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Fossil marine diatom resting spore morpho-genus *Xanthiopyxis* Ehrenberg in the North Pacific and Norwegian Sea

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Abstract. Fossil marine diatom resting spore species in the morpho-genus *Xanthiopyxis* Ehrenberg are described using samples from DSDP Site 338 in the Norwegian Sea, Sites 436 and 438 in the northwest Pacific and from the onland section at Newport Beach, California. *Xanthiopyxis* is characterized by numerous knobs, spines and bristles covering the entire valve face. In this paper eleven species, of which seven are new species, are described and their stratigraphic ranges are presented: *X. polaris* Gran, *X. norwegica* Suto, sp. nov., *X. brevispinosa* Suto, sp. nov., *X. teneropunctata* Suto, sp. nov., *X. lanceolatus* Suto, sp. nov., *X. circulatus* Suto, sp. nov., *X. reticulata* Suto, sp. nov., *X. obesa* Suto, sp. nov., *X. hirsuta* Hanna and Grant, *X. oblonga* Ehrenberg and *X. globosa* Ehrenberg. In addition, resting spores which lack sufficient characteristics to identify easily are assigned to three informal species: *Xanthiopyxis* type A (knobbly type), *X. type B* (short spiny type) and *X. type C* (long spiny type).

Key words: *Xanthiopyxis*, fossil resting spore, diatom, ODP, taxonomy

Introduction

The marine diatom genus *Chaetoceros* Ehrenberg is one of the most important taxa in the present oceans, especially in upwelling regions (e.g., Hasle and Syvertsen, 1996). When nutrient supplies are depleted, many species form thick-walled resting spores, which sink to the sea floor to await the return of favorable conditions for vegetative growth. Resting spores are therefore preserved in significant quantities in fossil marine diatom assemblages, although their respective vegetative frustules are mostly dissolved. Since *Chaetoceros* is one of the most abundant primary producers in the marine ecosystem in upwelling regions, fossil resting spores may provide useful information for reconstructing paleoproductivity and paleoenvironmental changes in these regions. Nevertheless, few detailed systematic and stratigraphic studies have been carried out on fossil resting spores. As a result, most fossil resting spore species have been left undescribed, or neglected in previous stratigraphic and paleoceanographic studies presumably because of difficulties in identification.

Xanthiopyxis is a resting spore morpho-genus. Since *Xanthiopyxis oblonga* was erected by Ehrenberg (1844

(1845)), the genus has come to be regarded as a taxon for fossil resting spores of the genus *Chaetoceros* (Lohman, 1938), and now many *Xanthiopyxis* species have been described (e.g., *X. globosa* Ehrenberg, *X. cingulata* Ehrenberg, *X. umbonatus* Greville, *X. polaris* Gran). The various species of *Xanthiopyxis* are frequently found in sediments, but no systematic study has been completed on the genus, and therefore its taxonomy remains confused.

Suto (2003a, b, 2004a, b) has already described the morphology and stratigraphic ranges of the resting spore morpho-genera *Dicladia* Ehrenberg, *Monocladia* Suto, *Syndendrium* Ehrenberg, *Periptera* Ehrenberg, *Liradiscus* Greville and *Gemellodiscus* Suto. This study examined Paleogene and Neogene sediments in the North Pacific and Norwegian Sea by detailed LM and SEM observations, and describes eleven *Xanthiopyxis* species, including seven new ones, and an additional three forms (Figure 1).

Samples and methods

In this study, samples from Deep Sea Drilling Project (DSDP) Site 338 in the Norwegian Sea (67°47.11' N, 05°23.26' E; water depth 400.8 m; Cores

