

44. TAXONOMY AND MORPHOSTRUCTURE OF NEOGENE DIATOMS FROM THE SOUTHERN OCEAN, ODP LEG 113¹

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ABSTRACT

Selected Neogene and Quaternary diatom taxa of the genera *Actinocyclus*, *Asteromphalus*, and *Thalassiosira*, that were recovered in ODP (Ocean Drilling Program) Leg 113 drillholes, are described and discussed based on light and scanning electron microscope observations. Some of these diatoms are useful stratigraphic markers or indicators for paleoceanographic reconstructions. Their stratigraphic range and abundance pattern in the southern high-latitudes is described and compared to their ranges in low- and northern high-latitudes, and their significance for paleoceanographic reconstructions is briefly discussed. Two new *Asteromphalus* species and the new variety *Actinocyclus ingens* var. *ovalis* are described, and *Coscinodiscus kolbei* Jousé is transferred to the genus *Thalassiosira*.

INTRODUCTION

The first studies on marine Quaternary diatoms from the southern high-latitude Ocean were accomplished by Heiden and Kolbe (1928) and Jousé et al. (1962), on surface sediment samples recovered in the Indian sector of the Antarctic Ocean. More comprehensive investigations on the taxonomy of marine Neogene and Quaternary diatoms are primarily biostratigraphically orientated studies on Deep Sea Drilling Project (DSDP) cores by McCollum (1975), Schrader (1976), Gombos (1977), Ciesielski (1983), and Gombos and Ciesielski (1983). Of these, especially Schrader (1976) contributed to the knowledge of Neogene diatom taxa from the Antarctic Ocean by describing and documenting 24 new taxa, and by illustrating a number of undescribed forms. Additional studies focused on the description and documentation of Neogene species from the Antarctic include those of Gombos (1974), Brady (1977), and Hendey (1981). Gersonde (in press) describes some new species ranging in the early Pliocene in a study on gravity and piston cores gathered on the Maud Rise near sites drilled during ODP Leg 113.

A very useful contribution on the taxonomy and morphology of Neogene diatom species was produced by Akiba (1985) and Akiba and Yanagisawa (1985) on material from the mid- and high-latitude North Pacific. I refer to these two contributions because they include a large number of well-documented (light [LM] and scanning electron microscope [SEM] micrographs) and well-discussed diatom taxa that have cosmopolitan distribution during Miocene time intervals.

In this paper selected diatom species recovered from Neogene sediment sequences drilled during ODP Leg 113 in the Weddell Sea area are described and discussed. The study is focused on diatoms from the hydraulic piston cores from Holes 689B and 690B (Maud Rise). The biostratigraphic and paleoceanographic significance of these species is discussed briefly. (For more biostratigraphic details see Gersonde and Burckle, this volume.)

Samples were taken aboard the *JOIDES Resolution*. The cleaning of the sediment samples, preparation of permanent mounts for light microscopy (using the resin Mountex) and SEM-investigations were accomplished according to the meth-

ods described by A. Abelmann, U. Bok, R. Gersonde, and U. Treppke (in prep.). Light microscope investigations were made with a Leitz Orthoplan microscope with apochromatic optics. Micrographs were made with an automatic Leitz Orthomat camera. The scanning electron microscope investigations were completed with a Philips SEM 515. Holotypes were marked on LM-slides with a diamond marker and are deposited in the Friedrich-Hustedt Diatom Collection at the Alfred Wegener Institute, Bremerhaven.

DESCRIPTION OF DIATOM TAXA

Genus *ACTINOCYCLUS* Ehrenberg 1838

A recent generic characterization of *Actinocyclus* that was classified by Simonsen (1975) in the family Hemidiscaceae based on the presence of a pseudonodulus, is given by Watkins and Fryxell (1986). Other characteristics besides the presence of a single marginal pseudonodulus are: (1) a marginal ring of internally expanded labiate processes with no external tubes; (2) no central processes; (3) fasciculated rows of areolae and hyaline bands with a large valvocopula.

Actinocyclus ingens Rattray 1890
(Pl. 1, Figs. 1, 3-5; Pl. 3, Figs. 8, 9; Pl. 4, Fig. 1)

Rattray, 1890, p. 149, pl. 11, fig. 7; Kanaya, 1959, p. 97, pl. 7, figs. 6-9; pl. 8, figs. 1-4; Whiting and Schrader, 1985, p. 74, pl. 1, figs. 1-2; pl. 2, figs. 4-10; pl. 3, figs. 12, 13.

Synonyms. *Coscinodiscus elegans* Greville, 1866, pl. 1, fig. 6.
Coscinodiscus novaezealandicus Hanna, 1932, p. 182, pl. 9, fig. 3.
Actinocyclus tsugaruensis Kanaya, 1959, p. 99, pl. 8, figs. 5-8.
Coscinodiscus margaritaceus Castracane, in Muchina, 1979, pl. 2, figs. 12, 13.

Actinocyclus ingens f. *ingens* (Rattray) Whiting and Schrader, 1985, p. 74, pl. 1, figs. 1-2; pl. 2, figs. 4-10; pl. 3, fig. 13.

Actinocyclus ingens f. *planus* Whiting and Schrader, 1985, p. 74, pl. 3, fig. 12. (For further references see Akiba and Yanagisawa, 1985, and Whiting and Schrader, 1985.)

Description and remarks. *A. ingens* is a coarsely silicified centric diatom with highly variable valve diameter and ornamentation of the valve face. The diameter of *A. ingens* in Antarctic material ranges from 15-75 μm , mostly 40-50 μm . Valve face flat, or with a more or less developed concentrically depressed or raised valve center. A clear relationship was not observed between increased undulation and valve diameter, as reported by Kanaya (1959). Cingulum hyaline, with narrow copula and broad open connecting bands. Transitional forms exist between those valve faces with closely spaced areolae, and those with broad hyaline valve center (up to 1/2 of valve diameter) and less dense areolation (Pl. 1, Figs. 1, 3-5; Pl. 3, Figs. 8, 9). In general, the areolae are rounded and isolated, arranged in alternating long and short rows with the longer ones (primary rows) extending radially toward the valve center.

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Rows of areolae are straight to slightly curved. Irregular areolar arrangement was observed particularly in small specimens (Pl. 1, Figs. 3, 4). The size of areolae generally decreases from the valve center toward the margin. Exterior of non-areolate valve center smooth (Pl. 3, Fig. 8) or rough (Pl. 4, Fig. 1). Areolae of valve face have external rounded cribra (Pl. 4, Fig. 1) and internal foramina with a coarsely silicified rim (Pl. 3, Fig. 9). Mantle areolae are distinct from valve face areolae and are small, approximately of equal size, densely spaced and arranged in tangential rows. External openings of mantle areolae are of rhombic to subrounded shape, and the internal foramina are round to subrounded with a coarsely silicified rim (Pl. 3, Fig. 9). Valve mantle edge narrow and hyaline. A ring of labiate processes which extend from the primary rows of areolae, is located on the upper or middle part of the valve mantle. On the inside the processes have a broadly extended, lip-like structure, the slit being parallel to the marginal tangent (Pl. 3, Fig. 9). The external opening of the labiate processes is difficult to distinguish from the mantle areolation (Pl. 3, Fig. 8; Pl. 4, Fig. 1). A pseudonodulus is located in the marginal zone of the valve face. It is of areolate-operculate type as defined by Simonsen (1975) and surrounded by a ring of smaller areolae (Pl. 3, Fig. 8; Pl. 4, Fig. 1). Because of its location in the marginal zone of the valve face the pseudonodulus is often difficult to recognize by LM-investigation. In a number of investigated specimens small and short spines were observed in the marginal zone of the valve face, mostly at equal spacing from each other.

