

## 2. OLIGOCENE RADIOLARIANS, DIATOMS, AND EBRIDIANS FROM THE GREAT AUSTRALIAN BIGHT (ODP LEG 182, SITE 1128)<sup>1</sup>

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### ABSTRACT

Eocene and Oligocene radiolarians were recovered from Site 1128 on the slope of the upper continental rise during Ocean Drilling Program (ODP) Leg 182 in the Australian Bight. The early Oligocene radiolarians cored at Site 1128 vary considerably in abundance and preservation. Many intervals are barren or contain only rare fragments of radiolarians. Early Oligocene assemblages are dominated by sponge spicules and diatoms, similar to faunas of modern cold temperate shelf waters, and age diagnostic radiolarians useful for stratigraphic determination are rare. The interval is characterized by abundant actinommids and a dominance of robust artostrobiids representing the genus *Siphocampe*. In contrast, tropical taxa are present sporadically in rare abundance in the Eocene sediments. The radiolarian assemblages from the Eocene–Oligocene sequence at Site 1128 lack zonal marker species reported from regions further south or north, and thus, age estimates cannot be made using previously published zonations. However, the presence of diverse and well-preserved radiolarians in these assemblages indicates that it should be possible to establish a zonation for this intermediate latitude sub-Antarctic region as more comparable material becomes available.

The ebridian *Ammodoichium ampulla* Deflandre is present at Site 1128. *A. ampulla* was originally described from the upper Eocene diatomite of Oamaru, New Zealand, and was previously recorded in assemblages

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Diatoms were either absent or rare and poorly preserved in the samples examined between Cores 182-1128C-9H and 21X. Zonal markers for both the low-latitude and the high southern latitude diatom zonations for the Oligocene are absent, and precise correlation of this interval is impossible. The diatom assemblage in Sample 182-1128C-8H-4, 130–132 cm, contains a combination of oceanic and neritic diatoms, and the presence of *Rocella vigilans* and *Coscinodiscus rhombicus* suggests a late Oligocene or earliest Miocene age. Between Cores 182-1128C-22X and 26X, the diatom assemblages contain a combination of neritic and oceanic taxa, including the species *Cestodiscus reticulatus* and *Cestodiscus convexus*, which are indicative of an early Oligocene age.

## INTRODUCTION

Sediments recovered in the Great Australian Bight during Leg 182 (Fig. F1) record siliceous and carbonate deposition in a middle- to high-latitude environment. The lower Eocene sediments at Site 1128 consist of shallow-water terrigenous sands and carbonates that deepen upward into Oligocene pelagic ooze and chalk. The middle Eocene–lower Oligocene sediment sequence was well recovered on the continental rise at Site 1128 in a water depth of 3875 m and contains an expanded (>350 m) siliceous biogenic record of Circum-Antarctic Current evolution.

Results indicate that the upper part of this basin contains a thick almost-continuous biosiliceous record of Southern Ocean development through the Paleogene. Calcareous microfossils indicate the presence of a hiatus (~18 m.y.) at the Miocene/Oligocene boundary (70 meters below seafloor [mbsf]), where the entire upper Oligocene is missing. Sedimentation rates were 50–60 m/m.y. during most of the early Oligocene and 4 m/m.y. in the late Eocene. In spite of poor core recovery and barren intervals, the sedimentation rates in the lower Eocene have been estimated at 40–45 m/m.y. (Shipboard Scientific Party, 2000a).

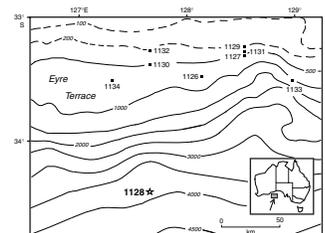
Biostratigraphic results from nannofossils and planktonic foraminifers suggest a largely continuous conformable succession across the Oligocene/Eocene boundary (Shipboard Scientific Party, 2000a). The expanded lower Oligocene section is indicated by nannofossils at Site 1128, where biostratigraphic resolution below 70 mbsf was largely achieved using calcareous nannofossils, because foraminifers were rare or absent in sediments dominated by siliceous oozes and packstones. The middle Eocene is represented by poorly preserved impoverished assemblages in various poorly recovered lithologies.

## MATERIALS AND METHODS

### Radiolarians

Samples of ~10 cm<sup>3</sup> were disaggregated by boiling in 20 wt% H<sub>2</sub>O<sub>2</sub> containing a 1 wt% solution of tetrasodium pyrophosphate. The disaggregated sediment was washed through a 44- $\mu$ m sieve, dried, and re-treated twice by boiling in the above solution. Calcareous components are dissolved by adding 10 wt% HCl, and the residues were rinsed. The microfossils were evenly pipetted onto labeled glass slides with an eye-

F1. Leg 182 drill sites, p. 15.



dropper, and the accompanying water evaporated without boiling. When completely dry, air is expelled from the skeletons by the addition of a few drops of xylene. The preparations are mounted in Canada balsam. Samples with high siliceous microfossil density were separated by sieving into three size fractions: 44–63  $\mu\text{m}$ , 63–150  $\mu\text{m}$ , and coarser than 150  $\mu\text{m}$  (Sanfilippo et al., 1985). Slides were made from each fraction for ease of viewing the radiolarians, with a minimum of interference from abundant sponge spicules.

Estimates, based on one slide, of total radiolarian abundance in each sample are expressed as trace (T; <150), very rare (VR; >151 to <300), rare (R; >301 to <1000), few (F; >1001 to <3000), and common (C; >3001). In some cases, the total number of radiolarians has been counted (Table T1). Abundances of individual taxa in Table T1 are given as present (P) or absent (–). Grades of preservation have been noted as the following:

- G = good; individual specimens exhibit little dissolution, and delicate parts of the skeleton are preserved.
- M = moderate; dissolution and breakage of individual specimens is apparent, but identification of species is not impaired.
- P = poor; individual specimens exhibit considerable breakage and dissolution.

### **Diatoms**

One sample per core from Hole 1128C was studied for diatoms, between Core 182-1128C-8H (upper Oligocene or lowermost Miocene) and 26X (lower Oligocene). Samples (~1  $\text{cm}^3$ ) were boiled in HCl and  $\text{H}_2\text{O}_2$ . The residues were rinsed by washing in distilled water and decanted after 8 hr; this cycle was repeated three times. Strewn slides were prepared by sampling the suspended residue with a pipette and spreading it on a 22 mm  $\times$  22 mm coverslip, which was air dried and mounted in Naphrax. At least one entire slide for each sample was scanned under the light microscope at 500 $\times$ . Identification of species was checked at 1250 $\times$ . Diatoms were identified using previous illustrated reports of Eocene and Oligocene diatoms from the middle to high latitude of the Southern Hemisphere, such as Hajós (1976), Fenner (1978, 1985), Desikachary and Sreelatha (1989), and Gombos and Ciesielski (1983). Results are reported in Table T2.

Abundance of diatoms in each sample is expressed as abundant (A), C, F, R, VR, or barren (B). Preservation is reported as good (G), moderate (M), poor (P), or very poor (VP). The presence of individual taxa in Table T2 are recorded as present (P).

### **PREVIOUS WORK**

In contrast to Eocene and Oligocene radiolarian stratigraphy for low latitudes, which is well understood and documented in a number of deep-sea sequences (for details see Sanfilippo and Nigrini, 1995, 1998), few studies document late Paleogene radiolarians in middle and high southern latitudes. Deep Sea Drilling Project (DSDP) Leg 28 provided a good composite sequence of sediments for constructing a Neogene radiolarian biostratigraphy, to extend earlier Pliocene and Pleistocene zonation, and it was the first opportunity to examine Oligocene

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T1. Presence of radiolarians, p. 17.