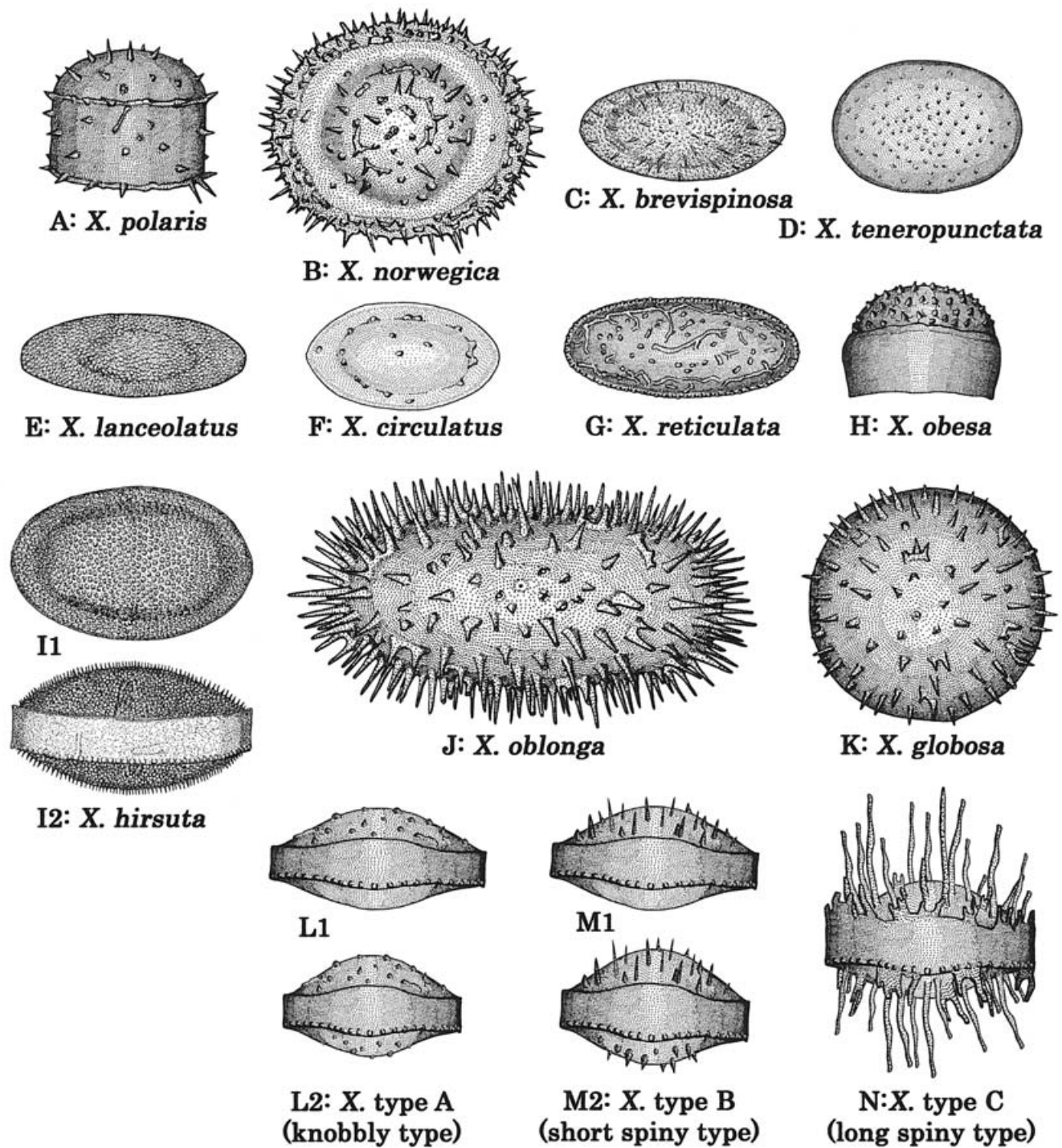


Figure 1. Sketches of valve and girdle view of *Xanthiopyxis* species (A, H, I2, L1, L2, M1, M2, N: girdle view; B, C, D, E, F, G, I1, J, K: valve view). All sketches were made using LM.

8–29) and Site 436 in the Northwest Pacific (39°55.96' N, 145°33.47' E; water depth 5,240 m; Cores 1–29), and Holes 438A and 438B in the Northwest Pacific (40°37.79' N, 143°14.15' E; water depth 1,558 m; Hole 438A, Cores 1–85; Hole 438B, Cores 6–16), and from the Capistrano and Monterey Formations at Newport Beach, California, were examined.

Strewn slides were prepared from the samples and counting and identification were carried out following the methods of Akiba (1986) and Suto (2003a).