Whiting and Schrader (1985) proposed to group the above described *A. ingens* into two types described as new forms. The nominate form *A. ingens f. ingens*, has frustules composed of singly undulate valves, homovalvate convex, homovalvate concave, or heterovalvate (one concave and one convex valve), and *A. ingens f. planus* Whiting and Schrader is characterized by homovalvate frustules, both being flat. The valve types found in Miocene and Pliocene-Pleistocene sediments from the Antarctic are in general raised submarginally and most of the central valve face is more or less flat. However, transitions to slightly undulate forms with a concentrically depressed or raised valve center were always encountered, and it was not possible to separate form *planus* and form *ingens* of Whiting and Schrader (1985) from each other in the Antarctic material. For this reason Whiting and Schrader's concept could not be followed.

Stratigraphic occurrence. Weddell Sea (ODP Leg 113): early middle Miocene to Pleistocene, ~15.2–0.6 Ma (see Gersonde and Burckle, this volume). Low latitudes: early middle to late middle Miocene, ~15.5–11.5 Ma (Barron 1985). High- and mid-latitudes of North Pacific: latest early Miocene to early Pliocene, ~16.8–4.4 Ma (Barron 1985).

Actinocyclus ingens var. *nodus* (Whiting and Schrader) stat. nov.
(Pl. 1, Fig. 6; Pl. 3, Figs. 4–7)

Basionym. *A. ingens f. nodus* (Baldauf) Whiting and Schrader, 1985, p. 74, pl. 1, fig. 3, pl. 2, fig. 11; pl. 3, fig. 14.

Synonyms. *Actinocyclus ingens* Rattray, in Jousé, 1977, pl. 53, fig. 1.

A. ingens var. 1, Barron, 1980, p. 671, pl. 5, figs. 8, 12.

A. ingens var. *nodus* Baldauf in Baldauf and Barron, 1980, p. 104, pl. 1, figs. 5–9.

Diagnosis. Differs from the nominate variety *A. ingens* var. *ingens* by doubly undulate valves. Valve face center may be depressed or raised (heterovalvate frustules) (Pl. 3, Figs. 5, 7). Generally, valve diameter is large (35–95 μm); central part of valve face with small hyaline area or areolate. Center may be covered by scattered, distinctly smaller areolae (Pl. 3, Fig. 6).

Remarks. Baldauf described *A. ingens* var. *nodus* as having a raised center and a concentric submarginal elevation (Baldauf and Barron, 1980, p. 104, pl. 1, figs. 5–9). However, SEM-investigation of Antarctic material recovered at Holes 689B and 690B showed that the double undulated valves may have a raised or a depressed central part of the valve face. The same pattern was noticed by Whiting and Schrader (1985), who emended Baldauf's description and made a combination in a lower rank: *A. ingens f. nodus*. Whiting and Schrader's argument for choosing a form name for this taxon is the co-occurrence of different forms of *A. ingens* and the continuum in sizes and degrees of undulation that would suggest that these represent a single population and not different genetic varieties. However, based on the investigations of the Neogene Antarctic material the contrary can be suggested. The distinct age range of the double undulated *Actinocyclus*, restricted to the early middle Mi-

ocene (see below), and the lack of transitions between this diatom and *A. ingens* Rattray indicate that they were probably not members of a single population. For this reason *Actinocyclus ingens* var. *nodus* was placed into the rank of a variety.

Stratigraphic occurrence. Weddell Sea (ODP Leg 113): early middle to middle middle Miocene, ~14.9–12.3 Ma (Gersonde and Burckle, this volume). High- and mid-latitudes of North Pacific: early middle to middle middle Miocene, ~15.2–13.7 Ma (Barron 1985).

Actinocyclus ingens var. *ovalis* var. nov.

(Pl. 1, Fig. 7; Pl. 3, Figs. 1–3; Pl. 5, Figs. 4, 7; Pl. 6, Figs. 1, 4, 5)

Synonym. ?*Hemidiscus karstenii* fo. 1 Ciesielski, 1983, p. 656, pl. 4, figs. 2–5.

Diagnosis. Differs from the nominate variety *A. ingens* var. *ingens* by slightly oval to slightly triangular valve outline, length 22–52 μm , length/width ratio ~1.1–1.2. Valve face generally flat.

Remarks. Structure, shape, and arrangement of areolae on valve face and valve margin, and structure and location of the pseudonodulus are the same as in flat *A. ingens* var. *ingens*. Girdle bands were not observed. Because of the distinct age range of the described taxon, it was named as a variety.

A. ingens var. *ovalis* has some affinities to a form described by Ciesielski (1983) from Neogene deposits in the Subantarctic as *Hemidiscus karstenii* f. 1. However, based on the photographic documentation of *H. karstenii* f. 1, it can be deduced that this form has larger valve size, a more densely packed areolar pattern of the valve face and an easily observable pseudonodulus, compared to *A. ingens* var. *ovalis*. Ciesielski (1983) states that this form is common only in sediments of "Chronozone 5 to upper Chronozone 6", at ~6.1–5.3 Ma, and thus is slightly younger than *A. ingens* var. *ovalis*. However, it is not clear how Ciesielski dated the range of his form based on the data he published, because no direct correlation with paleomagnetic data was available in his study.

Holotype. Deposited in the Friedrich-Hustedt Collection No. Zu 3/71 (Pl. 6, Fig. 1)

Type locality. Maud Rise, southeast Weddell Sea, ODP Site 689.

Type level. Marine late Miocene, ODP Sample 113-689B-3H-5, 28–29 cm.

Stratigraphic occurrence. Weddell Sea (ODP Leg 113): late Miocene, ~7.9–7.2 Ma (Gersonde and Burckle, this volume).

Genus *ASTEROMPHALUS* Ehrenberg 1844

A generic description of *Asteromphalus* is given in Hustedt (1930).

Asteromphalus inaequalis sp. nov.

(Pl. 2, Fig. 4; Pl. 6, Fig. 3)

Synonym. *Asteromphalus* sp. 2, Schrader 1976, p. 630, pl. 8, fig. 1, non fig. 2.

Description. Cells discoid, valves circular and slightly convex, 60–95 μm in diameter. Valve surface with central hyaline space occupying approximately 1/2 of valve diameter. Areolate part of valve divided by radially orientated hyaline rays extending from central portion of hyaline space into 5–8 peripheral sectors. Hyaline rays broad and of equal length, except one that is narrower and shorter than the others. A system of straight lines merging in center of hyaline portion extends radially and joins the areolate sectors in the middle of their straight to slightly concave periphery. Two lines that generally merge slightly eccentrically and continue toward the center in one line, join the two sectors adjacent to the narrow hyaline ray. Radial size of areolate sectors more or less equal, tangential length may be distinctly different, especially the sizes of the two sectors separated by the shorter and narrow hyaline ray, which are distinctly different from each other. Areolae of peripheral sectors hexagonal, of equal size and small (11–12/10 μm), arranged in straight to slightly curved lines; two parallel to the edges of the segments and one tangentially orientated. Hyaline rays terminate with a labiate process at valve margin.

Holotype. Deposited in the Friedrich-Hustedt Collection No. Zu 3/73 (Pl. 2, Fig. 4).

Type locality. Maud Rise, southeast Weddell Sea, ODP Site 689.

Type level. Marine early Miocene ODP Sample 113-689B-7H-6, 145–147 cm.

Stratigraphic occurrence. Weddell Sea (ODP Leg 113): early to early middle Miocene (Gersonde and Burckle, this volume).

Derivation of name. *inaequalis* (Latin)—unequal.

Asteromphalus kennettii sp. nov.
(Pl. 2, Fig. 1; Pl. 6, Fig. 2)

Description. Cells discoid, valves circular and slightly convex, 80–120 μm in diameter. Valve surface with central hyaline space occupying $\sim 1/2$ of valve diameter. Areolate part of valve divided by radially orientated hyaline rays extending from central portion of hyaline space into 10–13 peripheral sectors. Hyaline rays of equal length, but one of them narrower than the others. A system of straight lines merging in or near center of hyaline portion extends radially and joins areolate symmetric sectors in the middle of their straight to slightly convex periphery. Two lines that generally merge slightly eccentrically and continue toward the center in one line, join the two asymmetric sectors adjacent to the narrow hyaline ray. Areolae of peripheral sectors coarse, hexagonal, of equal size (6–8/10 μm), and arranged in slightly disordered and curved lines, two parallel to the edges of the segments and one tangentially orientated. Areolae close to valve margin distinctly smaller. Hyaline rays terminate with a labiate process at valve margin.