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T2. Presence of diatoms, p. 18.

radiolarians from the Antarctic (Chen, 1975). The late Paleogene assemblages from DSDP Leg 28 were, as expected, found to be very different from low-latitude faunas, and Chen (1975) did not attempt to establish an Oligocene radiolarian zonation. During the last decade, our knowledge of southern high-latitude radiolarians has improved markedly. Reports of the sporadic presence of Paleogene radiolarians reported from early DSDP Legs 28, 29, 35, 36, and 71, combined with observations from more recent ODP legs, have shown that the Paleogene radiolarian fauna is different from that of the low latitudes, and a separate zonation was needed. ODP Legs 113 and 114 (in the south Atlantic) and Legs 119 and 120 (in the southern Indian Ocean) have provided sediment sequences containing well-preserved radiolarians useful for establishing a Paleogene biostratigraphy for this region. In addition, work on land-based sequences from the Eocene and Oligocene of New Zealand has resulted in integrated Paleogene biostratigraphies, including foraminifers, calcareous nannofossils, radiolarians, dinoflagellates, and palynomorphs (e.g., Strong et al., 1995; Hollis et al., 1997; O'Connor, 1999, 2000). Figure F2 provides a correlation of the tropical south Pacific, and Southern Ocean radiolarian zonations to the geochronometric time-scale (for further details see Takemura and Ling, 1997; Hollis et al., 1997; O'Connor, 2000).

The goal of investigating the radiolarian assemblages from Site 1128 of ODP Leg 182 in the Great Australian Bight was to interpret the Oligocene and Eocene biostratigraphy where the calcareous microfossil record is too sparse for stratigraphic interpretation. The lack of southern high-latitude and tropical index species in Hole 1128C, however, has prevented biostratigraphic interpretation on the basis of previously published zonations of the lower Oligocene–lower Miocene sediments recovered from Sections 182-1128C-8H-1 through 26X-CC. This does not preclude future development of a zonal scheme from this intermediate latitude sub-Antarctic band as more comparable material becomes available.

## RESULTS

### Presence of Radiolarians and Diatoms at Site 1128

#### Hole 1128B

Hole 1128B was drilled at 34°23.4706'S, 127°5.4455'E at a water depth of 3874.6 m. The Oligocene (Cores 182-1128B-18X through 26X) consists of clay with nannofossils. The biosiliceous component consists of sponge spicules, radiolarians, diatoms, and silicoflagellates. The calcareous microfossils show signs of dissolution. Three samples per core were investigated for radiolarians. Their abundance is rare throughout, and preservation is moderately good. Sponge spicules are abundant. Samples 182-1128B-18X-2, 51–53 cm (157.41 mbsf); 19X-1, 60–62 cm (165.70 mbsf); 20X-1, 60–62 cm (175.30 mbsf); and 22X-2, 82–84 cm (196.22 mbsf) contain abundant unidentified actinommids, rare sphyrids, abundant *Siphocampe acephala* group, *Cyclampterium* fragments, and the rare presence of *Aphetocyrtis rossi*, *Cornutella profunda*, *Siphocampe nodosaria*, and *Stylodictya targaeformis*. Samples from Cores 22X through 26X contain, in addition to the above assemblage, rare unidentified eucyrtids, pterocorythids, and carpocaniids. Sponge spicules are

**F2.** Correlation of South Pacific, Southern Ocean, and tropical radiolarian zones, p. 16.

Age (Ma)	Epoch	Hollis et al. (1997) South Pacific	Age (Ma)	Sanfilippo & Negró (2000) Tropical	Age (Ma)	Takemura & Ling (1997) Southern Ocean	Age (Ma)
24	miocene				23.0		24
24				<i>L. elongata</i> RP22	24.0		
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abundant throughout, and diatoms are present in rare to common abundance.

### **Hole 1128C**

Hole 1128C was drilled at 34°23.4623'S, 127°35.4619'E at a water depth of 3874.3 m. Eocene, Oligocene, and Miocene sediments were recovered in Hole 1128C (Tables T1, T2). The Oligocene and Eocene deposits are represented mostly by claystone, except for a brief interval in the lower Oligocene of a pelagic ooze. Cores 182-1128C-8H and 9H (65.0–83.8 mbsf) consist of nannofossil ooze with foraminifers; Cores 10H to 15H (84.0–138.1 mbsf), clayey nannofossil ooze with radiolarians and diatoms; and Cores 16X to 26X (138.3–240.2 mbsf), greenish clay with nannofossil ooze and sponge spicules.

### **Radiolarians**

Three samples per core (Cores 182-1128C-8H through 26X) from the thick Oligocene to Miocene sequence recovered on the continental slope were examined for radiolarians. In Cores 182-1128C-8H through 15H, the radiolarians are fragmented and very rare (<300 radiolarians per slide) or absent; siliceous sponge spicules are common, and diatoms vary from trace abundance to few. In Cores 182-1128C-16X through 26X, radiolarians vary in abundance from rare to common (300–3000 per slide), and the preservation is moderately good. Sponge spicules are abundant, and diatoms are present in very rare to moderate abundance. Radiolarian abundance and preservation increases in the lower part of Cores 182-1128C-24X through 26X. The diversity is low throughout the Oligocene (Sections 182-1128C-9H-1 through 26X-CC), but it is difficult to judge whether this is due to the high abundance of sponge spicules diluting the radiolarians or low radiolarian diversity at this locality in the Oligocene. The fauna consists of deep-living forms such as cornutellids and artostrobiids, warm-water forms of pterocorythids, phacodiscids, spongurids, botryoids, eucyrtids, carpocaniids, and litheliids, and shallow living forms represented by cosmopolitan species of spyrids and lophophaenids. The sporadic presence of reworked Cretaceous dictyomitrids have been observed throughout the sequence. The stratigraphic zonation of the sediments containing radiolarians is difficult to determine because index species are absent. However, based on the concurrent presence of *A. rossi*, *Eucyrtidium spinosum*, *Lophocyrtis (Paralampterium) dimitricai*, *Periphaena decora*, *P. heliasticus*, and *Prunopyle hayesi*, the age represented in Samples 182-1128C-9H-1, 25–27 cm (74.75 mbsf), to 26X-CC, 20–22 cm (240.21 mbsf), is interpreted to approximate the *Axoprunum (?) irregularis* to *E. spinosum* Zones in the sense of Takemura and Ling (1997) and Hollis et al. (1997). The Oligocene/Miocene boundary between Cores 182-1128C-8H and 9H cannot be placed using radiolarians.

### **Diatoms**

Diatoms were either absent or rare and poorly preserved in the samples examined between Cores 182-1128C-9H and 21X. Zonal markers for both the low-latitude and the high southern-latitude diatom zonations for the Oligocene (i.e., *Bogorovia veniamini*, *Rocella gelida*, *Rhizosolenia antarctica*, and *Rhizosolenia gravida*) (see Fenner, 1985) are absent, and precise correlation of this interval is impossible. On the contrary,

samples examined in Core 182-1128C-8H and in Cores 22X through 26X are richer in diatoms, allowing for some stratigraphic and paleoenvironmental interpretation.

The diatom assemblage in Sample 182-1128C-8H-4, 130–132 cm, contains a combination of oceanic diatoms (e.g., *Coscinodiscus*, *Cestodiscus*, *Asteromphalus*, etc.) and neritic diatoms (e.g., *Paralia*, *Actinoptychus*, *Arachnoidiscus*, other neritic pennate diatoms, etc.). Stratigraphically significant diatoms in this sample include *R. vigilans* and *C. rhombicus*. The presence of *C. rhombicus* suggests that this sample is not older than late Oligocene (Fenner, 1985). The presence of *R. vigilans* in the earliest Miocene is reported by Fenner (1985) from low-latitude DSDP Hole 366A; however, neither Fenner (1985) nor Harwood and Maruyama (1992) report *R. vigilans* above the Oligocene/Miocene boundary in southern latitudes. There is no other evidence to support or reject an earliest Miocene age.

