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24. EOCENE-OLIGOCENE DIATOMS IN THE WESTERN INDIAN OCEAN: TAXONOMY, STRATIGRAPHY, AND PALEOECOLOGY[1]

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ABSTRACT

The occurrence of diatom species in the Eocene-Oligocene sections of Ocean Drilling Program (ODP) Leg 115 sites and Deep Sea Drilling Project (DSDP) Sites 219 and 236 in the low-latitude Indian Ocean are investigated. Diatoms are generally rare and poorly preserved in the Paleogene sequences we studied. The best-preserved assemblages are found close to ash layers in early Oligocene sediments.

The low-latitude diatom zonation established for the Atlantic region by Fenner in 1984 is fully applicable to the Paleogene sequences of the western Indian Ocean. Correlation of the diatom zones to the calcareous nannofossil stratigraphy of the sites places the *Coscinodiscus excavatus* Zone of Fenner within calcareous nannofossil Subzone CP16b.

For the Mascarene Plateau and the Chagos Ridge, the times when the sites studied, together with the areas upslope from them, subsided to below the euphotic zone are deduced from changes in the relative abundance between the group of benthic, shallow-water species and *Grammatophora* spp. vs. the group of fully planktonic diatom species.

The Eocene section of Site 707, on the Mascarene Plateau, is characterized by the occurrence of benthic diatoms (approximately 10% of the diatom assemblage). These allochthonous diatoms must have originated from shallow-water environments around volcanic islands that existed upslope from ODP Site 707 in Eocene times. In Oligocene and younger sediments of Sites 707 and 706, occurrences of benthic diatoms are rare and sporadic and interpreted as reworked from older sediments. This indicates that the area upslope from these two Mascarene Plateau sites had subsided below the euphotic zone by the early Oligocene. Only *Grammatophora* spp., for which a neritic but not benthic habitat is assumed, continues to be abundant throughout the Oligocene sequences.

The area of the Madingley Rise sites (Sites 709–710) and nearby shallower areas subsided below the euphotic zone already in middle Eocene times, as benthic diatoms are almost absent from these Eocene sections. Only sites located on abyssal plains, and which intermittently received turbidite sediments (e.g., Sites 708 and 711), contain occasionally single, benthic diatoms of Oligocene age.

The occurrence of the freshwater diatom *Aulacosira granulata* in a few samples of late early Oligocene and late Oligocene age at Sites 707, 709, and 714 is interpreted as windblown. Their presence indicates at least seasonally arid conditions for these periods in the source areas of eastern Africa and India.

Three new species and two new combinations are defined: *Chaetoceros asymmetricus* Fenner sp. nov.; *Hemiaulus gracilis* Fenner, sp. nov.; *Kozloviella meniscosa* Fenner, sp. nov.; *Cestodiscus demergitus* (Fenner) Fenner comb. nov.; and *Rocella princeps* (Jousé) Fenner comb. nov.

INTRODUCTION

Published information on Paleogene diatoms from the Indian Ocean is sparse. Poorly preserved diatoms from the Eocene to the early Oligocene were reported from eastern Indian Ocean DSDP Sites 216 and 217, on the northern extensions of the Ninetyeast Ridge, and from DSDP Site 220 on the Laccadive Ridge (Fenner, 1984b). During Leg 115, we recovered diatom-bearing sediments of Eocene-Oligocene age in eight of ten sites (Figs. 1 and 2). These sites were drilled along two north-south transects in the western tropical-subtropical Indian Ocean. The sites cover a wide range of water depths (Table 1).

In this paper, we analyze the diatom assemblages from these sites in detail. Where preservation is sufficient, the diatoms are used for stratigraphic assignments and paleoecological interpretation. In addition, diatomaceous Paleogene sections from Sites 236 and 219 are also included in the present study.

METHODS

Samples from Leg 115 holes were processed by placing approximately 2–3 g of each sample in a 250-ml beaker. Then, 25 ml of 10% hydrochloric acid was added, and the sample gently heated until the liquid became light yellow. Treatment with 30% hydrogen peroxide was rarely required. The residue sample was washed by adding 200 ml of distilled water three times. The liquid was decanted after 1½ hr. The decanting process was repeated three times. Smear slides were prepared by transferring the suspended material with a disposable pipette to a 22- × 40-mm cover slip, which was dried and mounted with Hyrax on 22- × 75-mm glass slides.

The sample processing method for the DSDP samples is given in Fenner (1984b).

The slides were scanned at a magnification of 1000× in Leitz Orthomat photomicroscopes with oil immersion objectives (PL Apo Oel 100/1.32). The relative abundances of diatoms and other noncalcareous microfossil groups in the HCl-insoluble residue were recorded. Abundances are presented as in Fenner (in press): single (S) = <0.1%; rare (R) = 0.1%–1.0%; frequent (F) = 1.0%–10.0%; common (C) = 10.0%–30.0%; abundant (A) = 30.0%–50.0%; and dominant (D) = >50.0%. For these abundance estimates, a minimum of 300 valves were checked. However, diatom preservation was too poor in a number of samples to provide reliable abundance estimates. A complete list of all samples checked for presence/absence of diatoms is given in Table 2.

Estimates of the diatom preservation were obtained by combining observations of the relative abundance of dissolution-resistant species as *Grammatophora* spp., *Arachnoidiscus* spp., *Cocconeis* spp., *Hemiaulus exiguus, Paralia sulcata*, and robust

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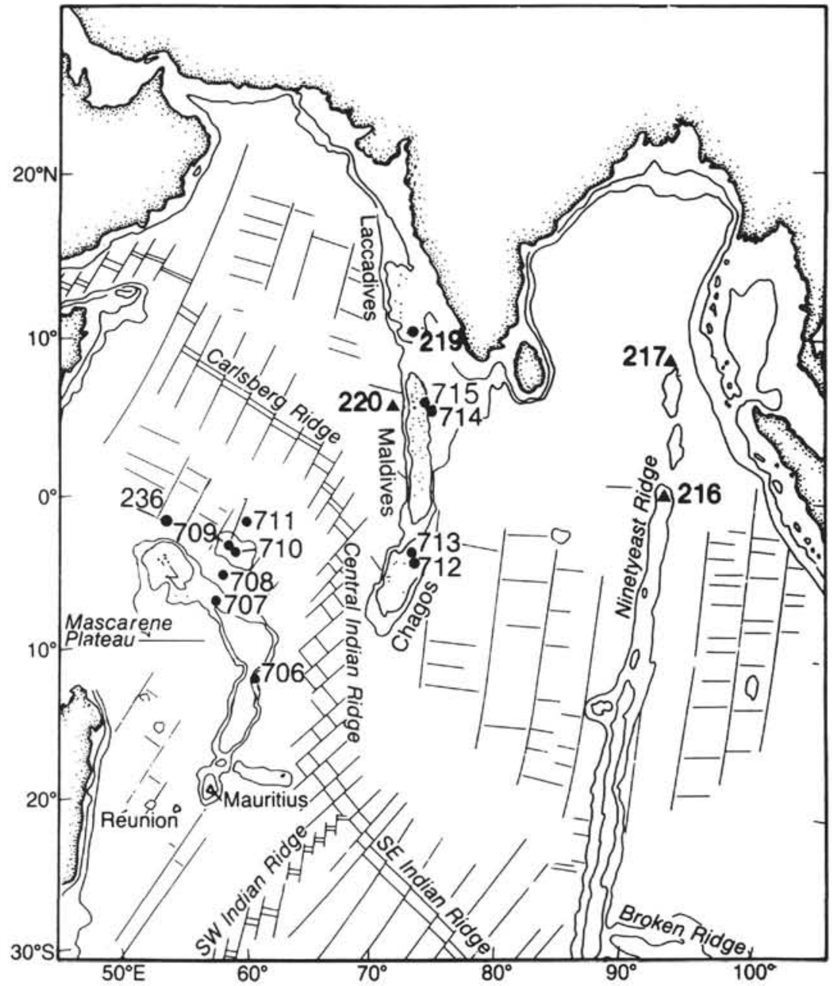

Figure 1. Regional setting and location of DSDP and ODP sites with Eocene-Oligocene diatomaceous sediments in the central Indian Ocean. Solid circles = sites analyzed for this study; Solid triangles = sites analyzed by Fenner (1984b).

shallow-water species of the genus *Triceratium* with observations of the degree of fragmentation and etching of the diatom valves. The categories differentiated are poor (P), moderate (M), good (G), and excellent (E).

RESULTS

Diatom Abundance and Preservation

The occurrences of diatoms through the middle Eocene to late Oligocene sections of the Leg 115 sites and DSDP Sites 219 and 236 are given in Figure 2 and Table 2.

In sediments of early middle Eocene age, diatoms are generally rare and poorly preserved. Moderately well-preserved diatom assemblages were encountered only in Holes 707C and 713A in the upper part of middle Eocene calcareous nannofossil Subzone CP13c. In Hole 707C a total number of not more than 8–16 species per sample were found, and in Hole 713A it was slightly more: 11–26 species per sample (Tables 3–5). In the late late Eocene sediments, diatom preservation improves. And in the Oligocene sections of sites around and from the Chagos-Mascarene Ridge system, an interval with well-preserved diatoms was recovered just below a series of ash layers occurring at the base of calcareous nannofossil Zone CP18. In the younger part of all the recovered Oligocene sequences, diatom preservation again is poorer.

Stratigraphy

In the middle Eocene and early late Eocene sections studied from the Indian Ocean, diatom preservation is so poor that no assignments to the diatom zones of Fenner (1984a) are possible. The middle Eocene is characterized by the occurrence of *Pseudopodosira* spp., *Craspedodiscus umbonatus, Abas wittii, Dextradonator eximius,* and *Strangulonema barbadense.* The fairly dissolution-resistant *Liostephania* spp. is enriched in these poorly preserved assemblages.

The late Eocene *Asterolampra marylandica* and *Baxteriopsis brunii* Zones of Fenner (1984a) are identified in the studied sections, the base of the later zone by the first abundant appearance (FAAD) of *B. brunii.* Other species that occur consistently in these late Eocene assemblages include *A. marylandica, Hemiaulus subacutus, H. altar,* and *H. lyriformis* (Fig. 3).

Correlation of the diatom FAADs with the calcareous nannofossil zones of Okada and Bukry (1980) determined for the Leg 115 sites by Okada (this volume) indicates that the early Oligocene *Coscinodiscus excavatus* Zone falls within Subzone CP16b. The strong increase in the abundance of *Cestodiscus* spp. occurs in the lower part of the *Cestodiscus reticulatus* Zone and in nannofossil Zone CP17 (Fig. 4). Whether the strong increase in *Chaetoceros asymmetricus* between 35.5 and 36 Ma is of stratigraphic importance or is environmentally controlled cannot be decided from the present material. Nor does the wide

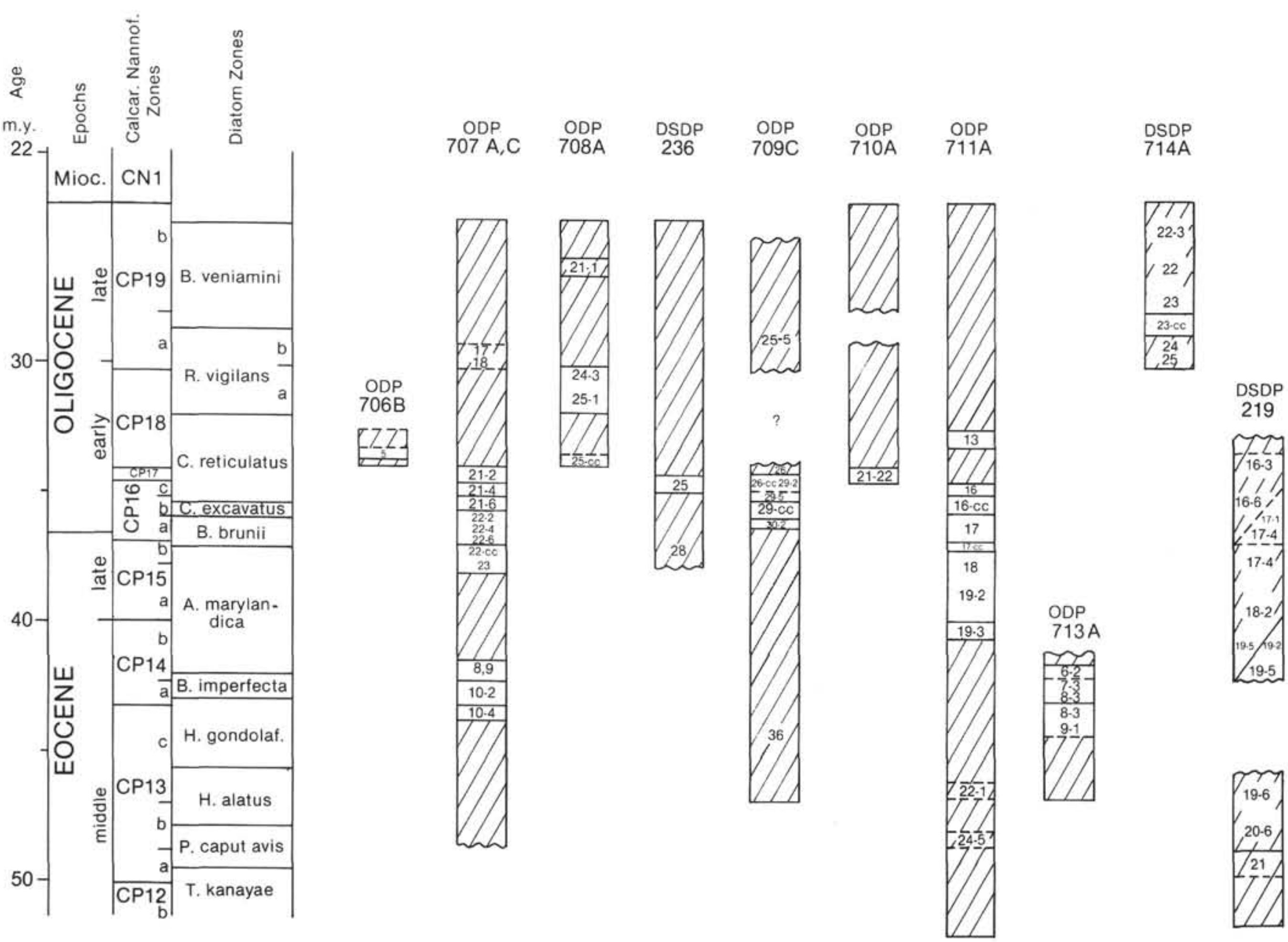

Figure 2. Summary of middle Eocene to late Oligocene diatom occurrences in the studied sites. The nannofossil zonation is of Okada and Bukry (1980) and the diatom zonation of Fenner (1984a). The Berggren et al. (1985) correlation of nannofossil zones against absolute time scale is used. Hatched intervals are barren of diatoms. In the marginally hatched intervals, diatoms are poorly preserved. The sites are arranged according to their latitudinal position north (right) to south (left).

Table 1. Location and water depth of studied Paleogene sections in DSDP and ODP sites of the western Indian Ocean.

