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ELECTRON MICROSCOPIC STUDIES ON UPPER EOCENE COCCOLITHS FROM THE OAMARU DIATOMITE, NEW ZEALAND

BY

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Frontispiece: Aerial oblique photograph of the Oamaru Diatomite outcropping at William's Bluff, near the top of hillside, ½ mile north of old Lorne railway siding, approximately 5 miles north-east of Oamaru, Otago, New Zealand.

The dashed lines indicate the limits of the Oamaru Diatomite at this locality.

New Zealand Geological Survey Laboratory sample numbers:

S 136/898 (New Zealand Fossil Record Number)
F 17 141 (Foraminifera)
N 1 276 (Nannoplankton)

Photograph taken by Mr. S. N. Beatus, N. Z. G. S.

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Electron Microscopic Studies on Upper Eocene Coccoliths from the Oamaru Diatomite, New Zealand

by Herbert STRADNER and Anthony R. EDWARDS *)

Contents

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Summary

Calcareous nannofossils are, on account of their restricted vertical range and their world-wide distribution, well-suited for interhemispheral correlations. They are the subject of this electronmicroscopic study on the Upper Eocene Diatomite of Oamaru, New Zealand.

A chapter with an aerial photograph of the outcrop and a stratigraphic range chart of guide fossils is devoted to the geology of the site.

The type-sample from William's Bluff, of well-established stratigraphic position, was found to contain 24 species of *coccoliths* sensu stricto, as well as *discoasters*, *trochoasters* and *thoracosphaeres*. Electronmicrographs were correlated with photomicrographs and radiomicrographs of identical species. Original descriptions from previous studies have been re-checked and supplemented with additional pictorial documentation. Besides some nomenclatorial changes one new genus: *Cruciolithus*, and two new species: *Cretarhabdus lentus* and *Blackites hayi*, are proposed.

Zusammenfassung

Aus dem obereozänen Diatomit von Oamaru auf Neu Seeland wurden Nannofossilien elektronenmikroskopisch untersucht, welche sich wegen ihrer weltweiten Verbreitung und wegen ihrer geringen vertikalen Reichweite gut für stratigraphische Korrelationen eignen. Die Geologie des Oamaru Diatomites wird an Hand einer Luftaufnahme und einer stratigraphischen Verbreitungstabelle der Leitarten erläutert.

Die Probe von der Typ-Lokalität William's Bluff aus gut gesicherter stratigraphischer Position enthält 24 Arten von *Coccolithen* im engeren Sinne, außerdem *Discoasteriden*, *Trochoasteriden* und *Thoracosphaeren*. Die elektronenmikroskopischen Aufnahmen wurden mit lichtmikroskopischen und röntgenmikroskopischen Aufnahmen derselben Coccolithen-Art verglichen. In der Literatur bereits vorliegende Original-Beschreibungen wurden überprüft und auf Grund zusätzlichen Bildmaterials erweitert. Außer einigen nomenklatorischen Änderungen werden eine neue Gattung: *Cruciolithus*, und zwei neue Arten: *Cretarhabdus lentus*, und *Blackites hayi* vorgeschlagen.

Acknowledgements

For sponsoring the project and for advice throughout its completion the authors are indebted to Prof. Dr. H. Küpper, Director of the Geological Survey of Austria and Dr. N. de B. Hornibrook, Chief Micropaleontologist, New Zealand Geological Survey. For permission to use the facilities of the Electronmicroscopical Laboratory and for technical advice we owe thanks to the staff of the Department of Medicine, Veterinary College, Vienna, especially to Dr. M. Sibalin and to Dr. D. Adamiker, now at the Reactor Center Seibersdorf. The radiomicrographs were kindly provided by Drs. W. L. Jongebloed, Technisch Physische Dienst T. N. O. & T. H., Delft, Netherlands, through the co-operation and assistance of Dr. M. C. Probine, Director of the Physics and Engineering Laboratory, Lower Hutt, New Zealand. Advice on preparation techniques was also given by Prof. W.W. HAY, Univ. of Illinois. The investigations were carried out with the support of the Austrian Ministry of Education. Part of the printing cost was generously covered by the Österreichische Bundeskammer der Gewerblichen Wirtschaft, Fachverband der Erdölindustrie. To all who helped to present this publication our best thanks.

H. STRADNER & A. R. EDWARDS

Introduction

The diatomite of Oamaru represents one of the best studied rock materials of the Southern Hemisphere. Within the last 85 years in more than 100 scientific papers over 1200 species of microfossils have been described from this deposit of diatomaceous mudstone (EDWARDS & HORNIBROOK, in preparation). In 1954 one of the first papers making wide use of electronmicroscopy for the study of calcareous nannofossils was published by DEFLANDRE & FERT. Among the samples studied from Mesozoic and Tertiary outcrops there was also the Oamaru Diatomite, then still regarded as of Oligocene age, and the following new species and genera * were reported:

Discolithus cocconeis DEFLANDRE
Discolithus macroporus DEFLANDRE
Discolithus oamaruensis DEFLANDRE
Discolithus radiatus DEFLANDRE
Discolithus obliquipons DEFLANDRE
Discolithus fenestratus DEFLANDRE & FERT
Discolithus cribrum DEFLANDRE & FERT
Discolithus dictyodus DEFLANDRE & FERT
Discolithus spinosus DEFLANDRE & FERT
Zygolithus bijugatus DEFLANDRE
Zygolithus tenansa DEFLANDRE
Cyclococcolithus leptoporus var. *inversus* DEFLANDRE
Tremalithus oamaruensis DEFLANDRE
Rhabdolithus costatus DEFLANDRE
Rhabdolithus rectus DEFLANDRE
Discoaster tani BRAMLETTE & RIEDEL
Isthmolithus * *recurvus* DEFLANDRE
Polycladolithus * *operosus* DEFLANDRE

Besides these BRAMLETTE & RIEDEL 1954 described:

Discoaster tani nodifer BRAMLETTE & RIEDEL
Discoaster tani tani BRAMLETTE & RIEDEL

and in 1961 BRAMLETTE & SULLIVAN reported on:

Zygrhablithus bijugatus (DEFLANDRE)
Polycladolithus operosus DEFLANDRE

from Oamaru, New Zealand. Also the paper by HAY, MOHLER & WADE 1966 reports on the occurrence of the following species at Oamaru:

Reticulofenestra sp. (= *Discolithus dictyodus* DEFLANDRE & FERT, text-fig. 16)
Chiasmolithus oamaruensis (DEFLANDRE)
Cyclococcolithus inversus DEFLANDRE
Transversopontis obliquipons (DEFLANDRE)

Within the last 10 years the method of electronmicroscopical examination of surface structures in nannofossils has been greatly improved by the introduction of carbon replication (BRADLEY 1954), which was first applied on coccoliths by DEFLANDRE & DURRIEU 1957, and used to a wide extent by later workers. A planned survey of Upper Eocene marine sediments in Austria required a closer examination of all the hitherto described species and genera of similar geologic age. Therefore the study of the type-material of the above-mentioned Upper Eocene nannofossils from Oamaru was considered a precondition for further studies on samples from Austria or any other country of the world.

AN OUTLINE OF THE STRATIGRAPHY

by A. R. EDWARDS, New Zealand Geological Survey, Lower Hutt, New Zealand

In the Waiareka Creek — Papakaio area of the Oamaru district (text-fig. 1) the Oamaru Diatomite, from which DEFLANDRE & FERT 1954 and BRAMLETTE & RIEDEL 1954 recorded many new calcareous nannoplankton taxa, is exposed in a number of sections on which the following generalized and composite sequence is based:

Top

150 ft or more of soft porous current sorted white polyzoan limestone, usually tuffaceous at the base, which GAGE 1957 mapped as Totara Limestone Formation, of late Runangan to Whaingaroan (upper Eocene to Oligocene) age.

75—150 ft of poorly exposed thick, fine soft tuffaceous beds with very variable diatom contents separated by occasional variably bedded coarse hard tuff beds 1 to 15 ft thick, or by thin sequences of finely stratified fine soft tuff beds. These strata, mapped by GAGE 1957 mainly as Waiareka Volcanic Formation and in part as Totara Limestone Formation, belong to the Oamaru Diatomite member of the Waiareka Volcanic Formation and are of Runangan (upper Eocene) age.

400 ft or more of poorly sorted coarse stratified basaltic tuff, together with associated dykes, sills and basalt flows (latter usually capping the tuffs) mapped by GAGE 1957 as Waiareka Volcanic Formation. These tuffs occasionally contain shallow water Mollusca and Foraminifera which indicate a Kaiatan to Runangan (upper Eocene) age.

Base, as exposed

A column of the relevant portion of the William's Bluff section showing the position of the sample studied (S 136/898) relative to the lithologic units listed above is given in table I.

The key microfossils of the upper Eocene and lower Oligocene of New Zealand are shown in table II. The ages adopted in this paper are based on recent investigations of the Foraminifera by Dr. N. de B. HORNIBROOK, New Zealand Geological Survey, and of the calcareous nannoplankton of the Oamaru Diatomite by the writer. Dr. HORNIBROOK (Pers. comm., 1965) states that *Bolivina pontis* and *Globigerapsis index*, zonal fossils for the Runangan stage, occur throughout the Oamaru Diatomite. The calcareous nannoplankton of the Oamaru Diatomite includes common long ranging forms such as *Ericsonia ovalis* sensu lato, *Reticulofenestra placomorpha*, *Zygrhablithus bijugatus* as well as the stratigraphically important *Chiasmolithus oama-*

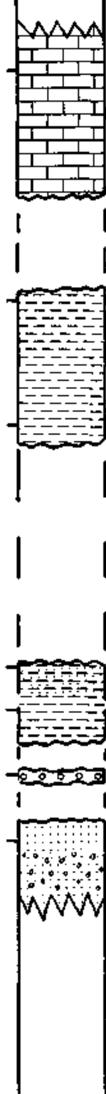
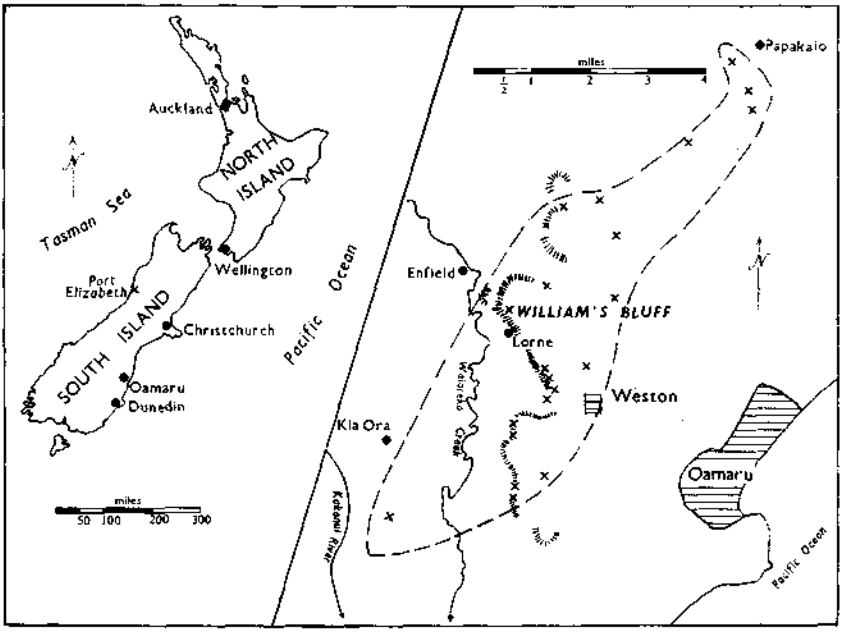
New Zealand Stages (Hornibrook, pers comm.)	Calcareous Nannoplankton Informal zones	Formation	Sample positions	Column	Lithology
WHAINGAROAN	Absent	TOTARA LIMESTONE			50 ft. Fine white highly polyzoan limestone.
?	?	TOTARA LIMESTONE			15 ft. ± obscured.
RUNANGAN	*Reticulofenestra oamaruensis* zone	WAIAREKA VOLCANICS	S136 /898		25 ft. Fine light yellow massive calcareous diatomaceous earth, diatom content decreasing towards top.
RUNANGAN	*Discoaster saipanensis* zone ? ?	WAIAREKA VOLCANICS			35 ft. ± obscured
RUNANGAN	*Discoaster saipanensis* zone	WAIAREKA VOLCANICS			6 ft Yellow-brown, highly tuffaceous, sandy calcareous siltstone.
					Contact obscured.
KAIATAN - RUNANGAN (undifferentiated)	Absent	WAIAREKA VOLCANICS			6 ft. Fine, thinly bedded Palagonite Tuff.
					4 ft. ± obscured.
					2 ft. Greenish brown basaltic conglomerate with mollusca.
					6 ft. obscured.
					50 ft. Brown, poorly bedded, highly tuffaceous conglomeratic sandstone becoming finer at top.
					underlain by
					350 ft. ± Brown, irregularly exposed, highly tuffaceous coarse sandstones.

Table I: Columnar section of William's Bluff, Lorne, Oamaru.



Text-fig. 1: Orientation map of the Oamaru district showing location of William's Bluff and outcrop limits of the Oamaru Diatomite.

ruensis, *Discoaster saipanensis*, *Discoaster tani nodifer* and *Isthmolithus recurvus* (a well known upper Eocene indicator) [see table II]. The presence of *I. recurvus* and *D. saipanensis* is considered to be particularly significant as these forms are known to be restricted to upper Kaiatan to lowermost Whaingaroan strata at the Port Elizabeth section (200 miles north of Oamaru, see text-fig. 1), which is the type locality of the Kaiatan and Runangan stages. In addition *Reticulofenestra oamaruensis* which is extremely rare at Port Elizabeth, can be used in the Oamaru district to define an upper zone within the Oamaru Diatomite.

Upper Eocene Coccoliths from the Oamaru Diatomite, New Zealand

SYSTEMATIC DESCRIPTIONS

by H. Stradner *)

46 plates and 11 text-figures

Calcareous nannofossils are by far the most numerous "forms" which life has produced in the geologic past. They are shell components of unicellular planktonic flagellates occuring abundantly in both past and present seas. Because of the small dimensions of the nannofossils (1—30 μ) their

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number in one ccm of marine sediment can exceed 1,000.000. They are "filling grains" between the bigger microfossils, such as Globigerina or diatoms or Radiolaria. The living nannoplankton has supplied and is still supplying the primary food source of all marine animal life. These unicellular flagellates are, because of their autotrophic properties, classified as "algae" of the

Phylum: *Chrysophyta*
Class: *Chrysophyceae*
Order: *Coccolithophorales*

according to B. FOTT 1959. The systematic arrangement of the 24 species of coccoliths encountered in the sample from the Oamaru Diatomite is based on the results of the electronmicroscopic investigation of their ultrastructure as well as on their appearance in light microscope. The system, as proposed by the author for the Oamaru coccoliths, is an attempt to evaluate the data of ultrastructure available by both types of microscopy. There is still much uncertainty among modern writers as to the status of several systematic units in calcareous nannoplankton, which is mostly due to the lack of information on the ultrastructure. Since it has been shown first by the Austrian E. KAMPTNER in 1944 and later in France on a larger scale by G. DEFLANDRE & C. FERT, 1954, that the application of the electron microscope brings new aspects into the study of fossil calcareous nannoplankton, the application of ultrastructure research has become obligatory for systematic work in this field.

Systematic Position of Coccoliths from the Upper Eocene Oamaru Diatomite

Ordo: COCCOLITHOPHORALES SCHILLER 1926

Subordo: Coccolithineae KAMPTNER 1928

Familia: **Coccolithaceae** KAMPTNER 1928

a) "Heterococcoliths"

Tribus: **Coccolitheae** KAMPTNER 1958

Subtribus: *Coccolithinae* KAMPTNER 1958

Genus: *Chiasmolithus* HAY, MOHLER & WADE 1966

Species: *C. oamaruensis* (DEFLANDRE) HAY, MOHLER & WADE

Genus: *Coccolithus* SCHWARZ 1894

Species: *C. eopelagicus* (BRAMLETTE & RIEDEL) BRAMLETTE & SULLIVAN
C. parvulus (DEFLANDRE & FERT) nov. comb.

Genus: *Cruciolithus* nov. gen.

Species: *C. cruciformis* (HAY & TOWE) nov. comb.

Genus: *Ericsonia* BLACK 1964

Species: *E. ovalis* BLACK
E. fenestrata (DEFLANDRE & FERT) nov. comb.

Genus: *Reticulofenestra* HAY, MOHLER & WADE 1966

Species: *R. dictyoda* (DEFLANDRE & FERT) HAY, MOHLER & WADE
R. dupouyi (DEFLANDRE & FERT) HAY, MOHLER & WADE
R. oamaruensis (DEFLANDRE) nov. comb.
R. placomorpha (KAMPTNER) nov. comb.

Genus: *Cyclolithella* LOEBLICH & TAPPAN 1963

Species: *C. inflexa* (KAMPTNER) LOEBLICH & TAPPAN

Subtribus: *Cyclococcolithinae* KAMPTNER 1958

Genus: *Cyclococcolithus* KAMPTNER 1954

Species: *C. inversus* (DEFLANDRE) HAY, MOHLER & WADE

Genus: *Ilselithina* STRADNER 1966

Species: *I. iris* STRADNER

Genus: *Coronocyclus* HAY, MOHLER & WADE 1966

Species: *C. prionion* (DEFLANDRE & FERT) nov. comb.

Subtribus: *Rhabdosphaerinae* nov. subtr. *)

Genus: *Blackites* HAY & TOWE 1962

Species: *B. rectus* (DEFLANDRE) nov. comb.
B. hayi nov. spec.

Genus: *Cretarhabdus* BRAMLETTE & MARTINI 1964

Species: *C. lentus* nov. spec.

*) *Rhabdosphaerinae:* As the name *Rhabdolithinae* HAY 1966 was pre-empted by DEFLANDRE in GRASSE 1952, p. 457 (subfamily), the new subtribe *Rhabdosphaerinae* (nom. subst. pro *Rhabdolithinae* HAY 1966) is proposed for those genera which are characterized by a basal plate composed of two or more concentric cycles of radially or tangentally arranged crystal elements surmounted by a distal shaft. Specifically excluded are those forms which have quincunxically arranged crystal elements in the basal plate. Genera placed in the subtribe *Rhabdosphaerinae: Rhabdosphaera* HAECKEL, *Blackites* HAY & TOWE, *Cretarhabdus* BRAMLETTE & MARTINI, *Deflandrius* BRAMLETTE & MARTINI and *Parhabdolithus* DEFLANDRE.

Tribus: **Cribrosphaerelleae** nov. trib. *)

Genus: *Goniolithus* DEFLANDRE

Species: *G. fluckigeri* DEFLANDRE

Tribus: **Pontosphaereae** HAY 1966

Genus: *Discolithina* LOEBLICH & TAPPAN 1963

Species: *D. multipora* (KAMPTNER) MARTINI
D. obliquipons (DEFLANDRE) nov. comb.
D. pulcheroides (SULLIVAN) nov. comb.

Genus: *Helicosphaera* KAMPTNER 1954

Species: *H. seminulum* BRAMLETTE & SULLIVAN

Genus of uncertain affiliation: *Isthmolithus* DEFLANDRE 1954

Species: *I. recurvus* DEFLANDRE

b) "Holococcoliths"

Tribus: **Zygosphaereae** KAMPTNER 1958

Genus: *Zygrhablithus* DEFLANDRE 1959

Species: *Z. bijugatus* DEFLANDRE

Genus: *Zygosphaera* KAMPTNER 1958

Species: *Z. aurea* (STRADNER) nov. comb.

The following taxonomic modifications were brought about by the interpretation of the coccolith ultrastructure:

1. Within the family of the *Coccolithaceae* a subdivision into heterococcoliths (a-flagellate phase) and holococcoliths (motile phase) can be made on account of the crystal size. The species of the genera *Zygrhablithus* and *Zygosphaera* have coccoliths composed of microcrystals of equal size and are therefore considered to be products of the motile phase in the life cycle of the coccolith, whereas all the other genera contain coccoliths composed of different sizes and shapes of crystals. The latter genera are based on the description of coccoliths from the nonmotile, a-flagellate phase. Coordination of the two phases is at present not indicated for lack of evidence of relationship.

*) *Cribrosphaerelleae:* A new tribe proposed for those genera which are characterized by a plate composed of quincunxically ordered crystal elements surrounded by one or more cycles of radially or tangentially arranged crystal elements. In some genera a stem surmounts the distal face of the plate. This new tribe includes the genera: *Cribrosphaerella* DEFLANDRE, *Ethmorhabdus* NOEL, *Goniolithus* DEFLANDRE, *Rhabdolithina* REINHARDT and *Rhagodiscus* REINHARDT.

2. The genera *Discolithina* and *Helicosphaera* can both be assigned to the tribe of the *Pontosphaereae*, as their coccoliths are likewise composed of two different crystal layers: a proximal one with radial and a distal one with spiral to tangential crystal directions. *Discolithina* and *Helicosphaera* are closer related to the genus *Zygolithus* than to the genus *Coccolithus*.

3. The genus *Goniolithus* can be included into the family of the *Coccolithaceae*, as its ultrastructure is very similar to that of some Mesozoic genera, such as *Cribrosphaerella*, *Ethmorhabdus*, *Rhabdolithina* and *Rhagodiscus*. No separate family taxon seems required.

All coccoliths encountered in the Oamaru Diatomite are considered to belong to the family Coccolithaceae Kamptner 1928. Genera, which are thought to belong into other families, such as

Discoaster
Thoracosphaera and
Trochoaster

are reserved for a later forthcoming paper and are therefore not included here.

Inspite of the many electronmicrographs taken, so much still remains to be learned and understood regarding the interior structure especially of the classical coccoliths in the subtribe *Coccolithinae* Kamptner 1958. Presumably the correlation of transmission electronmicrographs of non-replicated specimens with electronmicrographs of carbon replicas, and also comparisons with electronmicrographs from a scanning microscope will help to solve the complicated interior structures, of which as yet only the surface relief as furnished by the carbon replica is known.

One of the most remarkable properties of the unicellular coccolith-bearing flagellates is that they are able to gain complete control over the formation of the calcite crystals (Black 1963, p. 45). The crystal faces and angles of the rhombohedrons can be suppressed and complicated twisted forms can be moulded, as many of our electronmicrographs show. And the fossil species of the Cretaceous and Tertiary had this property even more than the recent representatives.

However, not only the living protoplasm determines the final shape of the coccolith, since its form is also determined, in a secondary way, by the forces inherent in the molecular arrangement which is the basis of the calcite rhombohedron crystal. However the original plan of the crystal is never totally suppressed. Thus we can describe the construction of a calcareous coccolith as a combination of two processes, on one hand the active forces of the living organic cell and on the other the resistent, passive crystal laws of inorganic calcite molecules (Küpper 1967, p. 6). We are approaching here the realm of biochemistry where no sharp boundary line can be drawn any more between living and dead matter and within the dimensions accessible by electronmicroscopy there seems to be a unison of the previously separating words organic and inorganic. No distinction can be made in the case of coccoliths as products of the metabolism of living protoplasm between living and dead matter. The coccolith in situ is part of the living entity of the cell. In fossil state, bare of any organic compounds it consists of nothing but a comparatively small number of calcite rhombohedrons, which nevertheless by their sculptured surfaces and their complicated arrangement still show all the grandeur of life.

The study of the protoplasmatic matrix within which the living flagellate cell secretes the coccolith, was begun by PARKE & ADAMS 1960 and continued by WILBUR & WATABE 1963. It throws new light on a process of life which has contributed much to the formation of rocks: the secretion of calcite by living organisms.

It is hoped that our paper will not only be of use to petroleum geologists and stratigraphers, but that it also will contribute to ultrastructure research in this direction in modern oceanography.

Description of Genera and Species

Family: **Coccolithaceae** KAMPTNER 1928, p. 34

a) "Heterococcoliths"

Tribus: **Coccolitheae** KAMPTNER 1958, pp. 70, 81, 82, 83.

Subtribus: *Coccolithinae* KAMPTNER 1958, pp. 70, 81, 82, 83

Genus: **Chiasmolithus** HAY, MOHLER & WADE 1966, p. 388

According to the original diagnosis only placoliths with the central opening spanned by an "x"-shaped structure orientated in a diagonal direction are included. Placoliths with "+"-shaped central structure orientated along the main axes of the elliptical central opening are included in the new genus *Cruciolithus* (p. 16).

Type species: *Tremalithus oamaruensis* DEFLANDRE 1954.

Chiasmolithus oamaruensis (DEFLANDRE), HAY, MOHLER & WADE

Plates 1—5

1945 *Large Coccolith*, CORNES, fig. 1.
1954 *Tremalithus oamaruensis* DEFLANDRE, in DEFLANDRE & FERT, p. 154, pl. 11, fig. 22; text-figs. 72—74.
1956 *Coccolithus cruciatus* SHAMRAI & LAZAREVA, p. 713, pl. 1, fig. 6.
1959 *Coccolithus cruciatus* SHAMRAI & LAZAREVA; ORAVECZ, p. 429.
1962 *Tremalithus oamaruensis* DEFLANDRE; MARTINI, in CURRY et al. p. 273.
1965 *Coccolithus oamaruensis* (DEFLANDRE) LEVIN, p. 265—266, pl. 41, fig. 3.
1966 *Chiasmolithus oamaruensis* (DEFLANDRE) HAY, MOHLER & WADE, p. 388—389, pl. 7, fig. 1.
non 1967 *Coccolithus oamaruensis* (DEFLANDRE) ?; LEVIN & JOERGER, p. 165, pl. 1, figs. 6 a—b.

Description: Elliptical coccoliths consisting of two shields which are connected by a central tube; the elliptical central opening is spanned by a diagonally orientated "x"-shaped structure with obtuse angles bisecting the longer axis of the ellipse.

The distal shield is rather narrow as compared with the proximal shield. It is composed of approximately 80 crystal segments which insert into the central tube at steep angles (Pl. 4, fig. 1 and 2). The number of the segments is about the same in the distal and in the proximal shield, though the latter looks as if it has more because of the narrower suture-lines caused by the strong inclination of the crystal segments there.

The proximal shield (pl. 1, 2, 3, fig. 1 and pl. 4, fig. 1) is connected with the central tube along an elliptical zone (pl. 3, fig. 2). This can be seen in specimens with the proximal shield partly or completely broken off. The characteristically pointed crystal-plates of this zone may have acted as something like hinges for the crystal segments of the proximal shield in vivo, that is as long as the single crystal segments where not yet fixed into their permanent position within the proximal shield. Proximal views show the strong inclination of the crystal segments in the concave proximal shield and the groove between the convex side of the proximal shield and the concave side of the distal shield.

The central tube, in which the two elliptical shields and the central structure are inserted, is composed of imbricating crystal plates. It is conical towards the distal side of the coccolith, from where the central structure originates as well as towards the proximal side, however it opens more towards the distal side (pl. 4, fig. 2).

The central "x"-shaped structure subdivides the central opening of the central tube into four windows, two large ones along the longer axis and two smaller ones along the shorter axis of the ellipse. The arches of the structure enclose obtuse angles bisecting the main axis. Their width can vary considerably (compare pl. 1 and 2). The specimen of plate 1 is not only twice as big as that of plate 2, but also its central structure is more robust. Depending on the width of the arches the two lateral windows are either subcircular or more triangular. The central structure is not in one level but it is vaulted towards the distal side. This can readily be seen in stereoscopic pictures and also in pl. 2. In this proximal view the central structure is viewed at from its concave side. During carbon evaporation the centre of the "x" structure was touching the supporting mica-plate and therefore was not carbon-coated there while all the other parts of the arches are carbon coated all the way round and therefore twice as dark. On the proximal side of the arches ridges composed of elongate crystals or edges of crystal lamellae can be observed. There is usually a double row of such crystals with a suture in between along the middle of the arches, similar to that of *Zygolithus crux* as described by Stradner & Adamiker 1966 (p. 340, pl. 3, fig. 3). On the distal side no sutures could be found. The serrate margin of the arches in the specimen shown in plate 2 may indicate that a reticulate structure originally spanned the openings.

Dimensions: Length of coccoliths ranging from 10,5 μ to 22,5 μ, width ranging from 9 μ to 17,5 μ.

New Zealand Occurrences: Restricted to late Kaiatan (Upper Eocene) to Duntroonian (late Oligocene) strata. First recorded from the Whaingaroan (early Oligocene) Oxford Chalk of the South Island.

Other Occurrences: Upper Eocene of Mississippi, U. S. A. (Yazoo formation); northwest Caucasus, USSR, deepwell NE of Nal'chick.

Genus **Coccolithus** SCHWARZ 1894, p. 346

To this genus are referred the following two species, the ultrastructure of which is only partially known. The genero-type is *Coccolithus pelagicus* (WALLICH) SCHILLER, a common species in the recent oceans, the life-cycle of which has been elucidated in the important paper by PARKE & ADAMS 1960.

Type species: *Coccolithus pelagicus* (WALLICH) SCHILLER.

Coccolithus eopelagicus (BRAMLETTE & RIEDEL 1954)

Plate 6

1892 "*Coccolithus*", JUKES-BROWNE & HARRISON, p. 178, fig. 8.
non 1954 *Coccolithus* cf. *pelagicus* DEFLANDRE & FERT, p. 151, pl. 10, fig. 20, pl. 11, fig. 23 and pl. 13, figs. 23, 24.
1954 *Tremalithus eopelagicus* BRAMLETTE & RIEDEL, p. 392, pl. 38, figs. 2 a, b.
1957 *Tremalithus eopelagicus* BRAMLETTE & RIEDEL; BRAMLETTE, p. 250, pl. 61, fig. 9.
1961 *Coccolithus eopelagicus* (BRAMLETTE & RIEDEL); BRAMLETTE & SULLIVAN, p. 141.
1962 *Tremalithus eopelagicus* BRAMLETTE & RIEDEL; BENESOVA & HANZLIKOVA, p. 121, pl. 4, fig. 10.
1962 *Coccolithus eopelagicus* (BRAMLETTE & RIEDEL); STRADNER, p. 178.
1962 *Coccolithus eopelagicus* (BRAMLETTE & RIEDEL); KAMPTNER, pp. 156—7, pl. 3, fig. 23 (Non text-figs. 12 a—b).
1963 *Coccolithus pelagicus* (WALLICH) — MARTINI & BRAMLETTE, pp. 849—50 (Non smaller specimens).
1964 *Coccolithus eopelagicus* BRAMLETTE & RIEDEL; STRADNER, p. 134, text-figs. 1—2 (non text-fig. 3).
1965 *Coccolithus pelagicus* (WALLICH), COHEN, p. 12, pl. 1, figs. a—c (Non smaller specimens).
1965 *Coccolithus pelagicus* (WALLICH); MARTINI, p. 402, pl. 34, figs. 1—3.
1965 *Coccolithus* aff. *C. eopelagicus* (BRAMLETTE & RIEDEL); LEVIN, p. 266, pl. 41, fig. 4.
1966 *Coccolithus eopelagicus* (BRAMLETTE & RIEDEL); HAY, MOHLER & WADE, p. 385, pl. 1, fig. 1.
? 1966 *Coccolithus eopelagicus* BRAMLETTE & RIEDEL; STRADNER & ADAMIKER, p. 331, pl. 1, fig. 2.
non 1966 *Coccolithus eopelagicus* (BRAMLETTE & RIEDEL); EDWARDS, figs. 8. 11.
non 1966 *Coccolithus eopelagicus* (BRAMLETTE & RIEDEL); HAQ, p. 29, pl. 1, fig. 4, pl. 2, fig. 4, pl. 5, fig. 6.
1967 *Coccolithus tortuosus* LEVIN & JOERGER, p. 165, pl. 1, figs. 8 a—d.
non 1967 *Coccolithus* sp. aff. *C. eopelagicus* (BRAMLETTE & RIEDEL) — LEVIN & JOERGER, p. 165, pl. 1, figs. 2 a—b.

Description: Comparatively large elliptical coccoliths with broad distal shield consisting of about 60 crystal segments. The proximal shield shows stronger birefringence than the distal shield. Both shields are curved convex toward the distal side and concave towards the proximal side. The single central window is elliptical and seems to be without reticular structure. As also with other coccoliths between crossed nicols the extinction lines are bent clockwise when viewed from the distal side. The specimen of plate 6 is seen from the proximal side. The white elliptical ring in the phase contrast photographs corresponds to the tube.

Electronmicrographs of this species from Oamaru are not available yet.

Dimensions of coccolith shown in plate 6: Length 15 μ, width 12·5 μ.

New Zealand Occurrences: Present (rare) in upper Heretaungan (early Middle Eocene ?) to Duntroonian (late Oligocene) strata.

Other Occurrences: According to the original description from the Upper Eocene (Oceanic formation) of Bath, Barbados also very common from Eocene to lower Oligocene from many parts of the world.

Coccolithus parvulus (Deflandre & Fert) nov. comb.

Plate 7, fig. 1 and 2

1954 *Tremalithus parvulus* Deflandre & Fert, p. 154, pl. 14, fig. 6.

non 1962 *Cyathosphaera parvula* (Deflandre & Fert), Hay & Towe, p. 509, p. 9, fig. 6.

Description: Elliptical coccoliths with a broad distal shield consisting of 16—20 crystal segments and a smaller proximal shield of about the same number of crystals. The central area is closed by a lamella of tightly joined plates which are arranged along a medial suture line. No pores or windows. Neither tube crystals nor a fourth crystal cycle as in *Ericsonia* are observable.

Dimensions: Length ranging from 2 μ to 2·8 μ, width from 1·4 μ to 2 μ.

Discussion: Only three specimens of such small dimensions as in the holotype and of such primitive structure have been observed. They are assigned to this species tentatively and may eventually prove to be small and reduced forms of *Ericsonia ovalis* Black, just the same as *Cyathosphaera parvula* (Deflandre & Fert) Hay & Towe seems to belong to that genus.

Other Occurrence: Lutetian of Donzacq, Landes, France.

Genus: **Cruciolithus** nov. gen.

Derivation of name: *crux* (lat.) = cross, *lithos* (greek) = stone

Placoliths with a central opening spanned by a "+" shaped structure, which lies in the direction of the main axes of the elliptical shields.

Type species: *Cruciolithus cruciformis* (Hay & Towe) nov. comb. Pending their electronmicroscopic investigation the following species are included tentatively: *Coccolithus staurion* Bramlette & Sullivan, *Coccolithus delus* Bramlette & Sullivan, and *Coccolithus helis* Stradner. Of the last mentioned species electronmicrographs are to be seen in Bramlette & Martini 1964, pl. 7, figs. 5 a, b, 6.

Cruciolithus cruciformis (HAY & TOWE) nov. comb.

Plate 44, figs. 1—4

1962 *Cyathosphaera cruciformis* HAY & TOWE, p. 508, pl. 2, fig. 6.
? 1967 *Zygolithus crux* (DEFLANDRE & FERT); LEVIN & JOERGER, p. 169, pl. 2, figs. 22 a—b.

Description: Elliptical coccoliths composed of two shields, which are connected by a tube. The central opening is spanned by an axial cross-shaped structure.

Dimensions: Length 6 μ, width 4·5 μ in the specimen of pl. 44.

Discussion: In the Oamaru Diatomite this species is rather rare, not so however in the European Upper Eocene. It differs from *C. staurion* by its smaller dimensions and lesser number of crystal elements in the shields.

Other Occurrence: Lutetian of Donzacq, Landes, France.

Genus: **Ericsonia** BLACK 1964, p. 311

Elliptical coccoliths with central area or central opening surrounded by three or more apparently concentric rings of granules or crystal plates, which are differently orientated in the adjacent rings of the proximal shield as can be seen in proximal view only.

Type species: *Ericsonia occidentalis* BLACK.

Some similar species of the "*Coccolithus pelagicus*"-group, which were described on account of electronmicrograms of the distal side, ought to be reexamined for their proximal views, as they might also belong into this genus; e. g. *Coccolithus celticus* BLACK & BARNES, *Coccolithus sarsiae* BLACK & BARNES, *Coccolithus litos* HAY, MOHLER & WADE and *Coccolithus pseudocarteri* HAY, MOHLER & WADE.

Ericsonia ovalis BLACK 1964

Plate 8 and 9

1964 *Ericsonia ovalis* BLACK 1964, p. 312, pl. 139, fig. 5 and 6.
1964 *Coccolithus muiri* BLACK 1964, p. 309, pl. 50, fig. 3 and 4.
1966 *Coccolithus muiri* BLACK; HAQ, p. 29, pl. 1, fig. 3.
1967 *Coccolithus* sp. aff. *C. eopelagicus* (BRAMLETTE & RIEDEL); LEVIN & JOERGER, p. 165, pl. 1, figs. 2 a, b.
Coccolithus sp. cf. *C. pelagicus* (WALLICH); ibidem, p. 165, pl. 1, figs. 4 a, b.
1967 *Coccolithus eopalagicus* (BRAMLETTE & RIEDEL); GARTNER & SMITH, p. 3, pl. 3, figs. 1—5.
1968 *Ericsonia ovalis* BLACK; HAQ (in press).

Description: Elliptical coccoliths consisting of four cycles of segments and an elongate central opening of about one third the width of the distal shield. The distal shield consists of 25 to 35 segments which are sloping and slightly inclined. The central opening is lined with a ring of radial crystal-plates sloping towards the centre. The number of these crystal plates equals approximately that of the distal shield. The proximal shield consists of two concentric cycles of crystals. The innermost cycle seen in proximal view seems to be the extension of the crystal segments or "rays" of the distal shield into the central area. The two rings of the proximal shield are inserted into the proximal side of the distal shield along an elliptical groove, which can be seen as zone of insertation in specimens where the proximal shield is partially or completely broken off. According to the specimen illustrated by HAQ 1968 the notches, where the crystals of the proximal shield insert, appear after some degree of corrosion as openings between the adjoining crystals segments of the distal plate. The two cycles of the proximal shield are inclined clockwise and counterclockwise respectively.

Dimensions: Length 6·5 μ, width 4·8 μ (Hypotype 2966/65).

Discussion: The distal side of *Ericsonia ovalis* BLACK is identified with the electronmicrograms of *Coccolithus muiri* BLACK, the proximal side of which was not illustrated in the original description. Regarding the species designation priority was given to the name used under the genus *Ericsonia*.

New Zealand Occurrences: Abundant in lowermost Waipawan (Upper Paleocene) to Waiauan (Middle Miocene) strata. Its upper limit has not been determined, but is definitely below the Opoitian (Pliocene).

Other Occurrences: Middle Eocene of Muir Seamount, north-east of Bermuda; Upper Eocene of Syria.

Ericsonia fenestrata (DEFLANDRE & FERT)

Plate 10 und 11

1954 *Discolithus fenestratus* DEFLANDRE & FERT, p. 25, pl. 11, fig. 25, text-figs. 18 (left) and 52.
1956 *Coccolithus sestromorphus* KAMPTNER, p. 10.
1968 *Ericsonia fenestrata* (DEFLANDRE & FERT); HAQ 1967 (in press).

Description: Elliptical coccoliths consisting of a broad distal shield composed of 27 to 33 sloping and slightly inclined crystal plates and a proximal shield consisting of two cycles of crystals, which are arranged in the typical *Ericsonia* manner: one cycle clockwise, the other one counterclockwise inclined. The central area is perforated by a number of circular pores, the number of which was found varying between 6 and 18. In some specimen the pores are arranged in such a way as to leave out a longitudinal central bridge, with one or two rows of pores on either side.

Dimensions: Length 5 μ, width 4 μ (Hypotype 2907/65).

Discussion: As there is no electronmicrogram of *Coccolithus sestromorphus* KAMPTNER 1956 available yet, the name *Ericsonia fenestrata* is used for the Tortonian specimens with reservation only.

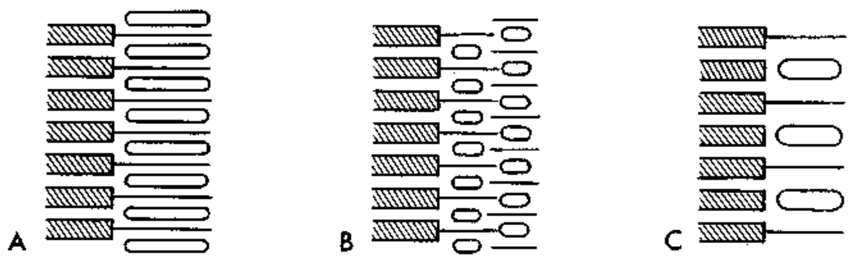
New Zealand Occurrence: From Middle Kaiatan (late Middle Eocene ?) to Duntroonian (late Oligocene).

Other Occurrence: Lutetian of Donzacq, Landes, France.

Genus: **Reticulofenestra** HAY, MOHLER & WADE 1966, p. 386, emend. (syn. *Dictyococcites* BLACK 1967, p. 141)

Broadly-elliptical to subcircular coccoliths with a large central opening spanned proximally by a reticulate membrane, which is an extension of the segments of the proximal shield towards the long axis of the central area. On the distal side the sloping inner walls of the central opening are lined with a conical tube of imbricate crystal plates, which distally can be contracted towards the centre of the ellipse to form a "ceiling"-like covering of the central area. Forms with the central space closed on the distal side as well as on the proximal side were originally described under different title (*Syracosphaera bisecta* HAY, MOHLER & WADE).

Type species: *Reticulofenestra placomorpha* (KAMPTNER) nov. comb. (syn. *Reticulofenestra caucasica* HAY, MOHLER & WADE).



Text-fig. 2: Diagram of the ultrastructure of shield and central membrane in the genus *Reticulofenestra* HAY, MOHLER & WADE:

A. *Reticulofencstra placomorpha:* Every element of the shield (striated) is contributing to the construction of the membrane. Pores elongate at margin of the membrane.
B. *Reticulofenestra oamaruensis:* Every element of the shield is contributing only a short extension to the membrane. Pores short and in alternating rows.
C. *Reticulofenestra dictyoda:* Only every second element of the shield is contributing to the construction of the membrane. Pores wider than in A and B.

Reticulofenestra dictyoda (DEFLANDRE & FERT) HAY, MOHLER & WADE

Plates 12—14, 22, fig. 4 and text-fig. 2 C

1954 *Discolithus dictyodus* DEFLANDRE & FERT, p. 140, text-fig. 15 (non text-fig. 16).
1963 *Cyclococcolithus dictyodus* (DEFLANDRE & FERT), HAY & TOWE, p. 503, pl. 5, fig. 4, pl. 7, fig. 1.
1966 *Reticulofenestra scissura* HAY, MOHLER & WADE, p. 387, pl. 5, figs. 1—6.
Coccolithus pseudocarteri HAY, MOHLER & WADE (pro parte), pl. 2, figs. 2—4 (non pl. 2, fig. 1).
Pontosphaera vadosa HAY, MOHLER & WADE (pro parte), pl. 8, figs. 1—3 (non pl. 8, fig. 4).
Reticulofenestra dictyodus (DEFLANDRE & FERT); ibidem, p. 387.
1967 *Dictyococcites danicus* BLACK, p. 141, fig. 2.

Description: Coccoliths consisting of two elliptical shields which are composed of between 40 to 60 wedge-like segments, the distal shield being about $^1/_4$ to $^1/_3$ larger than the proximal shield, both curved convex distally and having an equal number of segments. The serrate margin is better seen in specimens with less imbrication (pl. 12, fig. 3) than in those with more overlapping segments (pl. 13, fig. 1). The central area is closed by a reticulate membrane at the proximal side. This is formed by anastomosing laths and rods which are derivatives of the proximal shield. The central membrane shows much variation regarding the fenestration or reticulation. There are specimens with predominantly rounded pores (pl. 12, figs. 1 and 4), others with more elongate marginal pores (pl. 14, fig. 1). In some specimens elongate marginal pores together with rounded pores more towards the central line of commisive, which lies in the major axis of the ellipse, can be seen. The remarkable feature of this species is, that the central membrane tends to be partly or completely filled near the centre (pl. 13, fig. 1), by laths which are derivates of every second element of the proximal shield. Therefore the number of marginal pores is roughly half or only slightly more than the number of segments in the proximal shield (compare text-fig. 2C).

Dimensions: Length ranging up to 10 μ, width up to 9 μ, length of central membrane usually 3—4 μ.