Discussion. *A. kennettii* differs from *A. oligocaenicus* Schrader and Fenner (Schrader and Fenner, 1976, p. 965; pl. 21, figs. 8, 13, 14; pl. 28, fig. 1) by its larger hyaline central space, the coarser areolation of the peripheral sectors and the straight to slightly convex periphery of these sectors. It is different from *A. robustus* Castracane (see Hustedt, 1930, p. 496, fig. 278) by the hyaline rays of equal length and the arrangement of the lines in the central hyaline space. *A. hookeri* Ehrenberg has less coarse areolae, arranged more regularly and has also a different arrangement of the lines in the central hyaline space.

Holotype. Deposited in the Friedrich-Hustedt Collection No. Zu 3/72 (Pl. 2, Fig. 1).

Type locality. Maud Rise, southeast Weddell Sea, ODP Hole 689B.

Type level. Marine late Miocene, ODP Sample 113-689B-4H-1, 143–145 cm.

Stratigraphic occurrence. Weddell Sea (ODP Leg 113): late Miocene, ~ 9.6 –7.1 Ma (Gersonde and Burckle, this volume).

Derivation of name. Dedicated to James P. Kennett, Professor of Oceanography, Marine Science Institute, University of California, Santa Barbara, California; Co-chief Scientist of Leg 113.

Genus *THALASSIOSIRA* Cleve 1873

The genus *Thalassiosira* is characterized by the presence of strutted processes and areolae having external foramina and internal cribra. The strutted processes are arranged in a near-marginal ring. Additional strutted processes may occur in different arrangement patterns on the valve face (Hasle 1973a, b). The valves have one or more labiate processes.

Thalassiosira convexa var. *aspinosa* Schrader 1974

(Pl. 2, Figs. 2, 5; Pl. 4, Figs. 2–4)

Schrader, 1974, p. 916, pl. 2, figs. 8–9, 13a–21.

Description and remarks. Schrader (1974) describes this taxon as a variety of *T. convexa* Muchina (Muchina 1965, p. 22, table 2, figs. 1–2) differing by the non-spinous margin. Schrader states that all other morphological features of the variety are identical to the nominate variety.

In lower Pliocene sediments of Holes 689B and 690B, convex forms with fasciculate to slightly disordered areolae arrangement were recovered (Gersonde and Burckle, this volume). These forms are 15–30 μm in diameter. Based on LM-observations no marginal spines could be identified so that these forms were attributed to *T. convexa* var. *aspinosa* (Pl. 2, Figs. 2, 5). Subsequent SEM-investigations clearly showed the characteristics of the genus *Thalassiosira*, such as internal cribra and external foramina, the presence of strutted processes and of at least one labiate process. A ring of equally spaced strutted processes (~ 6 –8/10 μm) is located close to the valve edge. Additionally, 2–5 strutted processes were observed in the valve center, arranged in a cluster or in a row. The strutted processes seem to take the place of areolae, and are surrounded by four satellite pores and are flat on the outside. A labiate process is located approximately midway between the valve center and the valve margin (Pl. 4, Figs. 3, 4). At the external marginal zone of some specimens spherical granules were observed (Pl. 4, Fig. 2). The granules and the processes could not be observed during LM-investigations because of the convex outline of the valves.

Stratigraphic occurrence. Weddell Sea (ODP Leg 113): early Pliocene (see Gersonde and Burckle, this volume); low latitudes, and high-

and mid-latitudes of North Pacific: latest Miocene to late Pliocene, 6.2–2.1 Ma (Barron 1985).

Thalassiosira fraga Schrader in Schrader and Fenner 1976

(Pl. 2, Fig. 3; Pl. 4, Figs. 5, 6; Pl. 5, Figs. 1, 2)

Schrader and Fenner, 1976, p. 1001, pl. 16, figs. 9–12; Akiba and Yanagisawa, 1985, p. 498, pl. 51, figs. 5–10; pl. 53, figs. 1–8.

Description and remarks. The original description of the species is from lower and middle Miocene sediments recovered during Deep Sea Drilling Program (DSDP) Leg 38 in the Norwegian Sea. It is based on light microscope investigations and does not include information on the presence and location of strutted processes. Based on SEM-observations Akiba and Yanagisawa (1985) give a comprehensive emended description of *T. fraga* specimens recovered during DSDP Leg 87 in lower Miocene sequences in the mid- to high-latitude North Pacific. Akiba and Yanagisawa (1985) describe two rings of strutted processes. An outer ring with 4–5 processes/10 μm is located on the valve mantle and an inner ring with ~ 2 processes/10 μm is situated one areolae inside the edge of the valve face. The strutted processes of the outer ring have external tubes, while the strutted processes of the inner ring are flat at their external openings. The strutted processes have six struts and satellite pores. Akiba and Yanagisawa (1985) describe a single labiate process that is located between the two rings of strutted processes.

Diatoms with similar valve outline, areolar pattern, cribral structure, and location of processes were found in the lower Miocene of Holes 689B and 690B. These diatoms were attributed to *T. fraga* based on the emended description of Akiba and Yanagisawa (1985). However, in the Antarctic material the strutted processes of the outer and the inner ring are more closely spaced compared to the material described from the mid- to high-latitude North Pacific. The outer ring has ~ 6 –8 processes/10 μm , the inner ring 2–5/10 μm . The strutted processes in the Antarctic material may have 6–7 struts and satellite pores. The single labiate process is located between the rings of strutted processes, the slit being parallel to the marginal tangent (Pl. 4, Figs 5, 6).

Stratigraphic occurrence. Weddell Sea (ODP Leg 113): early Miocene, ~ 19.6 –interval between 17.6–15.4 Ma (Gersonde and Burckle, this volume); low latitudes: early Miocene, ~ 19.9 –16.2 Ma (Barron 1985); high- and mid-latitudes of North Pacific: early Miocene, ~ 19.9 –16.5 Ma (Barron 1985).

Thalassiosira kolbei (Jousé) comb. nov.

(Pl. 1, Fig. 2; Pl. 5, Figs. 3, 5, 6)

Basionym. *Coscinodiscus kolbei* Jousé, in Jousé et al., 1962, p. 73, pl. 1, figs. 7–9.

Description and remarks. The original description is in Russian. A short English description of the species is given by Barron (1985, p. 781, fig. 14.15). *T. kolbei* has a circular and heavily silicified valve. Valve diameter 35–110 μm . Valve face flat and slightly depressed in the center (Pl. 5, Fig. 5). Areolae large (3–5/10 μm), arranged in tangential rows, decrease slightly in size toward the margin. Central areola often surrounded by seven symmetrically arranged areolae (Pl. 1, Fig. 2). Valve margin low with a solid edge ornamented by equally spaced radial thickenings (Pl. 5, Fig. 5). Areolae with internal cribra (Pl. 5, Figs. 3, 6) and external foramina. A high number of strutted processes is scattered all over the valve face, located between the areolae. A marginal ring with equally spaced strutted processes (~ 5 –7/10 μm) is located on the valve margin (Pl. 5, Fig. 6). Strutted processes with 4–5 satellite pores, flat on the outside. One labiate process was observed, located at the valve face margin, the slit being parallel to the marginal tangent (Pl. 5, Fig. 5). There are irregularly spaced elongated tubes on the outside of the valve face margin that are interpreted to represent occluded processes (Pl. 5, Fig. 5).

Stratigraphic occurrence. Weddell Sea (ODP Leg 113): early to late Pliocene (Gersonde and Burckle, this volume). *T. kolbei* is endemic to the Antarctic.