The presence of *C. reticulatus* and *C. convexus* in samples examined between Cores 182-1128C-22X and 26X are indicative of an early Oligocene age (Fenner, 1981, 1985). The presence of *Azpeitia oligocenica*, *Distephanosira architecturalis*, *Pseudotriceratium radiosoreticulatum*, and *Pyxilla* sp. is consistent with this interpretation. The assemblages consist of a combination of oceanic and neritic species. In Sample 182-1128C-25X-2, 65–67 cm, the oceanic diatoms (*Azpeitia*, *Coscinodiscus*, *Cestodiscus*, and *Hemiaulus*) are dominant over the neritic diatoms (*Paralia*, *Actinoptychus*, etc.). In Sample 182-1128C-26X-3, 115–117 cm, however, the neritic species are more numerous, although not a major component of the assemblage.

### **Hole 1128D**

Hole 1128D was drilled at 34°23.4563'S, 127°35.4554'E a water depth of 3874.3 m. The Eocene sequence in Cores 182-1128D-3R to 23R is represented by claystone in its uppermost part (Cores 2R to 6R) and siltstone in its lower part (Cores 7R to 23R). Three samples per core were examined for radiolarians. Radiolarians are few and rather well preserved in the early Oligocene (Samples 182-1128D-1R-1, 100–102 cm [232.20 mbsf], and 1R-2, 100–102 cm [233.70 mbsf]). They are absent or present only in trace amounts throughout the remainder of the Eocene (Core 182-1128C-2R [240.80 mbsf] to 23R [445.90 mbsf]). Diatoms are mostly absent, and when they are present, they are very fragmented. Sponge spicules vary in abundance from trace amounts to rare and are weakly silicified. Preservation deteriorates rapidly in the upper Eocene section and most of the lower cores. Sample 182-1128C-12R-CC is barren of calcareous nannofossils (Shipboard Scientific Party, 2000b).

The Eocene/Oligocene boundary between Cores 182-1128C-2R (240.80 mbsf) and 3R (250.40 mbsf) falls in an interval barren of radiolarians and was determined on the basis of calcareous nannofossils. Biostratigraphic interpretation using radiolarians in the Eocene interval is currently not possible. Sample 182-1128D-10R-3, 50–52 cm, contains *Dictyoprora mongolfieri*, *D. urceolus*, *Lithocyclia ocellus*, *Lychnocanoma amphitrite*, *Periphaena decora*, and *Siphocampe quadrata*.

## **CONCLUSIONS**

Radiolarians vary in abundance from barren to common and are moderately diverse throughout the Oligocene and upper Eocene at Site

1128, suggesting bathyal water depths and high rates of biological productivity on the continental slope during the latest Paleogene. Tropical taxa (notably the genera *Podocyrtis*, *Thyrsocyrtis*, *Lithocyclia*, and *Eucyrtidium*) are nearly absent in the Australian Bight; whereas, actinomyxids, spongodiscids, porodiscids, litheliids, and cornutellids, considered the major component of high- to midlatitude faunas, predominate. The marker species for the Paleogene Southern Ocean are mostly absent. The concurrent presence of *Aphetocyrtis rossi*, *Eucyrtidium spinosum*, *Lophocyrtis (Paralampterium) dimitricai*, *Periphaena decora*, *P. heliasticus*, and *Prunopyle hayesi* indicate that the age represented in Samples 182-1128C-9H-1, 25–27 cm (74.75 mbsf), to 26X-CC, 20–22 cm (240.21 mbsf), is Oligocene, approximately equivalent to the *Axoprunum (?) irregularis* to *Eucyrtidium spinosum* Zones in the sense of Takekura and Ling (1997) and Hollis et al. (1997). The Oligocene/Miocene and Eocene/Oligocene boundaries cannot be placed using radiolarians.

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## APPENDIX

### Radiolarians

*Albatrossidium* sp.

**Remarks:** Rare pterocorythid fragments encountered in the Site 1128 material show great similarity with species illustrated in Sanfilippo and Riedel 1992, pl. 1, figs. 1, 2, 7, 8, 12, 13, 18, 19; pl. 2, figs. 1, 2, 7; pl. 6, fig. 3a, 3b (Pl. P2, fig. 21).

*Amphisphaera minor* (Clark and Campbell) Sanfilippo and Riedel, 1973, p. 486, pl. 1, figs. 1–5; pl. 22, fig. 4 (Pl. P2, fig. 6).

*Amphymerium splendarmatum* Clark and Campbell, 1942, p. 46, pl. 1, figs. 12, 14 (Pl. P2, fig. 18).

*Aphetocyrtis rossi* Sanfilippo and Caulet, 1998, p. 18, pl. 2, figs. 8, 9, 12, 13; pl. 7, figs. 1–9 (Pl. P2, figs. 1–3).

*Axoprunum pierinae* (Clark and Campbell) group Sanfilippo and Riedel, 1973, p. 488, pl. 1, figs. 6–12; pl. 23, fig. 3 (Pl. P2, fig. 7).

*Botryocella cribrosa* (Ehrenberg) group Hollis et al., 1997, p. 53, pl. 4, figs. 1–4 (Pl. P1, fig. 18).

**Remarks:** The Oligocene samples contain sporadic, very rare cannobotryids, which probably all belong to one species and are superficially similar to early members of the *Botryopyle dictyocephalus* Haeckel group, except that they have a postcephalic tube at the base of the cephalis.

*Botryostrobus* cf. *B. hollisi* O'Connor, 1997b, p. 105, pl. 1, figs. 9–12, pl. 5; figs. 1–4 (Pl. P1, figs. 13–15).

**Remarks:** The morphotypes encountered at Site 1128 differ from *B. hollisi* in that their general shape is cylindrical (as in O'Connor, 1997b, pl. 1, fig. 12, pl. 5, fig. 1) and in that the abdomen frequently has more than two transverse rows of pores. The forms described by O'Connor (1997b) are from lower Miocene deposits in New Zealand.

*Botryostrobus joides* Petrushevskaya group, Petrushevskaya, 1975, p. 585, pl. 10, fig. 37; Hull, 1996, p. 137, pl. 4, figs. 5, 6, 20 (Pl. P1, figs. 3, 12).

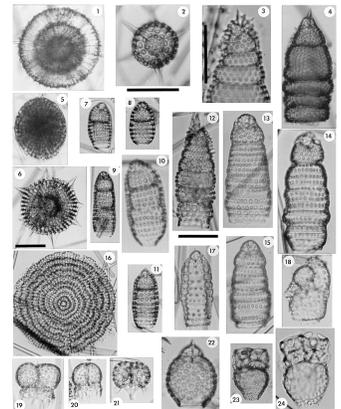
**Remarks:** Included in this group are forms with 6–10 segments. The thorax is truncate conical with three to five rows of pores. The features of the cephalis and thorax are obscured by a “cockscomb” or frilled ornamentation connecting the apical horn and vertical tube, which extends downward covering the surface of the cephalothorax and sometimes including the abdomen and the first postabdominal segment. The apical horn varies in length from equal in length to twice the length of the cephalis. Morphotypes have been observed where the horn is bladed, sharply pointed, or consists of a crown of thorns or a flared apical tube. The forms in Hole 1128C are rather similar to *Spirocyrtes* sp. A described by Hollis et al. (1997, p. 56, pl. 4; figs. 33–35) from southwest Pacific DSDP Site 277. Members of the *B. joides* group differ from *Spirocyrtes proboscis* O'Connor (1994, p. 341, pl. 2, figs. 1–4, pl. 3, figs. 13–16) in having smaller thoracic pores, no bandlike distinct lumbar stricture, and in having post-thoracic segments that are rounded rather than angular and from *Botryostrobus rednosus* Caulet (1991, p. 535, pl. 3, figs. 9, 10) in having a less robust shell and by having three to six rows of pores on the postabdominal segments in transverse rows. The resemblance of these taxa is striking, and the differences in morphological features may be ecologically controlled.

*Carpocanistrum* spp. (Pl. P1, fig. 22).