Discussion: In light-microscopy this species can be recognized by the smooth appearance of the shields, which is due to the high number of segments. With *Ericsonia ovalis* the striation is readily recognized (pl. 9), not so with *Reticulofenestra dictyoda* (pl. 14, figs. 2—5). The one oval central pore or the two focal pores in the photomicrographs of both species are to be understood as optical phenomena only. They cannot be proven by electron-micrographs.

New Zealand Occurrence: The only other known occurrence of this species in New Zealand is a sample S 61/531 from the Porangan (Middle Eocene) of the Hurunui River Gorge section.

Other Occurrences: Lutetian of Donzacq, Landes, France; Upper Eocene of Nal'chik, Northwest Caucasus, USSR.

Reticulofenestra dupouyi (DEFLANDRE & FERT) HAY, MOHLER & WADE

Plate 15

1952 *Discolithus dupouyi* DEFLANDRE & FERT, p. 2101, text-fig. 1 (nomen nudum).
1952 *Discolithus* sp. DEFLANDRE in GRASSE, p. 469, text-fig. 364 B.
1954 *Discolithus dupouyi* DEFLANDRE & FERT, p. 142, pl. 14, figs. 1, 9, 10, 12.
1957 *Cribrosphaerella dupouyi* (DEFLANDRE & FERT), DEFLANDRE & DURRIEU, p. 2950, text-fig. 1.
1962 *Cyathosphaera dupouyi* (DEFLANDRE & FERT), HAY & TOWE, p. 509, pl. 3, figs. 1—4.
1966 *Coccolithus dupouyi* (DEFLANDRE & FERT), HAY & TOWE; HAQ, p. 30, pl. 4, figs. 2, 6, pl. 6, figs. 1, 2.
1966 *Reticulofenestra dupouyi* (DEFLANDRE & FERT), HAY, MOHLER & WADE, p. 387.

Description: Elliptical coccoliths with distal shield larger and overlapping the proximal shield, both consisting of usually more than 30 imbricated segments. An inner cycle of crystal plates with strong sinistral imbrication surrounds the central area, which is filled on its proximal side by a complex grille consisting of short irregularly shaped anastomosing rods. As in *Reticulofenestra dictyoda* every second segment contributes a rod to the central membrane.

Dimensions: Length 3—4 μ, width 2—3 μ.

Discussion: *Reticulofenestra dupouyi* can be distinguished from small specimens of *R. dictyoda* by the more irregular pattern of the central membrane or grille. In overcalcified specimens, such as shown in pl. 15, fig. 2, it is rather a matter of choice than judgement to separate these two species, unless statistical work on size variations and on the number of crystal plates is done.

Other Occurrences: Lutetian of Donzacq, Landes, France; Upper Eocene of Nal'chik, northwest Caucasus, USSR.

Reticulofenestra oamaruensis (DEFLANDRE) nov. comb.

Plates 16—18 and text-fig. 2 B

1954 *Discolithus oamaruensis* DEFLANDRE, in DEFLANDRE & FERT, p. 139, pl. 12, figs. 1, 2.
1966 *Reticulofenestra caucasica* HAY, MOHLER & WADE (pro parte), pl. 2, figs. 6—8, non pl. 2, fig. 5 and pl. 3 and 4.
1967 *Discolithina oamaruensis* (DEFLANDRE), LEVIN & JOERGER, p. 167, pl. 2, figs. 1 a—b.
1968 *Reticulofenestra oamaruensis* (DEFLANDRE), STRADNER; HAQ, (in press).

Description: Coccoliths (placoliths) consisting of two distally convex shields composed of 80 to over 100 wedge-like segments. The wide reticulate membrane, which covers the proximal side of the central area is perforated by 9—13 concentric rows of oblique pores. From proximal views it can be seen, that each segment of the proximal shield is curved — more than in any other species of Reticulofenestra — in proximal direction. Within the "bowl" formed by the proximal shield lies the reticulate membrane. Plate 17 shows, that each segment of the proximal shield corresponds to one, in some places even two rods of the outermost circle of the membrane. The constituent elements of this membrane seem to be as in *Reticulofenestra placomorpha* composed of "monocrystals" *) with rhombohedric crystals in between: hammer shaped elements arranged in rows with alternating arrangement of elements in such a way, that all "handles" point in distal direction and are inserted between two "hammers" of the surrounding circle (pl. 17, fig. 1). The ultrastructure of the distal side seems to be rather similar if not identical with that of *Reticulofenestra placomorpha*.

Dimensions: Length ranging up to 18 μ, width up to 15 μ; diameters of membrane greater than half the diameter of the distal shield.

Discussion: This species differs from *Reticulofenestra placomorpha* by the different proportions of the diameters of membrane and shields and by the number and shape of the pores. There is no marginal elongate fenestration, but only reticulation in a strict geometrical pattern. In light-microscopy there is much similiarity with the genus *Discolithina* indeed: the narrow rim and slot-like "rhaphe" along the main axis of the membrane.

*) The term "monocrystals" is used here with reservation pending the outcome of electron diffraction pattern studies. Reference is made to the "Protocalcit" described by E. SCHROLL et al. (1965).

New Zealand Occurrence: Restricted to upper Runangan to lowermost Whaingaroan (late Upper Eocene) strata.

Other Occurrence: Upper Eocene to middle Oligocene of Alabama, USA.

Reticulofenestra placomorpha (KAMPTNER) nov. comb.

Plates 19—21, 22, fig. 1—3; 23, 24, 25, figs. 1 and 2, text-fig. 2 A

1948 *Tremalithus placomorphus* KAMPTNER, p. 7, pl. 2, fig. 11. (invalid ICBN Art. 43; LOEBLICH & TAPPAN 1966, p. 174).
1952 *Tremalithus placomorphus* KAMPTNER, DEFLANDRE in PIVETEAU, p. 111, fig. 3.
1954 *Discolithus dictyodus* DEFLANDRE & FERT, p. 140, text-fig. 16, non text-fig. 15, which was designated as holotype for *Reticulofenestra dictyoda* (DEFLANDRE & FERT) by HAY, MOHLER & WADE 1966.
1956 *Coccolithus placomorphus* KAMPTNER, p. 10 (validated by reference to description and figure published under invalid name; LOEBLICH & TAPPAN 1966, p. 112).
1962 *Coccolithus* (?) sp., BOUCHE, p. 84, pl. 1, figs. 21 a—c.
1962 *Coccolithus placomorphus* KAMPTNER; STRADNER, p. 178.
1963 *Coccolithus tenuistriatus* KAMPTNER, p. 160, pl. 2, figs. 14, 15; text-fig. 16.
1963 *Coccolithus placomorphus* KAMPTNER; STRADNER, p. 160, pl. 23, figs. 4, 5.
1964 *Coccolithus placomorphus* KAMPTNER; STRADNER, p. 135, text-fig. 10.
1964 *Ellipsoplacolithus spec.*; BACHMAYER, p. 184, pl. 2, fig. 10.
1965 *Coccolithus* ? sp.; COHEN, p. 13, figs. h and i.
1965 *Coccolithus umbilicus* LEVIN, p. 265, pl. 41, fig. 2.
1965 *Coccolithus tenuistriatus* KAMPTNER; MARTINI, p. 403, pl. 34, figs. 10—12.
1966 *Coccolithus* cf. *placomorphus* (KAMPTNER); REINHARDT, p. 21, pl. 22, figs. 29, 30; pl. 20, fig. 3.
1966 *Reticulofenestra caucasica* HAY, MOHLER & WADE, p. 386—387, pl. 2, fig. 5; pl. 3, figs. 1—2; pl. 4, figs. 1—2. Non pl. 2, figs. 6—8.
Apertapetra samodurovi HAY, MOHLER & WADE; p. 387, pl. 6, figs. 1—4, 6—7.
Syracosphaera bisecta HAY, MOHLER & WADE, p. 393, pl. 10, figs. 1—6.
1967 *Coccolithus pelycomorphus* REINHARDT, p. 515, pl. 1, figs. 2, 6, text-fig. 5.
Coccolithus coenurus REINHARDT, p. 516, pl. 1, fig. 7, text-fig. 6.
1967 *Coccolithus stavensis* LEVIN & JOERGER, p. 165, pl. 1, figs. 7 a—d.
Apertapetra umbilicus (LEVIN) LEVIN & JOERGER; ibidem, p. 166, pl. 1, figs. 9 a—c.
1967 *Coccolithus umbilicus* LEVIN; GARTNER & SMITH, p. 3, pl. 1, figs. 3, 4, pl. 2, figs. 1—3 b.
1968 *Reticulofenestra placomorpha* (KAMPTNER); HAQ (in press).

Description: Elliptical coccoliths with a large central opening spanned on the proximal side by a large reticulate membrane consisting of anastomosing rods, which are derivates of the proximal shield. The reticulate membrane shows an elongate fenestration marginally and a reticulation centrally. The rods are formed of elongate monocrystals with rhombohedric crystals inserted in between them at more or less regular intervals (pl. 23, fig. 2). Only the rhombohedric crystals bring about anastomosis with the monocrystals adjacent to them. The distal shield consists of between 60 to 100 imbricate wedge-shaped segments. The imbricate crystal plates of the inner ring in many specimens extend towards the centre thus completely closing the central opening on its distal mouth. (pl. 21, fig. 1). This central covering of the distal side has a depressed centre, which in oblique side view appears like a crater (pl. 21, fig. 2). The proximal shield is distinctly smaller than the distal shield and consists of about the same number of segments. According to HAQ 1968 it is distinctly clear from many of his electronmicrograms that the ring surrounding the central area in distal view is actually the continuation of the proximal plate on the distal side. This means that the reticulate membrane as well as the central covering of the distal side are both derivates of the proximal shield. Plate 22, fig. 2 showing the central ring only partly developed would support this assumption. The distal covering can also be found separately (pl. 22, fig. 3). Its proximal side (inner side) is shown in pl. 19, fig. 2. The unpublished steroscopic couple of this picture shows the difference in depth between the fragments of the reticulate membrane and the central covering in the background very impressively.

Dimensions: Length ranging up to 15 μ, width up to 12·8 μ (hypotype 3378/65).

Discussions: KAMPTNER's original description of this species, which was validated by the same author in 1956, clearly gives the important characteristics, such as proportions, crystal orientation and overall size, in spite of the limitations of the light microscope. As KAMPTNER had been using a ZEISS apochromate oil immersion objective combined with decentralized Abbe-condensor and polarizing filters, he could obtain a clear impression of the membrane *("Querseptum")*. The number of elements of the distal shield given by the original description *("70 Elemente")* falls within the variation of the species.

The species designation *Coccolithus placomorphus* KAMPTNER appears as the first valid name, as the previous Tremalithus placomorphus KAMPTNER 1948 regarding its generic status was called by the nomenclator himself provisional. KAMPTNER in 1948, p. 3 as well as in 1956, p. 5 and 10, regarded the genus Tremalithus as a "provisional collective genus without prejudice concerning future systematical assignment". He speaks of *Tremalithus* as "ein rein morphologisch definiertes, provisorisches Sammelgenus, dem kein Präjudiz einer künftigen speziellen systematischen Einordnung der betreffenden Form zukommt" (1948, p. 3) and substituted the artificial genus (künstliche Einheit) *Tremalithus* by the natural genus *Coccolithus* (Einheit des „natürlichen" Systems) for *Coccolithus placomorphus* in 1956, p. 10. The genus *Tremalithus* was restricted to such forms with completely reduced proximal shield. For this reason the name *Tremalithus placomorphus* as it was in use prior to 1956 is considered invalid according to the ICBN, as with the genus being regarded only provisional all species there referred were also invalidly named (compare also LOEBLICH & TAPPAN 1966, p. 87—88).

The species name *Discolithus dictyodus* DEFLANDRE & FERT 1954 could have had priority over *Coccolithus placomorphus* KAMPTNER 1956 in the case of the Oamaru specimens, if HAY, MOHLER & WADE had not designated the Doncaq specimen as holotype for *Reticulfenestra dictyoda* (DEFLANDRE & FERT). Fig. 16 in DEFLANDRE & FERT 1954 (p. 8) evidently shows a central plate with "placomorphus"-features in a specimen from Oamaru, while fig. 15 in that same paper shows a specimen from Doncaq, France, with a lesser number of rods composing the central membrane. As the specimen with the lesser number of rod-elements in the central membrane was chosen as holotype for *Reticulofenestra dictyoda*, the name which is next available and subsequent is to be used as valid name for the other species with the higher number of elements. Therefore: Reticulofenestra placomorpha (KAMPTNER

1956). *Reticulofenestra placomorpha* can be easily differentiated from the closely related *R. dictyoda* after carbon replication. In the former species the number of the monocrystals-rods near the margin of the central membrane equals that of the imbricate crystal plates of the tube, whereas in the latter species only every second crystal is contributing a rod to the construction of the membrane. In *R. dictyoda* every second crystal plate ends abruptly and does not produce a rod (compare pl. 20, fig. 2 with pl. 13, fig. 1).

New Zealand Occurrence: Abundant in upper Heretaungan (early Middle Eocene ?) to Waitakian (early Miocene) strata. Reworked specimens are occasionally found in younger strata.

Other Occurrences: In upper Eocene and reworked in lower Miocene strata of Lower Austria; Upper Eocene of Alabama and Mississippi, USA; Upper Eocene of Nal'chik, northwest Caucasus, USSR; Upper Eocene of Eastern and Western Germany.

Coccolithus sp. (Holococcolith)

Plate 44, fig. 5

1956 *Crystallolithus hyalinus* GAARDER & MARKALI, p. 1, pl. 1, fig. 1—8.
1960 *Coccolithus pelagicus* (WALLICH) SCHILLER; PARKE & ADAMS, p. 263, pl. 1—4.

Description: Elliptical coccoliths consisting entirely of rhombohedrons of calcite, which are arranged in approximately parallel rows. There are about 18 rows lengthwise and about 13 rows crosswise, but these rows do not correspond the main axes of the elliptical periphery. They enclose acute angles of about 70° between each other and more acute angles of about 15° with the long axis and 35° with the short axis of the ellipse. The rim of the coccolith is built of at least two rows of microcrystals, one overlying the other. The total number of microcrystals in the Oamaru specimen is larger than in the illustrations of holococcoliths of *Coccolithus pelagicus* from the recent ocean. The socalled "crystalloliths", under which name these forms were originally described, are products of the motile life-phase. As the systematics of the coccoliths is mainly based on the morphology of the "heterococcoliths", that is on the more robust products of the non-motile life-phase, no species determination can be given for this form. It is presumed, that the "crystallolith" of plate 44, fig. 5, which is more than twice as big as those of *Coccolithus pelagicus*, belonged to a species with heterococcoliths twice as large as those of *Coccolithus pelagicus*. Only four species in the Oamaru sample are of such dimensions: *Coccolithus eopelagicus*, *Chiasmolithus oamaruensis*, *Reticulofenestra oamaruensis* and *Reticulofenestra placomorpha*. Any assignment would be mere guess work.

Dimensions: Length 3·5 μ, width 2·5 μ in the only specimen found.

Genus: **Cyclolithella**

(KAMPTNER ex DEFLANDRE 1952) LOEBLICH & TAPPAN 1963, p. 192

Elliptical rings composed of bevelling wedge-shaped segments. Central area wide and open.

In its previous sense this genus is regarded as polyphyletic. Therefore the elliptical species under the genus *Cyclolithella* are assigned to the subtribe of the *Coccolithinae* KAMPTNER, the circular species under the genus *Coronocyclus* HAY, MOHLER & WADE to the subtribe of the *Cyclococcolithinae* KAMPTNER.

Type species: *Cyclolithella inflexa* (KAMPTNER ex DEFLANDRE) LOEBLICH & TAPPAN

Cyclolithella inflexa (KAMPTNER ex DEFLANDRE) LOEBLICH & TAPPAN

Plate 7, fig. 4

1952 *Cyclolithus inflexus* KAMPTNER ex DEFLANDRE in PIVETAU, p. 110, fig. 50.
1952 *Cyclolithus inflexus* KAMPTNER; DEFLANDRE in GRASSE, p. 465, fig. 362 B.
1959 *Cyclolithus armilla* BLACK, in BLACK & BARNES, p. 327, pl. 12, fig. 2.
1965a *Loxolithus armilla* (BLACK) NOEL, p. 3.
1965b *Loxolithus armilla* (BLACK) NOEL; p. 67—68, text-fig. 3.
1968 *Cyclolithella inflexa* (KAMPTNER ex DEFLANDRE) LOEBLICH & TAPPAN; STRADNER, ADAMIKER & MARESCH, pl. 10 (in print).
1968 *Cyclolithella inflexa* (KAMPTNER) LOEBLICH & TAPPAN; HAQ (in press).

Description: Elliptical rings composed of 30 or more bevelling plates. As indicated by the sutures inside the central opening the shape of the single segment is not that of a plane slab but seems to be crooked.

Dimensions: Length 5 μ, width 4 μ (hypotype 1819+1820/65).

Discussion: The Oamaru specimens assigned to this species appear to be more complicated than those described from the Mesozoic and cannot be clearly differentiated from the genus *Cricolithus* and *Coccolithus*. Compare the imbrication of the segments in pl. 7, fig. 1 *(Coccolithus parvulus)* with pl. 7, fig. 4 *(Cyclolithella inflexa)*. The latter might be interpreted as an unfinished stage in the construction of a more complicated coccolith.

Other Occurrences: Oxfordian of Niort, France; upper Cretaceous of Bedfordshire, England; Albian of the South Holland Basin.

Genus: **Cyclococcolithus** KAMPTNER 1954, pp. 23, 74 and 75.

Circular coccoliths with distal shield larger than the proximal shield. Both shields compact without perforations. Central area closed.

Type species: *Cyclococcolithus leptoporus* (MURRAY & BLACKMANN) KAMPTNER.

Cyclococcolithus inversus (DEFLANDRE) HAY, MOHLER & WADE

Plates 26 and 27

1954 *Cyclococcolithus leptoporus* var. *inversus* DEFLANDRE in DEFLANDRE & FERT, p. 150 (pro parte), pl. 9, figs. 4 and 5.

1964 *Markalius inversus* (DEFLANDRE) BRAMLETTE & MARTINI, p. 302, pl. 2, figs. 4—9, pl. 7, figs. 2 a, 2 b.
1964 *Markalius inversus* (DEFLANDRE), BRAMLETTE & MARTINI; MARTINI, p. 49, pl. 6, figs. 9 and 10.
1965 *Cyclococcolithus leptoporus* var. *inversus* DEFLANDRE; COHEN, p. 26, pl. 18, fig. e, pl. 20, fig. a.
? 1965 *Markalius inversus* (DEFLANDRE); MANIVIT, p. 192.
1966 *Cyclococcolithus inversus* (DEFLANDRE), HAY, MOHLER & WADE, p. 389, pl. 7, fig. 2.
1966 *Markalius inversus* (DEFLANDRE); EDWARDS, fig. 26, table 1.
1967 *Cyclococcolithus* ? sp. LEVIN & JOERGER, p. 166, pl. 1, figs. 10, 11.
1967 *Cyclococcolithus orbis* GARTNER & SMITH, p. 4, pl. 4, figs. 1—3 c.
1968 *Cyclococcolithus inversus* (DEFLANDRE) HAY, MOHLER & WADE; HAQ (in press).

Description: Circular coccoliths consisting of a convex distal shield composed of between 17 to 41 sinistrally imbricated segments with strongly inclined sutures and a smaller proximal shield with straight sutures and only little inclination of segments. The central area is filled on the proximal side by many smaller elements showing an intricate radial pattern of sutures. The marginal ones seem to be extensions of the elements of the proximal shield. This central circular area is set off from the proximal shield by a circular groove (pl. 26, fig. 2). As indicated by other electronmicrographs there is also a central ring forming an inner conical tube.

Dimensions: Diameter 7 to 10 μ.

Discussion: Specimens of this species usually show signs of heavy corrosion and sometimes also recrystallisation, as in pl. 26, fig. 1. Compare also the corroded specimen shown in electronmicrographs by COHEN 1965. It seems that the surface of these cyclococcoliths is more readily attacked by corrosive forces than in other species of coccoliths.

New Zealand Occurrences: Present in uppermost Haumurian (Upper Maastrichtian) to lower Whaingaroan (early Oligocene) strata.

Other Occurrences: Maastrichtian of Europe and North America; Danian and Paleocene of Europe, North Africa and North America; Middle Eocene strata of many areas; Upper Eocene of Nal'chik, northwest Caucasus, USSR.

Genus: **Ilselithina** STRADNER 1966, p. 339.

Circular coccoliths consisting of flat-conical proximal shield with narrow slots between the segments and a ring-shaped conical distal shield supported by spokes connecting it with the nave-shaped central core.

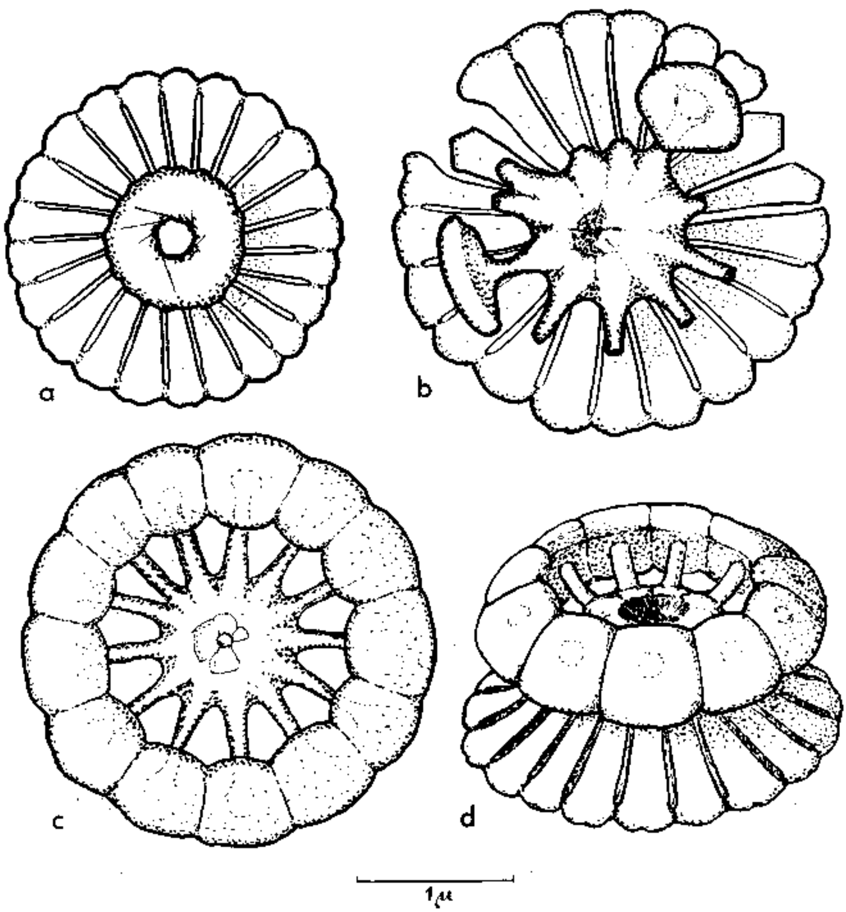
Type species: *Ilselithina iris* STRADNER.

Ilselithina iris STRADNER 1966

Plates 28 and 29

1966 *Ilselithina iris* STRADNER in STRADNER & ADAMIKER, p. 339, text-fig. 3 a—d, pl. 3, fig. 5.

Description: Circular coccoliths consisting of a central core composed of spirally arranged, imbricated crystal segments, which sometimes leave open a central axial canal. On the proximal side the segments of the core extend peripherally to form the spatula-shaped elements of the proximal shield, which as a rule has a higher number of elements than the distal shield. The suture-lines between these elements are crooked (pl. 29, fig. 5). The proximal shield is flat-conical and opens toward the proximal side. There are slightly inclined slot-shaped perforations between the peripherally joining elements. The circular outline of the proximal shield is as large as, or even somewhat larger than the outline of the distal shield. Both shields have shallow notches between the rounded tips of their elements. Occasionally also the tips of the proximal elements themselves are notched (pl. 29, fig. 5, below). In many specimens the proximal shield is not complete and shows intermediate stages of growth. The distal shield consists of a ring of "mushroom"-shaped elements which are also derivates of the central core. They



Text-fig. 3: *Ilselithina iris* STRADNER: a) distal view of proximal shield; b) distal view showing fragmentary distal shield; c) distal view of complete distal shield; d) oblique view (reconstruction). Reprinted with permission from Erdoel Erdgas Zeitschrift (1966, p. 339, figs. 12—15).

are inserted with their shafts at distally oblique angles and form with their rounded trapezoid-shaped peripheral plates a conical ring sloping towards the proximal side. The big central apical opening thus appears subdivided by the radial "spokes" of the distal shield in distal view. The number of elements in the distal shield was in all specimens found smaller (11—13) than in the proximal shield (18—28). Specimens with fragmentary or incomplete distal shield (pl. 28, fig. 6) are more frequent than those with complete distal shield (pl. 28, fig. 5). The level of the distal shield lies above the top level of the central core viewed from the distal side (text-fig. 3 d).

Dimensions: Diameter 3·1 μ in Holotype 2595—2596/65 from Williams Bluff, Oamaru, New Zealand. Other specimens not exceeding 3·4 μ in diameter.

Discussion: *Ilselithina iris* is a rather small and inconspicuous species in the lightmicroscope, but in phase-contrast its two shields can be clearly discerned (pl. 29, figs. 1—3). The central core shows strong birefringence between crossed nicols (pl. 29, fig. 4). The morphology of this species is self-evident in the 14 stereoscopic couples of electronmicrographs, which were taken before the description of this species.

Other Occurrence: Upper Eocene of Klein Schweinbarth, Lower Austria (Seismic drilling L 107/75 by ÖMVAG).

Genus: **Coronocyclus** HAY, MOHLER & WADE 1966, p. 394, emend.

Circular cycloliths with a wide central opening, constructed of a ring of bevelling wedge-shaped segments.

Type species: *Coronocyclus serratus* HAY, MOHLER & WADE.

The nodes and short spines, which were included in the genus-description of *Coronocyclus* could be the result of overcalcification and therefore are not included in the genus-diagnosis given above.

Coronocyclus prionion (DEFLANDRE & FERT) nov. comb.

Plate 7, fig. 3

1954 *Cyclolithus prionion* DEFLANDRE & FERT, p. 145, pl. 10, fig. 19.

Description: Circular rings consisting of about 50 bevelling, strongly inclined crystal slabs. Outer and inner margin of the ring slightly serrate.

Dimensions: Outer diameter: 2·8 μ, inner diameter 1·6 μ (hypotype 2917+2928/65).

Discussion: These circular rings possibly constitute internal structures of cyclococcoliths which were separated from the living matrix at a premature state, in other words uncompleted initial structures of otherwise more complicated cyclococcoliths; according to WILBUR & WATABE 1963, figs. 13—16 such unfinished stages in the production of coccoliths can be expected to be found. *Cyclolithus tenuissimus* KAMPTNER 1963, pl. 2, fig, 18 seems to be an even more immature specimen of the same species, whereas *Coronocyclus serratus* HAY, MOHLER & WADE with apparently two cycles of crystal plates can be taken as a more complete and more mature stage in the development of a cyclococcolith.

Other Occurrence: Diatomite of Jérémie, Haiti. Tertiary.

Genus: **Blackites** HAY & TOWE 1962, p. 505 emend.

Rhabdoliths with a distally tapering shaft attached to the distal side of a circular basal plate composed of at least three cycles of radially or tangentally arranged crystal elements.

Type species: *Blackites rectus* (DEFLANDRE) nov. comb. (syn. *Blackites spinosus* (DEFLANDRE & FERT) HAY & TOWE ex *Discolithus spinosus* DEFLANDRE & FERT).

The genus *Blackites* also includes *Blackites creber* (DEFLANDRE) nov. comb. (syn. *Rhabdosphaera crebra* [DEFLANDRE] HAY & TOWE), *Blackites vitreus* (DEFLANDRE) nov. comb. (ex *Rhabdosphaera vitrea* [DEFLANDRE] HAY & TOWE) and other fossil rhabdoliths which have basal plates like that of *Blackites rectus* (DEFLANDRE) nov. comb.

The genero-type of the genus *Rhabdosphaera* (*Rh. claviger* MURRAY & BLACKMAN) according to electronmicrographs published by COHEN 1965 (b) and unpublished electronmicrographs by GAARDER has a similar outer circle of crystals in the basal shield, which however is not circular but compressed elliptical and is lacking the cycle of interlocking ribs characteristic of *Blackites*.

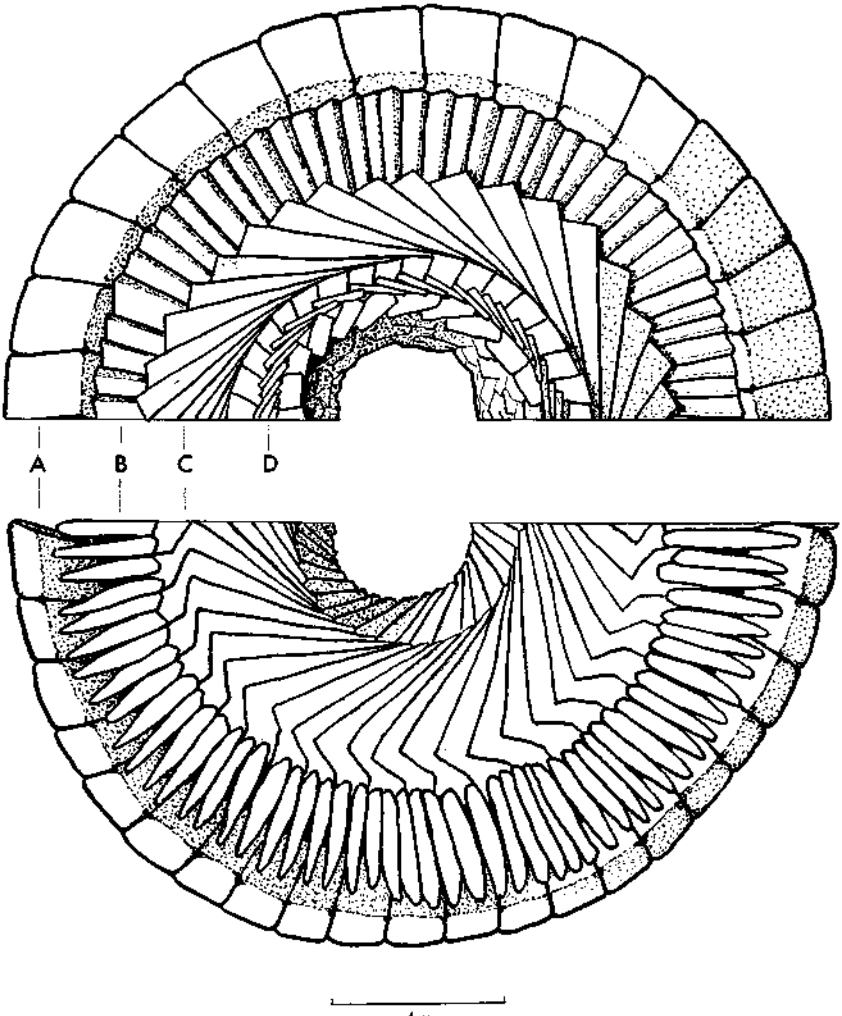
Blackites rectus (DEFLANDRE) nov. comb.

Plate 30 and 31, figs. 1—5; text-fig. 4

1954 *Rhabdolithus rectus* DEFLANDRE in DEFLANDRE & FERT, p. 157, pl. 11, fig. 12, etiam
Discolithus spinosus DEFLANDRE & FERT, ibidem p. 143, pl. 14, fig. 13—15.
1962 *Blackites spinosus* HAY & TOWE, p. 505, pl. 4, fig. 5.
1965 *Blackites spinosus* HAY & TOWE; BLACK, p. 135, fig. 17.
non 1965 *Rhabdolithus* cf. *rectus* DEFLANDRE; MANIVIT, p. 193, pl. 1, figs. 11 a, b.

Description: Basal plate circular, vaulted and surmounted by a central, slightly tapering tube. The basal plate consists of a proximally concave, ring-shaped structure composed of three cycles of differently shaped elements.

The outermost cycle (A) consists of 30 to 45 relatively large subtrapezoidal plates which are adjoining one another and are sloping in a proximal direction. They are supported at their proximal side by a ring of radial crystal rods of two to three times the number of the outer plates. The elements of the sup-



Text-fig. 4: *Blackites rectus* (Deflandre): Ultrastructure of basal shield in distal view (above) and proximal view (below). Outermost cycle of slanting trapezoid plates (A), cycle of supporting radial crystal rods (B), cycle of inclined crystal plates (C), inner cycle (D) at insertation of shaft. Reconstructed from the electronmicrographs shown in pl. 30.

porting cycle (B) are two or three each inserted with their peripheral ends into the two or three proximal grooves occurring in each of the plates of cycle A. If the outer cycle is broken off they form the "spines", which where responsible for the original denomination of fragmentary basal plates (Discolithus "spinosus"). Centrally the spine-shaped crystal rods of cycle B are held in position by a cycle of strongly imbricate and more than 45° inclined crystal plates, which on the distal side partly overlap the crystal rods of cycle B. Each crystal plate of this inner cycle (C) has on its peripheral proximal side an indention near the insertation of the cycle B crystals. The number of crystal elements in cycle C equals that of cycle A, in cycle B it is twice or more that of cycle C or cycle A. The central distal side of cycle C is adjoined onto a central ring of crystals, imbricate and inclined in the same direction as in cycle C. This fourth cycle (D), however, might be considered as belonging to the tubular shaft, which takes its origin here. The central tube is conical at its base where the crystal laths are more pronouncedly spiral than in the rest of its length. It is not exactly cylindrical, as it appears in the light microscope, but slightly tapering in distal direction. Its crystal laths are arranged in a spiral way up the tube in the same sense of coiling as indicated by cycle C and D. They seem to be penetrating each other similar as in *Rhabdolithina splendens* (compare STRADNER, ADAMIKER & MARESCH 1967, pl. 21—23).

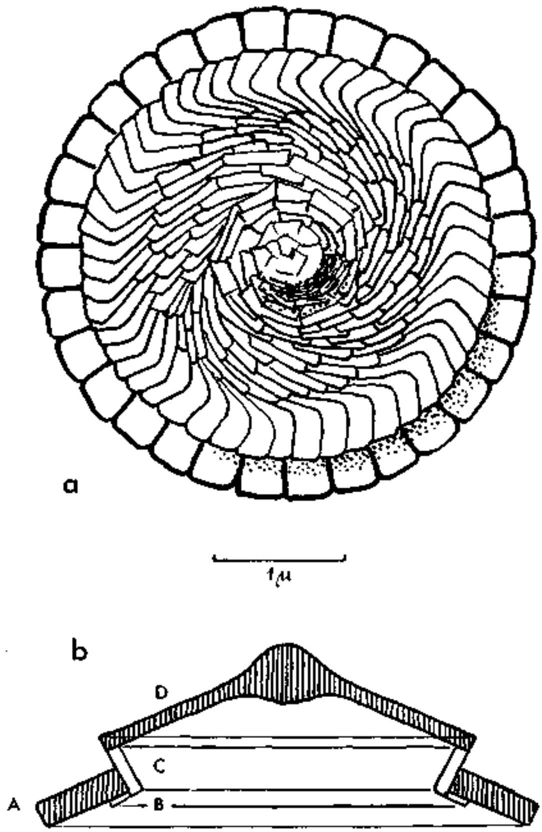
Dimensions: Diameter of basal plate 3—5 μ, height 13 μ.

Discussion: The original description of *Rhabdolithus rectus* DEFLANDRE is based on a photomicrograph of a specimen with the basal plate intact on the righthand side and partly destroyed on its lefthand side. The outer cycle (A) can be clearly discerned there from the higher central cycles. By means of the very detailed electronmicroscopic analysis of rhabdoliths by HAY & TOWE 1963 it was possible to identify the different views of this species as characteristic of the genus *Blackites* HAY & TOWE. The generotype of *Rhabdosphaera* (electron-micrographs in COHEN, 1965, pl. 22, figs. a, b; pl. 23, fig. e) also has a distinct outer cycle of crystal plates (cycle A in text above), but its basal shield is not circular but compressed elliptical and is lacking the cycle B crystals. As the name *Rhabdolithus rectus* DEFLANDRE was designating a more complete specimen than the name *Discolithus spinosus* DEFLANDRE & FERT, the former name demands priority over the latter as it could be shown that both names apply to one and the same species of *Blackites*.

The basal plate of *Blackites creber* (DEFLANDRE) differs from that of *Blackites rectus* (DEFLANDRE) by the stronger inclination of the crystal elements of the supporting cycle (B) as shown by HAY & TOWE 1963, pl. 1, fig. 4 and pl. 1, figs. 1 and 3.

New Zealand Occurrences: Present in upper Kaiatan to lowermost Whaingaroan (Upper Eocene) strata.

Other Occurrences: Lutetian of Donzacq, Landes, France. Lower Tertiary of Denmark.



Text-fig. 5: *Blackites hayi* n. sp.: a) Top view of distal side showing outermost cycle of trapezoid crystal plates (A) and cupula (D). b) Cross section reconstructed from stereo-electronmicrographs showing cycle (B) of supporting crystal rods and the reversed conical cycle (C), on which the cupula is mounted.

Blackites hayi nov. spec.

Plate 31, figs, 6 and 7, textfigs. 5 a, b

Derivation of name: Named in honour of Prof. William W. Hay, Univ. of Illinois.

Diagnosis and description: Rhabdoliths with a circular, cupula-shaped basalplate without central tube.

The outer ring (A) of trapezoid-shaped crystal plates is similar to that of *Blackites rectus* (Deflandre), as far as can be judged from the fragmentary specimen of plate 31, fig. 6. The inner cupula-shaped structure *(D)* of spirally arranged crystal units is overlapping two cycles which can be correlated with the cycles *(B)* and *(C)* of *Blackites rectus* (DEFLANDRE). There is a narrow cycle of radial crystals supporting the cycle *(A)* at its proximal side and another reversed-conical cycle *(C)* of crystal laths, which are thought to be analogous to cycle *(C)* in *Blackites rectus.* The cupula *(D)* is composed of a whirl of numerous elongated crystals adjoining and partly penetrating each other. At the centre they are turned upright so that the cupula is thicker there and appears tipped like the cupula of a mosque.

Dimensions: Diameter 3·7 μ in holotype (3376+3377/65); diameter of the cupula 2·9 μ in holotype, 2·2 μ in paratype (1899+1900/65).

Locus typicus: Diatomite at William's Bluff, Oamaru, N. Z.

Stratum typicum: Upper Eocene.

Discussion: *Blackites hayi* nov. spec. is an atypical representative of the genus because it lacks the characteristic tube or shaft. However, the ultrastructure of the basal plate leaves no doubt as to its generic position, since it shows all typical features of *Blackites* described first by HAY & TOWE.

Genus: **Cretarhabdus** BRAMLETTE & MARTINI 1964, p. 299.

Elliptical coccoliths with a central mesh structure extending distally up to a central stem or knob. Butressing bars, commonly four in number join the base of the stem.

Type species: *Cretarhabdus conicus* BRAMLETTE & MARTINI 1964.

Cretarhabdus lentus nov. spec.

Plate 44, fig. 7 and text-fig. 6

Derivation of name: lentus (lat.) = late.

Diagnosis and description: Coccoliths consisting of a broadelliptical basal plate with a narrow outer ring of about 32 relatively large, rectangular to trapezoidal plates and a wide central area completely filled in with a mesh structure of tighly packed irregular crystal units, which partly overlap each other like tiles. A robust axial cross is spanning the central area and pointing with its central knob in a distal direction.

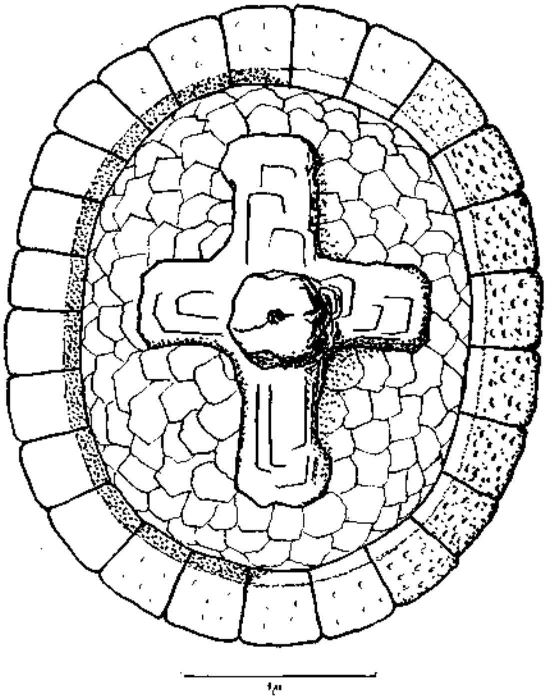
Dimensions: Length 3·8 μ, width 2·9 μ (holotype).

Holotype: 3325+3326/65.

Type-locality: Williams Bluff diatomite, Oamaru, New Zealand.

Stratum typicum: Upper Eocene.

Discussion: The stereoscopic couple of the only specimen encoutered yet does not show a second proximal basal plate. Up to now the genus *Cretarhabdus* has only been reported from Cretaceous sediments. Reworking



Text-fig. 6: *Cretarhabdus lentus* n. sp.: Reconstruction of the distal side (compare pl. 44).

has not been observed in any of the Oamaru samples. It therefore seems likely that this specimen is either of upper Eocene age or has been introduced during the laboratory preparation of this sample.

Genus: **Discolithina** * Loeblich & Tappan 1963 p. 192

Since *Discolithus vigintiforatus* Kamptner, which was designated by Loeblich & Tappan as genero-type, falls within the variation observed in *Discolithus multiporus* Kamptner, which coming first in text has priority over *Discolithus vigintiforatus*, the original description of *Discolithus multiporus* is used here as basis for the generic diagnosis.

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*) According to Noel 1965, p. 70, the genus name Discolithina Loeblich & Tappan is superfluous as in botanical nomenclature the previous genus name Discolithus Kamptner ex Deflandre 1952 cannot fall into synonymy with Discolithus Forti 1868 (foraminiferida; zool. nomencl.). As other literature shows the futile arguement as to whether the flagellata belong to the plant or animal kingdom will probably never end. Preference is given here to the new name Discolithina Loeblich & Tappan. The usage of this name will avoid any changing of the name merely because a taxon is transferred from one kingdom to the other. This is done inspite our treatment of these creatures as "algae" rather than as "animals". According to Loeblich & Tappan, p. 82, there are instances in which an organism has two different correct names, one under each code. Discolithina (zool. nomencl.) = Discolithus (bot. nomencl.) is such an example of two legal generic names.

Type species: *Discolithina multipora* (KAMPTNER) LOEBLICH & TAPPAN (incorporating *D. vigintiforatus* KAMPTNER).

Elliptical plates with tilted-up rim. Central area distally convex, proximally concave, perforated by pores in more or less circular arrangement in some species and by a central bridge structure in others. Ultrastructure of proximal surface shows radial sutures, on distal surface circular to spiral sutures, thus indicating two layers of crystal laths over all of the central area as well as in the bevelled rim.