Thalassiosira spumellaroides Schrader 1976

(Pl. 5, Figs. 8, 9)

Schrader 1976, p. 636, pl. 6, figs. 1, 2.

Description and remarks. In his original description, which was based on LM-observations, Schrader (1976) noticed that no labiate or

strutted processes were found in the strongly silicified valves. Schrader placed the species characterized by convex valves within the genus *Thalassiosira* because of its similarities to *T. convexa* Muchina.

SEM-observations in the course of the present study verified the correct generic placement of *T. spumellaroides*, having strutted processes and areolae with internal cribra and external foramina. However, the internal structure of the concave valve face of *T. spumellaroides* is unusual because of the presence of cribra arranged in continuous rows separated by well developed elongated internal vertical walls of the areolae, arranged in fasciculate pattern. The edges of these rows have a serrate outline (Pl. 5, Fig. 9). External openings of the areolae on the valve face are in straight fasciculate rows (6–7 areolae/10 μm), while the areolae on the valve margin are smaller and irregular in arrangement (10–12 areolae/10 μm) (Pl. 5, Fig. 8). Internal structure of valve margin consists of densely packed radially orientated rows of perforations of similar size to the cribra perforations of the valve face. No structure of areolae walls can be distinguished on the internal valve mantle surface. Strutted processes of *T. spumellaroides* are scattered in the area of the valve margin at a distance of 1–2 μm . On the inside, the strutted processes have 5–6 satellite pores and a slightly elevated central tube. On the outside the strutted process openings are flat. On the inside of the valve margin occur irregularly spaced and radial elongated openings, each prolonged into a 1–3 μm long tube on the valve outside (Pl. 5, Figs. 8, 9). The tubes have a diameter up to 1 μm . These structures possibly represent labiate processes with elongated external tube.

A similar internal structure of the valve face and valve mantle was described for *Thalassiosira leptopus* (Grunow) Hasle and Fryxell (Hasle and Fryxell 1977, p. 20, figs. 1–14, 94–96). *T. leptopus* has one labiate process in radial orientation with an extended external tube, and strutted processes (with 5 struts) arranged irregularly on the valve margin. Thus, there are resemblances in the ultrastructure between *T. leptopus* and *T. spumellaroides*. *T. spumellaroides* differs by its convex valve and the structure of the base of the valve mantle edge, characterized by closely spaced radial thickenings (Pl. 5, Fig. 9). Radial zig-zag paths of continuous cribra were also described from some tangential undulated freshwater and brackish-water species (*Thalassiosira lacustris* (Grunow) Hasle, *T. australiensis* (Grunow) Hasle and *T. gessneri* Hustedt) by Hasle and Lange (1989).

Stratigraphic occurrence. Weddell Sea (ODP Leg 113): early Miocene (Gersonde and Burckle, this volume); high- and mid-latitudes of North Pacific: early Miocene, ~21.7–17.0 Ma (Barron 1985).

DISCUSSION

Species of *Actinocyclus* were found in various quantities in most of the Neogene and Quaternary sediment sections recovered during Leg 113. Abundance fluctuations were determined from quantitative studies on Miocene sequences of Hole 689B (Maud Rise).

In lower Miocene sediments, specimens of *Actinocyclus* are sporadic and can be attributed to *Actinocyclus octonarius* Ehrenberg. The first appearance datums (FAD) of *Actinocyclus ingens* and *Actinocyclus ingens* var. *nodus* were placed by Gersonde and Burckle (this volume) in the lower portion of the early middle Miocene *Nitzschia grossepunctata* Zone and dated at ~15.2 and ~14.9 Ma, respectively. While *A. ingens* var. *nodus* is restricted to the middle Miocene, *Actinocyclus ingens* occurs in Antarctic sediments throughout the late Miocene and ranges into the Pleistocene. The last occurrence of *A. ingens* var. *nodus* falls into the lowermost part of the late middle Miocene *Denticulopsis praedimorpha* Zone and was dated to be at ~12.3 Ma (Gersonde and Burckle, this volume). The LAD (last appearance datum) of *A. ingens* in southern high latitudes can be placed around 0.6 Ma, according to Ciesielski (1983), and Gersonde and Treppke (in prep.). This LAD marks the top of the *A. ingens* Zone of Gersonde and Burckle (this volume) that ranges from the latest Pliocene into the middle Pleistocene.

The FAD of *A. ingens* in low latitudes and in the high- and mid-latitudes of the North Pacific is reported by Barron (1985) at ~15.5 and 16.8 Ma, respectively. Thus, according to these reports, the LAD's of *A. ingens* in different latitudes are relatively close together in time and the earliest occurrence of *A. ingens*

would be in the North Pacific. The LAD of *A. ingens* is distinctly diachronous. In the low-latitude regions it is in the late middle Miocene at ~11.5 Ma, while in the high- and mid-latitudes of the North Pacific, the LAD of *A. ingens* is in the early Pliocene, at ~4.4 Ma (Barron 1985); and in southern high latitudes in the Pleistocene. The diachronous last occurrence of *A. ingens* is probably triggered by changes in environmental conditions that occur at different time intervals at the different latitudes. The range of *A. ingens* var. *nodus* in the Antarctic is close to that reported by Barron (1985) from the high- and mid-latitude North Pacific as 15.2–13.7 Ma. Gersonde and Burckle (this volume) also report occurrences of *A. ingens* var. *nodus* from the middle late Miocene, however, the taxonomic affinities of these scattered, undulated *Actinocyclus* forms is not yet confirmed.

In Holes 689B and 690B (Maud Rise), *A. ingens* and *A. ingens* var. *nodus* show distinct abundance intervals (>15% of total diatom assemblages) during the middle Miocene between ~14.9 and 12.4 Ma. *A. ingens* has a second abundance interval (>15% of total diatom assemblages) during the late Miocene spanning from ~9.75 to ~8.8 Ma (Gersonde and Burckle, this volume). A third time-interval characterized by high *A. ingens* occurrence ranges from the latest Pliocene into the Pleistocene, from ~1.6 to 0.7 Ma (Abelmann et al., in press). The middle Miocene abundance interval of *A. ingens* coincides with a sharp $\delta^{18}\text{O}$ increase between ~15 and 13 Ma, recorded by benthic foraminifers in Atlantic and Pacific DSDP sites. This $\delta^{18}\text{O}$ increase indicates a distinct cooling event with intensification of glacial conditions (Miller et al., 1987, p. 9, figs. 1, 2). The *A. ingens* abundance interval in the late Miocene falls within a time interval characterized by high $\delta^{18}\text{O}$ values that ranges from ~10 to 8 Ma. Thus the middle and late Miocene acme intervals of *A. ingens* can be related to intervals marked by polar cooling and growth of Antarctic continental ice. The abundant occurrence of *A. ingens* recovered in latest Pliocene to Pleistocene gravity cores in the Weddell Sea area was interpreted to reflect relatively stable and warmer conditions intercalated between late Pliocene and a late Pleistocene time interval characterized by significant cooling, widespread occurrence of sea-ice and distinct climatic cyclicity (Abelmann et al., in press). This pattern indicates that *A. ingens* was probably a species adapted to moderately cold surface water. It became extinct in the Antarctic Ocean when, after a Pleistocene cooling event, surface-water temperature conditions comparable to the present situation were established.

Another *Actinocyclus* taxon, described herein as *Actinocyclus ingens* var. *ovalis* was recovered above the late Miocene *A. ingens* abundance interval. This taxon has a short range from ~7.9 to 7.2 Ma, falling within the late Miocene part of the *Cosmodiscus intersectus* Zone of Gersonde and Burckle (this volume). The stratigraphic significance of this taxon for refinement of the Neogene Antarctic diatom biostratigraphy is not yet clear. This question will probably be resolved during the study of Neogene sections recovered during ODP Legs 119 and 120 in the Indian Sector of the Antarctic Ocean.

