 478, text-figs. 17, 21.
- 1961. *Discoaster kuepperi* STRADNER, MARTINI, Senck. Leth., v. 42, p. 14, pl. 3, fig. 29.
- 1961. *Discoasteroides kuepperi* (STRADNER), BRAMLETTE and SULLIVAN, 1961, Micropaleontology, v. 7, p. 163, pl. 13, figs. 16a-b, 17, 18a-c, 19.
- 1961. *Discoaster kuepperi* STRADNER, STRADNER, Jb. geol. Bundesanst, Sdrbd. 7, p. 93, pl. 27, figs. 1-6, text-figs. 9 (6), 16.

Hypotype: UI-EML-2091D.

Dimensions: Diameter about 8 μ .

Remarks: M. N. BRAMLETTE, on seeing the electromicrograph figured here, noted that the stem is made of elements overlapping with a sinistral imbrication. There are 12 elements in the stem of the figured specimen, a number equal to the number of rays present in the disc.

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Plate I

Electron micrographs of coccoliths from the Cuisian marls of Donzacq (France).

- Fig. 1. *Helicosphaera seminulum* BRAMLETTE et SULLIVAN *seminulum* BRAMLETTE et SULLIVAN, bottom view, Hypotype: UI-EML-2097E, $\times 5000$.
- Fig. 2. *Helicosphaera seminulum* BRAMLETTE et SULLIVAN *seminulum* BRAMLETTE et SULLIVAN, top view, Hypotype: UI-EML-1906E, $\times 5000$.
- Fig. 3. *Helicosphaera seminulum* BRAMLETTE et SULLIVAN *seminulum* BRAMLETTE et SULLIVAN, top view, Hypotype: UI-EML-2093A, $\times 3200$.
- Fig. 4. *Helicosphaera* sp., top view, Hypotype: UI-EML-20908, $\times 5000$.
- Fig. 5. *Helicosphaera seminulum* BRAMLETTE et SULLIVAN *seminulum* BRAMLETTE et SULLIVAN, top view, Hypotype: UI-EML-2093A, $\times 15000$.
- Fig. 6. *Helicosphaera* sp., top view, Hypotype: UI-EML-2090B, $\times 15000$.

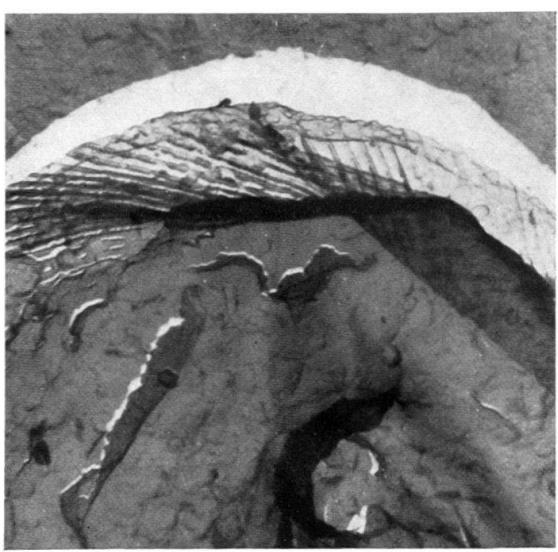
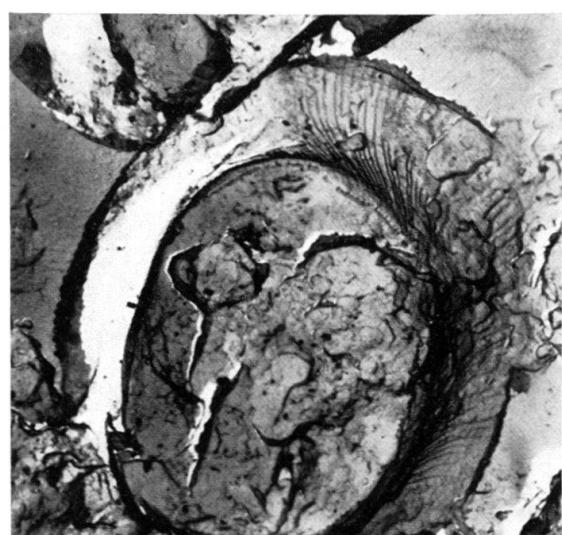
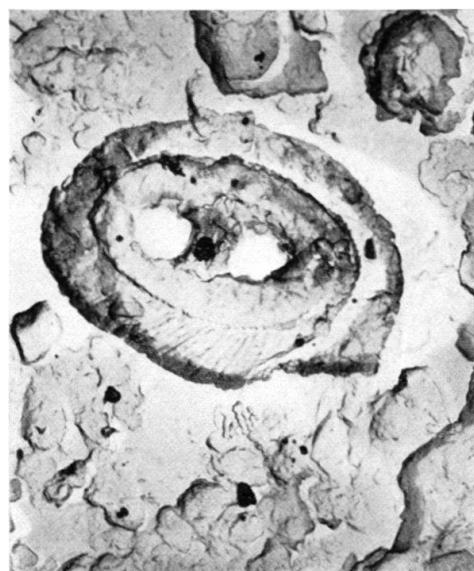


Plate II

Electron micrographs of coccoliths from the Cuisian marls of Donzacq (France).

Fig. 1. *Cyathosphaera crux* (DEFLANDRE et FORT), top view, Hypotype: UI-EML-1922B, $\times 5000$.

Fig. 2. *Zygrhablithus bijugatus* (DEFLANDRE), top view, Hypotype: UI-EML-2096C, $\times 15000$.

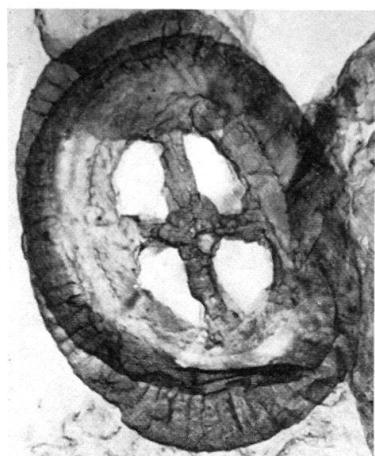
Fig. 3. *Umbilicosphaera arena* HAY et TOWE sp. nov., top view, Holotype: UI-EML-2095C, $\times 8500$.

Fig. 4. *Cyathosphaera* sp., top view, Hypotype: UI-EML-1935A, $\times 30000$.