Discolithina multipora (KAMPTNER) MARTINI

Plates 32—35, text-figs. 7 a, b

1948 *Discolithus multiporus* KAMPTNER, p. 5, pl. 1, fig. 9.
syn. *Discolithus vigintiforatus* KAMPTNER, ibidem, p. 5, pl. 1, fig. 8
1954 *Discolithus lineatus* DEFLANDRE in DEFLANDRE & FERT, pp. 137—138, pl. 10, figs. 17—18, text-fig. 50.
1960 *Discolithus* sp. B, BALDINE-BEKE, pl. 14, fig. 3.
1961 *Discolithus longiforaminis* BALDINE-BEKE, p. 164, pl. 1, figs. 3 and 3 a, b.
1961 *Discolithus distinctus* BRAMLETTE & SULLIVAN, p. 141, pl. 2, figs. 8 a, b; 9 a—c.
1962 *Cribrosphaerella* sp.; BENESOVA & HANZLIKOVA, p. 124, pl. 2, fig. 9.
1964 *Pontosphaera kautendorfensis* BACHMAYER, p. 185, pl. 2, figs. 8 and 9.
1964 *Discolithus distinctus* BRAMLETTE & SULLIVAN; SULLIVAN, p. 182, pl. 4, figs. 4, a and b.
1964 *Discolithus multiporus* KAMPTNER; STRADNER, p. 134, text-figs. 4—8.
1965 *Discolithus distinctus* BRAMLETTE & SULLIVAN; SULLIVAN p. 33, pl. 4, figs. 1 a, b; 2 a, b; 3 a, b; 4 a, b; 5 a, b; 6 a, b.
1965 *Discolithus* cf. *distinctus* BRAMLETTE & SULLIVAN; COHEN, p. 15, pl. 3, figs. r—t.
1965 *Discolithina multipora* (KAMPTNER ex DEFLANDRE) MARTINI; p. 400.
1966 *Discolithina confossa* HAY, MOHLER & WADE, p. 392, pl. 9, figs. 1—9
etiam
Pontosphaera vadosa HAY, MOHLER & WADE, p. 391, pl. 8, fig. 4, non pl. 8, figs. 1—3.
1966 *Discolithus multiporus* KAMPTNER; STRADNER & ADAMIKER, p. 340, pl. 2, fig. 1.
1967 *Discolithina distincta* (BRAMLETTE & SULLIVAN); LEVIN & JOERGER, p. 166, pl. 1, figs. 14 a, b, 15 a, b.
1967 *Discolithina* sp. aff. *D. distincta* (BRAMLETTE & SULLIVAN), GARTNER & SMITH, p. 5, pl. 6, figs. 4—6.
1968 *Discolithina multipora* (KAMPTNER) MARTINI; HAQ (in press).

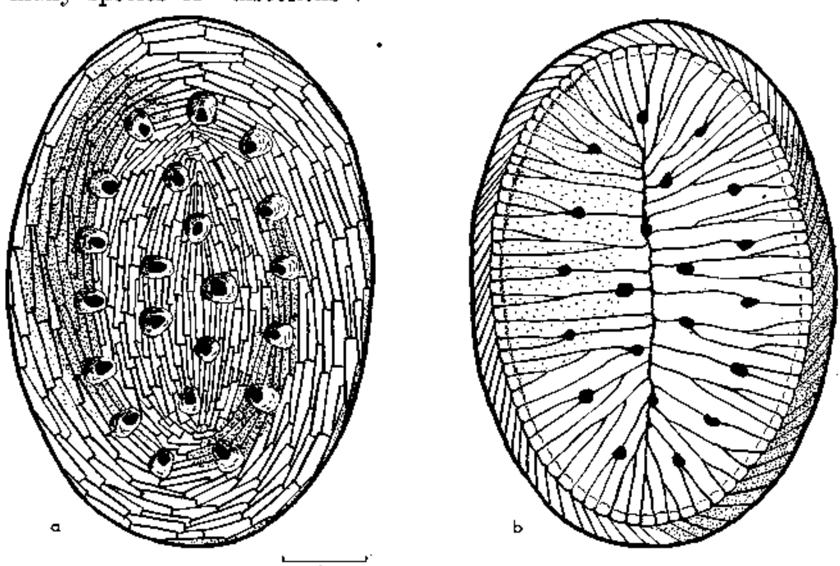
Description: Elliptical discoliths consisting of a distally vaulted basal plate with many perforations and a conically tilted-up rim without perforations. The number of pores varies from 10 to 44. The basal plate as well as the rim consist of two different layers of crystal laths having different orientations. The thicker proximal layer is composed of numerous laths which are extending peripherally from a line of commisive in the major axis of the ellipse, which terminates near the foci of the ellipse. Near the margin of the basal plate there are frequent intercalations of crystal plates which are part of the proximal layer of the rim (pl. 33, figs. 2 and 3). The proximal layer of the rim is composed of plates imbricated at an angle of 45° or more. The thinner distal layer is composed of more numerous, smaller longitudinal crystal units with inclination so strong that almost elliptical suture lines result. On close inspection one can see however that they form parts of spirals which meet the periphery after about half the way round the rim.

There is no difference in the ultrastructure of this distal layer on the basal plate and on the rim area except the different angles of sloping. The pores are arranged along one marginal ellipse which usually is very regular and in one to three irregular inner ellipses. The shape of the pores is not round, as it appears in lightmicroscope, but rather trapezoid as it is determined by the crystal arrangement of the proximal crystal layer.

Dimensions: Length: 6·4 μ, width 4·1 μ (hypotype 2960+2961/65).

Discussion: Carbon replicas usually show the surface of one side of the discolith only. However near the margin of the discolith sometimes double carbon coating of outer as well as inner surface can be observed. In such a case the different orientation of the suture lines can be seen. One such electronmicrogram is shown in Black & Barnes 1961, pl. 24, fig. 3: Due to heavy metal shadowing at a very flat angle the discolith shows on its left hand rim the striation of the under surface (proximal side) whereas the right hand side of that specimen shows the spiral striation of the upper surface (distal side) only. Another proof that the different sides of the discoliths have different surface patterns is given by transmission electronmicrographs (pl. 34, fig. 2). Still further evidence is offered by statistics (distal and proximal views equal about 50 : 50!) and by the fact that fragmentary discoliths pl. 34, fig. 1) show fracture lines along the sutures of the thicker proximal layer only disregarding the crystal arrangement of the thinner distal layer.

A new nomenclatorial problem arises from the fact that two different "views" could be proven in one species: the socalled "*Pontosphaera* view" (proximal view) and the socalled "*Discolithina* view" (distal view). A closer electronmicroscopic inspection of the genero-type of *Pontosphaera* Lohmann 1902, *P. syracusana*, will be required before deciding on the generic affiliation of many species of "discoliths".



Text-fig. 7: *Discolithina multipora* (Kamptner): Differences in the ultrastructure of the distal side (a) and the proximal side (B) due to the presence of two heterogenous layers of crystal elements.

New Zealand Occurrences: Basal Runangan (Upper Eocene) to at least Lillburnian (Middle Miocene). Its upper limit has not been determined but is definitely below the Opoitian (Pliocene).

Other Occurrences: From Middle Eocene to Miocene of Europe, North and Central America.

Discolithina obliquipons (DEFLANDRE)

Plate 36, 37; 38, figs. 1—5

1954 *Discolithus obliquipons* DEFLANDRE, in DEFLANDRE & FERT, p. 139, pl. 11, figs. 1 and 2, text-fig. 53.

1964 *Zygolithus* cf. *obliquipons* DEFLANDRE; STRADNER, p. 135, fig. 19 (err. cit. pro *Discolithus obliquipons*).

non 1966 *Transversopontis obliquipons* (DEFLANDRE) HAY, MOHLER & WADE, p. 391, pl. 8, fig. 5.

1968 *Discolithina obliquipons* (DEFLANDRE) STRADNER; HAQ (in press).

Description: Elliptical discoliths with a strongly oblique bridge consisting of two diagonally orientated extensions composed of two or more longitudinal crystal elements (pl. 36, fig. 4) tending to unite at the centre.

Analogous to *Discolithina multipora* the body of the discolith consists of two layers of crystal units with different orientation: The robust proximal layer, with radial sutures on the proximal side, forming the rim and the bridge (pl. 36, figs. 2—4), both covered by a thin layer of spirally arranged smaller crystal units on the distal side (pl. 36, fig. 1). The two oblique windows on each side of the oblique bridge are each filled with a grille composed of two rows of crystal laths (monocrystals). The rods of this grille tend towards a medial commisive, where they join to form a ridge of interpenetrating rhombohedrons, similar to that occurring in *Coccolithus parvidentatus*. Because of the oblique position of the bridge (from lower left to upper right in distal view) the medial line of the grille is shifted towards the longer diameter of the window. The grille as well as the major part of the bridge are derivates of the proximal crystal layer.

The distal crystal layer with crystal inclined between 80 and 90° is best seen on the inward sloping rim. Also the oblique bridge is covered by this layer as can be seen from the striation there in the direction of the main axis of the ellipse. The distal layer of the bridge can extend beyond the limits of the proximal crystal elements underneath it, as can be seen in pl. 36, fig. 1 and better still in electronmicrographs of discoliths from the Upper Eocene of Germany (HAQ 1968).

Dimensions: Length 4·5 μ, width 3 μ (hypotype 1072+1073/66).

Discussion: As *Discolithina obliquipons* agrees in many respects (different ultrastructure of distal and proximal side, greater emphasis on structure and sturdiness of the proximal elements) with the generotype *Discolithina multipora*, it is not separated from this genus here.

New Zealand Occurrences: Present in upper Runangan to lowermost Whaingaroan (late Upper Eocene) strata.

Other Occurrences: Upper Eocene of Lower Austria.

Discolithina pulcheroides (SULLIVAN) LEVIN & JOERGER

Plate 38, figs. 6—10

1961 *Discolithus* aff. *D. pulcher* BRAMLETTE & SULLIVAN, p. 143, pl. 3, figs. 9 a, b, 10.
1963 *Discolithus pulcher* DEFLANDRE, STRADNER, p. 160, pl. 23, fig. 10.
1964 *Discolithus pulcheroides* SULLIVAN, p. 183, pl. 4, figs. 7 a, b.
1965 *Discolithus pulcheroides* SULLIVAN, p. 43.
1966 *Transversopontis obliquipons* HAY, MOHLER & WADE, p. 391, pl. 8, fig. 5.
1967 *Discolithina pulcheroides* (SULLIVAN), LEVIN & JOERGER, p. 167, pl. 2, figs. 8 a—c.
1967 *Discolithina* sp. cf. *D. pulcheroides* (SULLIVAN); GARTNER & SMITH, p. 4, pl. 6, figs. 1—3.
1968 *Discolithina pulcheroides* (SULLIVAN), LEVIN & JOERGER; HAQ (in press).

Description: Elliptical discoliths with a somewhat oblique central bridge and a broad compact margin of basal plate. Rim conically tilted-up, widening in distal direction. Two oblique elongate openings on either side of the central bridge.

Dimensions: Length 10 μ, width 7·2 μ (specimen of pl. 38).

Discussion: This rather rare species has not been encountered in carbon films of the Oamaru sample as yet. The overall dimensions of the specimen shown in the photomicrographs of pl. 38 resemble those of the specimen shown by HAY, MOHLER & WADE in pl. 8, fig. 5.

Other Occurrences: Paleocene to Upper Eocene of Europe and North America.

Genus: **Helicosphaera** KAMPTNER 1954, pp. 21, 73, 87.

Helicoid flange surrounding a central plate, which consists of two layers of crystal units in different arrangement: the proximal side shows radial, the distal side spiral arrangement of crystal units.

Type species: *Helicosphaera carteri* (WALLICH) KAMPTNER

Helicosphaera seminulum BRAMLETTE & SULLIVAN

Plates 39 and 40

1961 *Helicosphaera seminulum* BRAMLETTE & SULLIVAN, p. 144, pl. 4, figs. 1—4.
1962 *Helicosphaera seminulum* BRAMLETTE & SULLIVAN; HAY & TOWE, p. 512, pl. 1, figs. 1—3, 5.
1964 *Helicosphaera seminulum* BRAMLETTE & SULLIVAN; SULLIVAN, p. 184, pl. 5, figs. 1 a, b; 2 a, b.
1965 *Helicosphaera seminulum* BRAMLETTE & SULLIVAN; SULLIVAN, p. 35, pl. 6, figs. 5 a, b.
1966 *Helicosphaera seminulum* BRAMLETTE & SULLIVAN; HAQ, p. 34.
1967 *Helicosphaera carteri* (WALLICH); LEVIN & JOERGER, p. 168, pl. 2, figs. 12 a—c.
1967 *Helicosphaera seminulum* BRAMLETTE & SULLIVAN; GARTNER & SMITH, p. 5, pl. 7, figs. 1—4.

Description: An elliptical basal plate with oblique central bridge and two oblique perforations surrounded by an anticlockwise coiling flange, which is a derivate of the proximal layer of crystal units of the basal plate and corresponds to the proximal layer of the rim in the genus Discolithina. The basal plate (shield in BLACK & BARNES 1961, p. 139—140) is built analogous to the basal plate of the genus Discolithina. It shows radial striation caused by the sutures between the adjoining crystal elements. Similar to the generotype *Helicosphaera carteri* not all elements reach the margin of the inner window, but some are pinched out between neighbouring plates. Bifurcating sutures are also met with on the proximal side of *Discolithina multipora* (compare pl. 33). The central bridge resembles that of *Discolithina obliquipons* in outline only. It is composed of two parts which are united at a line which may be coinciding with the minor axis of the ellipse and consists of two rows of shorter crystal elements which are aligned approximately perpendicular to a suture, which runs along the medial line of the oblique bridge. The oblique windows on either side of the bridge are filled in at their proximal side by a reticulate membrane, which, as far as can be gathered from rare fragments, at its margin consists of extensions of the crystal units of the basal plate and of smaller crystals surrounding numerous pores. The type of reticulation differs from that found in *Discolithina obliquipons* (compare pl. 36, fig. 3 and pl. 37, fig. 2). The flange of *Helicosphaera seminulum* is analogous to the proximal layer of the rim in the genus *Discolithina*. It consists of imbricate inclined crystal elements, which are inserted into and between the radial crystal elements of the proximal side of the basal plate. BLACK & BARNES aptly compared the grooved outer rim of the basal plate with the "milling of a coin". After the first half of its 1½ volutions the elements, which first are arranged in such a way that they point in peripheral and distal direction, become curved toward the proximal side and continue that way for the rest of the volution. In stereoscopic couples it can be clearly seen, that the flange is flaring out and bending concave towards the proximal side. It consists of at least 125 elongate crystal elements including the free end after the first complete volution.

Dimensions: Length 8·5 μ, width 5·4 μ in hypotype 2113+2114/65.

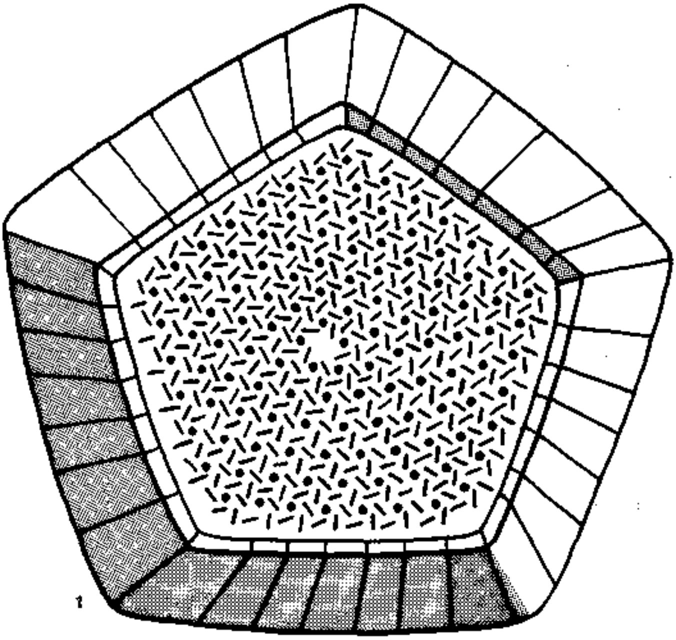
Discussion: As yet no distal view of *Helicosphaera seminulum* has been accomplished in electron microscopy. All four stereoscopic couples of Oamaru specimens as well as the electronmicrographs by HAY & TOWE 1963 show proximal views only. It can be excepted however that the distal side of this species has an ultrastructure similar to *Helicosphaera carteri* as shown by BLACK & BARNES 1961, pl. 23, fig. 2, that is a layer of spirally arranged crystal units almost in tangential direction covering the thicker proximal layer of the basal plate.

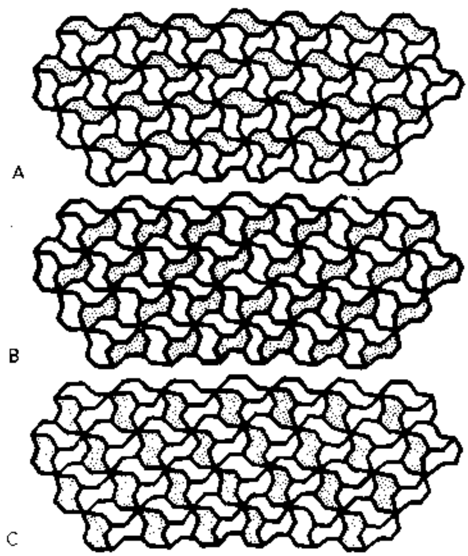
New Zealand Occurrences: Present (rare) in upper Heretaungan (early Middle Eocene ?) to Runangan (Upper Eocene) strata.

Other Occurrences: Paleocene (Ynezian) to Upper Eocene of North America and Europe.

Genus: **Goniolithus** DEFLANDRE 1957, p. 2539.

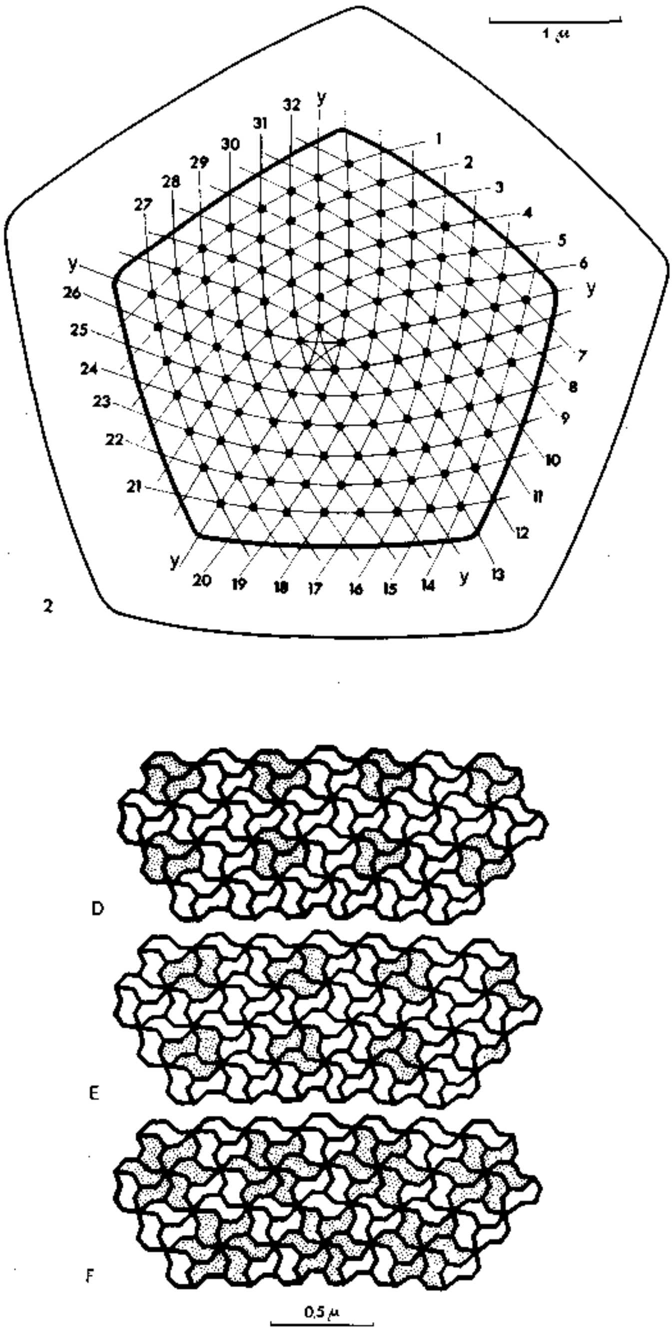
Pentagonal coccoliths consisting of a distally vaulted pentagonal basal plate composed of a great number of interpenetrating crystal triplets arranged in curved quincunx pattern. Oblique rim composed of rectangular or trape-





Text figure 8/1

Text-fig. 8/1 and 8/2: *Goniolithus fluckigeri* DEFLANDRE. Proximal view.
1. Diagram of crystal orientation in the central membrane.
A—C: Crystal pattern of central membrane with three possible directions of extinction (shaded).
2. Diagram showing position of crystal rosettes in central membrane as indicated by a dot drawn in the centre of each rosette and at the junctions of their tips. The curved



Text figure 8/2

lines connecting the centres of the rosettes are numbered clockwise from 1 to 32. Those five lines which are bifurcated at the centre are marked by the letter "y". The filling of the pentagonal central area is accomplished by means of an hexagonal quincunx pattern stressed in curved lines across a vaulted cupula-shaped field.

D—F: Different ways of interpreting the crystal pattern as "crystal triplets" (D) or (E), or as six-rayed "rosettes" (F).

zoid crystal-plates converging in proximal direction. Complete shell (resting stage ?) consisting of 12 gonioliths arranged to form a pentagon-dodekahedron.

Type species: *Goniolithus fluckigeri* DEFLANDRE.

Goniolithus fluckigeri DEFLANDRE

Plate 41 and text-figures 8/1, 2; A—F

1957 *Goniolithus fluckigeri* DEFLANDRE, p. 2539—2541, figs. 1—4.
1962 *Goniolithus fluckigeri* DEFLANDRE; DEFLANDRE, p. 5, fig. G—I.
1964 *Goniolithus fluckigeri* DEFLANDRE; MARTINI, p. 19—21, pl. 6, figs. 1—9.

Descriptions: "Gonioliths" of pentagonal outline consisting of a rim of five inclined flanks forming a frustum of a regular pentagonal pyramid opening towards the distal side. This rim is composed of 35 relatively large rectangular to trapezoidal, sometimes more rhombical crystal plates. Its outline is slightly rounded. The area within the proximal opening of the rim is filled in with a membrane composed of about 360 rhombohedrical crystals which are arranged in penetration triplets forming a quincunx pattern along curved lines (compare text-figs. 8/1 and 8/2). The membrane is distally convex and has small gaps at irregular intervals along the margin. Its centre appears rather compact. The crystal triplets are fitting together in such a way that three adjoining twisted triplets contribute to form a regular six-rayed rosette. Whether the crystal pattern is seen in terms of triplets or rosettes is more a psychological problem depending on the first impression one takes of the pattern. It is possible to let the pattern "jump" as is indicated by the text-figs. 8/A—F. No matter which view one takes of the triplets or rosettes, they are of systematic significance as is discussed below.

The ultrastructure of *Goniolithus fluckigeri* gives additional proof and explanation to the observations made by DEFLANDRE 1957 and MARTINI 1964. The heliolithic appearance in polarized light is partly due to the large plates of the rim, partly to the torsion of the crystal-rosettes of the central membrane. Those crystals which have their optical axes approximately in the same direction as the trapezoid plates of the rim, show also either extinction or birefringence together with the corresponding sector of the rim. Thus a typical heliolithic polarizing pattern results. The curvature of the central membrane, as described by MARTINI, is clearly seen in stereoscopic pictures. Viewed from the proximal side the crystal-rosettes are twisted clockwise, in distal view counterclockwise. They support MARTINI's observation, that the crystal elements of the gonioliths are arranged in a counter-clockwise way, when viewed in the complete shell, that is from the outside or distal side. The number of crystal triplets in the Oamaru specimen is approximately 120. No distal side has been observed of this species in the electronmicroscope. MARTINI's photomicrographs do not give any indication that there might be another membrane on the distal side of the goniolith.

Dimensions: Diameter 5·5 μ (hypotype 2529+2530/65).

Discussion: The ultrastructure of *Goniolithus fluckeri* proves it to be a "heterococcolith" with components of different size and form. Its pentagon-dodekahedral shell (coccosphere) is considered to be the product of the nonmotile (a-flagellate) phase in the life-cycle of this species. Also other species of flagellates and green algae, such as *Braarudosphaera bigelowi* (GRAN & BRAARUD) DEFLANDRE and *Mesotaenium dodekaedron* GEITLER produce dodekahedral shells for their non-motile phase.

On account of the crystal arrangement of the central membrane *Goniolithus fluckigeri* is related with the following genera, which are known to occur in the Mesozoic only:

Cribrosphaerella (compare *Cr. ehrenbergi* in HAY 1966, title-page),
Ethmorhabdus (compare *E. gallicus* in NOEL 1965, pl. 10, figs. 1—5),
Rhabdolithina (compare *Rh. splendens* in STRADNER, ADAMIKER & MARESCH, pl. 21—23) and
Rhagodiscus (compare *Rh. asper*, *ibidem* pl. 24).

All these genera have central membranes formed of crystal triplets.

Other Occurrences: Paleocene to Upper Eocene of Europe.

Genus incertae sedis: **Isthmolithus** DEFLANDRE 1954, p. 169

Elongate parallelograms with two transverse bars; four sutures along the main axis divide the entire frame into two identical halves.

Type species: *Isthmolithus recurvus* DEFLANDRE

Isthmolithus recurvus DEFLANDRE

Plate 45 and 46

1954 *Isthmolithus recurvus* DEFLANDRE, in DEFLANDRE & FERT, p. 169, pl. 12, figs. 9—13, textfigs. 119—122.
1956 *Coccolithus tunicellus* SHAMRAY & LAZAREVA, p. 711—714, pl. 1, fig. 12.
1958 *Isthmolithus recurvus* DEFLANDRE; MARTINI, p. 370, pl. 2, figs. 5 a—b.
1959 *Isthmolithus recurvus* DEFLANDRE; ORAVECZ, p. 429.
1960 *Isthmolithus recurvus* DEFLANDRE; MARTINI, p. 84, pl. 11, fig. 38.
1960 *Isthmolithus recurvus* DEFLANDRE; BRÖNNIMANN & STRADNER, p. 367, textfig. 44.
1960 *Isthmolithus recurvus* DEFLANDRE; BALDINE BEKE, M., p. 216, pl. 14, fig. 23.
1961 *Isthmolithus recurvus* DEFLANDRE; MARTINI, p. 18.
1962 *Isthmolithus recurvus* DEFLANDRE; MARTINI, p. 280.
1962 *Isthmolithus recurvus* DEFLANDRE; DEFLANDRE, p. 5, fig. E.
1962 *Isthmolithus recurvus* DEFLANDRE; BENESOVA & HANZLIKOVA, p. 124, pl. 2, fig. 14.
1964 *Isthmolithus recurvus* DEFLANDRE; STRADNER, p. 135, text-figs. 20 and 21.
1964 *Isthmolithus recurvus* DEFLANDRE, BYSTRICKA, p. 205, 209; pl. 5, fig. 12.
1965 *Isthmolithus recurvus* DEFLANDRE; LEVIN, pp. 269—270, pl. 42, fig. 10.
1965 *Isthmolithus recurvus* DEFLANDRE; BYSTRICKA, H. et. al., p. 227.
1966 *Isthmolithus recurvus* DEFLANDRE; HAY, MOHLER & WADE, p. 396, pl. 12, figs. 1—3, pl. 13, fig. 3.
1966 *Isthmolithus recurvus* DEFLANDRE; REINHARDT, p. 46, pl. 21, figs. 14 and 15.
1967 *Isthmolithus recurvus* DEFLANDRE; LEVIN & JOERGER, p. 173, pl. 4, fig. 11.
Isthmolithus triplus LEVIN & JOERGER, ibidem, p. 173, pl. 4, figs. 12 a, b.
1968 *Isthmolithus recurvus* DEFLANDRE; HAQ (in press).

Description: Coccoliths consisting of a wall of parallelly arranged upright crystal segments surrounding an elongate parallelogram outline. The space enclosed by this wall is subdivided by two thin septa thus forming the frames of one central rectangular and two apical trapezoid windows. Sutures are parting the septa as well as the shorter flanks of the parallelogram walls in the medial plane. Near the sutures the walls can be slightly overlapping or shifted along the medial plane. The nodular appearence near the sutures is due to a broadening of the walls and septa there. *Isthmolithus recurvus*, when lying on its side, is seen to have one margin somewhat broader than the other. The broader openings seem to point in distal direction. The ends of the parallelogram walls are slightly curved up like bow and stern of a boat.

Dimensions: Length 4·5 μ, width 1·8 μ (Hypotype 1721/65).

Discussion: It is improbable that these "isthmoliths" were solitary products of the flagellate cell, instead they are imagined to have been the elements of an elongate coccolith-shell similar to that of *Calciosolenia* with all the coccoliths orientated in one direction. It is probable that the pattern of arrangement was in accordance with the two directions of the parallelogram margins of the "isthmoliths". As yet there is no clue to the problem why this nannofossil appears to be composed of two separate asymetrical halves which have the relationship of object and shadow and identical extinction in polarizing light after 180° rotation.

Isthmolithus recurvus seems to be monotypic. *Isthmolithus claviformis* proved to belong to *Zygrhablithus bijugatus* of which it represents a certain stage of growth or a splitfragment of a disintegrated zygrhablith.

New Zealand Occurrence: Restricted to upper Kaiatan to lowermost Whaingaroan (Upper Eocene) strata.

Other Occurrences: Upper Eocene of Europe, North and Central America, Australia.

b) "Holococcoliths"

Genus: **Zygrhablithus** Deflandre 1959, p. 135

Holococcoliths consisting of an elliptic or subcircular *zygosphaera*-styled basal part in shape of a ring with a diagonal cross surmounted by a shaft with four longitudinal ridges. Entirely composed of microcrystals (calcite rhombohedrons).

Type species: *Zygrhablithus bijugatus* (Deflandre).

Zygrhablithus bijugatus (Deflandre)

Plates 42 and 43

1931 *Unnamed skeletal element*; Sujkowski, p. 510, text-fig. 1/27.
1954 *Zygolithus bijugatus* Deflandre in Deflandre & Fert, p. 148, pl. 11, figs. 20, 21; text-fig. 59.
Rhabdolithus costatus Deflandre, ibidem p. 157, pl. 11, figs. 8—11, text-figs. 41, 42, 77—79.
1959 *Zygrhablithus bijugatus* Deflandre, pp. 135—136.
1960 *Isthmolithus claviformis* Brönnimann & Stradner, p. 368, text-figs. 25—43.
1961 *Zygrhablithus bijugatus* Deflandre; Bramlette & Sullivan, p. 151, pl. 6, figs. 16 a—b, 17 a—c, 18.
Rhabdosphaera ? semiformis Bramlette & Sullivan, ibidem p. 147, pl. 5, figs. 8—10.

1962 *Zygrhablithus bijugatus* (DEFLANDRE); BOUCHE, p. 84, pl. 1, figs. 9—11.
non 1962 *Zygrhablithus bijugatus* (DEFLANDRE); HAY & TOWE, p. 502, pl. 2, fig. 2.
1962 *Zygrhablithus bijugatus* DEFLANDRE; BENESOVA & HANZLIKOVA, p. 124, pl. 2, fig. 16.
1964 *Zygrhablithus bijugatus* DEFLANDRE; SULLIVAN, p. 187, pl. 7, figs. 9 a, b; 10 a, b.
Rhabdosphaera semiformis BRAMLETTE & SULLIVAN, ibidem p. 185, pl. 7, fig. 7.
1965 *Zygrhablithus bijugatus* DEFLANDRE; SULLIVAN, p. 38.
Rhabdosphaera semiformis BRAMLETTE & SULLIVAN, ibidem p. 37, pl. 7, fig. 3.
1965 *Zygrhablithus bijugatus* DEFLANDRE, LEVIN, p. 267, pl. 42, figs. 1 a, b.
1966 *Sujkowskiella enigmatica* HAY, MOHLER & WADE, p. 397—398, pl. 13, figs. 6 and 7.
1967 *Rhabdosphaera semiformis* BRAMLETTE & SULLIVAN; LEVIN & JOERGER, p. 169, pl. 2, fig. 17.
Zygrhablithus bijugatus (DEFLANDRE); ibidem, p. 170, pl. 2, figs. 24 a—b, pl. 3, figs. 1—4.
1967 *Zygrhablithus bijugatus* (DEFLANDRE); GARTNER & SMITH, p. 5, pl. 8, figs. 1—6.
1968 *Zygrhablithus bijugatus* (DEFLANDRE) DEFLANDRE; HAQ (in press).

Description: Zygoform holococcoliths consisting entirely of microcrystals of equal size (0·1 μ). The proximal basal part is shaped to an elliptical conical ring widening towards the distal side. It is surmounted by a diagonally orientated cross-shaped bridge which extends in distal direction to form a long pyramidal shaft with four ridges. These do not extend the full length of the shaft but end somewhat underneath the rounded tip to form four projections (pl. 42, fig. 3). The grooves between the ridges begin within the four perforations of the basal part.

The two holes along the main axis are wider than the two along the minor axis. The outline of the microcrystals appears hexagonal on the surface of the shaft. It cannot be decided whether they are hexagonal prisms as supposed by HALLDAL & MARKALI in the case of the similar *Periphyllophora mirabilis* or whether they are calcite rhombohedrons as described by GAARDER for many species of holococcoliths. The distal view (pl. 42, fig. 4) indicates that the second interpretation of crystal shape may be the correct one. The hexagonal sutures between the tightly packed microcrystals can also be explained as the demarcation lines between obliquely inserted rhombohedrons instead of hexagonal prisms.

In light microscope this species usually offers itself in axial view, lateral view, or in oblique side view of key-shaped fragments. There is a plane of minor resistence against splitting along the two lateral grooves from the minor axis of the basal part up through the stem. Split halves of these coccoliths have been described under different title on several occasions.

Dimensions: Length 6·4 μ, width 4 μ, height 12 μ (pl. 42, fig. 1).

Discussion: *Zygrhablithus bijugatus* is a species of coccolithophorid, which is based on the description of the holococcoliths of the motile, presumably biflagellate, phase. Whether the nonmotile phase also built coccolithshells and of which shape these were is not known yet. Smaller holococcoliths of this species have a short shaft, which could indicate that there was dimorphism of components in one complete shell similar to the shells of living representatives of the genus *Zygosphaera*.

New Zealand Occurrences: Common in uppermost Waipawan (Lower Eocene) to Duntroonian (late Oligocene) strata.

Other Occurrences: Eocene of Europe, North and Central America.

Genus: **Zygosphaera** KAMPTNER 1936, p. 244

Zygoform holococcoliths with elliptical basal ring spanned by a transversal bridge. Dimorphism of shell components.

Type species: *Zygosphaera hellenica* KAMPTNER.

Zygosphaera aurea (STRADNER) nov. comb.

Plate 44, fig. 6

1962 *Zygolithus aureus* STRADNER, pp. 368—369, pl. 1, figs. 31—36.
1965 *Zygolithus aureus* STRADNER; LEVIN, p. 266, pl. 41, fig. 10.
1966 *Zygolithus aureus* STRADNER; STRADNER & ADAMIKER, p. 340, pl. 3, fig. 2.
1967 *Zygolithus aureus* STRADNER; LEVIN & JOERGER, p. 169, pl. 2, figs. 19—21; pl. 4, figs. 15 a, b.

Description: Zygoform holococcoliths consisting of an elliptical, distally widening conical basal ring the major axis of which is slightly arched concave towards the proximal side. The distal side of the ring is spanned by a broad bridge with two to three transversal rows of pores. These are usually arranged in a quincunx pattern.

Dimensions: Length 5 μ, width 2·8 μ (hypotype 3210+3211/65).

Discussion: The only specimen encountered in the Oamaru sample complies well with the original description of Austrian specimens.

New Zealand Occurrences: A very rare species: one specimen has been found in S 44/961 of lowermost Whaingaroan (late Upper Eocene) age at Port Elizabeth.

Other Occurrences: Upper Eocene of Lower Austria; common at Klein Schweinbarth (seismic drilling L 107/75 by ÖMVAG).

Explanations to the Plates *)

The pictorial documentation represents the essential part of every paper on calcareous nannoplankton. Without it the descriptive text would be empty words. The micrographs provide a two-dimensional record of three-dimensional entities. They are, inspite of all restrictions imposed by the technical processes, a statement about life, in our case of life about 40 million years ago (HOLMES 1959). The following 48 plates are a choice of more than 400 pictures, which in most cases are stereoscopic couples, best to be studied

*) For help in compiling the explanatory texts and for mounting the plates the authors owe thanks to Miss L. BLÜMERT and to Mrs. I. ZACK, Geologische Bundesanstalt.

with a mirror-stereoscope as is employed in photogeology. However for printing processes apart from direct photo-reproduction such stereo-couples are of limited value as they loose much of their sharpness. Therefore these stereoscopic pictures are not included here but are reserved for a special forthcoming issue.

The following plates show coccoliths from the Upper Eocene Diatomite of Williams Bluff at Oamaru, New Zealand. Three different ways of producing micrographs have been applied: light-microscopy, electron-microscopy and x-ray microscopy. The photomicrographs were taken with a REICHERT Zetopan-Pol microscope equipped with phase contrast and anoptral systems. All photomicrographs are of same magnification (5.200×). Before the photomicrographs were taken, the dry slides had received a heavy metal shadowing as recommended by DEFLANDRE & FERT 1954 and by HAY 1965. "Caedax" by E. MERCK AG, Darmstadt, with a refracting index of 1·55 was used for embedding. Only immersion objectives 100× were employed, together with ocular 12·5× and Ihagee EXAKTA VAREX for microphotography. The original magnification on the 35 mm Agfa Agepe FF film was 625×; the pictures were enlarged 10 times and afterwards reduced during the cliché making. Only positive prints of the photomicrographs as well as of the electronmicrographs are shown. The latter were taken with a SIEMENS ELMISKOP I electron microscope at the Laboratory for Electron Microscopy, Department of Medicine, Veterinary College, Vienna, at magnifications ranging from 2000 to 20.000×. The negative plates (Gevaert Scientia 23 D 50) were enlarged from 6·5×9 *cm* to the indicated scale. All plates are kept in the archives of the Electronmicroscopial Laboratory, a complete set of positive prints is deposited in the Nannoplankton Laboratory of the Geological Survey of Austria. In accordance with normal practice for carbon replicas the plates are, in the case of new species, to be considered as holotypes and paratypes respectively. The plates of the radiomicrographs taken by W. L. JONGEBLOED (pl. 47 and 48) are deposited at the Technisch Physische Dienst T. N. O. - T. H., Delft, Netherlands.

In the explanations to the micrographs the following abbreviations are used:

em	=	electronmicrograph of a platinum-iridium shadowed carbon replica
nl	=	photomicrograph, normal light, green filter
phc	=	photomicrograph, positive phase contrast, green filter
anc	=	photomicrograph, anoptral contrast, green filter
x-nic	=	photomicrograph, polarized light, crossed nicols, yellow filter

Electronmicroscopic Methods

In preparing the sample of the Oamaru Diatomite for electronmicroscopy the routine procedures and recipes given by BLACK 1961, DEFLANDRE & DURRIEU 1957, HAY 1965, NOEL 1964 and STRADNER & ADAMIKER 1966 were followed in general lines. After 15 seconds of ultrasonic treatment at 1 megahertz one drop of the water suspension was dried on a mica plate; metal-shadowing with platinum-iridium at appr. 45° was followed by carbon replication at 90° with the object rotating. The carbon film was floated off in 3% hydrochloric acid, rinsed and given a 24 hours' treatment with 3% hydrofluoric acid. After several rinsings with distilled water small patches of the film were mounted on copper grids, dried and examined in the SIEMENS ELMISKOP I. The majority of electronmicrographs are stereo-couples from exposures after + — 5 degree tilting of the grid. For further information on preparations techniques, technical data on electronmicroscopy and on the stereoscopical evaluation of electronmicrographs see: References, part 3.

Radiomicrographs

Although a practical high magnification X ray projection microscope has been available for almost 20 years (see COSSLETT & NIXON 1960), the only known application of this instrument to calcareous nannoplankton studies is by COHEN (1965, pl. 23, fig. f) who published a direct print of a radiomicrograph * of a coccolithophorid. As the instrument appeared to have considerable potential a processed ** residue of S 136/898 was sent to Drs. W. L. JONGEBLOED, Technisch Physische Dienst, Netherlands, for examination with the X-ray projection microscope. The 21 radiomicrographs provided by Drs. JONGEBLOED were obtained by the methods outlined in JONGEBLOED & JUTTE (1965), viz., the radiomicrographs are photographic enlargements of negatives taken at magnifications between 50 and 110×. Analysis of these radiomicrographs indicates that this instrument has the following applications:

1. High magnification (up to 2100×), contrast and resolution (0·3 microns) micrographs of unshadowed strew mounts for demonstrating the morphology of individual specimens (see pl. 48).

2. Stereoscopic pairs of unshadowed strew mounts, at various magnifications, for demonstrating both assemblages and individual specimens. The stereoscopic effect is more pronounced at low magnifications.

3. General survey micrographs of unshadowed strew mounts, at magnifications between 300 and 1000×, for illustrating assemblages (see pl. 47).

In all three cases the radiomicrographs are equivalent to or better than similar photomicrographs which, although capable of slightly greater resolution, have less depth of focus and a lower degree of contrast. Radiomicrographs of gold shadowed strew mounts were also provided by Drs. JONGEBLOED but the illusion of depth that resulted from this method was achieved at the expense of considerable loss in resolution. In summary the X-ray projection microscope is judged to have considerable potential as an aid in studies of the calcareous nannoplankton and other mineralized microfossils of similar size.

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*) Produced by the Technisch Physische Dienst, T. N. O. — T. H., Delft.