In comparison with the discussed *Actinocyclus* taxa, species of the genus *Asteromphalus* occur in general more rarely in Neogene and Quaternary Antarctic sediments. Extant species such as *Asteromphalus hookeri* Ehrenberg and *A. parvulus* Karsten occur in Pleistocene sediments. In their biostratigraphic studies Schrader (1976) and Ciesielski (1983) report several new *Asteromphalus* species from the Antarctic Miocene but none of these taxa were adequately described. One of those is the herein described *Asteromphalus kennettii* that occurs consistently in a late Miocene time interval recovered in Holes 689B and 690B. For this reason *A. kennettii* was used as the nominate species of a late Miocene biostratigraphic zone that ranges from ~9.6 to 7.9 Ma (Gersonde and Burckle, this volume). The other new

taxon *A. inaequalis*, occurs only rarely in lower and middle Miocene sequences and was not used for stratigraphic purposes.

Thalassiosira is one of the prominent diatom genera in the present-day Antarctic. Most of the important extant *Thalassiosira* species were described and illustrated with LM and SEM micrography by Johansen and Fryxell (1985). In Pleistocene sediments such species as *T. lentiginosa* (Janisch) Fryxell and *T. gracilis* (Karsten) Hustedt are widespread and common, and *T. lentiginosa* is the nominate species of the youngest biostratigraphic diatom zone ranging from ~0.6 Ma to present time (Gersonde and Burckle, this volume).

Another biostratigraphic marker species is *T. kolbei*, nominate species of a diatom zone that ranges from a time interval between 2.5 and 2.1 Ma to ~1.8 Ma (Gersonde and Burckle, this volume). *T. kolbei* ranges in Weddell Sea sediments (Antarctic Ocean) from the early Pliocene *Thalassiosira inura* Zone into the late Pliocene *T. kolbei* Zone of Gersonde and Burckle (this volume). Its last appearance date was placed at about 1.8 Ma and is coincident with the base of the *A. ingens* Zone as defined by Gersonde and Burckle (this volume). *T. kolbei* was originally described in Jousé et al. (1962) as *Coscinodiscus kolbei* and is transferred herein to the genus *Thalassiosira* because of the presence of strutted processes and the structure of areolae with external foramina and internal cribra.

In the early and early late Pliocene *T. complicata* Gersonde (in press), *T. inura* Gersonde (in press), and *T. oestrupii* (Ostenfeld) Proshkina-Lavrenko are of stratigraphic importance, *T. inura* being the nominate species of a diatom zone defined by Gersonde and Burckle (this volume) that ranges from ~4.47 Ma to an interval between 4.2 and 4.1 Ma. In the earliest Pliocene and/or the late Miocene, *Thalassiosira* taxa established as biostratigraphic markers in low latitudes occur in Antarctic sediments. These are taxa with convex valves: *Thalassiosira convexa* var. *aspinosa* Schrader, *T. miocenica* Schrader, and *T. praecconvexa* Burckle (Gersonde and Burckle, this volume). This may indicate that the environmental conditions during the time interval of their occurrence in Antarctic sediments were characterized by less developed latitudinal thermal gradients.

During most of the early late Miocene through the middle middle Miocene *Thalassiosira* species are rare or absent in the sediments recovered in the holes drilled during Leg 113 (Gersonde and Burckle, this volume). However, during the late middle and/or early Miocene *Thalassiosira spinosa* Schrader, *T. fraga* Schrader, and *T. spumellaroides* Schrader, all species with convex valve shape, occur consistently, rare to common. During the early Miocene these species are also present in low latitude and northern high-latitude areas (Barron 1983, 1985). This overall occurrence pattern may indicate that at least during the time interval middle and early early Miocene, which was recovered at Holes 689B and 690B, latitudinal partitioning of surface waters was not or only weakly developed. This could be linked to reduced glacial conditions on the Antarctic continent that leads to less developed climatic gradients between the low- and high-latitudes and to more uniform climatic conditions during this time interval. Such interpretation is supported by decreased or stable $\delta^{18}\text{O}$ values recorded by Miller et al. (1986) for a time interval between 24 and 16 Ma (early Miocene). Also Kennett and Hodell (1986) suggested that, during the early Miocene between 19.5 and 16 Ma the continental ice-sheet on Antarctica was substantially reduced.

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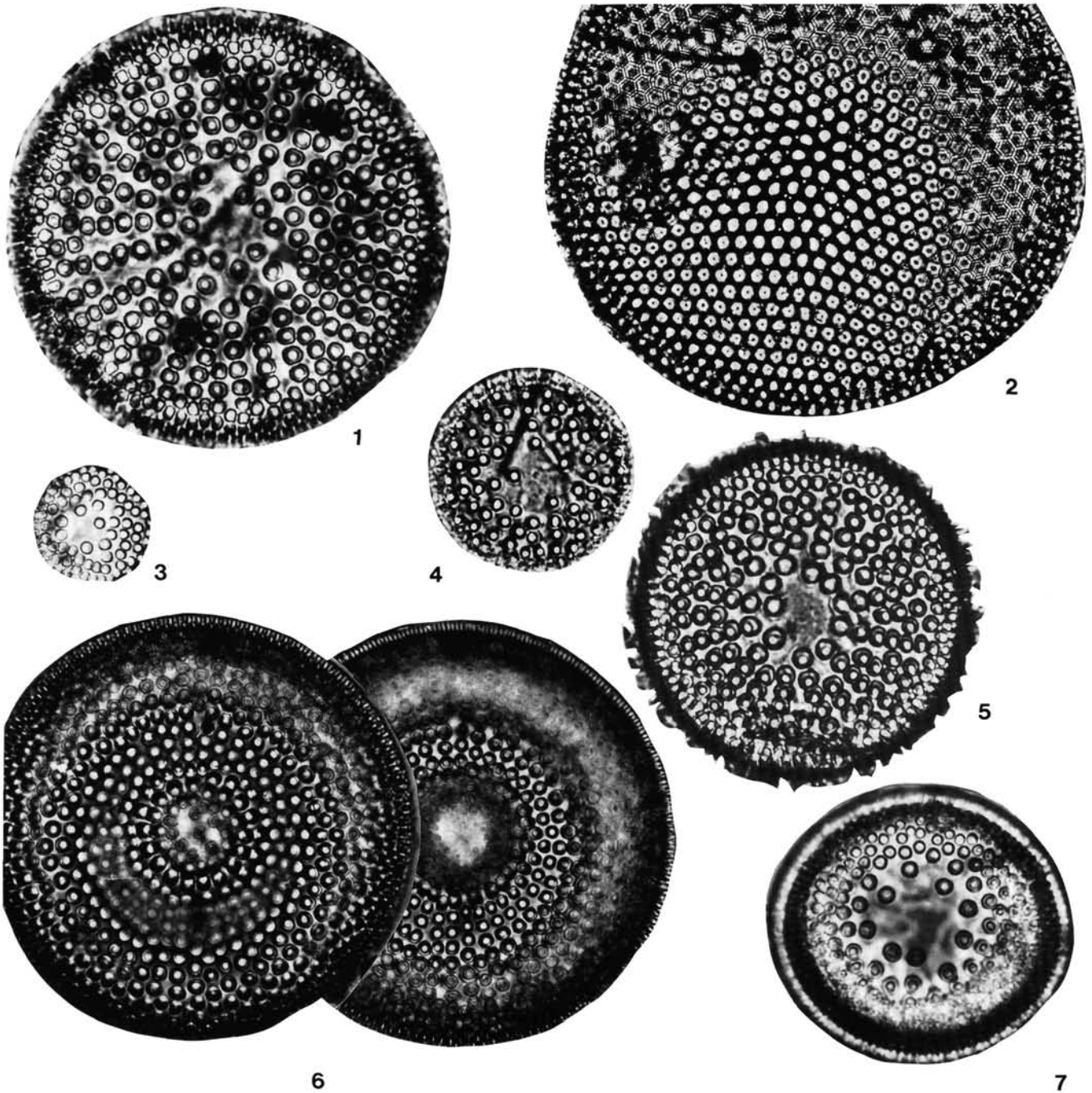


Plate 1. (All specimens at $\times 1500$ unless otherwise indicated) 1, 3-5. *Actinocyclus ingens* Rattray, (1) Sample 113-689B-6H-3, 28-29 cm; (3-5) Sample 113-689B-4H-2, 113-114 cm. 2. *Thalassiosira kolbei*, Sample 113-690B-2H-3, 28-29 cm, $\times 1050$. 6. *Actinocyclus ingens* var. *nodus* (Whiting and Schrader) stat. nov., at different focus, Sample 113-689B-7H-1, 28-29 cm, $\times 1050$. 7. *Actinocyclus ingens* var. *ovalis* var. nov., Sample 113-689B-3H-5, 28-29 cm.

