SVERIGES GEOLOGISKA UNDERSÖKNING

SER C NR 642 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 63 NR 5

URVE MILLER

FOSSIL DIATOMS UNDER THE SCANNING ELECTRON MICROSCOPE

A PRELIMINARY REPORT

WITH 25 PLATES

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Manuscript received December 1968
C. DAVIDSONS BOKTRYCKERI AB, VÄXJÖ

DEDICATED TO THE LATE

FRITZ BROTZEN

MY INSPIRING AND ENCOURAGING

TEACHER AND DEAR FRIEND

CONTENTS

ABSTRACT

Diatom micrographs taken with the scanning reflection electron microscope "Cambridge Stereoscan Mk IIa" show that the advantages over the micrographs taken with a light microscope are: about 15 times greater resolution and immensely greater depth of focus – about 300 times more than that of both light microscopes and transmission electron microscopes. The Stereoscan micrographs are almost three-dimensional, showing the shape and relief of both external and internal sides of fossil diatom frustules, with a clarity not earlier obtained either in light or transmission electron microscopy. These features, combined with the easy preparation, make the Stereoscan microscope a valuable contribution in the morphological studies of fossil and living diatoms and diatom colonies.

ACKNOWLEDGEMENTS

The present work has been carried out at the Geological Survey of Sweden (SGU).

I wish to acknowledge my thanks to Mr. K. A. Lindbergson, the General Director of SGU, to Dr. A. Danielsson, the chief of the Chemical Laboratory, SGU, and to Dr. O. Brotzen, the head of the Departement for Research and Applied Geology, SGU, for being well-disposed towards this work.

For the technical skill and assistance in all my work connected with the scanning electron microscope and for obtaining the electron micrographs, I express my gratitude and indebtness to fil. mag. Johan Malmkvist, fil. kand. Göran Alsterborg and other helpful personnel at the Chemical Laboratory, SGU.

My sincere thanks are due to Docent M.-B. Florin, the Institute of Quaternary Geology, Uppsala University, for valuable discussions and for critical reading of the manuscript and to Associate Professor C.-G. Wenner, the head of the Institute of Quaternary Geology, Stockholm University, for the loan of the Reichert Zetopan research microscope.

Further thanks to Mrs. I Signorelli, Miss I Sjöö and Mrs. L. Ulvegård, SGU, for proficient and careful preparation of photographic prints, to Mrs. I. Palmaer for the final preparation and lay-out of the plates, to Mr. E. Bragg for correcting the language and to Mrs. K. Brodén for typing the manuscript.

INTRODUCTION

The present paper is a preliminary report on the experimental work with fossil diatoms in the scanning reflection electron microscope "Cambridge Stereoscan Mk IIa". This new microscope, the second one in Scandinavia, was installed in March 1968 in the Chemical Laboratory at the Geological Survey of Sweden, SGU, Frescati, Stockholm. It is a donation from the Wallenberg Foundation to the State Museum of Natural History and SGU together.

The instrument shows complex surface structures from 20 x to some 50 000 x magnification. To quote the pamphlet from Cambridge Instrument CO: "Complementary and supplementary to transmission electron microscopy and light microscopy, some of the techniques it provides produce results unobtainable by other methods". It is "particulary useful for morphological studies of surfaces difficult to replicate for transmission electron microscopy". (Cambridge Instrument Co, 1967.)

Consequently, the new microscope must offer revolutionizing possibilities for micropaleontological and palynological research.

Diatoms form one of the microfossil groups in many ways suited to this type of microscope. The well preserved and stable diatom frustules, composed of silica, are easy to prepare. Their size varies in general between 10 and 100 microns and they possess fine and complex surface structures.

On account of their delicate structure, diatoms have long been used to test the resolution of light microscopes, and later on also of transmission electron microscopes. They also fill this function in the scanning electron microscopy.

At SGU diatoms have already been practically applied in conjunction with the servicing of the Stereoscan microscope.

The diatom frustules contain structures of varying shape and degree of fineness. The same diatom species can present structures gradually diminishing in dimensions. Several of the finer structures lie at or below the resolution limit of the light microscope. The resolution of a transmission electron microscope is about 100–200 times better than that of a light microscope and about 10–20 times better than that of the Stereoscan microscope, but there are still diatom structures lying at and below the limit of its resolution. Diatoms have thus contributed to the development of microscopy, and certainly in the future their fine and regular structures will be an incentive to further improvements (Kolbe & Gölz 1943).

METHODS

CONCENTRATION

The concentration of fossil diatoms for study under the scanning electron microscope is carried out largely in the same way as when working with light microscopy (Hustedt 1958, Miller 1964). However, the concentrated sample must be rich in diatoms and free from organic matter and colloidal clay. The Stereoscan is too expensive to be used for timeconsuming searching for objects.

PREPARATION

The specimens were prepared as follows:

1) A drop of the concentrated sample (diatom frustule + distilled water) was spread as a thin uniform layer on a circular cover glass of 12 mm diameter, and gently dried.

2) During the drying the material on the cover glass was examined at low magnification under a light microscope to check the thickness, uniformity and purity of the diatom layer.

3) If approved, the cover glass was fixed onto a standard stub with a little dab of synthetic glue.

4) The cover glass, fixed on the standard stub with the diatom layer upwards, was coated with a conductive substance (gold) in a vacuum evaporator.

In coating specimens for examination under the Stereoscan microscope, the stub is placed in a special holder and rotated at 200 revolutions per minute in a vacuum, while a weighed amount of gold wire is evaporated onto the spinning disk from varying angles. This ensures that all surfaces of the sample are made electrically conducting.

MICROSCOPICAL WORK

The probe stub is plugged into the specimen stage of the Stereoscan microscope. Column vacuum is maintained during specimenchanging, and the total vacuum is restored within a few minutes.

In the instrument a beam of electrons is focused to a fine point on the specimen and made to sweep or scan the surface in a "raster" as in a television system. For a more detailed description of the construction and instrumentation of the Stereoscan microscope the following papers are referred to: Smith & Oatley 1955, Oatley *et al.* 1965, Thornton 1965, Oatley 1966, Dwornik 1966, Echlin 1968.

In the Stereoscan microscope the specimen can be moved both rotationally and linearly. The rotation is around the stub axis and (through 90°) around an axis perpendicular to the probe. The linear movements are possible in X, Y and Z directions.

A resulting image of marked three-dimensional character of the surface topography of the object studied is presented on the screen and can be photographed either with a Polaroid camera or on 35 mm film.

The area scanned can be varied from a few square microns to several square millimetres with magnifications between 20 x and about 50 000 x.

If required, stereomicrographs may be prepared by changing the probe angle slightly (about 7°) between exposures. The 35 mm film used was Kodak Plus X Panchromatic, PX 410.

MATERIAL

REMARKS ON THE SHAPE, STRUCTURE AND CONDITION OF FOSSIL DIATOMS

Diatoms are unicellular algae, with a siliceous skeleton (frustule) built up of two parts, like a box with a lid. The frustules are of circular, trigonal, polygonal, oblong or elongated shape with ornamented cell walls showing various structures. The siliceous cell wall makes them very resistent. Most diatom frustules remain as fossils in sediments. Fossil diatoms are used in paleontology and stratigraphy as indicators of the sedimentation conditions, due to their sensitivity to salinity, depth, viscosity, temperature, clearness, nutriment, pH and other factors. Every combination of these factors produces its own characteristic diatom flora preserved as fossils in the sediments.

Diatom morphology and classification are mainly based on the shape and structure of diatom frustules as they appear under the light microscope. A diatom frustule, also known as a theca, consists of two parts, each of which is built up by a valve and a girdle. The valve consists of valve surface and valve mantle, bent at about 90° angle to join the girdle. The girdles are expandable bands of silica connecting the two valves. Between the valve mantle and the girdle there may in many diatoms be one or several intermediate elements known as intercalary bands. In slides viewed under the light microscope the diatom frustules usually can be seen either in valvar view or in girdle view.

The class Diatomae is divided into two orders: Centrales and Pennales. To Centrales belong diatoms with radial symmetry and radial or concentric structures. To Pennales belong diatoms with bilateral symmetry and cross-striped or feathery structure.

The structural elements consist of striae, chambers, pores, knobs, various processes, hyaline areas and a raphe. Every structural element may in its turn be built up of several still finer structural elements, visible only under the electron microscope. Under the transmission electron microscope the details of frustule openings that transmit light have been studied in detail.

There are two main types of openings: holes and chambers. The holes may be simple (without membranes) or contain a perforated membrane. The chambers always have membranes, usually two or three different perforated ones.

The perforation may consist of one large pore (cover pore) or many minute pores (sieve pores). The membranes are accordingly called cover membranes and sieve membranes.

Each diatom species has its own characteristic structure of frustule openings.

For further information and results of diatom studies in transmission electron microscope, see Kolbe & Gölz 1943, Hustedt 1945, Kolbe 1948, Hendey 1959, Helmcke & Krieger 1953–64, Reimann 1960, Okuno 1964.

Other surface structural elements do not transmit light; raphes, thickenings, processes, spines and knobs cannot be seen in transmission electron microscope. In this respect, and also in studying the general shape of diatoms, the scanning electron microscope is especially suitable.

Fossil diatom frustules are mostly found as separate valves, girdles and intercalary bands.

In spite of the very good resistance of the diatom frustules, they sometimes occur more or less corroded and destroyed in the sediments. The frustules may be broken into fragments or the fine sieve membranes may be abraded. The amount and type of damage that the fossil diatom frustules have suffered in some way reflect the degree and duration of weathering and other geological events (pressure, heatening by folding, volcanism etc) that the deposits have undergone. There is also a risk that diatom frustules will be destroyed during concentration in the laboratory. For that reason violent mechanical treatment (crushing, grinding, violent boiling) must be avoided.

ORIGIN OF THE MATERIAL STUDIED

Fossil diatoms from three localities have been studied under the Stereoscan microscope. They represent different types of diatom floras, deposited in different sedimentation conditions and at different geological ages.

1) Marine diatoms, deposited in a tropical sea during the Lower Eocene period, Tertiary age. Material from diatomaceous deposits on the islands Fur and Mors in Limfjorden, Denmark. Collected by the author in the summer of 1967 (Plates 1–11).

2) Fresh water diatoms, deposited in a meso- to eutrophic lake during an Interglacial (Eemian) period, Pleistocene age (Lundqvist 1968). Diatomite layer under swamp peat at Leveäniemi, Lapland, Northern Sweden. Material,

collected in the summer of 1967, belongs to Dr. J. Lundqvist, Mapping Department, SGU. (Plates 12–19.)

3) Lagoon diatoms, deposited at the time of isolation from a brackish sea (Litorina sea) during the Post Glacial period. Lagoon mud under the peat in Öja moor, geological map "Örebro SV", Middle-Sweden. Material, collected in the summer of 1966, belongs to Dr. E. Fromm, Mapping Department, SGU. (Plates 20–25.)

OBSERVATIONS ON THE STEREOSCAN MICROSCOPE

ADVANTAGES

1) The scanning electron microscope has a great depth of focus combined with good resolution. The micrographs obtained have a three-dimensional effect, giving a picture of the shape and the relief of diatoms, which is not shown by micrographs taken with a light microscope or an ordinary electron microscope.

Objects with complex shapes and uneven surfaces can be examined at high magnifications and the instrument will resolve structures as small as 200 Å – about fifteen times the resolving power of the light microscope. The depth of focus of the Stereoscan microscope is about three hundred times greater than that of utilizable in light and transmission electron microscopes.

2) As the fossil diatom material mainly consists of separate valves, girdles and intercalary bands, there are excellent possibilities of studying the different outside and structures of the diatom thecas.

Almost every diatom species studied in the Stereoscan microscope has shown new structural elements not previously seen or known. The light microscope gives a joint picture of the inside and outside structures of diatom frustules. For example, it can be difficult to decide if a fine structural element that looks like a dot in the light microscope is a pore or a knob, or if it is situated on the inside or on the outside of a diatom frustule. In the transmission electron microscope only the structural elements that transmit light (holes, chambers, pores) are visible.

3) The possibility of rotating the specimen in the Stereoscan microscope makes it easy to study the same object from different angles. In this way the same diatom frustule can be studied in all positions from valvar view to girdle view. The best micrographs are taken when the specimen is inclined at 45°. (Se Plate 1.)

4) The preparation of diatom samples for study under the Stereoscan microscope is a simple procedure.

5) As every diatom species has its own characteristic fine structure, it will be easier to identify small diatom fragments and damaged and corroded diatoms, which is almost impossible under the light microscope.

6) Thanks to Stereoscan micrographs of diatoms, it will be easier to interpret the shape and structure of diatoms later under the light microscope. The identification of diatoms during analyses will be easier and more reliable.

DISADVANTAGES

1) Although both the rotational and linear adjustments are graduated it is difficult to refind the object studied. Once removed from the specimen stage, it is impossible to replace the circular stub bearing the specimen in the same position as in an earlier study.

This disadvantage can easily be rectified by marking the position of the stub in the stage so that the stub is always plugged into the stage exactly in the same position.

2) The centering of the rotation axis could be better. Rotation of an object is possible only under low magnification and by adjusting the X and Y axes.

3) Interesting rare objects, which habe been found in diatom slides prepared for the light microscope are impossible to study under the Stereoscan microscope. Theoretically it may be possible, but the remounting would require time, patience and extreme exactitude to a degree not applicable to current studies.

CONCLUDING REMARKS

The results of the experimental work with fossil diatoms under the Stereoscan microscope, and the great advantages of this kind of instrument, are best shown by the micrographs (Plates 1–25). The plates are arranged in such a way as to make it possible to compare the micrographs taken with the Stereoscan microscope with the micrographs taken with a light microscope (Reichert Zetopan with photoautomatic. Kodak Plus X Panchromatic, PX 410 film. Diatoms mounted in Caedax).

The beautifully sculptured diatom frustules, with their ingenious, regular and practical constructions for filtering water, are each one a masterpiece designed by Nature. I hope they will also offer new ideas and inspiration to human designers.

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ALPHABETIC LIST OF DIATOMS REPRODUCED ON THE PLATES 1–25

PLATE 1

Paralia? ornata? GRUNOW

Marine. Tertiary. Lower Eocene. Limfjorden. Stereoscan micrographs.

Fig. 1. General picture in girdle view. (45°). Magnification x 1,250. Film S 17:12.

Fig. 2. Do., magnification x 2,500. Film 17:13.

Fig. 3. General picture in valvar view. (82°). Magnification x 1,200. Film S 17:15.

Fig. 4. General picture in girdle view. (82°). Magnification x 1,150. Film S 17:16.