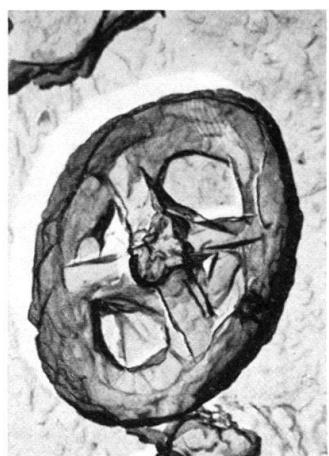
Fig. 5. *Umbilicosphaera arena* HAY et TOWE sp. nov., top view, Paratype: UI-EML-1922D, $\times 8500$.

Fig. 6. *Cyathosphaera cruciformis* HAY et TOWE sp. nov., top view, Holotype: UI-EML-1907A, $\times 12000$.

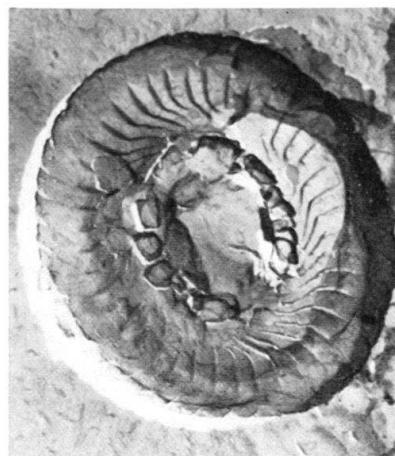
Fig. 7. *Aspidorhabdus ovalis* HAY et TOWE sp. nov., top view, Holotype: UI-EML-1909E, $\times 10000$.



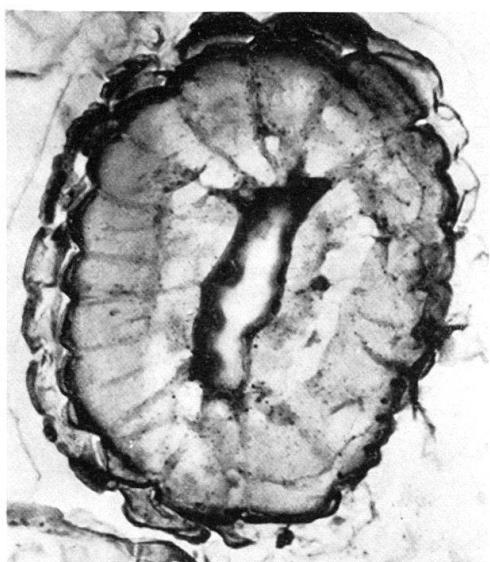
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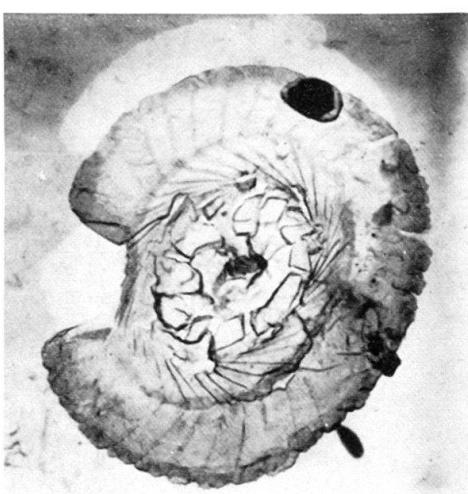


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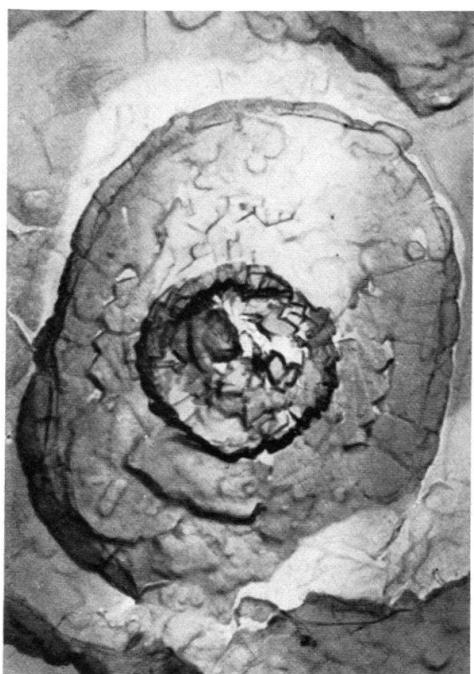


Plate III

Electron micrographs of coccoliths from the Cuisian marls of Donzacq (France).

Fig. 1. *Cyathosphaera dupouyi* (DEFLANDRE et FERT), top view, Hypotype: UI-EML-1670B, $\times 25000$.

Fig. 2. *Cyathosphaera dupouyi* (DEFLANDRE et FERT), top view, Hypotype: UI-EML-2092A, $\times 15000$.

Fig. 3. *Cyathosphaera dupouyi* (DEFLANDRE et FERT), top view, Hypotype: UI-EML-2098C, $\times 21000$.

Fig. 4. *Cyathosphaera dupouyi* (DEFLANDRE et FERT), top view, Hypotype: UI-EML-1904E, $\times 21000$.

Fig. 5. *Cyathosphaera oculus-electrae* (DEFLANDRE et FERT), top view, Hypotype: UI-EML-1909D, $\times 15000$.

Fig. 6. *Cyathosphaera oculus-electrae* (DEFLANDRE et FERT), top view, Hypotype: UI-EML-1909B $\times 21000$.