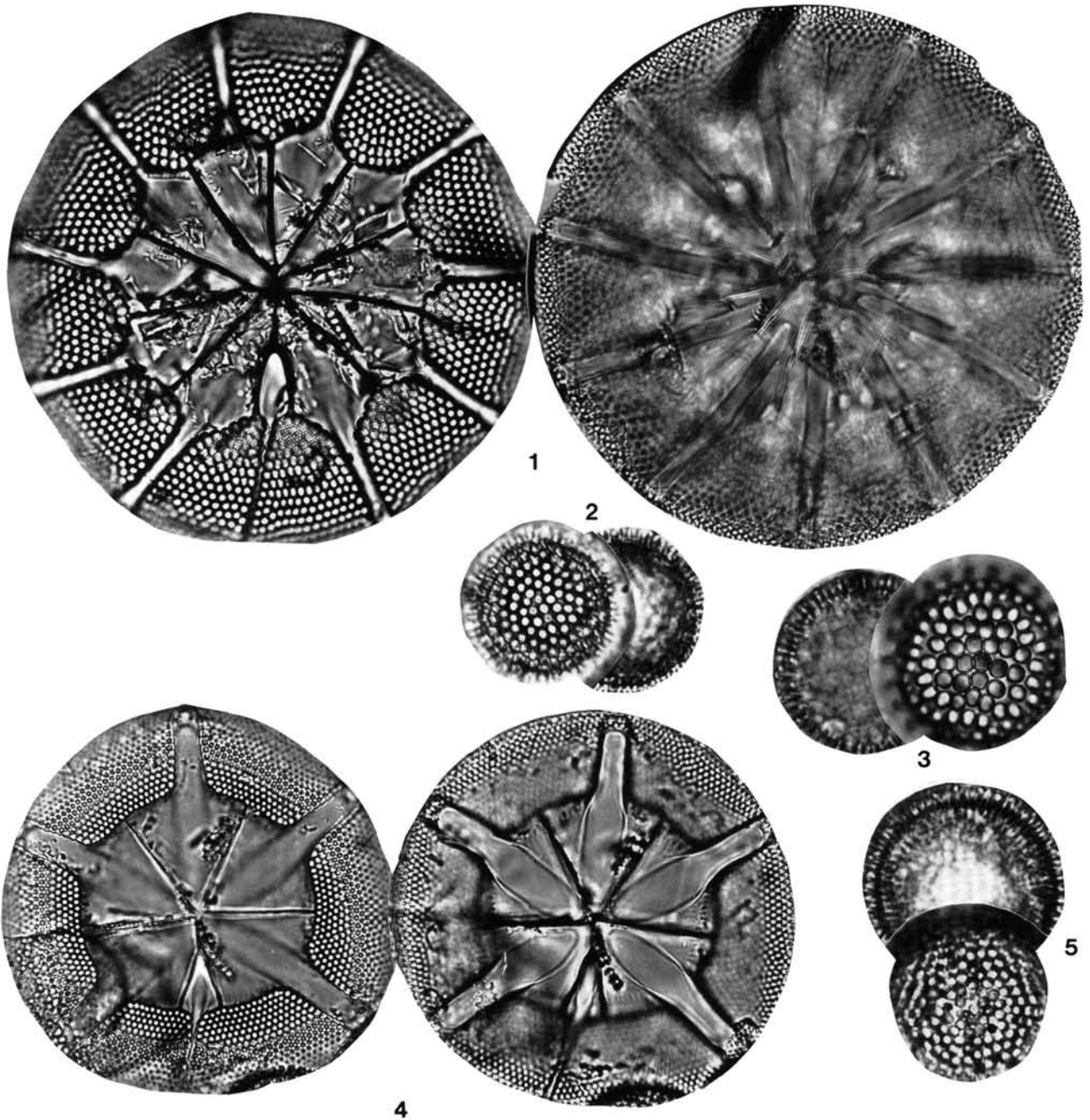


Plate 2. (All specimens at $\times 1500$ unless otherwise indicated) 1. *Asteromphalus kennettii* sp. nov., holotype at different focus, Sample 113-689B-4H-1, 143-145 cm, $\times 915$. 2, 5. *Thalassiosira convexa* var. *aspinosa* Schrader, both specimens at different focus, Sample 113-689B-3H-2, 114-115 cm. 3. *Thalassiosira fraga* Schrader, at different focus, Sample 113-689B-8H-1, 88-90 cm. 4. *Asteromphalus inaequabilis* sp. nov., holotype at different focus, Sample 113-689B-7H-6, 145-147 cm, $\times 915$.