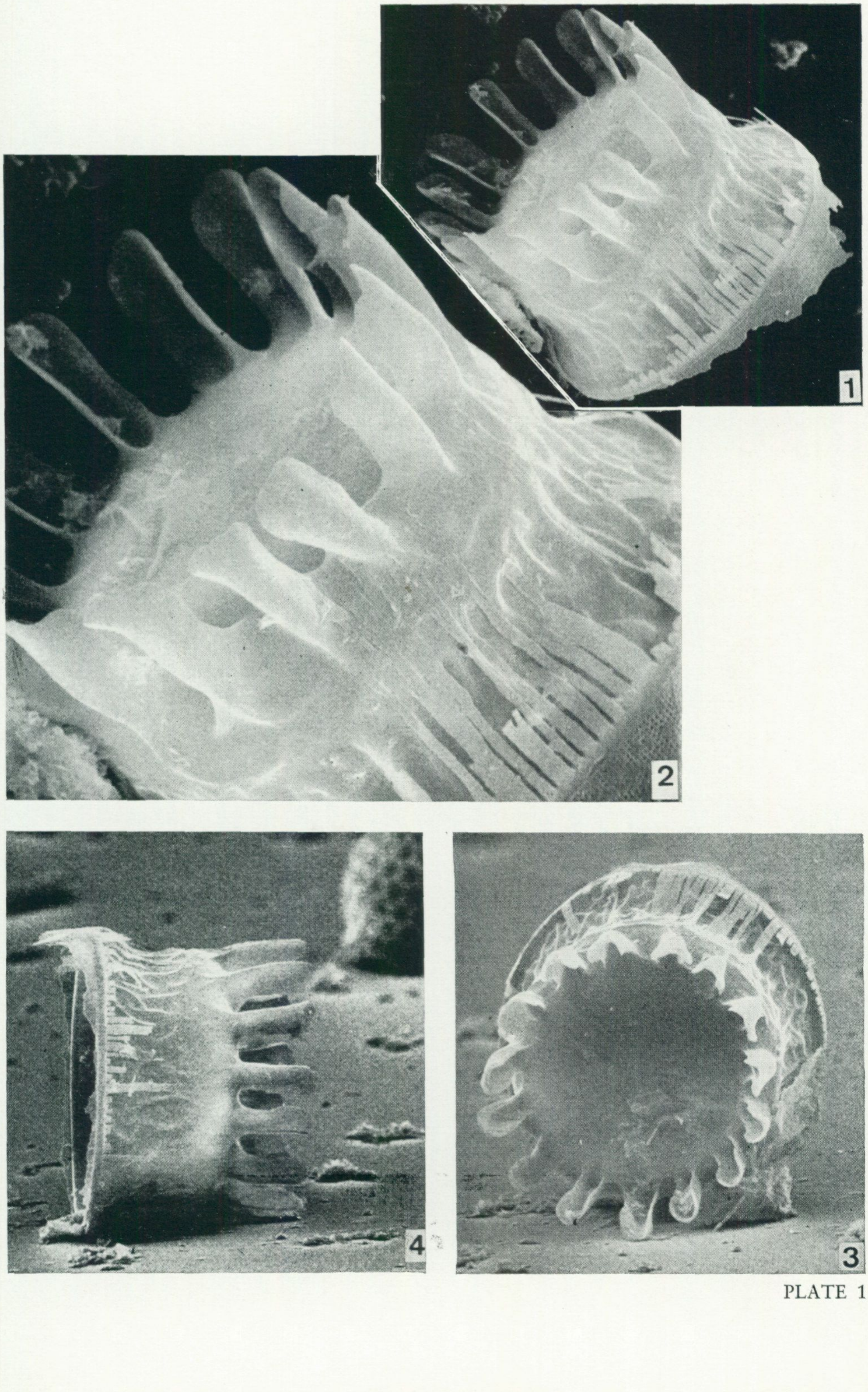


PLATE 1

PLATE 2

Stephanopyxis turris var. *cylindrus* GRUNOW f. *paucispina*
Marine, Tertiary. Lower Eocene. Limfjorden.

Fig. 1. Light micrograph. General picture in girdle view. High focus. Magnification x 3,000. Film L 8:3.

Fig. 2. Do., low focus. Film L 8:4.

Fig. 3. Stereoscan micrograph. General picture of a whole theca in girdle view. (45°). Magnification x 2,500. Film S 3:18.

Fig. 4. Stereoscan micrograph. Detail of the exterior structure of the valve mantle. Openings with regularly perforated sieve membranes. Magnification x 6,200. Film S 3:19.

Fig. 5. Stereoscan micrograph. Detail of an opening with sieve membrane and surrounding ridges. Magnification x 25,000. Film S 3:20.

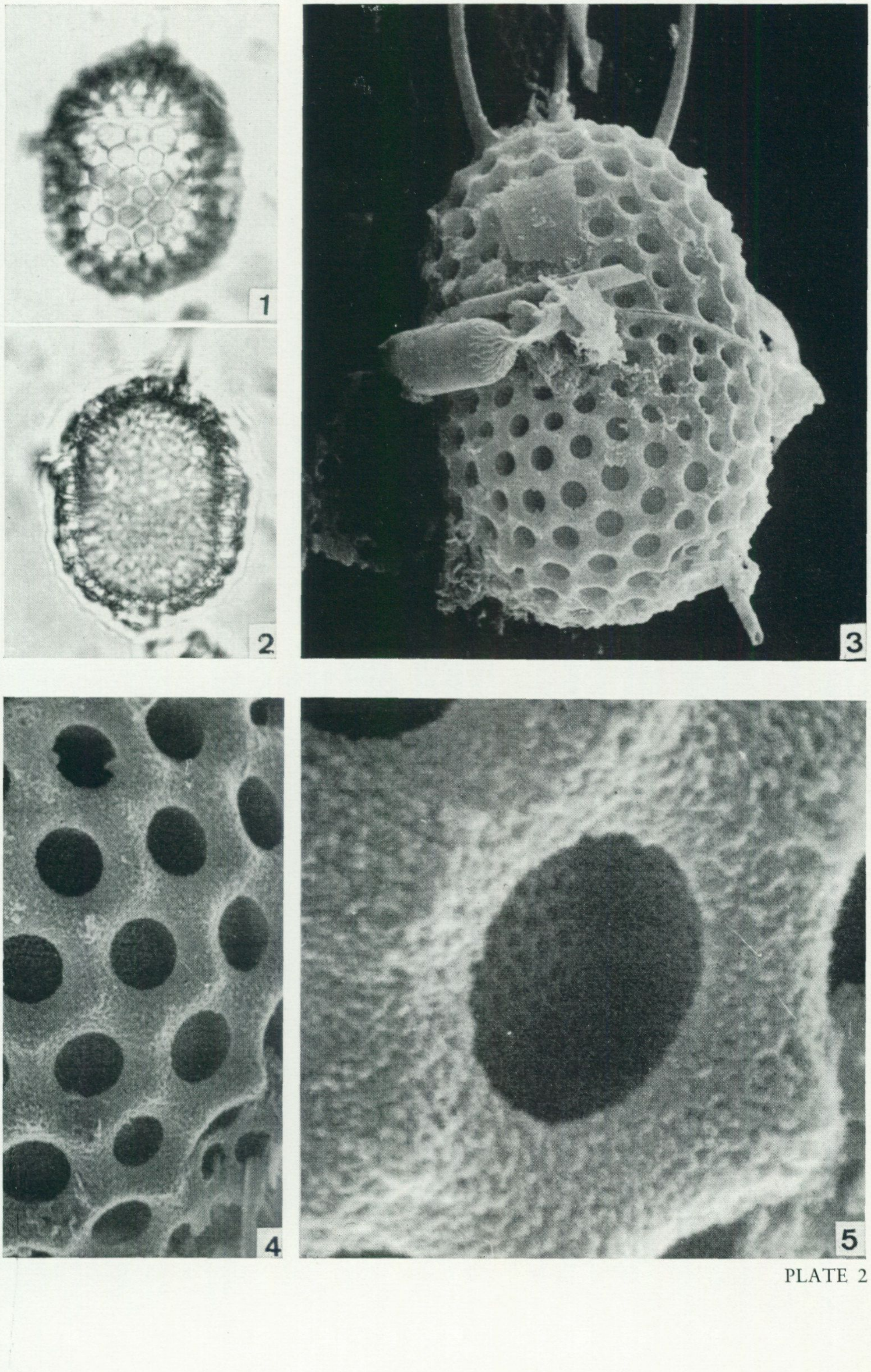


PLATE 2

PLATE 3

Cosinodiscus sp.

Marine. Tertiary. Lower Eocene. Limfjorden.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 3,000. Film L 10:34

Fig. 2. Stereoscan micrograph. General picture of the exterior side of the valve surface and mantle (45°). Magnification x 2,450. Film S 3:1.

Fig. 3. Stereoscan micrograph. Detail of the exterior structure of the valve surface. Magnification x 12,500. Film S 3:2.

Fig. 4. Stereoscan micrograph. Detail of the exterior structure of the valve surface. Depressions with perforated sieve membranes. Magnification x 25,000. Film S 3:3.

Fig. 5. Stereoscan micrograph. Detail of the structure of the valve mantle. Magnification x 25,000. Film S 3:4.

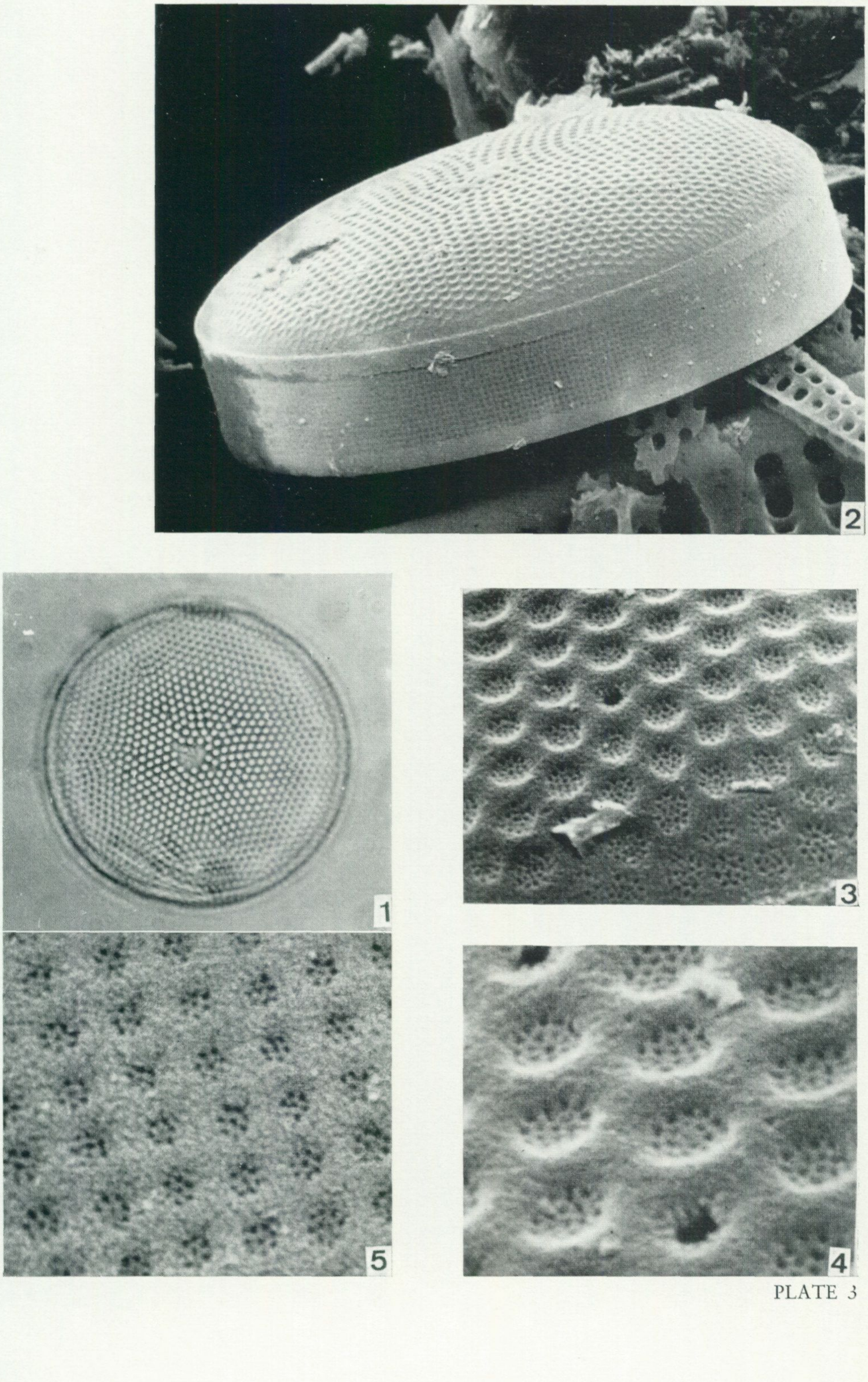


PLATE 3

PLATE 4

Pseudo-Stictodiscus angulatus Grunow
Marine. Tertiary. Lower Eocene. Limfjorden.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 1,500. Film L 10:37.

Fig. 2. Stereoscan micrograph. General picture of the interior side of the valve surface (0°). Magnification x 4,500. Film S 14:1.

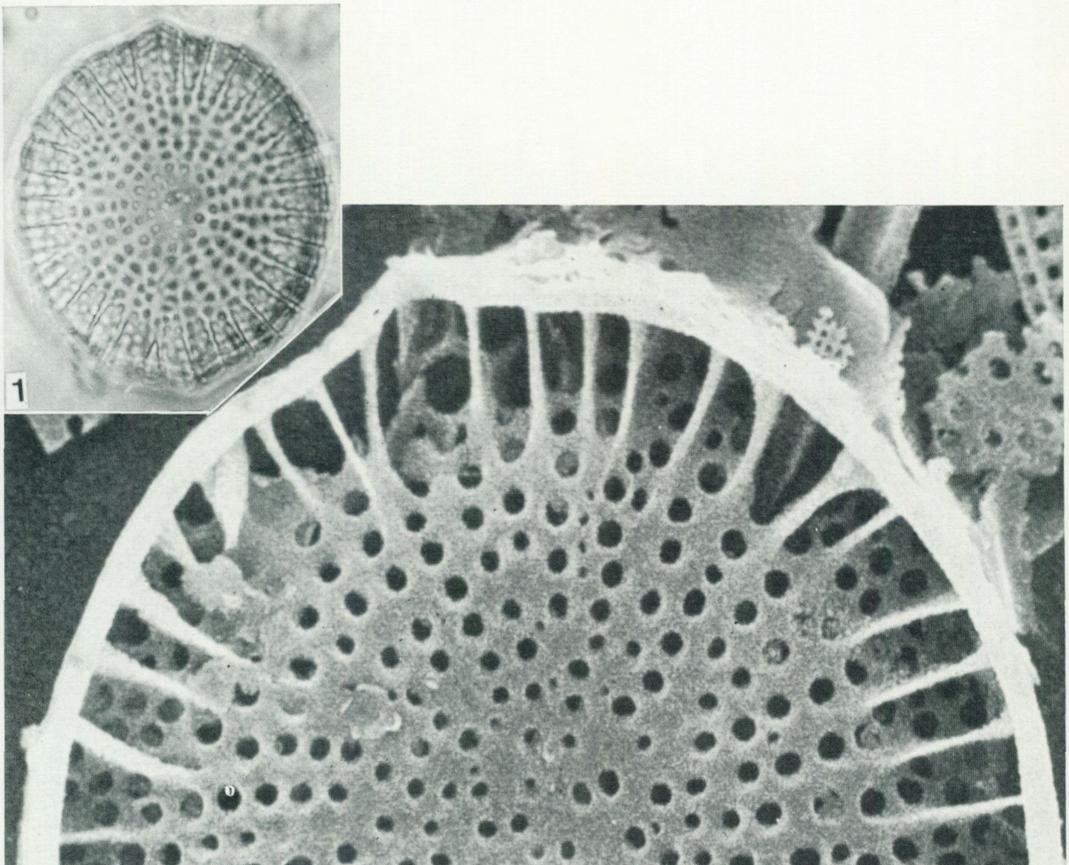


PLATE 4

PLATE 5

Trinacria exsculpta (HEIBERG) HUSTEDT
Marine. Tertiary. Lower Eocene. Limfjorden.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 3,000. Film L 10:27.