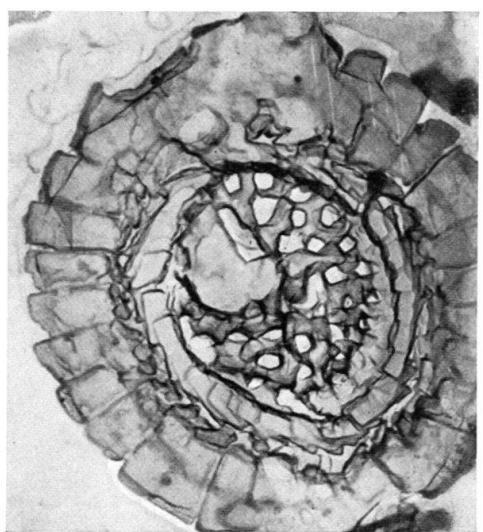
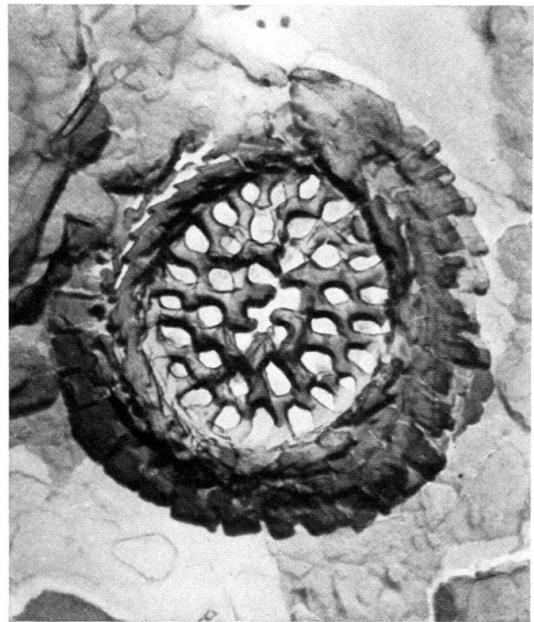
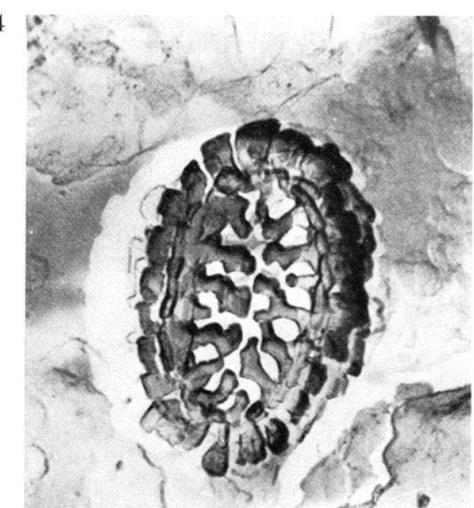
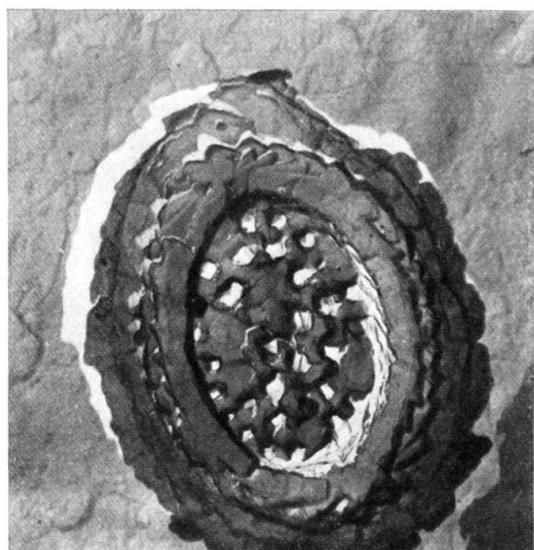
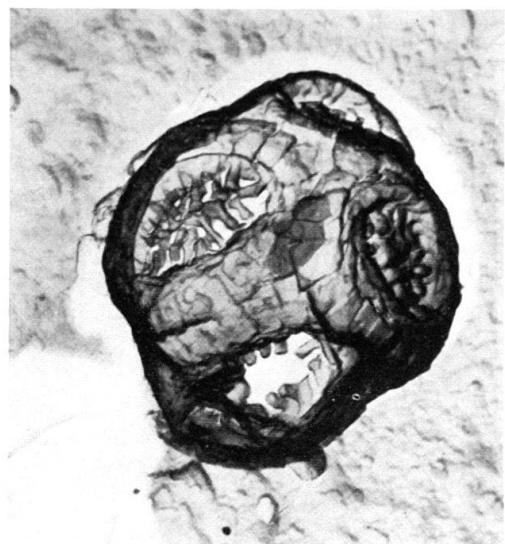
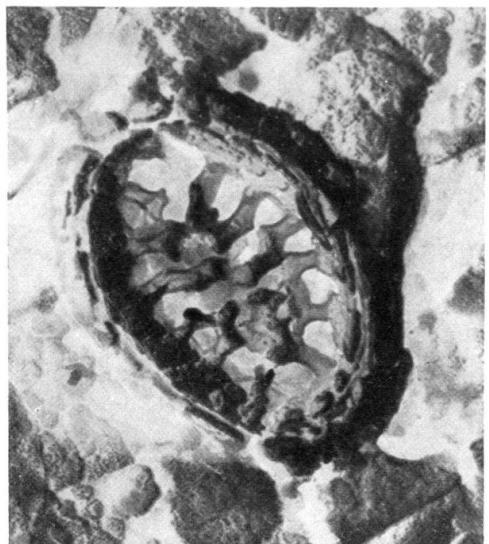


Plate IV

Electron micrographs of coccoliths from the Cuisian marls of Donzacq (France).

Fig. 1. *Cyathosphaera lacrima* HAY et TOWE sp. nov., top view, Holotype: UI-EML-1910C, $\times 15000$.

Fig. 2. *Cyathosphaera(?) martinii* HAY et TOWE sp. nov., top view, Paratype: UI-EML-2093C, $\times 21000$.

Fig. 3. *Cyathosphaera martinii* HAY et TOWE sp. nov., top view, Holotype: UI-EML-2093E, $\times 21000$.

Fig. 4. *Cyathosphaera martinii* HAY et TOWE sp. nov., top view, Paratype: UI-EML-2097C, $\times 21000$.

Fig. 5. *Blackites spinosus* (DEFLANDRE et FERT), top view, Hypotype: UI-EML-2091C, $\times 10000$.

Fig. 6. *Pyrocyclus inversus* HAY et TOWE sp. nov., top view, Holotype: UI-EML-2094C, $\times 15000$.

