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Exceptionally well-preserved early Oligocene diatoms from glacial sediments of Prydz Bay, East Antarctica

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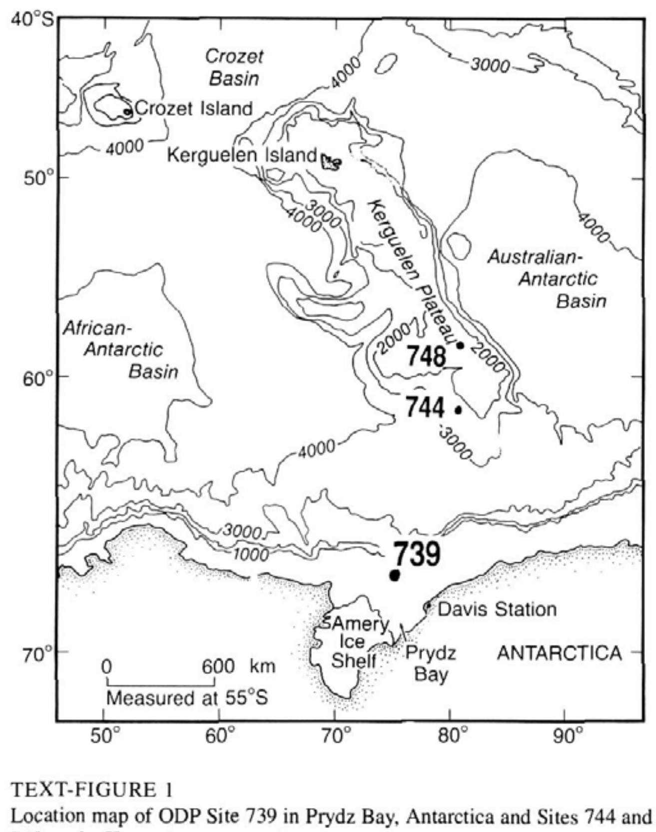
ABSTRACT: An exceptionally well-preserved early Oligocene diatom assemblage is documented and illustrated from the internal sediment of a gastropod shell, which was collected from glacial sediments recovered at Ocean Drilling Program Site 739 on the continental shelf in Prydz Bay, Antarctica. The diatoms were deposited between 35.9 and 34.8 Ma according to diatom and calcareous nannofossil stratigraphy, apparently soon after a period of major ice sheet advance across the Prydz Bay continental shelf. The diatom assemblage is neritic in character, but it can readily be correlated with open ocean assemblages from the Southern Ocean as well as with similar material recovered from the CIROS-1 drillhole in the Ross Sea.

INTRODUCTION

Early Oligocene diatoms were recovered from a 13m-thick sequence of glacial sediments in Cores 739C-25R through -39R of Ocean Drilling Program Leg 119, Hole 739C in Prydz Bay, Antarctica (Baldauf and Barron 1991; Barron et al. 1991a). Site 739 is located about 30km landward from the shelf edge in Prydz Bay where seismic stratigraphy indicated there was a transition from generally flat-lying seismic reflectors that characterize the middle parts of the Prydz Bay continental shelf to prograding reflectors that are typical of the outer part of the shelf (text-fig. 1) (Cooper et al. 1991). Site 739 was chosen in hopes that this transition of seismic reflector character would represent a transition from nonglacial to glacial sediments (Barron et al. 1989). A 486.8m-thick section of glacial diamictite was cored at Site 739 without reaching preglacial sediments.

The lower Oligocene diatom assemblage recovered from Cores 739C-25R through -39R closely resembles Assemblage Zone B of Harwood (1989) which was recovered from the CIROS-1 drill hole in the western McMurdo Sound area of west Antarctica (Baldauf and Barron 1991; D. M. Harwood, pers. comm., 1989). Harwood et al. (1989) assigned an age of 36.0-34.5 Ma to Assemblage Zone B within the *Rhizosolenia oligocaenica* Zone. Calcareous nannofossil stratigraphy from Site 739 suggest a similar age for the diatom assemblage, although calcareous nannofossils are very sporadic, show very low diversity and may be reworked (Wei and Thierstein 1991). The presence of the calcareous nannofossil *Isthmolithus recurvus* in Samples 119- 739C-28R-1, 30-32cm and 119-739C-30R-1, 108-110cm suggests a late Eocene to early Oligocene age (38.8-34.8 Ma) within the *Isthmolithus recurvus* Zone to *Blackities spinosus* Zone (Wei and Thierstein 1991). Dinoflagellate assemblages recovered from Cores 119-739C-41R, 119-739C-47R, and 119-739C-51R (331, 386 and 426 meters below seafloor [mbsf], respectively) belong to a provincial Antarctic flora of Eocene to early Oligocene age according to Truswell (1991) and also support the diatom and calcareous nannofossil stratigraphies.

Because the early Oligocene age suggested by these microfossils was in conflict with a late Oligocene to early Miocene age obtained from strontium isotope studies on molluscan shells (Thierstein et al. 1991), one of the gastropod (*Amauropsis* sp.) shells from Sample 119-739C-30R-1, 108cm was broken open and its sediment contents were examined for diatoms (Barron et al. 1991a). Exceptionally well-preserved early Oligocene diatoms including a 400μm-long delicate frustule of *Sceptroneis lingulatus* and frustules of *Pyxilla* joined by their apical spines were obtained from the internal sediment of the gastropod shell. Barron et al. (1991a) argued that these diatoms were probably not reworked into younger sediments. Furthermore, the absence of such distinctive diatoms as *Cymatosira biharensis, Azpeitia oligocenica, Asteromphalus symmetricus, Stephanopyxis spino-*



TEXT-FIGURE 1
Location map of ODP Site 739 in Prydz Bay, Antarctica and Sites 744 and 748 on the Kerguelen Plateau. Contours in meters.

TABLE 1
Diatom taxon frequency in Sample 119-739C-30R-1, 108cm. * = not observed in the frequency count but observed in the sample; + = represents less than 1% of the diatom assemblage.

TAXA	COUNT	%
Actinocyclus? cf. *A. octonarius*	*	+
Actinoptychus senarius	4	1
Anaulus sp.	*	+
Asterolampra gradiata	6	2
Asterolampra punctifera	*	+
Azpeitia oligocenica	1	+
Baxteriopsis brunii	1	+
Chaetoceros panduraeformis	*	+
Chaetoceros spp.	*	+
Chaetoceros sp. (oval form) (pl. 16, figs. 3, 4)	1	+
Coscinodiscus hajosiae	*	+
Coscinodiscus obscurus	*	+
Coscinodiscus oculusiridis	2	+
Coscinodiscus sp. A	*	+
Coscinodiscus? sp. B	3	1
Dicladia trinodis	*	+
Dicladia sp.	10	3
Hemiaulus caracteristicus	5	1
Hemiaulus danicus	*	+
Hemiaulus dissimilis?	*	+
Hemiaulus incisus	5	1
Hemiaulus polycistinorum	46	12
Hemiaulus polymorphus	5	1
Hemiaulus sp. A	2	+
Hemiaulus spp.	4	1
Kannoa hastata	16	4
Kannoa japonica	17	4
Kisseleviella carina	7	2
Liradiscus ovalis	6	2
Maluina sp.	*	+
Muelleriopsis limbata	*	+
Navicula udinsevii	3	1
Navicula sp. (length 55µm)	*	+
Odontella fimbriata	2	+
O. sp. (cf. *O. fimbriata* with unequal processes)	1	+
Odontella sp.	1	+
Pseudotriceratium adlerii	4	1
Pseudotriceratium radiosoreticulatum	8	2
Pterotheca clavata	1	+
Pterotheca sp. D of Harwood	*	+
Pterotheca spp.	3	1
Pyxilla reticulata	4	1
Pyxilla spp.	2	+
Rhizosolenia oligocaenica	2	+
Rhizosolenia sp. C	*	+
Rhizosolenia sp. (tip of horn)	30	8
Rouxia granda	4	1
Rutilaria sp.	*	+
Sceptroneis lingulatus	24	6
Sceptroneis pesplanus	1	+
Sceptroneis talwanii	12	3
Sceptroneis spp.	1	+
Skeletonema barbadensis	7	2
Sphynctolethus pacificus	*	+
Stellarima stellaris	3	1
Stephanopyxis grunowii	11	3
Stephanopyxis oamaruensis	*	+
Stephanopyxis splendidus	3	1
Stephanopyxis superba	14	4
Stephanopyxis turris	29	8
Stephanopyxis sp. (resting spore)	2	+
Stephanopyxis spp.	31	8
Stictodiscus kittonianus	1	+
Thalassiosira? cf. *T. manifesta*	*	+
Thalassiosira? *mediaconvexa*	*	+
Triceratium polymorphus	*	+
Trinacria excavata	*	+
Tumulopsis fogedi	*	+
unknown centric diatom (very small)	28	7
Xanthiopyxis sp?	*	+
Resting spore A	8	2
Resting spore B	*	+
Resting spore C	*	+
Total	379	100

sissima, S. vasta, Synedra jouseana, Rocella vigilans and *Lisitzinia ornata*, which have been documented in late Oligocene assemblages from throughout the Southern Ocean (Gombos and Ciesielski 1983; Baldauf and Barron 1991) and on the Antarctic continental shelf (Harwood 1986, 1989), argues against a late Oligocene age.