Hole	Geographic position (latitude, longitude)	Water depth (m)
706B	13°06.86′S, 61°22.27′E	2507.5
707A	7°32.72′S, 59°01.00′E	1541.4
707C	7°32.73′S, 59°01.01′E	1541.4
708A	5°27.23′S, 59°56.63′E	4096.5
709B, C	3°54.72′S, 60°33.16′E	3038.2
710A	4°18.69′S, 60°48.76′E	3812.0
711A	2°44.46′S, 61°09.75′E	4428.2
712A	4°12.99′S, 73°24.38′E	2892.4
713A	4°11.58′S, 73°23.65′E	2909.5
714A	5°03.69′N, 73°46.98′E	2231.5
715A	5°04.89′N, 73°49.88′E	2269.3
219	9°01.75′N, 72°52.67′E	1764.0
236	1°40.62′S, 57°38.85′E	4487.0

sample spacing allow a decision to be made whether the onset of dominance of *C. asymmetricus* is time transgressive or not.

The identification of the base of the early Oligocene *Cestodiscus reticulatus* Zone and its accurate stratigraphic position is doubtful because of an interval of poor opal-A preservation at the base of the zone. Thus, *C. reticulatus* could be missing there because of dissolution rather than evolution.

The early to late Oligocene *Rocella vigilans* Zone with common *Synedra jouseana* and the name-giving species is represented in Section 115-708A-24X-3, 118–119 cm, to 115-708A-25X-1, 102–103 cm. Part of the *Bogorovia veniamini* Zone with *Rossiella symmetrica, Coscinodiscus rhombicus,* and *Lisitzinia ornata* as additional stratigraphic marker species is present in Section 115-714A-22X-CC to 115-714A-23X-CC.

The sequence of first appearances of stratigraphically important diatom species in the Oligocene of the Indian Ocean and their stratigraphic distribution (Fig. 3) agrees well with the observations by Fenner (1984a) from the low-latitude Atlantic.

Paleoecology

The dominant planktonic diatoms in the Eocene and early Oligocene Leg 115 sequences are typical low- to mid-latitude species such as *Hemiaulus altar, H. lyriformis, H. subacutus, Skeletonema barbadense, Chaetoceros asymmetricus, Cestodiscus gemmifer, C. reticulatus, C. parmula,* and *Coscinodiscus excavatus*. In the late Oligocene assemblages, cosmopolitan species such as *Synedra jouseana, Rocella vigilans, Coscinodiscus rhombicus,* and *Lisitzinia ornata* become dominant. These observations agree with the paleogeographic reconstructions of

Table 2. List of samples analyzed for presence/absence of diatoms. The abundance of diatoms is abbreviated as follows: present, +; fragments present but extremely rare and poorly preserved, (+); and absent, −.

Core, section, interval (cm)	Diatom abundance	Nannofossil zone	Diatom zone
115-706A-			
3H-1, 52–53	−	CP18	—
4H-CC	−	CP18	—
5H-CC	−	CP18	—
6H-CC	−	CP18	—
115-706B-			
1H-CC	−	CP18	—
2H-CC	−	CP18	—
3H-CC	−	CP18	—
4H-CC	−	CP18	—
5X-CC	(+)	CP18	*C. reticulatus*
6X-CC	−	CP18	—
7X-CC	−		
115-707A-			
16H-2, 105–106	−	CP19b	—
16H-4, 105–106	−	CP19b	—
16H-6, 105–106	−	CP19a	—
16H-CC	−	CP19a	—
17H-CC	+	CP19a	Oligocene
18H-CC	(+)	CP19a	Oligocene
19H-CC	(+)	CP18	—
20X-1, 105–106	−	CP18	—
20X-3, 105–106	−	CP17–CP16c	—
20X-CC	−	CP17–CP16c	—
21X-2, 105–106	+	CP17–CP16c	*C. reticulatus*
21X-4, 105–106	+	CP17–CP16c	*C. reticulatus*
21X-6, 105–106	+	CP16ab	*C. reticulatus*
21X-CC	−	CP16ab	—
22X-2, 105–106	(+)	CP16ab	—
22X-4, 105–106	(+)	CP16ab	—
22X-6, 105–106	(+)	CP16ab	*B. brunii*
22X-CC	+	CP15b	*A. marylandica*
23X-2, 105–106	(+)	CP15b	*A. marylandica*
23X-4, 105–106	(+)	CP15b	*A. marylandica*
23X-6, 105–106	−	CP15b	—
23X-CC	−	CP15a	—
115-707C-			
3R-2, 110–111	(+)	CP16a	early Oligocene
3R-4, 110–111	(+)	CP16a	*B. brunii*
3R-6, 110–111	(+)	CP16a	*B. brunii*
3R-CC	+	CP15b	*B. brunii*
5R-CC	−	CP15a	—
6R-CC	−	CP15a	—
7R-CC	−	CP14b	—
8R-CC	−	CP14b	—
9R-2, 51–52	(+)	CP14b	middle Eocene
9R-CC	+	CP14b	middle Eocene
10R-2, 110–111	+	CP14a	middle Eocene
10R-4, 110–111	(+)	CP13c	middle Eocene
10R-CC	−	CP13c	—
11R-CC	−	CP13c	—
13R-CC	−	CP13c	—
15R-CC	−	CP9a	—
16R-CC	−	CP8b	—
19R-CC	−	CP3–CP4	—
20R-CC	−	CP3–CP4	—
21R-1, 55–56	−	CP3–CP4	—
21R-CC	−	CP3–CP4	—
115-708A-			
20X-CC	−	CP19b	—
21X-1, 102–103	−	CP19b	—
21X-CC	−	CP19b	—
22X-2, 102–103	−	CP19a	—
22X-CC	−	CP19a	—

Table 2 (continued).

Core, section, interval (cm)	Diatom abundance	Nannofossil zone	Diatom zone
115-708A- (Cont.)			
23X-5, 102–103	−	CP19a	—
23X-CC	−	CP19a	—
24X-3, 118–119	(+)	CP18	*R. vigilans*
24X-CC	+	CP18	*R. vigilans*
25X-1, 102–103	(+)	CP18	*R. vigilans*
25X-CC	(+)	CP18	*C. reticulatus*
115-709B-			
22X-CC	−	CP19b	—
23X-CC	−	CP19b	—
24X-CC	−	CP19a	—
25X-CC	−	CP19a	—
26X-CC	−	CP18	—
27X-2, 102–103	(+)	CP17–CP18	—
27X-5, 102–103	(+)	CP17–CP18	—
27X-CC	+	CP17–CP18	*C. reticulatus*
115-709C-			
22X-CC	−	CP19b	
23X-CC	−	CP19b	
24X-CC	−	CP19a	
25X-CC	−	CP19a	
26X-2, 102–103	(+)	CP18	*C. reticulatus*
26X-5, 102–103	(+)	CP18	*C. reticulatus*
26X-CC	−	CP17	*C. reticulatus*
27X-2, 102–103	−	CP17	*C. reticulatus*
27X-4, 102–103	+	CP17	*C. reticulatus*
27X-CC	+	CP17	*C. reticulatus*
28X-2, 102–103	(+)	CP17	*C. reticulatus*
28X-CC	+	CP17	*C. reticulatus*
29X-2, 102–103	+	CP17	*C. reticulatus*
29X-5, 102–103	+	CP16c	*C. excavatus/ C. reticulatus*
29X-CC	+	CP16ab	*C. excavatus*
30X-2, 102–103	+	CP16ab	late Eocene
30X-5, 102–103	(+)	CP16ab	—
30X-CC	−	CP15b	—
31X-CC	−	CP15a	—
32X-CC	−	CP15a	—
33X-CC	−	CP14b	—
34X-CC	−	CP14b	—
35X-CC	−	CP13c	—
36X-CC	(+)	CP13c	middle? Eocene
37X-CC	−	CP13b	
115-710A-			
16X-2, 102–103	−	CP19b	—
16X-CC	−	CP19b	—
17X-2, 102–103	−	CP19b	—
17X-CC	−	CP19a	—
18X-2, 102–103	−	CP19a	—
18X-CC	−	CP19a	—
19X-2, 102–103	−	CP19a	—
19X-5, 102–103	−	CP19a	—
19X-CC	−	CP19a	—
20X-2, 102–103	−	CP19a	—
20X-5, 102–103	−	CP18	—
20X-CC	−	CP18	—
21X-2, 102–103	−	CP17	*C. reticulatus*
21X-5, 102–103	(+)	CP17	*C. reticulatus*
21X-CC	−	CP17	*C. reticulatus*
22X-2, 102–103	(+)	CP17	*C. reticulatus*
22X-CC	−	CP17	
115-711A-			
9H-CC	−	CP19b	—
10H-CC	−	CP19b	—
11H-CC	−	CP19a	—
12X-CC	−	CP19a	—
13X-5, 102–103	−	CP18	—
13X-CC	+	CP18	*C. reticulatus*

Table 2 (continued).

Core, section, interval (cm)	Diatom abundance	Nannofossil zone	Diatom zone
115-711A- (Cont.)			
14X-CC	-	CP17	—
15X-CC	-	CP16c	—
16X-1, 102–103	+	CP16c	*C. reticulatus*
16X-3, 102–103	(+)	CP16c	*C. excavatus/ C. reticulatus*
16X-5, 102–103	-	CP16c	*C. excavatus/ C. reticulatus*
16X-CC	(+)	CP16ab	*C. excavatus*
17X-1, 102–103	(+)	CP16ab	*B. brunii*
17X-3, 102–103	-	CP16ab	—
17X-5, 102–103	-	CP16ab	—
17X-CC	+	CP15	*B. brunii*
18X-1, 103–104	(+)	CP15	*A. marylandica*
18X-3, 103–104	-	CP15	—
18X-CC	-	CP15	—
19X-1, 102–103	-	CP15	—
19X-2, 7–8	(+)	CP15	*A. marylandica*
19X-2, 79–80	+	CP15	*A. marylandica*
19X-3, 102–103	(+)	CP14	*A. marylandica*
19X-5, 102–103	-	CP14	—
19X-CC	-	CP14	—
20X-1, 102–103	-	CP14	—
20X-3, 45–46	-	CP14	—
20X-CC	-	CP14	—
21X-3, 102–103	-	CP14	—
21X-CC	-	CP13c	—
22X-1, 102–103	(+)	CP13c	middle? Eocene
22X-3, 102–103	-	CP13c	—
22X-CC	-	CP13c	—
23X-1, 102–103	-	CP13c	—
23X-3, 102–103	-	CP13c	—
23X-CC	-	CP13b	—
24X-3, 102–103	-	CP13b	—
24X-5, 102–103	-	CP13b	middle? Eocene
24X-CC	-	CP13b	—
25X-3, 102–103	-	CP13a	—
25X-CC	-	CP13a	—
115-711B-			
10H-CC	-	CP19b	—
11H-CC	-	CP19a	—
115-712A-			
11R-CC	-	CP19a	—
12R-1, 102–103	-	CP14b	—
12R-3, 102–103	-	CP14b	—
12R-CC	-	CP14b	—
115-713A-			
5R-1, 102–103	-	CP14b	—
5R-3, 102–103	-	CP14b	—
5R-CC	-	CP14b	—
6R-3, 102–103	(+)	CP14b	middle Eocene
6R-CC	-	CP14b	—
7R-1, 103–104	-	CP14b	—
7R-3, 103–104	(+)	CP14a	middle Eocene
7R-5, 103–104	(+)	CP14a	middle Eocene
7R-CC	(+)	CP14a	—
8R-1, 102–103	(+)	CP14a	middle Eocene
8R-3, 100–101	(+)	CP14a	—
8R-CC	(+)	CP13c	middle Eocene
9R-1, 102–103	(+)	CP13c	middle Eocene
9R-CC	-	CP13c	—
10R-CC	-	CP13c	—
11R-CC	-	CP13c	—
17R-1, 91–92	-	CP13c	—
115-714A-			
22X-CC	(+)	CP19b	*B. veniamini*
23X-1, 102–103	(+)	CP19b	*B. veniamini*
23X-3, 102–103	(+)	CP19b	*B. veniamini*
23X-CC	+	CP19a	*B. veniamini*
24X-1, 102–103	(+)	CP19a	Oligocene
24X-CC	-	CP19a	Oligocene

Table 2 (continued).

Core, section, interval (cm)	Diatom abundance	Nannofossil zone	Diatom zone
115-714A-(Cont.)			
25X-1, 102–103	(+)	CP19a	—
25X-CC	-	CP19a	—
115-715A-			
14R-CC	-	early Eocene	—
23-219-			
15-1, 64–69	-	CP17	—
15-2, 56–60	-	CP17	—
15-3, 57–62	-	CP17	—
15-5, 54–59	-	CP17	—
15-6, 54–59	-	CP17	—
16-1, 42–47	-	CP16	—
16-2, 63–68	-	CP16	—
16-3, 63–68	-	CP16	—
16-4, 43–48	-	CP16	—
16-4, 104–109	(+)	CP16	—
16-5, 63–68	(+)	CP16	—
16-6, 76–81	(+)	CP16	—
17-1, 60–65	(+)	CP15	—
17-1, 89–93	+	CP15	—
17-2, 44–49	+	CP15	—
17-3, 61–66	+	CP15	late Eocene?
17-4, 61–66	+	CP15	late Eocene?
17-4, 102–106	+	CP15	late Eocene?
17-5, 41–46	+	CP15	late Eocene?
17-5, 61–66	+	CP15	late Eocene?
18-1, 61–66	(+)	CP15	—
18-1, 93–98	+	CP15	late Eocene?
18-2, 61–66	+	CP15	late Eocene?
18-4, 61–66	+	CP14	late Eocene?
18-5, 61–66	(+)	CP14	—
18-6, 61–66	+	CP14	—
19-1, 58–63	(+)	CP14	late Eocene?
19-2, 61–66	+	CP14	—
19-3, 61–66	(+)	CP14	—
19-4, 61–66	+	CP14	—
19-5, 61–66	+	CP14	—
19-6, 61–66	-	CP14	—
20-1, 122–127	(+)	CP14	—
20-2, 68–73	(+)	CP14	—
20-3, 68–73	(+)	CP14	—
20-4, 60–65	(+)	CP14	—
20-5, 60–65	(+)	CP14	—
20-6, 40–45	(+)	CP14	—
21-1, 60–65	(+)	CP14	—
21-2, 65–70	(+)	CP14	—
21-3, 60–65	(+)	CP14	—
24-236-			
23-5, 60–65	-	CP17	—
24-3, 60–65	-	CP17	—
25-3, 60–65	-	CP16–CP17	—
26-3, 60–65	-	CP16	—
27-2, 60–65	-	CP16	—
28-1, 46–48	+	CP15	late Eocene?

McKenzie and Slater (1971), indicating that all of the sites studied here were located during Eocene and early Oligocene times between 20°S and 5°N of the equator. The change to more cosmopolitan species in the late early Oligocene and late Oligocene is not a local phenomenon but found also in age-equivalent sediments of other ocean basins, from low and high latitudes (see Fenner 1982, 1984a, 1985).

Eocene

Mascarene Plateau, Chagos Ridge

Where middle and late Eocene diatom assemblages are preserved (Cores 115-707A-22X and -23X, 115-707C-3R to -10R,

Table 3. Occurrence charts of Paleogene diatoms species in Holes 706B, 707A, 707C, and 708A from the Mascarene Plateau and the abyssal plain north of it.