Fig. 2. Stereoscan micrograph. General picture of the exterior side of the valve (66°). Magnification x 1,100. Film S 17:30.

Fig. 3. Stereoscan micrograph. Detail of the exterior valvar structure with raised sieve membranes and irregularly situated small processes – apiculi. Magnification x 12,000. Film S 17:25.

Fig. 4. Stereoscan micrograph. Detail of the exterior valvar structure. One of the central apiculi. Magnification x 11,000. Film S 17:32.

Fig. 5. Stereoscan micrograph. General picture of two attached frustule halves of different thecas. Uppermost the interior of the valve surface (45°). Magnification x 1,200. Film S 3:5.

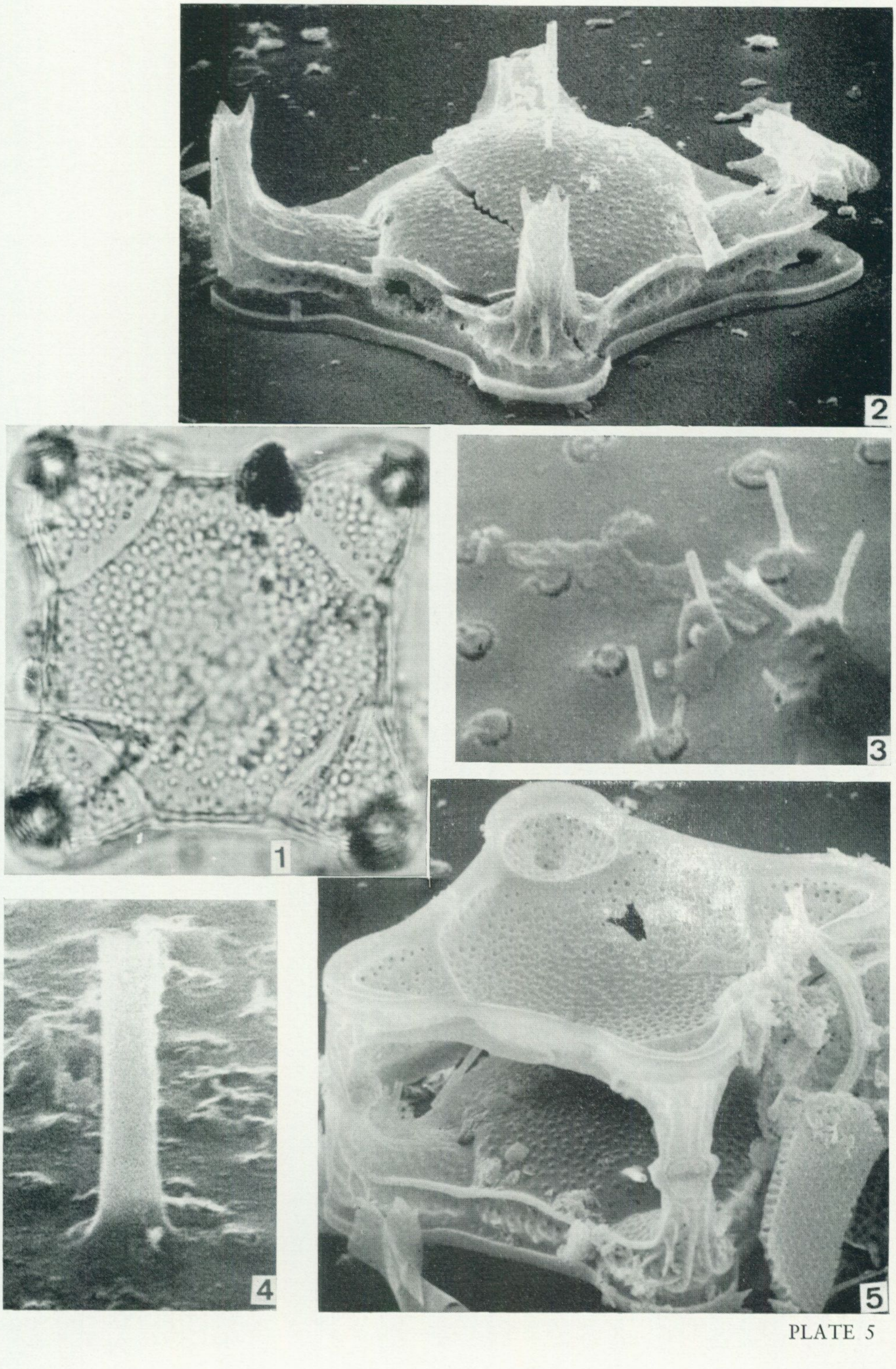


PLATE 5

PLATE 6

Trinacria exsculpta (HEIBERG) HUSTEDT

Marine. Tertiary. Lower Eocene. Limfjorden. Stereoscan micrographs.

Fig. 1. General picture of the exterior side of valve surface (45°). Magnification x 1,200. Film 17:22.

Fig. 2. Detail of the process arising from the upper left angle of the valve. Magnification x 2,400. Film S 17:24.

Fig. 3. Detail of the upper part of the wavy sculptured process. Magnification x 6,000. Film S 17:26.

Fig. 4. Detail of the uppermost part of the process. Circle of teeth with perforated centre. Indistinctly formed openings on the sides of the process. Magnification x 12,000. Film S 17:27.

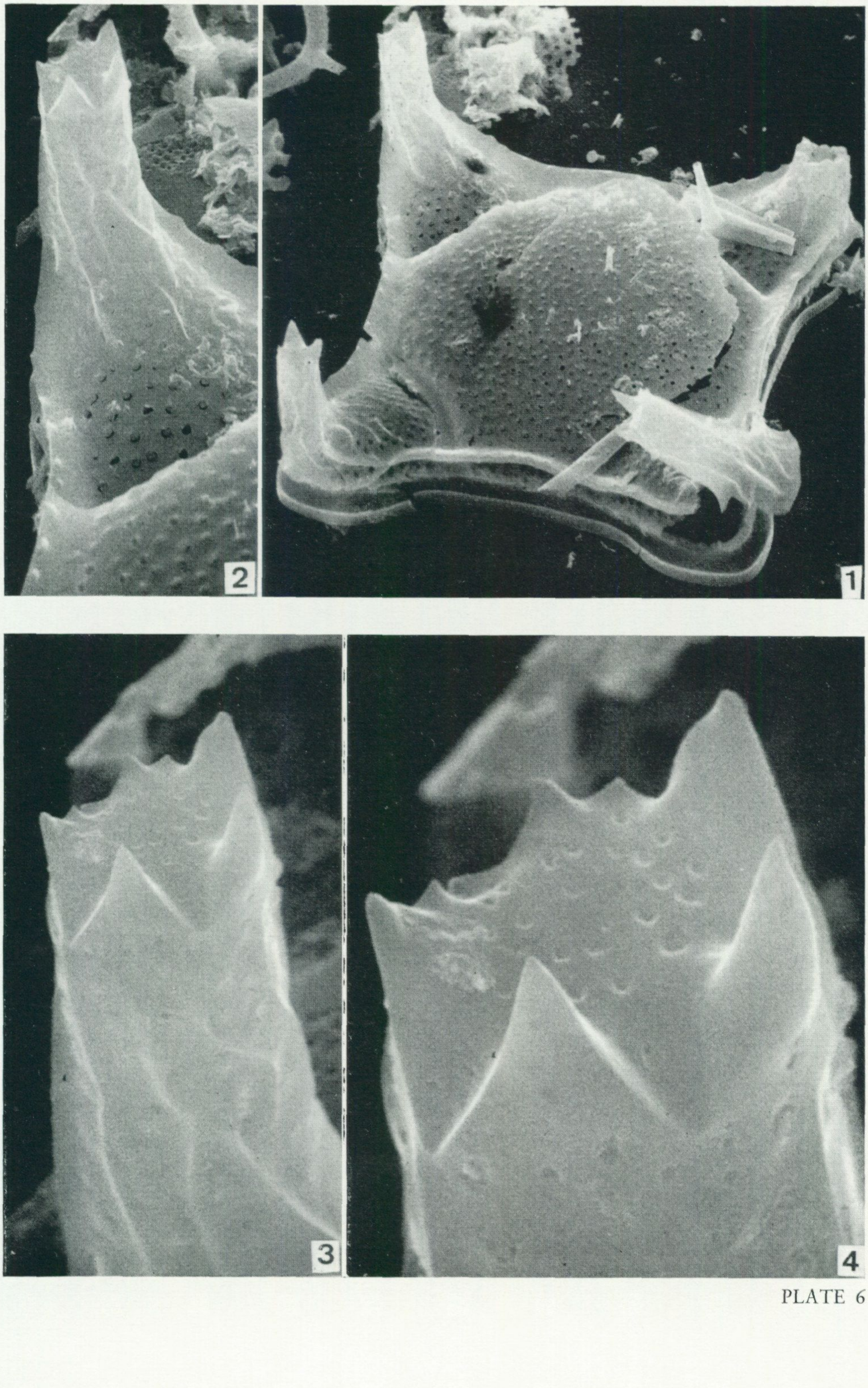


PLATE 6

PLATE 7

Trinacria pileolus (Ehrenberg?) Grunow
Marine. Tertiary. Lower Eocene. Limfjorden. Stereoscan micrographs.

Fig. 1. General picture of the interior side of the valve surface and two of the processes (45°). Magnification x 650. Film S 3:25.

Fig. 2. Detail of the interior valve structure. Openings with sieve membranes. Magnification x 13,000. Film S 3:26.

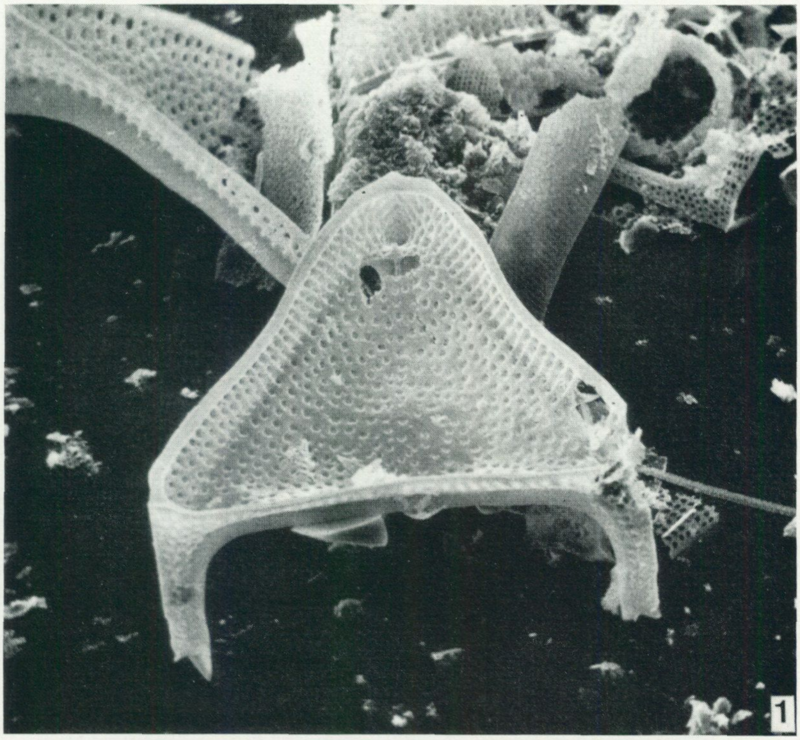


PLATE 7

PLATE 8

Trinacria regina HEIBERG
Marine. Tertiary. Lower Eocene. Limfjorden.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 1,000. Film L 10:33.

Fig. 2. Stereoscan micrograph. General picture of the interior of the valve and the exterior of the valve mantle (45°). Magnification x 625. Film S 2:29.

Fig. 3. Stereoscan micrograph. Detail of the interior valvar structure. Openings with sieve membranes. Magnification x 2,450. Film S 2:31.

Fig. 4. Stereoscan micrograph. Detail. Interior valvar opening with sieve membrane. Magnification x 24,500. Film S 2:36.

Fig. 5. Stereoscan micrograph. Detail of the structure of valve mantle. Openings with sieve membranes. Magnification x 17,000. Polaroid film.

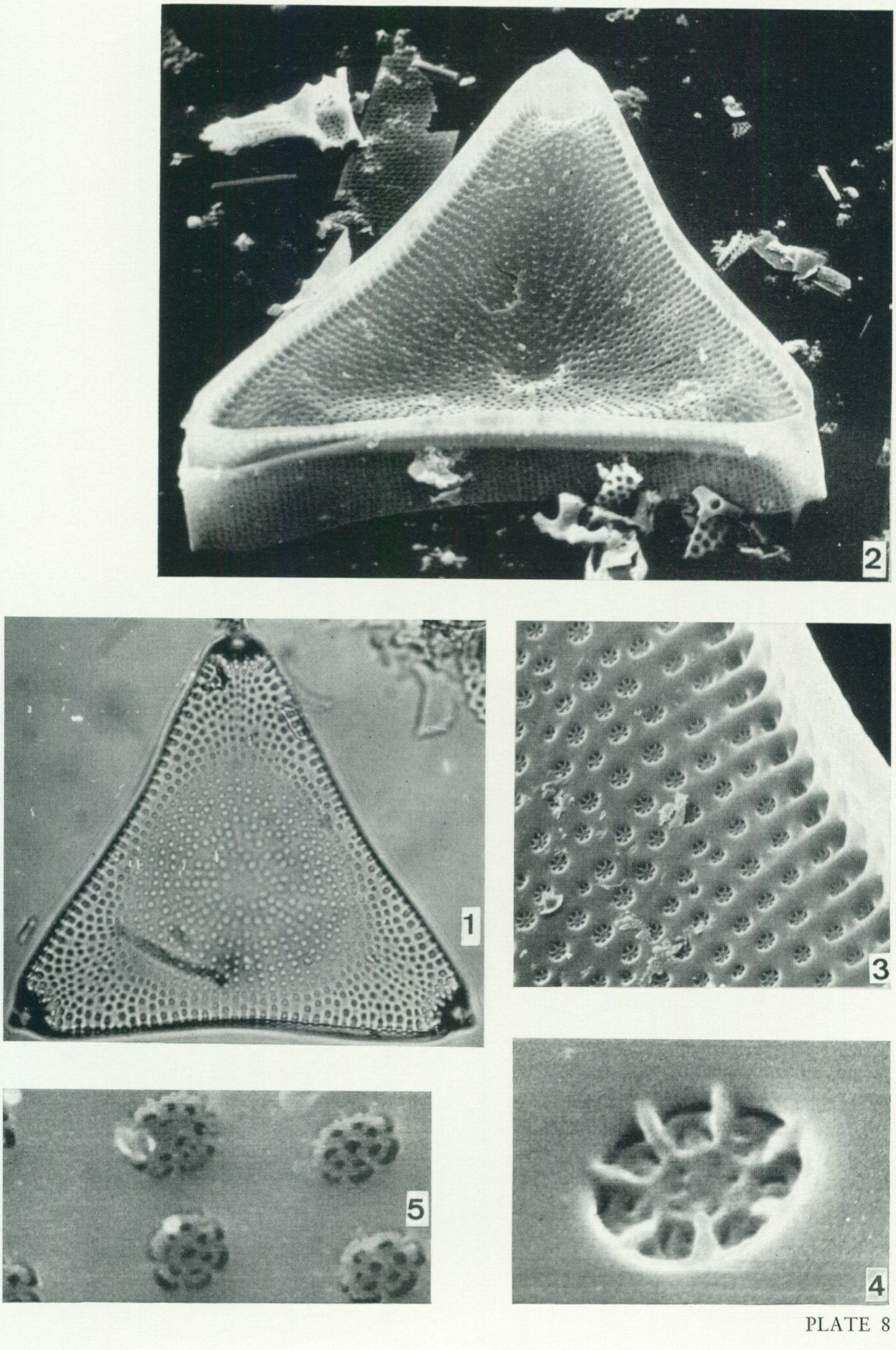


PLATE 8

PLATE 9

Hemiaulus elegans (Heiberg) Grunow
Marine. Tertiary. Lower Eocene. Limfjorden.