The strontium isotope ages were concluded to be in error, possibly due to abnormally high concentrations of strontium measured in pore waters of the sediments and which were associated with large quantities of fresh igneous and metamorphic debris found in the glacial sediments (Barron et al. 1991a).

Further study of the diatoms from the gastropod mold was warranted by their excellent state of preservation and their importance in dating glacial sediments which imply an extensive early Oligocene ice sheet in Prydz Bay, Antarctica, (Barron et al. 1991b). Diatoms in this important assemblage are documented, illustrated and tabulated in the present paper. Some new and taxonomically interesting taxa are treated in detail in a companion paper by Mahood et al. (in press).

METHODS AND MATERIALS

The sediment from ODP Leg 119 Hole 739C-30R-1, 108cm, was processed for light (LM) and scanning electron (SEM) microscopy by the Van der Werff (1955) hydrogen peroxide method. Strewn slides were prepared for light microscopy using the mounting medium Hyrax. Forty strewn slides (some with 15mm-diameter circular cover slides and others with rectangular cover slides 22 × 30mm) were examined in entirety using either a Leitz Ortholux II or an Olympus IMT at ×500 and ×1250. Light microscope photography was also completed using these microscopes. Four hundred fifty diatom valves were arranged on four SEM stubs for examination and photography using a Cambridge 250 Mark II SEM at the U.S. Geological Survey in Menlo Park and a Hitachi S520 at the California Academy of Sciences.

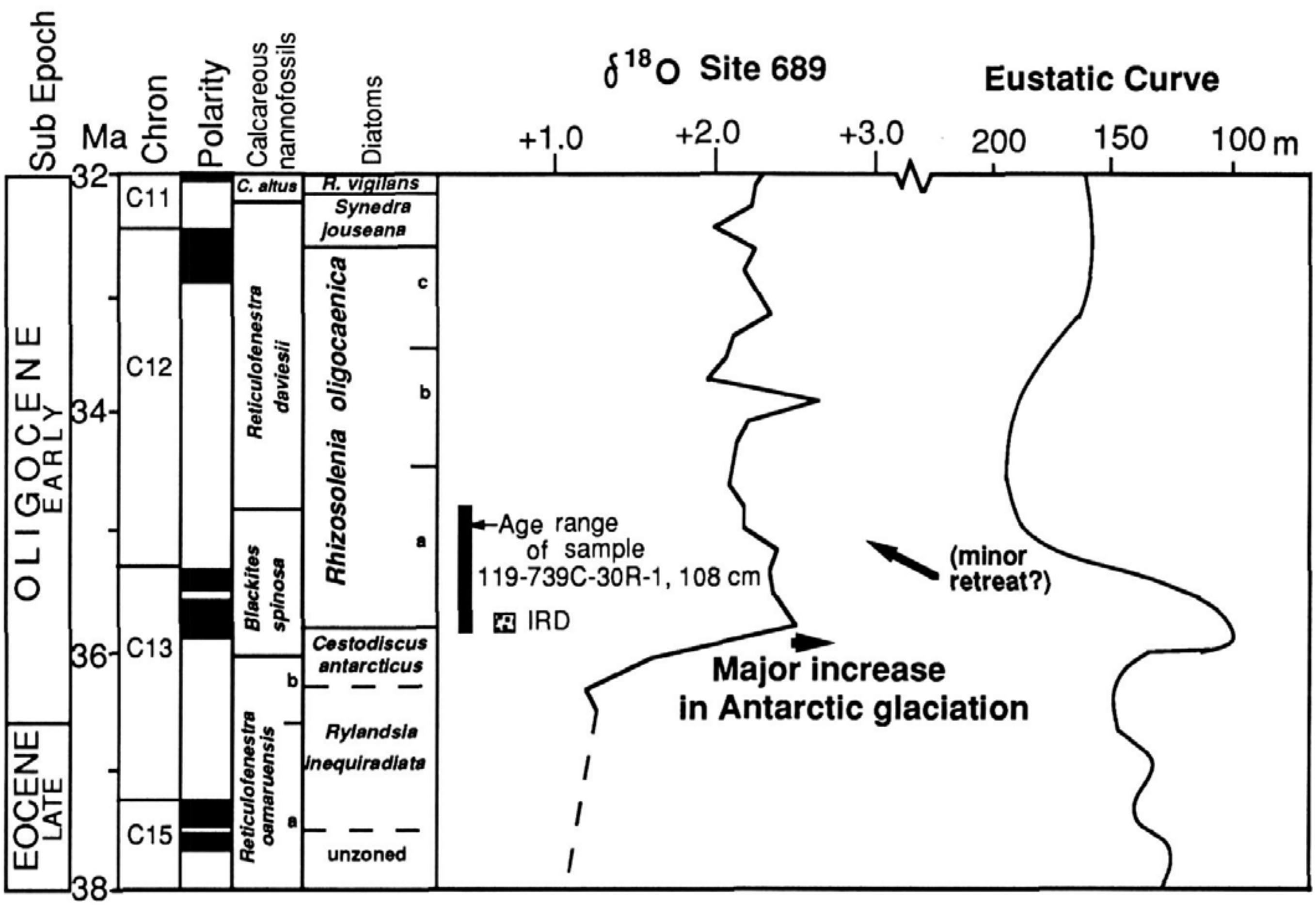
RESULTS

Forty strewn slides and four picked and mounted SEM stubs were examined. The diatom taxa encountered during examination are listed and discussed in Appendix 1. The frequency of their occurrence in a smear slide count of 379 individuals is presented in table 1. Many of these taxa are illustrated in plates 1-7 as well as in Mahood et al. (in press).

Sixty-four diatom taxa including resting spore forms have been recorded from the gastropod mold sample, but at least 10 other taxa are present. The relatively high numbers of *Hemiaulus, Sceptroneis* and *Stephanopyxis* forms are typical for an outer shelf to upper slope assemblage, and resting spores are also fairly common (table 1). Truly benthic taxa (*Navicula* spp., *Rutilaria* spp.) are relatively rare. Planktonic diatom taxa such as *Asterolampra, Azpeitia, Coscinodiscus, Pyxilla, Rhizosolenia* and *Triceratium* are relatively numerous, so that comparison with other early Oligocene diatom assemblages from the Southern Ocean is possible.

DIATOM BIOSTRATIGRAPHY

The diatom assemblage of Sample 739C-30R-1, 108cm correlates best with the upper part of Harwood's (1989) Assemblage Zone B from the Ross Sea based on the presence of *Triceratium polymorphus* (= *T. hebetatum* of Harwood 1989), *Asterolampra punctifera, Cotyledon fogedi* (= *Tumulopsis fogedi* of this



TEXT-FIGURE 2
Correlation of the diatom assemblage of Sample 119-739C- 30R-1, 108cm to geologic time, the oxygen isotope curve for ODP Site 689 of Kennett and Stott (1990), and the eustatic curve of Haq et al. (1987). Calcareous nannofossil zones after Wei and Thierstein (1991); diatom zones after Harwood and Maruyama (in press) for the Oliogcene and after Fenner (1985) for the late Eocene; geologic time scale and magnetic polarity scale after Berggren et al. (1985); IRD = interval of ice-rafted detritus at Sites 744 and 748.

report), *Rhizosolenia oligocaenica, Sceptroneis lingulatus, Stephanopyxis splendidus* and *Pyxilla reticulata*. Harwood et al. (1989) correlate this interval with the *Rhizosolenia oligocaenica* Zone and assign an age of 36.0-34.5 Ma to this interval, which is truncated by an overlying unconformity in the CIROS-1 drillhole. As mentioned earlier, the presence of the calcareous nannofossil *Isthmolithus recurvus* in Sample 119-739C-30R-1, 108-110cm would seem to further constrain the age of this interval to no younger than 34.8 Ma (Wei and Thierstein 1991).

Early Oligocene provincialism (Fenner 1985; Harwood 1989, 1991; Baldauf 1992) makes it difficult to correlate the Prydz Bay diatom assemblage with more oceanic diatom assemblages recorded from the lower Oligocene of the Southern Ocean (Baldauf and Barron 1991). In referring to Gombos and Ciesielski's (1983) South Atlantic DSDP Site 511, the diatom assemblage of Sample 119-739C-30R-1, 108cm correlates best with the lower Oligocene interval of Samples 71-511-12-1, 11-13cm through -13-1, 6-8cm based on the restricted occurrences of *T. polymorphus* (recorded as *T. macroporum* [concave form]), *R. oligocaenica* (recorded as *R. gravida*), *Asterolampra gradiata, Baxteriopsis brunii* (recorded as *Baxteria brunii*) and *S. splendidus* (recorded as *Thalassiosira hydra*) (Gombos and Ciesielski 1983). This interval is assigned to the *Melosira architecturalis* Zone through lower *Brightwellia spiralis* Zone by Gombos and Ciesielski (1983) at DSDP Site 511 but is equivalent to the lower portion of the *Rhizosolenia oligocaenica* Zone.