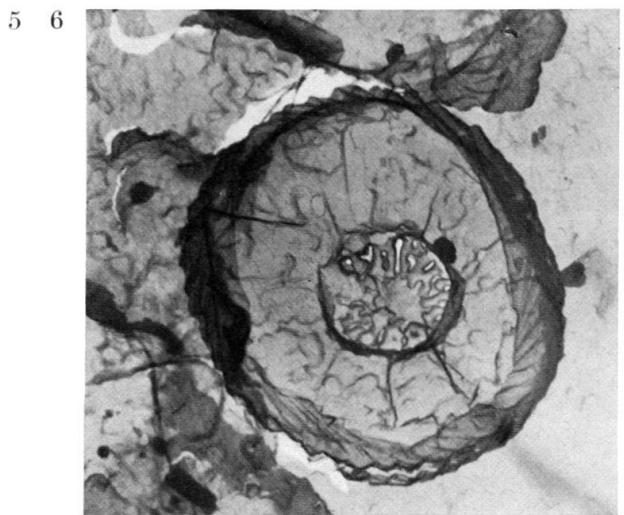
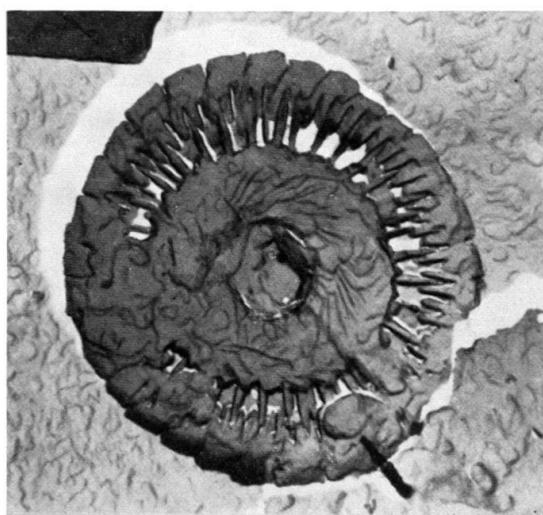
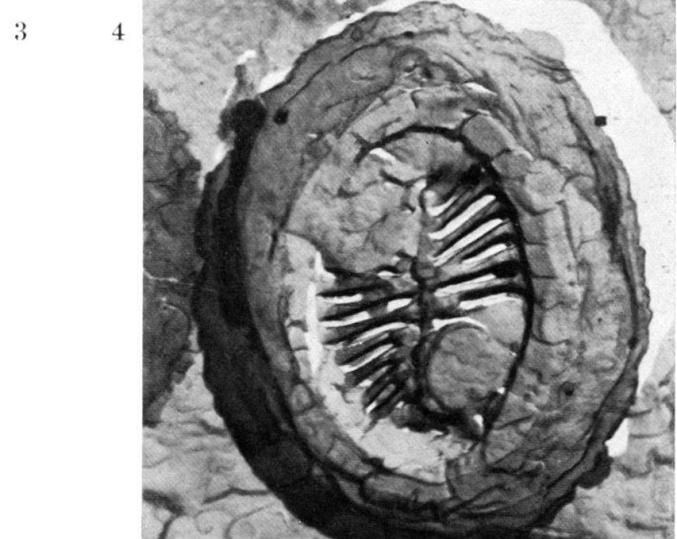
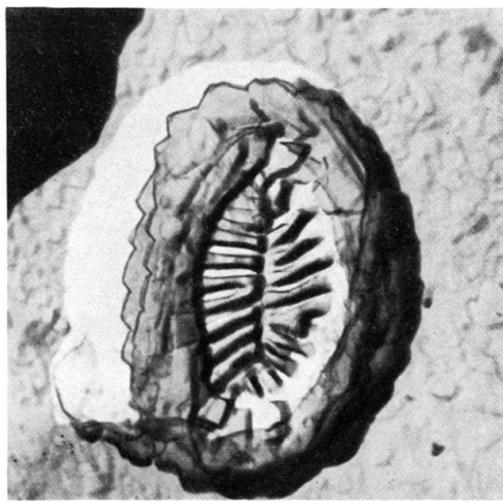
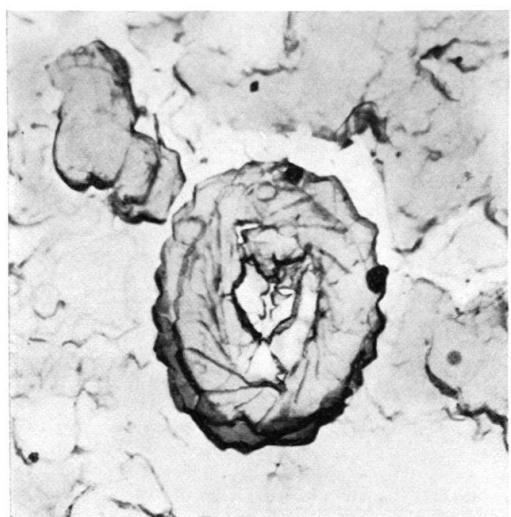


Plate V

Electron micrographs of coccoliths from the Cuisian marls of Donzacq (France).

Fig. 1. *Heliolithus helianthus* HAY et TOWE sp. nov., top view, Paratype: UI-EML-1905A, $\times 15000$.

Fig. 2. *Heliolithus helianthus* HAY et TOWE sp. nov., top view, Paratype: UI-EML-1904E, $\times 15000$.

Fig. 3. *Heliolithus helianthus* HAY et TOWE sp. nov., top view, Holotype: UI-EML-1907E, $\times 10000$.

Fig. 4. *Cyclococcolithus dictyodus* (DEFLANDRE et FERT), bottom view, Hypotype: UI-EML-2097D, $\times 8500$.

Fig. 5. *Cyclococcolithus ? dictyodus* (DEFLANDRE et FERT), bottom view, corroded specimen ?, Hypotype: UI-EML-1916B, $\times 7000$.

Fig. 6. *Cyclolithus bramletti* HAY et TOWE sp. nov., top view, Holotype: UI-EML-1910B, $\times 8500$.