Fig. 1. Light micrograph. General picture of the interior valve surface. Magnification x 3,000. Film L 4:14.

Fig. 2. Light micrograph. General picture of a whole theca in girdle view. Magnification 1,900 x. Film L 4:30.

Fig. 3. Stereoscan micrograph. General picture of the interior valve surface (45°). Magnification x 1,225. Film S 16:23.

Fig. 4. Stereoscan micrograph. General picture of the exterior side of the valve (45°). Magnification x 1,225. Film S 16:12.

Fig. 5. Stereoscan micrograph. Detail of the exterior valve structure with perforated sieve membranes and pipe-like processes. Magnification x 6,125. Film S 16:14.

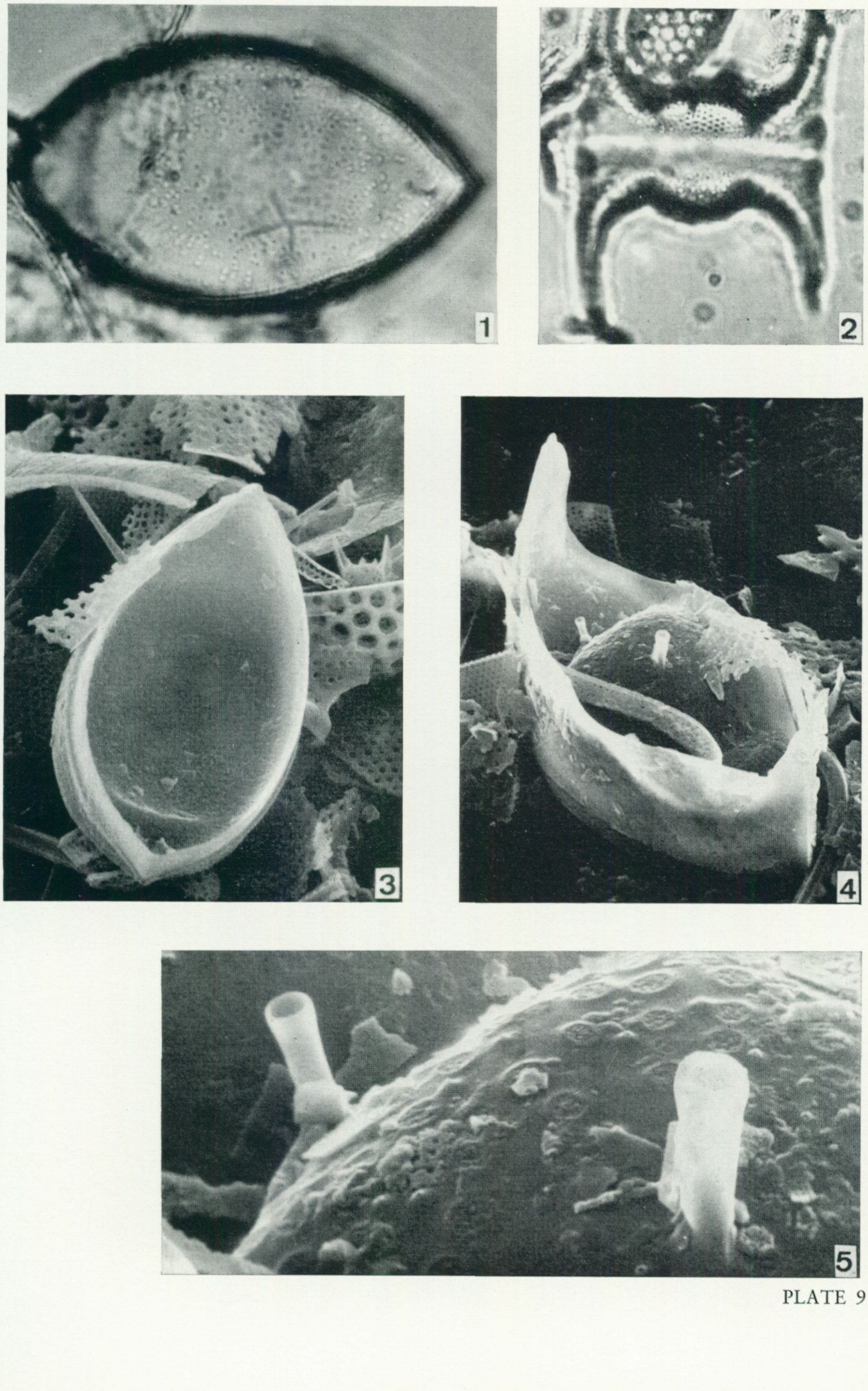


PLATE 9

PLATE 10

Hemiaulus weissei GRUNOW?
Marine. Tertiary. Lower Eocene. Limfjorden.

Fig. 1. Light micrograph. General picture. A whole theca in girdle view from the short side. Magnification x 3,000. Film L 4:36.

Fig. 2. Light micrograph. General picture. A theca, separating along the girdle. Girdle view from the long side. Magnification x 3,000. Film L 1:18.

Fig. 3. Stereoscan micrograph. General picture in girdle view (45°). Magnification x 2,500. Film S 3:9.

Fig. 4. Stereoscan micrograph. Detail of the structure of valve mantle. Openings with sieve membranes. Magnification x 12,500. Film S 3:11.

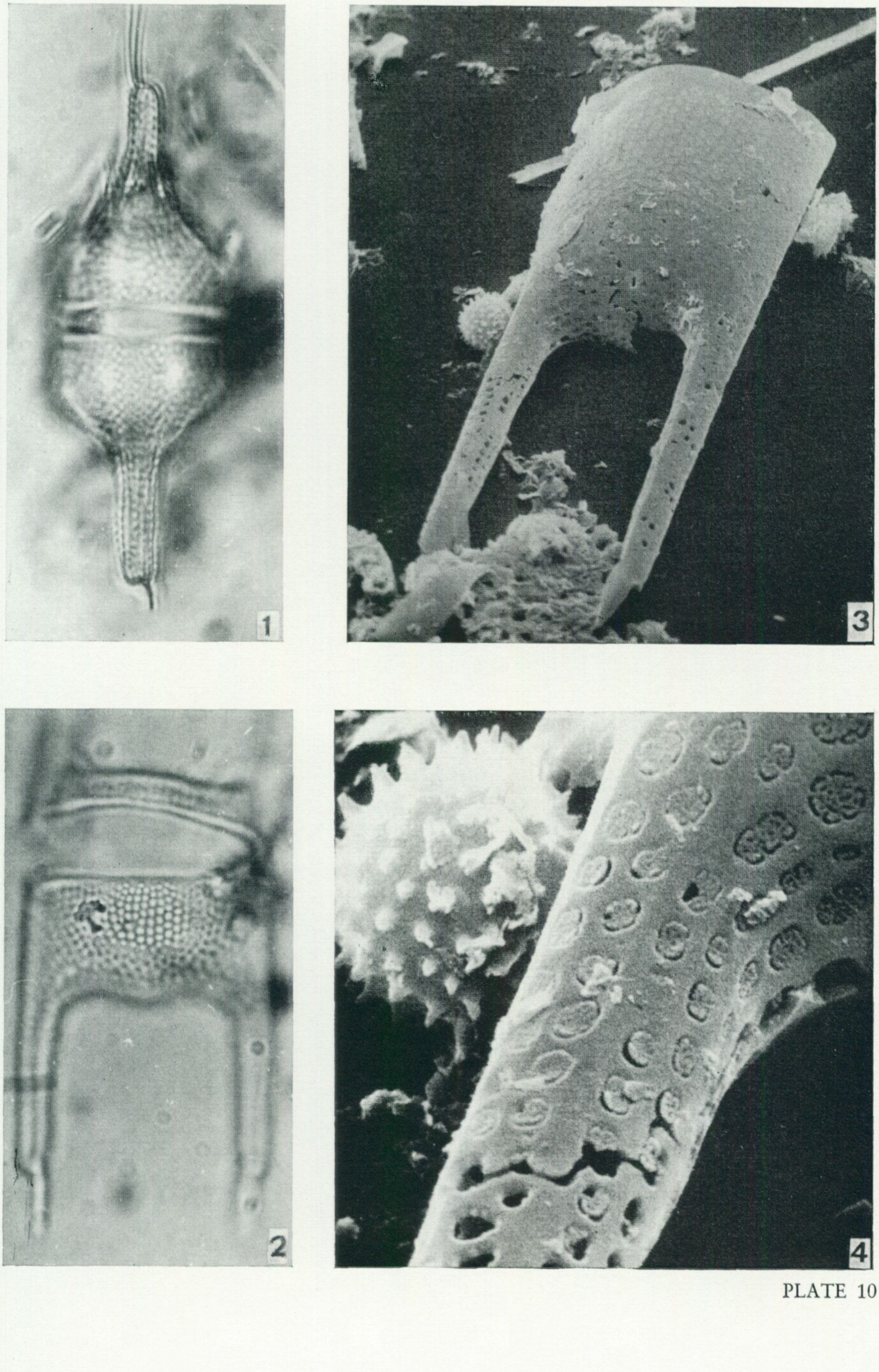


PLATE 10

PLATE 11

Sceptroneis gemmata Grunow
Marine. Tertiary. Lower Eocene. Limfjorden.

Fig. 1. Light micrograph. Valvar view of half of a frustule. Magnification x 3,000. Film L 4:9.

Fig. 2. Stereoscan micrograph. General picture of the exterior side of the valve and mantle (45°). Magnification x 1,250. Film S 3:6.

Fig. 3. Stereoscan micrograph. Exterior structure of the valve and valve mantle. Magnification x 6,250. Film S 3:7.

Fig. 4. Stereoscan micrograph. Detail of the exterior valve structure. Oval holes with marginal exterior pearl border. Magnification x 25,000. Film S 3:8.

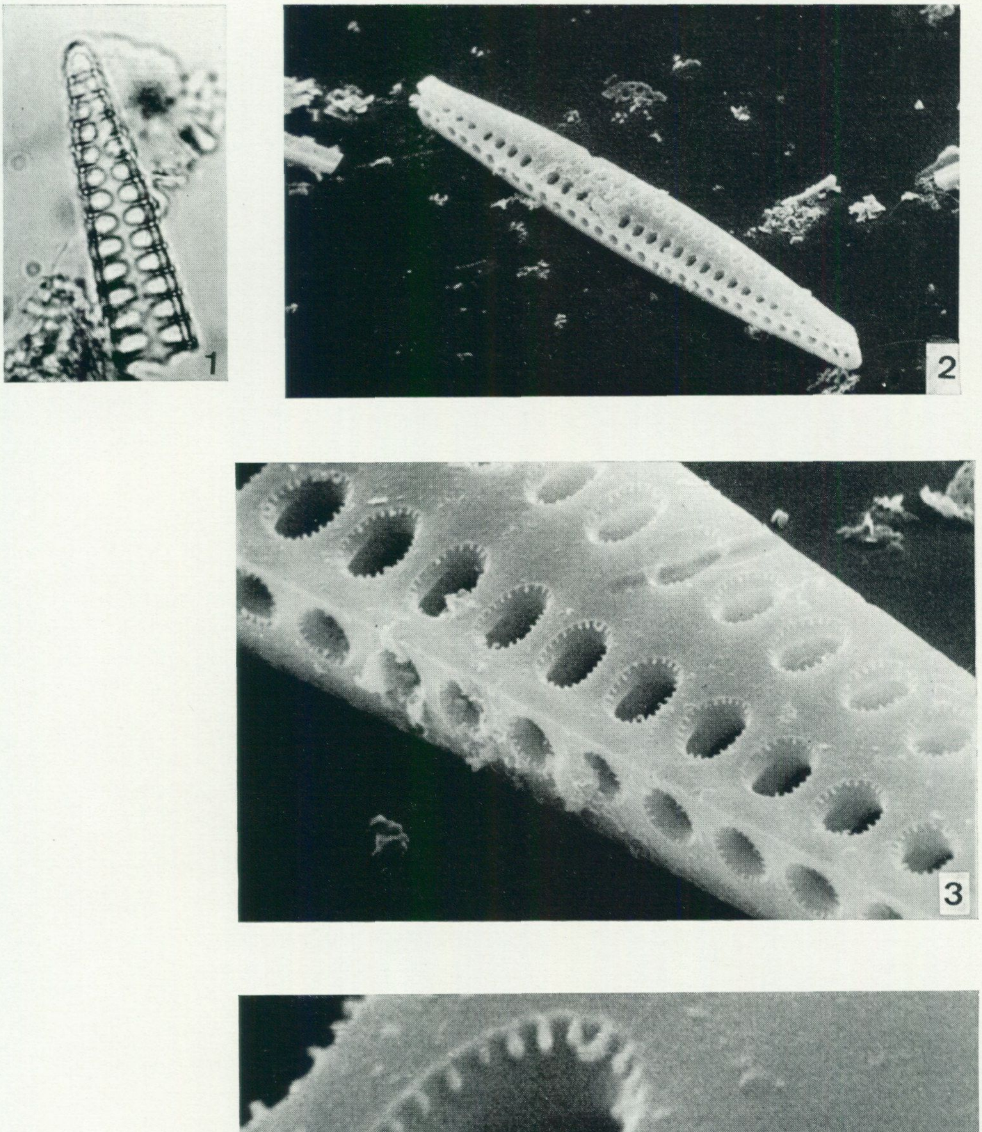


PLATE 11

PLATE 12

Melosira italica (Ehrenberg) Kützing
Melosira distans (Ehrenberg) Kützing
Fresh water. Pleistocene. Interglacial. Leveäniemi.

Fig. 1. Light micrograph of *M. italica* in girdle view. General picture of the valve mantle of two frustule halves of different thecas, attached by rows of teeth. High focus. Magnification x 3,000. Film L 6:21.

Fig. 2. Do., low focus. Film L 6:23.

Fig. 3. Light micrograph of *M. distans* in girdle view. General picture of the valve mantle of two frustule halves of different thecas, attached by rows of teeth. High focus. Magnification x 3,000. Film L 7:13.