**) Preparation method as given by EDWARDS 1963.

Captions to Plates 1 — 48

Plate	Fig.	Object	Type of Micrograph	Magnification	Text reference
1		*Chiasmolithus oamaruensis* (DEFLANDRE), HAY, MOHLER & WADE; proximal view of coccolith with robust central cross. Hypotype: 2144/65	em	8,300×	p. 13
2		*Chiasmolithus oamaruensis* (DEFLANDRE), HAY, MOHLER & WADE; proximal view of smaller coccolith with delicate cross. Hypotype: 3212/65	em	16,350×	
3	1	*Chiasmolithus oamaruensis* (DEFLANDRE), HAY, MOHLER & WADE; proximal view showing structure and thickness of proximal shield. Hypotype: 2965/65	em	20,000×	
	2	*Chiasmolithus oamaruensis* (DEFLANDRE), HAY, MOHLER & WADE; proximal view showing the relief inside the groove between distal shield (left) and the proximal shield (broken off). Insertation of proximal shield crystals marked by arrows. Hypotype: 1919+1920/65	em	26,000×	
4	1	*Chiasmolithus oamaruensis* (DEFLANDRE), HAY, MOHLER & WADE; oblique proximal view showing thickness of proximal shield and depth of groove. Hypotype: 3394+3395/65	em	15,000×	
	2	*Chiasmolithus oamaruensis* (DEFLANDRE), HAY, MOHLER & WADE; distal view; lateral part of coccolith showing insertation of central cross. Hypotype: 3387/65	em	16,500	
5	1	*Chiasmolithus oamaruensis* (DEFLANDRE), HAY, MOHLER & WADE; proximal view.	nl		
	2	Same specimen	phc		
	3	Same specimen	anc		
	4	Same specimen	x-nic	4,300×	
6	1	*Coccolithus eopelagicus* (BRAMLETTE & RIEDEL), BRAMLETTE & SULLIVAN; proximal view of coccolith.	nl	5,200×	p. 15
	2	Same specimen	phc		
	3	Same specimen	anc		
	4	Same specimen	x-nic		
7	1	*Coccolithus parvulus* (DEFLANDRE & FERT), nov. comb.; distal view. Hypotype: 2140+2141/65	em	28,200×	p. 16
	2	*Coccolithus parvulus* (DEFLANDRE & FERT), nov. comb.; proximal view. Hypotype: 2119+2120/65	em	40,600×	
	3	*Coronocyclus prionion* (DEFLANDRE & FERT), nov. comb.; plan view. Hypotype: 2927+2928/65	em	24,000×	p. 28
	4	*Cyclolithella inflexa* (KAMPTNER), LOEBLICH & TAPPAN; plan view. Hypotype: 1819+1820/65	em	21,600×	p. 25
8	1	*Ericsonia ovalis* BLACK; distal view of a specimen with 31 crystal plates in distal shield. Hypotype: 2893+2894/65	em	12,500×	p. 17

Plate	Fig.	Object	Type of Micrograph	Magnification	Text reference
8	2	*Ericsonia ovalis* BLACK; proximal view of distal shield, proximal shield completely broken off.			p. 17
		Hypotype: 1905+1906/65	em	12,500×	
	3	*Ericsonia ovalis* BLACK; proximal view of fairly complete specimen.			
		Hypotype: 2966/65	em	13,300×	
	4	*Ericsonia ovalis* BLACK; proximal view of two specimens in same position as in the complete coccosphere. The distal shield of the specimen in the upper right is inserted in the groove between distal and proximal shield of the specimen in the lower left.			
		Hypotype: 3167+3168/65	em	12,500×	
9	1	*Ericsonia ovalis* BLACK; distal view.	nl		
	2	Same specimen	phc		
	3	Same specimen	anc		
	4	Same specimen	x-nic		
	5	Ericsonia ovalis BLACK; proximal view.	phc		
	6	Same specimen; high focus	anc		
	7	Same specimen; low focus.	anc		
	8	Same specimen	x-nic	5,200×	
10	1	*Ericsonia fenestrata* (DEFLANDRE & FERT), nov. comb.; distal view.			p. 18
		Hypotype: 2922/65	em	17,500×	
	2	*Ericsonia fenestrata* (DEFLANDRE & FERT), nov. comb.; proximal view.			
		Hypotype: 1901+1902/65	em	17,000×	
	3	*Ericsonia fenestrata* (DEFLANDRE & FERT), nov. comb.; distal view.			
		Hypotype: 1929+1930/65	em	15,000×	
	4	*Ericsonia fenestrata* (DEFLANDRE & FERT), nov. comb.; distal view.			
		Hypotype: 2907+2908/65	em	17,500×	
11	1	*Ericsonia fenestrata* (DEFLANDRE & FERT), nov. comb.; distal view.			
		Hypotype: 1979/65	em	25,000×	
	2	*Ericsonia fenestrata* (DEFLANDRE & FERT), nov. comb.; plan view.	nl		
	3	Same specimen	phc		
	4	Same specimen	anc		
	5	*Ericsonia fenestrata* (DEFLANDRE & FERT), nov. comb.; plan view.	phc		
	6	Same specimen	anc		
	7	Same specimen	x-nic	5,200×	
12	1	*Reticulofenestra dictyoda* (DEFLANDRE & FERT), HAY, MOHLER & WADE; distal view of specimen with small central area.			p. 19
		Hypotype: 1977+1978/65	em	10,800×	
	2	*Reticulofenestra dictyoda* (DEFLANDRE & FERT), HAY, MOHLER & WADE; distal view of smaller specimen with wide central area.			
		Hypotype: 3164/65	em	18,250×	
	3	*Reticulofenestra dictyoda* (DEFLANDRE & FERT), HAY, MOHLER & WADE; proximal view of specimen with serrate margin.			
		Hypotype: 1807+1808/65	em	10,800×	

Plate	Fig.	Object	Type of Micrograph	Magnification	Text reference
12	4	*Reticulofenestra dictyoda* (Deflandre & Fert), Hay, Mohler & Wade; proximal view. Hypotype: 1893+1894/65	em	10,800×	p. 19
13	1	*Reticulofenestra dictyoda* (Deflandre & Fert), Hay, Mohler & Wade; proximal view of specimen with overcalcification of central area. Hypotype: 1907+1908/65	em	15,000×	
	2	*Reticulofenestra dictyoda* (Deflandre & Fert), Hay, Mohler & Wade; oblique proximal view of fragmentary coccolith showing part of proximal shield with rods of reticule; distal shield in the background separated by groove. Hypotype: 2987+2988/65	em	24,000×	
14	1	*Reticulofenestra dictyoda* (Deflandre & Fert), Hay, Mohler & Wade; proximal view of specimen with comparatively wide central area. Hypotype: 2929/65	em	33,200×	
	2	*Reticulofenestra dictyoda* (Deflandre & Fert), Hay, Mohler & Wade; proximal view.	nl		
	3	Same specimen	anc		
	4	Same specimen	phc		
	5	Same specimen	x-nic	5,200×	
15	1	*Reticulofenestra dupouyi* (Deflandre & Fert), Hay, Mohler & Wade; distal view of specimen. Hypotype: 2142+2143/65	em	32,500×	p. 20
	2	*Reticulofenestra* cf. *dupouyi* (Deflandre & Fert), Hay, Mohler & Wade; distal view, central area and surrounding tube overcalcified. Hypotype: 1839+1840/65	em	20,000×	
	3	*Reticulofenestra dupouyi* (Deflandre & Fert), Hay, Mohler & Wade; distal view, central net slightly damaged. Hypotype: 2921+2922/65	em	20,000×	
	4	*Reticulofenestra dupouyi* vel *dictyoda* (Deflandre & Fert), Hay, Mohler & Wade; proximal view, central net not fully developed. Hypotype: 2151+2152/65	em	24,000×	
16	1	*Reticulofenestra oamaruensis* (Deflandre & Fert), nov. comb.; proximal view. Hypotype: 1911+1912	em	16,600×	p. 21
17	1	*Reticulofenestra oamaruensis* (Deflandre & Fert), nov. comb.; proximal view showing suture-line of central net (near upper margin); pores partly filled in. Hypotype: 3249+3250/65	em	24,000×	
	2	*Reticulofenestra oamaruensis* (Deflandre & Fert), nov. comb.; proximal view showing insertation of central net. Hypotype: 2500+2501/65	em	22,400×	

Plate	Fig.	Object	Type of Micrograph	Magnification	Text reference
18	1	*Reticulofenestra oamaruensis* (DEFLANDRE & FERT) nov. comb.; plan view.	nl		p. 21
	2	Same specimen	phc		
	3	Same specimen	anc		
	4	Same specimen	x-nic	5,200 ×	
19	1	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; distal view of coccolith without central net. Hypotype: 1903+1904/65	em	10,800 ×	p. 22
	2	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; proximal view showing a few remaining rods of central net-structure and proximal side of central cover. Hypotype: 3385+3386/65	em	20,750 ×	
20	1	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; distal view of central net. Hypotype: 1795+1796/65	em	23,250 ×	
	2	*Reticulofenestra placomorpha* (KAMPTNER); distal view showing insertation of central net. Hypotype: 1823+1824/65	em	20,750 ×	
21	1	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; distal view of coccolith with central cover. Hypotype: 2964/65	em	9,000 ×	
	2	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; oblique distal view into the crater of the central cover. Hypotype: 2932/65	em	15,000 ×	
22	1	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; distal view of specimen with broad central ring (= partly formed central cover). Hypotype: 2589+2590/65	em	16,600 ×	
	2	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; distal view of small specimen with traces of central ring (see arrow!). Hypotype: 2975+2976/65	em	19,900 ×	
	3	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; distal view of separate central cover. Hypotype: 3165+3166/65	em	14,100 ×	
	4	*Reticulofenestra dictyoda* (DEFLANDRE & FERT), HAY, MOHLER & WADE; proximal view of large coccolith with comparatively small central area. Hypotype: 2923+2924/65	em	14,100 ×	p. 19
23	1, 2	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; Electron transmission micrographs of non-replicated specimens showing structure of central net. a = monocrystal, b = rhombohedric crystal. Hypotypes: 1076/66 and 1074/66		50,500 × (fig. 1) 47,750 × (fig. 2)	p. 22

Plate	Fig.	Object	Type of Micrograph	Magnification	Text reference
24	1	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; distal view.	nl		p. 22
	2	Same specimen (high focus)	phc		
	3	Same specimen (low focus); also proximal shield clearly visible.	phc		
	4	Same specimen	anc	5,200 ×	
25	1	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; a) larger specimen in proximal view, central area partly closed by fragmentary central cover; b) smaller specimen in distal view, central area open. Hypotypes: 2504/65 (a+b)	em	10,000 ×	
	2	*Reticulofenestra placomorpha* (KAMPTNER) nov. comb.; distal view; (same specimen as shown in plate 24).	x-nic	5,200 ×	
	3	Undetermined small coccolith, possibly *Coccolithus parvulus* (DEFLANDRE & FERT) nov. comb.	phc		p. 16
	4	Same specimen	anc		
	5	Same specimen	x-nic		
	6	Undetermined small coccolith, possibly *Cyclolithella inflexa* (KAMPTNER)	anc	5,200 ×	p. 25
26	1	*Cyclococcolithus inversus* (DEFLANDRE), HAY, MOHLER & WADE; distal view. Hypotype: 1895+1896/65	em	14,000 ×	p. 25
	2	*Cyclococcolithus inversus* (DEFLANDRE), HAY, MOHLER & WADE; proximal view. Hypotype: 2945+2946/65	em	14,000 ×	
27	1	*Cyclococcolithus inversus* (DEFLANDRE), HAY, MOHLER & WADE; coccosphere.	nl		
	2	Same specimen	x-nic		
	3	*Cyclococcolithus inversus* (DEFLANDRE), HAY, MOHLER & WADE; distal view of single coccolith at high focus, showing distal shield.	nl		
	4	Same specimen, at low focus showing proximal shield.	nl		
	5	Same specimen	anc		
	6	Same specimen	x-nic	5,200 ×	
28	1	*Ilselithina iris* STRADNER; distal view of proximal shield and central core. Distal shield broken off. Paratype: 2502+2503/65	em	20,000 ×	p. 26
	2	*Ilselithina iris* STRADNER; proximal view showing proximal shield and central core, distal shield in the background. Paratype: 3206+3207/65	em	20,000 ×	
	3	*Ilselithina iris* STRADNER; proximal view of perforated central core with fragments of distal shield. Paratype: 2897+2898/65	em	20,000 ×	

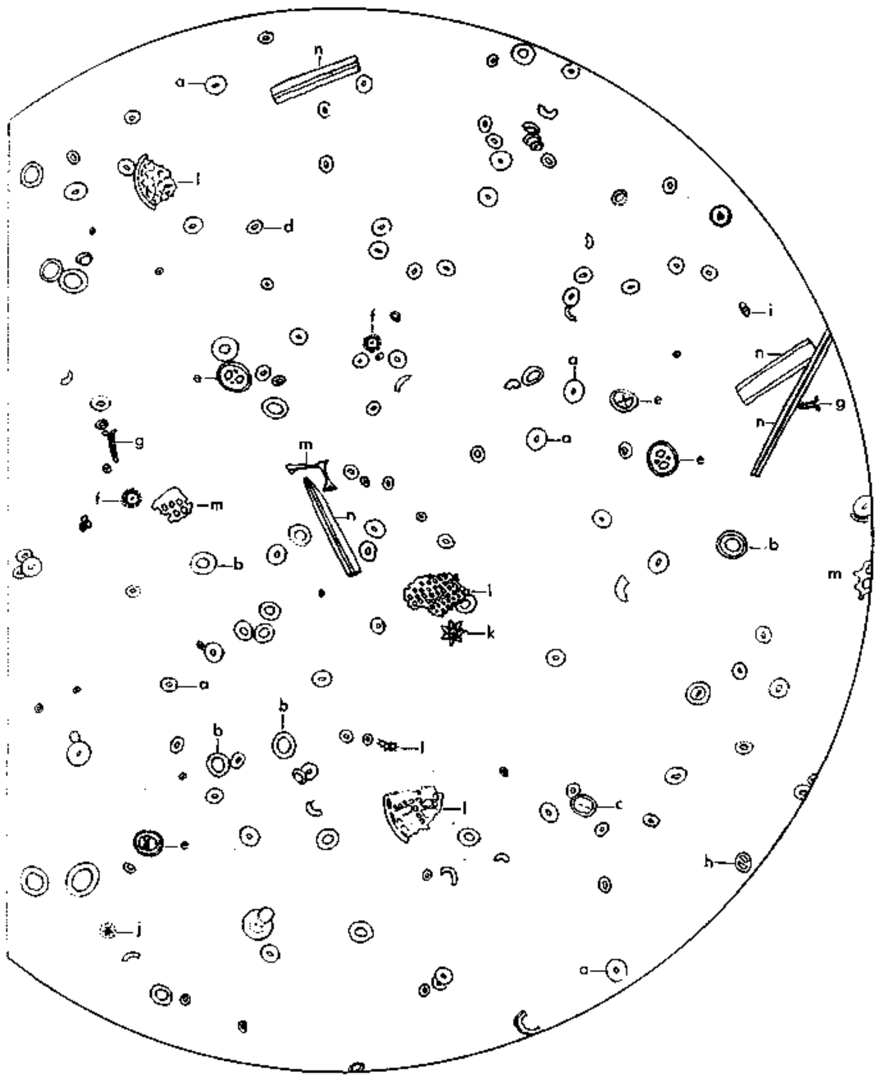
Plate	Fig.	Object	Type of Micrograph	Magnification	Text reference
28	4	*Iselithina iris* STRADNER; distal view of separate core with narrow perforation.			p. 26
		Paratype: 2505+2506/65	em	20,000×	
	5	*Iselithina iris* STRADNER; distal view showing complete distal shield, central core and fragmentary proximal shield in background (marked by arrow).			
		Holotype: 2595+2596/65	em	20,000×	
	6	*Iselithina iris* STRADNER; distal view showing fragmentary distal shield (two "mushrooms" only) and proximal shield in the background.			
		Paratype: 3349+3350/65	em	20,000×	
29	1	*Iselithina iris* STRADNER; distal view of specimen in high focus showing distal shield (a) and outline of proximal shield (b).	phc		
	2	Same specimen at low focus showing core and proximal shield (b) One element missing.	phc		
	3	Same specimen at low focus	anc		
	4	Same specimen	x-nic	5,200×	
	5	*Iselithina iris* STRADNER; proximal view of proximal shield showing crooked suture lines on the central core.			
		Paratype: 2533+2534/65	em	36,500×	
	6	*Iselithina iris* STRADNER; electron transmission micrograph showing elements of distal shield (a) and proximal shield (b).			
		Paratype: 1071/66			
30	1	*Blackites rectus* (DEFLANDRE) nov. comb.; lateral view of stem and fragmentary shield.			p. 29
		Hypotype: 2913+2914/65	em	20,000×	
	2	*Blackites rectus* (DEFLANDRE) nov. comb.; lateral view of a more distal portion of the stem.			
		Hypotype: 2609+2610/65	em	20,000×	
	3	*Blackites rectus* (DEFLANDRE) nov. comb.; distal view of shield, stem broken off or not developed.			
		Hypotype: 2983+2984/65	em	19,000×	
	4	*Blackites rectus* (DEFLANDRE) nov. comb.; proximal view of shield showing cycle of crystal-rods supporting the outer rim.			
		Hypotype: 3327+3328/65	em	19,000×	
31	1	*Blackites rectus* (DEFLANDRE) nov. comb.; lateral view.	nl		
	2	Same specimen	phc		
	3	Same specimen	anc		
	4	Same specimen	x-nic		
	5	Same specimen	x-nic	5,200×	
	6	*Blackites hayi* nov. spec., distal view showing complete cupula and fragmentary outer rim.			p. 32
		Holotype: 3376+3377/65	em	24,000×	
	7	*Blackites hayi* nov. spec., oblique side view of proximal side of cupula.			
		Paratype: 1899+1900/65	em	40,500×	

Plate	Fig.	Object	Type of Micrograph	Magni-fication	Text reference
32	1	*Discolithina multipora* (KAMPTNER), MARTINI; distal view showing spiral arrangement of crystals. Hypotype: 2960+2961/65	em	14,000×	p. 35
	2	*Discolithina multipora* (KAMPTNER), MARTINI; distal view. Hypotype: 2593+2594/65	em	14,000	
	3	*Discolithina multipora* (KAMPTNER), MARTINI; distal view. Hypotype: 2917+2918/65	em	14,000×	
	4	*Discolithina multipora* (KAMPTNER), MARTINI; distal view. Hypotype: 2947+2948/65	em	24,000×	
33	1	*Discolithina multipora* (KAMPTNER), MARTINI; proximal view showing radial arrangement of crystals in elliptical shield. Hypotype: 1821+1822/65	em	20,000×	
	2	*Discolithina multipora* (KAMPTNER), MARTINI; proximal view showing irregularity in marginal crystals (contact with adjoining discolith?) Hypotype: 1913+1914/65	em	20,750×	
	3	*Discolithina multipora* (KAMPTNER), MARTINI; proximal view; intercalations of crystals near the margin of elliptical shield. Hypotype: 1925+1926/65	em	20,000×	
34	1	*Discolithina multipora* (KAMPTNER), MARTINI; distal view of fragmentary discolith showing fracture lines along the radial suture lines of the proximal layer (a und b) and along the main axis (c). Hypotype: 2517/65	em	19,000×	
	2	*Discolithina multipora* (KAMPTNER), MARTINI; Electron transmission micrograph of non-replicated specimen showing predominant radial bars of the thick proximal crystal layer (p) and spiral arrangement of thin distal crystal layer (d). Hypotype: 1077/66		22,500×	
35	1	*Discolithina multipora* (KAMPTNER), MARTINI; plan view.	nl		
	2	Same specimen	anc		
	3	Same specimen	x-nic		
	4	Same specimen	x-nic	5,200×	
	5	*Discolithina multipora* (KAMPTNER), MARTINI; plan view.	phc		
	6	Same specimen	anc		
	7	Same specimen	x-nic		
	8	Same specimen	x-nic	5,200×	
36	1	*Discolithina obliquipons* (DEFLANDRE) nov. comb.; distal view. Hypotype: 1878+1879/65	em	20,000×	p. 37
	2	*Discolithina obliquipons* (DEFLANDRE) nov. comb.; proximal view. Hypotype: 1915+1916/65	em	20,000×	

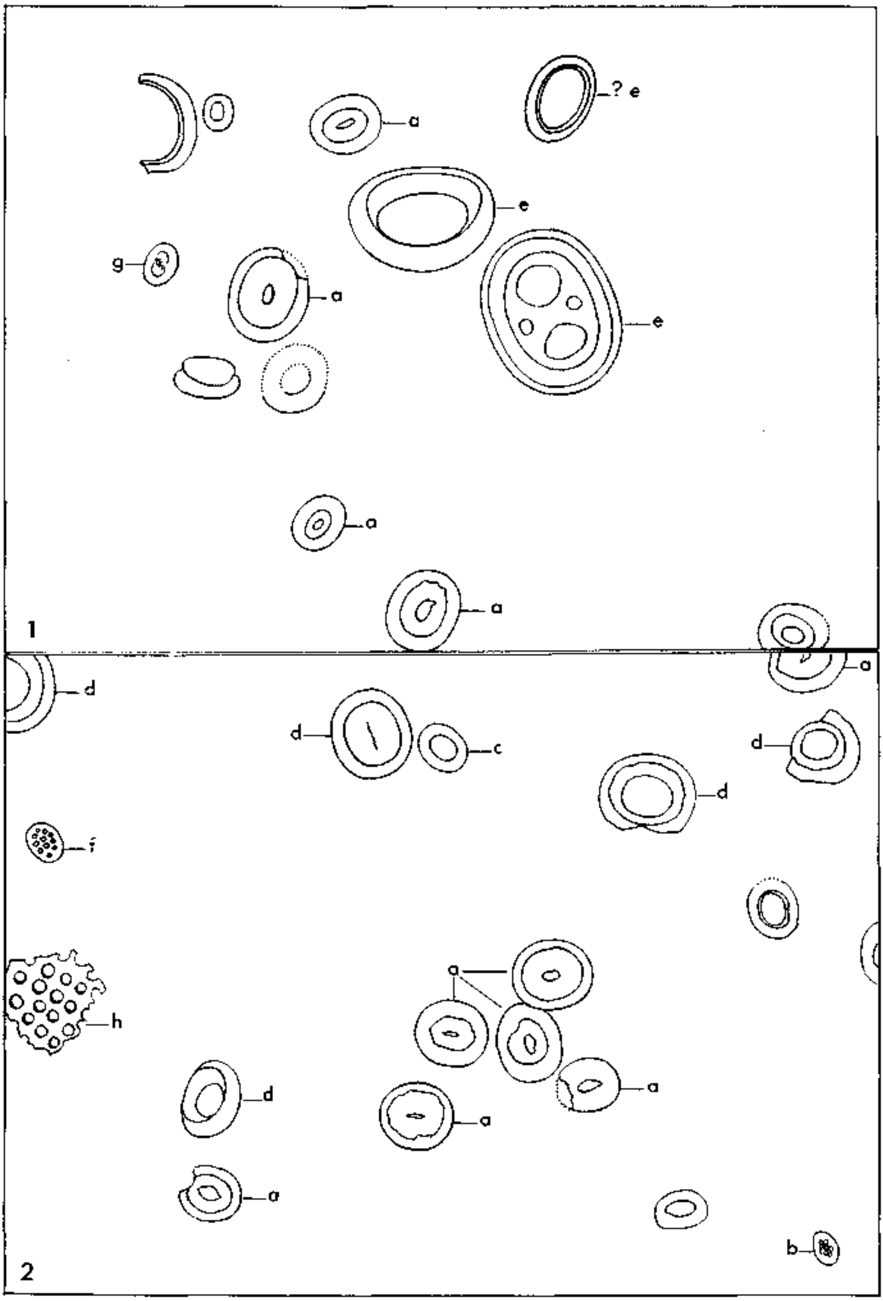
Plate	Fig.	Object	Type of Micrograph	Magnification	Text reference
36	3	*Discolithina obliquipons* (DEFLANDRE) nov. comb.; proximal view showing partly preserved reticulate filling of the two windows. Hypotype: 2115+2116/65	em	20,000×	p. 37
	4	*Discolithina obliquipons* (DEFLANDRE) nov. comb.; proximal view. Hypotype: 2979/65	em	20,000×	
37	1	*Discolithina obliquipons* (DEFLANDRE) nov. comb.; distal view. Hypotype: 3247/65	em	25,000×	
	2	*Discolithina obliquipons* (DEFLANDRE) nov. comb.; Electron transmission micrograph showing fairly well preserved grids in both windows. Hypotype: 1072/66		30,000×	
38	1	*Discolithina obliquipons* (DEFLANDRE) nov. comb.; distal view.	nl		
	2	Same specimen	phc		
	3	Same specimen	anc		
	4	Same specimen	x-nic		
	5	Same specimen	x-nic		
	6	*Discolithina pulcheroides* (SULLIVAN) nov. comb.; plan view.	nl		p. 38
	7	Same specimen	phc		
	8	Same specimen	anc		
	9	Same specimen	x-nic		
	10	Same specimen	x-nic	5,200×	
39	1	*Helicosphaera seminulum* BRAMLETTE & SULLIVAN; proximal view. Hypotype: 2113+2114/65	em	23,250×	p. 38
40	1	*Helicosphaera seminulum* BRAMLETTE & SULLIVAN; proximal view showing arrangement of crystals in basal plate. Hypotype: 1799+1800/65	em	24,000×	
	2	*Helicosphaera seminulum* BRAMLETTE & SULLIVAN; distal view.	nl		
	3	Same specimen	phc		
	4	Same specimen	anc		
	5	Same specimen	x-nic	5,200×	
41	1	*Goniolithus fluckigeri* DEFLANDRE; proximal view showing crystal arrangement of concave central plate. Hypotype: 2529+2530/65	em	24,000×	p. 42
	2	Upper left margin of central plate in same specimen.	em	45,000×	
42	1	*Zygrhablithus bijugatus* DEFLANDRE; lateral view. Hypotype: 2933+2934/65	em	15,000×	p. 44
	2	*Zygrhablithus bijugatus* DEFLANDRE; ultrastructure of lateral groove at about the middle of stem. Hypotype: 3388/65	em	40,000×	

Plate	Fig.	Object	Type of Micrograph	Magnification	Text reference
42	3	*Zygrhablithus bijugatus* DEFLANDRE; lateral view of specimen with pronounced ridges. Hypotype: 3160+3161/65	em	15,000×	p. 44
	4	*Zygrhablithus bijugatus* DEFLANDRE; distal (or apical) view of small specimen. Hypotype: 2919+2920/65	em	15,750×	
43	1	*Zygrhablithus bijugatus* DEFLANDRE; plan view.	nl		
	2	Same specimen	phc		
	3	Same specimen	anc		
	4	Same specimen	x-nic	5,200×	
	5	*Zygrhablithus bijugatus* DEFLANDRE; lateral view of separate fragment.	phc		
	6	Same specimen	anc	5,200×	
	7	*Zygrhablithus bijugatus* DEFLANDRE; lateral view; lateral perforation marked by arrow.	phc		
	8	Same specimen	x-nic		
	9	Same specimen	x-nic	5,200×	
44	1	*Cruciolithus cruciformis* (HAY & TOWE) nov. comb.; plan view.	nl		p. 17
	2	Same specimen	phc		
	3	Same specimen	anc		
	4	Same specimen	x-nic	5,200×	
	5	*Coccolithus* sp., Holococcolith of the motile phase. Hypotype: 2989+2990/65	em	27,500×	p. 24
	6	*Zygosphaera aurea* (STRADNER) nov. comb.; distal view showing perforated bridge. Hypotype: 3210+3211/65	em	19,000×	p. 46
	7	*Cretarhabdus lentus* nov. spec. Distal view. Holotype: 3325+3326/65	em	24,000×	p. 33
45	1	*Isthmolithus recurvus* DEFLANDRE; plan view, showing suture-lines between flank-sections. Hypotype: 1704/65	em	30,000×	p. 43
	2	*Isthmolithus recurvus* DEFLANDRE; oblique plan view. Hypotype: 1721+1722/65	em	30,000×	
	3	*Isthmolithus recurvus* DEFLANDRE; inner view of a separate flank-section. Hypotype: 1837+1838/65	em	30,000×	
	4	*Isthmolithus recurvus* DEFLANDRE; oblique side-view showing crystal-arrangement of flank-section. Hypotype: 2911+2912/65	em	30,000×	
46	1	*Isthmolithus recurvus* DEFLANDRE; side view showing lateral relief of flank. Hypotype: 2970+2971/65	em	15,000×	
	2	*Isthmolithus recurvus* DEFLANDRE	nl		
	3	Same specimen	phc		
	4	Same specimen	anc		
	5	Same specimen	x-nic	5,200×	
	6	*Isthmolithus recurvus* DEFLANDRE; side view.	anc	5,200×	

Plate	Fig.	Object	Magnification	Text reference
47		Radiomicrograph taken by Drs. W. L. JONGEBLOED with the X-ray projection microscope of the Technical Physics Department, T.N.O. & T.H., Delft, Netherlands.		p. 48
		Plate no. 6149, k. V. 12, target Au.	370×	
		Key to the nannofossils shown in the radiomicrograph (text-fig. 9).		
	a	*Ericsonia ovalis*, sensu lato		
	b	*Reticulofenestra placomorpha*		
	c	*Reticulofenestra oamaruensis*		
	d	*Reticulofenestra dictyoda*		
	e	*Chiasmolithus oamaruensis*		
	f	*Blackites rectus*		
	g	*Zygrhablithus bijugatus*		
	h	*Discolithina pulcheroides*		
	i	*Isthmolithus recurvus*		
	j	*Trochoaster operosus*		
	k	*Discoaster saipanensis*		
	l	Fragments of diatoms *(Centrales)*		
	m	Fragments of Radiolaria		
	n	Sponge spicules		
48		Radiomicrographs taken by Drs. W. L. JONGEBLOED with the X-ray projection microscope of the Technical Physics Department, T.N.O. & T.H., Delft, Netherlands.		
		Plate no. 6349 (picture 1) and plate no. 6353 (picture 2), k. V. 12, target Au.	1,750×	
		Key to the nannofossils shown in the radiomicrographs (text-fig. 10)		
	a	*Ericsonia ovalis*, sensu lato		
	b	*Ericsonia fenestrata*		
	c	*Reticulofenestra dictyoda*		
	d	*Reticulofenestra placomorpha*		
	e	*Chiasmolithus oamaruensis*		
	f	*Discolithina multipora*		
	g	*Discolithina obliquipons*		
	h	Fragment of diatom *(Centrales)*		



Text-fig. 9: Key to the nannofossils shown in the radiomicrograph of pl. 47.



Text-fig. 10: Key to the nannofossils shown in the radiomicrographs of pl. 48.

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a) Electronmicroscopy and Preparation Techniques

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b) X-ray Projection Microscopy

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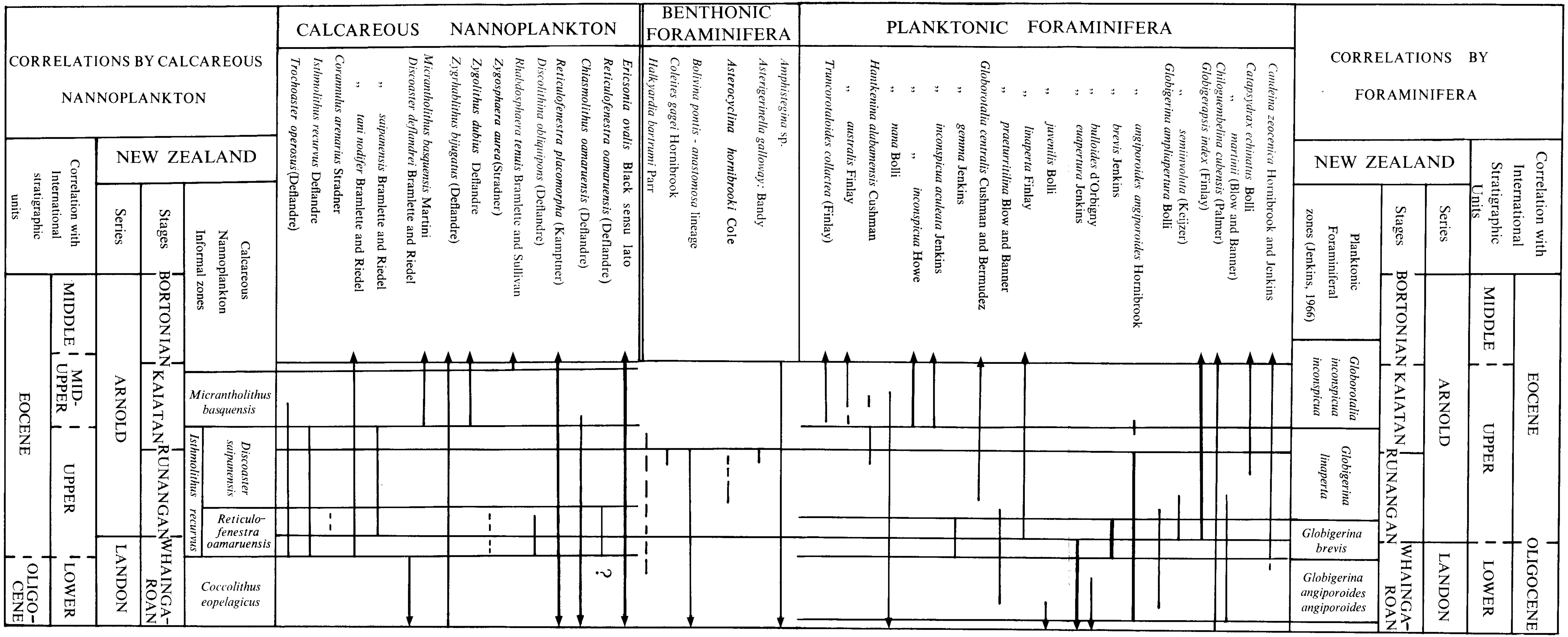
TABLE II



New Zealand Upper Eocene Key Species (compiled from COLE, 1967; HORNIBROOK, 1961; JENKINS, 1966; and unpublished investigations by A. R. EDWARDS).

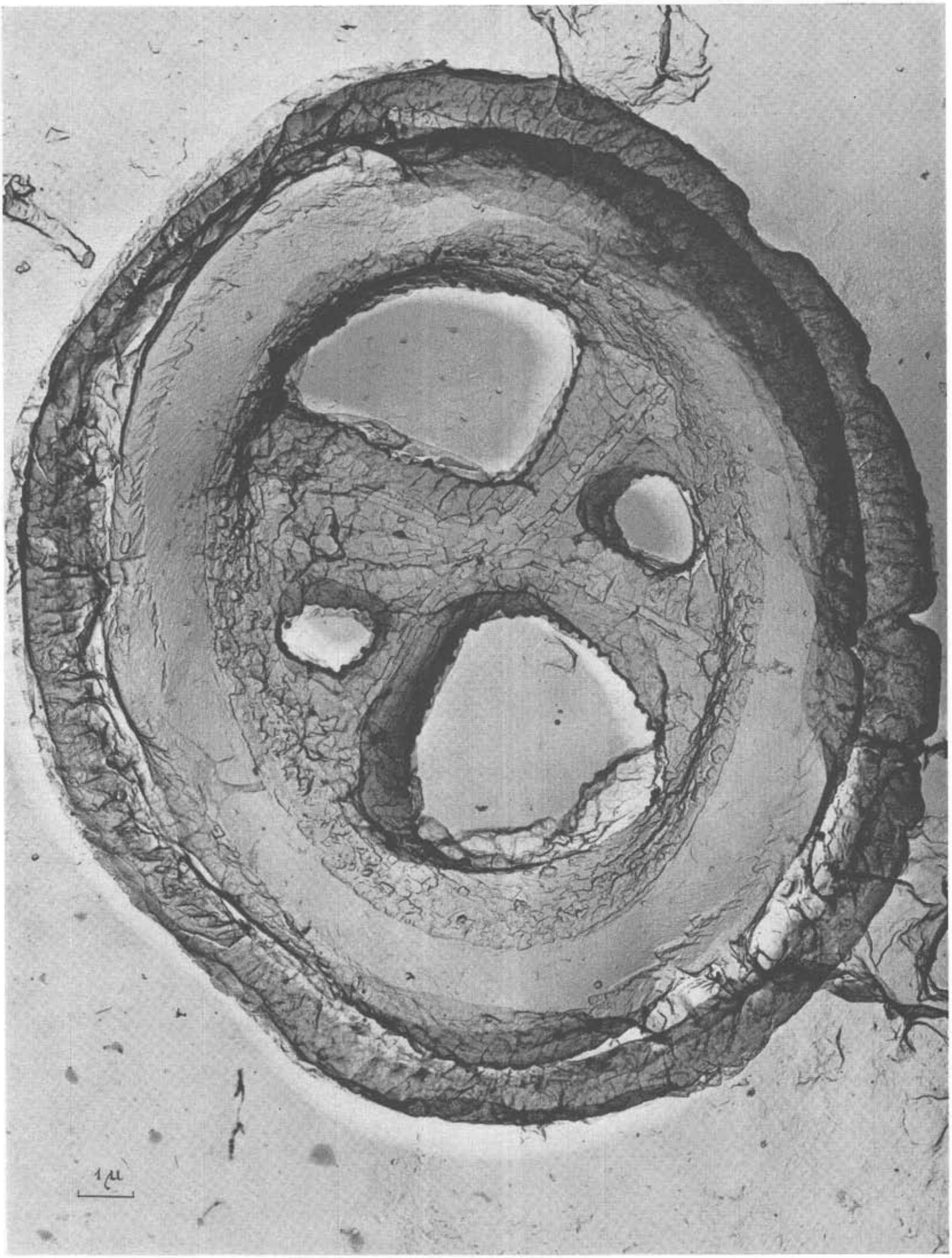
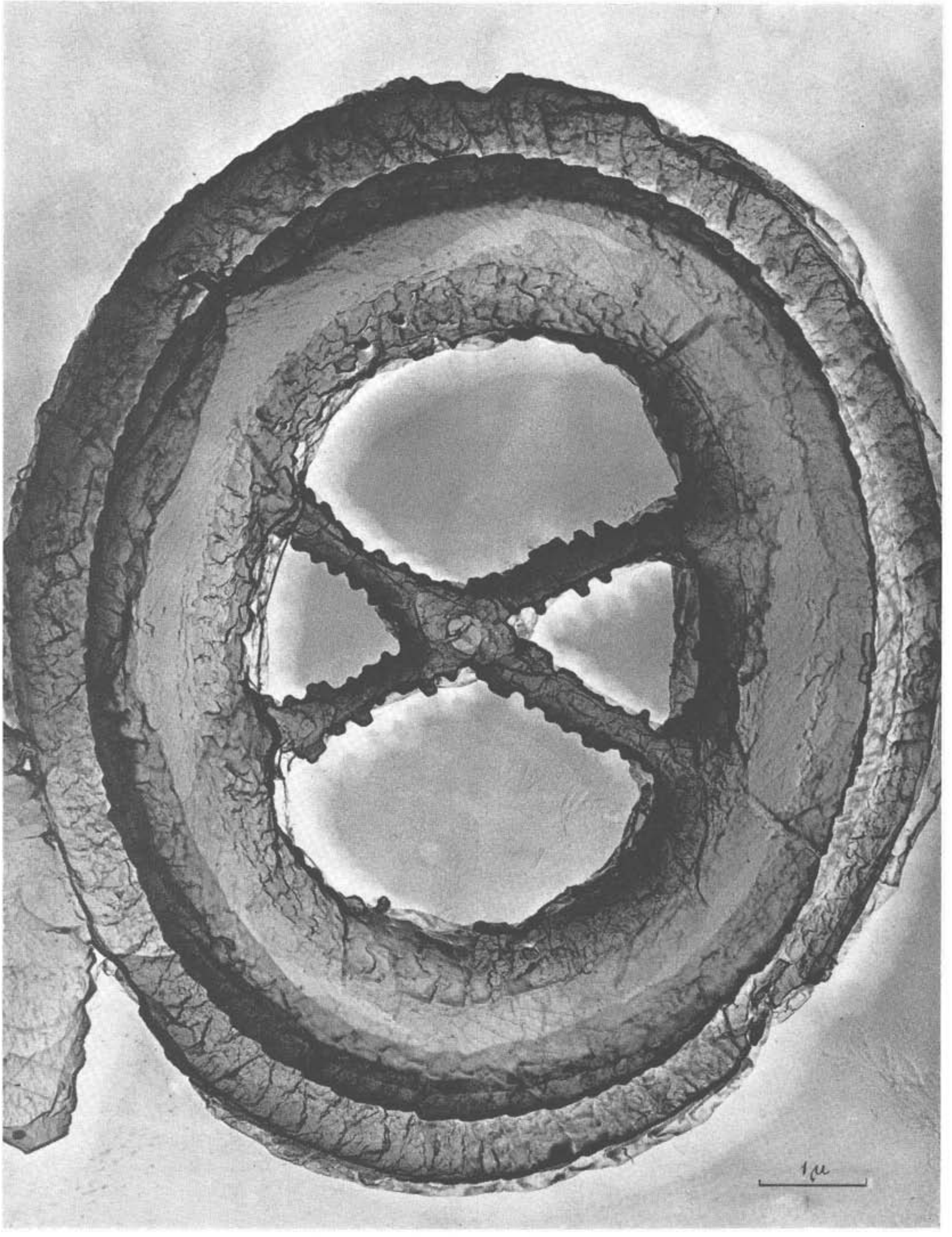
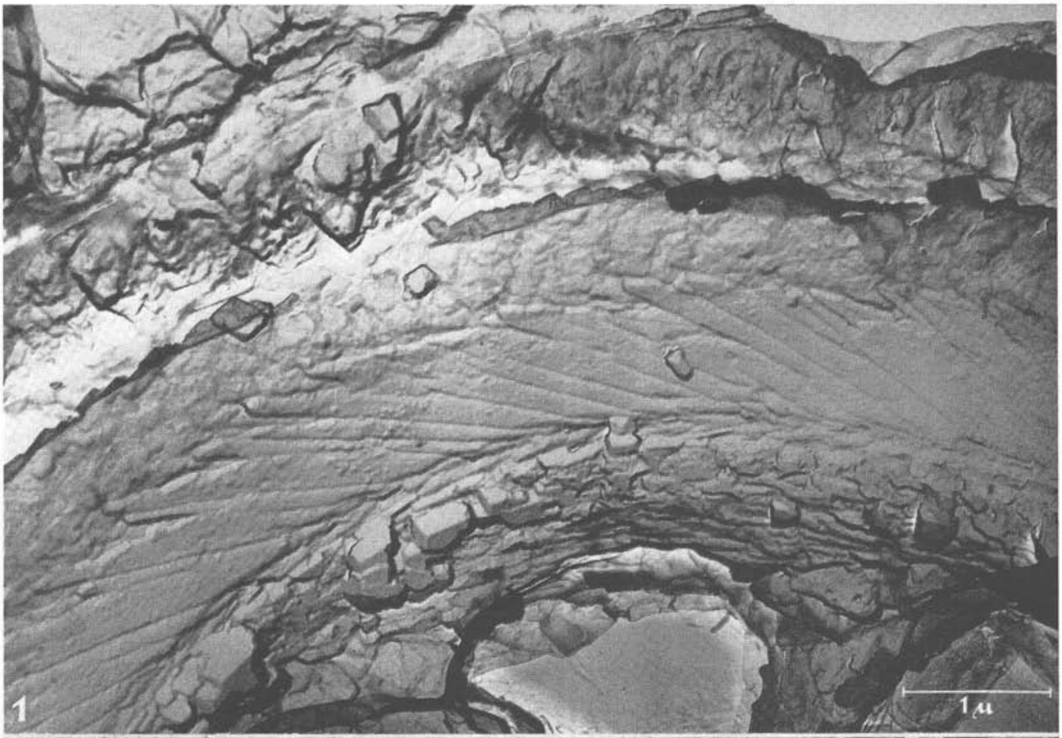

1μ

PLATE 2




1
1 μ

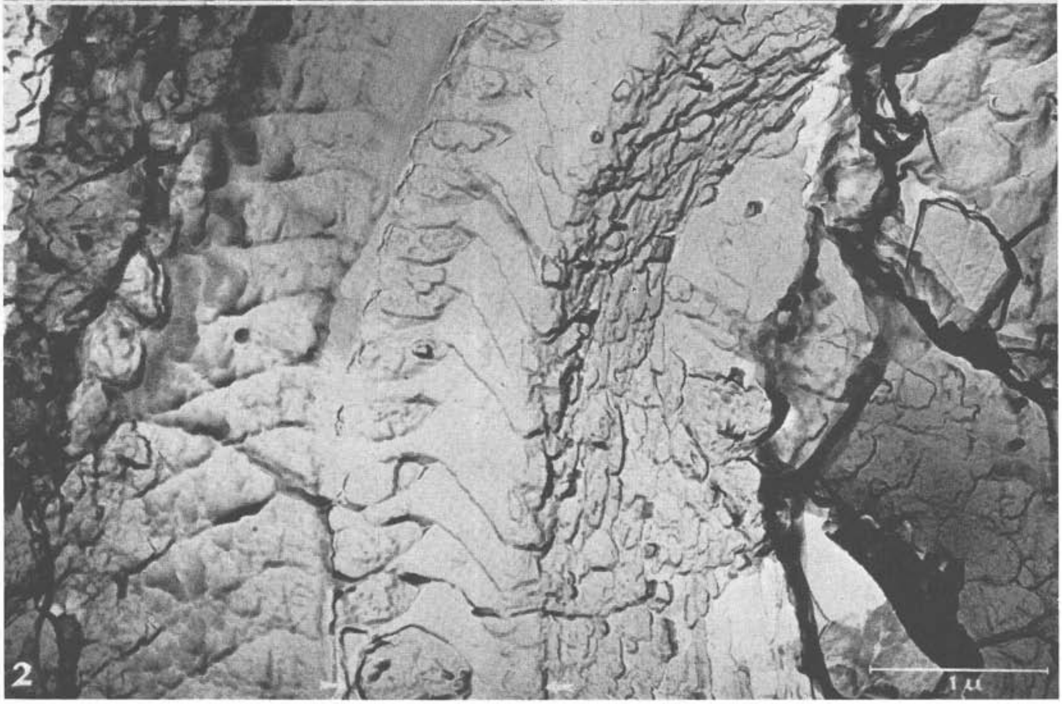
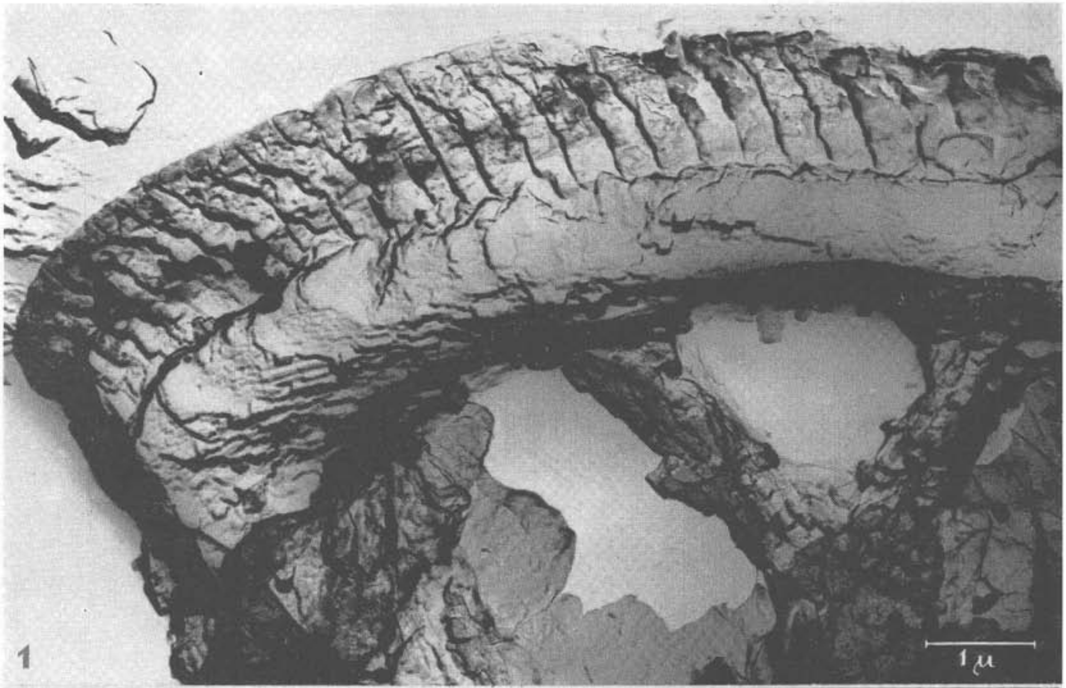