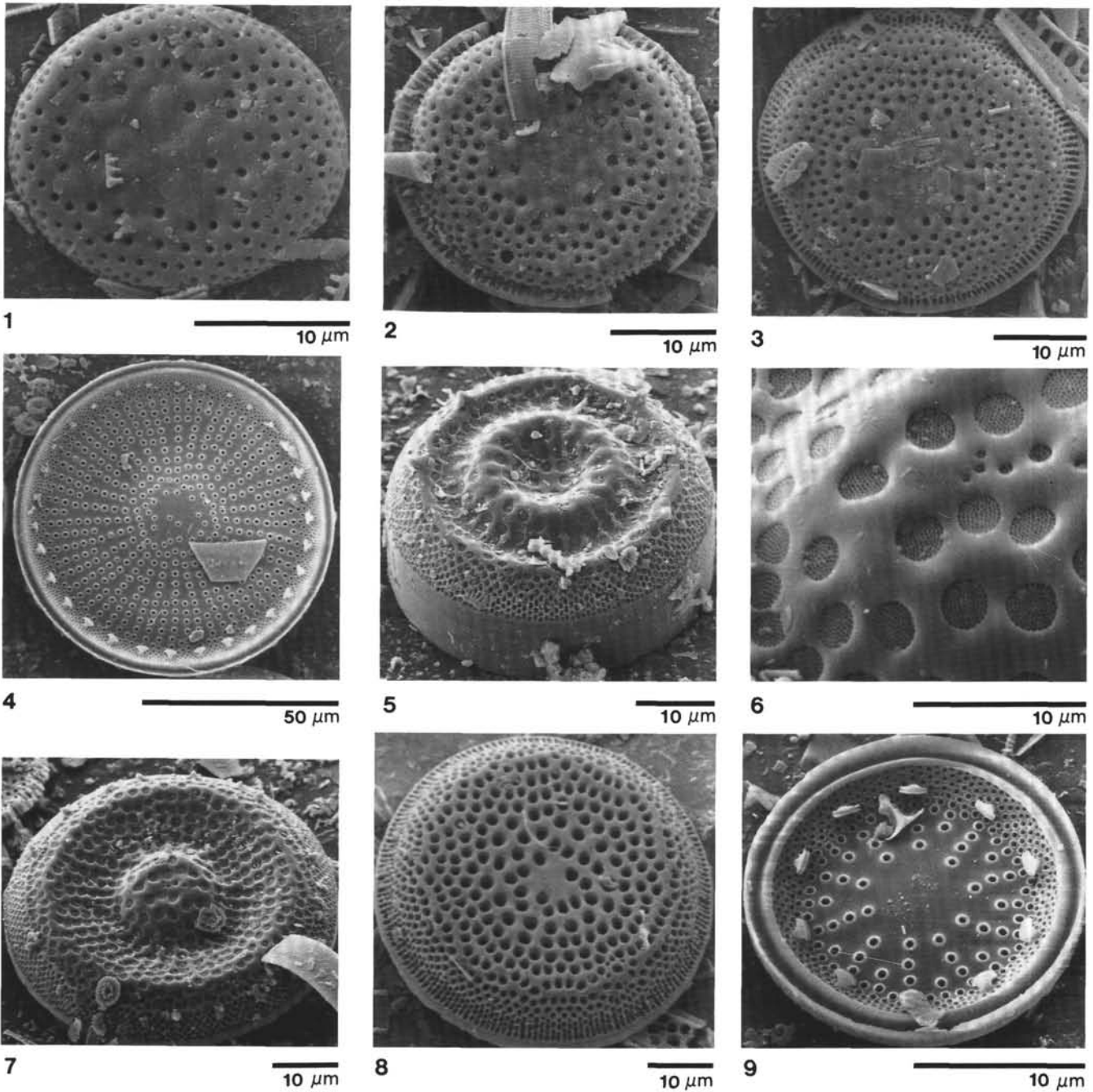


Plate 3. (Scale bar = 10 μm , unless otherwise indicated) 1-3. *Actinocyclus ingens* var. *ovalis* var. nov., SEM, external view of valve face, Sample 113-689B-3H-5, 28-29 cm. 4-7. *Actinocyclus ingens* var. *nodus* (Whiting and Schrader) stat. nov., SEM, (4) internal view of valve face (bar = 50 μm); (5, 7) oblique view of external valve; (6) detail of specimen in (7), central portion of valve face with external cribra, Sample 113-689B-6H-5, 28-29 cm. 8, 9. *Actinocyclus ingens* Rattray, SEM, (8) external view of valve face; (9) internal view of valve face with marginal ring of labiate processes, Sample 113-689B-6H-5, 28-29 cm.

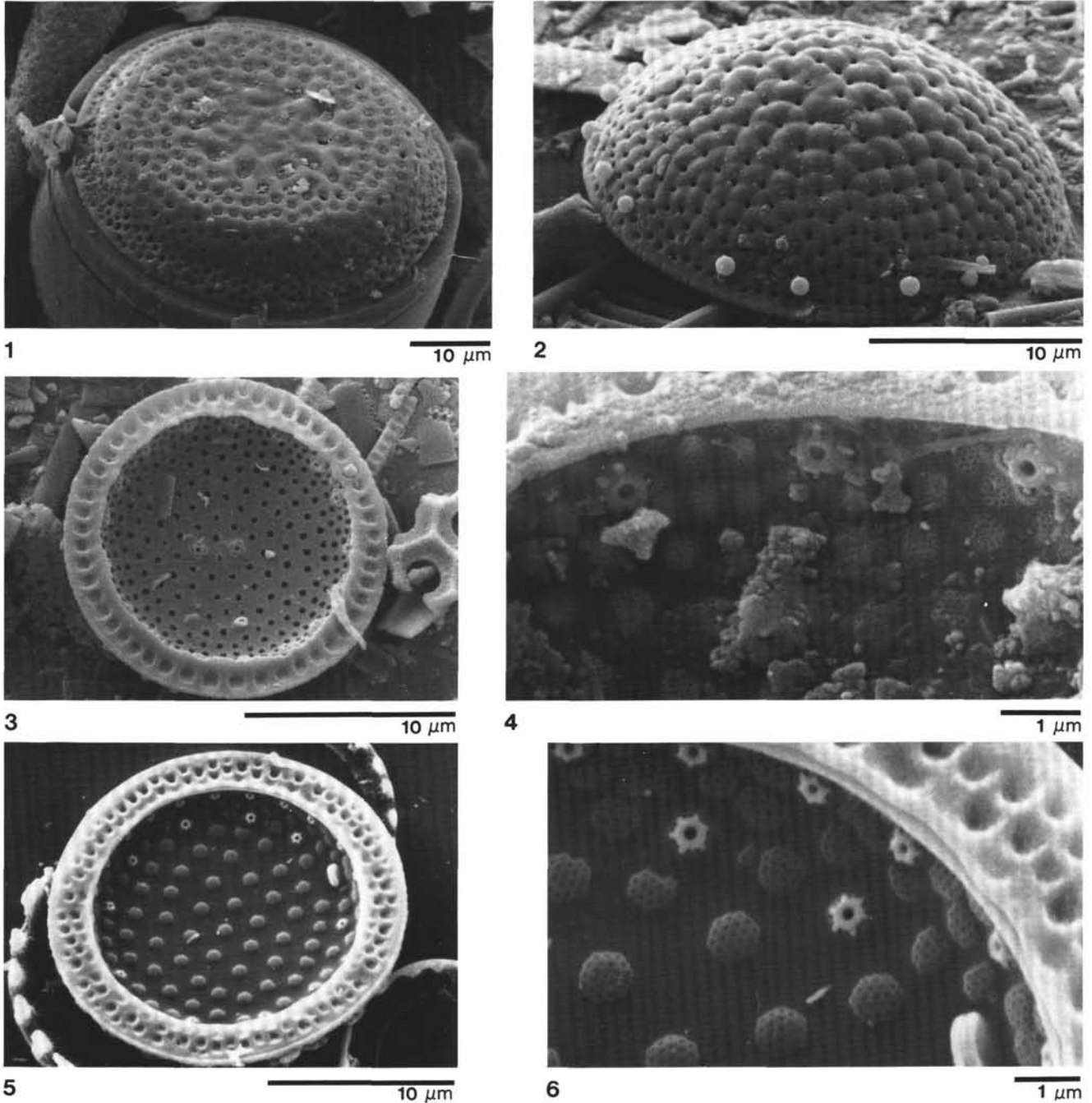


Plate 4. (Scale bar = 10 μm , unless otherwise indicated) 1. *Actinocyclus ingens* Rattray, SEM, external view of frustule, Sample 113-689B-6H-5, 28–29 cm. 2–4. *Thalassiosira convexa* var. *aspinosa* Schrader, SEM, (2) oblique view of valve outside with marginal granules; (3) inside view of valve with central and marginal strutted processes and single labiate process; (4) inside view of marginal part of valve with cribra and strutted processes (bar = 1 μm), Sample 113-689B-3H-2, 114–115 cm. 5, 6. *Thalassiosira fraga* Schrader, SEM, (5) oblique view of valve inside with marginal and submarginal rings of strutted processes and submarginal labiate process; (6) detail showing cribral structure, strutted processes, and labiate process (bar = 1 μm), Sample 113-689B-8H-1, 88–90 cm.