Fig. 4. Stereoscan micrograph of *M. distans* and *M. italica* in girdle view. General picture of the valve mantles of different thecas, attached by zip-like construction (50°). Magnification x 3,000. Film S 7:13.

Fig. 5. Stereoscan micrograph. Detail of the zip-like construction, attaching *M. italica* thecas. Magnification x 13,000. Film S 7:15.

Fig. 6. Stereoscan micrograph. Detail of the mantle border with small granules. Magnification x 26,000. Film S 7:16.

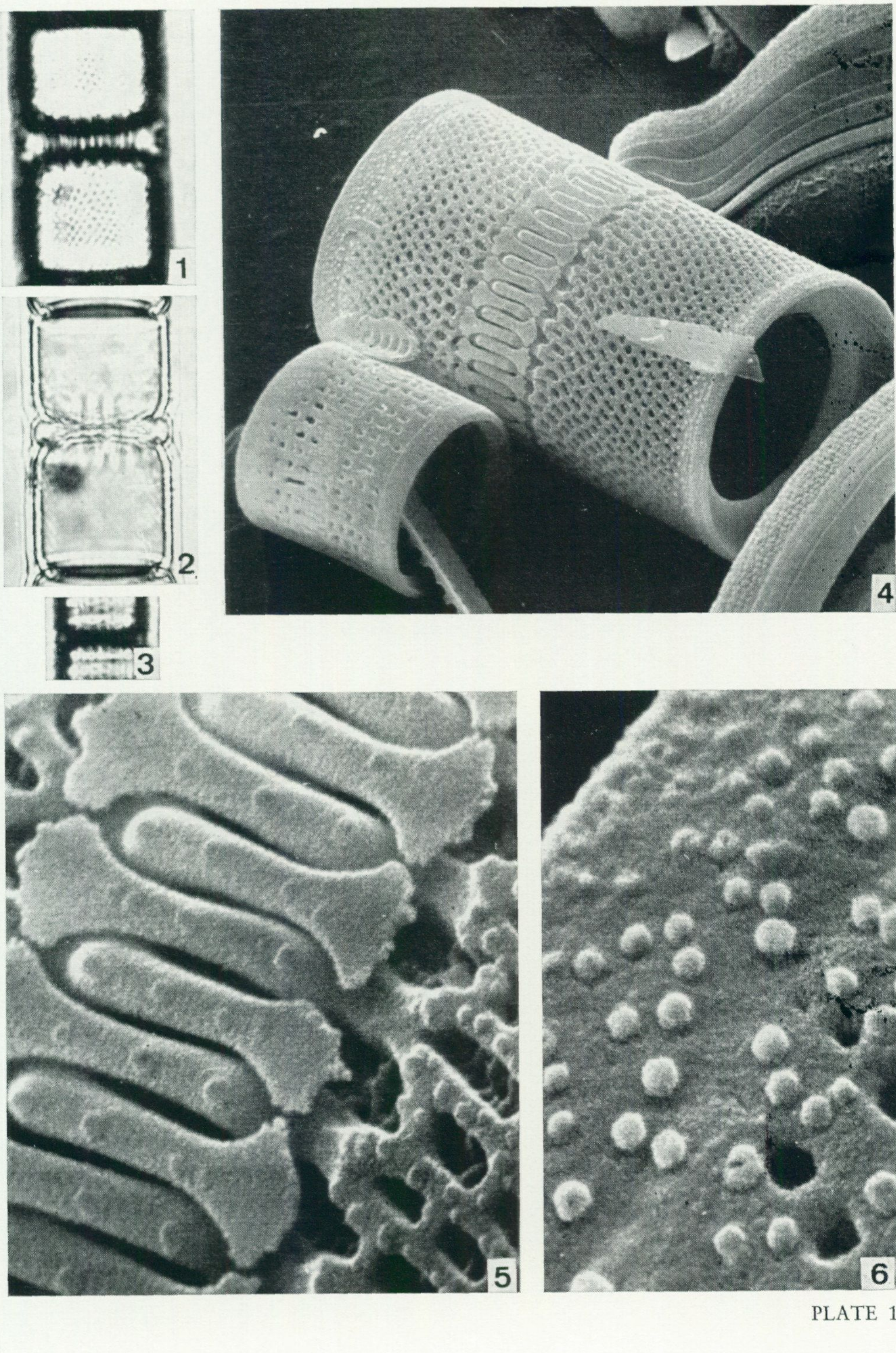


PLATE 12

PLATE 13

Fragilaria pinnata Ehrenberg

Fresh water. Pleistocene. Interglacial. Leveäniemi.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 2,000. Film L 7:11.

Fig. 2. Light micrograph. General picture. Girdle view. Magnification x 2,000. Film L 7:17.

Fig. 3. Stereoscan picture. General picture of the interior valvar structure and the side structure of two attached frustule halves of different thecas (50°). Magnification x 6,500. Film S 7:6.

Fig. 4. Stereoscan picture. Detail of the lineolate striae with small granules between the lineolae. Magnification x 26,000. Film S 7:8.

Fig. 5. Stereoscan picture. Detail of the attachment construction. Magnification x 26,000. Film S 7:7.

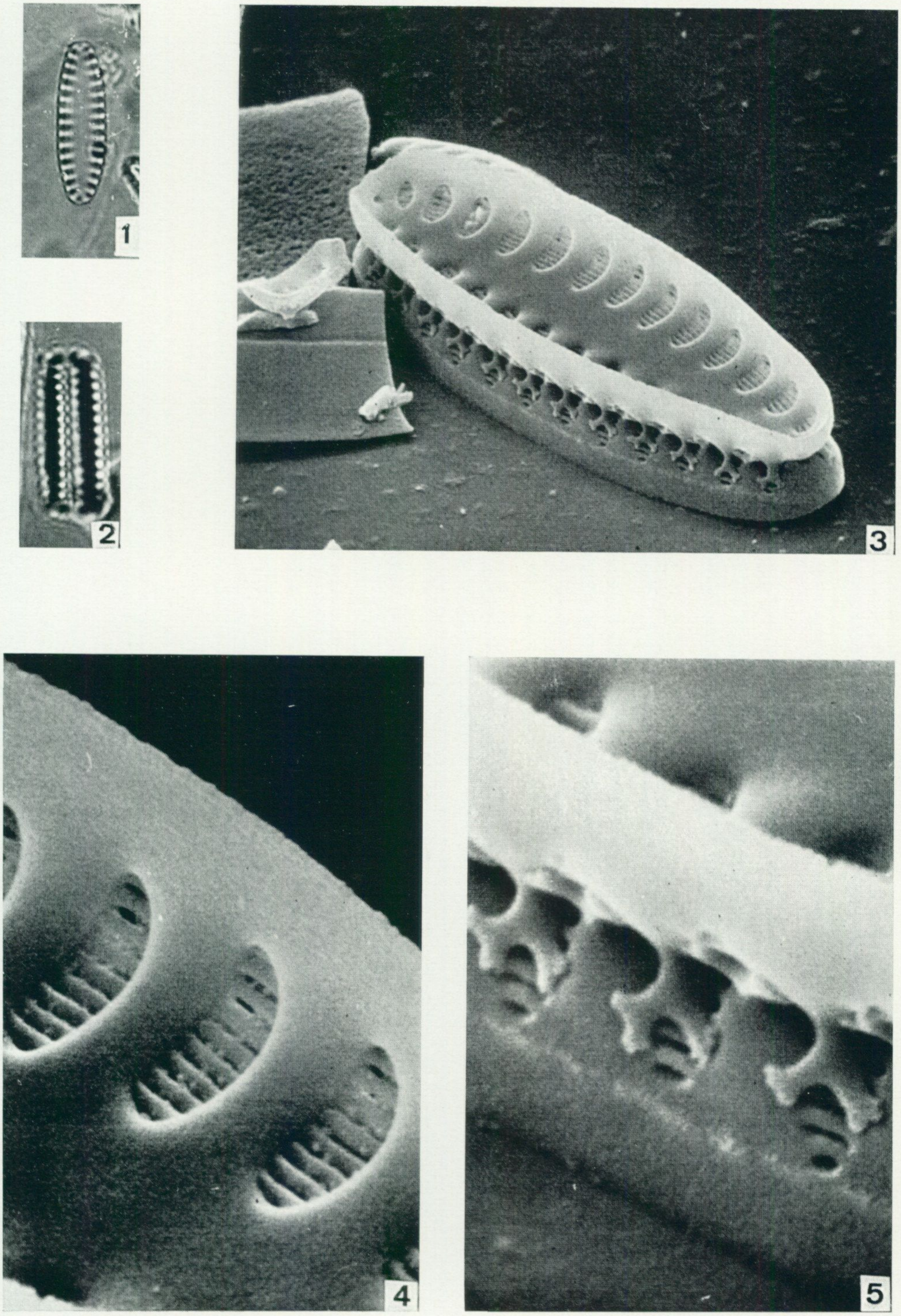


PLATE 13

PLATE 14

Cocconeis placentula EHRENBERG

Fresh water. Pleistocene. Interglacial. Leveäniemi.

Fig. 1. Light micrograph. General picture of the pseudoraphe valve. Magnification x 3,000. Film L 6:37.

Fig. 2. Stereoscan micrograph. General picture of the pseudoraphe valve. Interior side (50°). Magnification x 2,450. Film S 7:18.

Fig. 3. Stereoscan micrograph. Detail of the interior side of the pseudoraphe valve. Perforated striae and the thickening of pseudoraphe. Magnification x 24,500. Film S 7:20.

Fig. 4. Stereoscan micrograph. General picture of a theca with corroded raphe valve and whole pseudoraphe valve (45°). Magnification x 2,400. Film S 14:19.

Fig. 5. Stereoscan micrograph. The corroded exterior of the raphe valve with raphe channel and punctate striae, interrupted near the margin by a hyaline area isolating a short, striate submarginal area. Magnification x 6,000. Film S 14:18.

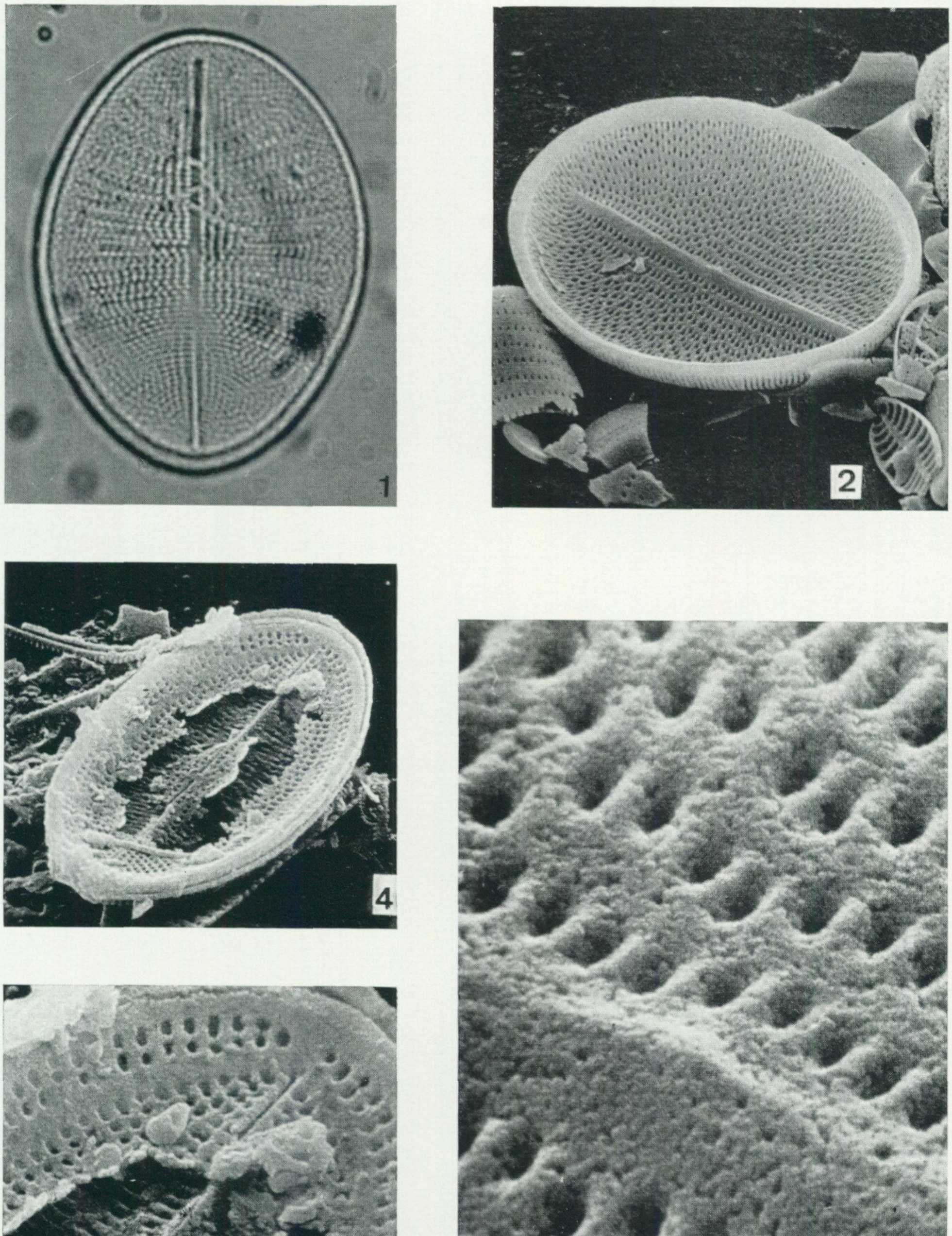


PLATE 14

PLATE 15

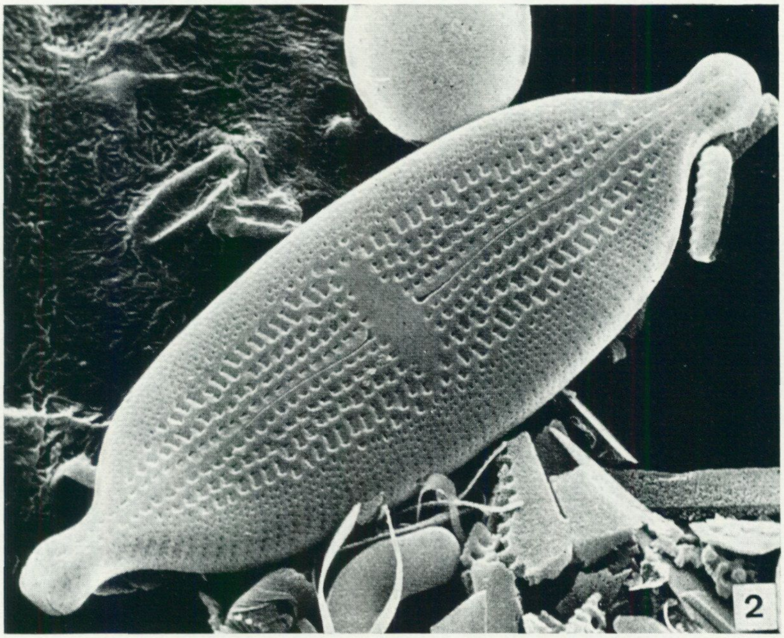
Navicula tuscula Ehrenberg

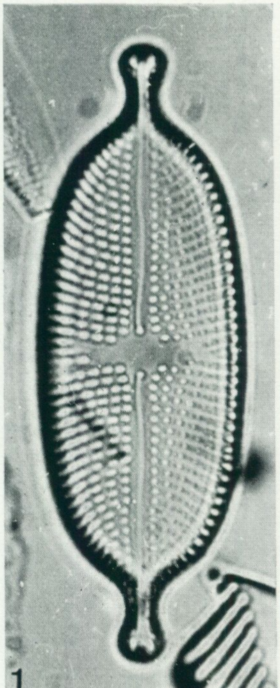
Fresh water. Pleistocene. Interglacial. Leveäniemi.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 3,000. Film L 7:7.