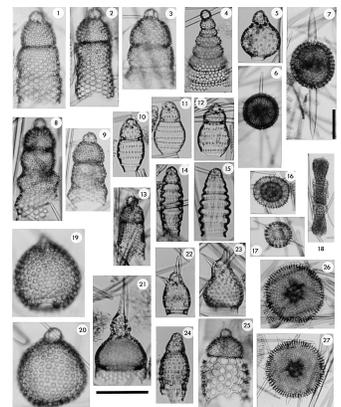
**Remarks:** Forms included here vary in the degree of the longitudinal alignment of the thoracic pores, degree of constriction of the mouth, and presence or absence of peristomial teeth.

?*Cyrtocapsa osculum* O'Connor, 1997a, p. 75, pl. 1, figs. 15–17; pl. 2, figs. 1, 2; pl. 8, figs. 3–10 (Pl. P2, figs. 19, 20).

P1. Oligocene radiolarians and ebridians, Hole 1128C, p. 19.



P2. Oligocene radiolarians, Hole 1128C, p. 21.



**Remarks:** Moderately rare two-segmented forms without any trace of a third segment and a very constricted mouth are questionably tabulated as *C. osculum*. These forms are present only in Sample 182-1128C-13H-2, 130–132 cm.

*Cyrtolagena laguncula* Haeckel, 1887, p. 1451, pl. 75, fig. 10 (Pl. P2, fig. 4).

*Dictyoprora urceolus* (Haeckel) Nigrini, 1977, p. 251, pl. 4, figs. 9, 10; Hollis et al., 1997, p. 56, pl. 4, figs. 36, 37 (Pl. P2, figs. 10–12).

**Remarks:** Specimens encountered at Site 1128 resemble *Dictyoprora gibsoni* described by O'Connor (1994, p. 338, pl. 1, figs. 5–8; pl. 3, figs. 4–7) but differ in having a more inflated thorax, an abdomen that is elliptical to inflated medially, and varying in its degree of lateral compression in the sagittal plane. The transverse section of the abdomen of the forms, herein identified as *D. urceolus*, varies from elliptical to circular but is not as markedly compressed as that described by O'Connor (1994) in *D. gibsoni*.

?*Eucyrtidium spinosum* Takemura, 1992, p. 746, pl. 5, figs. 5–8 (Pl. P1, fig. 4).

**Remarks:** Takemura (1992) separates *E. spinosum* from *E. cheni* (Takemura, 1992, p. 746, pl. 4, figs. 1–4), based on the length of the apical horn. In *E. spinosum*, the apical horn is approximately twice the length of the cephalis, whereas in *E. cheni*, it is shorter than the length of the cephalis. The forms herein are questionably assigned to *E. spinosum* because the apical horn is often broken.

*Helioliscus inca* Clark and Campbell, 1942, p. 38, pl. 3, fig. 17; Hollis et al., 1997, p. 53, pl. 4, figs. 1–4 (Pl. P1, fig. 6).

*Hexacantium* sp. A (Pl. P2, fig. 17).

**Remarks:** Spherical cortical shell, thick-walled with a rough surface and hexagonally framed rosette-shaped pores, rather regular in size and arrangement. Six external spines, mutually perpendicular, short, pronouncedly bladed near the bases. Medullary shell double, joined to the cortical shell by six strong bars colinear with the external spines.

?*Lithelius nautiloides* Popofsky, 1908, p. 230, pl. 27, fig. 4 (Pl. P2, fig. 16).

*Lophocyrtis biaurita* (Ehrenberg) Haeckel, 1887, p. 1141; Cita et al., 1970, p. 404, pl. 2, figs. I–K (Pl. P2, figs. 22, 23).

*Lophocyrtis (Paralampterium) dumitricai* Sanfilippo, 1990, p. 308, pl. 3, figs. 7–13 (Pl. P2, fig. 25).

*Periphaena decora* Ehrenberg, 1873, p. 246; Ehrenberg, 1875, pl. 28, fig. 6; Sanfilippo and Riedel, 1973, p. 523, pl. 8, figs. 8–10; pl. 27, figs. 2–5 (Pl. P2, fig. 26).

*Periphaena heliastericus* (Clark and Campbell) Sanfilippo and Riedel, 1973, p. 523, pl. 9, figs. 1–6; pl. 27, figs. 8, 9 (Pl. P2, fig. 27).

*Plannapus ?aitai* O'Connor, 2000, p. 199, pl. 2, figs. 16a–21b; pl. 3, figs. 9–18 (Pl. P1, fig. 17).

*Plannapus microcephalus* (Haeckel) O'Connor, 1997a, p. 70, pl. 1, figs. 10–14; pl. 5, figs. 10–12; pl. 6, figs. 1–5 (Pl. P2, fig. 5).

*Prunopyle hayesi* Chen, 1975, p. 454, pl. 9, figs. 3–5 (Pl. P1, fig. 5).

*Siphocampe acephala* (Ehrenberg) Nigrini, 1977, p. 254, pl. 3, fig. 5; *Siphocampe acephala* (Ehrenberg) new group Hollis et al., 1997, p. 54, pl. 4, figs. 8–20 (Pl. P1, figs. 7–11).

*Siphocampe nodosaria* (Haeckel) Nigrini, 1977, p. 256, pl. 3, fig. 11; Hollis et al., 1997, p. 55, pl. 4, figs. 28–32 (Pl. P2, figs. 14, 15).

*Siphocampe (?) quadrata* (Petrushevskaya and Kozlova) Nigrini, 1977, p. 257, pl. 3, fig. 12 (Pl. P2, fig. 24).

*Spongurus bilobatus* Clark and Campbell, 1942, p. 36, pl. 1, figs. 7–9.

*Stylodictya targaeformis* (Clark and Campbell) Petrushevskaya and Kozlova, 1972, p. 526, pl. 18, fig. 10 (Pl. P1, fig. 16).

*Theocorys bianulus* O'Connor, 1997a, p. 84, pl. 4, figs. 1–4; pl. 10, figs. 1–4; pl. 11, fig. 5 (Pl. P2, figs. 9, 13).

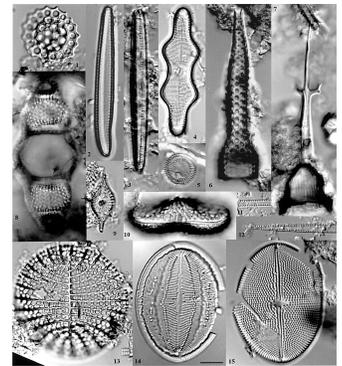
**Remarks:** The specimens encountered herein are similar to *T. bianulus* in all respects except that the cylindrical abdomen only has one annular part instead of two. In this respect, the Site 1128 forms are more like *Eucyrtidiidae* gen. et sp. “rocket” illustrated by Petrushevskaya and Kozlova 1972, p. 547, pl. 28, figs. 2, 3 and *Eucyrtidium* sp. cf. *E. “rocket”* in Ling 1975, p. 731, pl. 12, fig. 19.

## Diatoms

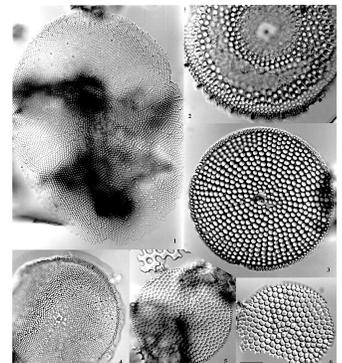
Each species identified at Hole 1128C is listed below with its author and a reference to a good illustration in a recent paper.