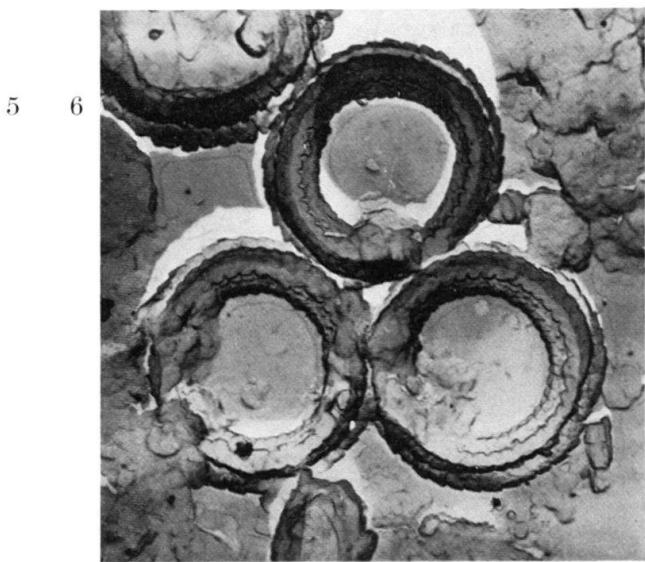
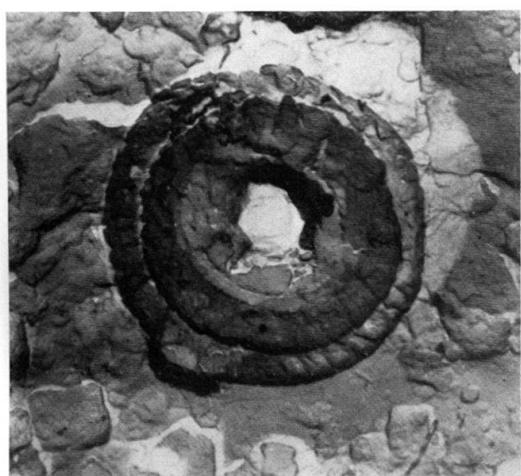
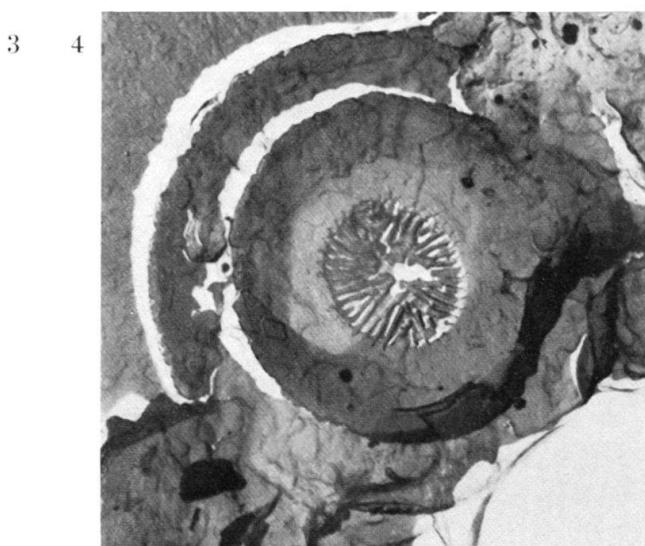
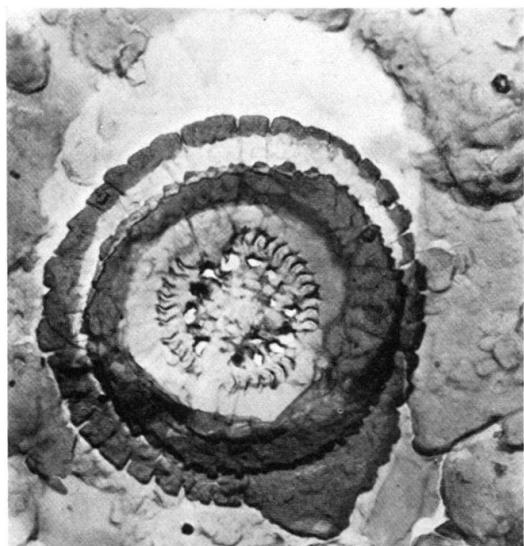
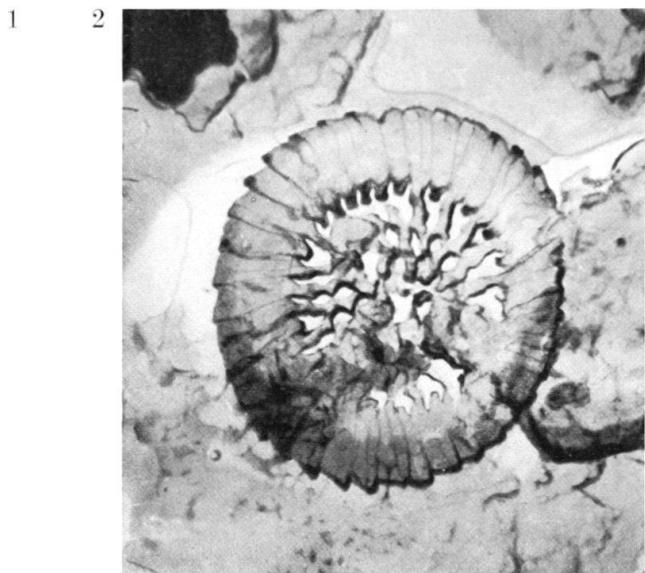
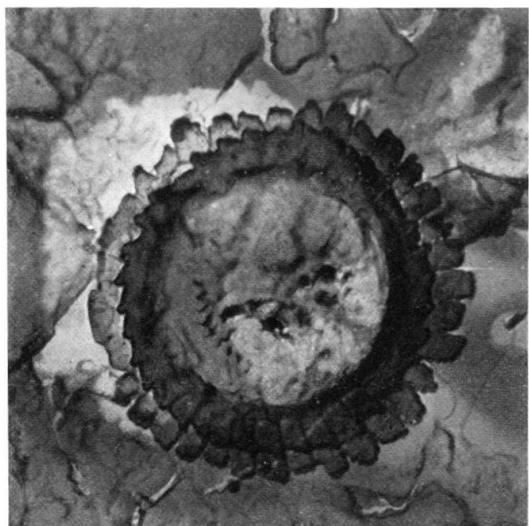


Plate VI

Electron micrographs of coccoliths from the Cuisian marls of Donzacq (France).

Fig. 1. *Cyathosphaera* cf. *diaphragma* HAY et TOWE, sp. nov., top view, Hypotype: UI-EML-1934D, $\times 10000$.