Fig. 2. Stereoscan micrograph. General picture of the valve exterior (35°). Observe the curved raphe, the irregular central area and the difference between the central and marginal structure (35°). Magnification x 2,200. Film S 11:4.

Fig. 3. Stereoscan micrograph. Detail of the two different types of valvar exterior structure. Magnification x 11,000. Film S 11:5.





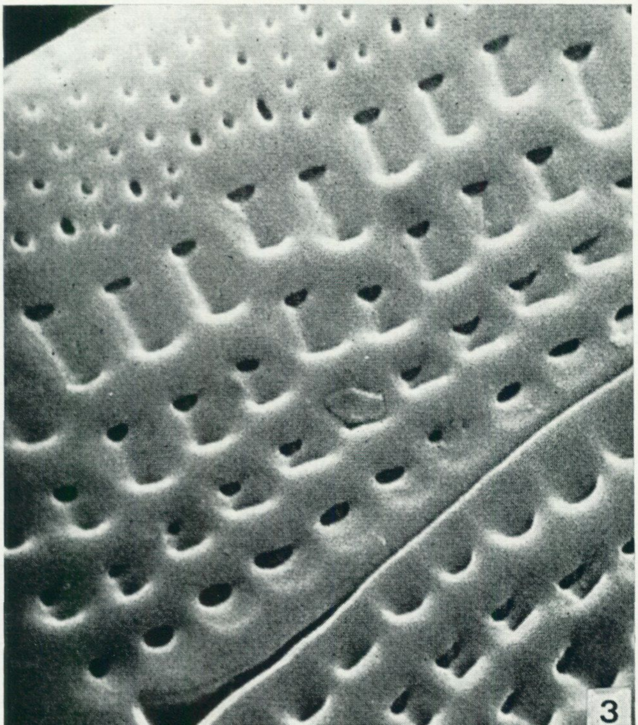


PLATE 15

PLATE 16

Navicula tuscula EHRENBERG

Fresh water. Pleistocene. Interglacial. Leveäniemi.

Fig. 1. Light micrograph. General picture valvar view. Magnification x 3,000. Film L 7:7.

Fig. 2. Stereoscan micrograph. General picture of the valve interior (50°). Magnification x 2,500. Film S 7:22.

Fig. 3. Stereoscan micrograph. Detail of the interior valvar structure with central holes and marginal striae. The both types of openings contain perforated sieve membranes. Magnification x 25,000. Film S 7:25.

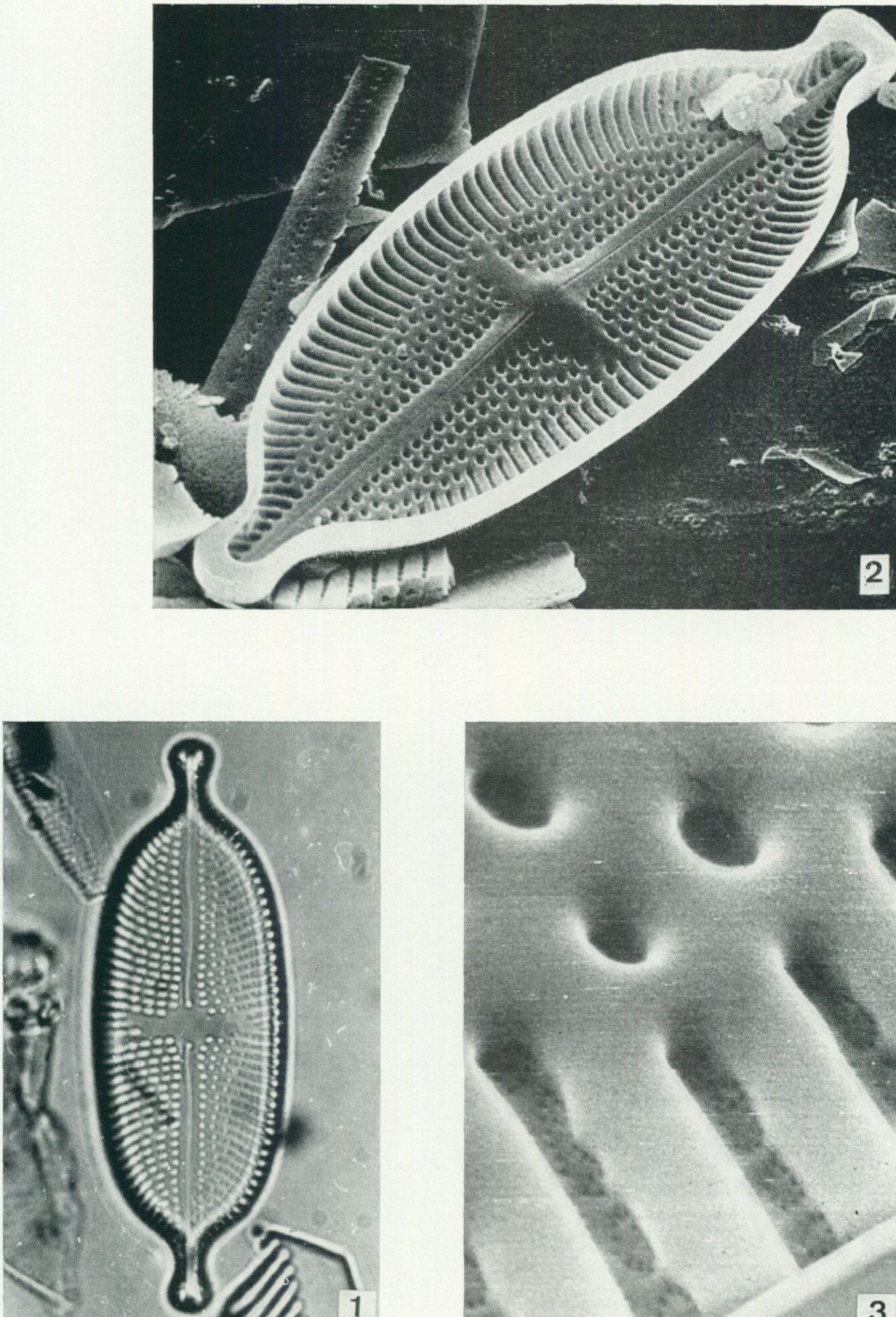


PLATE 16

PLATE 17

Pinnularia nodosa Ehrenberg

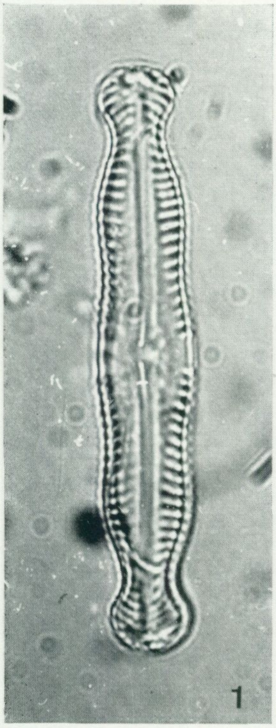
Fresh water. Pleistocene. Interglacial. Leveäniemi.

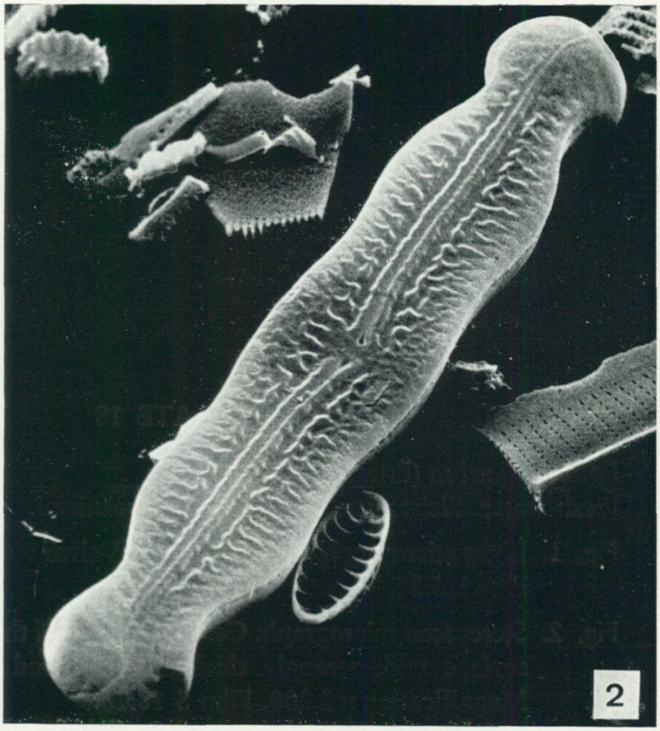
Fig. 1. Light micrograph. General picture of the valvar view. Magnification x 3,000. Film L 7:6.

Fig. 2. Stereoscan micrograph. General picture of the exterior valve (50°). Magnification x 2,600. Film S 7:2.

Fig. 3. Stereoscan micrograph. Central part of the exterior valve with the central raphe nodule, and raphe channel, wavy sculptured axial and central areas, and the perforated marginal striae. Magnification x 6,500. Film S 7:3.

Fig. 4. Stereoscan micrograph. Detail of the perforated striae and structure of the axial area. Magnification x 26,000. Film S 7:4.





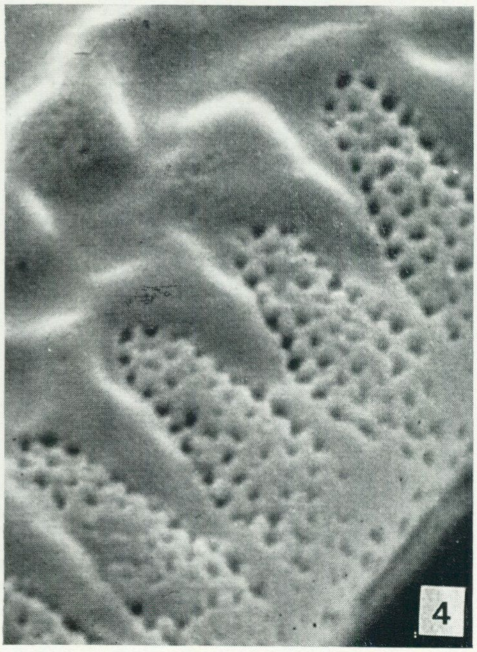


PLATE 17

PLATE 18

Epithemia zebra (EHRENBERG) KÜTZING

Fresh water. Pleistocene. Interglacial. Leveäniemi.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 3,000. Film L 6:34.

Fig. 2. Stereoscan micrograph. General picture of the interior side of the valve surface with strongly thickened ribs and internal openings (45°). Magnification x 2,200. Film S 18:16.

Fig. 3. Stereoscan micrograph. Detail of the interior structure of the valve surface. Observe the fissure through the thickened ribs. Magnification x 5,500. Film S 18:15.

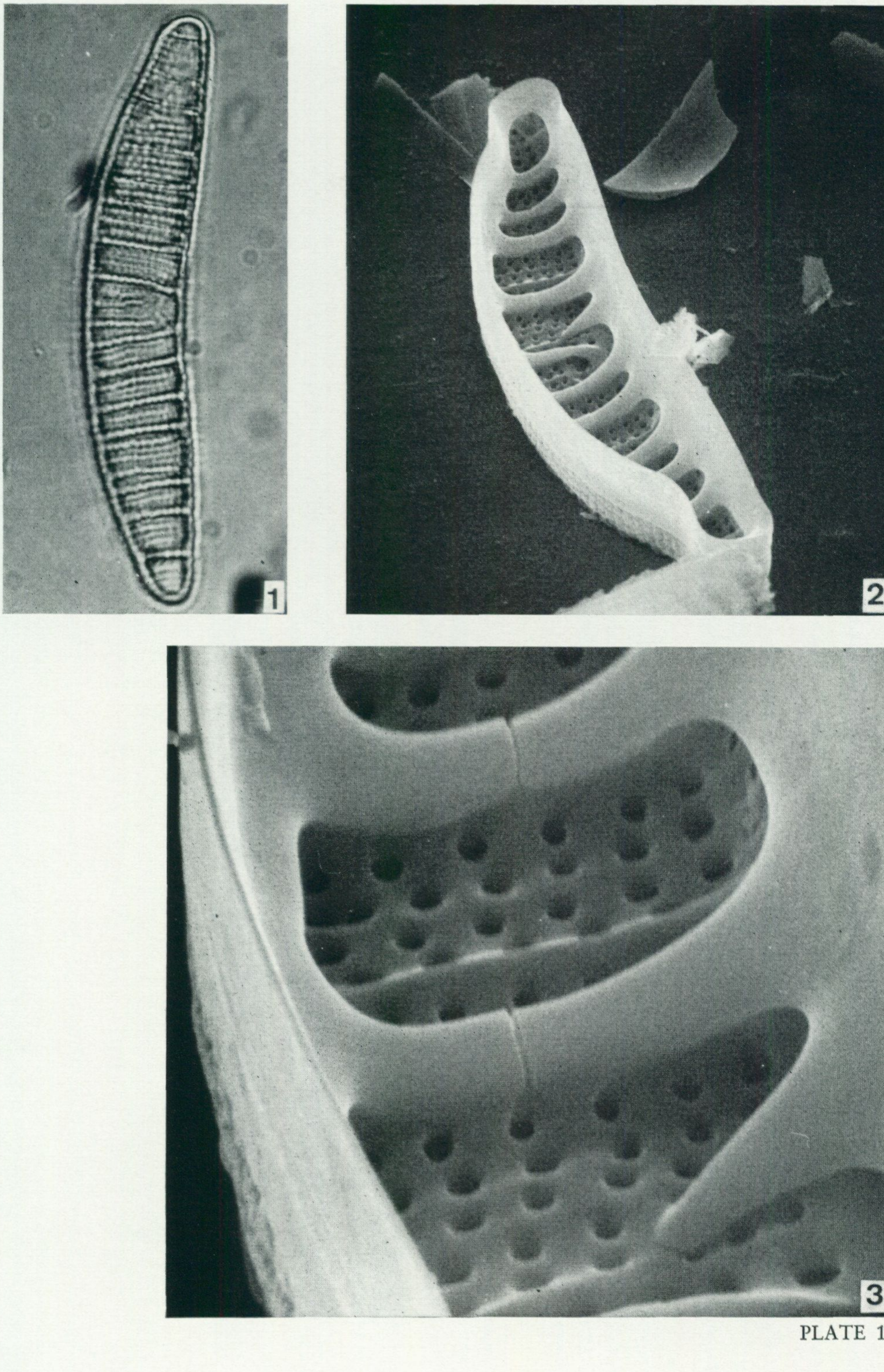


PLATE 18

PLATE 19

Epithemia turgida (EHRENBERG) KÜTZING
Fresh water. Pleistocene. Interglacial. Leveäniemi.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 1,000. Film L 6:25.