- Actinoptychus senarius* (Ehrenberg) Ehrenberg; Fenner, 1978, p. 510, pl. 6, fig. 9 (as *Actinoptychus undulatus*).
- Actinoptychus* sp.
- Arachnoidiscus* sp.
- Asterolampra marylandica* Ehrenberg; Gombos and Ciesielski, 1983, p. 600, pl. 1, fig. 7.
- Asterolampra schmidtii* Hajós; Hajós 1976, p. 827, pl. 8, figs. 1, 2.
- Asteromphalus* sp.
- Azpeitia oligocenica* (Jousé) Sims; Harwood and Maruyama, 1992, p. 701 (Pl. P4, figs. 3, 5).
- Azpeitia* sp.
- Biddulphia* spp. (Pl. P3, fig. 8).
- Campyloneis totara* (Brun) Schrader; Schrader, 1969, p. 39, pl. 17, fig. 8; pl. 28, fig. 17 (Pl. P3, fig. 13).
- Cavitatus jouseanus* (Sheshukova-Poretzkaya) Williams; Gladenkov and Barron, 1995, p. 31, pl. 5, figs. 1, 2, 27 (Pl. P3, figs. 2, 3).
- Cavitatus miocenicus* (Schrader) Akiba and Yanagisawa in Akiba et al.; Gladenkov and Barron, 1995, p. 31, pl. 5, fig. 3 (Pl. P3, fig. 12).
- Cestodiscus* aff. *intersectus* (Brun) Reinhold; Strelnikova et al., 2002, figs. 1–5, 6–12 (Pl. P4, fig. 4).
- Cestodiscus convexus* Castracane; Fenner, 1981, p. 86, pl. 13, figs. 1–3.
- Cestodiscus reticulatus* Fenner; Fenner, 1985, p. 728, figs. 12.6: 1, 4.
- Cestodiscus* spp. (Pl. P4, figs. 1, 2).
- Cocconeis vitrea* Brun; Desikachary et al., 1989, p. 120, pl. 51, fig. 1 (Pl. P3, fig. 14).
- Cocconeis* spp. (Pl. P3, fig. 15).
- Coscinodiscus marginatus* Ehrenberg; Fenner, 1978, p. 515, pl. 8, figs. 3, 7.
- Coscinodiscus* aff. *radiatus* Ehrenberg
- Coscinodiscus rhombicus* Castracane; Fenner, 1985, p. 729, figs. 7, 1–4.
- Coscinodiscus* spp.
- Diploneis* spp.
- Distephanosira architecturalis* (Brun) Gleser; Fenner, 1978, pl. 13, fig. 6 (as *Melosira architecturalis* Brun) (Pl. P3, fig. 5).
- Hemiaulus polycystinorum* Ehrenberg; Fenner, 1978, p. 521, pl. 21, figs. 13, 14; pl. 22, figs. 4–5; pl. 23, figs. 1–4.
- Hemiaulus polymorphus* Grunow; Fenner, 1978, p. 522, pl. 21, fig. 11; pl. 22, fig. 13; pl. 23, figs. 10–11.
- Hemiaulus* sp.
- Hyalodiscus* sp.
- Macrora stella* Hanna; Hanna, 1932, p. 196, pl. 12, fig. 7 (Pl. P3, fig. 1).
- Paralia sulcata* (Ehrenberg) Cleve; Fenner, 1978, pl. 13, fig. 6.
- Pseudotriceratium radiosoreticulatum* Grunow; Gombos and Ciesielski, 1983, p. 603, pl. 17, figs. 1–3; Fenner, 1985, p. 735, fig. 12.11.
- Pterotheca aculeifera* Grunow; Fenner, 1978, p. 527, pl. 17, figs. 8–21 (Pl. P3, fig. 7).
- Pyxilla reticulata* Grove & Sturt; Fenner, 1985, p. 735, figs. 11.6–10.
- Pyxilla* sp. (Pl. P3, fig. 6).
- Rocella praenitida* (Fenner) Fenner; Harwood and Maruyama, 1992, p. 705, pl. 4, figs. 1–3, 5.
- Rocella vigilans* Fenner; Fenner, 1985, p. 737, figs. 7.14–15 (Pl. P4, fig. 6).
- Rouxia* sp.
- Rutilaria* sp. (Pl. P3, fig. 9).
- Sceptroneis* sp.
- Stellarima* sp.
- Stephanopyxis grunowii* Grove & Sturt; Hajós, 1976, p. 824, pl. 3, figs. 3–4; pl. 4, figs. 1, 2.

P3. Early Oligocene diatoms, Hole 1128C, p. 23.



P4. Early Oligocene diatoms, Hole 1128C, p. 24.



*Stephanopyxis* spp.

*Stictodiscus* sp.

*Thalassiosira bukryi* Barron; Harwood and Maruyama, 1992, p. 706–707, pl. 2, figs. 13–16.

*Thalassiothrix* sp. (Pl. P3, fig. 11).

*Triceratium inconspicuum* var. *trilobata* Fenner; Fenner, 1978, p. 534–535, pl. 30, figs. 23–26.

*Triceratium* sp.

*Trinacria excavata* forma *tetragona* Schmidt; Fenner, 1985, p. 741, figs. 8.29–30.

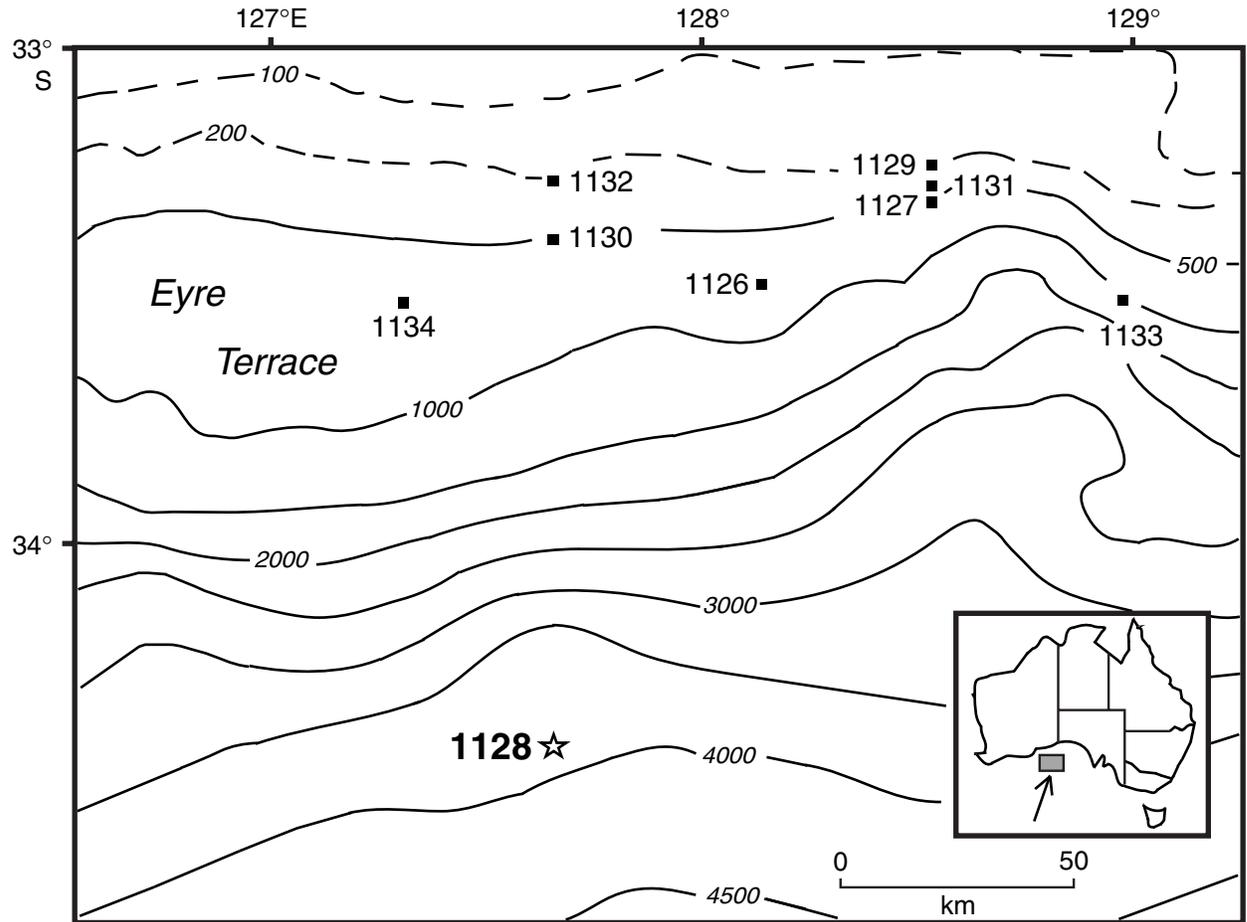
*Trinacria* sp.