The assemblage correlates with Samples 748B-13H-6, 116-118cm; -13H,CC and -14H-1, 52-54cm of Harwood and Maruyama (1992). Of these three, correlation is best with Sample -13H-6 based on the presence of *Rouxia granda, Sceptroneis grunowii, S. pesplanus* and the isolated occurrence of *S. lingulatus* in that sample. It is thus correlative to Subzone a of the *Rhizosolenia oligocaenica* Zone of Harwood and Maruyama (1992) to which they assign an age of 35.5-34.5 Ma. Barron et al. (1991a), however, place the base of this subzone at 35.9 Ma based on correlation with magnetostratigraphy at nearby Site 744. Other taxa supportive of this correlation are *Triceratium polymorphus* and *Asterolampra gradiata*. Such a correlation suggests that the Prydz Bay assemblage of Sample 119-739C-30R- 1, 108cm was deposited immediately following the deposition of a pulse of ice-rafted detritus (IRD), which was documented by Shipboard Scientific Party (1989a) between Samples 120-748B-14H-1, 137-150cm and -14H-2, 0-24cm. Because a 1.5 per mil increase in the δ^{18}O of benthic foraminifers was measured by Zachos et al. (1992) within the same IRD

horizon, the Prydz Bay sample seemingly was deposited just after the oxygen isotope event.

Subsequent study by the senior author of Baldauf and Barron's (1991) samples from ODP Site 744 on the southern Kerguelen Plateau reveals that Sample 119-739C-30R-1, 108cm is most similar to Sample 119-744A-16-6, 60-62cm based on the co-occurrence of *Asterolampra gradiata, A. punctifera, R. oligocaenica* and *T. polymorphus*. As at Site 748, IRD was found immediately below in Section 744A-16H-7 (Shipboard Scientific Party 1989b). At Site 744 a similar major $\delta^{18}O$ increase of 1.15 per mil was recorded by Barrera and Huber (1991) in benthic foraminifers between Samples 119-744A-18H-2, 95cm and -16-6, 95cm (150.07-145.67mbsf), which is just below the diatom assemblage that correlates best with that of the gastropod mold. This earliest Oligocene isotopic event, recorded at Sites 748 and 744, is recognized globally (Kennett and Stott 1990) and presumably signals a major growth of an ice sheet in East Antarctica (Barron et al. 1991b). The calcareous nannofossil *I. recurvus* suggests a minimum age of 34.8 Ma (*Blackities spinosus* Zone), whereas the diatom *Rhizosolenia oligocaenica* argues for a maximum age of 35.9 Ma (*R. oligocaenica* Zone, Subzone a). Thus, Sample 119-739C-30R-1, 108cm appears to have been deposited soon after this period of major ice sheet growth in the earliest Oligocene (ca. 35.9 to 34.8 Ma), perhaps during a period of minor retreat or stability in the ice sheet (Barron et al. 1991b; Hambrey et al. 1991) (text-fig. 2).

ENVIRONMENT OF DEPOSITION

The gastropod shell of Sample 119-739C-30R-1, 108cm was taken from a weakly to well stratified diamictite, which is interpreted by Hambrey et al. (1991) to represent proximal glaciomarine sediment subject to periodic strong current reworking. Based on seismic stratigraphy, the unit containing the early Oligocene diatoms consists of sediments deposited on the upper paleo-continental slope between the continental shelf break and a level 200m down-slope (Cooper et al. 1991). With the grounding point of the ice shelf at the shelf break, this implies a free seawater connection beneath the floating ice shelf to the points of deposition. The presence of well-preserved benthic taxa such as *Navicula* would seem to imply that at least parts of the shelf were free from ice cover during parts of the year. Thus, deposition on the upper slope seaward of an ice sheet is envisioned. Presumably, the sediment entered the shell shortly after the death of the gastropod, and the shell provided some protection from bioturbational and other mechanical reworking of the sediment which would normally cause abrasion, fragmentation and dissolution of the diatom frustules.

SUMMARY COMMENTS

An exceptionally well-preserved diatom assemblage containing over 65 different taxa is documented and illustrated from glacial sediments recovered from ODP Site 739 on the outer continental shelf in Prydz Bay, Antarctica. The neritic assemblage correlates with Harwood's (1989) Assemblage Zone B from the CIROS-1 drillhole in the Ross Sea and with Harwood and Maruyama's (1992) Subzone a of the *Rhizosolenia oligocaenica* Zone and is earliest Oligocene in age, approximately 35.9-34.8 Ma. It is suggested that the assemblage was deposited soon after a major expansion of the ice sheet in East Antarctica, possibly during a minor phase of retreat of that ice sheet. The excellent preservational state of the diatom assemblage is probably due to the protection from mechanical and bioturbational abrasion and subsequent dissolution which was provided by a gastropod shell.

ACKNOWLEDGMENTS

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PLATE I

1a,b *Coscinodiscus oculusiridis* Ehrenberg. 1a, diameter 274μm; 1b, center.

2 *Coscinodiscus* sp. A. compare with *Aulacodiscus* (radius 63μm).

3 *Coscinodiscus hajosiae* Fenner (diameter 82μm).

4, 5 *Stellarima stellaris* (Roper) Hasle and Sims. 4, diameter 45μm; 5, diameter 27μm.

6 *Azpeitia oligocenica* (Jousé) Sims (diameter 45μm).

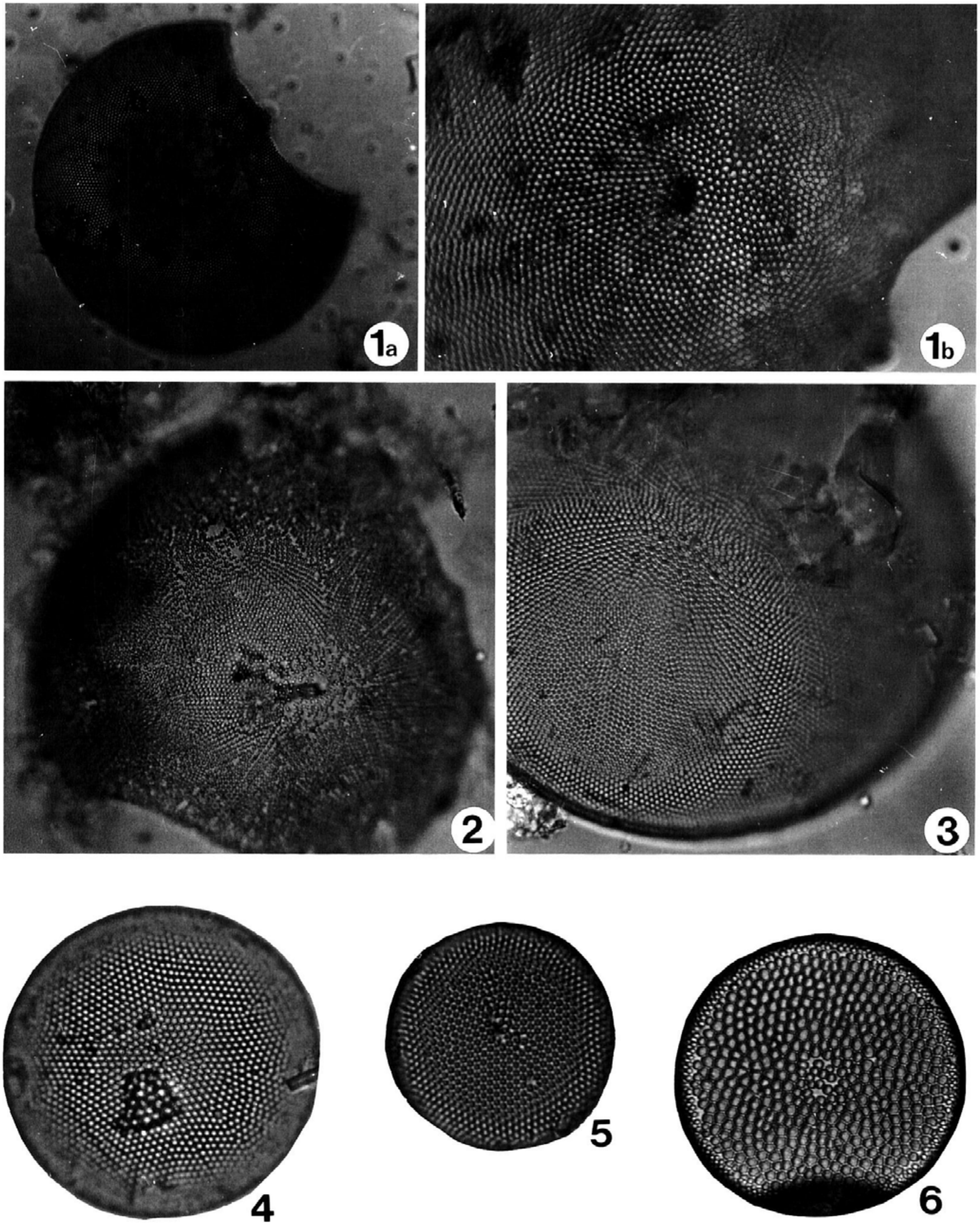
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PLATE 2

1, 2 *Stephanopyxis grunowii* Grove and Sturt in Schmidt. 1a, b, c, low to high focus, diameter 67µm; 2, diameter 37.6µm.