Age	Zone	Hole	Core, section, interval (cm)	Ash	Clinoptilolite	Pollen	Fish scales	Foraminifer casts	Phytoliths	Endoskeletal dinoflagellates	Spermatogonia	Sponge spicules	Radiolarians	Archaeomonadaceae	Silicoflagellates	Diatoms	Diatom preservation	*Aulacosira granulata* (freshwater diatom)	*Actinocyclus octonarius*	*Abas wittii*	*Arachnoidiscus* spp.
early Oligocene	*C. ret.*	706B	5-CC	F		S						D	—	F		R	P				
?	?	707A	17H-CC	F	R			R	R			A	C			S	P	D			
			18H-CC									C	A			R	P				R
early Oligocene	*C. retic.*		21X-2, 105–106	R			F	F				A	A			F	P/M				
			21X-4, 105–106	S			S	S				C	A			A	M		R		
			21X-6, 105–106	R			S				R	C	A		S	A	M		S		
	?		22X-2, 105–106						S			A	A			F	P/M				F
			22X-4, 105–106	F			S		S			A	A	S		R	P/M				F
late Eocene	*B. brun.*		22X-6, 105–106	R		S						C	A	S	S	C	P/M				F
			22X-CC									C	A			C	P/M				C
	A. maryl.		23X-2, 105–106	S			S					C	A			C	P/M				F
			23X-4, 105–106	R								A	A	S		F	P/M				F
early Oligocene	?	707C	3R-2, 110–111			S	R					C	A			C	P/M				
	B. brunii		3R-4, 110–111				S					A	A		S	R	P/M				F
			3R-6, 110–111						S			A	A			C	P/M				F
late Eocene			3R-CC						S		S	A	A		S	C	M				F
middle Eocene	?		9R-2, 51–52	S			R					A	A			F	P			F	F
			9R-CC									A	A		S	R	P/M				F
			10R-2, 110–111				S					A	A			R	P			F	F
			10R-4, 110–111									A	A			R	P			F	F
early Oligocene	*R. vigil.*	708A	24X-3, 118–119	S			S		S			D	R	S	R	R	M				S
			24X-CC	R			R	R				A	A		F	R	M				F
			25X-1, 102–103	R					S			A	A	S	R	R	P/M				
	C. ret.		25X-CC	S			S		S	S		R	A	S		C	M				

Note: For explanation of symbols for diatom preservation and abundance, see "Methods" section, this chapter.

and 115-713A-6R to -9R), the high abundance of benthic diatom species of the genera *Triceratium, Entogonia, Isthmia, Cocconeis, Diploneis,* and *Arachnoidiscus* is conspicuous. Based on benthic foraminifers (Backman, Duncan, et al., 1988), these sequences are interpreted as deposited under middle to upper bathyal conditions. Benthic diatoms account on average for 10%–20% of the diatom assemblages in these sections, with maximum values around 30%.

Most of the benthic, shallow-water diatom species found in the sites from the Indian Ocean were described originally from the Eocene island-arc environments around Barbados (Greville, 1860 ff.). The shallow-water diatoms are also allochthonous and embedded in slope sediments there. Barbados, like the other lesser Antilles islands, formed in the open ocean in connection with an active subduction zone, thus creating an environment similar to that of the ridge systems in the Indian Ocean.

In addition to the supply from the coastal environment, the abundance of thickly silicified, more dissolution-resistant valves of shallow-water species is probably enhanced in slope sediments as a result of selective dissolution of the more fragile valves of oceanic species. It is difficult to assess the magnitude of silica dissolution. But whatever its size, upslope from both sites on the northern part of the Chagos Ridge and the Mascarene Plateau (Sites 707 and 713), islands with coastal environments must have existed that supplied the biosiliceous shallow-water components to the area of the drilling sites.

Madingley Rise

In contrast, Site 709 on the Madingley Rise contains only few and very poorly preserved diatom fragments (Cores 115-709C-30X and -36X). These assemblages consist almost entirely of planktonic diatoms with only single and sporadically occurring fragments of shallow-water species. This is interpreted as sediment deposition far away from coastal environments of volcanic islands, inferring that by late Eocene times the Madingley Rise must have subsided to at least below the euphotic zone, if not much deeper. Also, the better-preserved late Eocene diatom assemblages recovered from Site 711 (Cores 115-711A-17X to -24X) on the abyssal plain north of Madingley Rise reflect deposition in an open-ocean environment.

Oligocene

Diatomaceous sediments of early Oligocene age were recovered from practically all sites from the Mascarene Plateau and Madingley Rise.

Mascarene Plateau

By early Oligocene time, the island or islands on the Mascarene Plateau directly upslope from Sites 706 and 707 must have subsided below the euphotic zone, as only sporadic fragments of benthic diatoms are present in the sediments. These fragments very probably were reworked from older shallow-water

Table 3 (continued).

Asterolampra affinis	*Asterolampra grevillei*	*A. marylandica*	*A. punctifera*	*A. vulgaris*	*A. vulgaris* var. a	*Baxteriopsis brunii*	*Bogorovia veniamini*	*Briggera* spp.	*Cestodiscus convexus*	*C. demergitus*	*C. gemmifer*	*C. mukhinae*	*C. parmula*	*C. pulchellus*	*C. reticulatus*	*C. stokesianus*	*C. trochus*	*C.* sp. 1	*C.* sp.	*Chaetoceros asymmetricus*	*Ch.* sp. 1	*Ch.* sp. 2	*Ch.* sp.	*Clavicula* spp.	*Cocconeis* spp.	*C. excavatus*	*C. grossheimii*
											F						R			R					R		
		S											S														
		C						S																			
	F	F				R					C		S	F			R	R		F							
		C				R			R	S	F			F		S	F			D						R	
	S	F		S		S				R	F			R	S		F	S		D						F	
			S					S			S	R						S		F	C		F	S	S		
						S											F			F			S	S	F		
		F	S	R		F		R				F					F	S			C	R		S	F		
		F		S		S		S		S		F					S				C	F			F		
				S		S		R				R									C				F		
								S				R				S					C				F		
		F	F	S		S		R				F						F	F	C					F		
												R								F				F	F		
		R	R			R		S		S							R				C			R	F		
		R	S	R	S	R		R				R					S				C	F		R	F		
								C																	C		
								F																	S		
																									F		
								F																	F		
S		R				R					S		S							F				S	F		
	R	R						S			R	R	R			R			S	C					R		
						R														C							
												R	R							D					R		

sediments. Only *Grammatophora* spp., which was common to dominant already in the Eocene sediments at these sites, continues to be common to dominant in the early Oligocene diatom assemblages. The present-day habitat of species of this genus is described (e.g., Simonsen, 1974) as littoral and also present in the plankton of the shelf areas. Thus, the dominance of this species in the assemblages is not in conflict with the proposed subsidence of the upslope areas to below the euphotic zone. In addition, one of the authors (J. Fenner) has found that the septa of *Grammatophora* spp. are very dissolution resistant, and in strongly dissolved Oligocene assemblages these septa are frequently the last diatom-derived particles to be dissolved. Thus, their high abundance in the sequences studied is a result, at least in part, of selective dissolution.

Madingley Rise

Like during the Eocene, diatoms recovered from Sites 709 and 710 on the Madingley Rise continue to reflect sedimentation unaffected by shallow-water input also during the Oligocene. In the abyssal sites (in abyssal Site 708 on the abyssal plain between the Mascarene Plateau and the Madingley Rise and Site 711 north of the Madingley Rise), the Oligocene sections furnish a few benthic shallow-water diatoms. These diatoms have presumably been transported over long distances, as the sections are characterized by frequent interbedded turbidites (Backman, Duncan, et al., 1988). Based on reworking of planktonic foraminifers, Premoli Silva and Spezzaferri (this volume) believe that the source area of the turbidites is well below the lysocline. Diatom assemblage analyses point in the same direction. The scarcity of shallow-water diatoms and of reworked diatoms in these turbidite sediments indicate that they must have originated from a region rarely reached by dislocated coastal diatoms. Turbidite sedimentation is not recorded at the abyssal DSDP Site 236 northeast of the Seychelles Islands. Furthermore, this site is far from land; therefore, it is not astonishing that only very rare diatom remains are found.

Late Oligocene sediments are generally barren of diatoms or have been eroded as at Sites 219 and 713 on the Chagos-Laccadive Ridge. Only at Site 714 on the northern Maldives Ridge are moderately preserved diatom assemblages of late Oligocene age encountered. These assemblages with admixed benthic diatoms reflect a deposition not too far away from a coastal island environment.

A few late early Oligocene and late Oligocene samples from Sites 707, 709, and 714 (Tables 3–5) contain relatively high numbers of freshwater diatoms (in Hole 707A, up to approximately 50%). These occurrences of the freshwater diatom *Aulacosira granulata* are interpreted as wind-blown since no brackish water and benthic freshwater diatoms co-occur. If this conclusion is correct, periods of at least seasonally arid conditions have to be assumed for the source areas of these diatoms (eastern Africa and India, respectively) in the late early Oligocene and the late Oligocene.

Table 3 (continued).

Age	Zone	Hole	Core, section, interval (cm)	*C. hajosiae*	*C. marginatus*	*C. oligocenicus*	*C. radiatus*	*C.* sp.	*Craspedodiscus coscinodiscus*	*C. umbonatus*	*Dextradonator eximius*	*Diploneis* spp.	*Entogonia* spp.	*Ethmodiscus* spp.	*Grammatophora* spp.	*Hemiaulus altar*	*H. barbadensis*	*H. claviger*	*H. exiguus*	*H. incisus*	*H. klushnikovii*
early Oligocene	*C. ret.*	706B	5-CC												D						
?	?	707A	17H-CC									R			A						
			18H-CC												D						
early Oligocene	*C. retic.*		21X-2, 105–106												A	R					S
			21X-4, 105–106			F	S								F	R					
			21X-6, 105–106	R		R			S						R	F					
	?		22X-2, 105–106			S							S		D	S			S		
late Eocene			22X-4, 105–106										S		D	S			F		
	B. brun.		22X-6, 105–106			F								S	A	F			F		
	A. maryl.		22X-CC			F						F			C	F			F		
			23X-2, 105–106			S								S	A	R			F		
			23X-4, 105–106											S	D			S	S	F	
early Oligocene / late Eocene	?	707C	3R-2, 110–111			S								R	A	F	S				
	B. brunii		3R-4, 110–111			F							F		D	R					
			3R-6, 110–111					R					F		A	S			F		
			3R-CC			F						R	F		A	S			F		
middle Eocene	?		9R-2, 51–52										C	C							
			9R-CC							C	F	R	C	R	R						
			10R-2, 110–111							C			C	F							
			10R-4, 110–111							C			C		F						
early Oligocene	*R. vigil.*	708A	24X-3, 118–119												D	F				F	
			24X-CC			R	R								A	F					
			25X-1, 102–103			F	R	F							F	F					
	C. ret.		25X-CC			F		R							F	F			S		

TAXONOMY

All species encountered in the Eocene-Oligocene sequences studied are listed alphabetically in the following taxonomic list. References to the first description, and in some cases to a later, more informative description, and a better illustration are provided. For a comprehensive list of synonyms, the reader is referred to Mills (1933–1935) and Van Landingham (1967–1979).

Genus *ACTINOCYCLUS* Ehrenberg (1837)

Actinocyclus octonarius Ehrenberg (1837)

Description. Hustedt (1930), sp. 525–528, fig. 298 as *A. ehrenbergii* Ralfs in Pritchard (1861).

Genus *ABAS* Ross and Sims (1980)

Abas wittii (Grunow) Ross and Sims (1980)

Description. Van Heurck (1880–1885), pl. 106, fig. 4 (1883), Ross and Sims (1980), p. 120, pl. 2, figs. 10–15.

Genus *ACTINOPTYCHUS* Ehrenberg (1841)

Actinoptychus senarius Ehrenberg (1837)

Description. Hustedt (1930), pp. 475–478, fig. 264 as *A. undulatus* (Bailey) Ralfs, in Pritchard (1861).

Remark. All "senarius-like" species, which have six alternatively raised or depressed radial sectors and no special structure (e.g., hyaline central or marginal areas), were listed under this name.

Actinoptychus splendens (Shad.) Ralfs in Pritchard (1861)

Description. Hustedt (1930), pp. 478–479, fig. 265.

Genus *ARACHNOIDISCUS* Deane ex Pritchard (1852)

Arachnoidiscus spp.

Remarks. All recent species of this genus are littoral (Hustedt, 1930). Therefore, the occurrence of species of this genus has been used in this study as a paleoenvironmental indicator. Taxonomic identification was not pursued to the species level.

Genus *ASTEROLAMPRA* Ehrenberg (1844a)

Asterolampra affinis Greville (1862)

Description: Greville (1862), pp. 45–46, pl. 7, figs. 7–9.

Asterolampra grevillei (Wallich) Greville (1860)

Description. Hustedt (1930), p. 489, fig. 274.

Asterolampra marylandica Ehrenberg (1844a)

Description. Hustedt (1930), pp. 485–487, fig. 271.

Asterolampra punctifera (Grove) Hanna (1927)

Synonym. *Asterolampra affinis* Grev. var. *punctifera* Grove (1896) in A. Schmidt et al. (1874–), pl. 202, fig. 18.
Description. Hanna (1927), p. 109, pl. 17, fig. 3.

Table 3 (continued).

H. longicornis	*H. gracilis*	*H. lyriformis*	*H. polycystinorum*	*H. polycystinorum* var. *mesolepta*	*H.* sp. ("*pyxilloides*")	*H. subacutus*	*H. taurus*	*H.* sp.	*Hyalodiscus* spp.	*Isthmia* spp.	*Liostephania* of *Asterolampra* spp.	*Lisitzinia ornata*	*Melosira architecturalis*	*Navicula* spp.	*Paralia sulcata*	*Pseudopodosira* spp.	*Rhaphoneis immunis*	*Rhizosolenia hebetata*	*R. interposita*	*R.* sp. 1	*Rocella vigilans*	*R. vigilans* (concentrically undulated)	*R. vigilans* — *R. praenitida* (transitional forms)	*Sceptroneis* spp.	*Skeletonema barbadense*	*Stephanopyxis* spp.	*Synedra* aff. *hennedyuna*
													R		F												
S		S											R														
S		R				F												S	S						F		S
S	S	R	S			F	R						S	S				S	S						S		
		S				F	S				F		F		F			S								S	
	S	S	S			C							S		F												
	S	R	S	S		C							F	S	C									S			
R				S		R									C												
		S				R					C				C												
						S			S		F				C												
		F				F	S						F		F					S					R		
			S			F		F							F												
		S				F							S		C												
		F	S	S		F		R							C										F		
															A											S	
										R					D	R			S								
											C				A												
											C				A	R											
						F							F		F						R		F	S			
		R			R	F		S					F	R	F			R					F	R	R	R	
		R				F							F		R		S	R			F	F	F	R			
R		R				F							S					S					R				

Asterolampra vulgaris Greville (1862)

Description. Greville (1862), p. 47, pl. 7, figs. 17–25; Fenner (1985), p. 727, fig. 7.27.

Genus *AULACODISCUS* Ehrenberg (1844a)

Aulacodiscus spp.