Fig. 2. Stereoscan micrograph. General picture of the exterior side of valve surface (2°). Magnification x 1,250. Film S 13:27.

Fig. 3. Stereoscan micrograph. Part of the interior side of the valve surface. The triangle of the central nodule and the thickened ribs between the rows of openings (45°). Magnification x 5,500. Film S 18:18.

Fig. 4. Stereoscan micrograph. Detail of the interior structure of the valve surface. Magnification x 22,000. Film S 18:17.

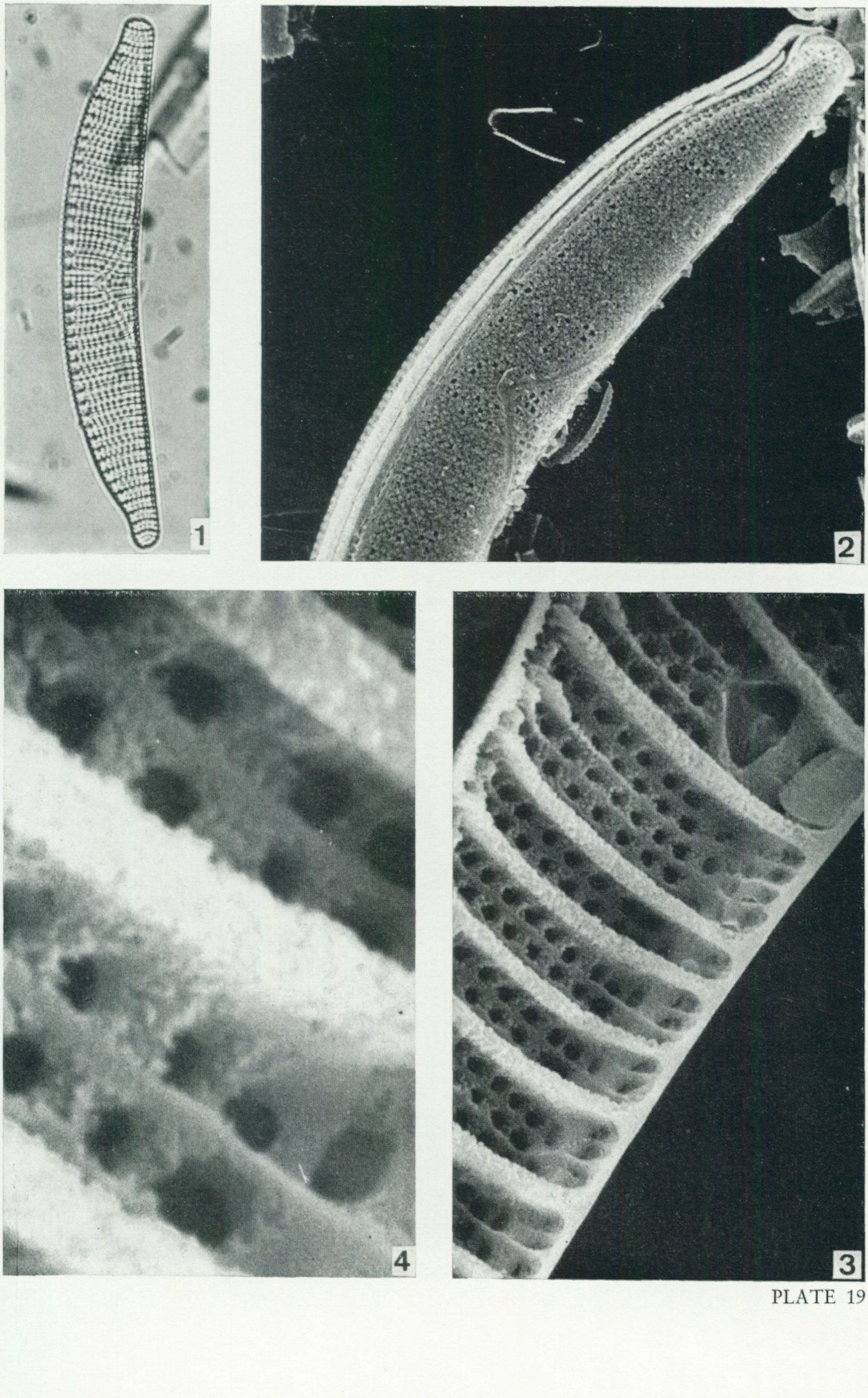


PLATE 19

PLATE 20

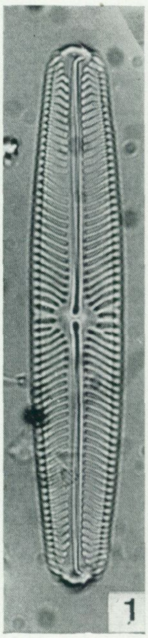
Navicula oblonga KÜTZING

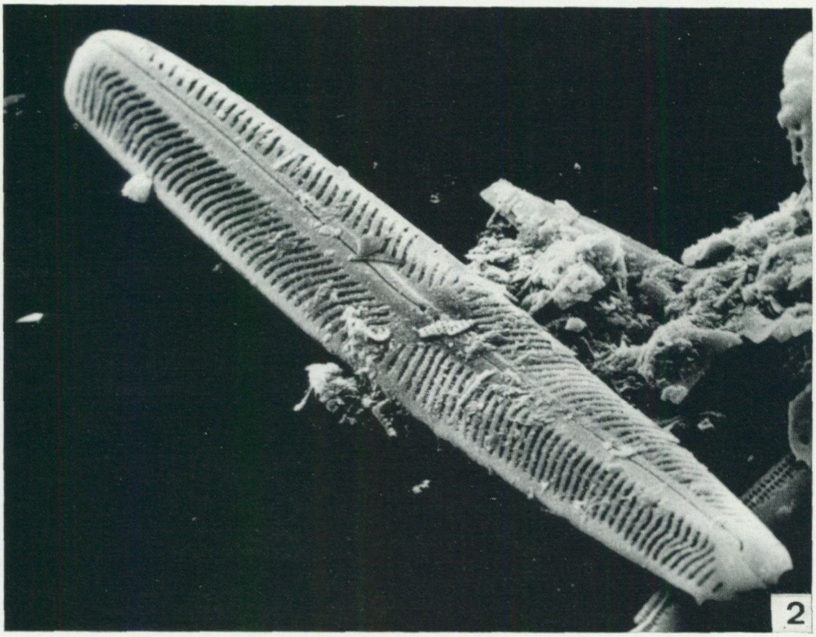
Brackish-lagoon. Postglacial. Öja moor.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 1,500. Film L 6:9.

Fig. 2. Stereoscan micrograph. General picture. Valvar view, exterior (45°). Magnification x 1,300. Film S 2:2.

Fig. 3. Stereoscan micrograph. Detail of valvar exterior structure. Striae with corroded lineolae. Magnification x 13,000. Film S 2:3.





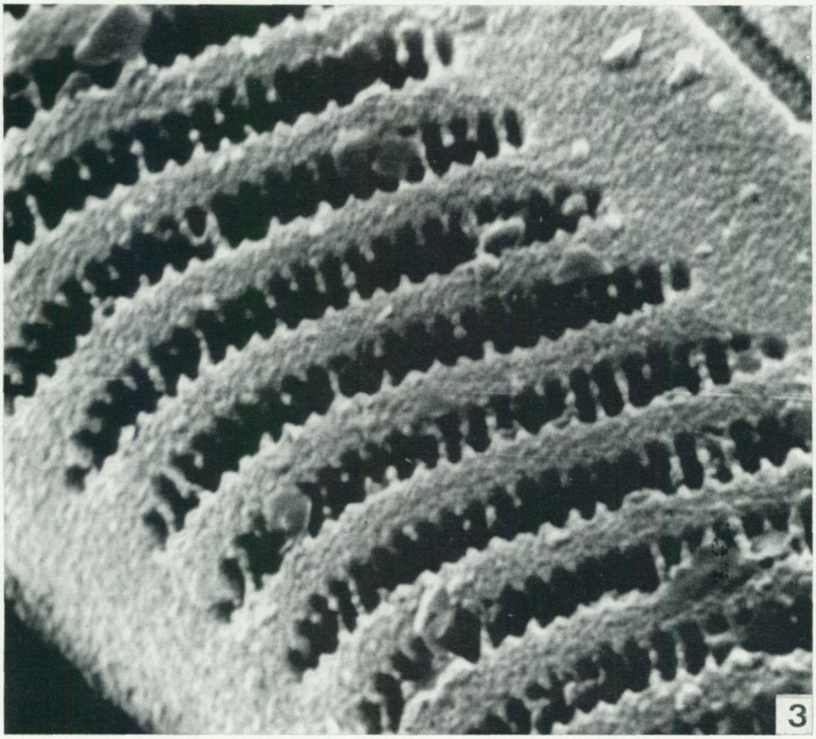


PLATE 20

PLATE 21

Navicula oblonga Kützing

Brackish-lagoon. Postglacial. Öja moor.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 1,500. Film L 6:6.

Fig. 2. Stereoscan micrograph. General picture of the interior side of the valve (50°). Magnification x 1,225. Film S 5:16.

Fig. 3. Stereoscan micrograph. Central part of the interior side of the valve with radiate, lineate striae and the central nodule thickening. Magnification x 6,200. Film S 5:18.

Fig. 4. Stereoscan micrograph. Detail of the interior side of the valve with lineolate striae. Magnification x 25,000. Film S 5:24.

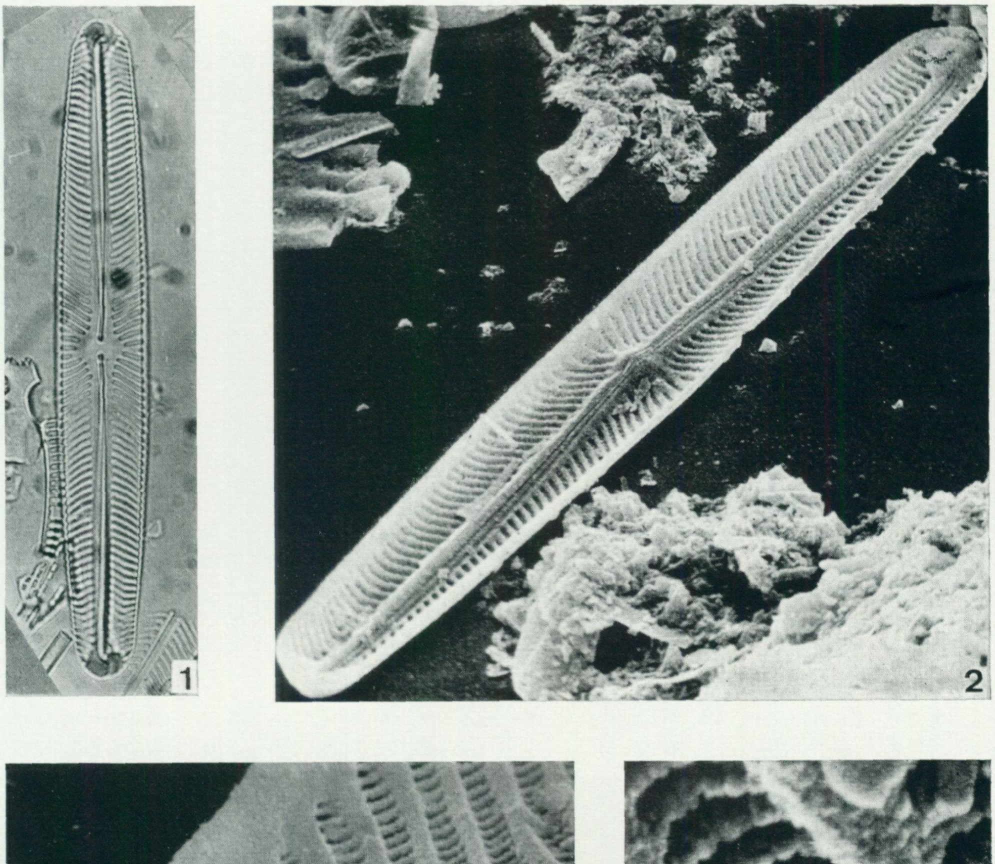


PLATE 21

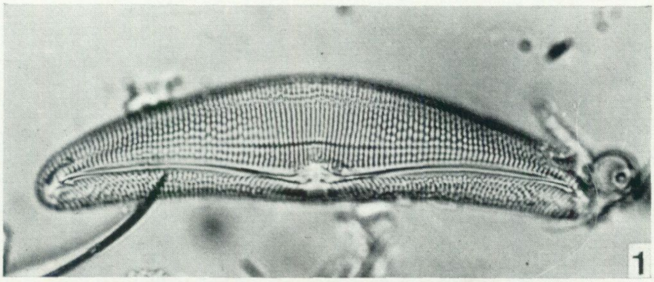
PLATE 22

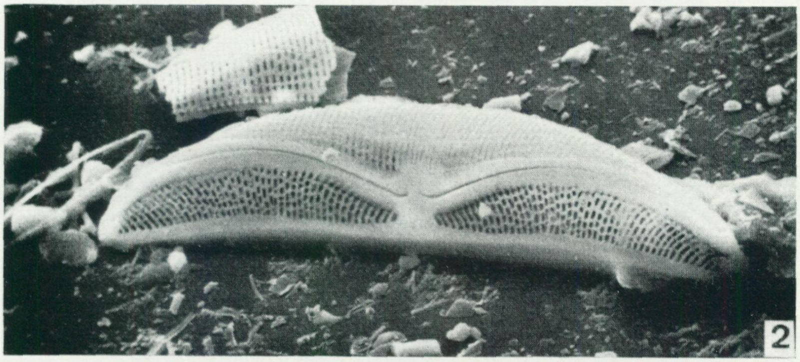
Amphora mexicana A. Schmidt
Brackish-lagoon. Postglacial. Öja moor.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 1,000. Film L 6:10.

Fig. 2. Stereoscan micrograph. General picture of the exterior side of the valve surface (30°). Magnification x 675. Film S 19:26.

Fig. 3. Stereoscan micrograph. The central part of the exterior valve surface with the central raphe nodule, central and axial hyaline areas, and perforated striae. Magnification x 2,700. Film S 19:27.