3, 4 *Stephanopyxis superba* (Greville) Grunow. 3, diameter 27µm; 4, diameter 23µm.

5 *Stephanopyxis oamaruensis* Hajós (diameter 69.5µm).

6 *Actinoptychus senarius* (Ehrenberg) Ehrenberg (diameter 45µm).

7, 9, 10 *Tumulopsis fogedi* Hendey. 7, 10, ornamented valves, diameters 31.2µm and 31.2µm; 9, plain valve, diameter 55.3µm.

8 *Stictodiscus kittonianus* Greville (diameter 42µm).

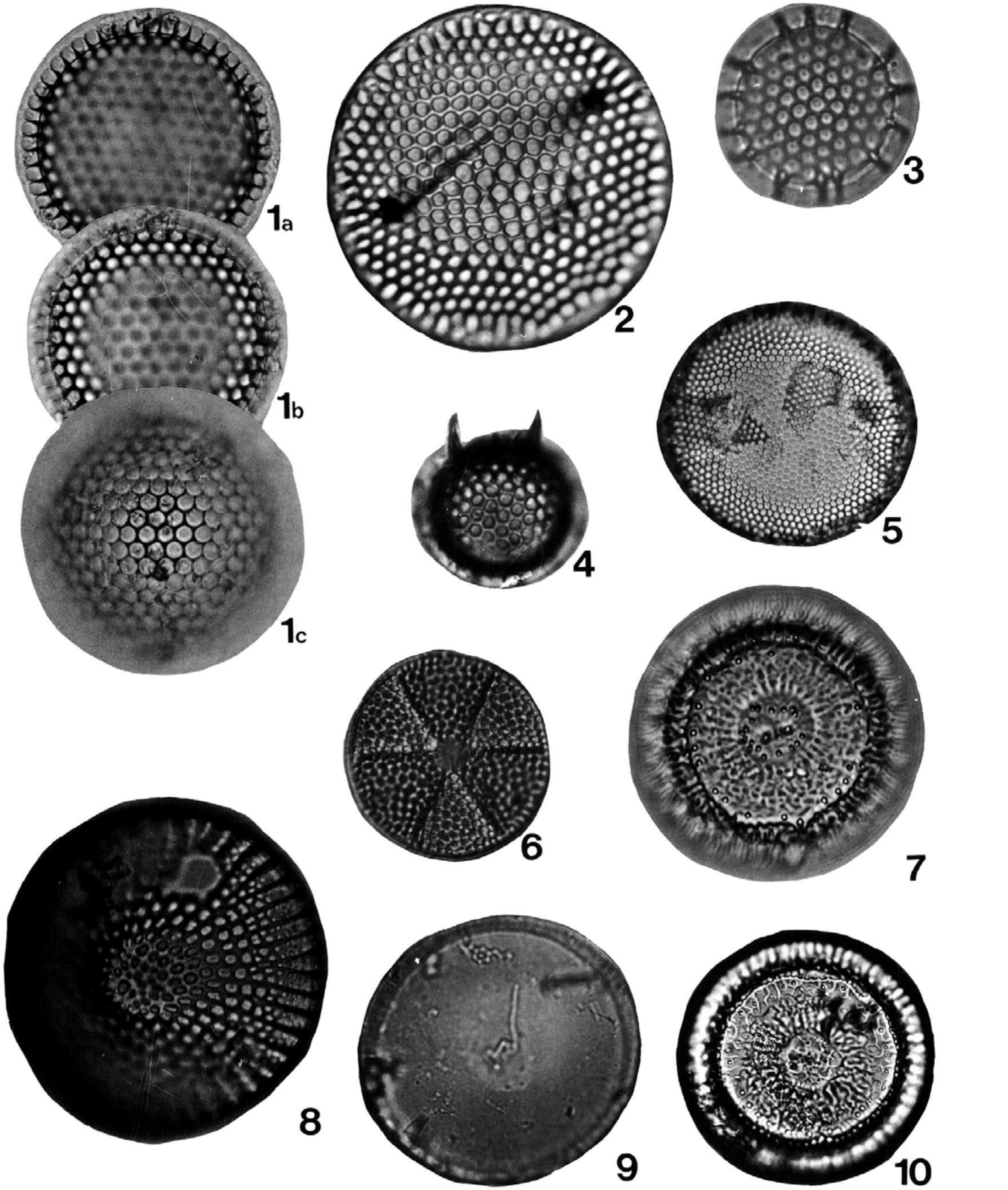
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PLATE 3

1, 2a,b *Pseudotriceratium adlerii* Mahood. 1, base 110μm; 2, low and high focus, base 95μm.

3 *Trinacria excavata* Heiberg (base 75μm).

4 a,b *Pseudotriceratium* sp. (low and high focus, base 41μm).

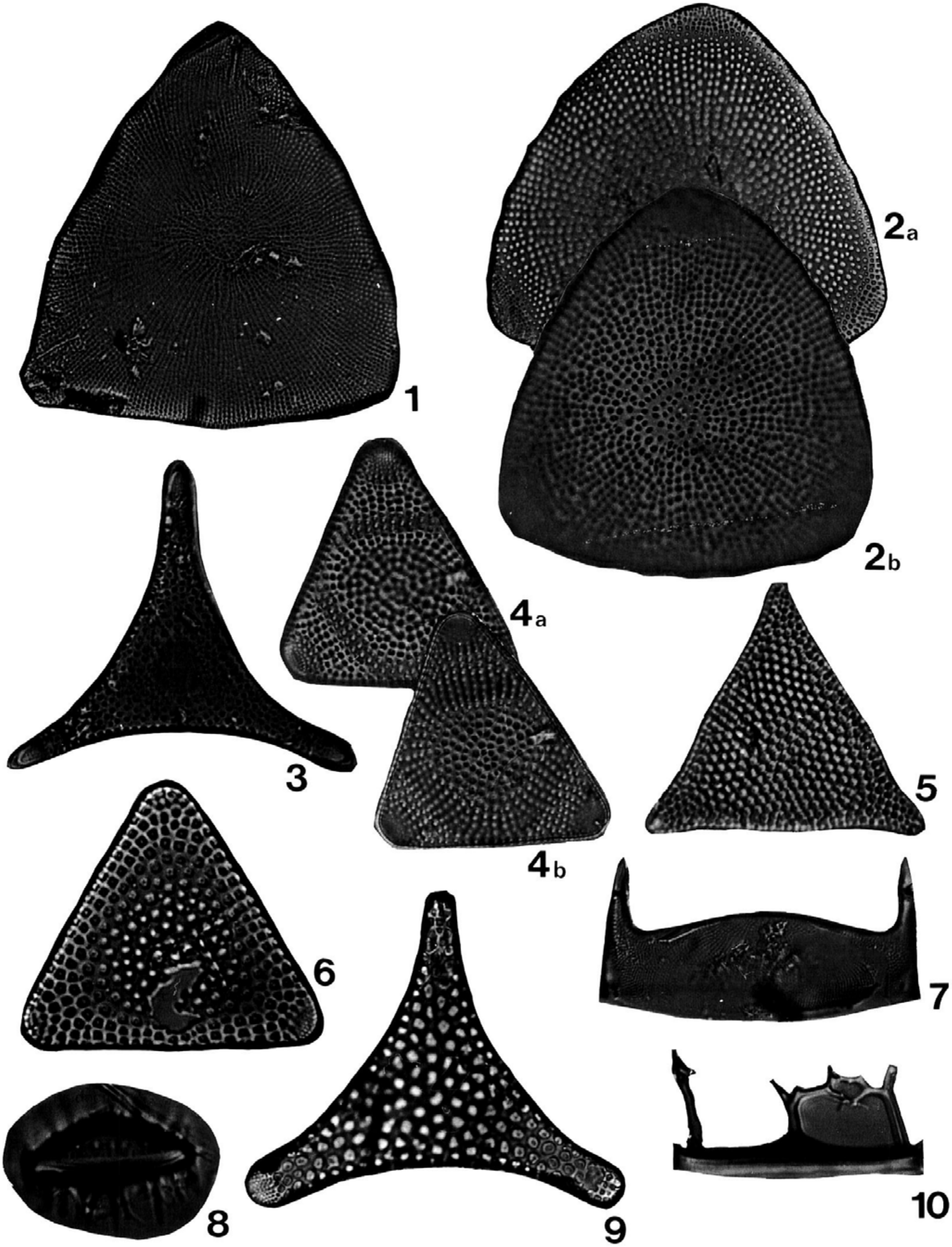
5 *Pseudotriceratium radiosoreticulatum* Grunow in Van Heurck (base 38μm).