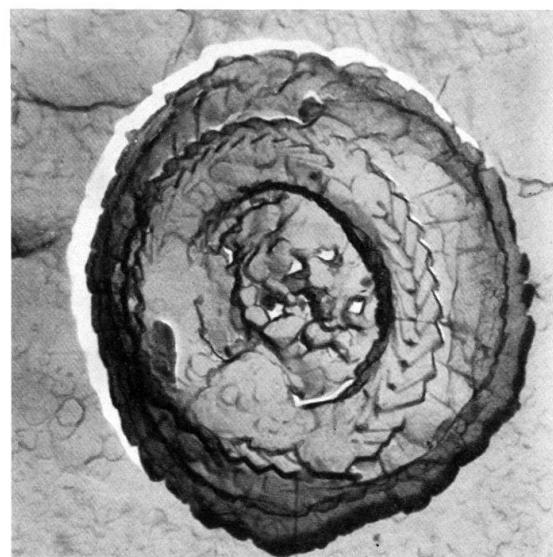
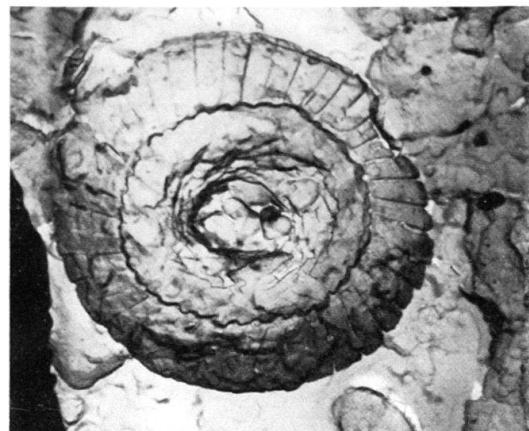
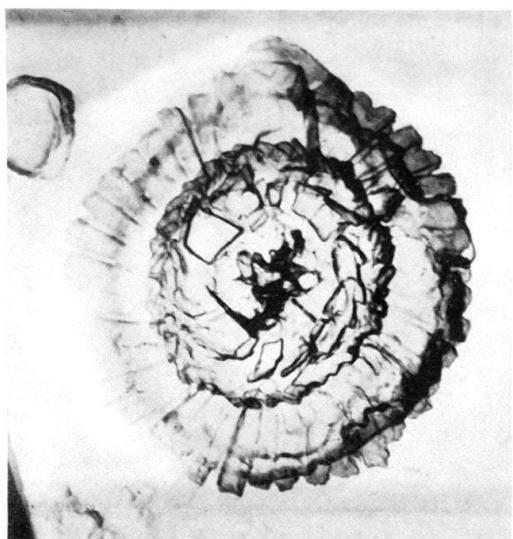
Fig. 2. *Cyathosphaera diaphragma* HAY et TOWE sp. nov., top view, Paratype: UI-EML-1905C, $\times 8500$.

Fig. 3. *Cyathosphaera diaphragma* HAY et TOWE sp. nov., top view, Holotype: UI-EML-2090A, $\times 21000$.

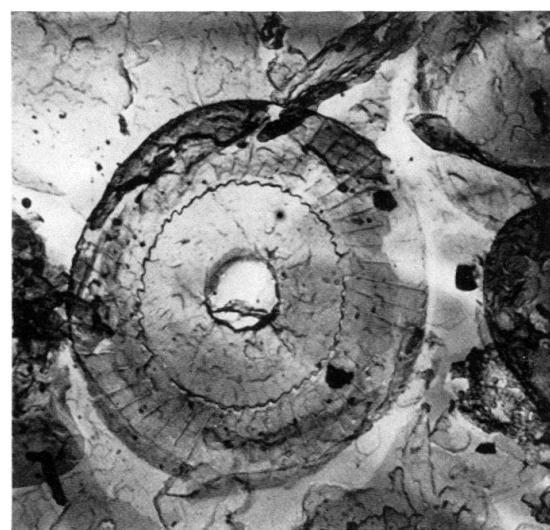
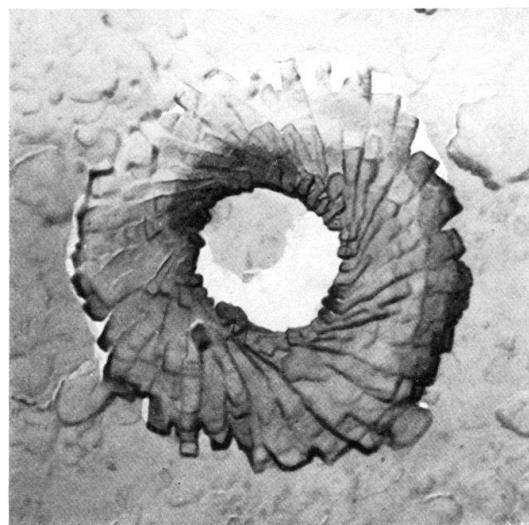
Fig. 4. *Cyathosphaera* ? *diaphragma* HAY et TOWE sp. nov., single cycle of tube wall plates ?, Hypotype: UI-EML-1922D, $\times 15000$.

Fig. 5. *Cyathosphaera diaphragma* HAY et TOWE sp. nov., basal shield, Paratype: UI-EML-1910A, $\times 10000$.

Fig. 6. *Cyathosphaera* ? *diaphragma* HAY et TOWE sp. nov., single cycle of tube wall plates ?, Hypotype: UI-EML-1907D, $\times 6000$.



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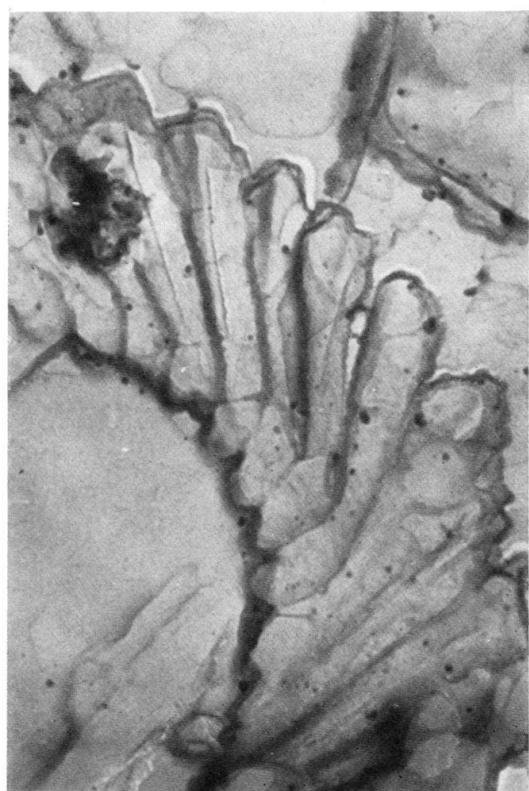