2
1 μ

PLATE 4



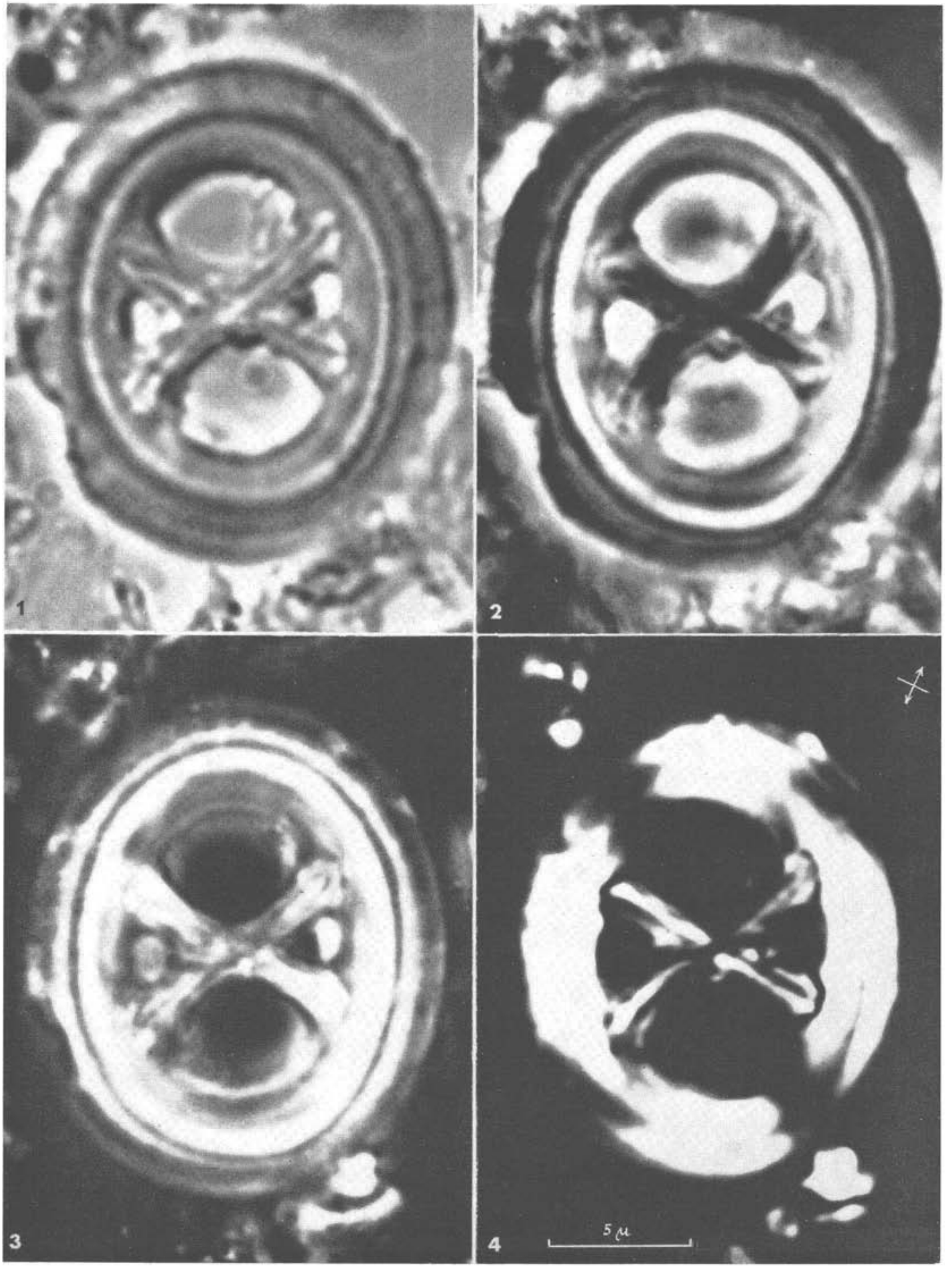
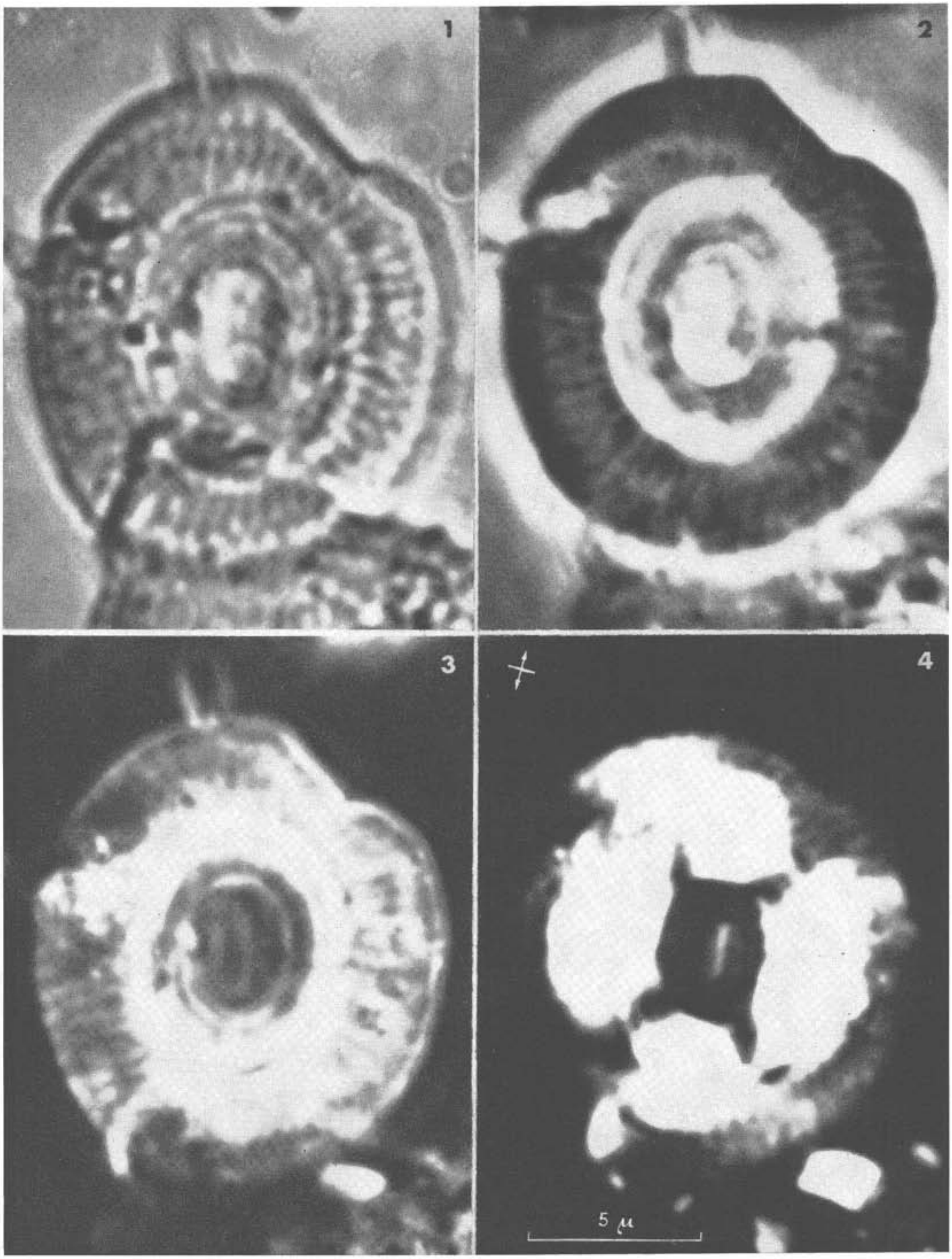

1
2
3
4
5 μ

PLATE 6



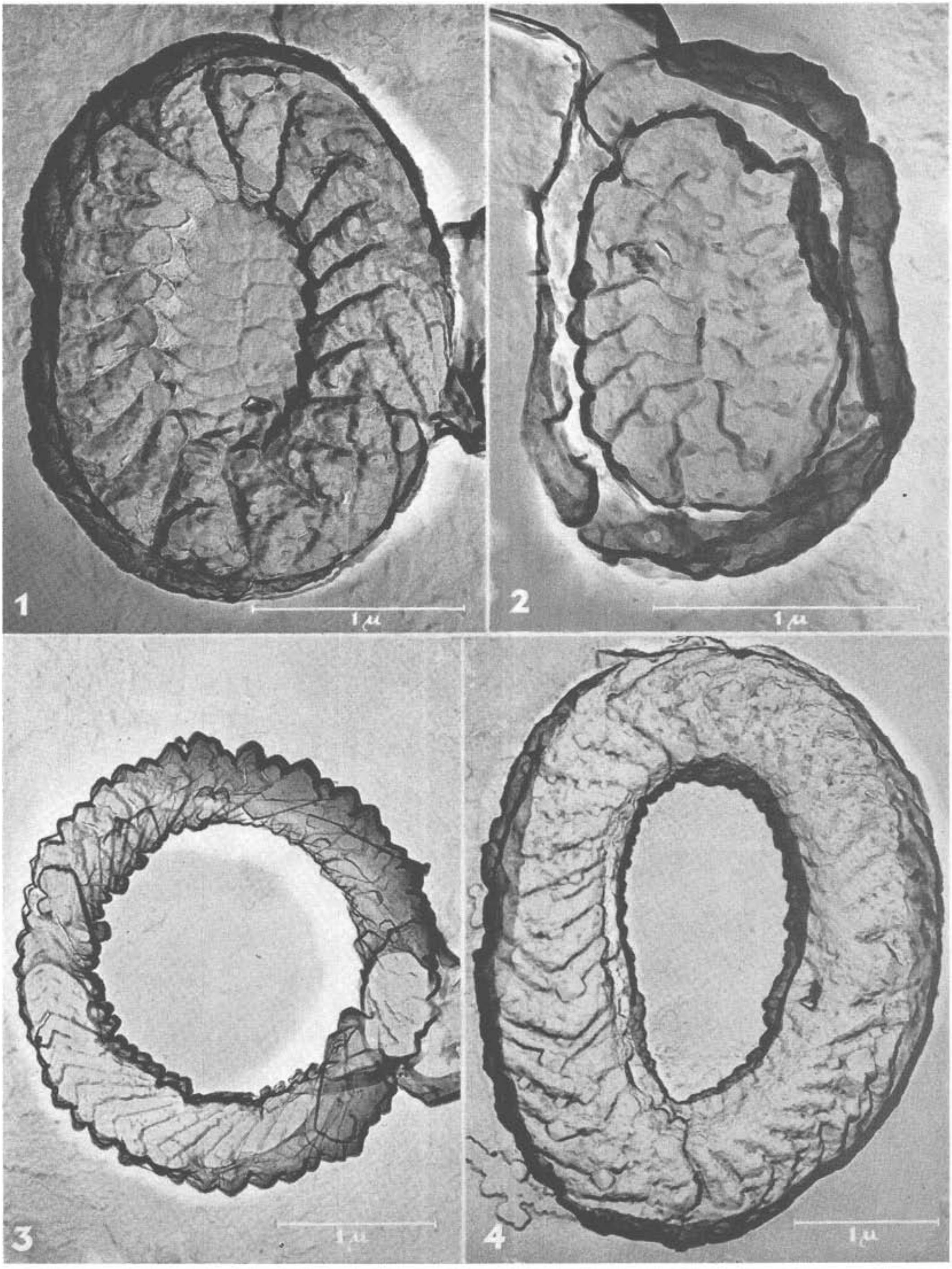
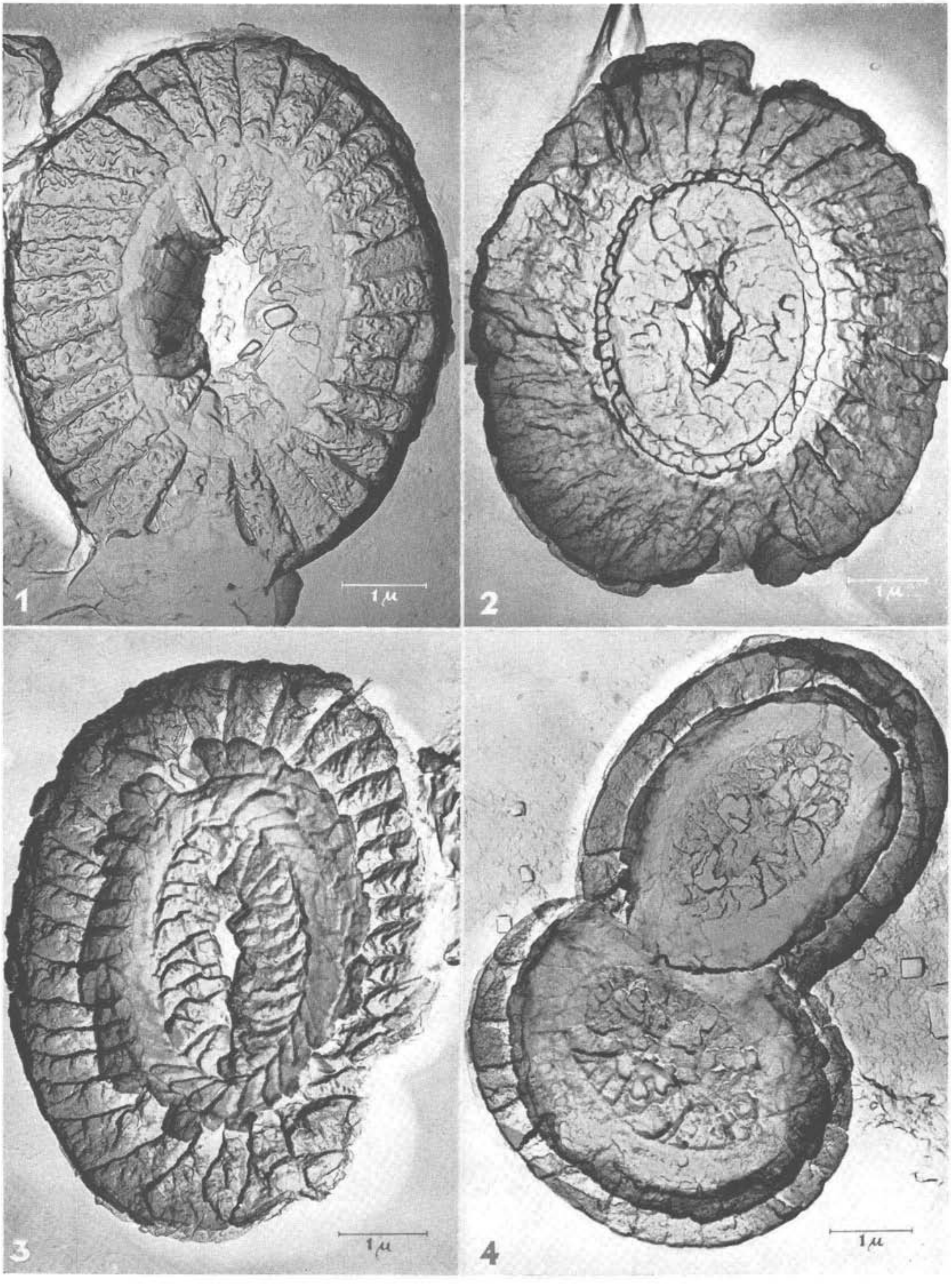

1
1 µ
2
1 µ
3
1 µ
4
1 µ

PLATE 8



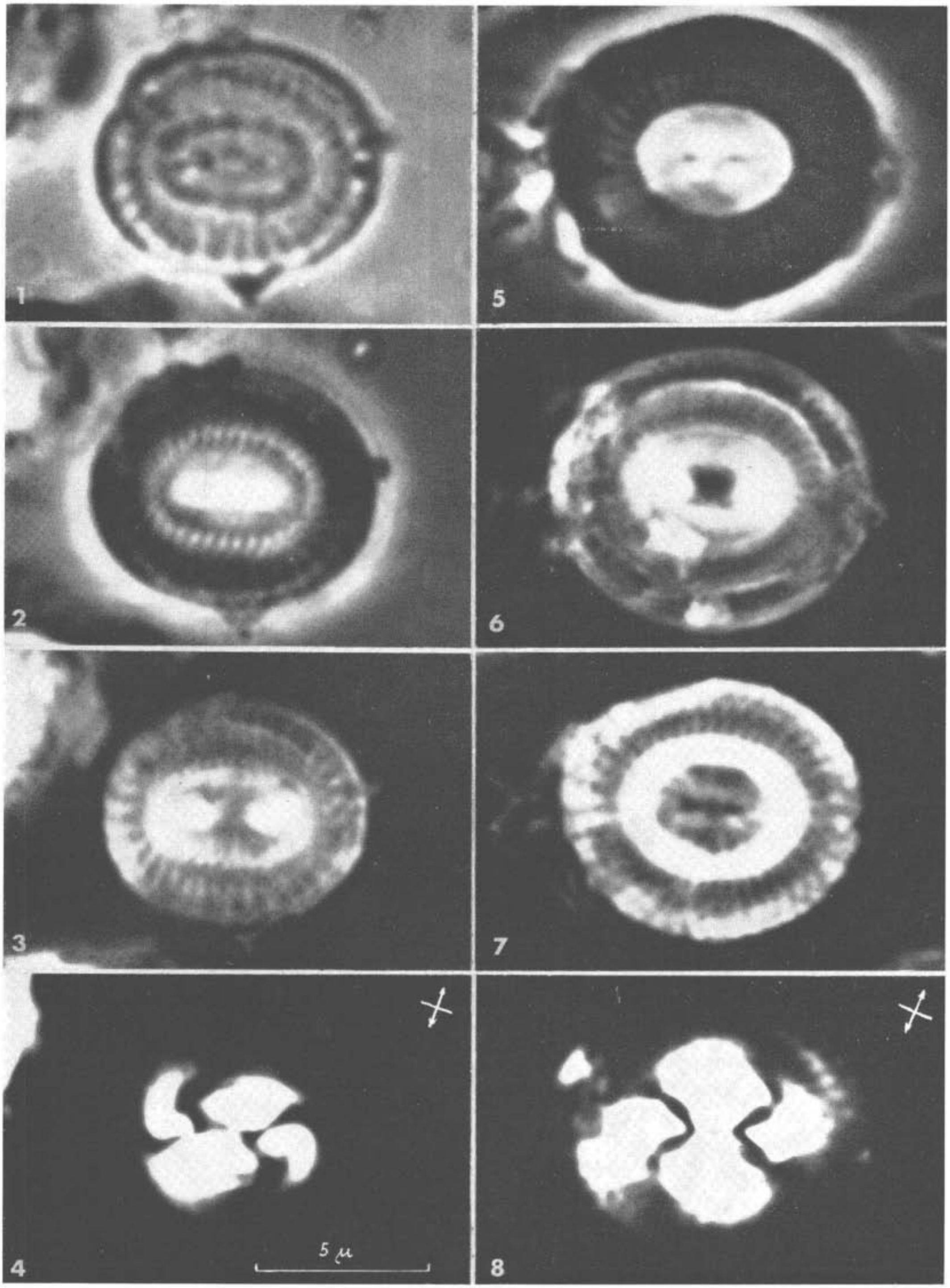
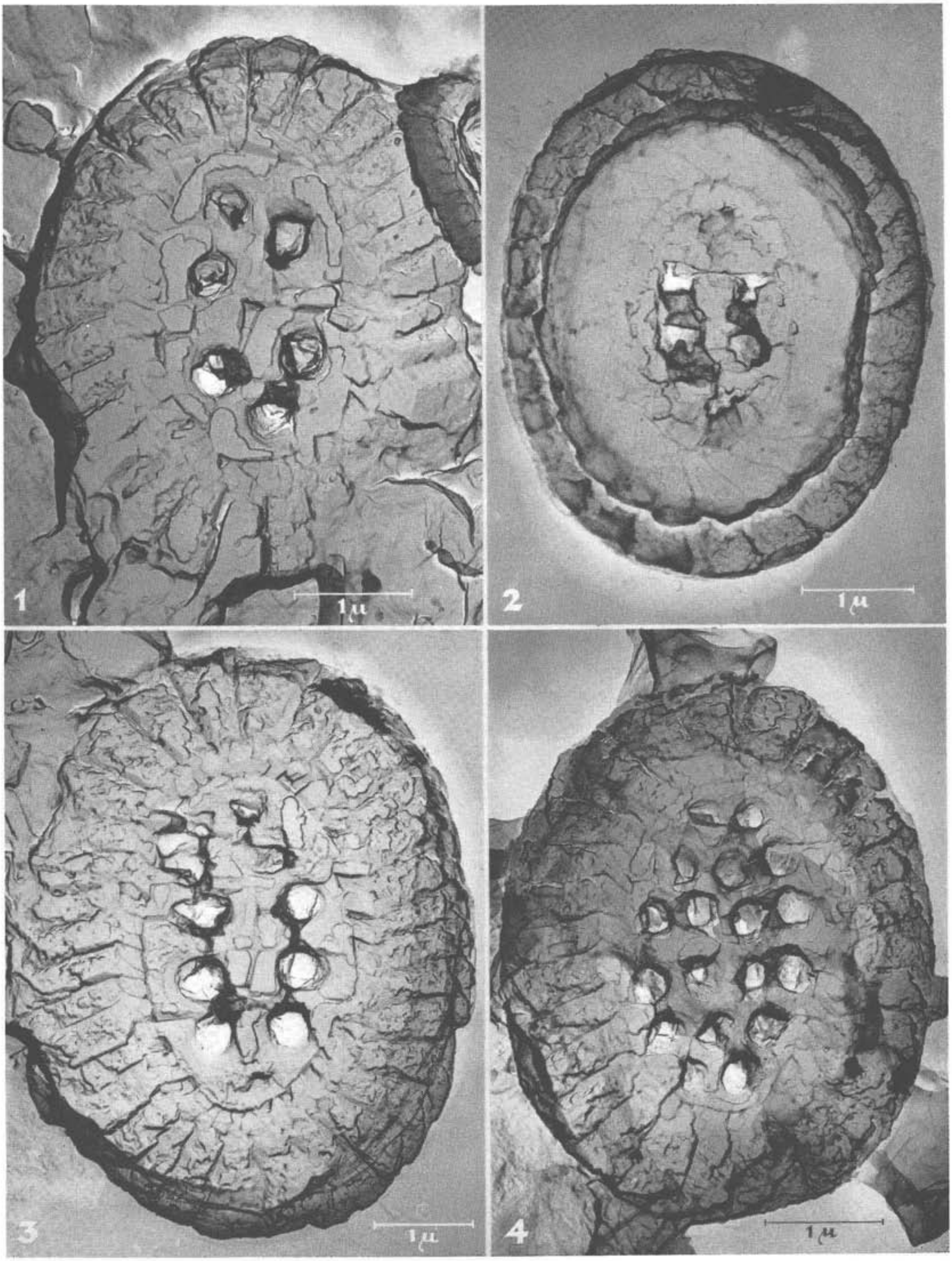

1
5
2
6
3
7
4
5 μ
8

PLATE 10



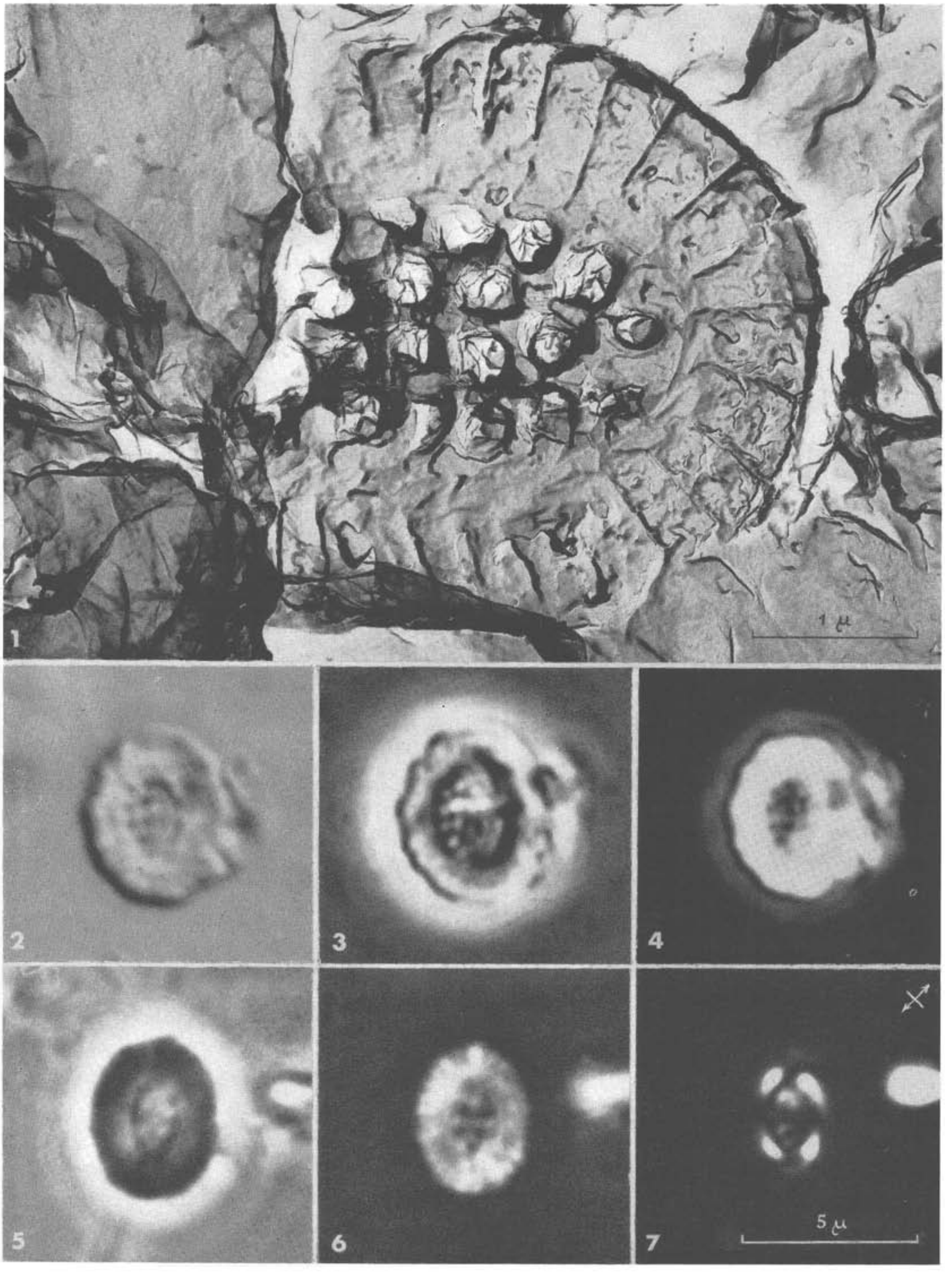
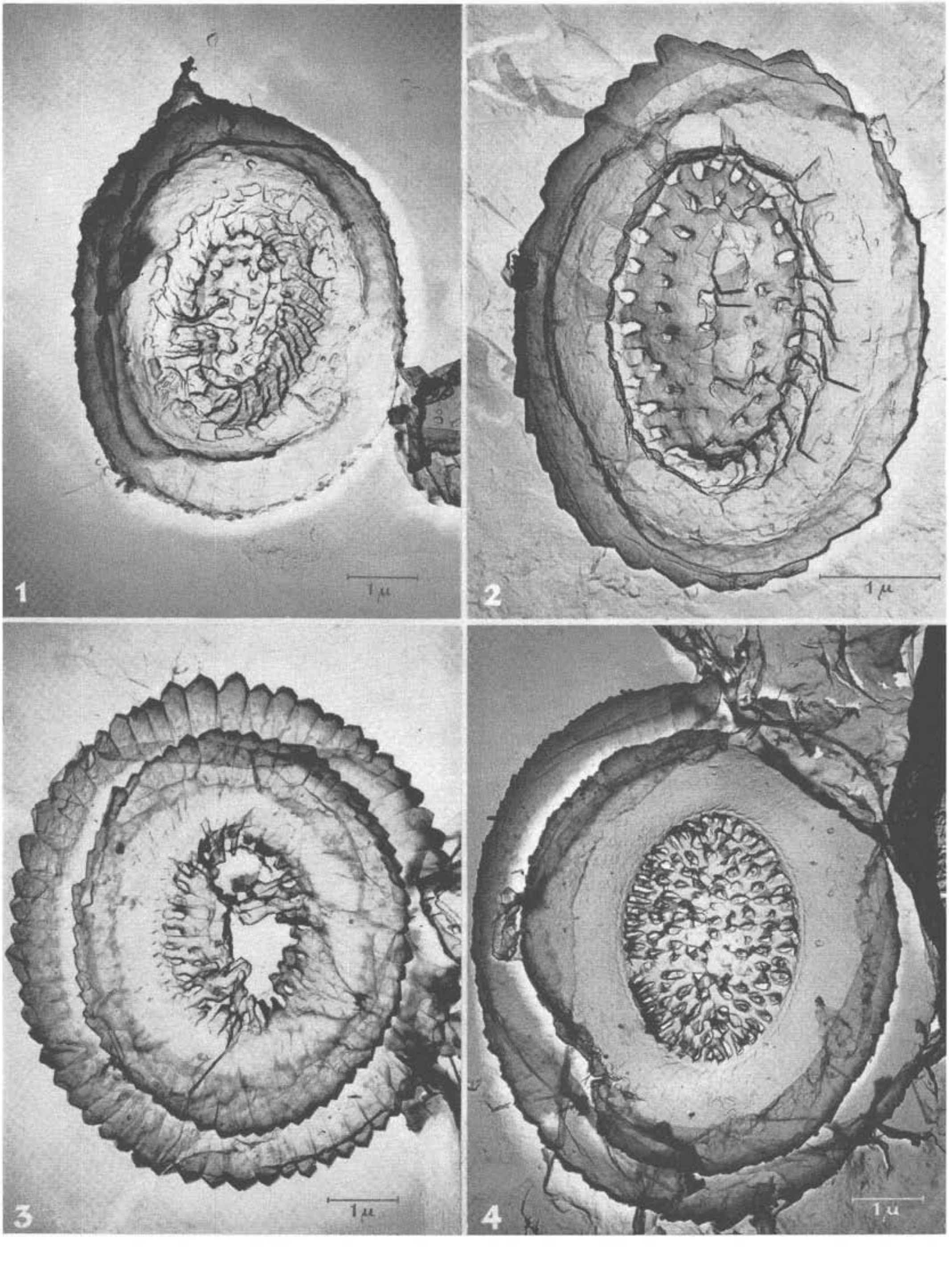
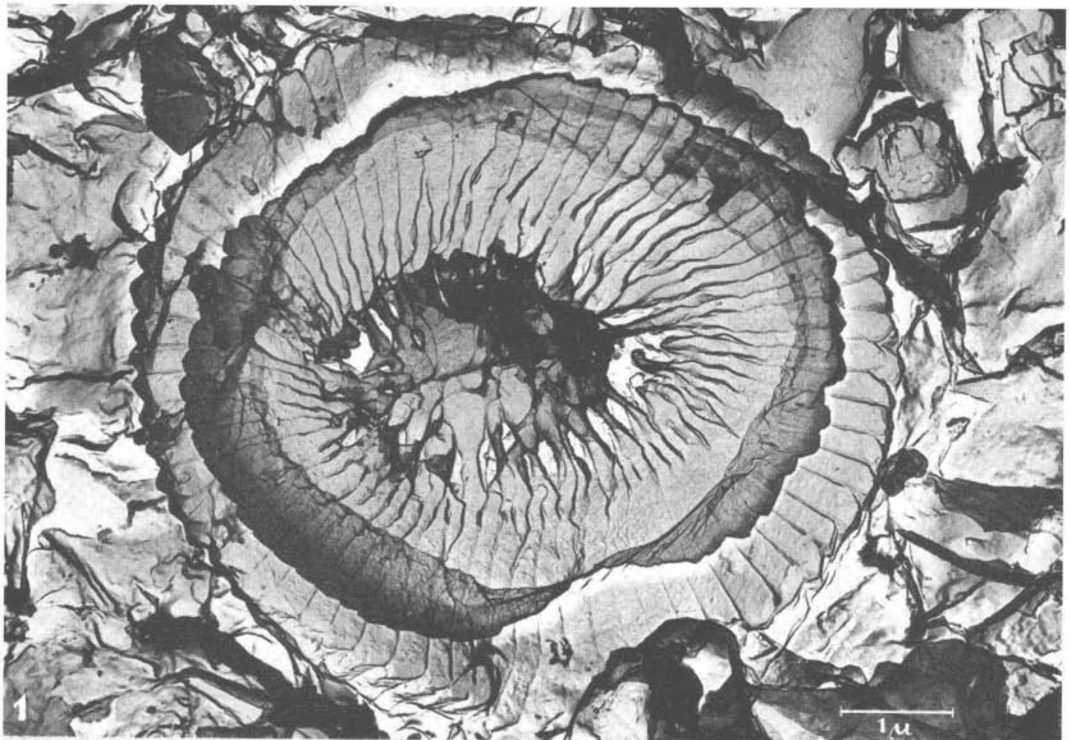

1 μ
1
2
3
4
5 μ
5
6
7

PLATE 12




1
1μ

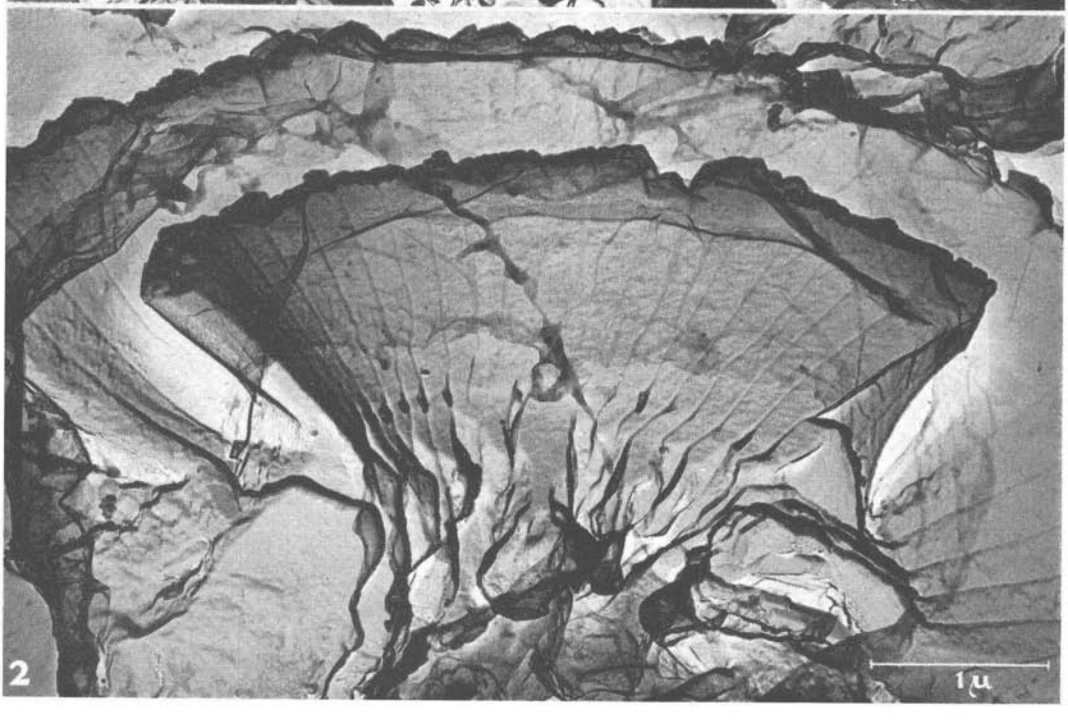
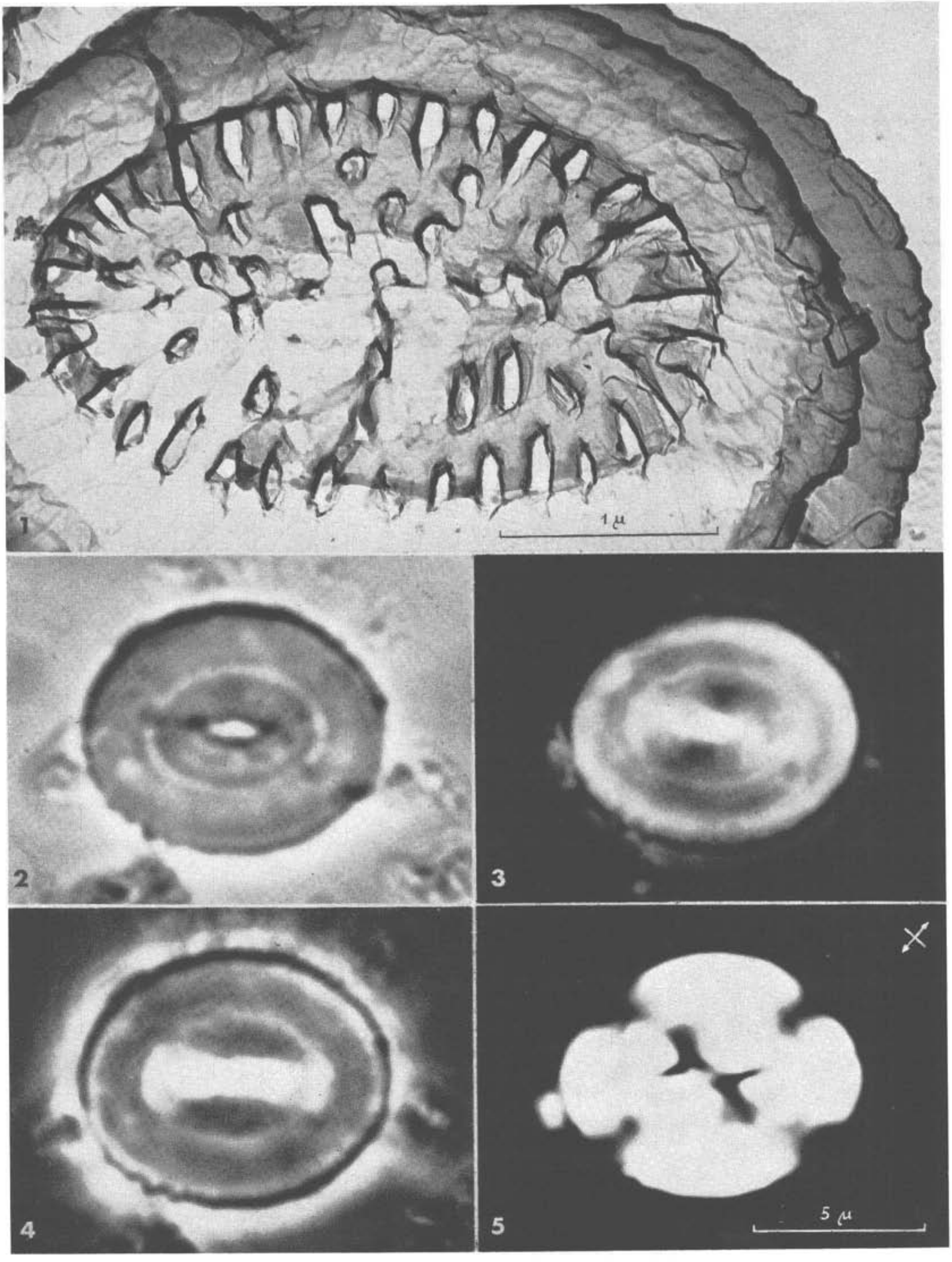

2
1μ

PLATE 14



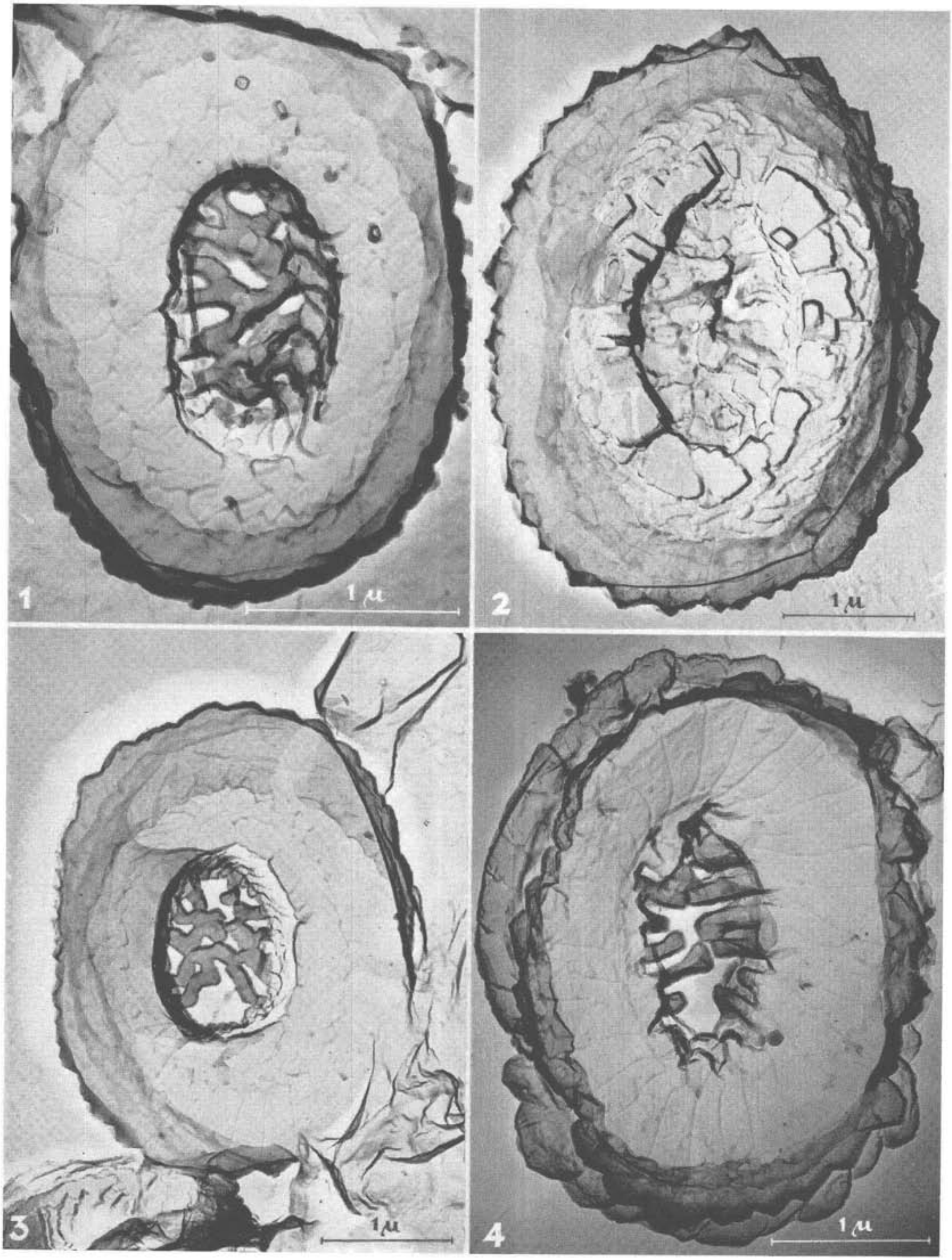
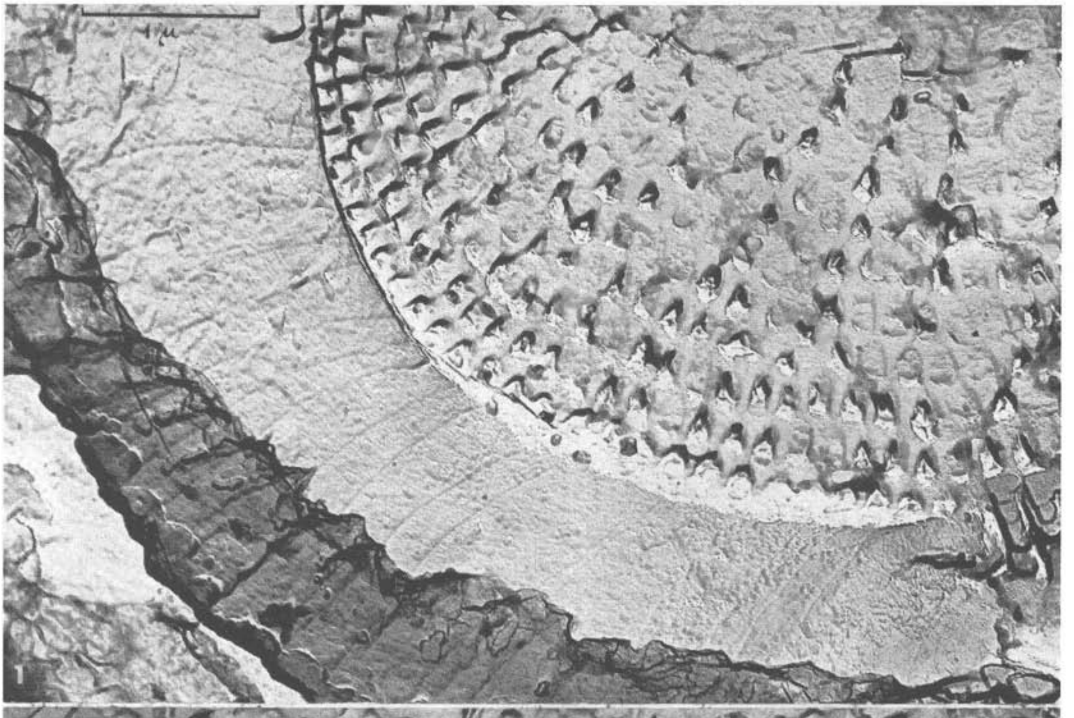