6, 9 *Triceratium polymorphus* Harwood and Maruyama, in press. 6, base 40μm; 9, base 56μm.

7 *Hemiaulus* sp. A (width 24μm).

8 *Dicladia* sp. (width 21μm).

10 *Dicladia trinodis* Hanna (width 55μm).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APPENDIX 1
List and remarks on diatom taxa

Actinocyclus*? cf. *A. octonarius Ehrenberg sensu Hajós 1976, p. 827, pl. 9, fig. 4.

Actinoptychus senarius (Ehrenberg) Ehrenberg
Plate 2, figure 6

Remarks: Both typical forms and forms with quadrate-shaped valves were observed.

***Anaulus* sp.**
Plate 4, figure 7

Remarks: Compare with figure 534 (*Anaulus mediterraneus* Grunow) in Hustedt 1930, v. 1, p. 893.

Asterolampra gradiata Gombos in Gombos and Ciesielski 1983, p. 606, pl. 1, figs. 4-6.
Plate 4, figure 10

Asterolampra punctifera (Grove) Hanna; Gombos and Ciesielski 1983, p. 600, pl. 2, figs. 4-8, pl. 5, figs. 8-10; Harwood 1989, p. 77, pl. 5, figs. 1, 2.
Plate 4, figure 13

Azpeitia oligocenica (Jousé) Sims in Sims et al. 1989, p. 302, pl. 2, figs. 1-3, pl. 3, figs. 8, 9. As *Coscinodiscus oligocenicus* Jousé in Fenner 1978, p. 515, pl. 4, figs. 5-10.
Plate 1, figure 6

Baxteriopsis brunii (van Heurck) Karsten; Fenner 1985, p. 726, figs. 10.7, 10.8. As *Baxteria brunii* van Heurck sensu Gombos and Ciesielski 1983, p. 600, pl. 21, figs. 5-7.
Plate 7, figure 8

Chaetoceros panduraeformis (Pantocsek) Gombos in Fenner 1978, p. 513, pl. 36, figs. 7, 8, 12. As *Xanthiopyxis panduraeformis* Pantocsek, Schrader and Fenner 1976, p. 1003, pl. 45, fig. 7; *Chaetoceros* sp. A sensu Gombos 1976, p. 592, pl. 24, figs. 1-6.
Plate 5, figure 14; plate 6, figures 6, 7

***Chaetoceros* sp.** (oval form)
Plate 6, figures 3, 5

Coscinodiscus hajosiae Fenner 1984, p. 331, pl. 2, fig. 1; Fenner 1985, p. 728, fig. 7.25. As *C. spiralis* Hajós 1976, pl. 7, figs. 1-3.
Plate 1, figure 3

Coscinodiscus obscurus A. Schmidt; Schrader and Fenner 1976, p. 976, pl. 33, fig. 1.

Coscinodiscus oculusiridis Ehrenberg; Harwood 1989, p. 78, pl. 1, fig. 1.
Plate 1, figures 1a, b

***Coscinodiscus* sp.? B**

Remarks: Figured as *Thalassiosira bukryi* (?) Barron by Harwood and Maruyama, 1992, pl. 2, figs. 13-14 (possibly not 15, 16).

Dicladia trinodis Hanna; Harwood 1989, pl. 4, fig. 22.
Plate 3, figure 10

***Dicladia* sp.**
Plate 3, figure 8

Remarks: Compare specimen illustrated in Schrader and Fenner 1976, pl. 45, fig. 16.

***Fenestrella* sp.**
Plate 1, figure 2

Remarks: Refer to Sims (1990); only one specimen observed.

Hemiaulus caracteristicus Hajós 1976, p. 828-829, pl. 15, fig. 10; Gombos and Ciesielski 1983, p. 602, pl. 20, figs. 1-5.
Plate 4, figure 4

Remarks: The delicate mantle of this taxon is described in Mahood et al. (in press) for the first time.

PLATE 4

1 *Odontella* sp. cf. *O. fimbriata* (Greville) Schrader in Schrader and Fenner (form with unequal horns, width 41μm).

2, 3 *Rouxia granda* Schrader in Schrader and Fenner. 2, length 37μm; 3, length 27μm.

4 *Hemiaulus caracteristicus* Hajós (width 55μm).

5 *Odontella* sp. (width between spines 80μm).

6a, b *Odontella fimbriata* (Greville) Schrader in Schrader and Fenner (low and high focus, width 52μm).

7 *Anaulus* sp. (length 26μm).

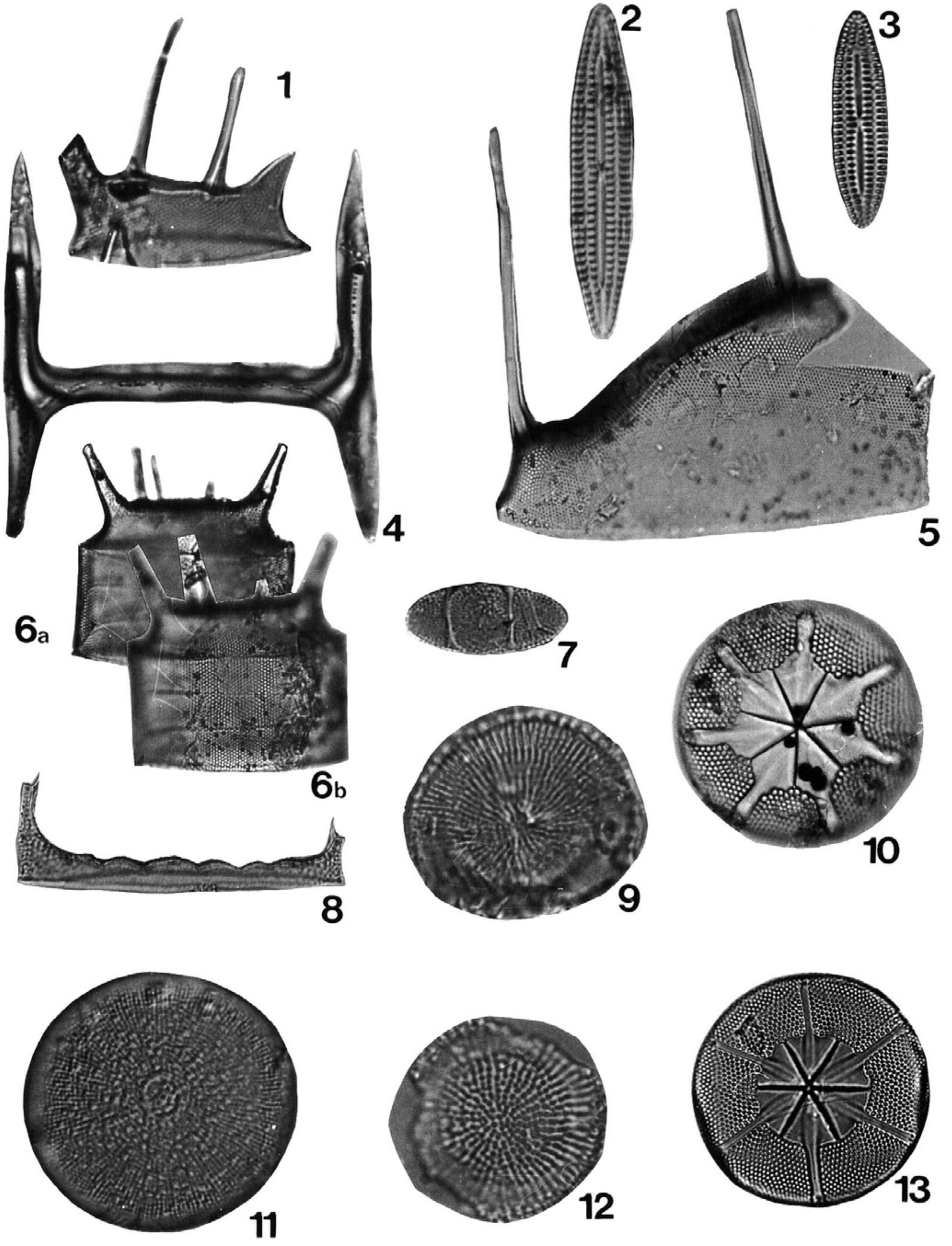
8 *Hemiaulus polycistinorum* Ehrenberg (width 86μm).