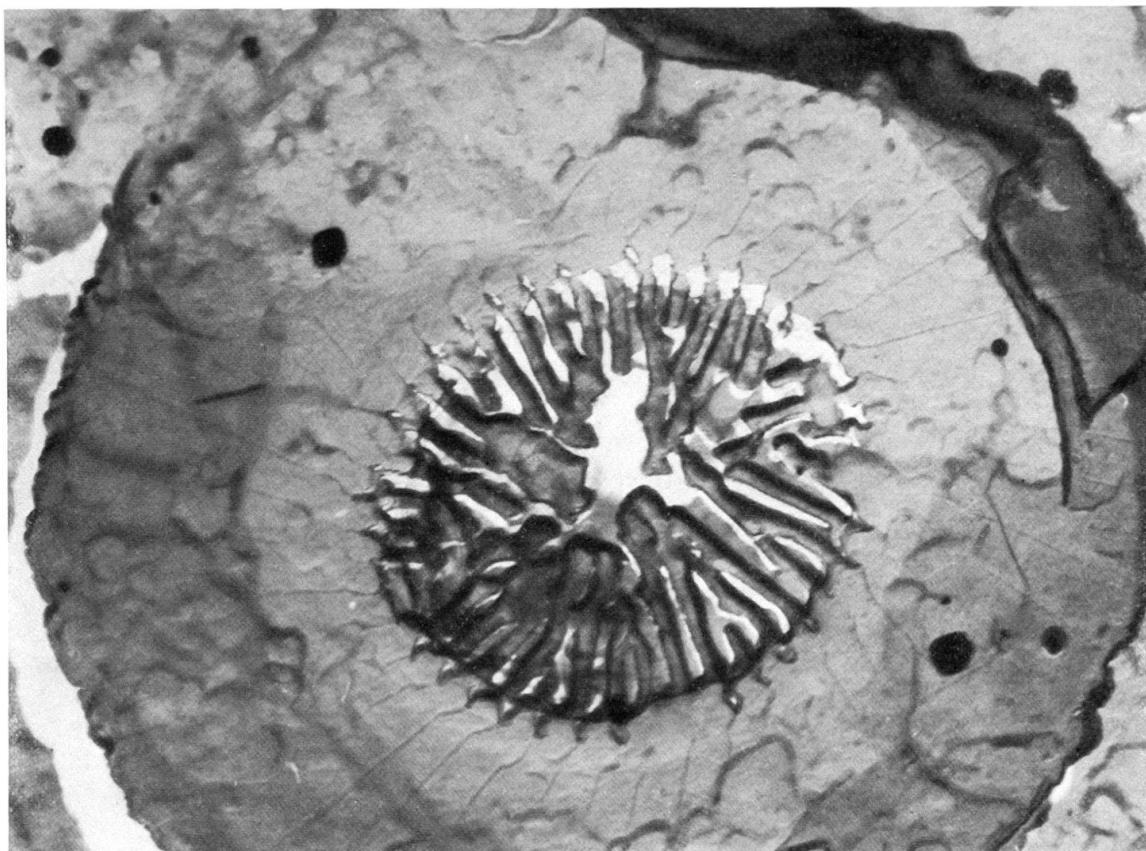
Plate VII

Electron micrographs of coccoliths from the Cuisian marls of Donzaeq (France).

Fig. 1. *Cyclococcolithus dictyodus* (DEFLANDRE et FERT), bottom view, Hypotype: UI-EML-2097D, $\times 30000$.

Fig. 2. *Cyclolithus bramletti* HAY et TOWE sp. nov., top view, Holotype: UI-EML-1910B, $\times 30000$.

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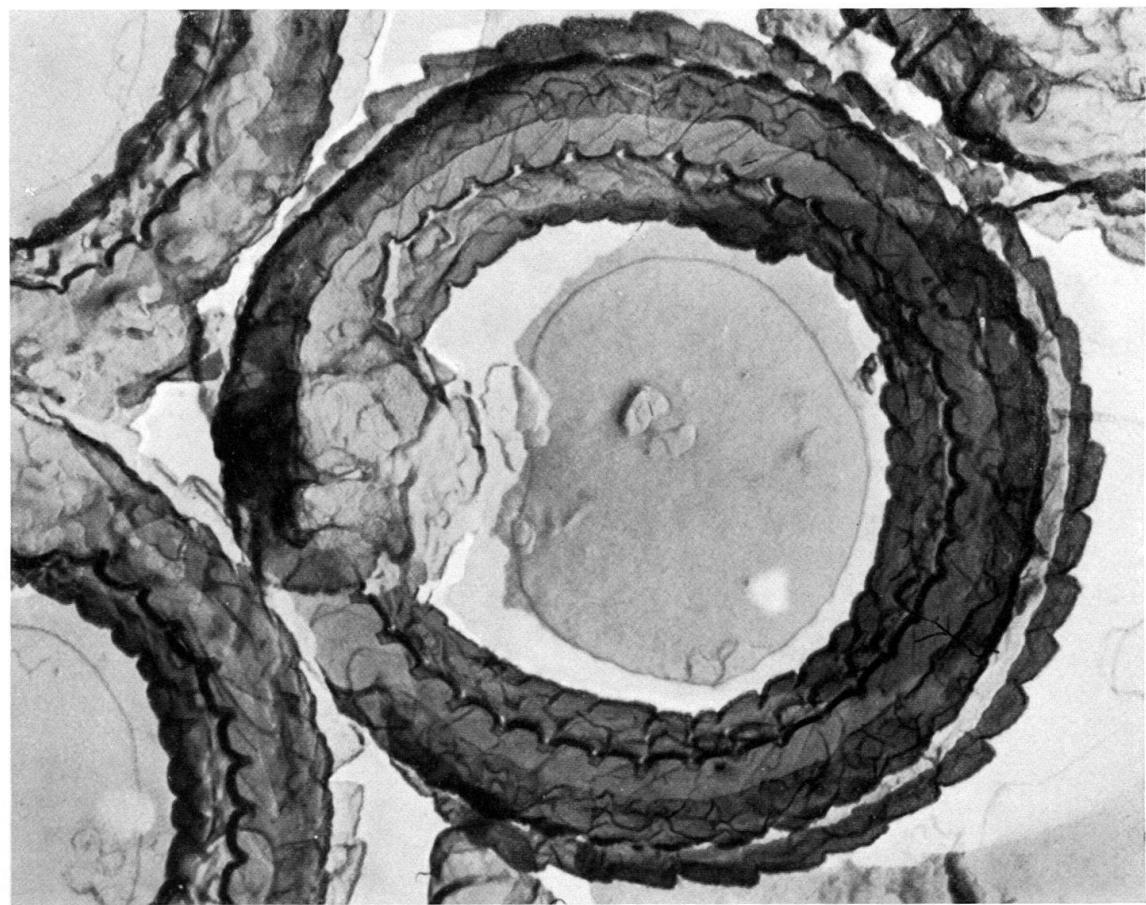


Plate VIII

Electron micrograph of coccoliths from the Cuisian marls of Donzacq (France).

Discolithus ocellatus BRAMLETTE et SULLIVAN, top view, Hypotype: UI-EML-1614C, $\times 25000$.