*Xanthiopyxis* sp. (Pl. P3, fig. 10).

### **Ebridians**

Ebridians (marine planktonic silica-secreting organisms commonly found in cold or temperate waters) were found to be rare to few in the siliceous sediments cored at Site 1128 (Pl. P1, figs. 23, 24). Their fossil record goes back to the Paleocene, although most genera and species are recorded from the Eocene and Miocene. The species *Ammodochium ampulla* Deflandre, 1934, is present at Site 1128. Perch-Nielsen (1975) recorded this species in assemblages from the sub-Antarctic southwest Pacific, DSDP Sites 277, 281, and 283. *A. ampulla* was originally described from the upper Eocene diatomite of Oamaru, New Zealand.

Figure F1. Locations of Site 1128 and other Leg 182 drill sites in the western Great Australian Bight (modified after figure F1 of Shipboard Scientific Party [2000b]).



**Figure F2.** Correlation of South Pacific, Southern Ocean, and tropical radiolarian zones. Note that datums from Hollis et al. (1997), Sanfilippo and Nigrini (1998), and Takemura and Ling (1997) were used to calibrate radiolarian zonations to timescale of Berggren et al. (1995). Numerical ages (Ma) for Sanfilippo and Nigrini (1998) and Takemura and Ling (1997) are approximations.

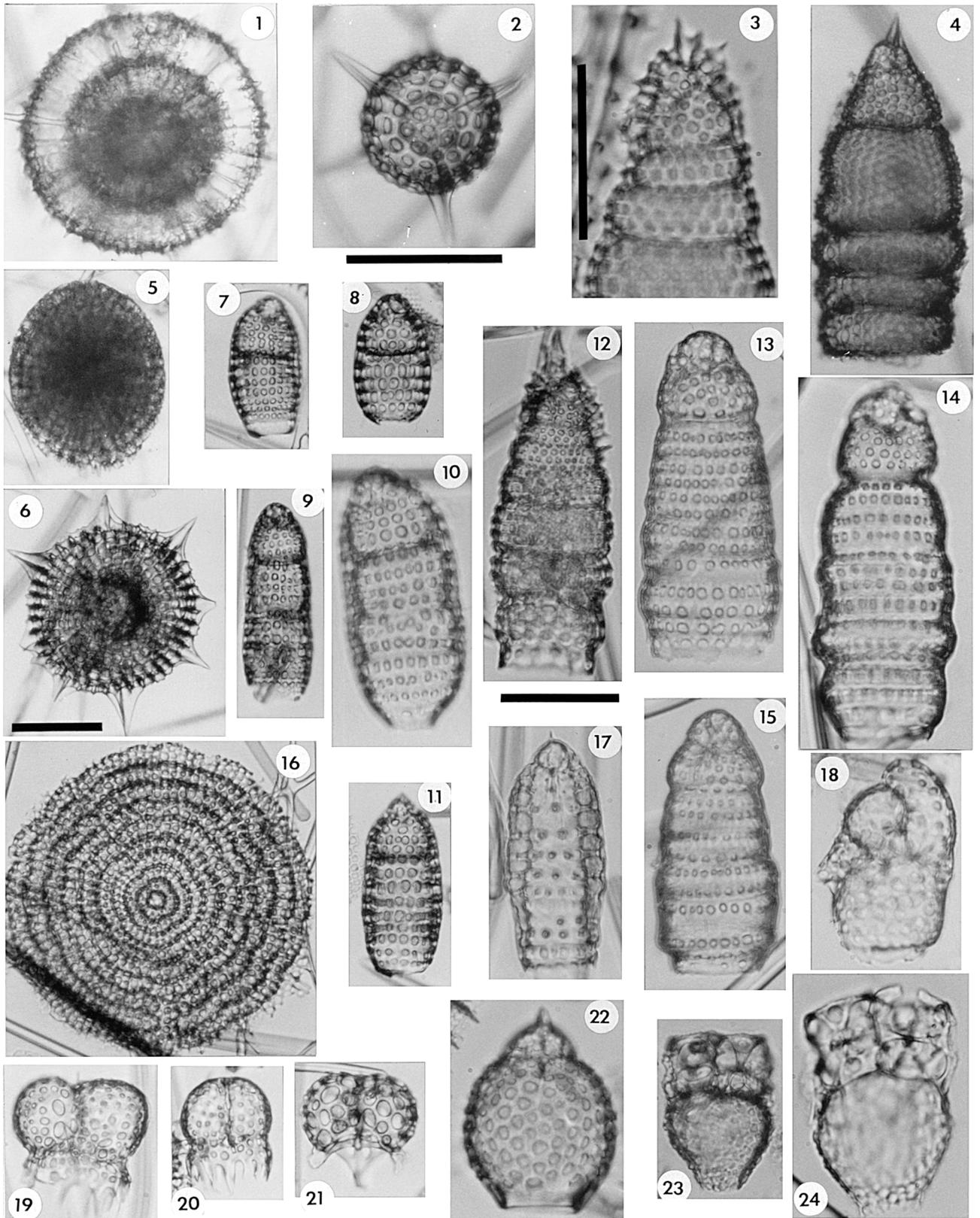
Age (Ma)	Epoch		Hollis et al. (1997) South Pacific	Age (Ma)	Sanfilippo & Nigrini (1998) Tropical	Age (Ma)	Takemura & Ling (1997) Southern Ocean	Age (Ma)
23	Mio.	early	Unzoned	27.5	<i>C. tetrapera</i> RN1	23.6		
24					<i>L. elongata</i> RP22	24.6		24
25		late	Unzoned	27.5	<i>Dorcadospyris ateuchus</i> RP21		<i>Lychnocanoma conica</i>	27
26								
27		early	<i>Axoprunum irregularis</i> RP15	27.5	<i>Theocyrtis tuberosa</i> RP20		<i>Axoprunum irregularis</i>	27
28								
29	Oligocene		Unzoned	27.5				27
30								
31		late	<i>Eucyrtidium spinosum</i> RP14	33.0	<i>Cryptocarpium ornatum</i> RP19	32.8	<i>Eucyrtidium spinosum</i>	33
32								
33	Eocene		Unzoned	33.0	<i>Calocyclus bandyca</i> RP18			33
34								
35		middle	<i>Lithapium mitra</i> RP13	37.0	<i>Carpocanistrum azyx</i> RP17	36.4		37
36								
37			Unzoned	37.0	<i>P. goetheana</i> RP16			37
38								
39			<i>Eusyringium fistuligerum</i> RP12	39.0	<i>P. chalara</i> RP15	38.8		37
40								
					<i>P. mitra</i> RP14	39.5		