Results

The results of counting and the stratigraphic distribution of each species are shown in Figures 2–6 and Tables 1–4. All values listed in Tables 1–4 indicate numbers of valves. The stratigraphic ranges and ages are described according to the NPD (Neogene North Pacific Diatom Zone) code of Akiba (1986) and Yanagisawa and Akiba (1998) for the Miocene, Pliocene and Pleistocene, and to the diatom zones of Schrader and Fenner (1976) for the Eocene and Oligocene.

Xanthiopyxis species are similar to the resting spores of extant *Chaetoceros* species, but the taxonomic relationship between fossil species of *Xanthiopyxis* and resting spores of extant species of *Chaetoceros* cannot be determined because the vegetative valves of *Xanthiopyxis* species were not preserved as fossils. Accordingly, it is appropriate to use the genus name *Xanthiopyxis* as a morpho-genus for the fossil resting spores according to Articles 3.2 and 3.3 of the ICBN (Greuter *et al.*, 2000), as in the case of fossil resting spores of dinoflagellates (Edwards, 1991). The synonym lists in this paper include only fossil spores.

Systematic paleontology

Division Bacillariophyta
Subdivision Bacillariophytina
Class Mediophyceae
Order Chaetocerotales
Suborder Biddulphineae
Family Chaetocerotaceae
Genus *Xanthiopyxis* Ehrenberg

Type species.—*Xanthiopyxis oblonga* Ehrenberg 1844 (1845).

Description.—Epivalve circular, oval or narrowly to broadly elliptical in valve view, valve face convex, covered with numerous knobs, spines, bristles and veins. Mantle of epivalve hyaline or with numerous knobs. Hypovalve face convex or with one hump,

hyaline or with numerous spines and knobs. Mantle of hypovalve hyaline with a single ring of puncta at its base.

Stratigraphic occurrence.—Middle Eocene to Recent (Figure 2).

Remarks.—The genus *Xanthiopyxis* is characterized by numerous knobs, spines, bristles and veins covering the entire valve face. Eleven species of the genus, including seven new ones, are described in this paper: *X. polaris* Gran, *X. norwegica* Suto, sp. nov., *X. brevispinosa* Suto, sp. nov., *X. teneropunctata* Suto, sp. nov., *X. lanceolatus* Suto, sp. nov., *X. circulatus* Suto, sp. nov., *X. reticulata* Suto, sp. nov., *X. obesa* Suto, sp. nov., *X. hirsuta* Hanna & Grant, *X. oblonga* Ehrenberg and *X. globosa* Ehrenberg (Figure 1).

Xanthiopyxis may represent the fossil resting spores of extant and extinct *Chaetoceros* species, but it is difficult or impossible to classify the spores correctly due to the fact that their respective vegetative stages are not preserved in association with their resting spores. Therefore, in this study, some resting spores which lack characteristics and are therefore difficult to identify easily are assigned to three informal species: *Xanthiopyxis* type A (knobbly type), *X.* type B (short spiny type) and *X.* type C (long spiny type).

Etymology.—Greek *xanthio-*, meaning “yellow” but applied as a genus name *Xanthium* to the cockle-burs, hence spiny-textured, + *pyxis*, “box, case.”

Key to species

- 1a. Mantle of epivalve with numerous knobs..... 2
- 1b. Mantle of epivalve hyaline..... 3
- 2a. Knobs covering the entire epivalve face
..... *Xanthiopyxis polaris*
- 2b. Knobs covering the central and marginal epivalve face..... *X. norwegica*
- 3a. Valve face covered with knobs 4
- 3b. Valve face covered with spines..... 6
- 3c. Valve face covered with knobs and spines
..... *X. brevispinosa*
- 4a. Knobs are weak *X. teneropunctata*
- 4b. Knobs are very small (micro-knobs)
..... *X. lanceolatus*
- 4c. Knobs are strong and encircled *X. circulatus*
- 4d. Knobs are strong and with veins 5
- 5a. Knobs covering the entire valve face
..... *X. type A* (knobbly type)
- 5b. Knobs encircled by veins *X. reticulata*
- 5c. Mantle expanded..... *X. obesa*
- 6a. Spines are very small (micro-spines)
..... *X. hirsuta*
- 6b. Spines are strong and short
..... *X. type B* (short spiny type)