Remarks. Species of the genus *Aulacodiscus* are known to be predominantly littoral. The occurrences of species of this genus were used in this study as paleoenvironmental indicators. Determination to the species level was not done.

Genus *AULACOSIRA (AULACOSEIRA)* Thwaites (1848)

Aulacosira granulata (Ehr.) Simonsen (1979)

Description. Hustedt (1930), pp. 248–252, figs. 104–105.
Remarks. This species is a planktonic freshwater species and allochthonous in marine sediments. It is known from sediments of middle Eocene age to the present. Varieties of this species were not differentiated.

Genus *BAXTERIOPSIS* Karsten (1928)

Baxteriopsis brunii (Van Heurck) Karsten (1928)

Description. Van Heurck (1896), p. 460, fig. 190 as *Baxteria brunii*, Fenner (1985), p. 727, fig. 10.7–10.8.

Genus *BOGOROVIA* Jousé (1974)

Bogorovia veniamini Jousé (1974)

Description. Jousé (1974), p. 351, pl. 4, figs. 1–3.

Genus *BRIGGERA* Ross and Sims (1985)

Briggera spp.

Remarks. Species of this genus were not differentiated because no complete specimens were found.

Genus *CESTODISCUS* Greville (1865b)

Cestodiscus convexus Castracane (1886)

Synonym. *Cestodiscus pulchellus* Grev. sensu Jousé (1974), p. 345, 348, pl. 1, figs. 12–13.
Description. Castracane (1886), p. 123, pl. 7, fig. 6.

Cestodiscus demergitus (Fenner) comb. nov.

Synonym. *Coscinodiscus demergitus* Fenner (1978), p. 514, pl. 4, figs. 1–3.
Description. Fenner (1978), p. 514, pl. 4, figs. 1–3.
Remarks. Because of the marginal ring of labiate processes and the lack of any other labiate process on the valve face, and because of the structurally offset margin, this species is transferred to the genus *Cestodiscus* Grev.

Cestodiscus gemmifer Castracane (1886)
Plate 1, Figure 3

Synonyms. *Coscinodiscus superbus* Hardman, ms, in Rattray (1889), p. 458; *Cestodiscus* aff. *pulchellus* Jousé (1974) in part, Jousé (1974), pl. 1, fig. 11, not figs. 9–10.

Cestodiscus mukhinae Jousé (1974)

Description. Jousé (1974), pp. 344–345, pl. 1, figs. 1–5.

Table 3 (continued).

Age	Zone	Hole	Core, section, interval (cm)	*S. jouseana*	*Thalassionema nitzschioides*	*Thalassiosira bukryi*	*Thalassiothrix longissima*	*Triceratium americanum*	*T. areolatum*	*T.* sp. (large, shallow-water species)	*Trinacria subcapitata*	*Trochosira* aff. *trochlea*	*Xanthiopyxis* spp.	Genus et Species indet. 1	Genus et Species indet.	*Macrora barbadensis*	*M. stella*
early Oligocene	*C. ret.*	706B	5-CC										R				
?	?	707A	17H-CC														
			18H-CC														
early Oligocene	*C. retic.*		21X-2, 105–106			R		R						R		F	F
			21X-4, 105–106			S					S		S	S		R	F
			21X-6, 105–106								S			S		R	F
	?		22X-2, 105–106											S	S	S	S
			22X-4, 105–106							S					S		
late Eocene	*B. brun.*		22X-6, 105–106							F				F	S	F	F
			22X-CC							F				F		F	
	A. maryl.		23X-2, 105–106							F			S	R		F	
			23X-4, 105–106											R		F	
early Oligocene / late Eocene	?	707C	3R-2, 110–111							S					S	F	F
	B. brunii		3R-4, 110–111							F				S	R	F	R
			3R-6, 110–111							F				S	S	F	
			3R-CC							F			R		S	F	S
middle Eocene	?		9R-2, 51–52							C							
			9R-CC							C				R		S	
			10R-2, 110–111							F							
			10R-4, 110–111							F							
early Oligocene	*R. vigil.*	708A	24X-3, 118–119	F	R		F			F			R		S	R	F
			24X-CC						S	R		S		S		F	R
			25X-1, 102–103		F											F	F
	C. ret.		25X-CC	S	R	S							S				F

Cestodiscus parmula Castracane (1886)

Description. Castracane (1886), p. 125, pl. 7, fig. 5.

Cestodiscus pulchellus Greville (1866b)

Description. Greville (1866b), p. 123, pl. 11, fig. 5.

Cestodiscus reticulatus Fenner (1984a)

Description. Fenner (1984a), p. 331, pl. 1, fig. 10.

Cestodiscus stokesianus Greville (1866b)

Description. Greville (1866b), p. 123, pl. 11, fig. 4.

Cestodiscus trochus Castracane (1886)

Description. Castracane (1886), p. 123, pl. 7, figs. 1 and 3.

Cestodiscus sp. 1

Description. The valve outline is circular. The valves have an undulated valve face and a steep margin. The valve diameter varies between 20 and 100 μm. The number of areolae is 4–6 in 10 μm. A ring of marginal processes is present along the upper border of the structurally offset margin.

Genus *CHAETOCEROS* Ehrenberg (1844b)

Chaetoceros asymmetricus Fenner sp. nov.
Plate 5, Figures 3–4

Description. From a rather small, convex valve of oval outline two setae rise. One is relatively robust, carries punctae, and is curved. The other is much thinner and mostly broken off close to the valve face. On the sloping valve face between the center and the margin of the valve, a circular area is surrounded by spines. In the center of this area, a large, inward protruding, labiate process is located.

Paleogeographic occurrence. This species was found in early Oligocene sediments off northwest Africa (Fenner, 1982; listed as *Chaetoceros* sp. 1) and in all early Oligocene diatomaceous Leg 115 sediments.

Differential diagnosis. This species differs from all other species of the genus *Chaetoceros* by the two very different setae on the valve face, the position of the labiate process, and the structure surrounding it.

Holotype. Plate 5, Figure 3, from DSDP Sample 41-369A-22-5, 128–129 cm.

Chaetoceros sp. 1

Description. Only fragments of the setae of this species were found. They are robust and curved and carry punctae.

Chaetoceros sp. 2
Plate 5, Figure 5

Description. The setae of this species have longitudinal ribs and punctae in between the depressions. Characteristic is an inflation of the setae. Because this inflation is fairly robust and thickly silicified, it is often the only part that is preserved of this species.

Genus *CLAVICULA* Pantocsek (1886)

Clavicula spp.

Remarks. Only fragments of species belonging to this genus were found.

Genus *COCCONEIS* Ehrenberg (1838b)

Cocconeis spp.
Plate 2, Figure 1

Remarks. All recent species of this genus are today living attached to a substratum, and most of them are shallow-water species. Some were found attached to whale skins and thus survived in the oceanic environment (Hart, 1935). In the material studied, some very large species were found (e.g., Plate 2, Fig. 1).

Genus *COSCINODISCUS* Ehrenberg (1838b)

Coscinodiscus argus Ehrenberg (1838b)

Description. Hustedt (1930), pp. 422–424, fig. 226.

Coscinodiscus excavatus Greville in Pritchard (1861)

Synonyms. *Coscinodiscus diophthalamus* Castracane (1886), p. 163, pl. 16, fig. 4; *Coscinodiscus sellatus* Jousé (1974), p. 348–349, pl. 2, figs. 2–4.
Description. Greville ms, Ralfs, in Pritchard (1861), p. 829, pl. 8, fig. 26; Grunow (1884), p. 73.

Coscinodiscus extravagans A. Schmidt (1878) in A. Schmidt et al. (1874–)

Description. A. Schmidt et al. (1874–), pl. 58, fig. 33; Rattray (1889), p. 506.

Coscinodiscus grossheimii Gleser in Sheshukova-Poretzkaya and Gleser (1962)

Description. Sheshukova-Poretzkaya and Gleser (1962), p. 178, pl. 1, figs. 5a–b.

Coscinodiscus hajosiae Fenner (1984a)

Synonym. *Coscinodiscus spiralis* sensu Hajós (1976), p. 826, pl. 7, figs. 1–3, non: *Coscinodiscus spiralis* Karsten (1905), p. 81, pl. 5, figs. 5a–b.
Description. Hajós (1976), p. 826, pl. 7, figs. 1–3; Fenner (1984a), p. 331, pl. 2, fig. 2.

Coscinodiscus lewisianus Greville (1866a)

Description. Greville (1866a), p. 78, pl. 8, figs. 8–10.

Coscinodiscus marginatus Ehrenberg (1841a)

Description. Hustedt (1930), p. 416, fig. 223.

Coscinodiscus nodulifer A. Schmidt (1878) in A. Schmidt et al. (1874–)

Description. A. Schmidt et al. (1874–), pl. 59, fig. 20–23; Hustedt (1930), pp. 426–427, fig. 229.

Coscinodiscus oligocenicus Jousé (1974)

Description. Jousé (1974), p. 348, pl. 1, figs. 6–8 and 16; Fenner (1978), pp. 515–516, pl. 4, figs. 5–10.

Coscinodiscus radiatus Ehrenberg 1839 (1841)

Description. Hustedt (1930), pp. 420–421, fig. 225.

Coscinodiscus rhombicus Castracane (1886)

Description. Castracane (1886), p. 164, pl. 22, fig. 11; Fenner (1985), p. 729, fig. 7.14

Genus *CRASPEDODISCUS* Ehrenberg (1844c)

Craspedodiscus coscinodiscus Ehrenberg (1844c)

Description. Schmidt et al. (1874–), pl. 66, fig. 3–5, Ehrenberg (1844a), p. 266, fig. 12.

Craspedodiscus oblongus (Grev.) Grunow (1878) in A. Schmidt et al. (1874–)

Synonym. *Porodiscus oblongus* Grev. (1863b), p. 65, pl. 4, fig. 5 (illustration mislabeled *Porodiscus ovalis).*
Description. Gombos (1982), p. 232, figs. 16–17.

Craspedodiscus umbonatus Greville (1866a).
Plate 3, Figure 8

Synonym. Genus et species indet. 2, Fenner 1984b, p. 1263, pl. 2, fig. 5.
Description. Greville (1866a), p. 79, pl. 8, fig. 15.

Genus *DEXTRADONATOR* Ross and Sims (1980)

Dextradonator eximius (Grunow) Ross and Sims (1980)
Plate 2, Figures 6 and 12

Description. Van Heurck (1880–1885), pl. 106, figs. 1 and 3 (1883); Ross and Sims (1980), p. 118, pl. 1, figs. 1–4.

Genus *DIPLONEIS* Ehrenberg (1840)

Diploneis spp.

Remarks. Specimens belonging to this genus were only sporadically found. All species of this genus lived attached to a substratum and are considered shallow-water species.

Genus *ENDICTYA* Ehrenberg (1845)

Endictya robustus (Grev.) Hanna and Grant (1926)

Description. Hanna and Grant (1926), p. 144, pl. 16, figs. 2–3.

Genus *ENTOGONIA* Greville (1863b)

Entogonia spp.
Plate 3, Figure 3

Remarks. Because only fragments of species belonging to this genus were found, determination to the species level was not done. All members of this genus are considered to be shallow-water species.

Genus *ETHMODISCUS* Castracane (1886)

Ethmodiscus spp.

Remarks. Only fragments of species of this genus were found.

Genus *GRAMMATOPHORA* Ehrenberg (1839)

Grammatophora spp.

Remarks. Septa belonging to species of this genus were abundant, especially in diatom-bearing early Oligocene sediments. These septa seem to be one of the most dissolution-resistant skeletal remains of diatoms.

Genus *HEMIAULUS* Ehrenberg (1844a)

Hemiaulus aff. *affinis* Grunow in Van Heurck (1883)

Description. Van Heurck (1883), pl. 106, figs. 10–11.

Hemiaulus altar Brun (1896)
Plate 4, Figure 5

Description. Brun (1896), p. 238, pl. 20, figs. 19 and 20.

Hemiaulus barbadensis Grunow (1884)

Description. Grunow (1884), p. 63.

Hemiaulus bipons (Ehr.) Grunow in Van Heurck (1882)

Synonym. *Biddulphia suborbicularis* Barron (1975), p. 126, pl. 4, fig. 17.
Description. Van Heurck (1882), pl. 103, figs. 6–9, Grunow (1884), p. 65.

Hemiaulus claviger A. Schmidt in Schmidt et al. (1874–)
Plate 4, Figure 6

Description. A. Schmidt et al. (1874–), pl. 143, figs. 5 and 6.

Hemiaulus dubius Grunow (1884)

Description. Grunow (1884), p. 61, pl. 5(E), fig. 54.

Hemiaulus exiguus Greville (1865a)

Description. Greville (1865a), p. 29, pl. 4, fig. 20; Fenner (1985), p. 731, fig. 8.6–8.7.

Table 4. Occurrence charts of Paleogene diatom species from the Madingley Rise sites (Holes 709C, 710A, and 711A).

Age	Zone	Hole	Core, section, interval (cm)	Clinoptilolite	Ash	Phytoliths	Fish scales	Foraminifer casts	Endoskeletal dinoflagellates	Spermatogonia	Ebridians	Sponge spicules	Radiolarians	Archaeomonadaceae	Silicoflagellates	Diatoms	Diatom preservation	*Aulacosira granulata* (freshwater diatom)	*Actinocyclus octonarius*	*Abas wittii*	*Arachnoidiscus* spp.
early Oligocene	*C. reticulatus*	709C	26X-2, 102–103				S					R	D			S	P				
			26X-5, 102–103		S							R	D		S	R	P	F			
			26X-CC				S					R	D			R	P/M				
			27X-4, 102–103				S					R	D			C	M				
			27X-CC			R	R	R	R			R	D			R	M				
			28X-2, 102–103			R	S		R			R	D			R	P				
			28X-CC		S	R	S			S		R	A		S	C	M		S		
			29X-2, 102–103						S	S		R	A		R	C	M				
	C. exc.		29X-5, 102–103		S	R	S		S			R	A			R	P/M				
			29X-CC		S		S					R	A		R	C	M				
Eocene	late		30X-2, 102–103		S		S				R	C	D	R	S	R	P/M				S
	middle?		36X-CC				R	R				C	D			R	P				
early Oligocene	*C. reticulatus*	710A	21X-2, 102–103		S		S					F	D	S	S	R	P				
			21X-5, 102–103				S	S				F	D		R	R	P/M				
			22X-2, 102–103			R		R				F	D	S		R	P				
early Oligocene	*C. ret.*	711A	13X-CC	F			S	S				F	D	S	S	R	P			S	
			16X-1, 102–103		S		S		S	S		R	A		S	A	M				
	C. exc.		16X-3, 102–103		S		S	S				R	D			R	P				
			16X-CC		S		S		S			R	C		F	A	M				
late Eocene	*B. brun.*		17X-1, 102–103		R							R	A	R	R	A	P	S?			
			17X-CC		S		S					R	D			R	P				
	A. maryland.		18X-1, 103–104	S	S	F						R	D			R	P				
			19X-2, 7–8	F	R							R	D			S	P				
			19X-2, 79–80	R	F		S			S		S	D	S	F	R	P				
			19X-3, 102–103	S	S		S	S				S	D	S		R	P				
Eocene	middle?		22X-1, 102–103				S					R	D			S	P				
			24X-5, 102–103					R				R	D			S	P				

Note: For explanation of symbols for diatom preservation and abundance, see "Methods" section, this chapter.