1
1 μ
2
1 μ
3
1 μ
4
1 μ

PLATE 16


1 µ
1

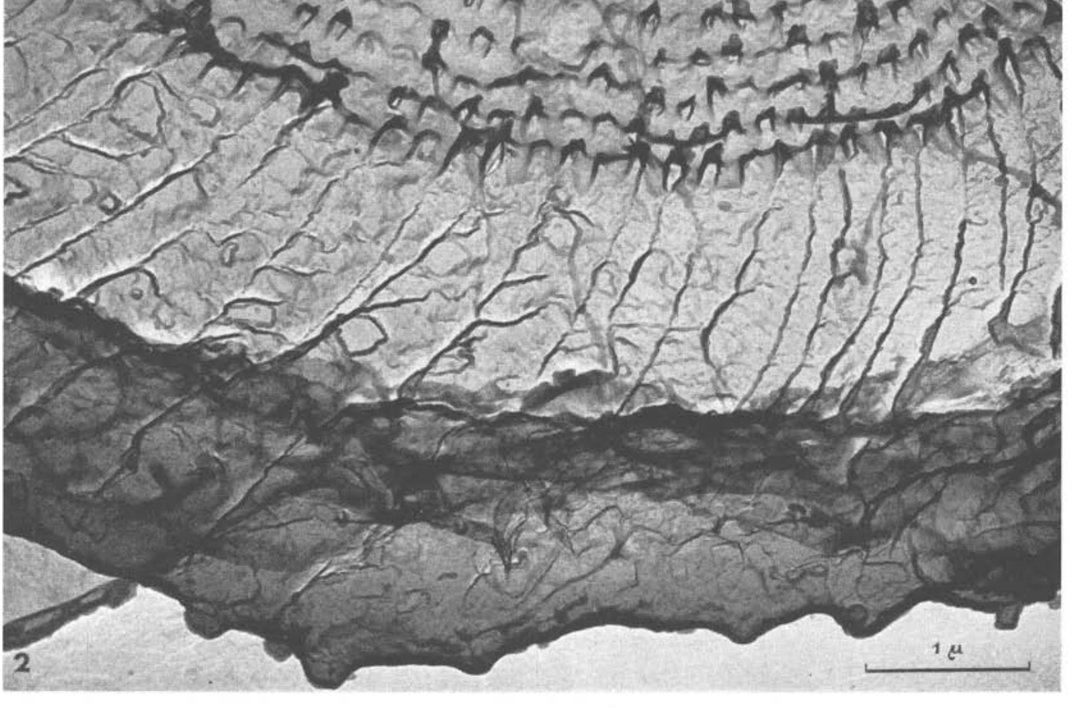

2
1 µ

PLATE 18

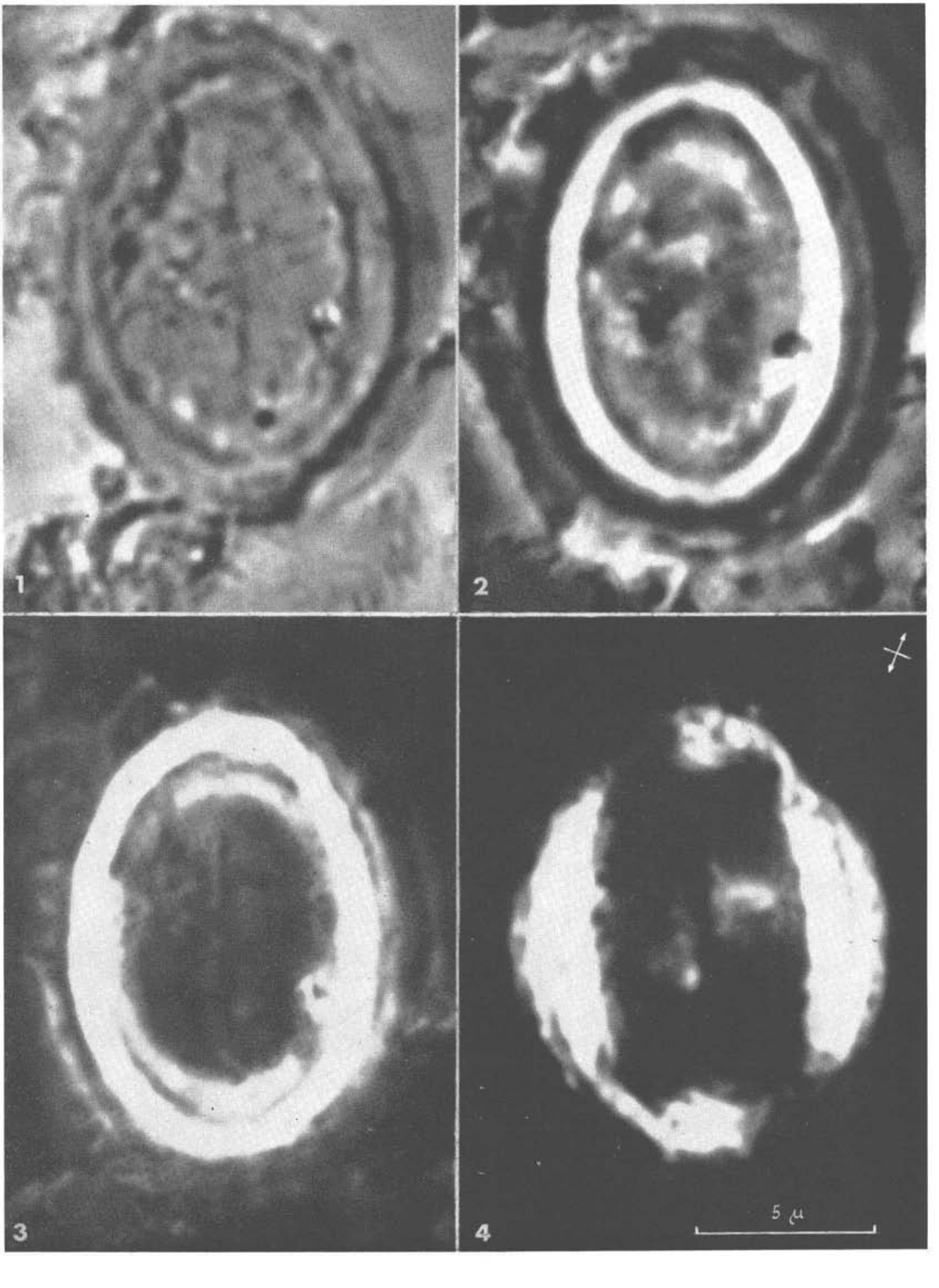
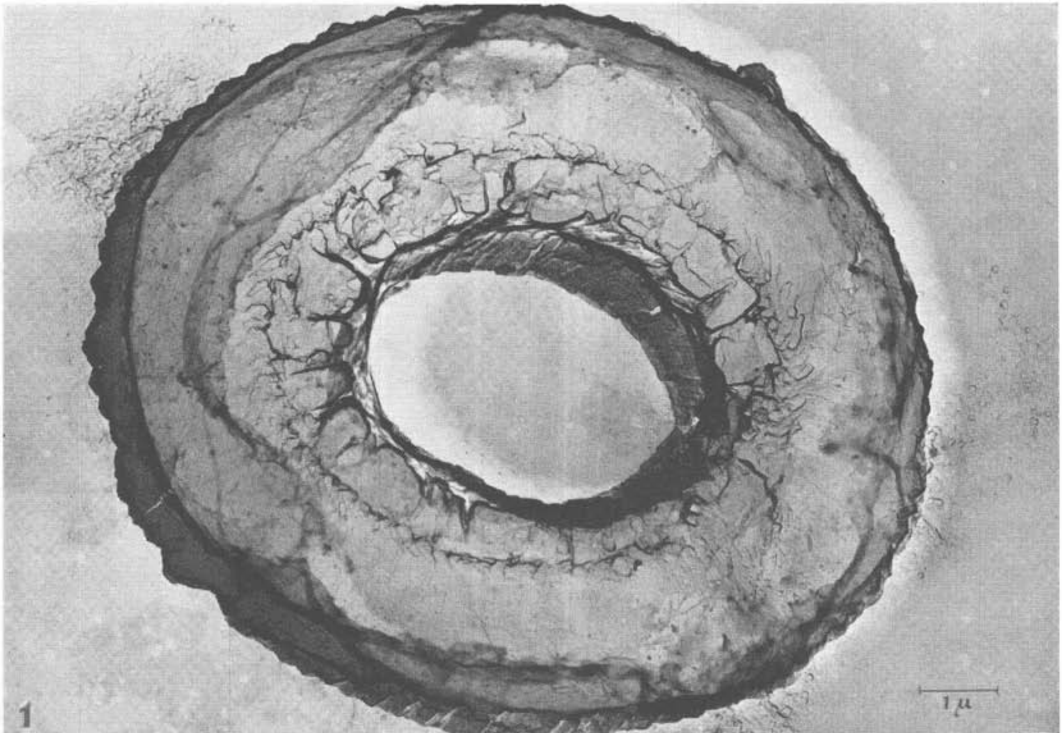
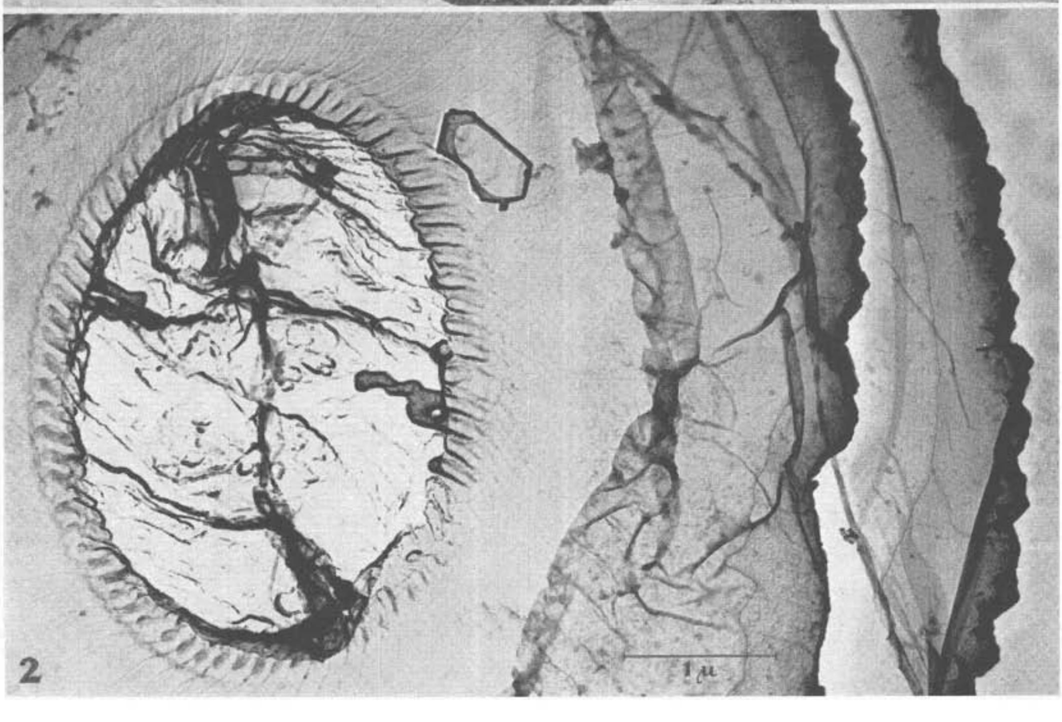


PLATE 19





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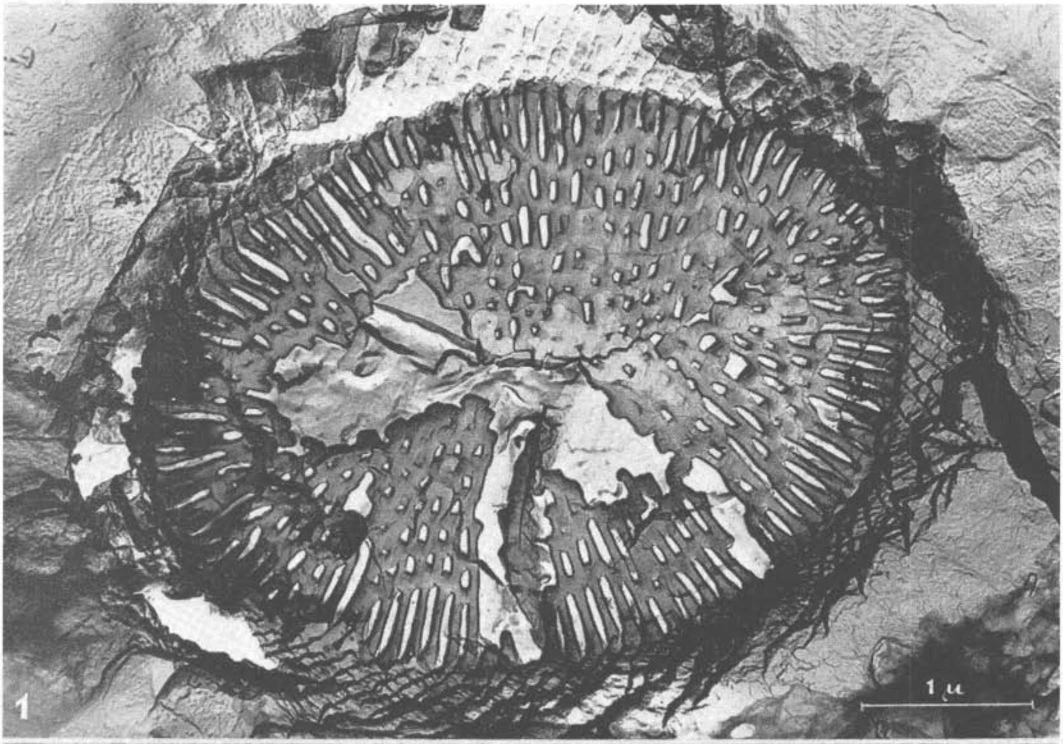
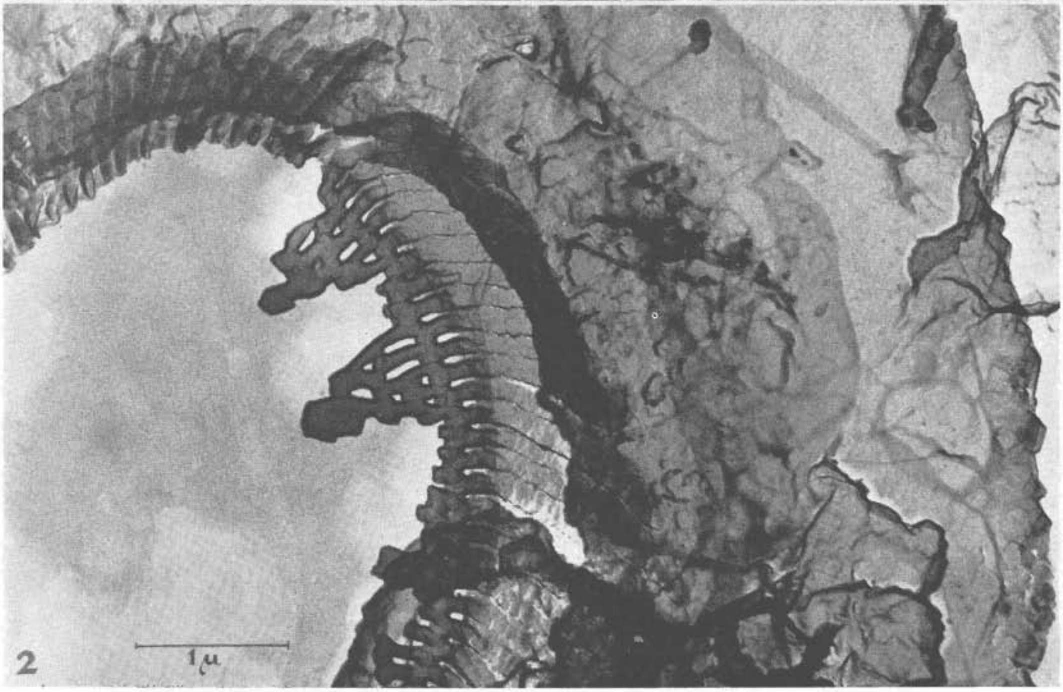
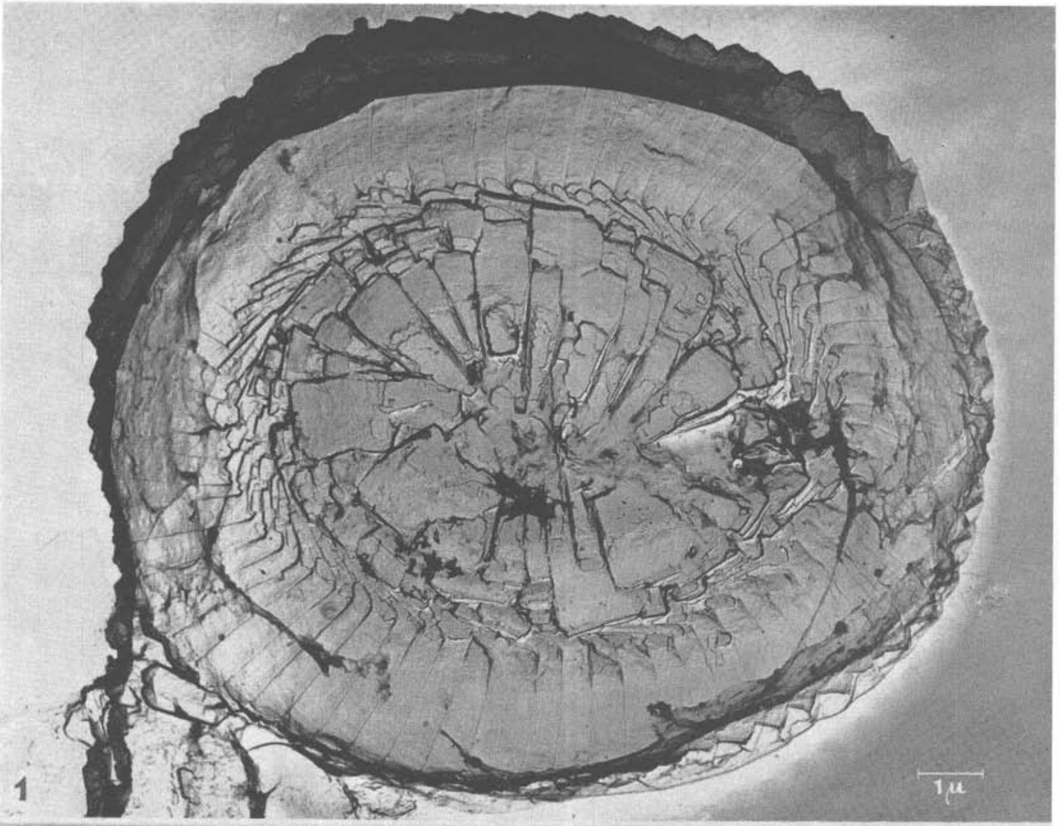





1
1μ

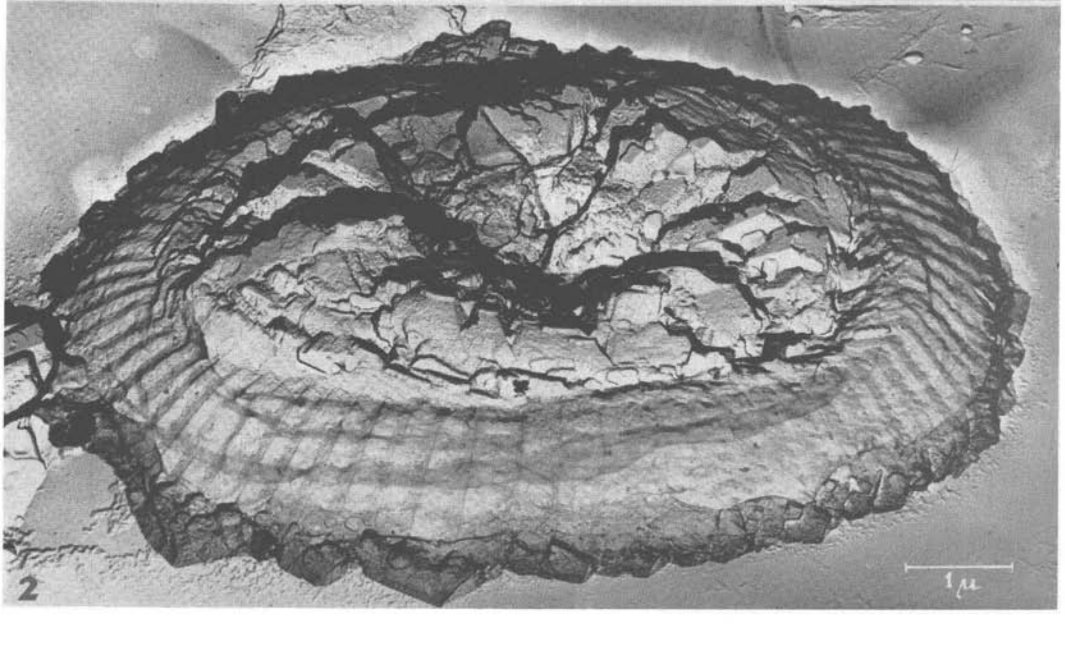
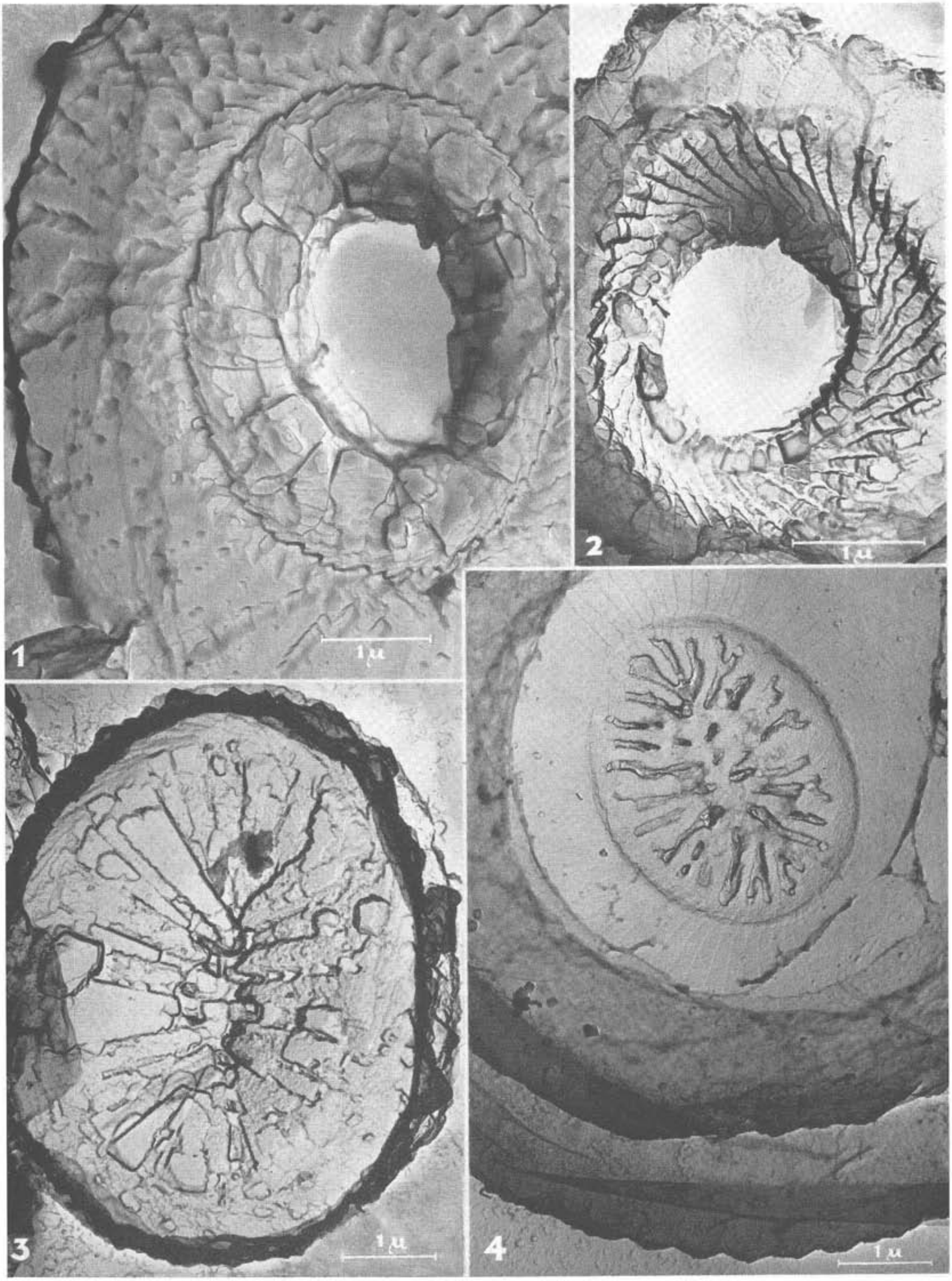

2
1μ

PLATE 22



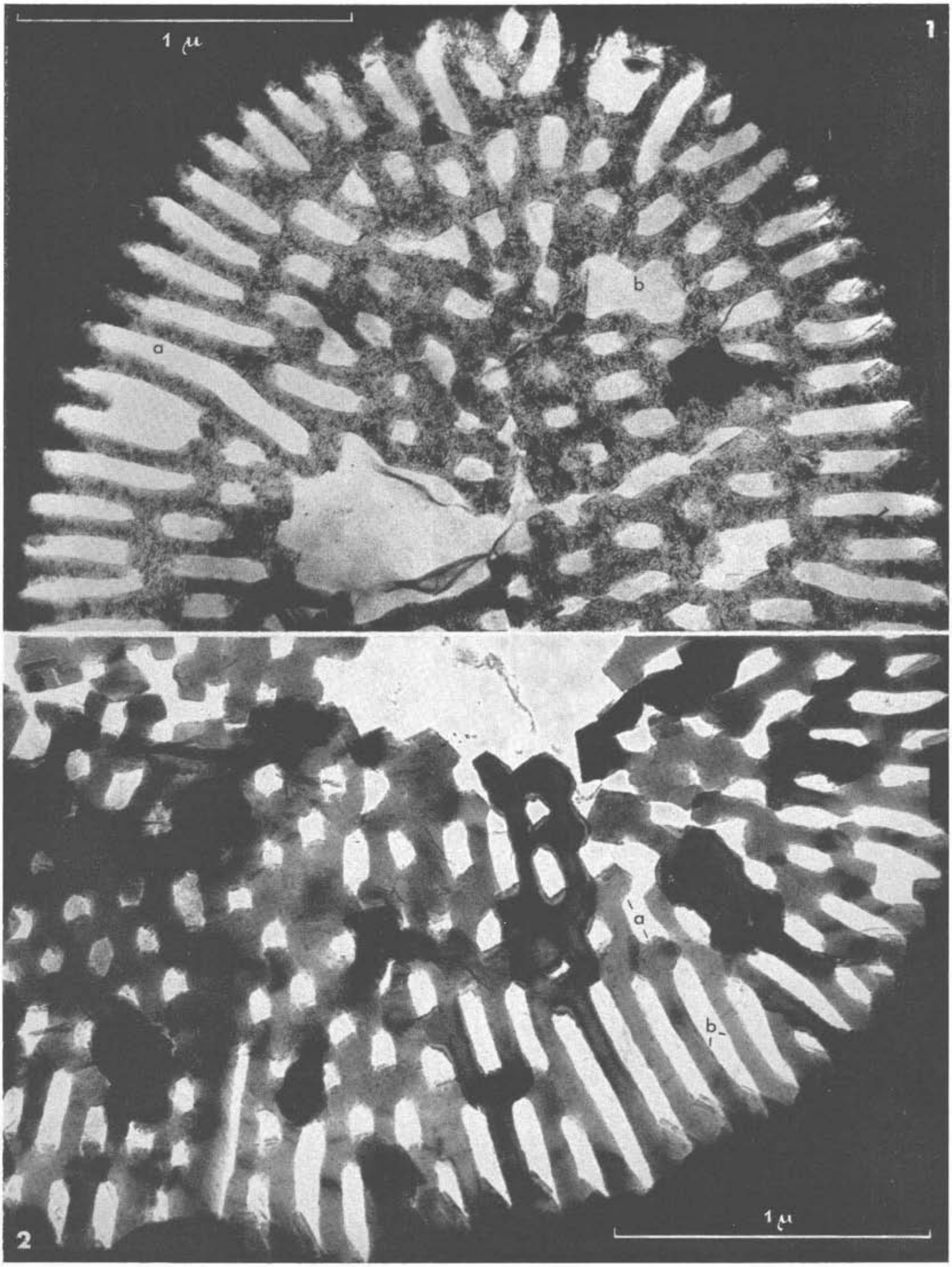
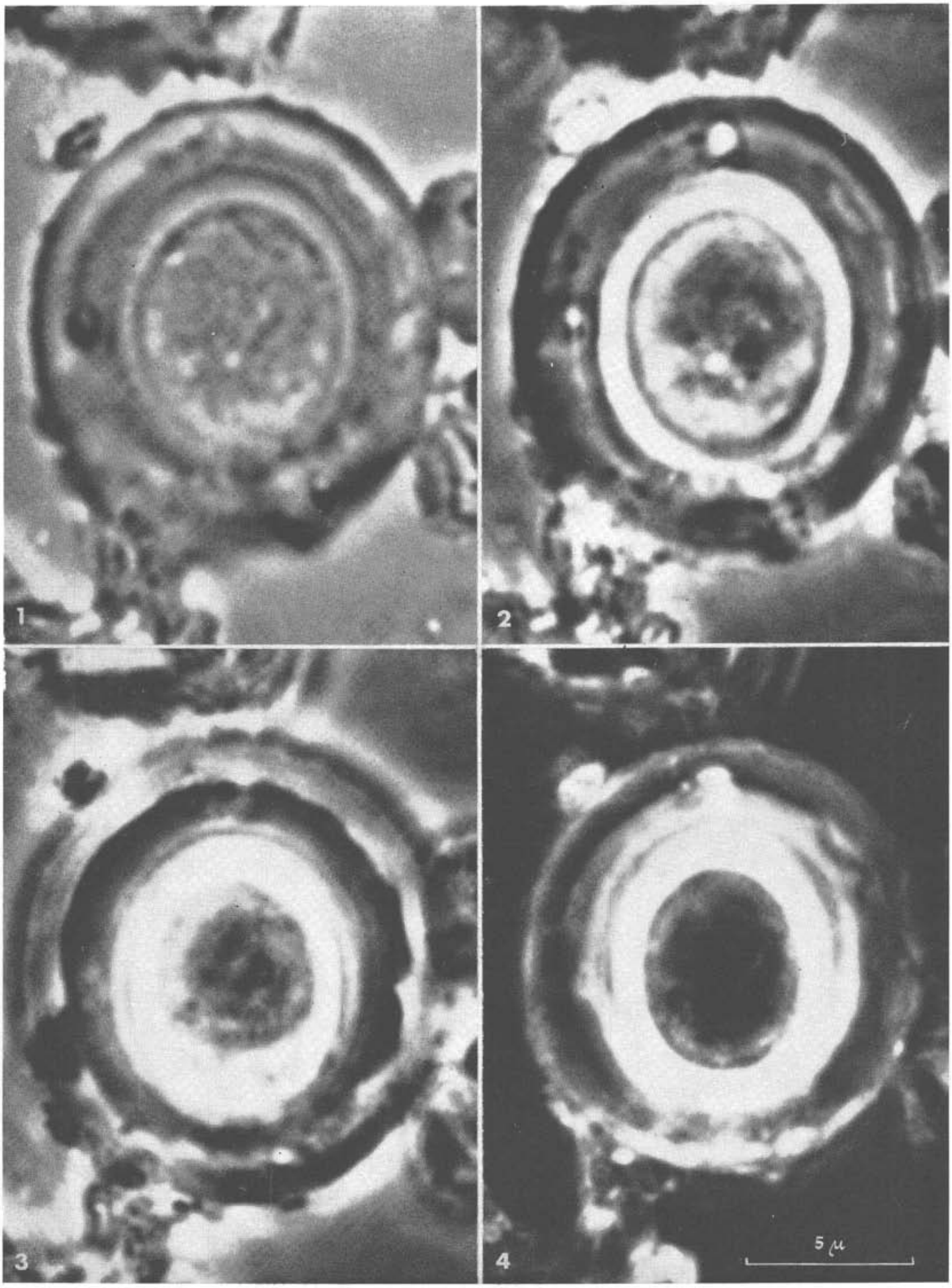

1 μ
1
b
a
a
b
2
1 μ

PLATE 24



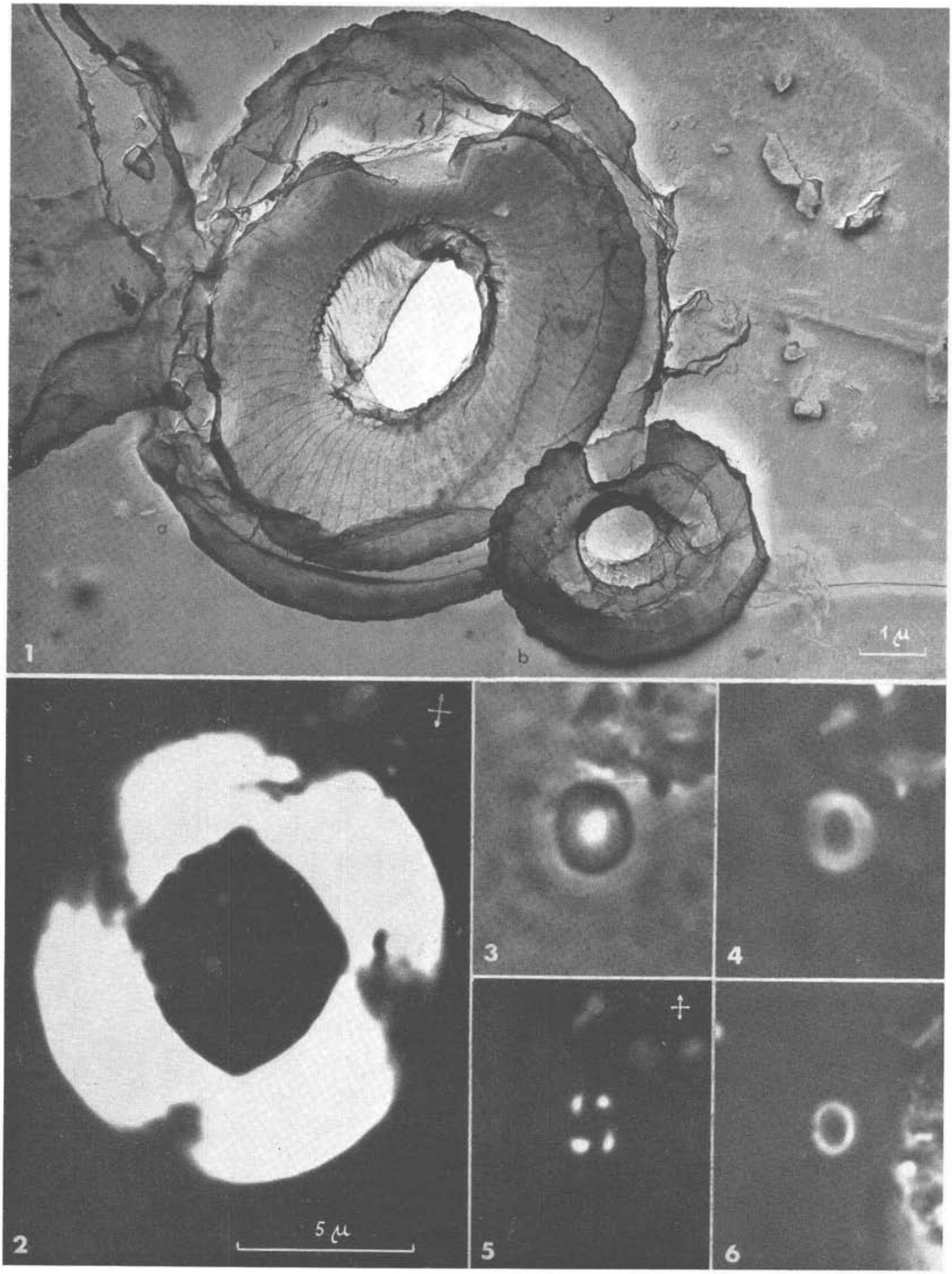
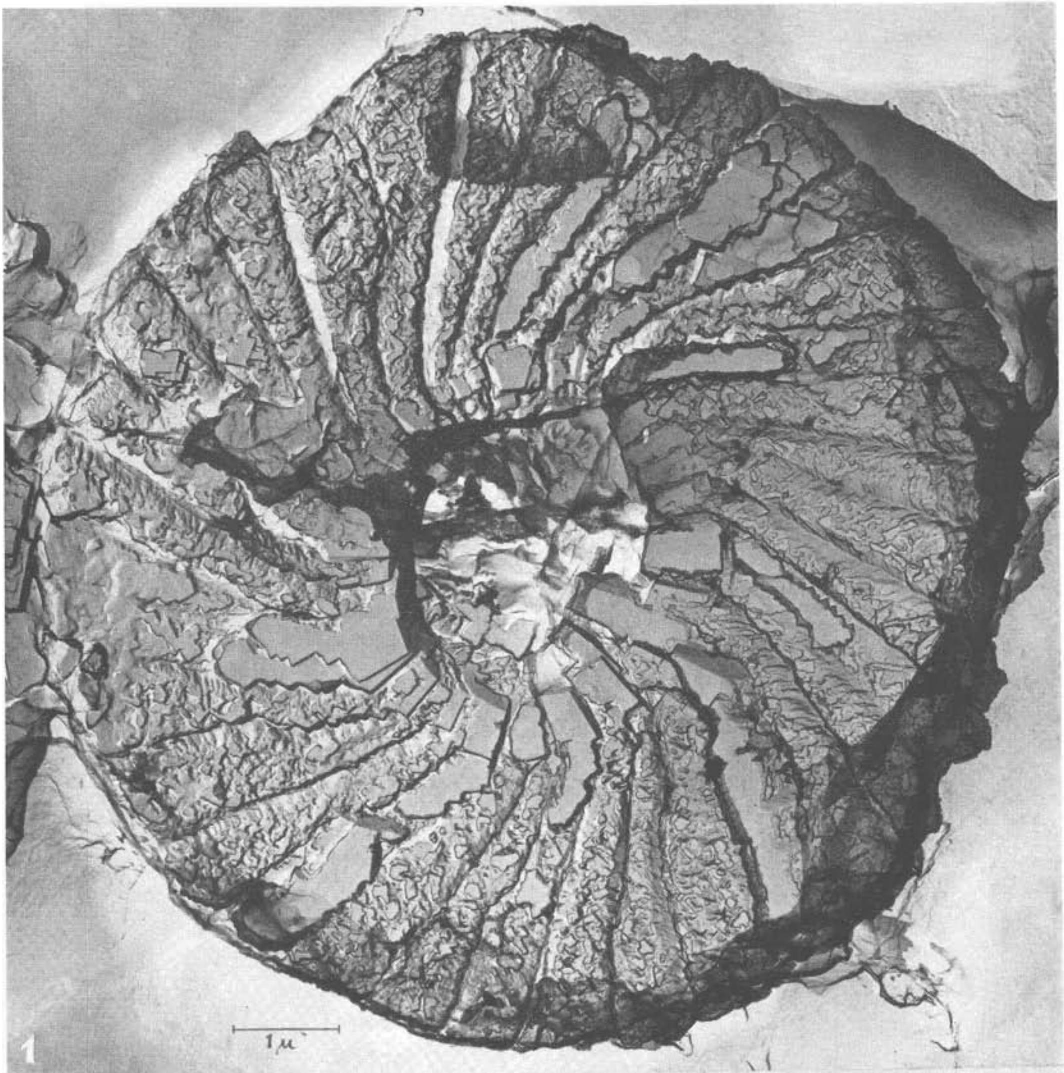
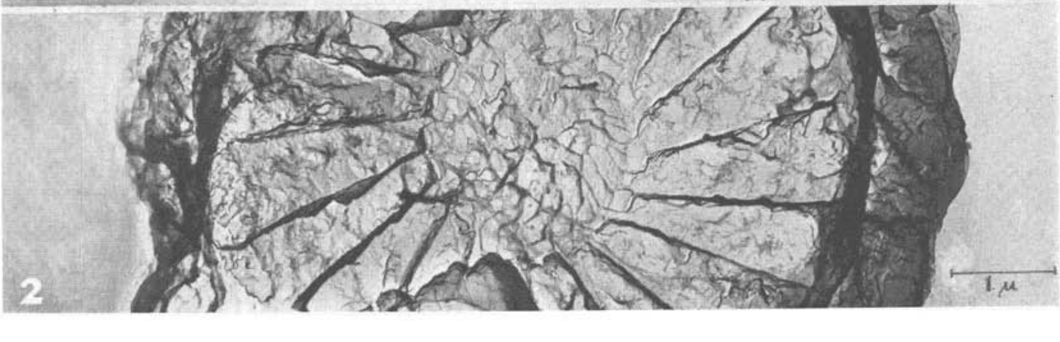