Plate IX

Electron micrographs of coccoliths from the Cuisian marls of Donzacq (France).

Fig. 1. *Rhabdosphaera* sp., oblique view, Hypotype: UI-EML-2098B, $\times 15000$.

Fig. 2. *Cyclolithus* ? sp., coccosphere, Hypotype: UI-EML-1624D, $\times 15000$.

Fig. 3. *Tiarolithus obscurus* (DEFLANDRE et FERT), top view, Hypotype: UI-EML-1926B, $\times 10000$.

Fig. 4. *Cyclolithus* sp., coccosphere, Hypotype: UI-EML-2098A, $\times 8500$.

Fig. 5. *Tiarolithus* ? sp., top view, Hypotype: UI-EML-1909C, $\times 21000$.

Fig. 6. *Cyathosphaera parvula* (DEFLANDRE et FERT), top view, Hypotype: UI-EML-2096A, $\times 21000$.

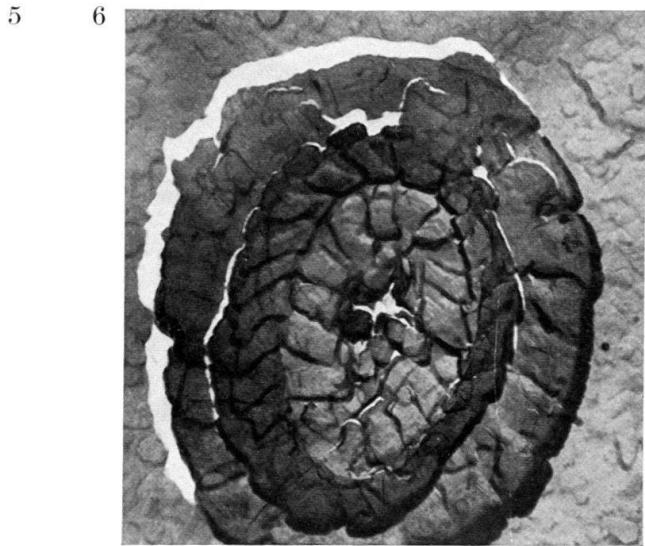
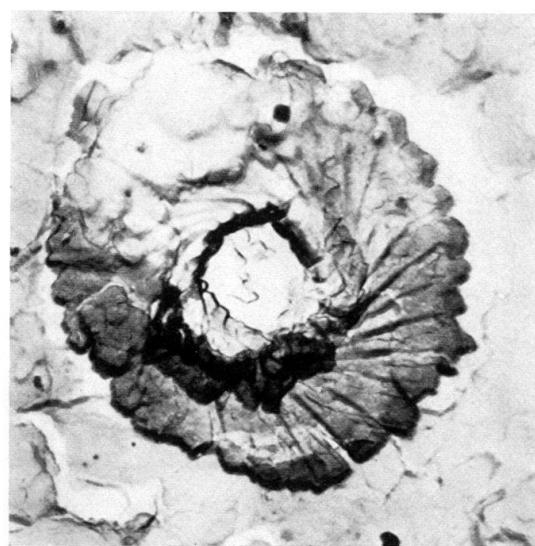
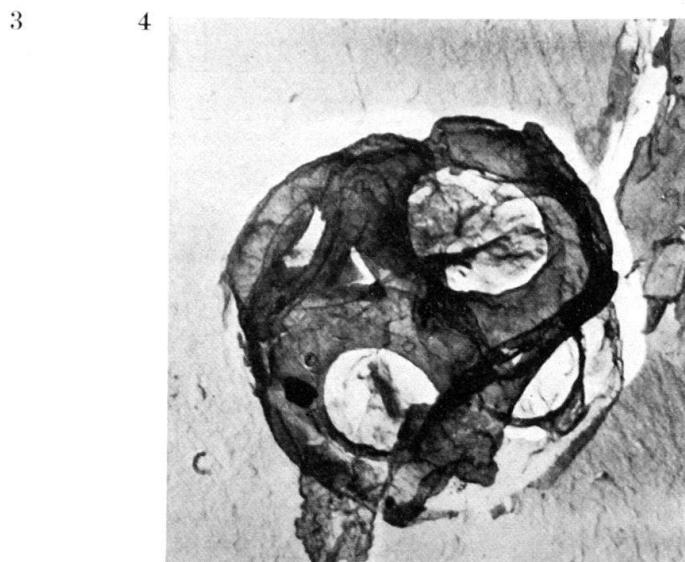
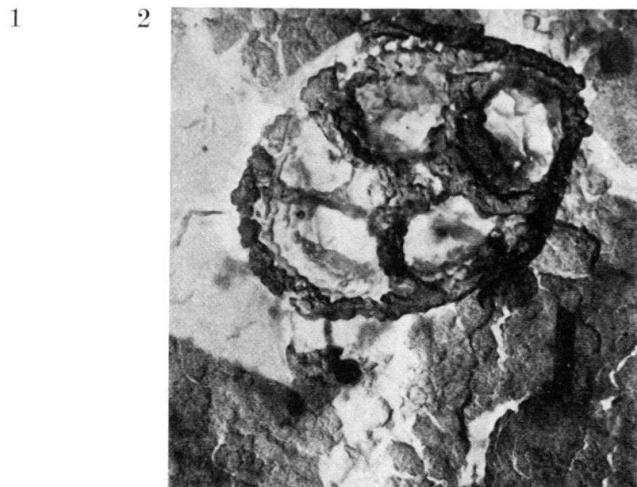


Plate X

Electron micrographs of discoasterids from the Cuisian marls of Donzacq (France).

- Fig. 1. *Discoasteroides kuepperi* (STRADNER), proximal view, Hypotype: UI-EML-2091D, $\times 5000$.
- Fig. 2. *Discoaster lodoensis* BRAMLETTE et RIEDEL, view of facies laevogyra, Hypotype: UI-EML-1922C, $\times 3200$.
- Fig. 3. *Discoaster barbadiensis* TAN SIN HOK, proximal view, Hypotype: UI-EML-1904D, $\times 3200$.
- Fig. 4. *Discoaster lodoensis* BRAMLETTE et RIEDEL, side view, Hypotype: UI-EML-2091A, $\times 5000$.
- Fig. 5. *Discoaster barbadiensis* TAN SIN HOK, oblique view, Hypotype: UI-EML-2093D, $\times 3200$.
- Fig. 6. *Discoaster lodoensis* BRAMLETTE et RIEDEL, view of facies dextrogyra, type: Hypo UI-EML-2085B, $\times 3200$.