Hemiaulus gracilis Fenner sp. nov.
Plate 5, Figures 8–9

Description. The valve outline is lanceolate. The valves are thin and delicate. The long apical prolongations are narrow and carry a straight upward-pointing spine on their top. The central part of the valve is highly domed. The round opening in its center is the external opening of the labiate process. One row of pores is found on each of the apical prolongations. Across the valve face connecting the basal parts of the two apical prolongations spans a thin siliceous sheet, which is characteristically stabilized by a net of thin, anastomosing ridges on it.

Differential diagnosis. No similar species were found in the literature.

Stratigraphic and paleogeographic occurrence. This species was found in the latest Eocene and early Oligocene sediments off northwest Africa (DSDP Sites 366 and 369A; Fenner, 1982) and in the Indian Ocean (Sites 707 and 709).

Holotype. Plate 5, Figure 8 from DSDP Sample 41-366-10-6, 132–133 cm.

Hemiaulus incisus Hajós (1976)

Description. Hajós (1976), p. 829, pl. 23, figs. 4–9.

Hemiaulus klushnikovii Gleser in Sheshukova-Poretzkaya and Gleser (1964).

Description. Sheshukova-Poretzkaya and Gleser (1964), p. 87, pl. 3, fig. 8

Hemiaulus longicornis Greville (1865a)
Plate 4, Figures 12–13

Description. Greville (1865a), p. 31, pl. 3, fig. 13.

Hemiaulus lyriformis Greville (1865a)

Description. Greville (1865a), p. 30, pl. 3, fig. 11; Fenner (1985), p. 732, fig. 10.15.

Hemiaulus polycystinorum (Ehr.) Grunow (1884)

Description. Grunow (1884), p. 65; Cleve-Euler (1951), p. 125; A. Schmidt et al. (1874–), pl. 143, figs. 24(?) and 28.

Hemiaulus polycystinorum Ehr. var. *mesolepta* Grunow (1884)

Description. Grunow (1884), p. 65, pl. 2(B), fig. 43; Fenner (1985), p. 733, fig. 8.10.

Hemiaulus rectus var. *twista* Fenner (1984a)

Description. Fenner (1984a), p. 332, pl. 2, fig. 6.

Hemiaulus robustus Greville (1865b)
Plate 2, Figure 11

Description. Greville (1865b), p. 54, pl. 6, fig. 23.

Hemiaulus subacutus Grunow (1884)
Plate 2, Figure 10

Description. Grunow (1884), p. 61, pl. 5(E), fig. 55; Fenner (1978), p. 522, pl. 24, figs. 8 and 14.

Hemiaulus taurus Gombos in Gombos and Ciesielski (1983)
Plate 2, Figure 8

Description. Gombos and Ciesielski (1983), p. 606, pl. 19, figs. 1–8.

Hemiaulus sp. *(pyxilloides)* Schrader and Fenner (1976)

Description. Schrader and Fenner (1976), p. 984, pl. 10, figs. 1–3.

Table 4 (continued).

Asterolampra grevillei	*A. marylandica*	*A. punctifera*	*A. vulgaris*	*A. vulgaris* var. a	*Baxteriopsis brunii*	*Briggera* spp.	*Cestodiscus convexus*	*C. demergitus*	*C. gemmifer*	*C. mukhinae*	*C. parmula*	*C. pulchellus*	*C. reticulatus*	*C. stokesianus* •	*C. trochus*	*C.* sp. 1	*C.* sp.	*Chaetoceros asymmetricus*	*Ch.* sp. 1	*Cocconeis* spp.	*Coscinodiscus excavatus*	*C. extravagans*	*C. grossheimii*	*C. hajosiae*	*C. marginatus*	*C. oligocenicus*	*C. radiatus*
																		F								F	
	F								C	F	C				F			D									F
R	F						S		F	R	S		F		F			D			S					R	S
	F								C	F	F	S	R		F	F		D			R					R	
S	F						F		C	F	F		F		C			D									
R	F						R		R	R	F	S	R	R	R	R		D			R					R	
S	F		S				F		F	F	F		R	S	S			D			R					S	S
	C						R		C	F					F	F		C		S				S		S	
	F				R		S	S		S					F	F		D			R					F	S
															F			F	F							R	
											D																
										F	F							C								F	
											C		R					C	R							R	
						R					R						S		R								
R	F	S			S		F	S	F	F			F	S	F			D			R					F	
									R							R		D								C	
	F	S			F			S	S	S						F	R	D			R			S		F	
	R									S							S	D						S		R	
	F	S			F					F					S		S	F	F							R	S
				S				R							R	F	R	S	F							F	
	R		R													C										F	
			R													R											

Genus *HYALODISCUS* Ehrenberg (1845)

Remarks. Species belonging to this genus were extremely rare and therefore were not determined to the species level.

Genus *ISTHMIA* Agardh (1832)

Isthmia sp.
Plate 3, Figure 9

Remarks. Only fragments of a species and one complete specimen belonging to this genus were found in the Eocene sediments of Site 707.

Genus *KOZLOVIELLA* Jousé (1974)

Kozloviella meniscosa Fenner sp. nov.
Plate 5, Figures 1–2

Description. The valve outline is broadly sickle-shaped, with one side convex, and the other concave to straight. The shorter axis of the valve diameter varies between 55 and 100 μm. The valve is slightly convex. The areolae are arranged in rows that radiate from the hyaline area and are slightly curved near the poles. The areolae are larger in the central part of the valve (6–7 areolae in 10 μm) than in the marginal part (10–12 areolae in 10 μm). The areolae have an outer cribrum that has the shape of cross- or tripod-like bars. These rather robust cribra, or at least their remnants, the siliceous thickenings on the areolae margin where the bars are broken off, are characteristic for this species and are always observed. The hyaline rays that radiate from the hyaline area end at the margin in a small process. The margin is hyaline.

Differential diagnosis. This species differs from *Kozloviella pacifica* Jousé by its valve shape and the position of the hyaline area eccentrically displaced toward the concave side.

Stratigraphic and paleogeographic occurrence. At DSDP Sites 366 and 369A off northwest Africa (Fenner, 1982), this species ranges from the late middle Eocene (planktonic foraminifer Zone P14) into the early Oligocene (planktonic foraminifer Zone P19). In addition to its occurrence at Site 709, it is also found by one of the authors (J. Fenner) in late Eocene–early Oligocene sediments from higher latitudes (i.e., DSDP Sites 277, 328, and 511).

Holotype. Plate 5, Figure 1, from DSDP Sample 41-366-10-4, 89–90 cm.

Kozloviella subrotunda Fenner (1984a)

Description. Fenner (1984a), pp. 332–333, pl. 2, fig. 2.

Liostephania spp.
Plate 2, Figures 2–4

Remarks. *Liostephania* Ehr. is interpreted by A. Schmidt in A. Schmidt et al. (1874–), by Hanna and Brigger (1970), and by Schrader (1974, p. 919) as internal opal molds of valves. They are found especially in the middle and late Eocene, where they belong to species of the genus *Asterolampra*. In the early Oligocene, where *Liostephania* has a rare occurrence, they are not only from the genus *Asterolampra* but also of *Asteromphalus, Paralia*(?), and *Coscinodiscus*(?). Because the discus of *Liostephania* are very solution resistant, they become concentrated in poorly preserved diatom assemblages.

Genus *LISITZINIA* Jousé (1978)

Lisitzinia ornata Jousé (1978)

Description. Jousé (1978), p. 47–48, pl. 10, figs. 1–6; Fenner (1985), p. 734, fig. 10.11.

Table 4 (continued).

Age	Zone	Hole	Core, section, interval (cm)	*C. rhombicus*	*C.* sp.	*Craspedodiscus coscinodiscus*	*Diploneis* spp.	*Entogonia* spp.	*Ethmodiscus* spp.	*Grammatophora* spp.	*Hemiaulus* aff. *affinis*	*Hemiaulus altar*	*H. barbadensis*	*H. bipons*	*H. claviger*	*H. dubius*	*H. exiguus*	*H. gracilis*	*H. klushnikovii*	*H. longicornis*	*H. lyriformis*
early Oligocene	*C. reticulatus*	709C	26X-2, 102-103		R					F											
			26X-5, 102-103							F							A				
			26X-CC																		
			27X-4, 102-103														R				S
			27X-CC							S		F		S						R	F
			28X-2, 102-103							S											
			28X-CC						R	S		F					S			R	R
			29X-2, 102-103									F				R				F	F
	C. exc.		29X-5, 102-103							F		R		R						S	R
			29X-CC			S					S	F		R			S			F	F
Eocene	late		30X-2, 102-103							C		F					F	S		S	F
	middle?		36X-CC																		
early Oligocene	*C. reticulatus*	710A	21X-2, 102-103							R							R				
			21X-5, 102-103		F					C		R					R		S		F
			22X-2, 102-103							C							R				
early Oligocene	*C. ret.*	711A	13X-CC					R					S								
			16X-1, 102-103						S		S	F	R		S		S			R	F
	C. exc.		16X-3, 102-103							R											R
			16X-CC		S				S			F	R							F	F
late Eocene	*B. brun.*		17X-1, 102-103							S		F	S		S					R	F
			17X-CC						R	R		F					R				F
	A. maryland.		18X-1, 103-104						R	F		F					S				F
			19X-2, 7-8							S											
			19X-2, 79-80		R				F			F			F	S	R			F	F
			19X-3, 102-103									F			F				F	F	F
Eocene	middle?		22X-1, 102-103					S													
			24X-5, 102-103					S													

Genus *MELOSIRA* Agardh (1824)

Melosira architecturalis Brun (1892) in A. Schmidt et al. (1874–)
Plate 1, Figure 8

Synonym. *Cyclotella hannae* Kanaya (1957), pp. 82–84, pl. 3, figs. 10–14.

Description. A. Schmidt et al. (1874–), pl. 177, figs. 45–50.

Genus *NAVICULA* Bory (1822)

Navicula spp.

Remarks. The few specimens found belonging to this genus were not identified to species level.

Genus *NEOBRUNIA* Kuntze (1894)

Neobrunia spp.

Remarks. Rare valve fragments presumably belonging to *Neobrunia mirabilis* were found in the late Oligocene sediments of Site 714.

Genus *PARALIA* Heiberg (1863)

Paralia sulcata (Ehr.) Cleve (1873)
Plate 1, Figure 10

Description. Hustedt (1930), pp. 276–278, figs. 118–120.

Paralia(?) *ornata* Grunow *in* Van Heurck (1882)

Description. Van Heurck (1882), pl. 91, figs. 19–21.

Genus *PORODISCUS* Greville (1863a)

Porodiscus elegans Greville (1863a)
Plate 1, Figure 11

Description. Greville (1863a), p. 64, pl. 4, fig. 1.

Genus *PSEUDOPODOSIRA* Jousé in Proshkina-Lavrenko (1949)

Pseudosira bella Posnova and Gleser in Gleser and Posnova (1964).

Description. Gleser and Posnova (1964), p. 61, fig. 1.

Pseudopodosira simplex (Jousé) Strelnikova (1974)

Description. Strelnikova (1974), pp. 51–52, pl. 2, figs. 10–11.

Genus *PSEUDOTRICERATIUM* Grunow (1884)

Pseudotriceratium radiosoreticulatum (Grunow) Jousé in Dzinoridze et al. (1979)

Description. Van Heurck (1883), p. 112, fig. 5; Fenner (1985), p. 735, fig. 12.11.

Genus *PYXILLA* Greville (1865a)

Pyxilla prolongata Brun (1893)

Description. Brun (1893), p. 176, pl. 24, fig. 7.

Genus *RHAPHONEIS* Ehrenberg (1844b)

Rhaphoneis(?) *immunis* Lohmann (1948)

Description. Lohmann (1948), p. 182, pl. 11, fig. 6.

Genus *RHIZOSOLENIA* Ehrenberg (1841b)

Rhizosolenia hebetata Bailey (1856)

Description. Grunow (1884), p. 44, pl. 5, figs. 48–50.

Rhizosolenia interposita Hajós (1976)

Description. Hajós (1976), p. 827, pl. 21, fig. 8.

Table 4 (continued).

H. polycystinorum	*H. rectus* var. *twista*	*H. subacutus*	*H. taurus*	*H.* sp.	*Hyalodiscus* spp.	*Kozloviella meniscosa*	*K. subrotunda*	*Liostephania* spp.	*Lisitzinia ornata*	*Melosira architecturalis*	*Neobrunia?* spp.	*Paralia sulcata*	*P.? ornata*	*Porodiscus elegans*	*Pseudotriceratium radiosoreticulatum*	*Rhaphoneis immunis*	*Rhizosolenia hebetata*	*R. interposita*	*R.* sp. 1	*Rouxia hannae*	*R. obesa*	*Sceptroneis pesplanus*	*Skeletonema barbadense*	*Stellarima primalabiata*	*Synedra* aff. *hennedyana*	*S. jouseana*	*Thalassionema nitzschioides*
										R																	
		C																F									F
								R										F									
		R																S	S								
		F																F		S							
		F																									
		F													S			R	R		S		S				R
		F				S				F							S	S	S		S		R				
		C								S		S						R			S		S				
R		F	S															R			S						
F		C					S	S				F	S														
								C				R															
								R																			
		C			S					A																	R
		R		S				C																			
S		F	S							F													R				
		R								F																	
F	S	F	R													R								S			
S		F	S							S													R				
		C						F				S						F					S				S
		C			S			F		S								S									
												S		S													
		F						R				F		S								S	F				
		C						F						F									R				
								F																			
								S				F															

Rhizosolenia sp. 1

Description. Of this species only the conical valve (calyptra) was found. The valve is coarsely areolated, and small spines are arranged around its truncate top. This species was found in the early Oligocene sediments of Site 709.

Genus *RIEDELIA* Jousé and Sheshukova-Poretzkaya (1971)

Riedelia pacifica Jousé *in* Jousé and Sheshukova-Poretzkaya (1971)

Description. Jousé and Sheshukova-Poretzkaya (1971), p. 22, pl. 2, figs. 3–4; Gleser and Jousé (1974), p. 60, pl. 3, fig. 11.

Genus *ROCELLA* Hanna (1930)

Rocella princeps (Jousé) Fenner comb. nov.

Basionym. *Coscinodiscus princeps* Jousé (1974), p. 350, pl. 3, figs. 8–12.

Description. Jousé (1974), p. 350, pl. 3, figs. 8–12.

Rocella vigilans Fenner (1984a)

Description. Fenner (1984a), p. 333, pl. 1, fig. 11.

Genus *ROSSIELLA* Desikachary and Maheshwari (1958)

Rossiella symmetrica Fenner (1984a)

Description. Fenner (1984a), p. 333–334, pl. 1, figs. 2–4.

Genus *ROUXIA* Brun and Héribaud in Héribaud (1893)

Rouxia hannae Jousé (1974)

Description. Jousé (1974), pp. 349–350, pl. 2, fig. 13.

Rouxia obesa Schrader in Schrader and Fenner (1976)

Description. Schrader and Fenner (1976), p. 997, pl. 24, figs. 5–6.