9, 12 *Thalassiosira* sp.? cf. *T. mediaconvexa* Schrader in Schrader and Fenner. 9, diameter 22μm; 12, diameter 21μm.

10 *Asterolampra gradiata* Gombos in Gombos and Ciesielski (diameter 62.7μm).

11 *Thalassiosira* sp.? cf. *T. manifesta* Sheshukova-Poretzkaya (diameter 28μm).

13 *Asterolampra punctifera* (Grove) Hanna (diameter 45.5μm).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Hemiaulus danicus Grunow; Harwood 1989, p. 79, pl. 4, fig. 2, pl. 5, fig. 26.
Plate 7, figure 6

Hemiaulus dissimilis? Grove and Sturt; Harwood 1989, p. 79, pl. 4, figs. 3-5, 9, 10; pl. 5, fig. 25.
Plate 7, figure 12

Hemiaulus incisus Hajós 1976, p. 829, pl. 23, figs. 4-9; Gombos and Ciesielski 1983, p. 602, pl. 2, fig. 6; Harwood 1989, pl. 4, fig. 6.
Plate 7, figure 9

Hemiaulus polycistinorum Ehrenberg; Harwood 1989, pl. 4, fig. 13.
Plate 4, figure 8; plate 7, figure 11

Hemiaulus polymorphus Grunow
Plate 7, figure 10

***Hemiaulus* sp. A**
Plate 3, figure 7

Remarks: Only a single specimen was observed.

Kannoa hastata Komura 1980, p. 376, text-fig. 3, pl. 46, figs. 13a, b. As *Ikebia tenuis* (Brun) Akiba 1986, p. 439, pl. 19, figs. 1-5; Harwood 1989, p. 79, pl. 4, fig. 34; *Goniothecium tenue* var. *structuralis* Schrader and Fenner 1976, p. 983, pl. 37, figs. 6, 8, 9.
Plate 5, figures 8, 12; plate 7, figure 5

Remarks: Akiba (1986, p. 440) followed Komura (1980) in suggesting that *Ikebea* may be a resting spore of *Kannoa*, because he observed colonies of *Ikebea* and *Kannoa* valves, with the former being inside, in an early Miocene assemblage from Japan.

Kannoa japonica Komura 1980, p. 374, text-figs. 2, pl. 46, figs. 1-12.
Plate 5, figure 6; plate 7, figure 7

Kisseleviella carina Sheshukova-Poretzkaya; Harwood 1986, p. 86, pl. 6, figs. 12-15; Harwood 1989, p. 79, pl. 4, figs. 35-37.
Plate 5, figure 11

Liradiscus ovalis Greville; Harwood 1989, pl. 3, fig. 36.
Plate 5, figure 15

***Maluina* sp.**
Plate 6, figure 9

Remarks: See Ross and Sims 1987, p. 285 for the definition of this genus.

Muelleriopsis limbata (Ehrenberg) Hendey; Hajós 1976, p. 826, pl. 11, figs. 1- 3.

Navicula udintsevii Schrader and Fenner 1976, p. 991, pl. 22, fig. 33, pl. 24, figs. 1?, 2; Gombos and Ciesielski 1983, p. 602, pl. 21, fig. 8; Harwood and Maruyama, 1992, pl. 2, fig. 12.
Plate 6, figure 10

Odontella fimbriata (Greville) Schrader in Schrader and Fenner 1976, p. 992, pl. 20, fig. 6. As *Biddulphia fimbriata* Greville sensu Hajós 1976, p. 828, pl. 22, figs. 7, 8. As *Odontella aurita* (Lyngbye) Agardh group in Harwood 1989, p. 79, pl. 4, fig. 14.
Plate 4, figures 6a, b

Odontella*. sp. cf. *O. fimbriata (Greville) Schrader in Schrader and Fenner.
Plate 4, figure 1

Remarks: Form with unequal processes.

***Odontella* sp.**
Plate 4, figure 5

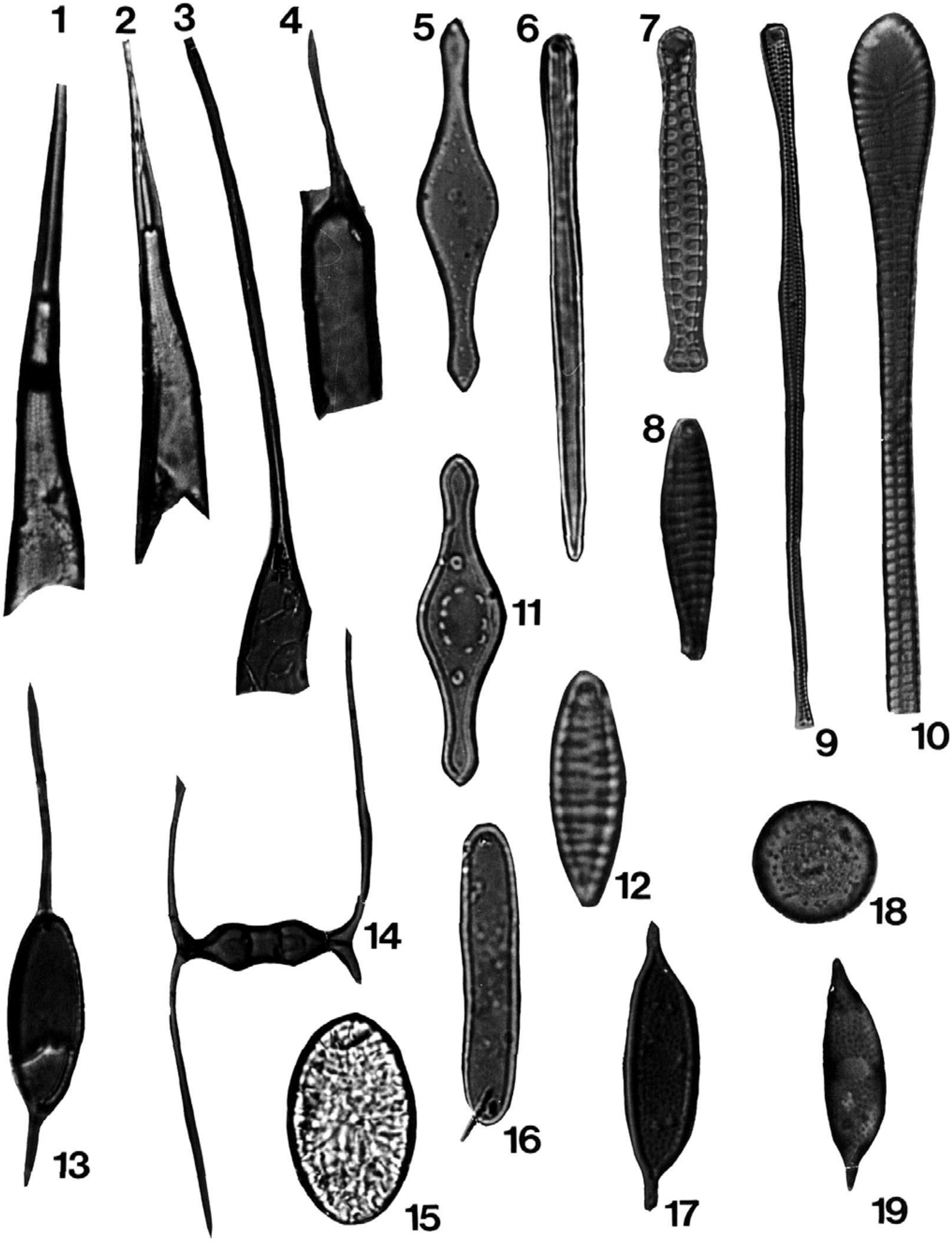
Remarks: Single specimen observed.

Pseudotriceratium adlerii Mahood, n. sp. in Mahood et al., in press; As Genus and species uncertain #3 of Gombos and Ciesielski 1983, p. 606, pl. 25, figs. 8, 9.
Plate 3, figures 1, 2a,b

Remarks: Differs from *Pseudotriceratium* by deep mantle, swollen hypovalve and possible heterovalvate condition.