**Plate P1.** Note that codes after sample descriptions are slide designation and England Finder coordinates, respectively. The scale bar below figure 2 equals 100  $\mu\text{m}$ . Use this scale bar for figs. 1, 2, 4, 7–9, 11, 16, and 19–21. The scale bar on figure 3 equals 50  $\mu\text{m}$ . Use this scale bar for figs. 3 and 24. The scale bar on figure 6 equals 50  $\mu\text{m}$ . Use this scale bar for figures 5 and 6. The scale bar below figure 12 equals 50  $\mu\text{m}$ . Use this scale bar for figures 10, 12–15, 17, 18, 22, and 23. **1, 2.** *Actinommid* gen. et spp. indet., (1) Sample 182-1128C-17X-2, 70–72 cm, Sl.3, R18/3; (2) Sample 182-1128C-26X-4, 110–112 cm, Cs.2, E32/0. **3, 12.** *Botryostrobus joides* Petrushevskaya, (3) Detail of cephalis and apical horn in Sample 182-1128C-26X-4, 110–112 cm, Ph.2, G43/0; (12) Sample 182-1128C-17X-2, 70–72 cm, Sl.4, B20/0. **4.** *Eucyrtidium spinosum* Takemura, Sample 182-1128C-25X-3, 60–62 cm, Cs.1, C4/4; **5.** *Prunopyle hayesi* Chen, Sample 182-1128C-25X-3, 60–62 cm, Cs.1, T10/0; **6.** *Heliodiscus inca* Clark and Campbell, Sample 182-1128C-13H-2, 130–132 cm, Sl.2, C39/0. **7–11.** *Siphocampe acephala* (Ehrenberg) group, (7) Sample 182-1128C-26X-4, 110–112 cm, Sl.2, E39/0; (8) Sample 182-1128C-25X-1, 110–112 cm, F.1, J34/0; (9) Sample 182-1128C-17X-2, 70–72 cm, Sl.3, T18/1; (10) Sample 182-1128C-26X-4, 110–112 cm, F.1, W40/4; (11) Sample 182-1128C-26X-4, 110–112 cm, Sl.2, K46/4. **13–15.** *Botryostrobus* cf. *B. hollisi* O'Connor, Sample 182-1128C-25X-3, 60–62 cm, Cs.1, (13) R24/1; (14) M45/3; (15) N14/1. **16.** *Stylodictya targaeformis* (Clark and Campbell), Sample 182-1128C-26X-4, 110–112 cm, Cs.2, V26/4. **17.** *Plannapus* ? *aitai* O'Connor, Sample 182-1128C-26X-4, 110–112 cm, Sl.2, M39/3. **18.** *Botryocella cribrosa* (Ehrenberg), Sample 182-1128C-26X-3, 48–59 cm, Sl.2, M9/3. **19–21.** *Spyrids* gen. et spp. indet., (19) Sample 182-1128B-22X-2, 82–84 cm, Sl.1, U11/3; (20) Sample 182-1128C-25X-1, 110–112 cm, F.1, P11/3; (21) Sample 182-1128C-26X-4, 110–112 cm, Ph.2, V28/4. **22.** *Carpocanistrum* sp., Sample 182-1128B-26X-3, 48–50 cm, Sl.2, N32/4. **23, 24.** *Ammodochium ampulla* Deflandre, Sample 182-1128B-25X-3, 78–80 cm, Sl.2, (23) B23/4; (24) K28/2. (**Plate shown on next page.**)

Plate P1 (continued). (Caption shown on previous page.)



**Plate P2.** Codes after sample descriptions are slide designation and England Finder coordinates, respectively. The scale bar below figure 21 equals 100  $\mu\text{m}$ . Use this scale bar for figs. 1–5, 8–15, and 19–24. The scale bar on figure 7 equals 100  $\mu\text{m}$ . Use this scale bar for figs. 6, 7, 16–18, and 25–27. 1–3. *Aphetocyrtis rossi* Sanfilippo and Caulet, Sample 182-1128C-25X-3, 60–62 cm; (1) Sl.1, C24/3; (2) Ph.1, M17/4; (3) Cs.1, G23/0. 4. *Cyrtolagena laguncula* Haeckel, Sample 182-1128C-20X-4, 55–57 cm, Sl.1, F28/1. 5. *Plannapus microcephalus* (Haeckel), Sample 182-1128C-17X-2, 70–72 cm, Sl.4, Q11/2. 6. *Amphisphaera minor* (Clark and Campbell), Sample 182-1128C-26X-4, 110–112 cm, Ph.2, K16/2. 7. *Axoprunum pierinae* (Clark and Campbell) group, Sample 182-1128C-18X-1, 60–62 cm, Sl.4, N13/3. 8. ?*Theocorys bianulus* O'Connor, Sample 182-1128C-22X-7, 20–22 cm, Sl.1, W18/0. 9, 13. *Theocorys bianulus* O'Connor, (9) Sample 182-1128C-18X-1, 60–62 cm, Sl.2, H26/4; (13) Sample 182-1128C-18X-1, 60–62 cm, Sl.4, L6/0. 10–12. *Dictyoprora urceolus* (Haeckel), (10) Sample 182-1128C-26X-4, 110–112 cm, F.1, R28/4; (11) Sample 182-1128C-22X-7, 20–22 cm, Ph.1, D41/4; (12) Sample 182-1128C-26X-4, 110–112 cm, Sl.2, F35/2. 14, 15. *Siphocampe nodosaria* (Haeckel), (14) Sample 182-1128D-1R-1, 100–102 cm, Sl.2, E36/0; (15) Sample 182-1128C-26X-4, 110–112 cm, Sl.2, W41/0. 16. ?*Lithelius nautiloides* Popofsky, Sample 182-1128C-26X-4, 110–112 cm, Ph.2, G4/0. 17. *Hexacontium* sp. A., Sample 182-1128C-26X-4, 110–112 cm, Cs.2, G27/0. 18. *Amphymenium splendiararmatum* Clark and Campbell, Sample 182-1128C-18X-1, 60–62 cm, Sl.4, J21/2. 19, 20. ?*Cyrtocapsa osculum* O'Connor, Sample 182-1128C-13H-2, 130–132 cm, Sl.2; (19) Showing basal aperture, H20/1; (20) M30/2. 21. *Albatrossidium* sp. Sample 182-1128B-25X-3, 78–80 cm, Sl.2, A26/0. 22, 23. *Lophocyrtis biaurita* (Ehrenberg), (22) Sample 182-1128C-17X-2, 70–72 cm, Sl.2, D9/2; (23) Sample 182-1128C-22X-7, 20–22 cm, Sl.1, T20/4. 24. *Siphocampe* (?) *quadrata* (Petrushevskaya and Kozlova), Sample 182-1128C-18X-1, 60–62 cm, Sl.2, D6/3. 25. *Lophocyrtis* (*Paralampertium*) *dumitricai* Sanfilippo, Sample 182-1128C-26X-4, 110–112 cm, Cs.2, Q15/2. 26. *Periphaena decora* Ehrenberg, Sample 182-1128C-18X-1, 60–62 cm, Sl.4, Q38/0. 27. *Periphaena helias-tericus* (Clark and Campbell), Sample 182-1128C-25X-3, 60–62 cm, Cs.1, O21/0. (Plate shown on next page.)

Plate P2 (continued). (Caption shown on previous page.)