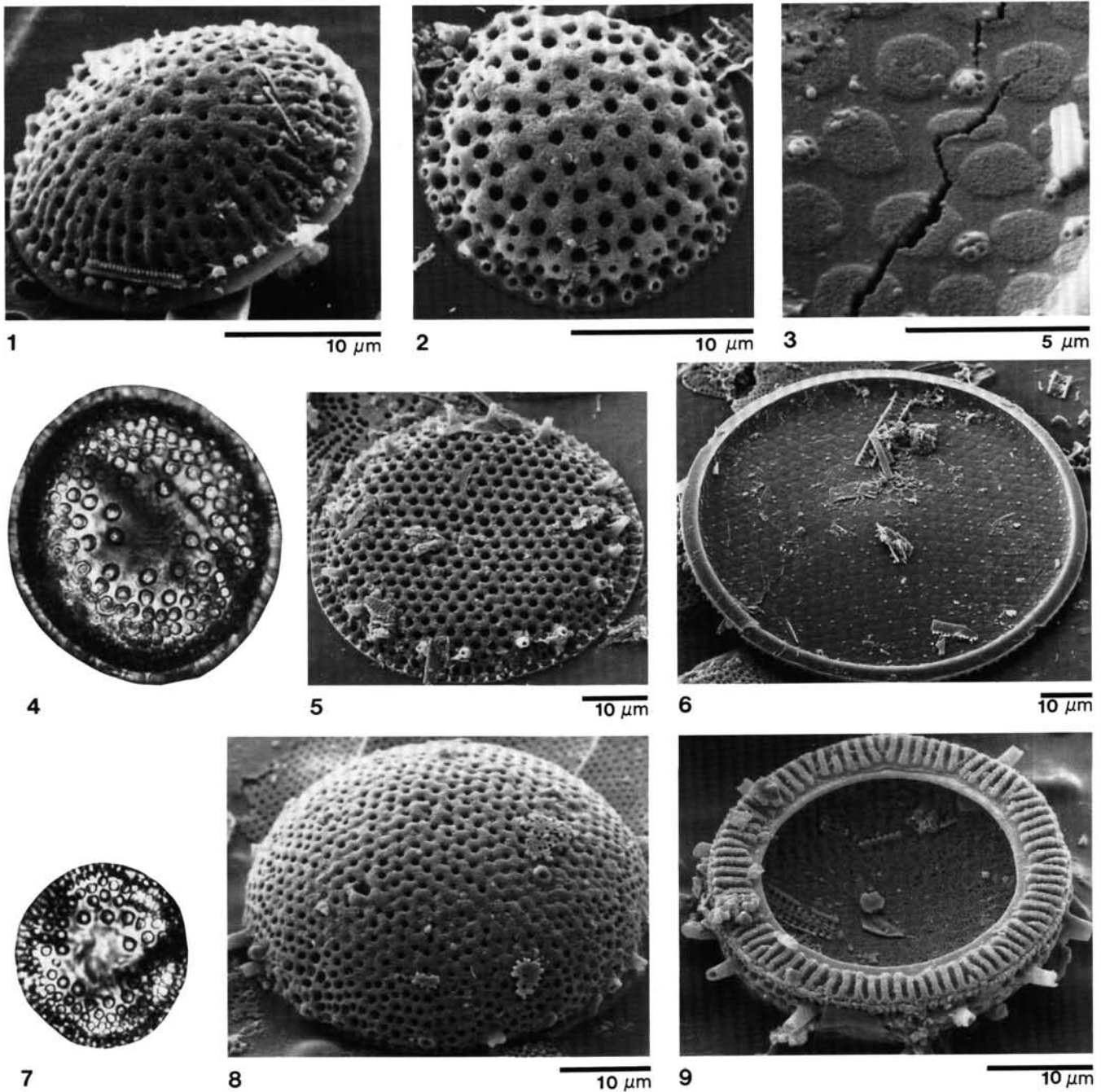


Plate 5. (Scale bar = 10 μm , unless otherwise indicated) 1, 2. *Thalassiosira fraga* Schrader, SEM, view of valve exterior showing outer openings of marginal and submarginal ring of strutted processes, Sample 113-689B-8H-1, 88–90 cm. 3, 5, 6. *Thalassiosira kolbei* (Jousé) comb. nov., SEM, (3) detail of internal cribral structure, strutted processes, and labiate process (bar = 5 μm); (5) oblique view of valve exterior with marginal ring of occluded processes; (6) oblique view of well preserved valve interior, Sample 113-689B-2H-3, 28–29 cm. 4, 7. *Actinocyclus ingens* var. *ovalis* var. nov., Sample 113-689B-3H-5, 28–29 cm, LM, $\times 1500$. 8, 9. *Thalassiosira spumellaroides* Schrader, SEM, (8) oblique view of valve exterior showing valve margin with elongated external tubes; (9) oblique view of valve interior showing cribral rows, structure of basal part of valve margin and external tubes, Sample 113-690B-7H-1, 28–29 cm.

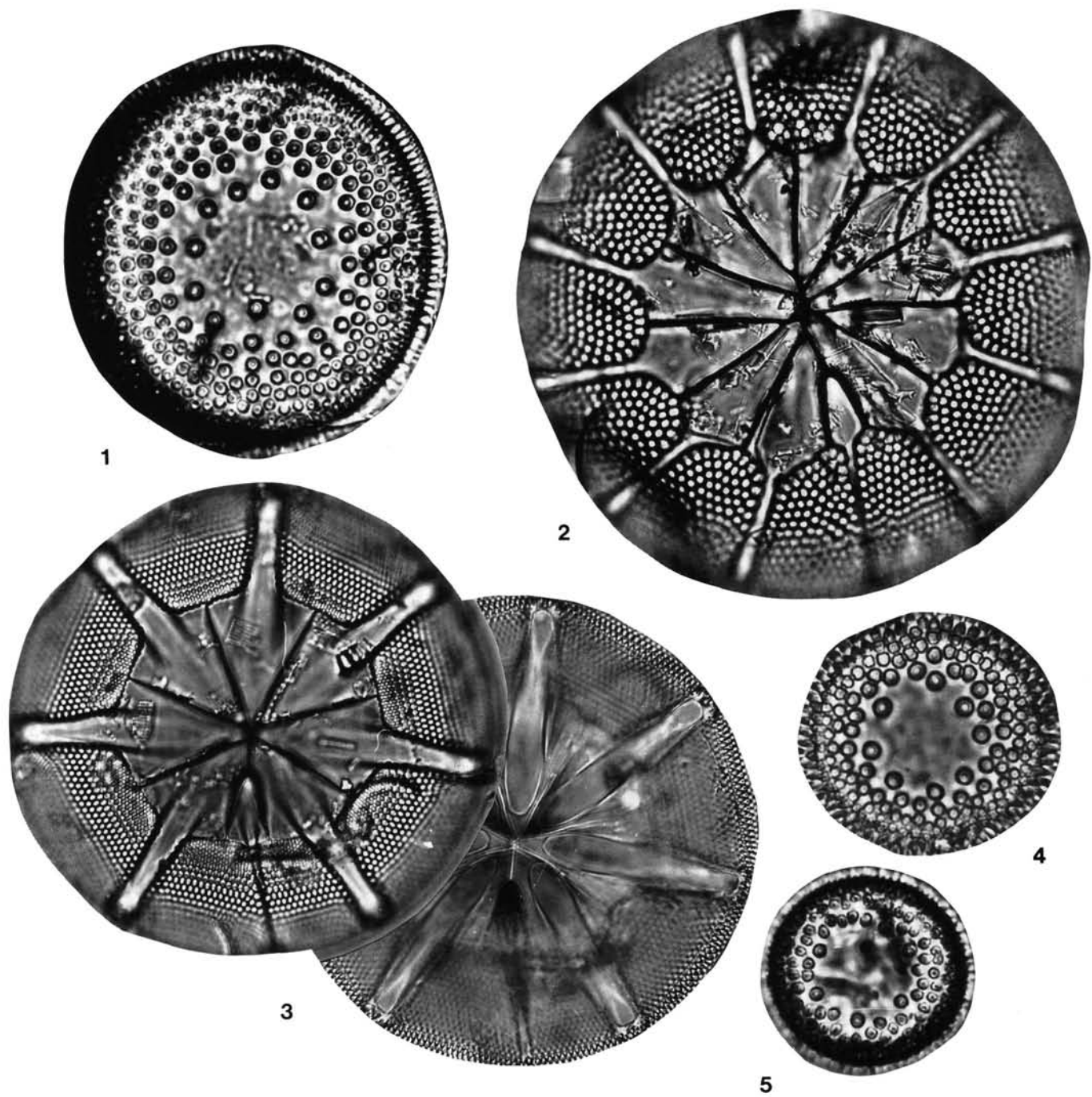


Plate 6. (All specimens at $\times 1500$ unless otherwise indicated) 1, 4, 5. *Actinocyclus ingens* var. *ovalis* var. nov., (1) holotype, Sample 113-689B-3H-5, 28-29 cm. 2. *Asteromphalus kennettii* sp. nov., Sample 113-689B-4H-1, 143-145 cm, $\times 915$. 3. *Asteromphalus inaequabilis* sp. nov., Sample 113-689B-7H-6, 145-147 cm, $\times 915$.