1
a
b
1 μ
2
5 μ
3
4
5
6

PLATE 26



1



2

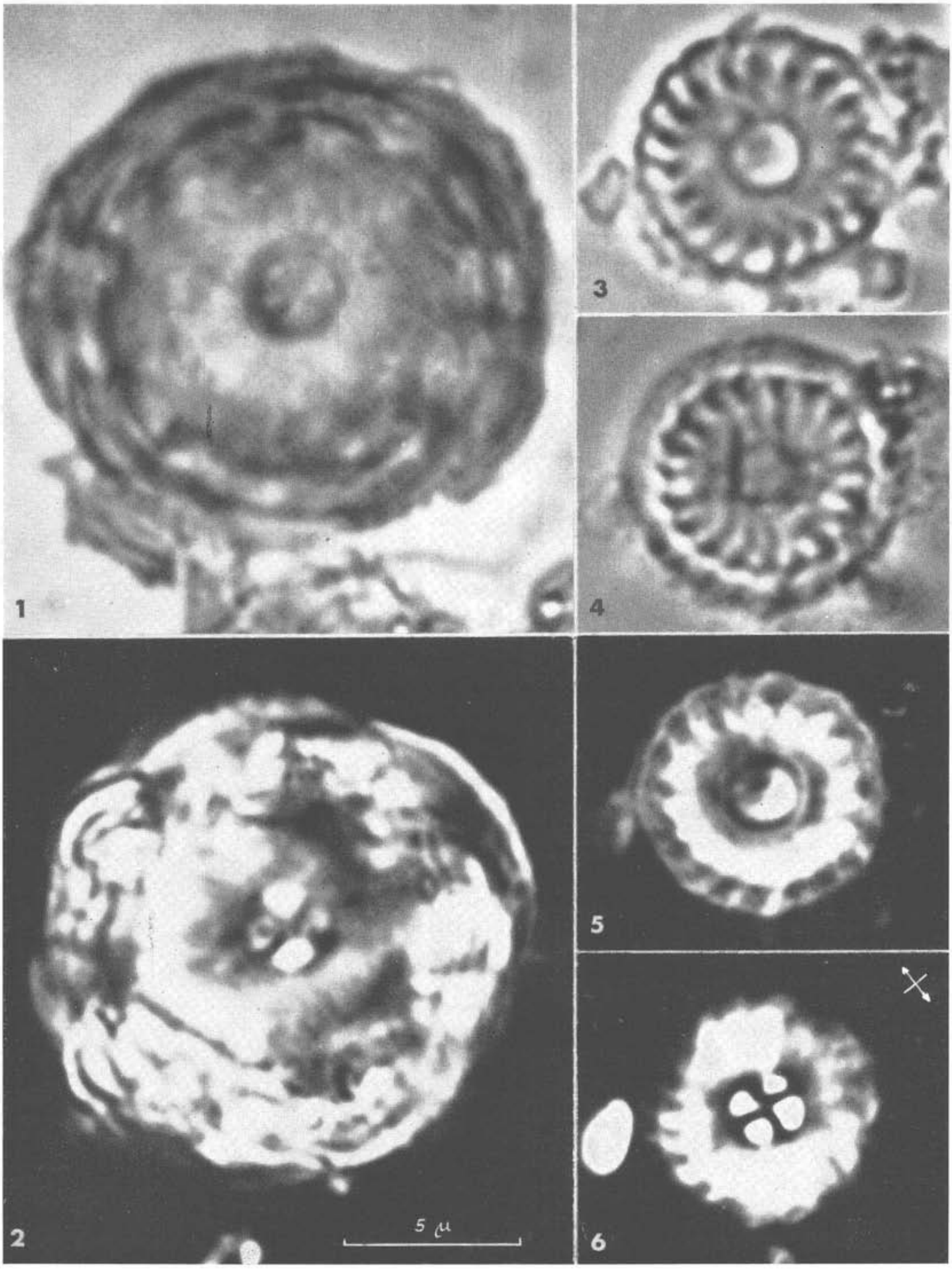
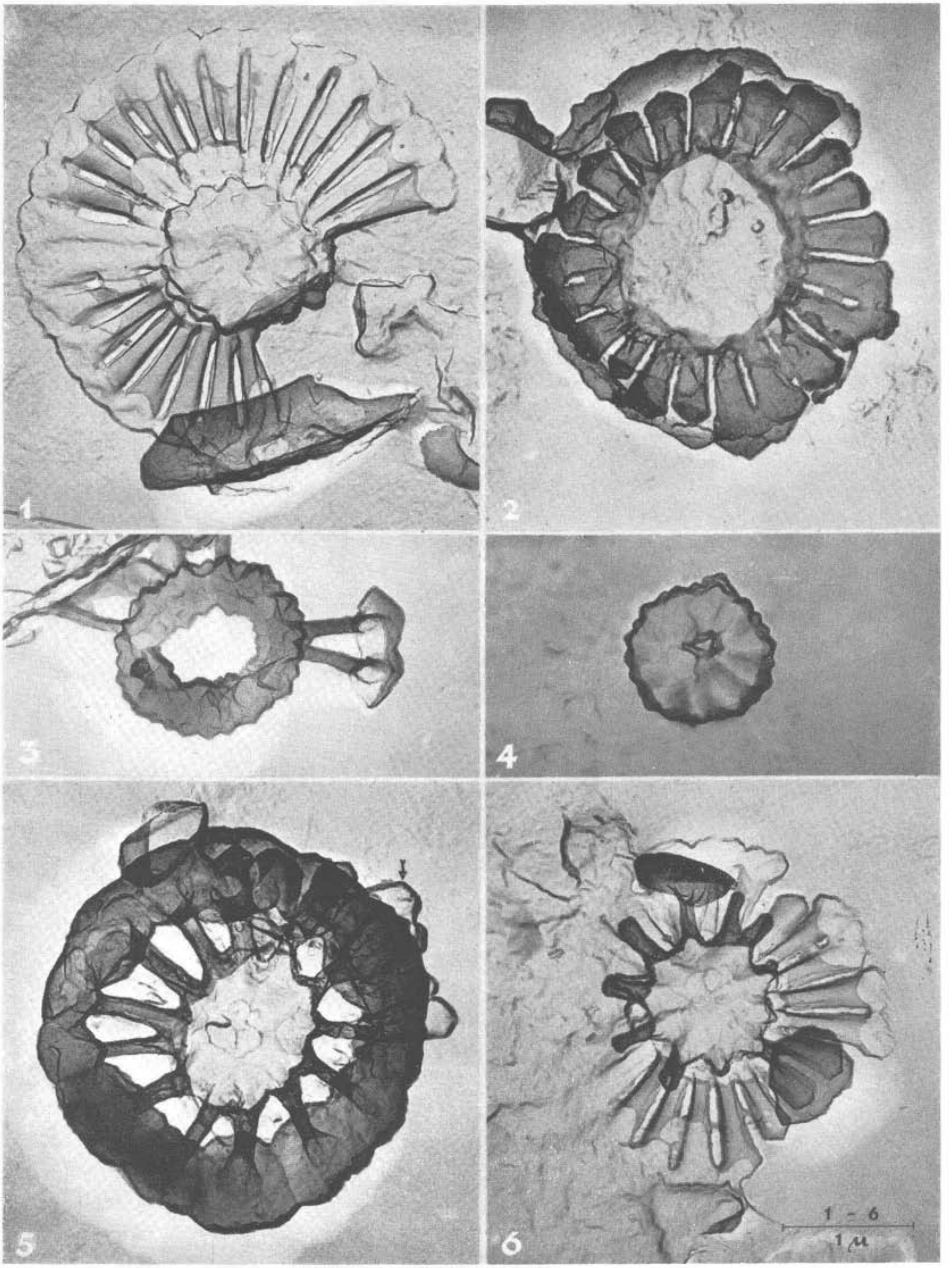

1
2
3
4
5
6
5 µ

PLATE 28



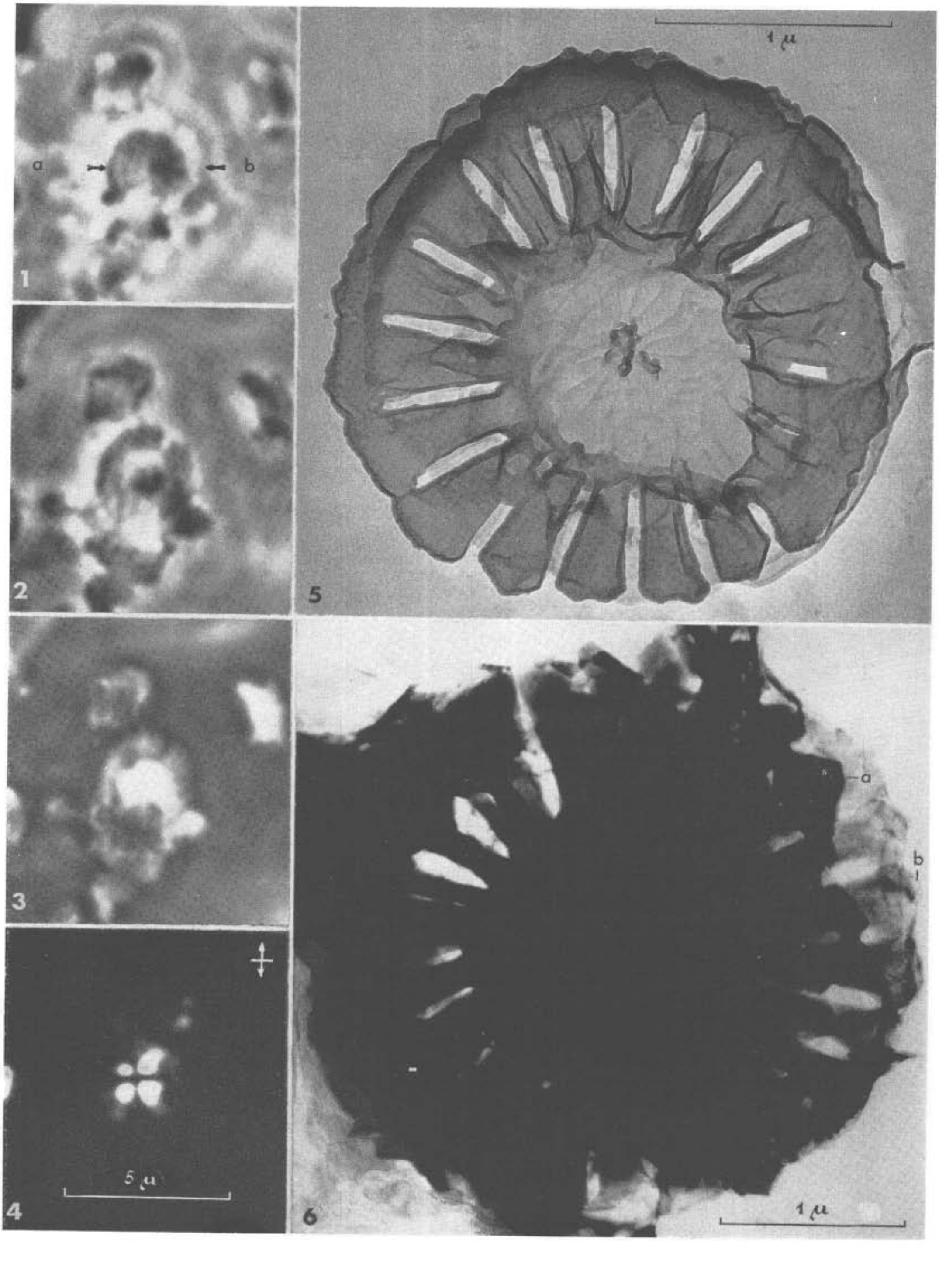
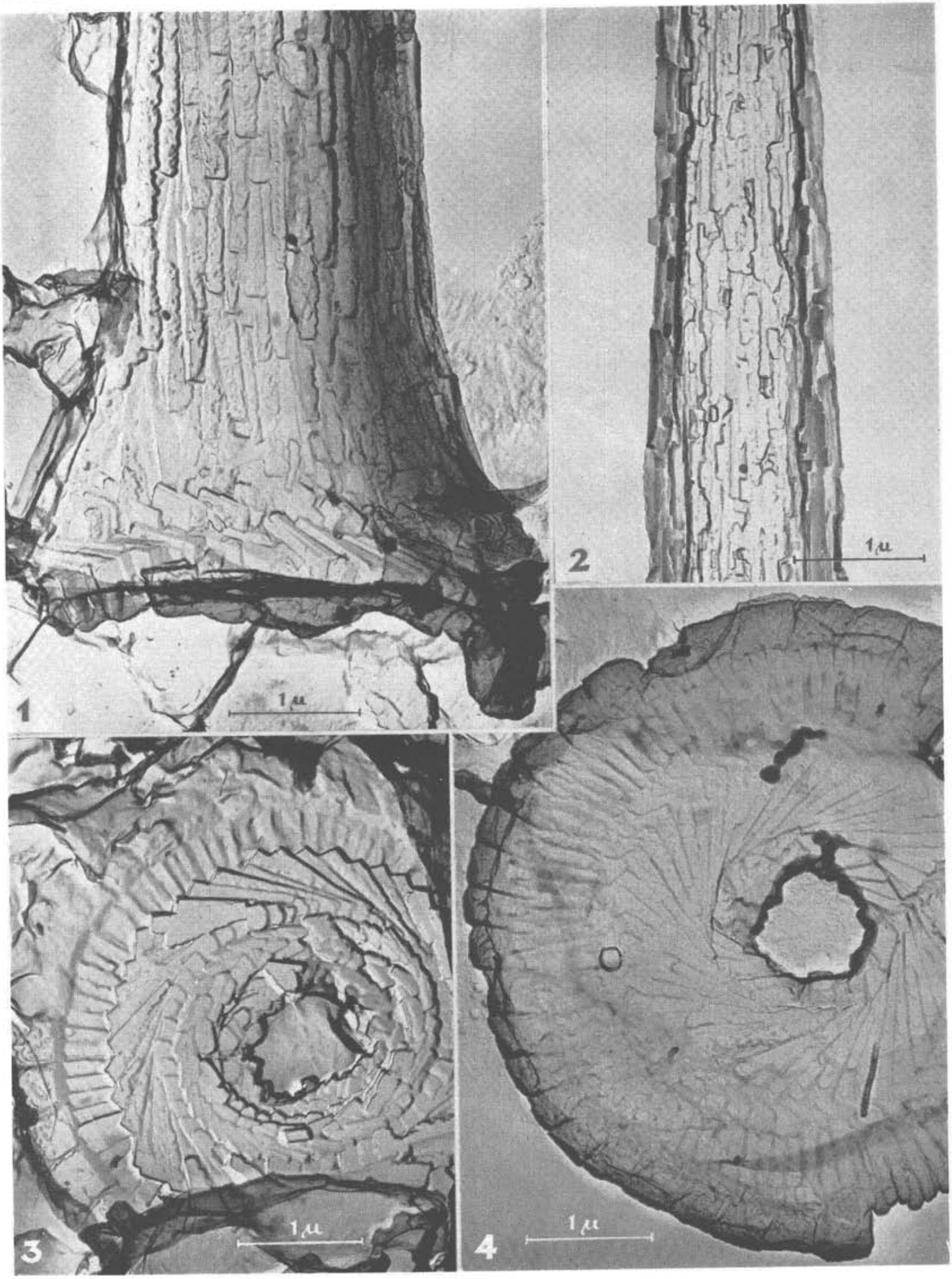

a
b
1
2
3
4
5 μ
5
1 μ
6
a
b
1 μ

PLATE 30



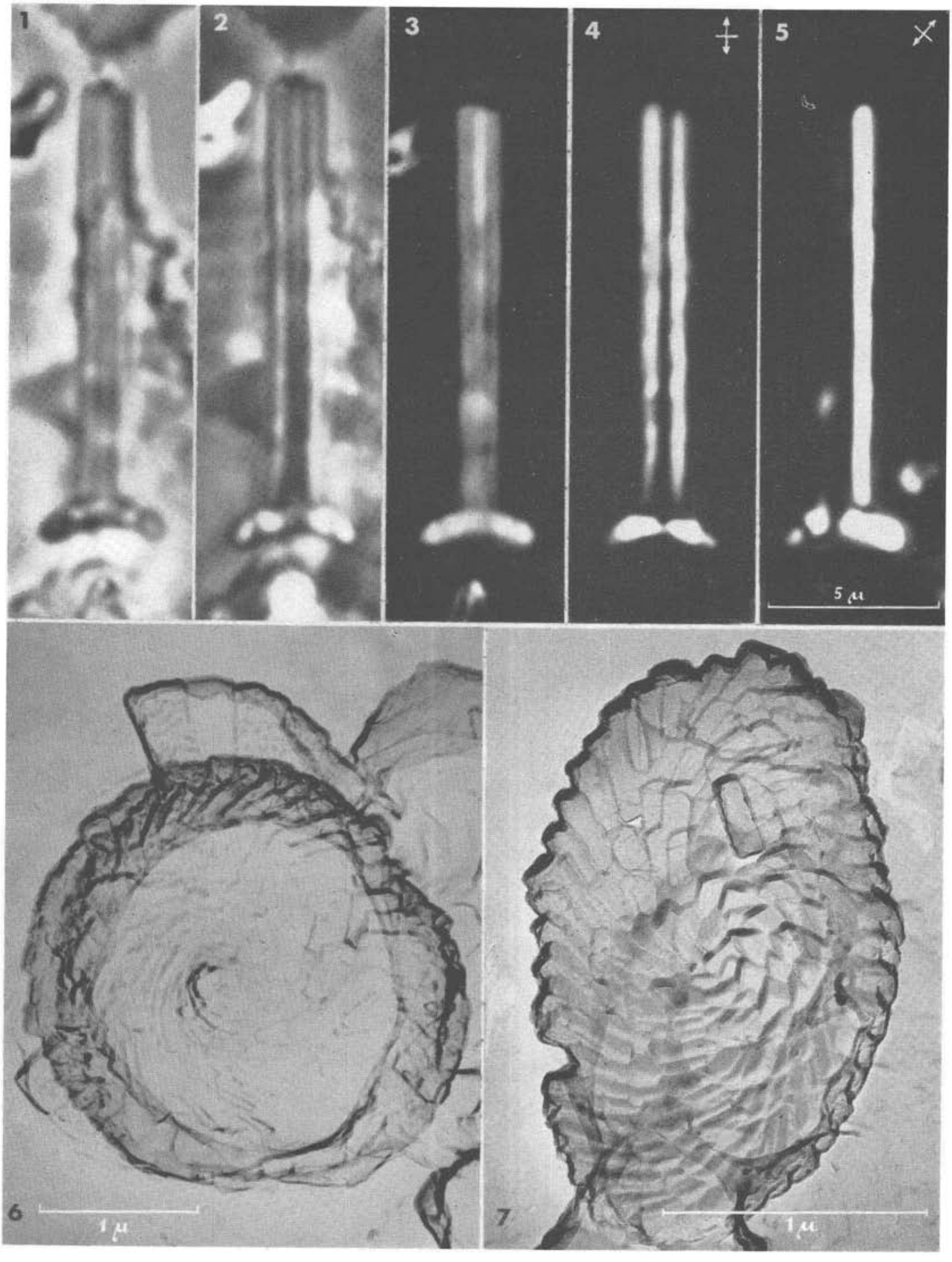
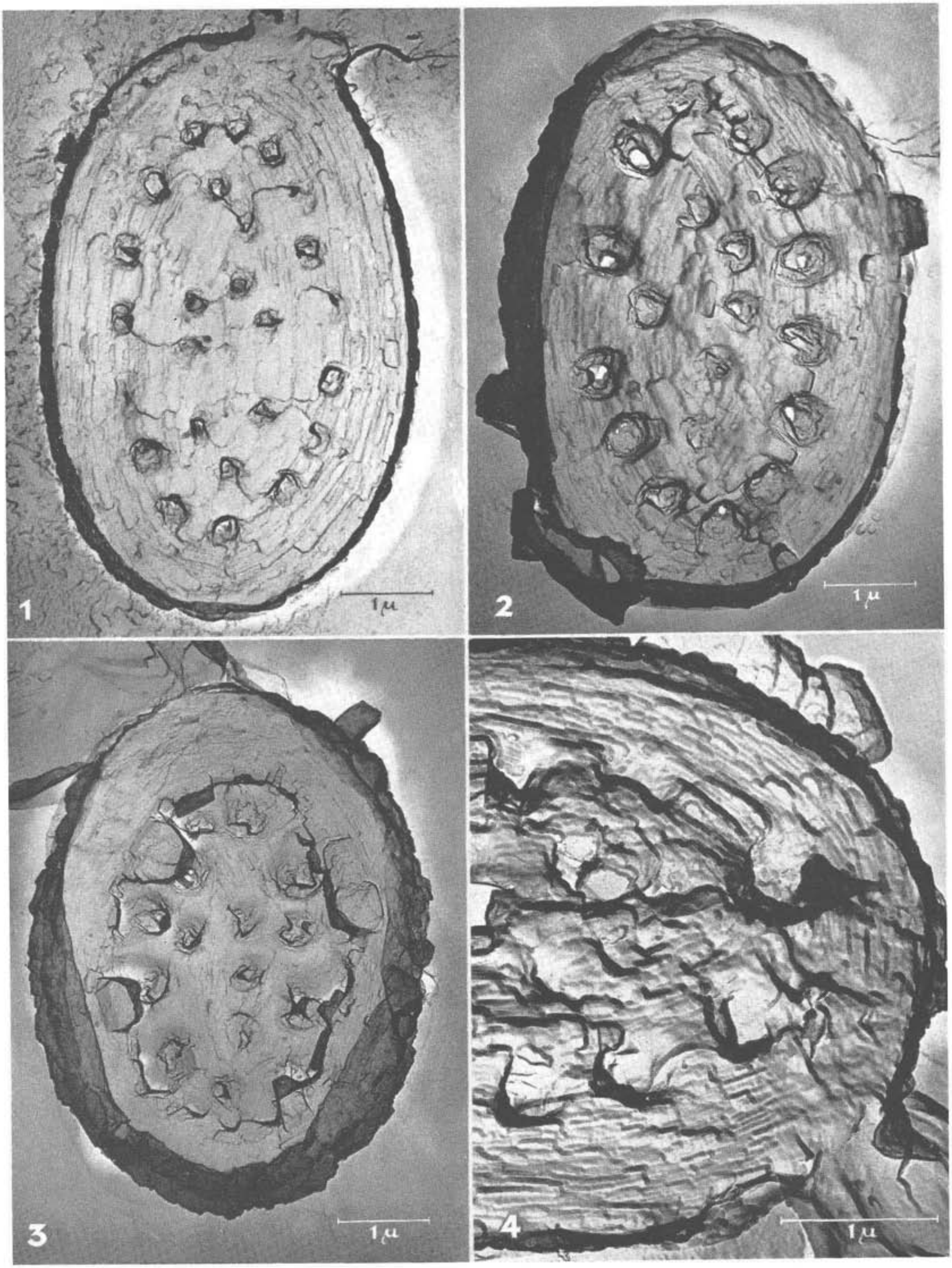

1
2
3
4
5
5 μ
6
1 μ
7
1 μ

PLATE 32



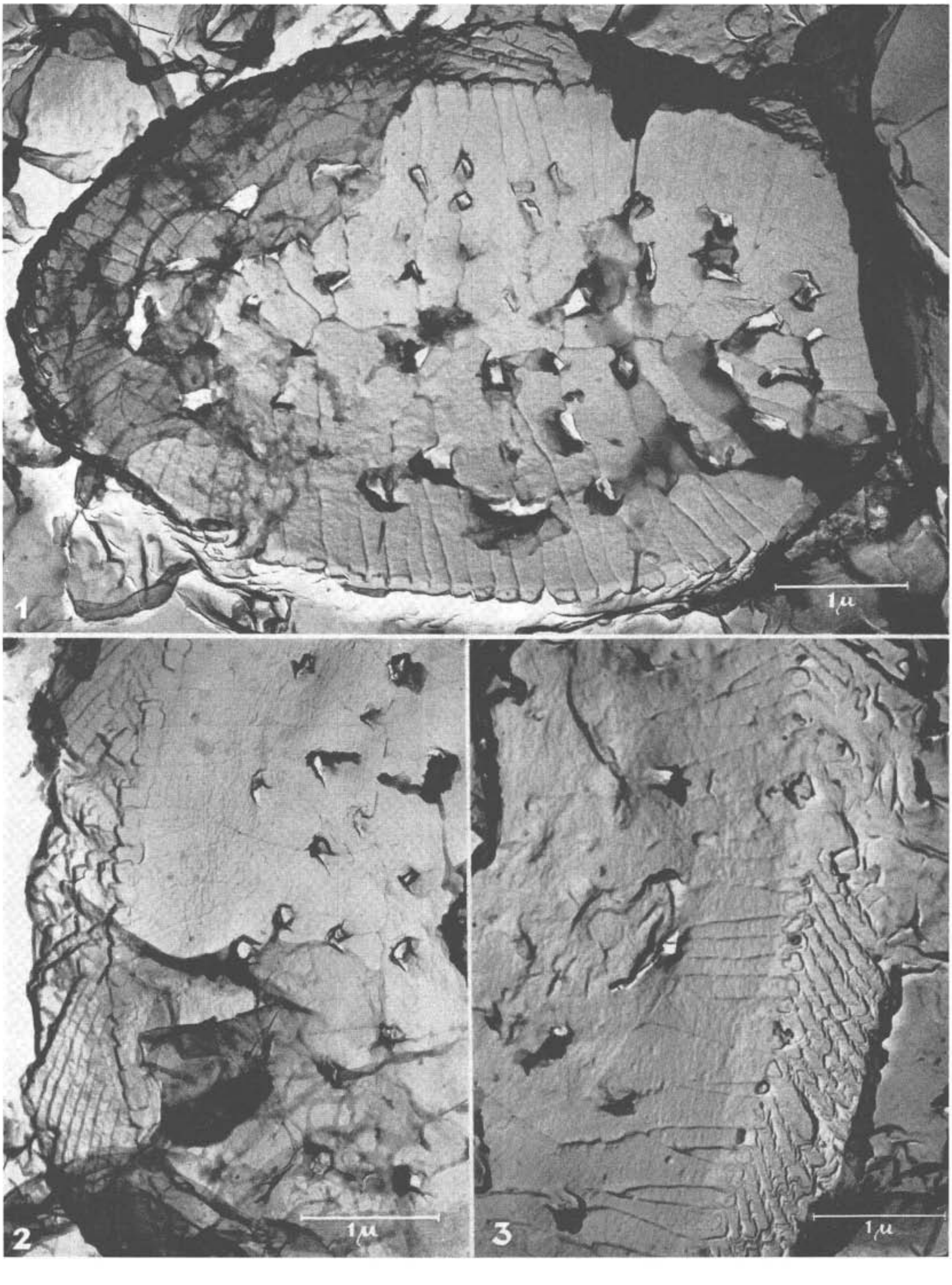
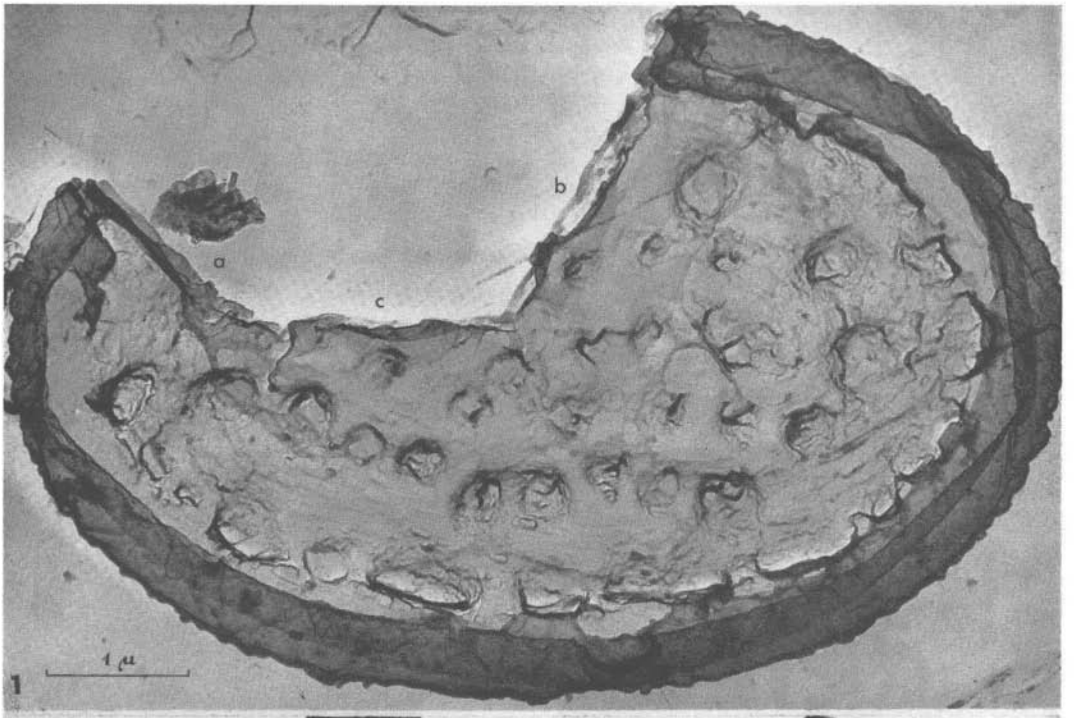
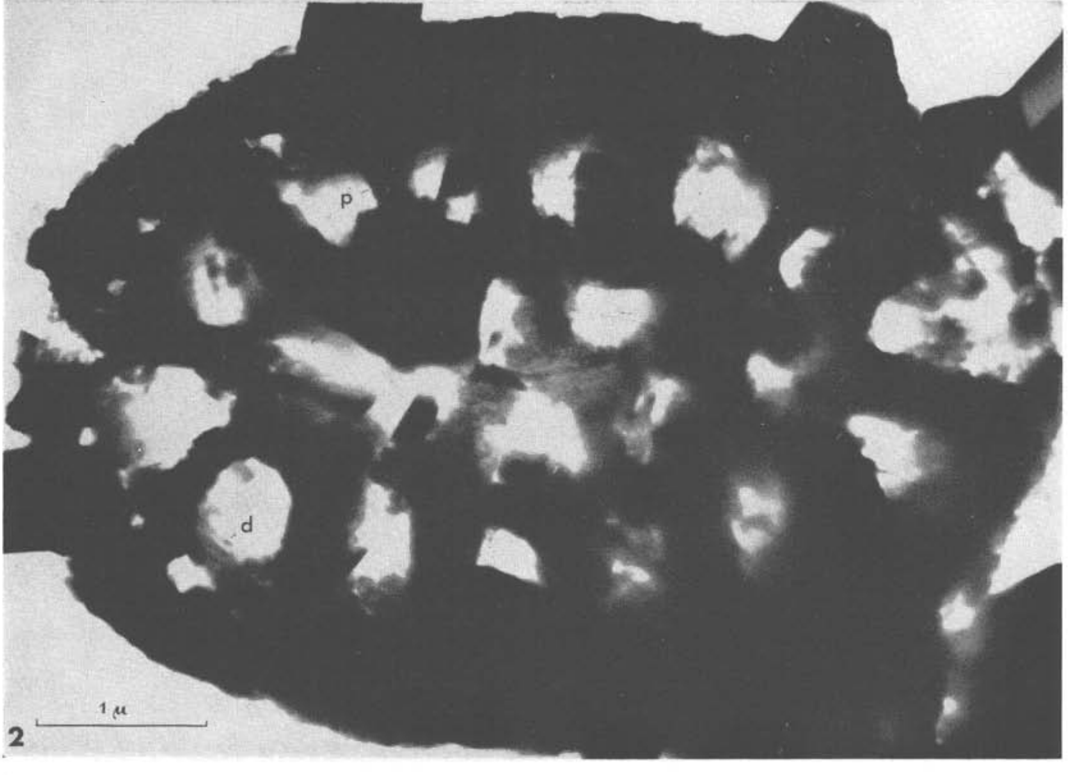

1
1μ
2
1μ
3
1μ

PLATE 34





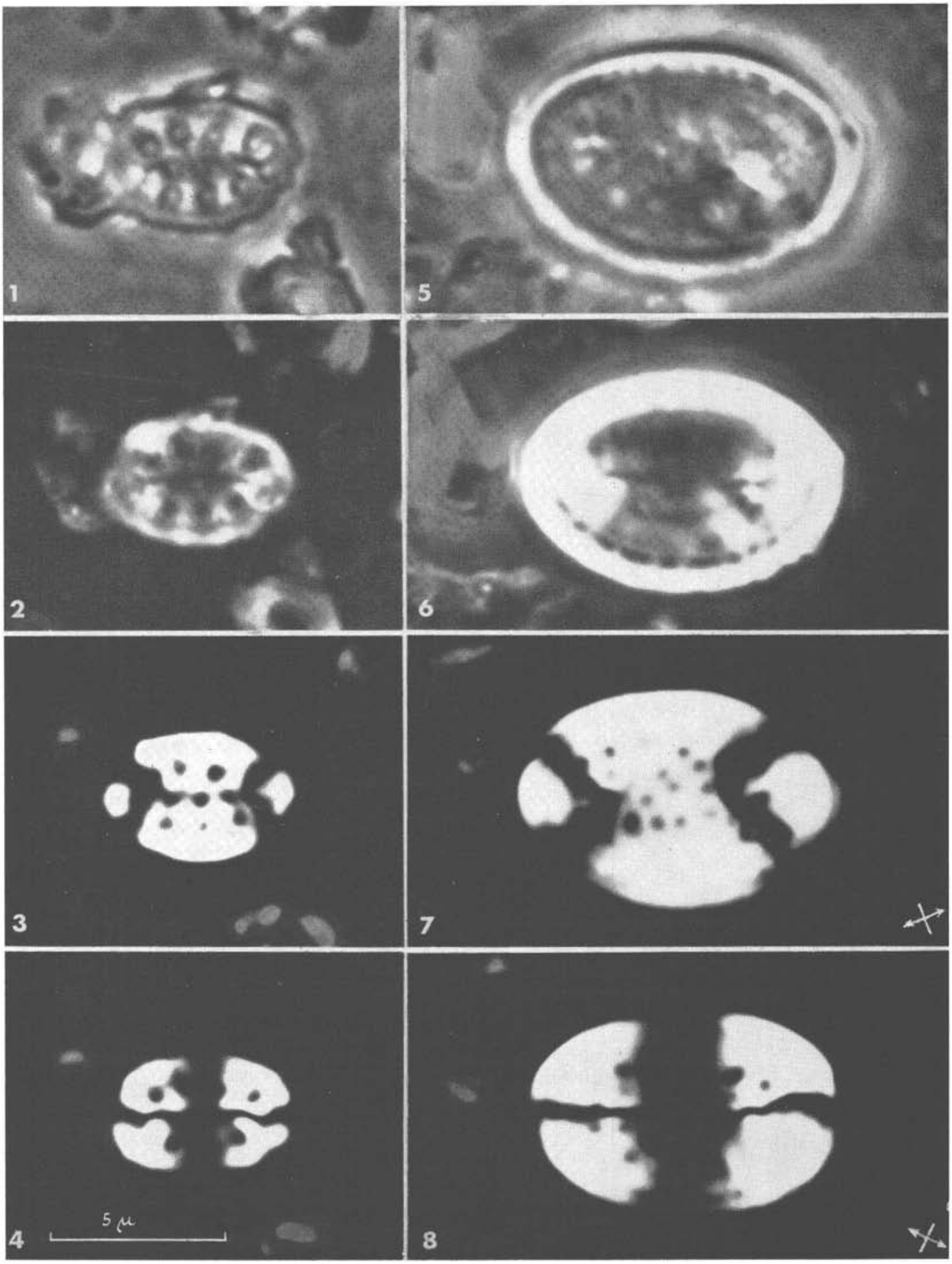
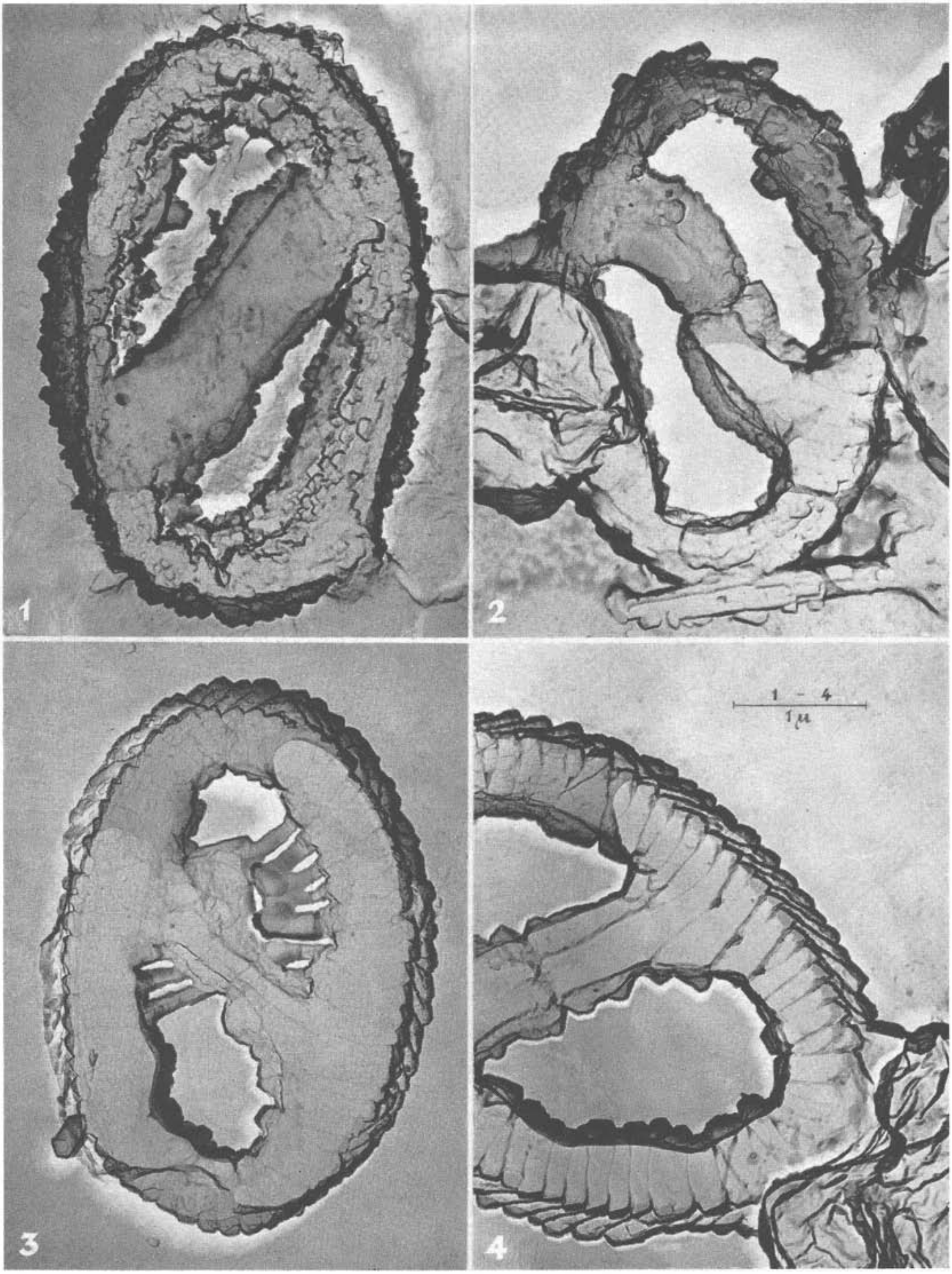
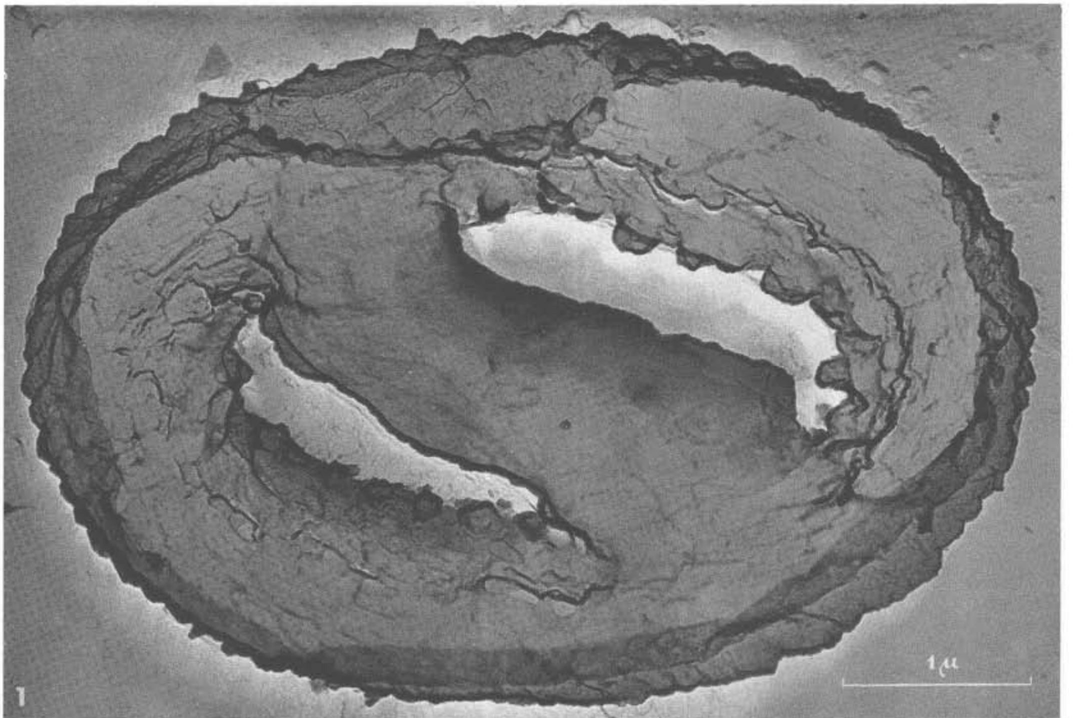