PLATE 5

1, 2	*Rhizosolenia oligocaenica* Schrader. 1, length 66μm; 2, length 68μm.
3	*Rhizosolenia* sp. C of Harwood 1989 (length 91μm).
4	*Pterotheca* sp. D of Harwood 1989 (length 50μm).
5	*Rutilaria* sp. (length 40μm).
6	*Kannoa japonica* Komura (length 53μm).
7	*Sceptroneis pesplanus* Fenner and Schrader in Schrader and Fenner (length 36.5μm).
8, 12	*Kannoa hastata* Komura. 8, length 24μm; 12, length 16μm.
9	*Sceptroneis talwanii* Schrader and Fenner (length 165μm).
10	*Sceptroneis lingulatus* Fenner (width 14μm).
11	*Kisseleviella carina* Sheshukova-Poretzkaya (length 35μm).
13, 16	Resting spore A. 13, width 10μm; 16, length 27μm.
14	*Chaetoceros panduraeformis* (Pantocsek) Gombos in Fenner (with 38μm).
15	*Liradiscus ovalis* Greville (width 19μm).
17, 19	Resting spore B. 17, length 23μm; 19, length 28μm.
18	Resting spore C (diameter 12.5μm).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Pseudotriceratium radiosoreticulatum Grunow in Van Heurck; Gombos and Ciesielski 1983, p. 603, pl. 17, figs. 1-3; Harwood 1989, p. 80, pl. 3, figs. 14, 15.
Plate 3, figure 5

***Pseudotriceratium* sp.**
Plate 3, figures 4a, b

Pterotheca clavata Strelnikova, Harwood 1988, p. 86, fig. 13.32.

***Pterotheca* sp. D** of Harwood 1989, p. 80, pl. 5, fig. 16, 17.
Plate 5, figure 4

Pyxilla reticulata Grove and Sturt; Fenner 1985, p. 735, figs. 11.6-11.10.
Plate 7, figures 1-3

Remarks: Frustules are covered with split ring girdle bands (see pl. 7, fig. 3) which resemble the girdle bands of *Rhizosolenia alata* Brightwell according to Strelnikova and Nikolayev (1989). This implies that *Pyxilla* is a resting spore of a *Rhizosolenia*-like diatom as suggested by Strelnikova and Nikolayev (1989).

Rhizosolenia oligocaenica Schrader 1976, p. 635, pl. 9, fig. 7. As *R. gravida* Gombos and Ciesielski 1983, p. 606, pl. 11, figs. 1-7; Harwood and Maruyama, 1992, pl. 4, fig. 17.
Plate 5, figures 1, 2

***Rhizosolenia* sp. C** of Harwood 1989, pl. 3, fig. 25
Plate 5, figure 3

Rouxia granda Schrader in Schrader and Fenner 1976, p. 997, pl. 7, fig. 17.
Plate 4, figures 2, 3

***Rutilaria* sp.**
Plate 5, figure 5

Sceptroneis lingulatus Fenner 1978, p. 531, pl. 31, figs. 8-10; Gombos and Ciesielski 1983, p. 604, pl. 24, fig. 8; Harwood 1989, p. 80, pl. 6, fig. 11. (Ornamented valve — pl. 5, fig. 10.)

Sceptroneis pesplanus Fenner and Schrader in Schrader and Fenner 1976, p. 998, pl. 22, figs. 30, 31 and pl. 25, figs. 10, 11; Gombos and Ciesielski 1983, p. 604, pl. 21, fig 10?.
Plate 5, figure 7

Remarks: Valves without ornamentation most common.

Sceptroneis talwanii Schrader and Fenner 1976, p. 999, pl. 24, figs., 28, 29.
Plate 5, figure 9; plate 7, figures 4a, b

Skeletonema barbadensis Greville; Gombos and Ciesielski 1983, p. 605, pl. 5, figs. 1-4, pl. 21, fig. 4; Fenner 1985, p. 738, figs. 9.1, 9.2.
Plate 6, figure 1

Remarks: SEM studies underway reveal 4-5 evenly spaced rimoportulae around the margin. Marginal connecting processes appear to be hollow but no openings could be resolved on the internal valve surface.

Sphynctolethus pacificus (Hajós) Sims 1986, pp. 250-252, figs. 29-34; Harwood 1989, p. 80, pl. 5, figs. 18-27.
Plate 6, figure 5

Stellarima stellaris (Roper) Hasle and Sims; Harwood 1989, pl. 1, fig. 3.
Plate 1, figures 4, 5

Stephanopyxis grunowii Grove et Sturt in Schmidt; Hajós 1976, p. 824, pl. 3, figs. 3, 4, pl. 4, figs. 1, 2; Harwood 1989, p. 81, pl. 2, figs. 5, 6.
Plate 2, figures 1a-c

Stephanopyxis oamaruensis Hajós 1976, p. 825, pl. 19, fig. 280; Harwood 1989, p. 81, pl. 2, figs. 27-29.
Plate 2, figure 5

Stephanopyxis splendidus (Greville) Harwood 1989, p. 81, pl. 2, figs. 1-4.
Plate 2, figure 2.)

Remarks: Thalassiosira hydra Gombos in Gombos and Ciesielski 1983, p. 606, pl. 7, figs. 1-6 is identified by Harwood (1989) as the resting spore of *S. splendidus*.

Stephanopyxis superba (Greville) Grunow; Hajós 1976, p. 825, pl. 1, figs. 11-13; Harwood 1989, p. 81, pl. 2, figs. 14-20, 26.
Plate 2, figures 3, 4

Stephanopyxis turris (Greville and Arnott) Ralfs; Harwood 1989, p. 81, pl. 2, figs. 21-23.
Plate 6, figure 8

Remark: Semi-endogenous resting spore.

PLATE 6

1 *Skeletonema barbadensis* Greville (scale bar = 4μm).

2a, b *Thalassiosira*? sp. cf. *T. manifesta* Sheshukova-Poretzkaya (2a, scale bar = 4μm; 2b, details of margin, scale bar = 1μm.

3, 4 *Chaetoceros* sp. (scale bar = 20μm). 3, resting spores, arrows.

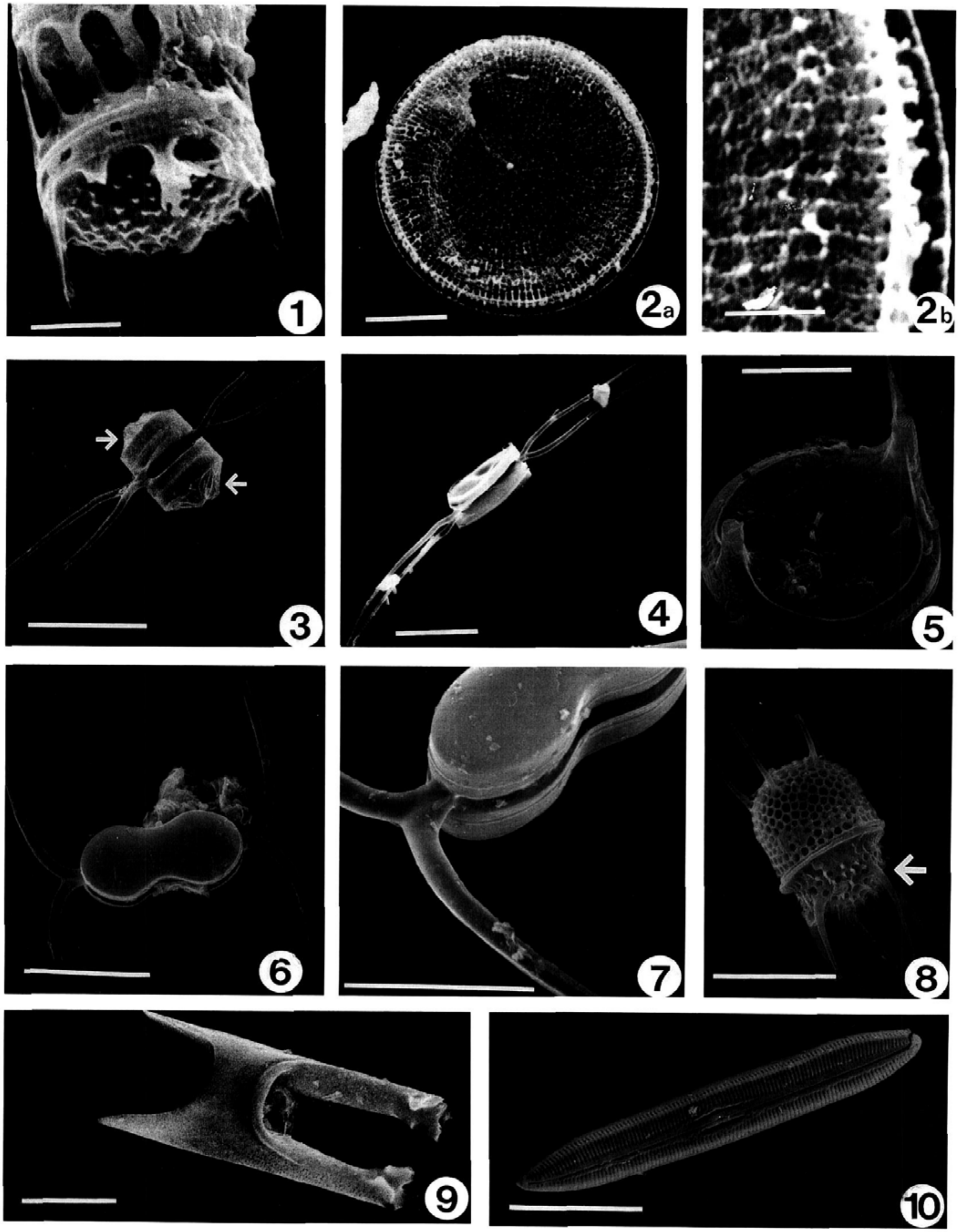
5 *Sphynctolethus pacificus* (scale bar = 20μm).