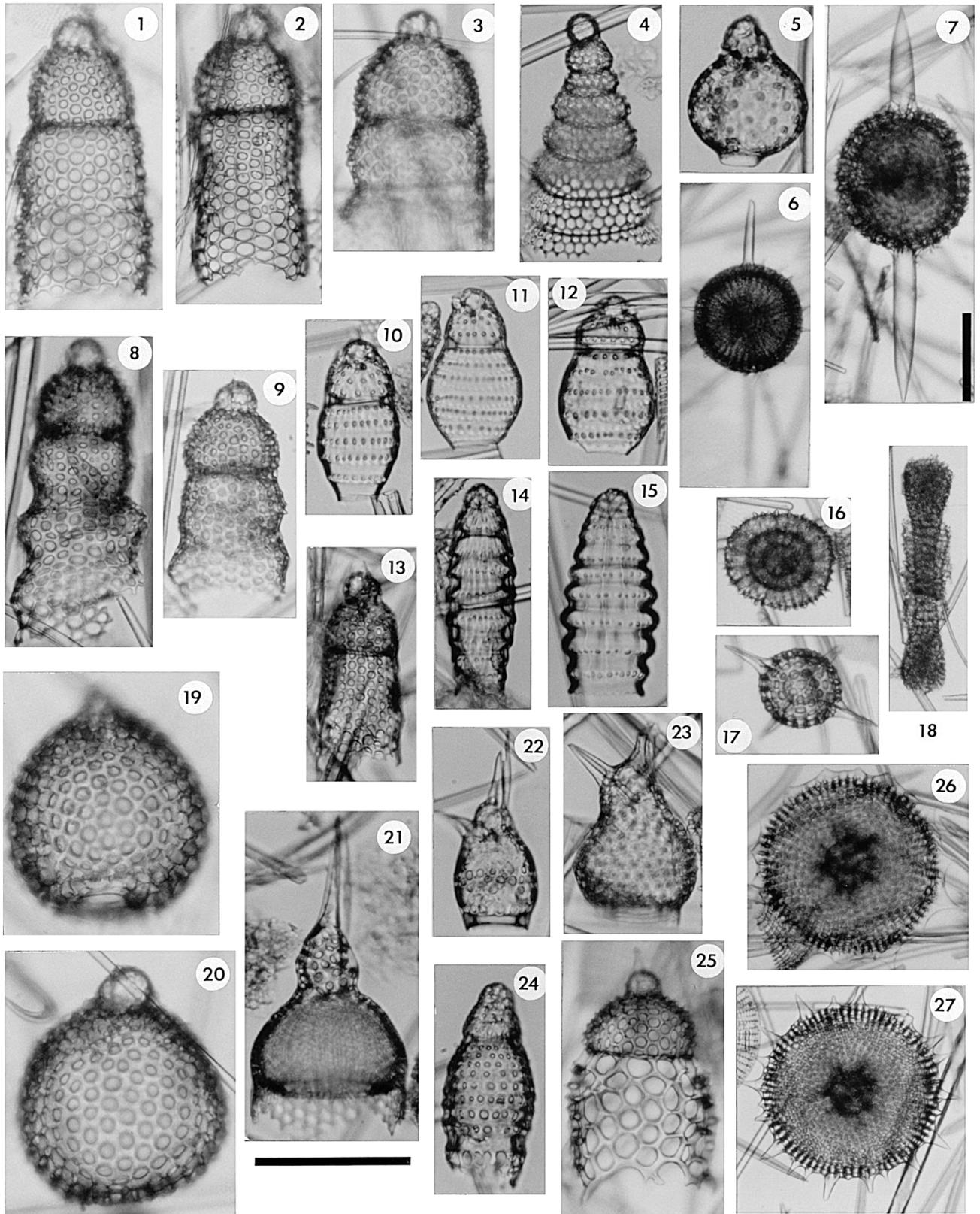


Plate P3. Scale bar = 10  $\mu\text{m}$  (magnification = 1250 $\times$ ). 1–3, 5–7, 11, 12. Sample 182-1128C-8H-4, 130–132 cm. 4, 8, 9, 10, 13–15. Sample 182-1128C-26X-3, 115–117 cm. (1) *Macrora stella* Hanna. (2, 3) *Cavitatus jouseanus* (Sheshukova-Poretzkaya) Williams. (4) Gen. & sp. indet. (5) *Distephanosira architecturalis* (Brun) Gleser. (6) *Pyxilla* sp. (7) *Pterotheca aculeifera* Grunow. (8) *Biddulphia* sp. (9) *Rutilaria* sp. (10) *Xanthiopyxis* sp. (11) *Thalassiothrix* sp. ? (12) *Cavitatus miocenicus* (Schradler) Williams. (13) *Campyloneis totarae* (Brun) Schradler. (14) *Cocconeis vitrea* Brun. (15) *Cocconeis* sp.

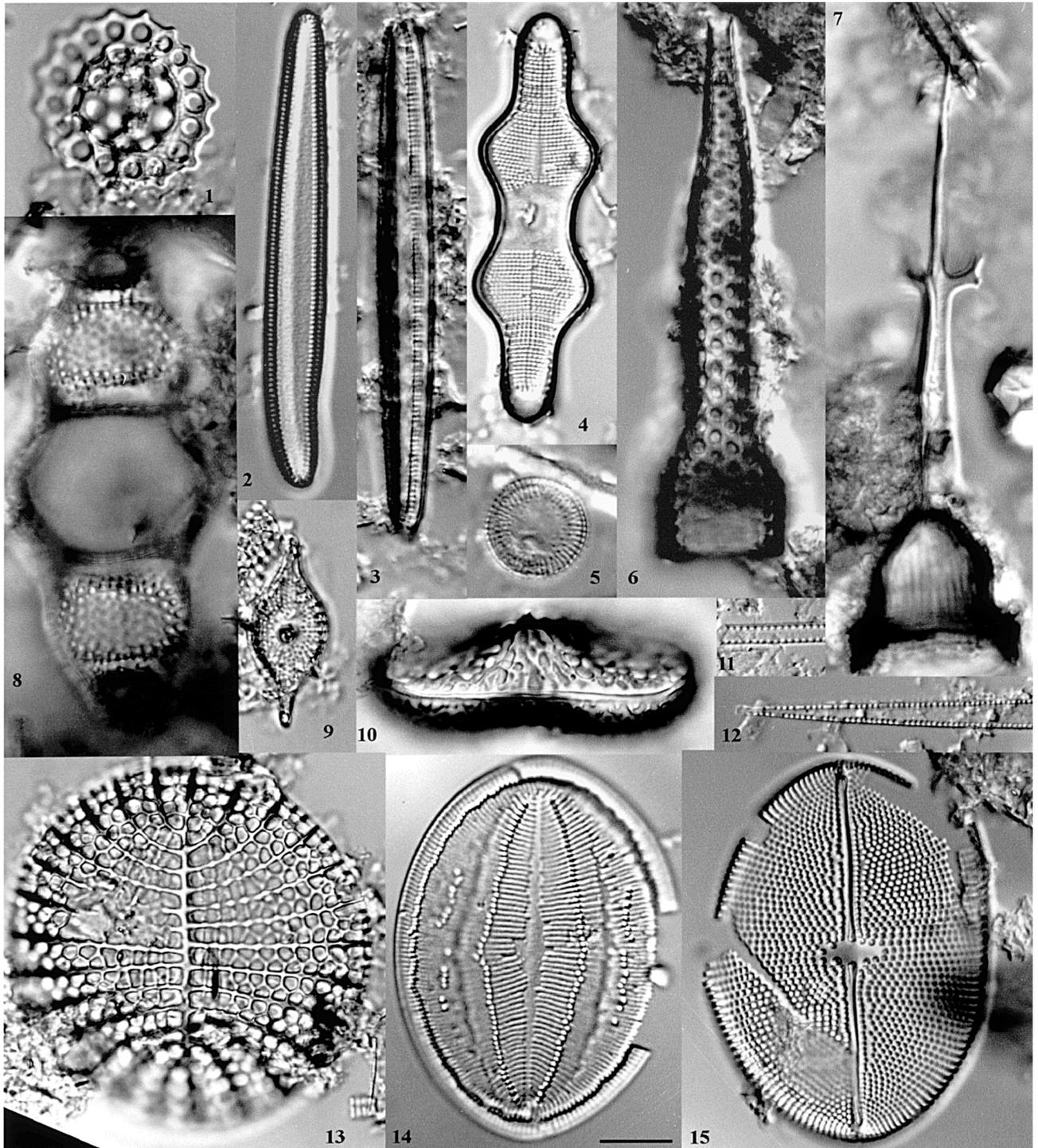


Plate P4. Scale bar = 10  $\mu\text{m}$  (magnification = 1250 $\times$ ). 1–5. Sample 182-1128C-26X-3, 115–117 cm. 6. Sample 182-1128C-8H-4, 130–132 cm. (1) *Cestodiscus* sp. (2) *Cestodiscus* sp. (3) *Azpeitia oligocenica* (Jousé) Sims. (4) *Cestodiscus* aff. *intersectus* (Brun) Reinhold. (5) *Azpeitia oligocenica* (Jousé) Sims. (6) *Rocella vigilans* Fenner.