1
2
3
4
5 μ
5
6
7
8

PLATE 36




1
1 μ

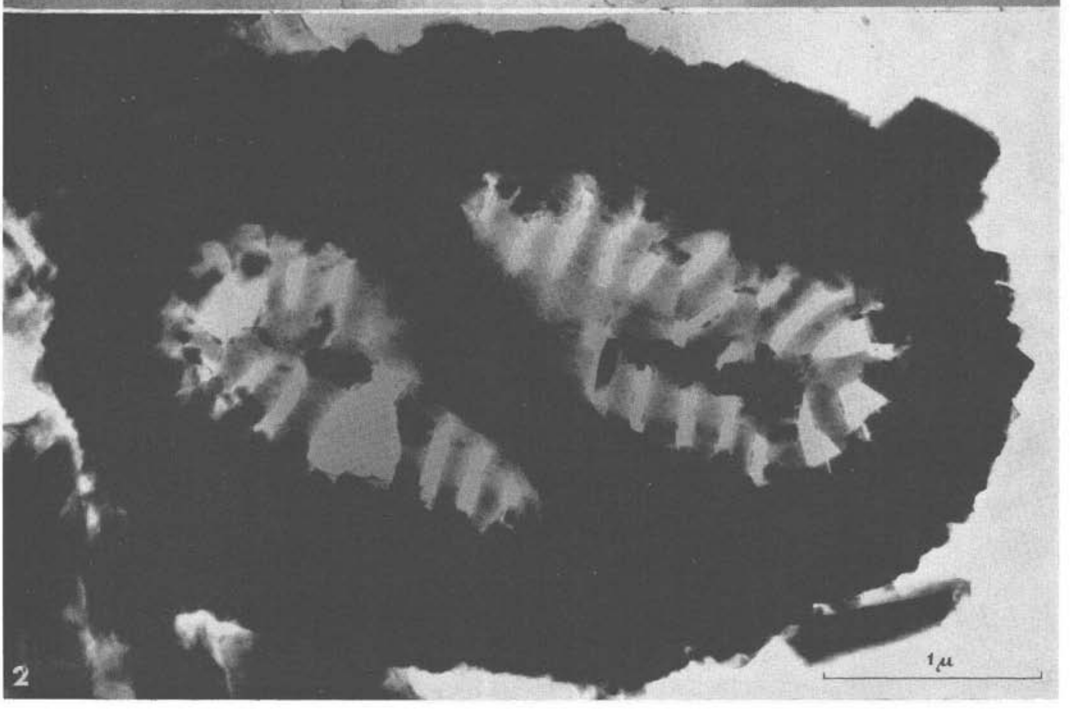
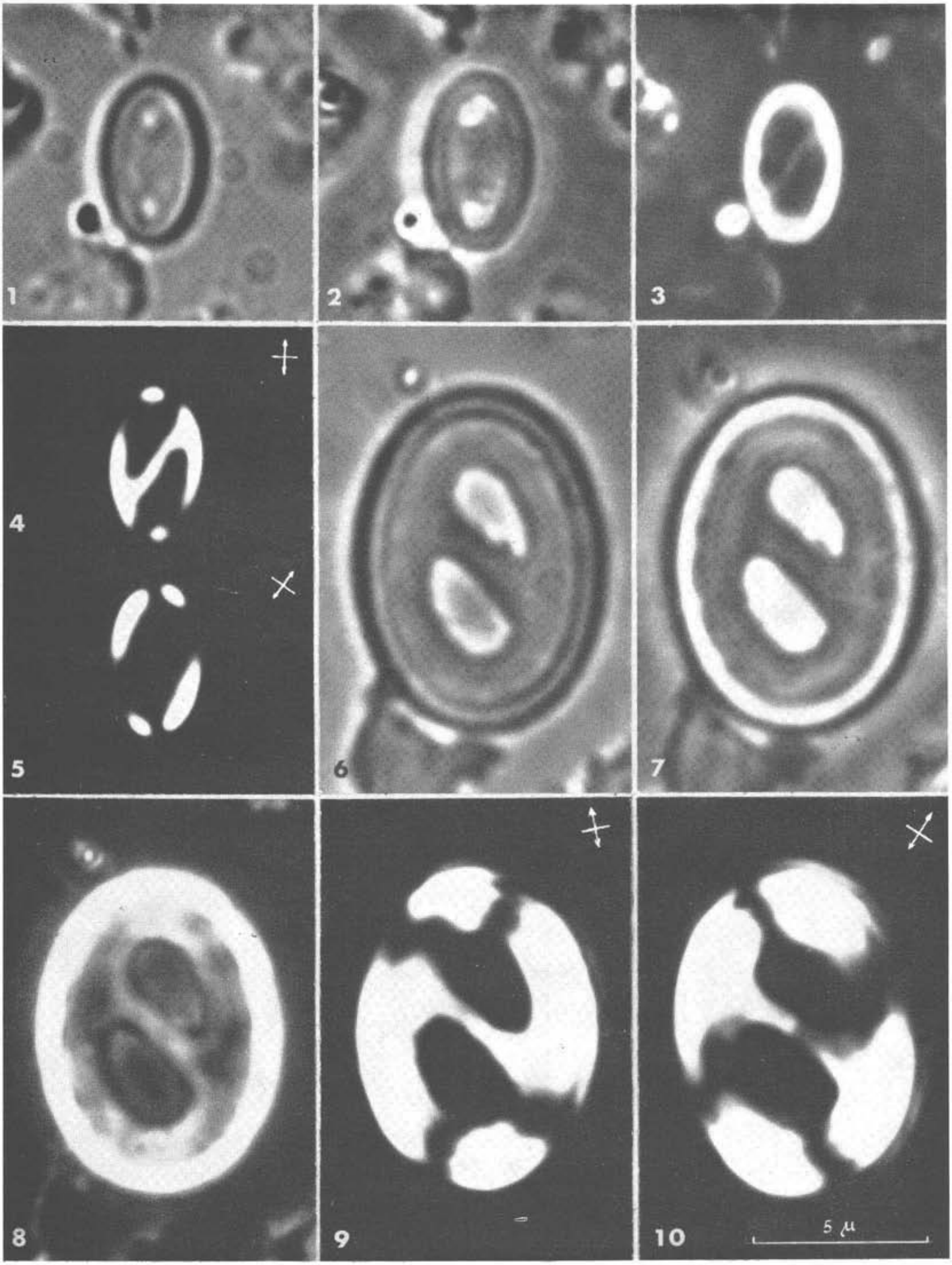

2
1 μ

PLATE 38



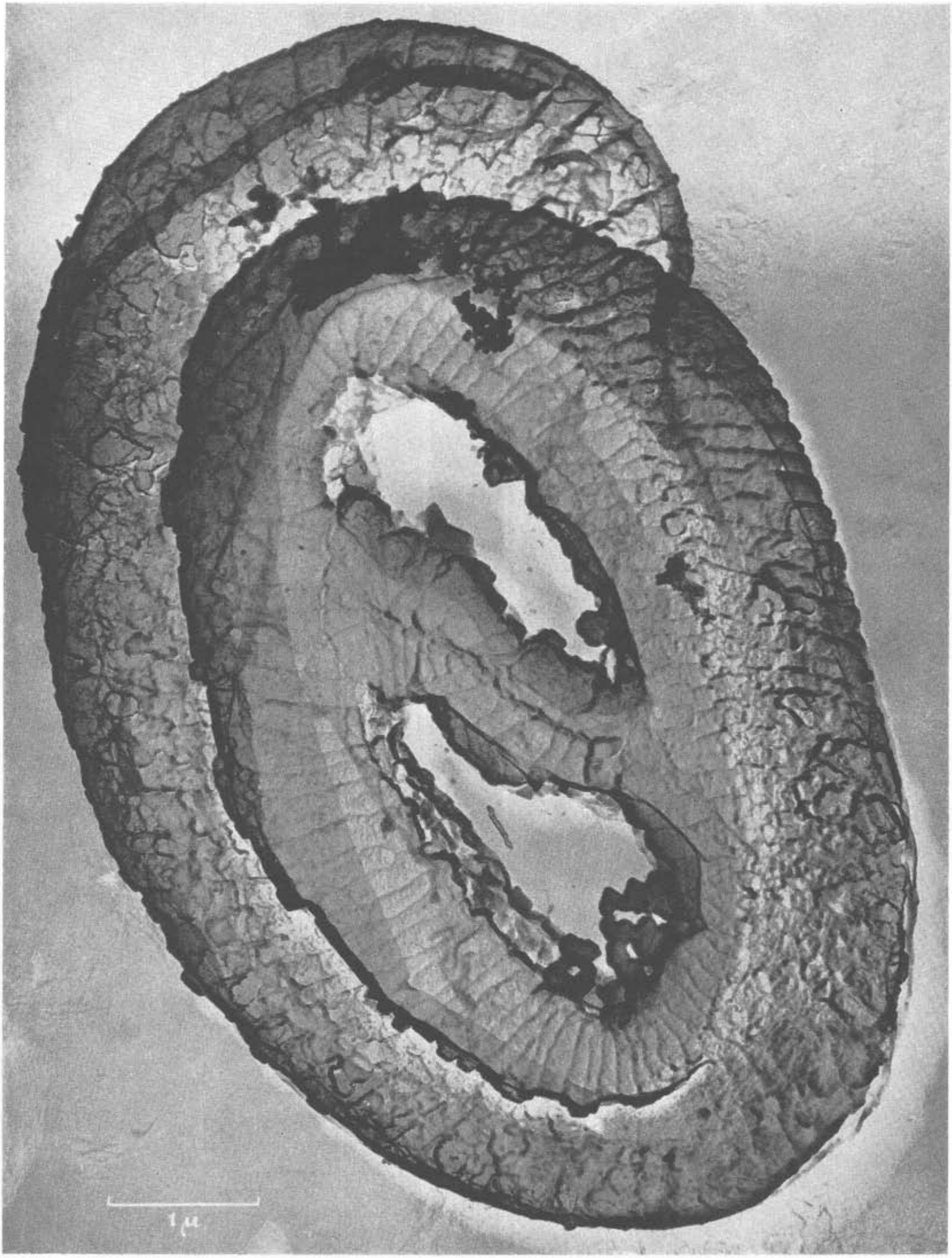
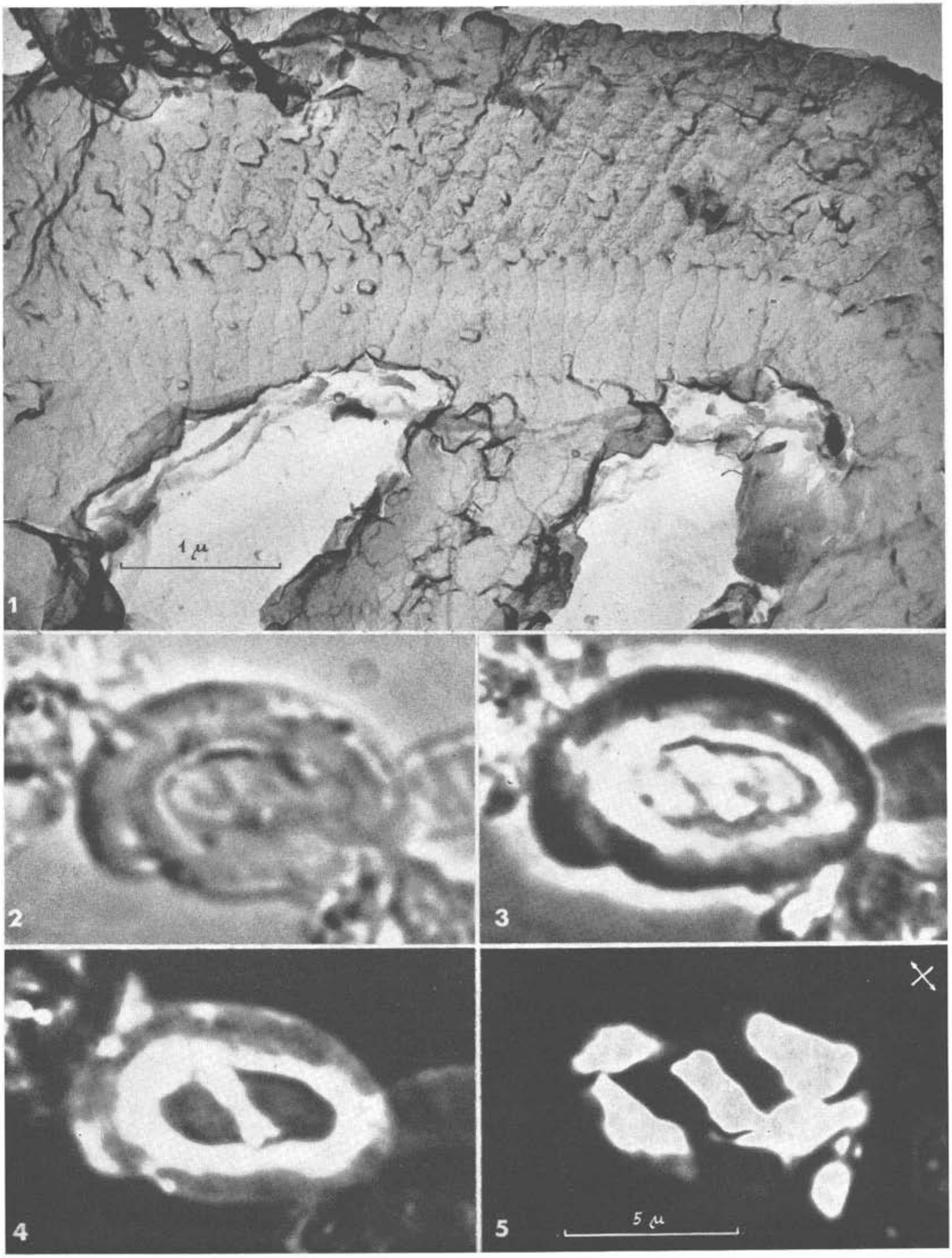
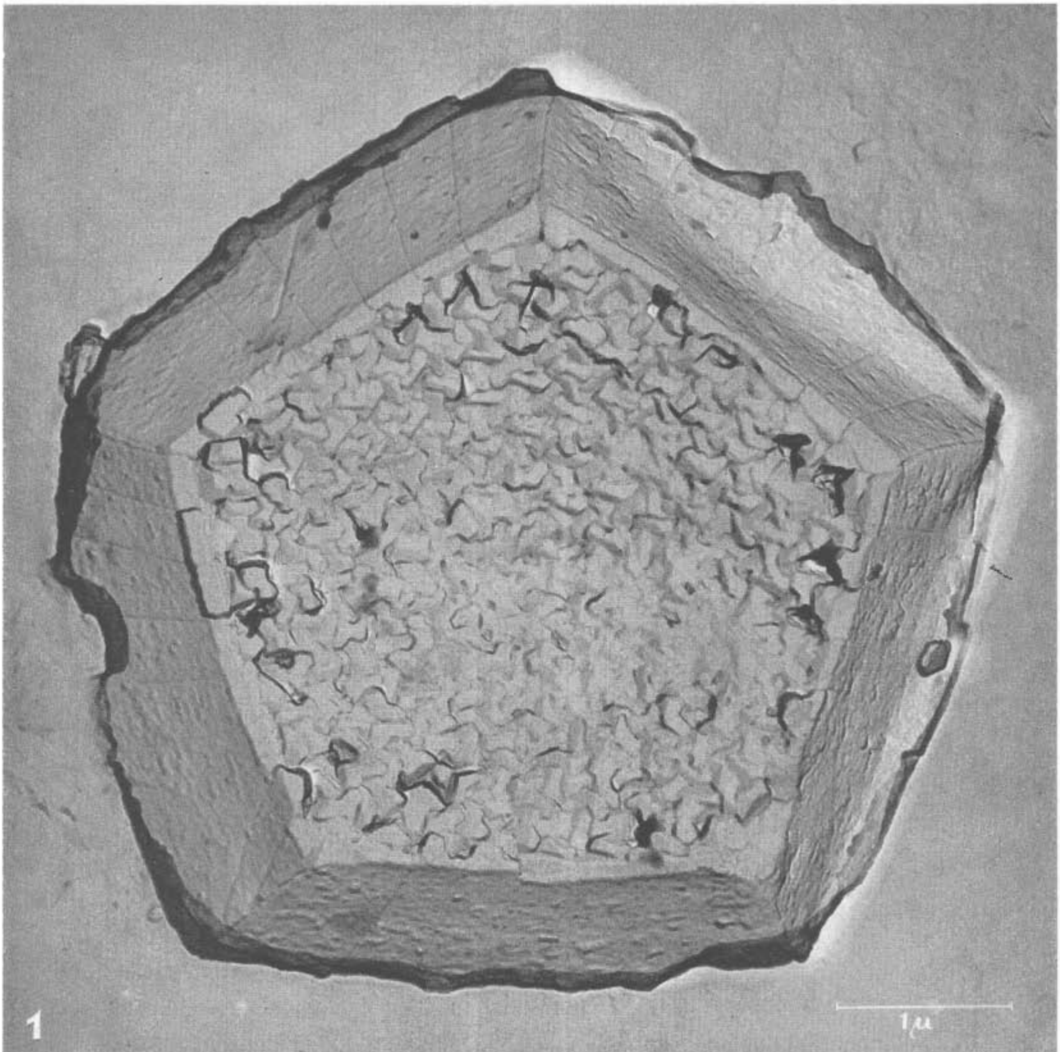

1 μ

PLATE 40




1
1μ

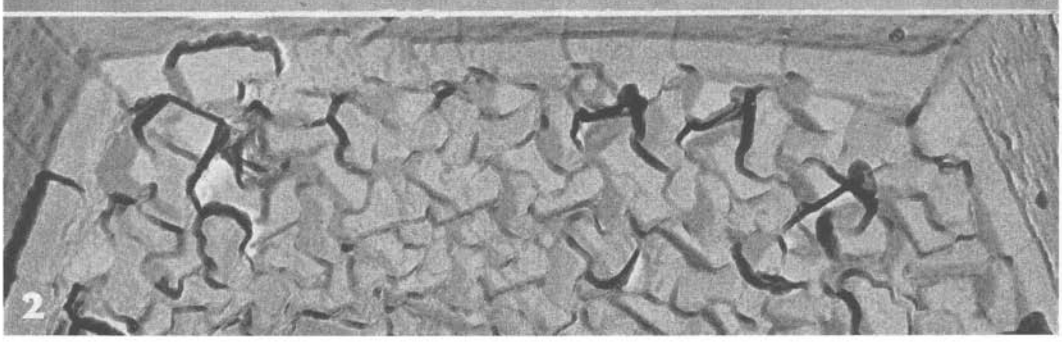
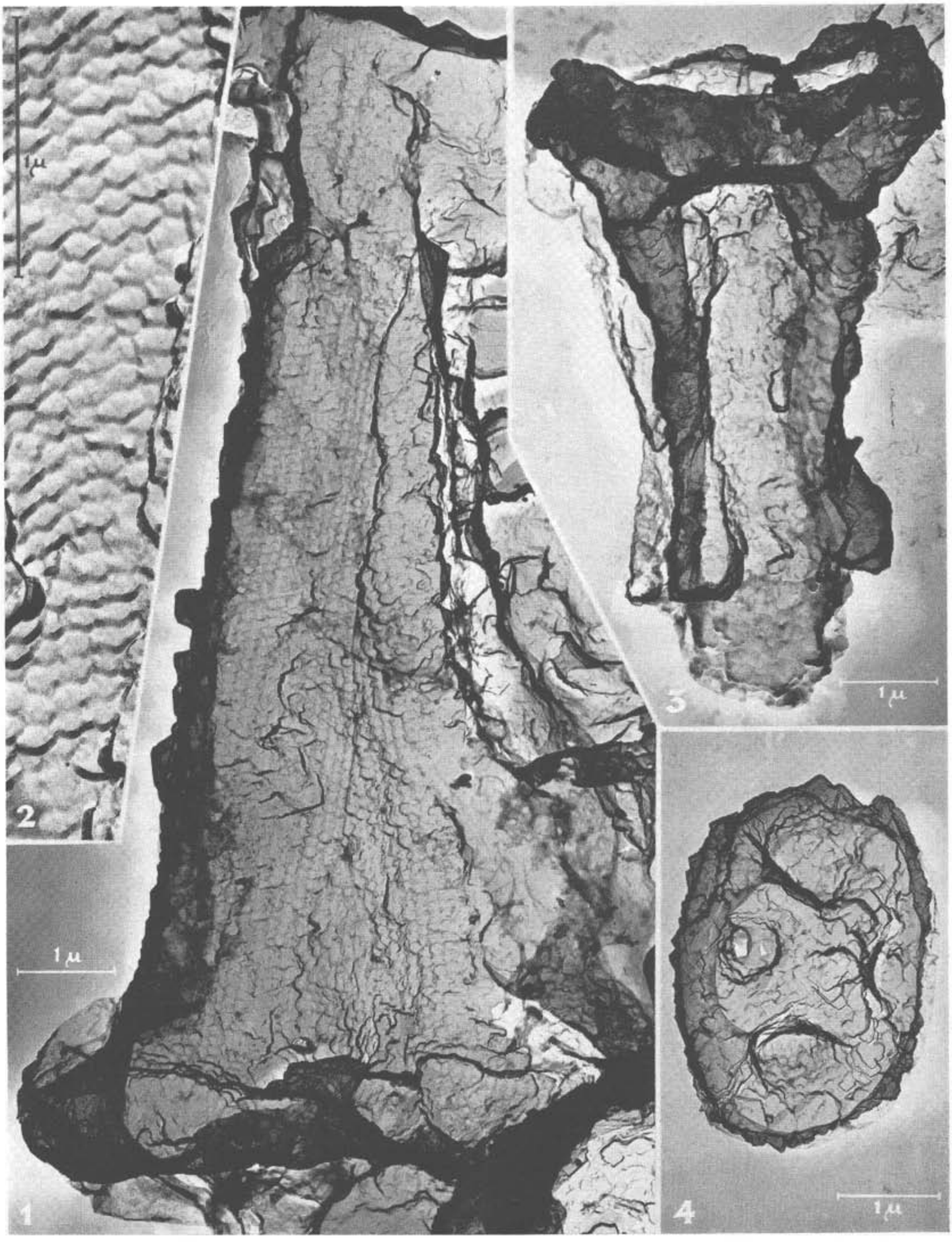

2

PLATE 42



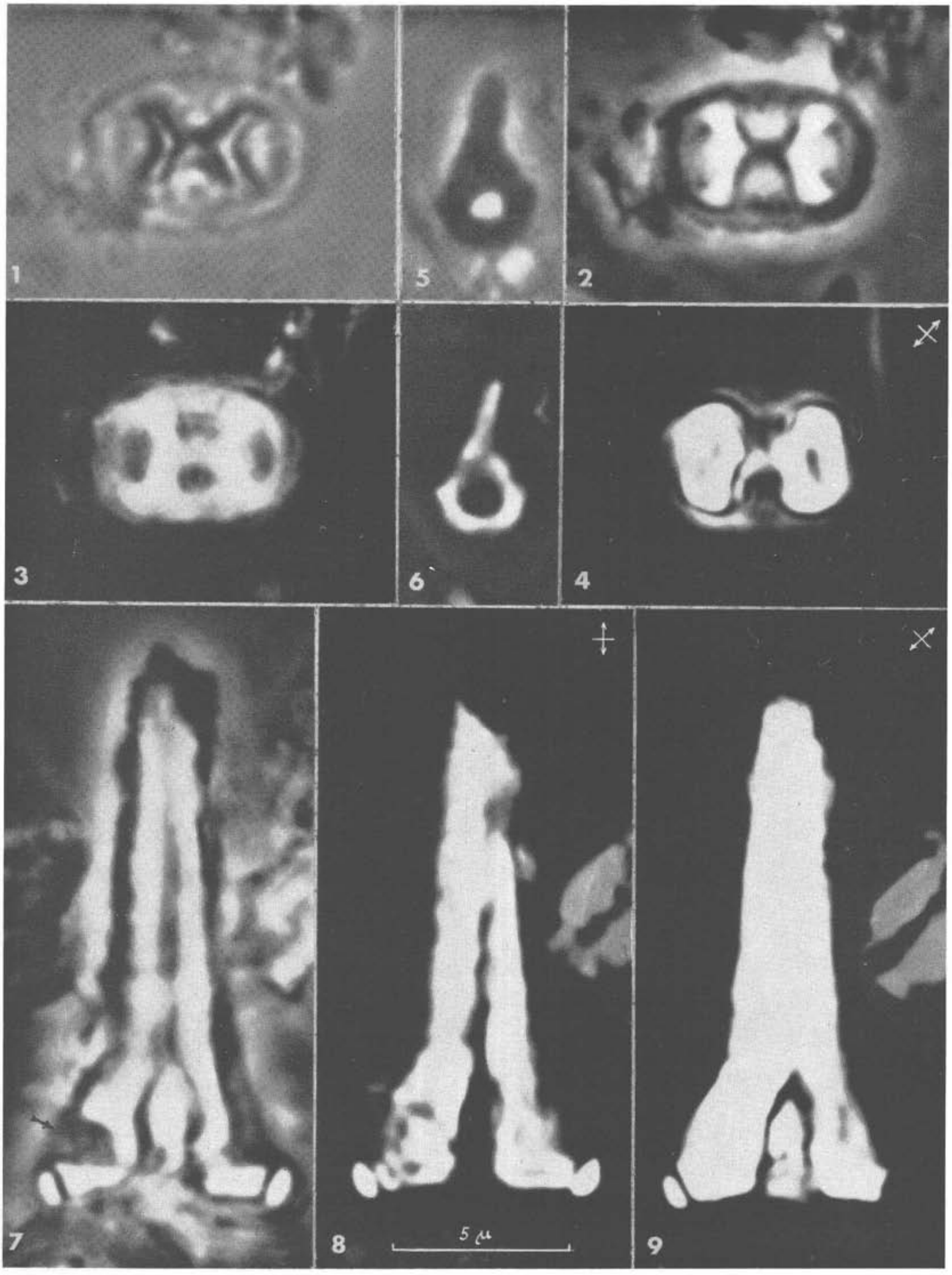
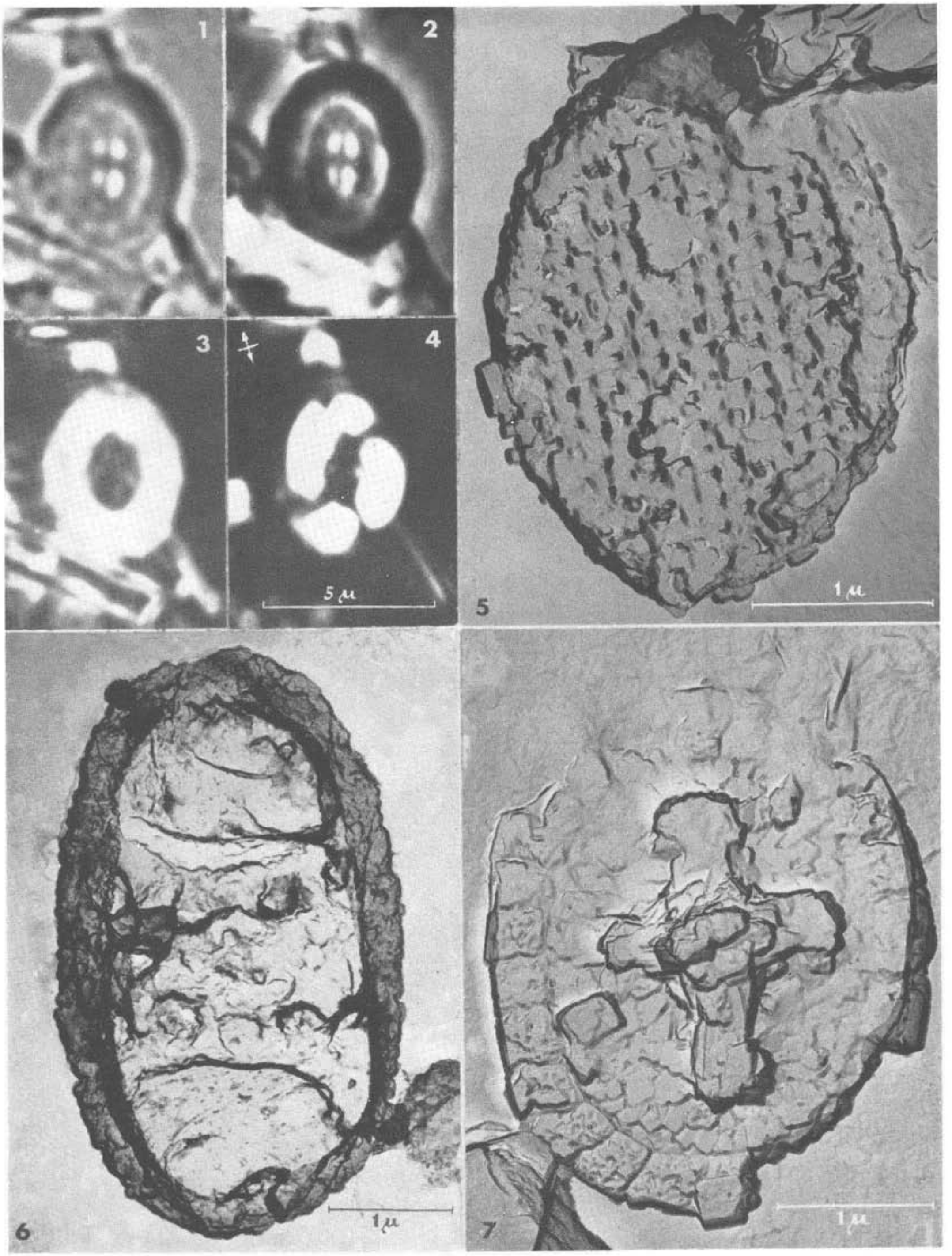

1
5
2
3
6
4
7
8
5 µ
9

PLATE 44



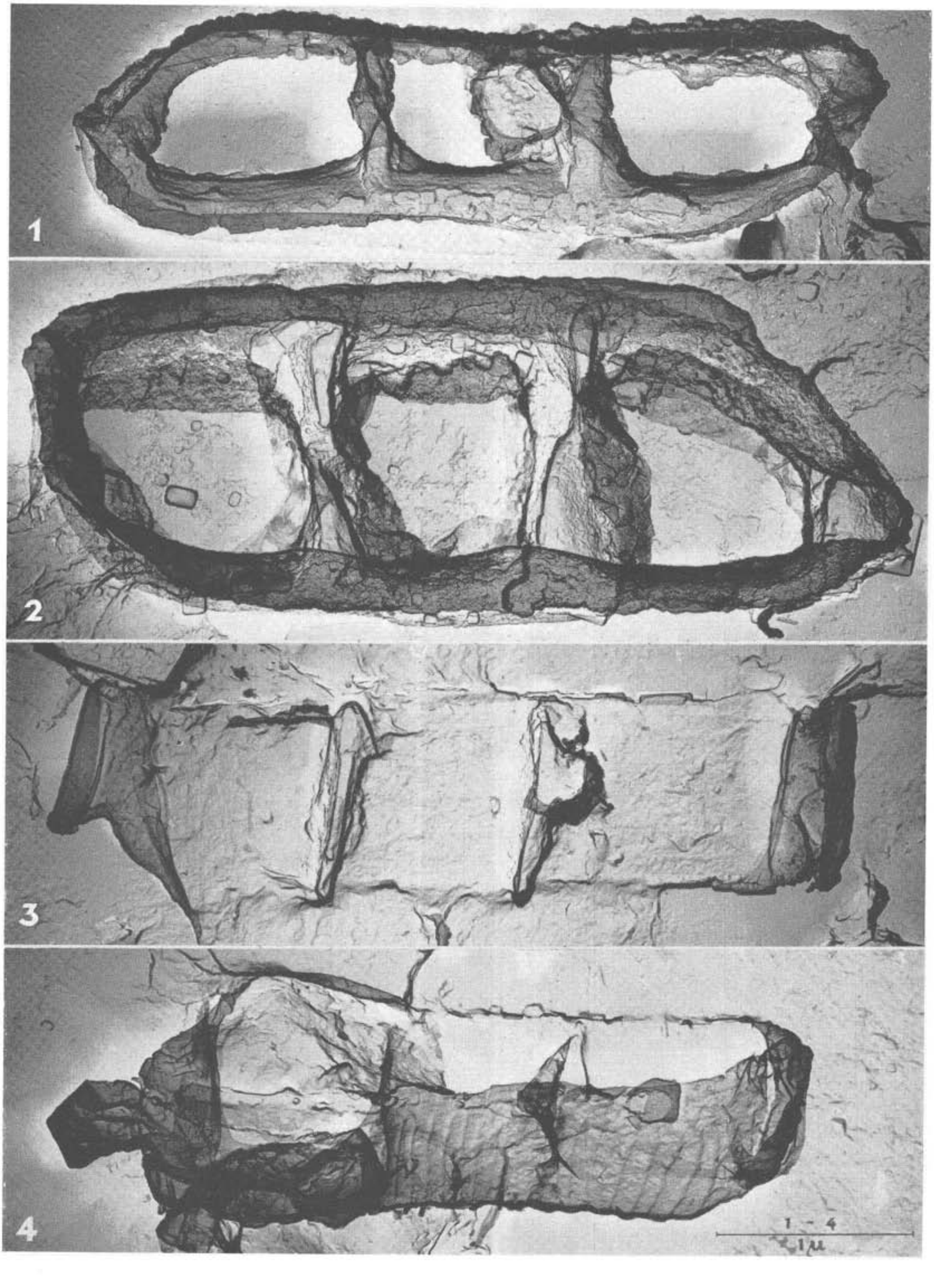
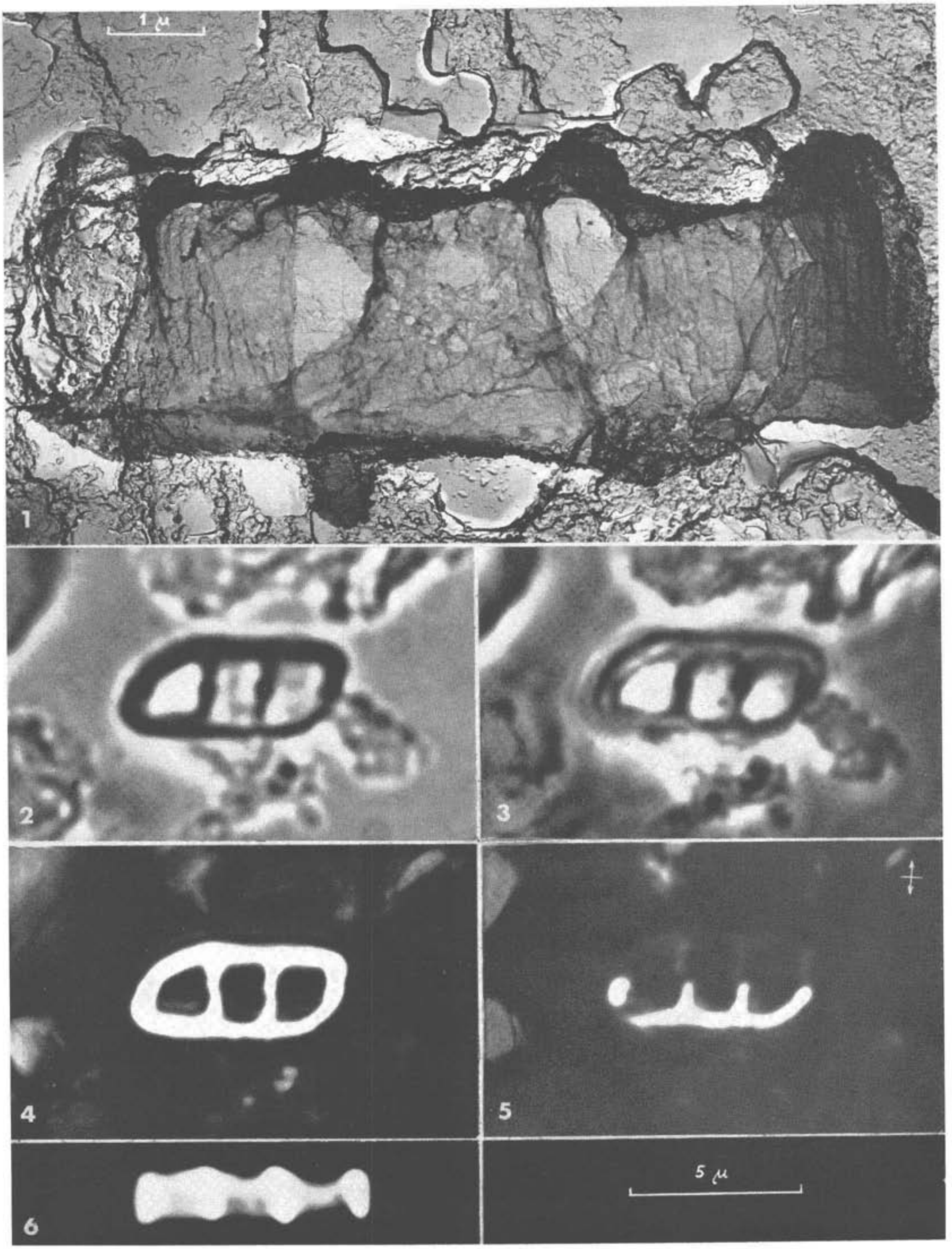

1
2
3
4
1 - 4
1 μ

PLATE 46



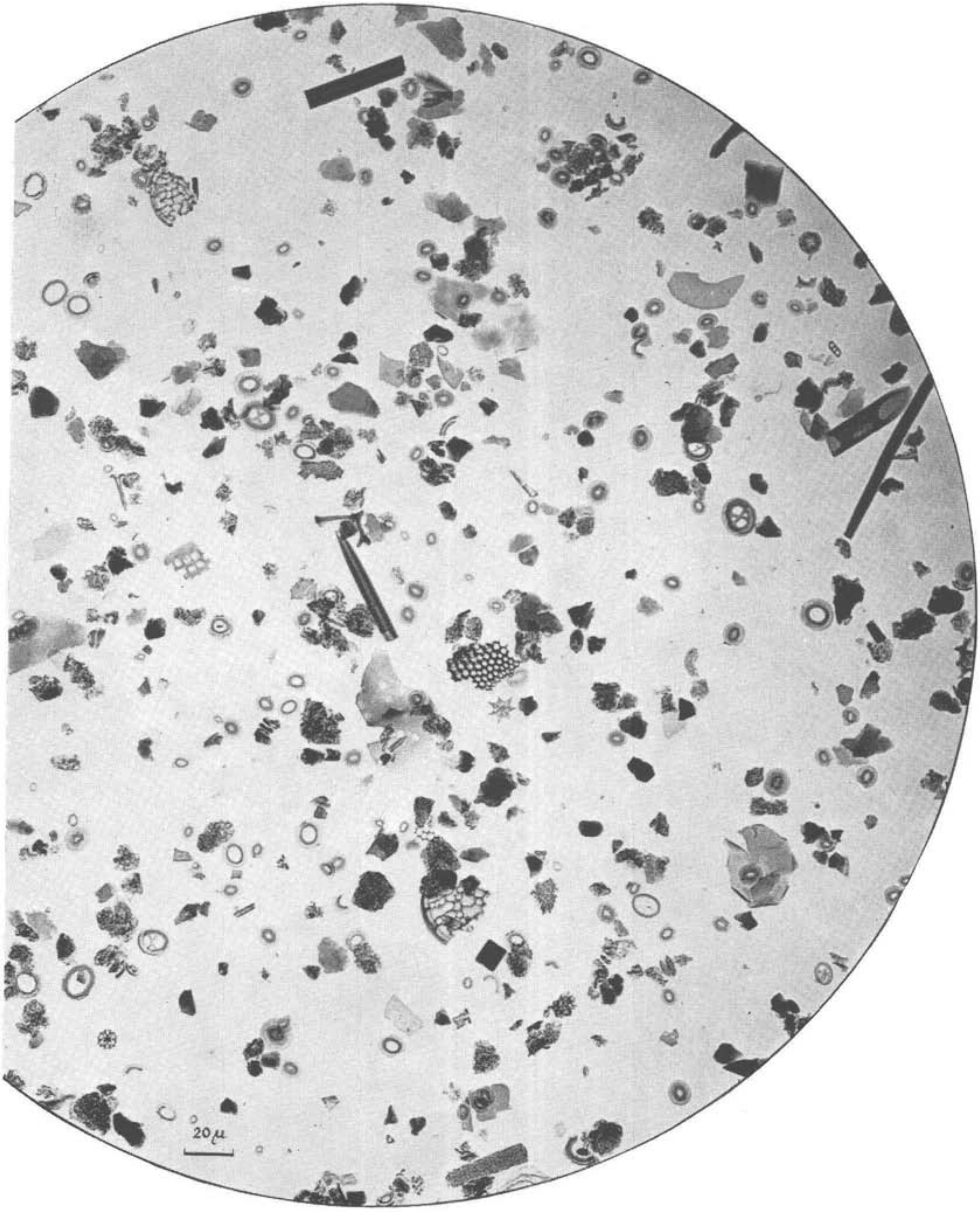
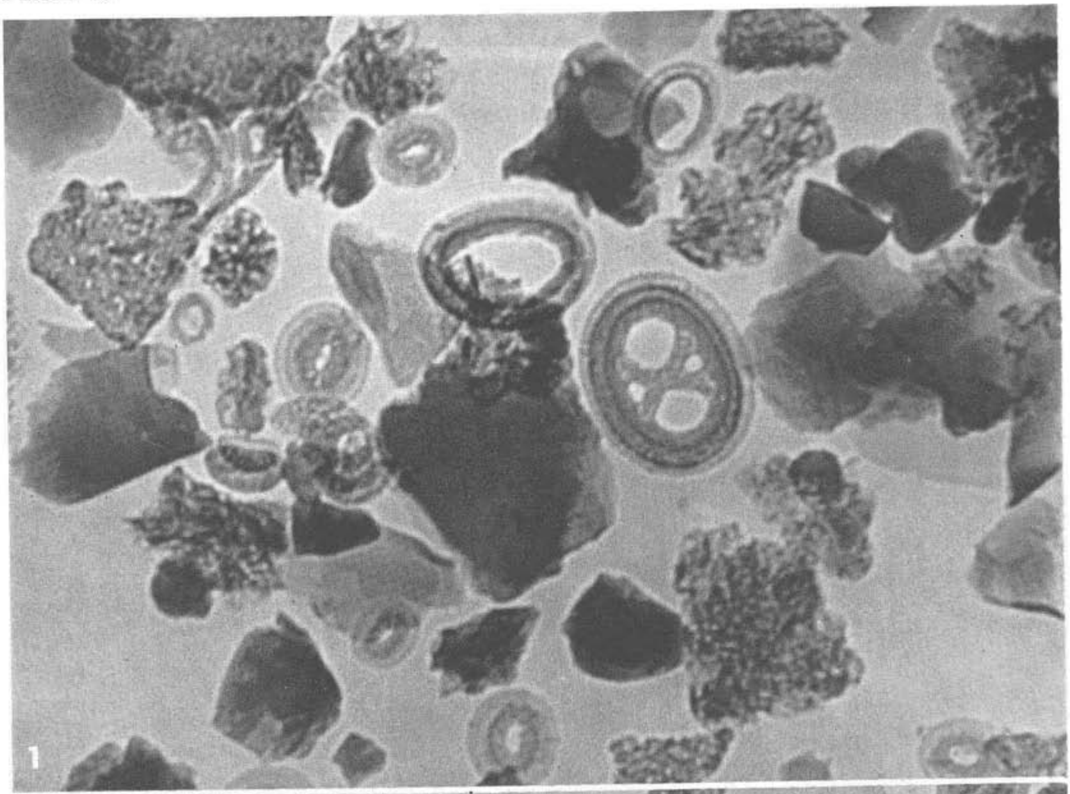
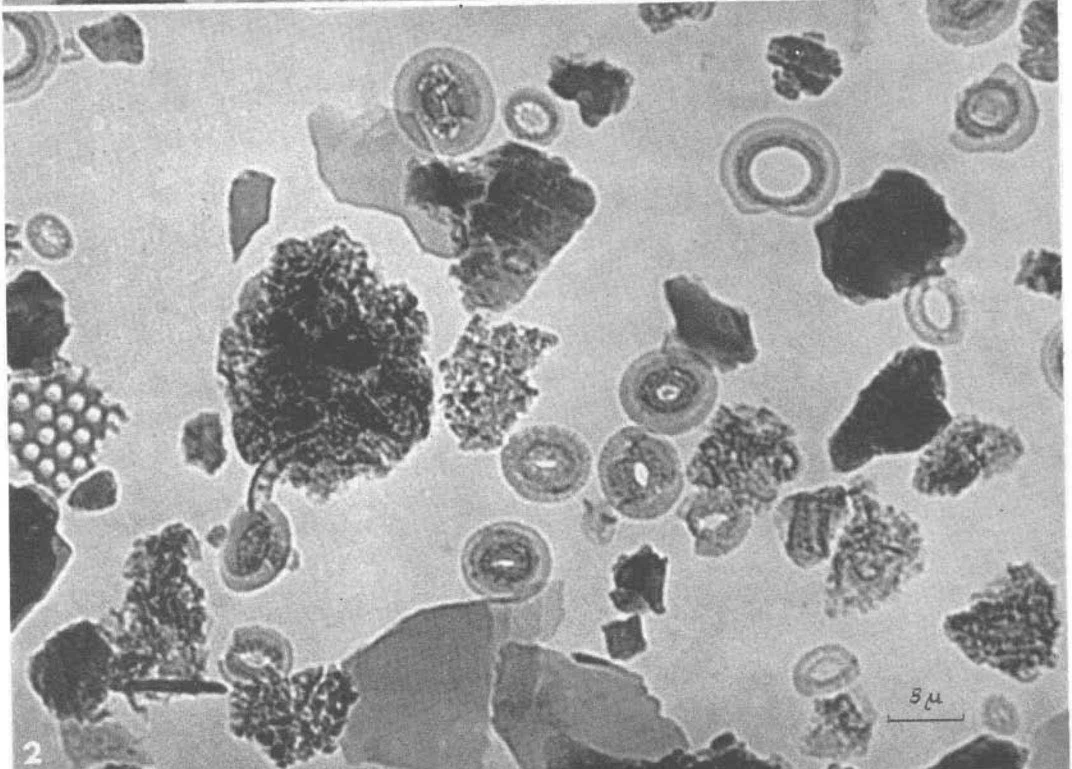

20 µ

PLATE 48


1



2