Genus *RUTILARIA* Greville (1863b)

Rutilaria sp.

Remarks. Only one specimen of a not-yet-described species belonging to this genus was found. The specimen has a nearly circular outline and coarse areolation.

Genus *SCEPTRONEIS* Ehrenberg (1844c)

Sceptroneis pesplanus Fenner and Schrader in Schrader and Fenner (1976)

Description. Schrader and Fenner (1976), p. 998, pl. 22, figs. 30–31; pl. 25, figs. 10–11.

Genus *SKELETONEMA* Greville (1865b)

Skeletonema barbadense Greville (1865b)
Plate 1, Figure 5

Description. Greville (1865b), p. 43, pl. 5, fig. 1.

Genus *STELLARIMA* Hasle and Sims (1986)

Stellarima primalabiata (Gombos) Hasle and Sims (1986)

Description. Gombos and Ciesielski (1983), p. 606, pl. 9, figs. 1–8.

Genus *STEPHANOPYXIS* Ehrenberg (1844c)

Stephanopyxis turris (Greville and Arnott) Ralfs *in* Pritchard (1861)

Description. Hustedt (1930), p. 304, fig. 140; Grunow (1884), p. 87.

Table 4 (continued).

Age	Zone	Hole	Core, section, interval (cm)	*Thalassiosira bukryi*	*T.* aff. *irregulata*	*Thalassiothrix longissima*	*Triceratium americanum*	*T. groningensis*	*T.* sp.	*Trinacria subcapitata*	*Trochosira coronata*	Genus et Species indet. 1	*Macrora barbadensis*	*M. stella*
early Oligocene	*C. reticulatus*	709C	26X-2, 102–103											
			26X-5, 102–103										F	
			26X-CC											
			27X-4, 102–103											R
			27X-CC											S
			28X-2, 102–103											
			28X-CC	S								S	S	S
			29X-2, 102–103	S	S		S					S	R	S
	C. exc.		29X-5, 102–103											S
			29X-CC					S		R		S	R	
Eocene	late		30X-2, 102–103									F	R	
	middle?		36X-CC											
early Oligocene	*C. reticulatus*	710A	21X-2, 102–103											
			21X-5, 102–103									R	F	F
			22X-2, 102–103											
early Oligocene	*C. ret.*	711A	13X-CC											
			16X-1, 102–103	S								S	R	S
	C. exc.		16X-3, 102–103	R										
			16X-CC				R		R	R			F	F
late Eocene	*B. brun.*		17X-1, 102–103										R	
			17X-CC									F	F	R
	A. maryland.		18X-1, 103–104									S	F	R
			19X-2, 7–8								S			
			19X-2, 79–80									F	C	
			19X-3, 102–103									F	F	S
Eocene	middle?		22X-1, 102–103											
			24X-5, 102–103						S					

Genus *STRANGULONEMA* Greville (1865b)

Strangulonema barbadense Greville (1865b)

Description. Greville (1865b), p. 44, pl. 5, fig. 2.

Genus *SYNEDRA* Ehrenberg (1830)

Synedra aff. *hennedyana* Gregory (1857)

Description. Gregory (1857), p. 532, pl. 14, fig. 108.
Remarks. Fragments of valves similar to this species were only sporadically found.

Synedra jouseana Sheshukova-Poretzkaya (1962)

Description: Sheshukova-Poretzkaya (1962), p. 208, fig. 4; Schrader (1973), p. 710, pl. 23, figs. 21–23, 25, 38.

Genus *THALASSIONEMA* Grunow in Van Heurck (1881)

Thalassionema nitzschioides (Grunow) Van Heurck (1896)

Description. Van Heurck (1896), p. 319, fig. 75; Hustedt (1932), p. 244, fig. 725.

Genus *THALASSIOSIRA* Cleve (1873)

Thalassiosira bukryi Barron (1983)
Plate 1, Figure 4

Description. Barron (1983), p. 511, pl. 4, figs. 1–2; pl. 6, fig. 9; Fenner (1985), p. 739.

Thalassiosira aff. *irregulata* Schrader and Fenner (1976)

Description. Schrader and Fenner (1976), p. 1002, pl. 20, fig. 13.

Genus *THALASSIOTHRIX* Cleve and Grunow (1880)

Thalassiothrix longissima Cleve and Grunow (1880) var.

Description. Hustedt (1932), p. 244, figs. 725 and 726.
Remarks. The species occurring in the Oligocene sediments of Leg 115 is fairly delicate, and the areolae are smaller than in *T. longissima*.

Genus *TRICERATIUM* Ehrenberg (1839)

Remarks. A multitude of large shallow-water species of this genus were found. Because only single specimens or fragments of the different species occurred, they were not listed as separate species. Among these shallow-water species were *Triceratium* aff. *exornatum* Grev., *T. westianum* Grev., *T. rotundatum* Grev., *T. productum* Grev., *T. pauperculum* Grev., *T. venosum* Brightwell, *T. areolatum* Grev., *T. zonatum* Grev., and, most commonly, fragments of a large species that has valves with a characteristic structure of radiating ribs like *T. polycystinorum* Pantocsek or *T. morlandii* Grove and Sturt.

Triceratium aff. *americanum* Ralfs in Pritchard
(1861)
Plate 3, Figure 2

Description. A. Schmidt et al. (1874–), pl. 76, fig. 27 (pl. 76, fig. 28 is in error, see Boyer, 1900, p. 721).
Remarks. The specimens encountered in the Leg 115 material are more coarsely areolated than the specimens illustrated in A. Schmidt et al. (1874–).

Triceratium aff. *brachiatum* Brightwell (1856)
Plate 3, Figure 7

Description. Brightwell (1856), p. 274, pl. 17, fig. 3.

Triceratium groningensis Reinhold (1937)

Description. Reinhold (1937), p. 126, pl. 20, fig. 9.

Triceratium westianum Greville (1861)
Plate 3, Figures 5-6

Description. Greville (1861), p. 43, pl. 4, fig. 11.

Genus *TRINACRIA* Heiberg (1863)

Trinacria subcapitata (Grev.) Grunow (1884)

Description. Greville (1863b), p. 234, pl. 10, fig. 20; Grunow (1884), p. 69.

Genus *TROCHOSIRA* Kitton (1871)

Trochosira aff. *trochlea* Hanna (1927)

Description. Hanna (1927), p. 123, pl. 21, figs. 8 and 9.
Remarks. The specimens observed near the Eocene/Oligocene boundary are smaller and more finely areolated than the species described from the middle Eocene by Hanna.

Trochosira coronata Schrader and Fenner (1976)

Description. Schrader and Fenner (1976), p. 1003, pl. 29, figs. 9-11; pl. 35, figs. 7-13 and 20-21.

Genus *XANTHIOPYXIS* Ehrenberg (1844c)

Xanthiopyxis spp.

Remarks. Under this name are generally listed the resting spores of unknown species, in most cases species belonging to the genus *Chaetoceros*. In this study different types of resting spores of this genus were not differentiated.

Genera *Incertae Sedis*

Genus *MACRORA* Hanna (1932)

Macrora barbadensis (Deflandre) Bukry (1978)

Description. Bukry (1977), p. 832, pl. 2, figs. 3-8.

Macrora stella (Azpeitia) Hanna (1932)
Plate 4, Figure 1

Description. Hanna (1932), p. 196, pl. 12, fig. 7.

Genus et Species indet. (1)

Remarks. This species is identical with "Genus et species indet. (1)" illustrated in Fenner (1982).

Genus *SPERMATOGONIA* Leuduger-Fortmorel (1892)

Spermatogonia spp.

Remarks. Very rare fragments of species belonging to this genus have been found in the Oligocene sediments recovered during Leg 115.

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Table 5. Occurrence charts of Paleogene diatom species in Holes 713A, 714A, and DSDP Hole 219 from the Chagos-Laccadive Ridge, and Site 236 in the abyssal plain northeast of the Seychelles Bank.

Age	Zone	Hole	Core, section interval (cm)	Clinoptilolite	Ash	Pollen	Fish scales	Foraminifer casts	Phytoliths	Endoskeletal dinoflagellates	Sponge spicules	Radiolarians	Archaeomonadaceae	Silicoflagellates	Diatoms	Diatom preservation	*Aulacosira granulata* (freshwater diatom)	*Abas wittii*	*Actinoptychus senarius*	*A. splendens*	*Arachnoidiscus* spp.
Eocene	middle	713A	6R-3, 102–103	R			S	F			C	D			R	P		A			F
			7R-3, 103–104		F			F			C	D	R		R	P/M		F			F
			7R-5, 103–104		C		S	F	R		C	D			R	P		F		S	F
			8R-1, 102–103		A			F			C	A	R		R	P					F
			8R-3, 100–101		R		S	F	S		C	D	S		R	P		R			F
			8R-CC		R		S	F	S		A	A	R		R	P/M		F	R		F
			9R-1, 102–103	S	S		S	R			A	A	R		C	P/M		F			F
late Oligoc.		714A	22X-1, 102–103					F		S	C	D			S	P					
	B. veniam.		22X-3, 102–103		S		R	R			A	A			R	P					C
			22X-CC				S	R		S	A	A	S	R	F	P/M	R				F
			23X-1, 102–103				S	R	S		A	A			S	P					C
			23X-3, 102–103					R			A	A			R	P					F
			23X-CC					R			A	C			F	P/M					R
			24X-1, 102–103					R			D	C			S	P					
			24X-CC					S			D	R			S	P					R
late Eocene?		236	28-1, 46–48								A	F			S	P					
Eocene	late	219	17-3, 61–66	C							A	C	R		R	P					
			17-4, 61–66	S					S		C	A	R		S	P					
			17-4, 102–106	S							C	A	R		S	P					
			17-5, 41–46	C							C	A	R		S	P					S
			17-5, 61–63	F					S		C	A	R		S	P					
			18-1, 93–98	C							C	C	F		S	P					
			18-2, 61–66	F							C	A	F		S	P					
			18-4, 61–66	R							C	C	F		S	P					S
	middle		19-1, 58–63	C							F	F	F		S	P					

Note: For explanation of symbols for diatom preservation and abundance, see "Methods" section, this chapter.

Table 5 (continued).

Asterolampra grevillei	*A. marylandica*	*A. punctifera*	*A. vulgaris*	*Aulacodiscus* spp.	*Baxteriopsis brunii*	*Bogorovia veniamini*	*Briggera* spp.	*Cestodiscus convexus*	*C. demergitus*	*C. gemmifer*	*C. mukhinae*	*C. parmula*	*C. pulchellus*	*C. reticulatus*	*C. stokesianus*	*C. trochus*	*C.* sp.	*Chaetoceros asymmetricus*	*Ch.* sp. 1	*Clavicula* spp.	*Cocconeis* spp.	*Coscinodiscus argus*	*C. extravagans*	*C. grossheimii*	*C. lewisianus*	*C. marginatus*	*C. oligocenicus*
																					F						
							F														F						
							R														F						
																					R						
																					F						
				S			R													S	F						
							F													S	C						
																										R	
											R															F	
R	R					F	S				S		F		R		F	C		S	F		S			R	R
R																		C									
R					S	S							A		R		R	C				R		R	S	S	R
											S																
																			S								

Table 5 (continued).

Age	Zone	Hole	Core, section interval (cm)	*C. radiatus*	*C. rhombicus*	*C.* sp.	*Craspedodiscus coscinodiscus*	*C. oblongus*	*C. umbonatus*	*Dextradonator eximius*	*Endictya robustus*	*Entogonia* spp.	*Ethmodiscus* spp.	*Grammatophora* spp.	*Hemiaulus altar*	*H. exiguus*	*H. polycystinorum*	*H. polycystinorum* var. *mesolepta*	*H. subacutus*	*H. taurus*	*Hyalodiscus* spp.
Eocene	middle	713A	6R-3, 102–103						C			R		F							R
			7R-3, 103–104					S	F			F	F								
			7R-5, 103–104						C			F	C								
			8R-1, 102–103						C			R	C								
			8R-3, 100–101						C			R	C	R							R
			8R-CC			S			F			F	F	R							S
			9R-1, 102–103						C	S		F		S				S			S
late Oligoc.		714A	22X-1, 102–103				F							F							
			22X-3, 102–103				R							D							
	B. veniam.		22X-CC		F		F						F	A					F		
			23X-1, 102–103											C							
			23X-3, 102–103											D							
			23X-CC	S	F		S				R		F	F	F	S					
			24X-1, 102–103											R							
			24X-CC											S							
late Eocene?		236	28-1, 46–48																		
Eocene	late	219	17-3, 61–66											C							
			17-4, 61–66											C							
			17-4, 102–106											R							
			17-5, 41–46											S							
			17-5, 61–63											R							
			18-1, 93–98											S							
			18-2, 61–66																		
			18-4, 61–66																		
	middle		19-1, 58–63																		

Table 5 (continued).

Isthmia spp.	*Kozloviella meniscosa*	*K. subrotunda*	*Liostephania* of *Asterolampra* spp.	*Lisitzinia ornata*	*Melosira architecturalis*	*Navicula* spp.	*Neobrunia*? spp.	*Paralia* sp.	*P.*? *ornata*	*Pseudopodosira simplex*	*P. bella*	*Pseudotriceratium radiosoreticulatum*	*Rhizosolenia hebetata*	*R. interposita*	*R.* sp. 1	*Riedelia pacifica*	*Rocella princeps*	*R. vigilans*	*Rossiella symmetrica*	*Rouxia hannae*	*Rutilaria* sp.	*Sceptroneis* sp.	*Stephanopyxis turris*	*Stranguloneme barbadense*	*Synedra* aff. *hennedyana*	*S. jouseana*	*Thalassionema nitzschioides*
					R	S		C																			
R			C			S		A		F	S																
			F					C	R	F																	
			C		F			A		F												R					
			R					A		F																	
S			F		F			D		C				R		S						S	S	S			
F			F		F			A	F	C											S	S		S			
																										R	
					F		R	F				S	S	S			R	F				S				C	R
																		F									
								F																		F	
	S			R			R											C	F	S?		S				F	
			S					S																			
			S					S																			
			S					S																			
								S																			
			R					R																			
								R																			
								R																			
			S					F																			
			S					R																			

Table 5 (continued).