6, 7 *C. panduraeformis* (scale bar = 20μm).

8 *Stephanopyxis turris* (scale bar = 20μm, resting spore, arrow).

9 *Maluina* sp. (scale bar = 10μm).

10 *Navicula udintsevii* (scale bar = 20μm).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Stictodiscus kittonianus Greville; Schrader and Fenner 1976, p. 1001, pl. 35, fig. 27; Harwood 1989, p. 81, pl. 1, figs. 7, 8.
Plate 2, figure 8

Thalassiosira*? cf. *T. manifesta Sheshukova-Poretzkaya. Compare *Porosira glacialis* (Grunow) Joergensen sensu Schrader and Fenner 1976, pl. 16, figs. 3, 13.
Plate 4, figure 11; plate 6, figures 2a, b

Thalassiosira*? *mediaconvexa Schrader in Schrader and Fenner 1976, p. 1002, pl. 36, fig. 1.
Plate 4, figures 9, 12

Triceratium polymorphus Harwood and Maruyama, 1992, p. 605, pl. 1, figs. 1-3. As *T. macroporum* Hajós sensu Gombos and Ciesielski 1983, pl. 17, fig. 6. As *T. hebetatum* (Grunow) Andrews forms A, B and C in Harwood 1989, pp. 81-82, pl. 3, figs. 2-6.
Plate 3, figures 6, 9

Trinacria excavata Heiberg; Hajós 1976, pl. 14, fig. 9, pl. 15, figs. 8, 9; Harwood 1989, p. 82, pl. 3, fig. 1.
Plate 3, figure 3

Tumulopsis fogedi Hendey 1982, p. 277, pl. 1, figs. 1-3.
Plate 2, figures 7, 10 (ornamented valves); plate 2, figure 9 (plain valves)

Synonyms: Cotyledon fogedi (Hendey) Harwood 1989, p. 78, pl. 4, figs. 30, 31 (sparsely ornamented spore valve); Genus and species uncertain #2 of Gombos and Ciesielski 1983, p. 606, pl. 25, figs. 5-7; *Podosira polita* Hanna and Grant sensu Gombos and Ciesielski 1983, p. 603, pl. 4, fig. 11 (differs from type slide CAS 201009 of *P. polita*).

Remarks: According to De Toni in Van Heurck (1896, p. 519), the generic name *Cotyledon* is a later homonym of a plant genus and should be rejected. The junior synonym *Gutwinskiella* De Toni (1894) is not available to replace *Cotyledon*, because *Gutwinskiella clypeolus* (Brun) De Toni, the type species for the genus *Gutwinskiella*, is apparently a species of *Acanthodiscus* (Van Heurck 1896). Another possibility to replace the name *Cotyledon* would be *Bruniella*, which Van Heurck (1896, p. 512) proposed for specimens that were named *Cotyledon cornalis* by Brun (1891, p. 24, pl. 11, fig. 3). Brun's (1891, pl. 11, fig. 3) drawing of *C. cornalis* resembles *T. fogedi*, suggesting that the latter taxon should be transferred to *Bruniella*; however, study of Brun's (1891) type material is required for confirmation.

This diatom also resembles *Hyalodiscus elegans* Strelnikova sensu Baldauf and Barron 1987, p. 6, pl. 1 fig. 2.

Similar to Harwood (1989), we observed ornamented valves attached to plain valves.

***Xanthiopyxis* sp. ?;** As genus and species indet. 1 of Fenner 1978, pl. 34, figs. 16-18.

Resting spore A
Plate 5, figures 13, 16

Resting spore B
Plate 5, figures 17, 19

Remark: Similar forms have been observed as modern resting spores of *Chaetoceros* by A. D. Mahood in San Francisco Bay.

Resting spore C
Plate 5, figure 18

PLATE 7

1, 2, 3 *Pyxilla reticulata*. 1, scale bar = 40µm; 2, scale bar = 10µm, split ring girdle band, arrow; 3, scale bar = 20µm, split ring girdle band, arrow.

4a,b *Sceptroneis talwanii*. 4a, internal head pole view, arrow points to labiate process, scale bar = 4µm; 4b, internal foot pole view, arrow points to labiate process, scale bar = 4µm).

5 *Kannoa hastata* (scale bar = 10µm).

6 *Hemiaulus danicus* (scale bar = 10µm).

7 *K. japonica* (scale bar = 10µm).

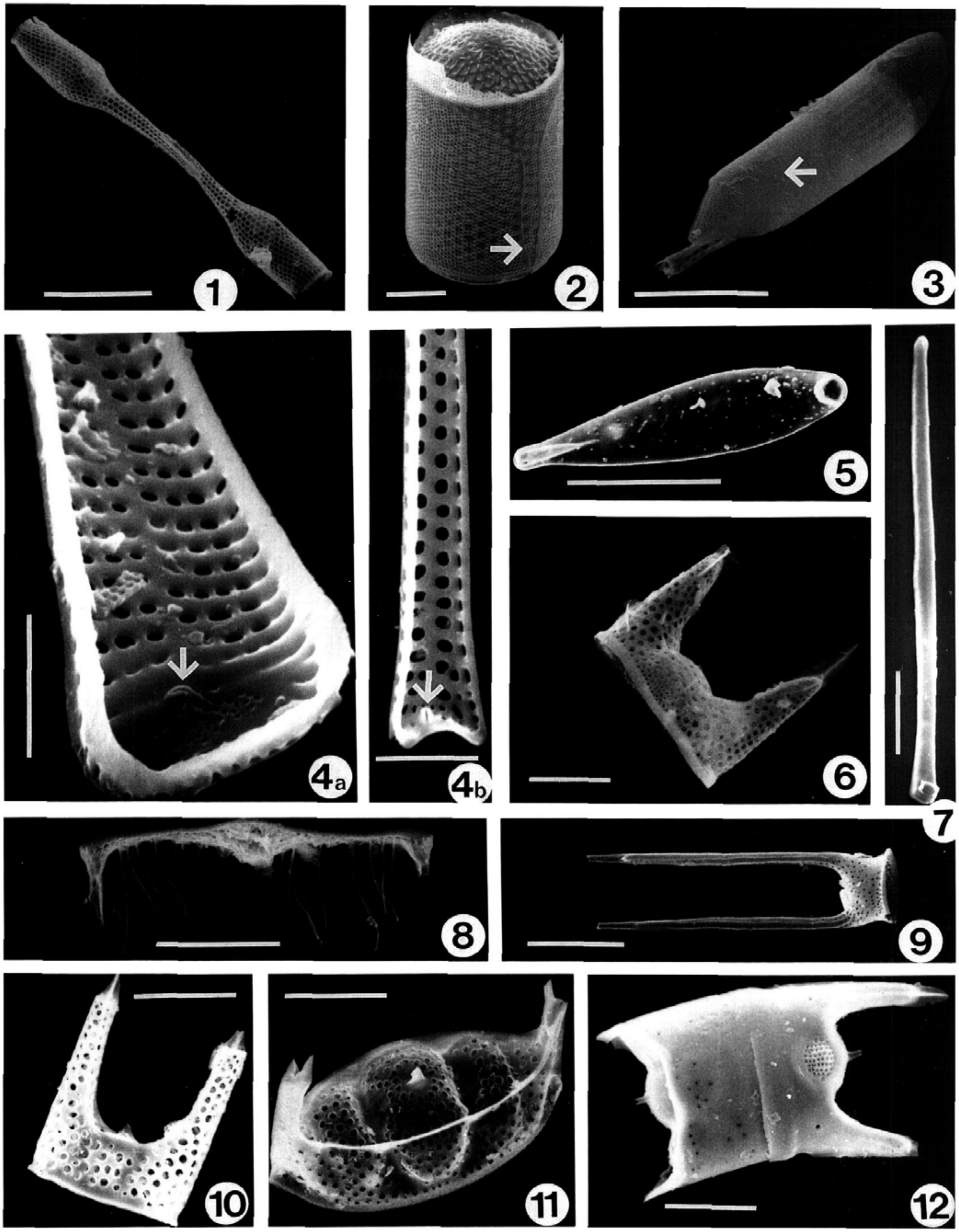
8 *Baxteriopsis brunii* (scale bar = 20µm).

9 *H. incisus* (scale bar = 10µm).

10 *H. polymorphus* (scale bar = 20µm).

11 *H. polycistinorum* (scale bar = 10µm).

12 *H. dissimilis* (scale bar = 10µm).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