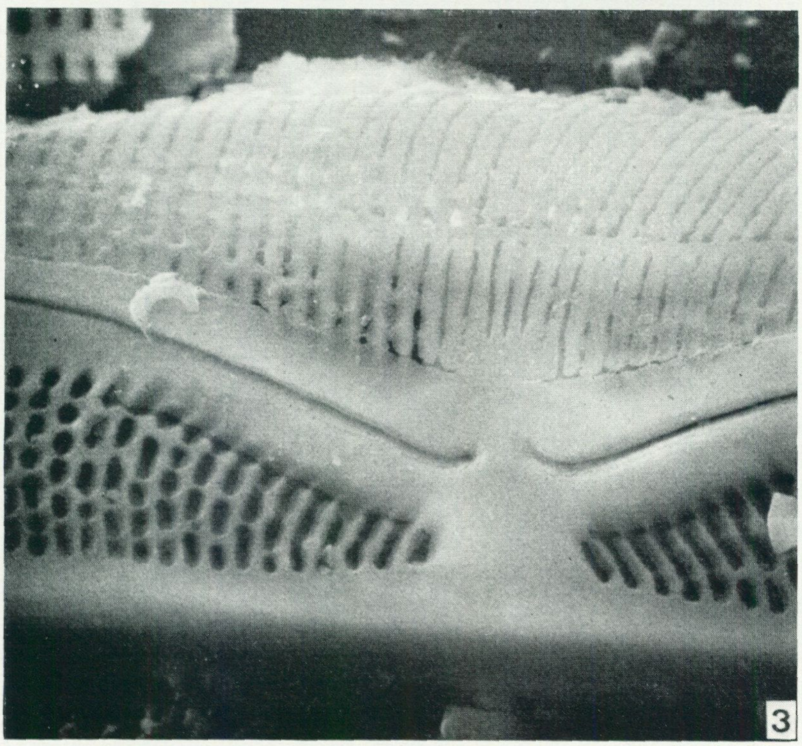


PLATE 22

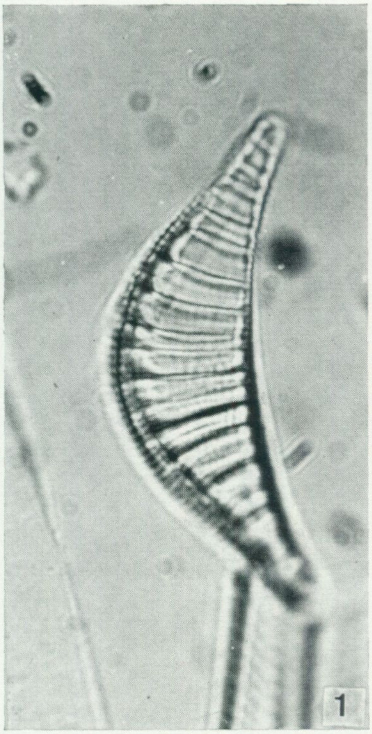
PLATE 23

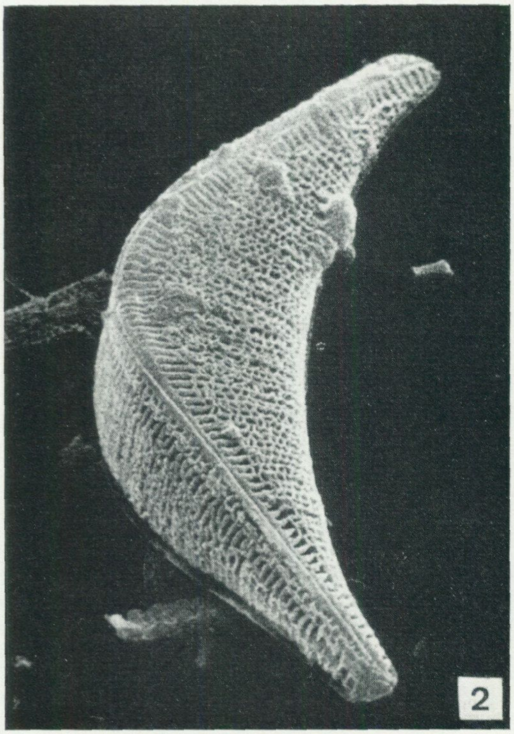
Rhopalodia gibberula (Ehrenberg) O. Müller
Brackish-lagoon. Postglacial. Öja moor.

Fig. 1. Light micrograph. General picture of the frustule in girdle view. Magnification x 3,000. Film L 6:19.

Fig. 2. Stereoscan micrograph. General picture of the exterior of the frustule with high convex dorsal side and concave ventral side. The raphe channel runs along the extreme edge of the valve in girdle view (50°). Magnification x 2,200. Film S 10:32.

Fig. 3. Stereoscan micrograph. Detail of the exterior side of the valve. Magnification x 11,000. Film S 10:29.





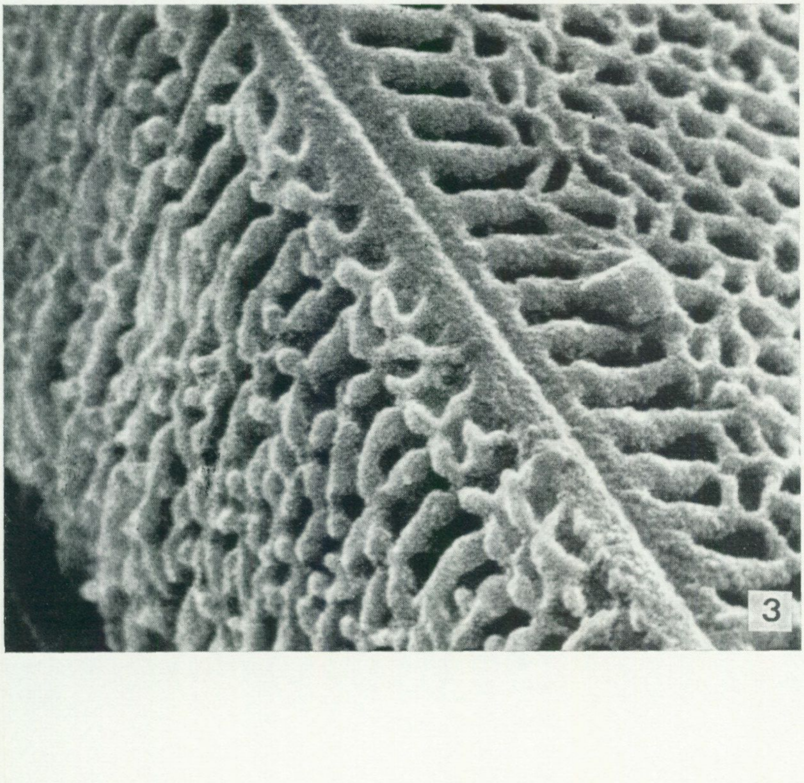


PLATE 23

PLATE 24

Campylodiscus clypeus Ehrenberg
Brackish-lagoon. Postglacial. Öja moor.

Fig. 1. Light micrograph. General picture. Valvar view. Magnification x 1,000. Film L 6:1.

Fig. 2. Stereoscan micrograph. General picture of the exterior side of the valve (45°). Magnification x 280. Film S 2:16.

Fig. 3. Stereoscan micrograph. Part of the exterior valve structure with irregularly perforated striae and the marginal wing-like canal raphe. Magnification x 700. Film S 2:19.

Fig. 4. Stereoscan micrograph. Detail of the perforated windows in the wing-like canal raphe. Magnification x 7,000. Film S 2:25.

Fig. 5. Stereoscan micrograph. Detail of the exterior valve structure with perforated striae and granular hyaline areas. Magnification x 2,800. Film S 2:22.

Fig. 6. Stereoscan micrograph. Detail of the granular exterior valve surface with perforated striae. Magnification x 14,000. Film S 2:21.

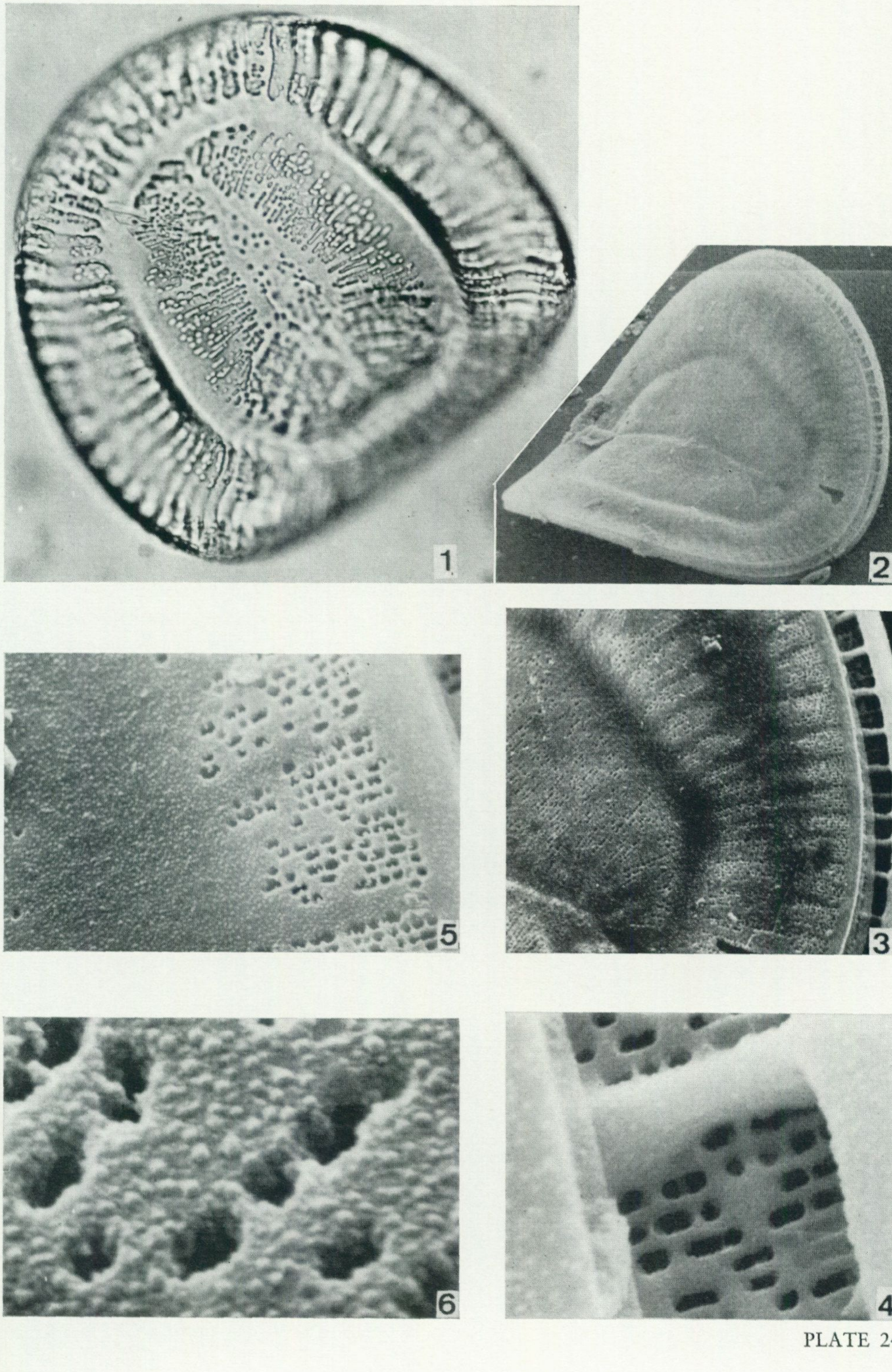


PLATE 24

PLATE 25

Campylodiscus clypeus Ehrenberg

Brackish-lagoon. Postglacial. Öja moor. Stereoscan micrographs.

Fig. 1. General picture of the exterior side of the valve (50°). Magnification x 620. Film S 4:18.

Fig. 2. Detail of the central part of the exterior valve surface with irregularly perforated striae and the furrow of the pseudoraphe. Magnification x 2,500. Film S 4:19.

Fig. 3. Corroded side structure of the exterior valve surface. Magnification x 2,500. Film S 4:25.

Fig. 4. Detail of the corroded structure of the marginal wing-like canal raphe and of the submarginal striae. Magnification x 6,200. Film S 4:23.

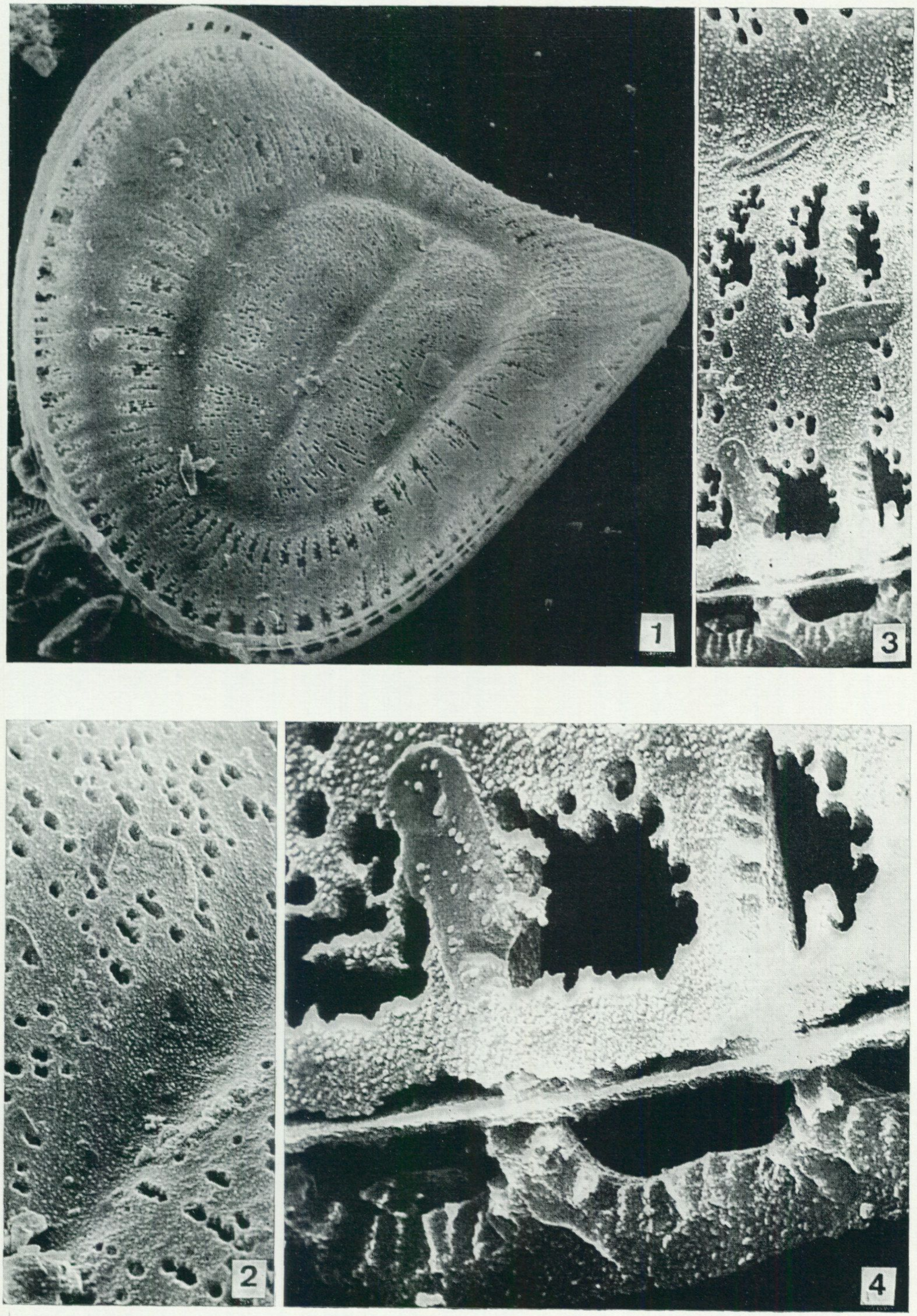


PLATE 25

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