Age	Zone	Hole	Core, section interval (cm)	*Thalassiosira bukryi*	*T.* sp.	*Thalassiothrix longissima* aff.	*Triceratium insignis*	*T. pauperculum*	*T. venosum*	*T.* sp. (large, shallow-water species)	*Xanthiopyxis* spp.	Genus et Species indet. 1	*Macrora barbadensis*
Eocene	middle	713A	6R-3, 102–103							C			
			7R-3, 103–104										
			7R-5, 103–104							C			
			8R-1, 102–103						R	C			
			8R-3, 100–101							C	F		
			8R-CC				S			F			F
			9R-1, 102–103							C		S	S
late Oligoc.		714A	22X-1, 102–103										
			22X-3, 102–103										
			22X-CC		R	F		S		R	F		
	B. veniam.		23X-1, 102–103								R		
			23X-3, 102–103							F			
			23X-CC			F					F		
			24X-1, 102–103										
			24X-CC										
late Eocene?		236	28-1, 46–48										
Eocene	late	219	17-3, 61–66								S		
			17-4, 61–66										
			17-4, 102–106										
			17-5, 41–46										
			17-5, 61–63			S							
			18-1, 93–98										
			18-2, 61–66										
			18-4, 61–66										
	middle		19-1, 58–63										

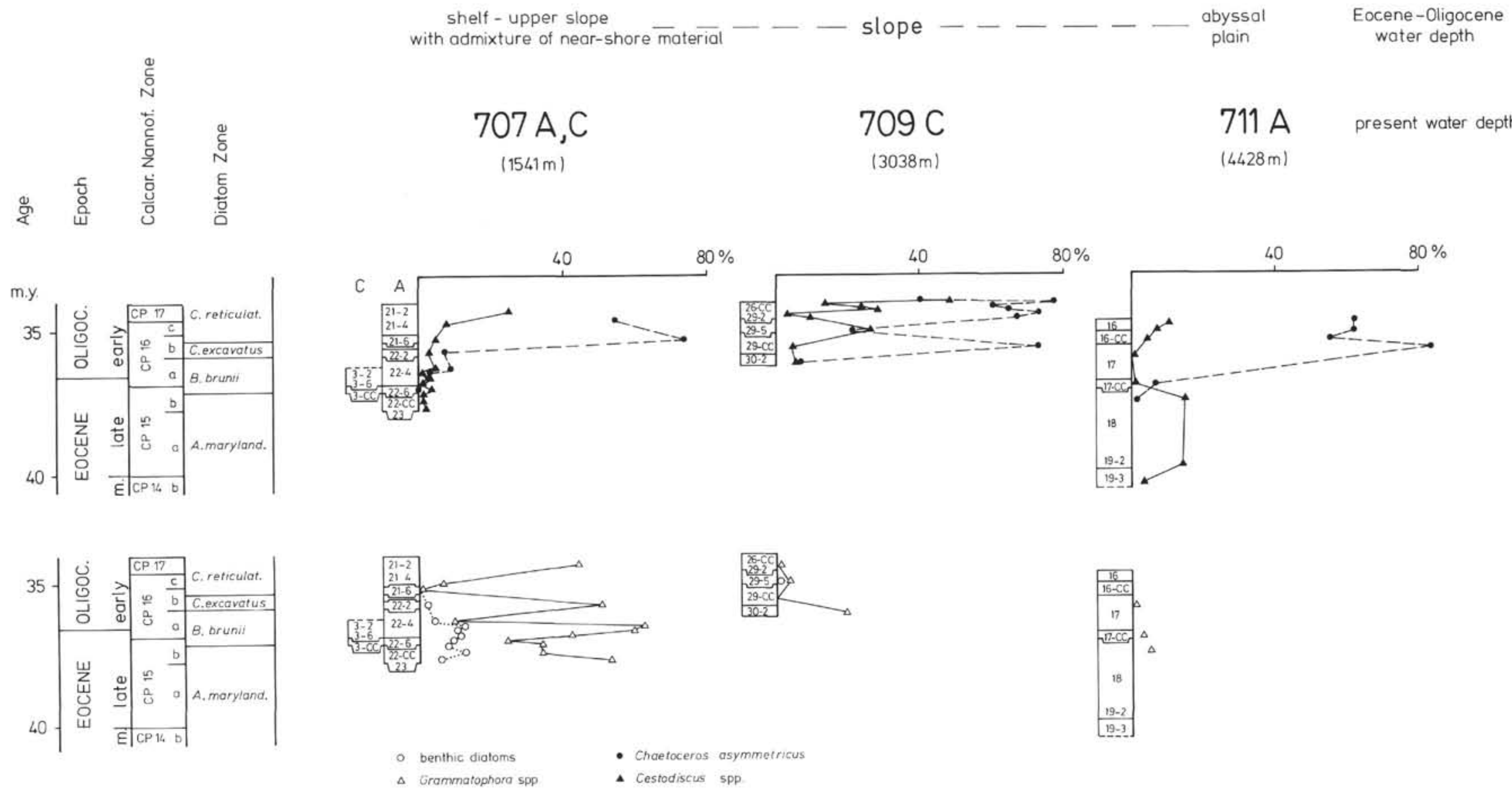

Figure 3. Summary diagram with ranges of stratigraphically important diatom species for the late Eocene to Oligocene in the western Indian Ocean. Diatoms are absent or poorly preserved in hatched areas.

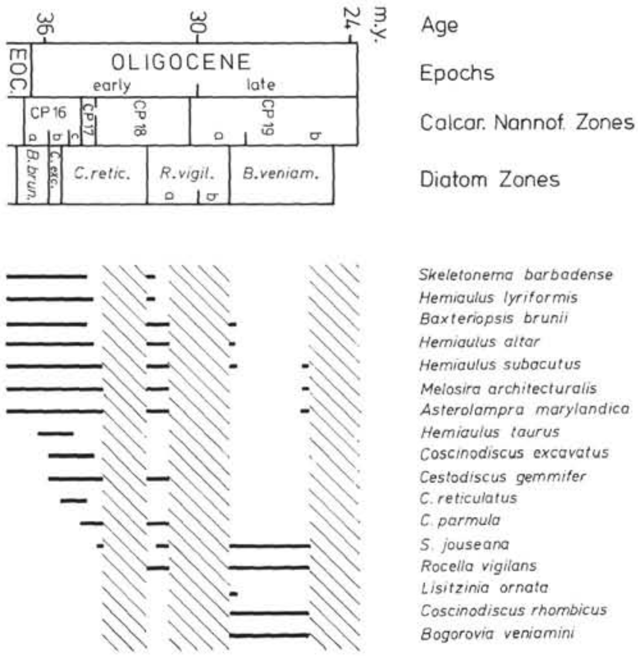

Figure 4. Percent abundance of selected ecological indicator species and species groups of diatoms in the latest Eocene to early Oligocene sediments of three sites on the northern slopes of the Mascarene Plateau and Madingley Rise. The sites are arranged by water depth.

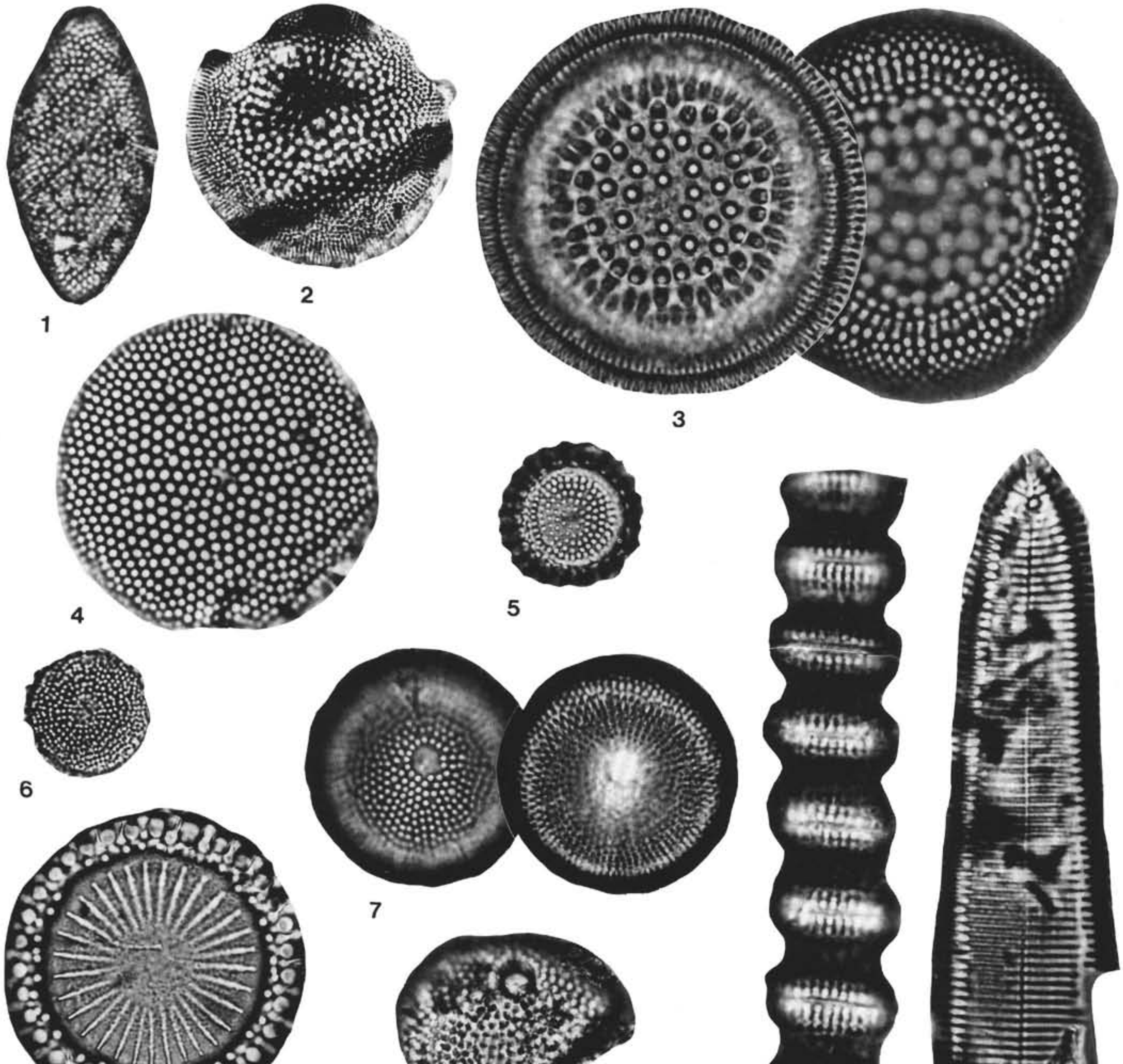

Plate 1. Magnification 1500× if not otherwise indicated. **1.** *Coscinodiscus*(?) sp., Sample 115-711A-16X-CC. **2.** *Cestodiscus* sp., 900×, Sample 115-714A-22X-CC. **3.** *Cestodiscus gemmifer,* Sample 115-707A-21X-6, 105–106 cm. **4.** *Thalassiosira bukryi,* Sample 115-707A-21X-2, 105–106 cm. **5.** *Skeletonema barbadense,* Sample 115-711A-19X-2, 79–80 cm. **6.** *Thalassiosira* sp., Sample 115-714A-22X-CC. **7.** *Thalassiosira*(?) sp., Sample 115-707A-21X-4, 105–106 cm. **8.** Chain of *Melosira architecturalis,* Sample 115-707A-21X-5, 102–103 cm. **9.** *Synedra clavata*(?), Sample 115-707C-3R-2, 110–111 cm. **10.** *Paralia sulcata* var., Sample 115-707A-23X-2, 105–106 cm. **11.** *Porodiscus elegans,* 900×, Sample 115-711A-19X-3, 102–103 cm.

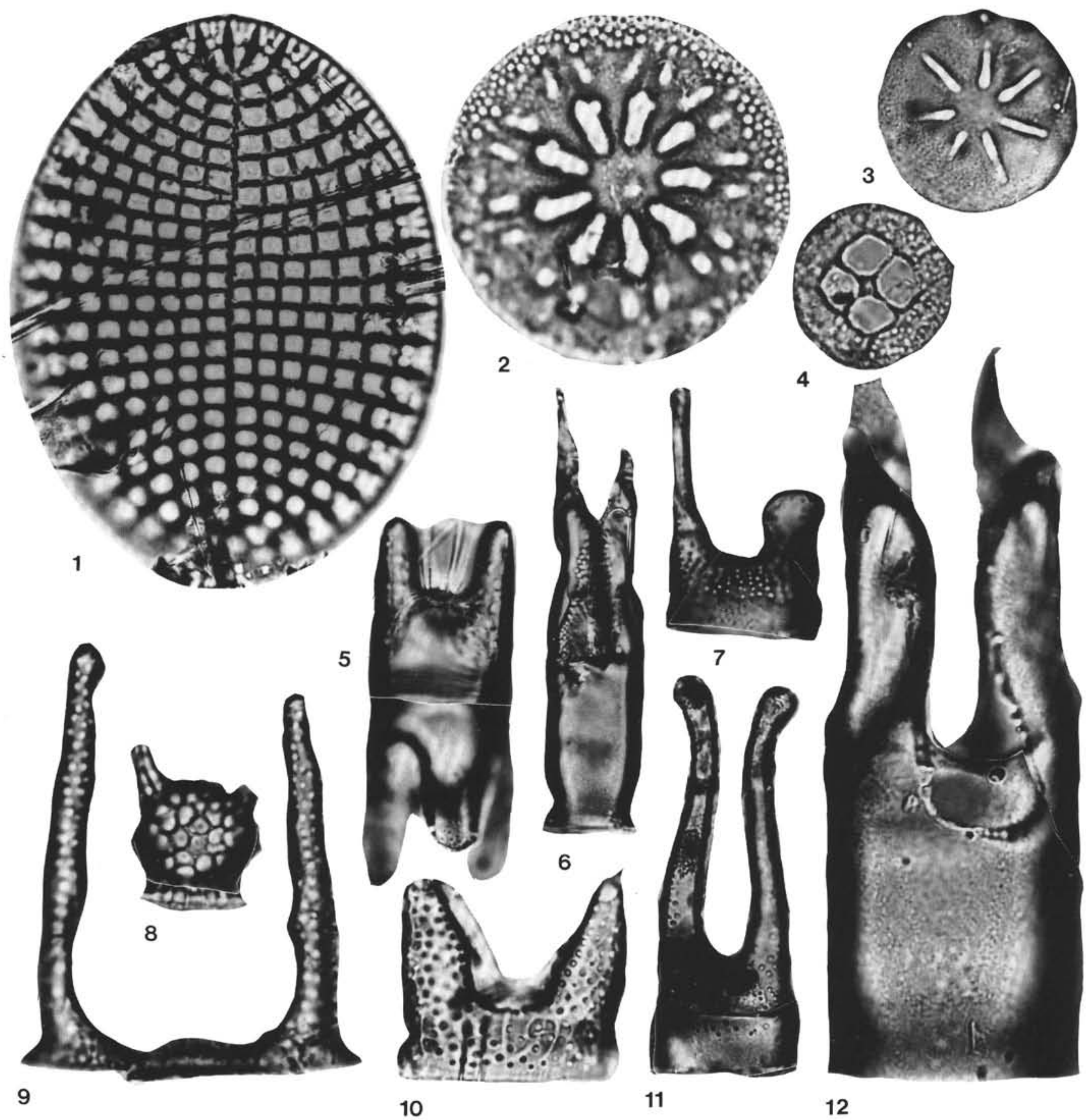

Plate 2. Magnification 1500× if not otherwise indicated. **1.** *Cocconeis* sp., 900×, Sample 115-707C-9R-2, 51–52 cm. **2.** *Liostephania* of *Asterolampra vulgaris*(?), Sample 115-709C-30R-2, 102–103 cm. **3.** *Liostephania* sp., Sample 115-707A-23X-2, 105–106 cm. **4.** *Liostephania* sp., Sample 115-713A-8R-1, 102–103 cm. **5.** Genus et species indet., Sample 115-707A-23X-2, 105–106 cm. **6.** *Dextradonator eximius,* 900×, Sample 115-713A-9R-1, 102–103 cm. **7.** Genus et species indet., Sample 115-707A-21X-6, 105–106 cm. **8.** *Hemiaulus taurus,* Sample 115-707A-21X-6, 105–106 cm. **9.** *Hemiaulus* sp., Sample 115-707A-21X-6, 105–106 cm. **10.** *Hemiaulus subacutus* var., Sample 115-711A-18X-1, 103–104 cm. **11.** *Hemiaulus robustus,* 900×, Sample 115-713A-8R-CC. **12.** *Dextradonator eximius,* Sample 115-707C-9R-CC.

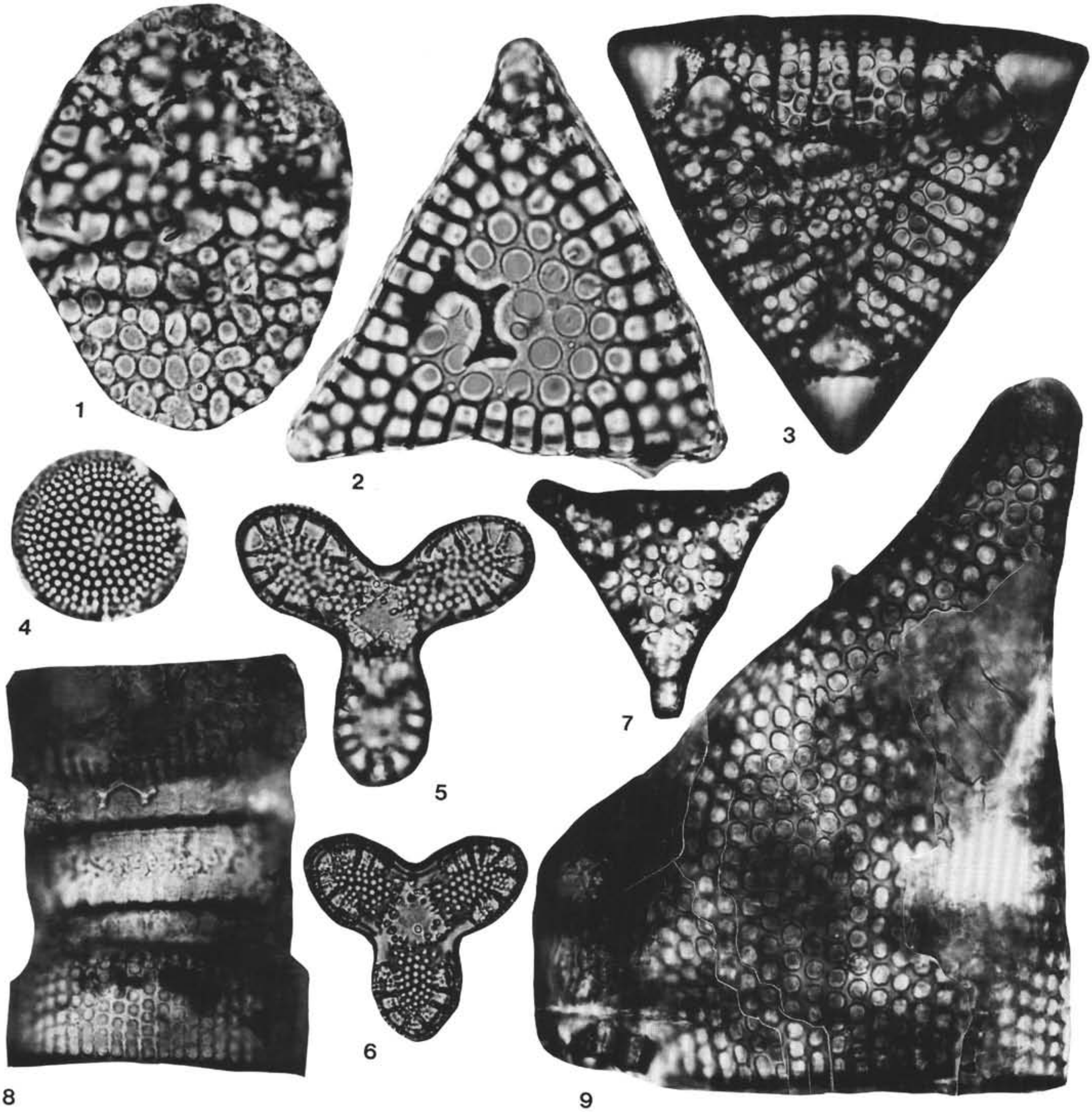

Plate 3. Magnification 1500× if not otherwise indicated. **1.** Genus et species indet., Sample 115-714A-22X-CC. **2.** *Triceratium* aff. *americanum,* Sample 115-707A-21X-2, 105–106 cm. **3.** *Entogonia* sp., 900×, Sample 115-713A-7R-5, 103–104 cm. **4.** *Thalassiosira* sp., Sample 115-707A-21X-2, 105–106 cm. **5–6.** *Triceratium westianum,* 900×; (5) Sample 115-707C-9R-2, 51–52 cm; (6) Sample 115-713C-9R-1, 102–103 cm. **7.** *Triceratium* aff. *brachiatum,* Sample 115-708A-25X-1, 102–103 cm. **8.** *Craspedodiscus umbonatus* lateral view, 900×, Sample 115-713A-7R-3, 103–104 cm. **9.** *Isthmia* sp., 900×, Sample 115-713A-7R-3, 103–104 cm.

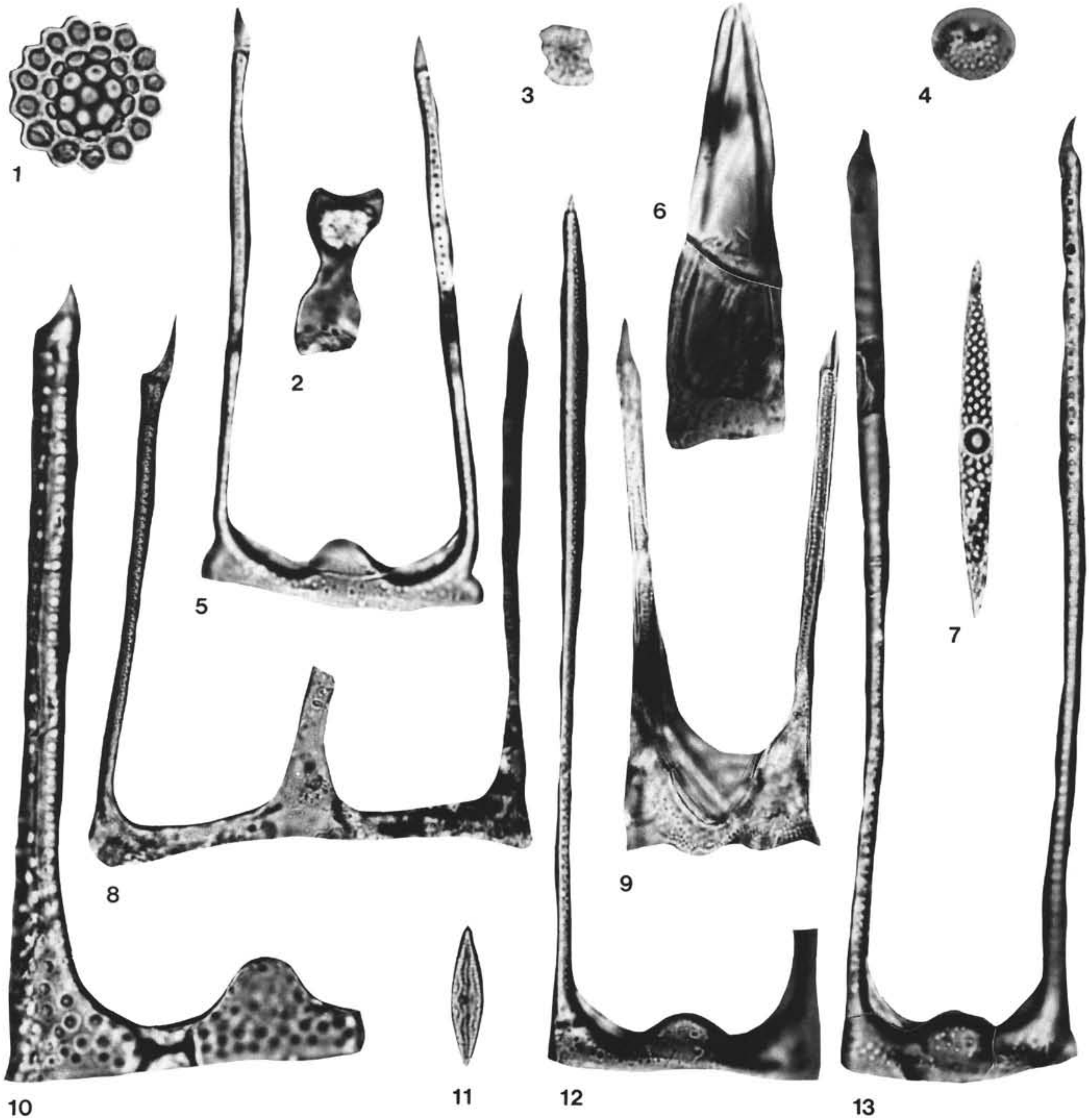

Plate 4. Magnification 1500× if not otherwise indicated. **1.** *Macrora stella,* Sample 115-707C-3R-2, 110–111 cm. **2–3.** *Phytoliths;* (2) Sample 115-707C-3R-6, 110–111 cm; (3) Sample 115-707C-3R-CC. **4.** Genus et species indet. (Diatom?, *Mallomonas* scale?), Sample 115-707A-21X-4, 105–106 cm. **5.** *Hemiaulus altar,* Sample 115-707A-21X-4, 105–106 cm. **6.** *Hemiaulus claviger,* Sample 115-707A-23X-2, 105–106 cm. **7.** *Rutilariopsis*(?) sp., Sample 115-708A-25X-1, 102–103 cm. **8.** *Hemiaulus altar* var., Sample 115-711A-16X-CC. **9.** *Hemiaulus* sp., Sample 115-707A-23X-2, 105–106 cm. **10.** *Hemiaulus* sp. (Sample 115-707A-18H-CC). **11.** *Navicula*(?) sp., Sample 115-707A-22X-6, 105–106 cm. **12–13.** *Hemiaulus longicornis;* (12) 1200×, Sample 115-707A-21X-2, 105–106 cm; (13) Sample 115-709C-29X-2, 102–103 cm.

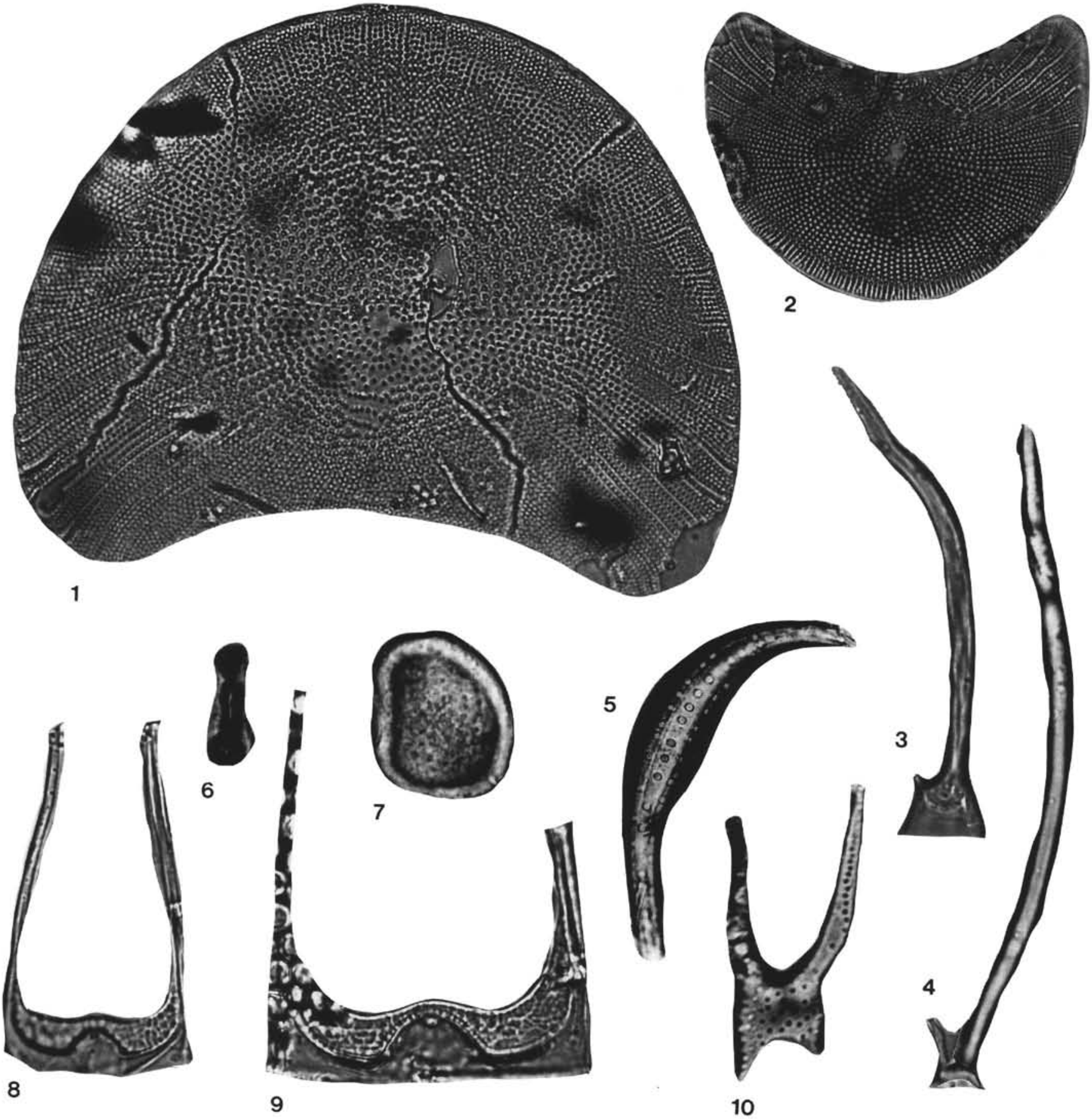

Plate 5. Magnification 1500× if not otherwise indicated. **1–2.** *Kozloviella meniscosa* sp. nov.; (1) Holotype, 850×, DSDP Sample 366-10-4, 89–90 cm; (2) 660×, DSDP Sample 366-8-4, 41–42 cm. **3–4.** *Chaetoceros asymmetricus* sp. nov.; (3) Holotype, DSDP Sample 369A-22-5, 128–129 cm; (4) Sample 115-707A-21X-6, 105–106 cm. **5.** *Chaetoceros* sp. 2, 900×, Sample 115-707C-3R-CC. **6–7.** Spore of mycophyta (fungi)?; (6) lateral view, Sample 115-711A-17X-1, 102–103 cm; (7) Sample 115-707C-3R-2, 110–111 cm. **8–9.** *Hemiaulus gracilis* sp. nov.; (8) Holotype, DSDP Sample 366-10-6, 132–133 cm; (9) DSDP Sample 366-9-3, 121–122 cm. **10.** *Dicladiopsis*? sp., Sample 115-707C-3R-6, 110–111 cm.