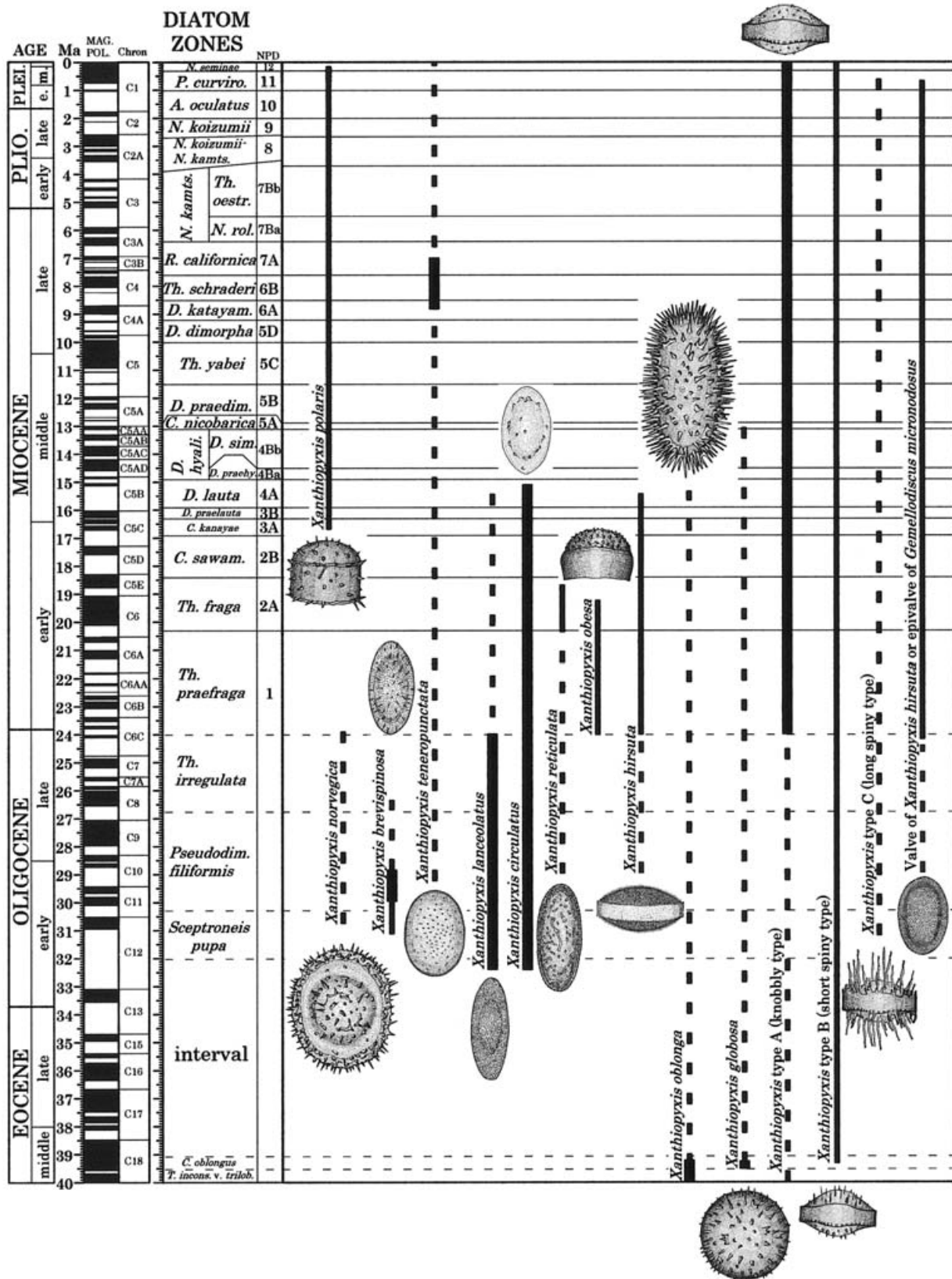


Figure 2. Stratigraphic ranges of *Xanthiopyxis* species. Diatom zones and NPD codes are after Yanagisawa and Akiba (1998) for the Miocene, Pliocene and Pleistocene, and after Schrader and Fenner (1976) for the Eocene and Oligocene.

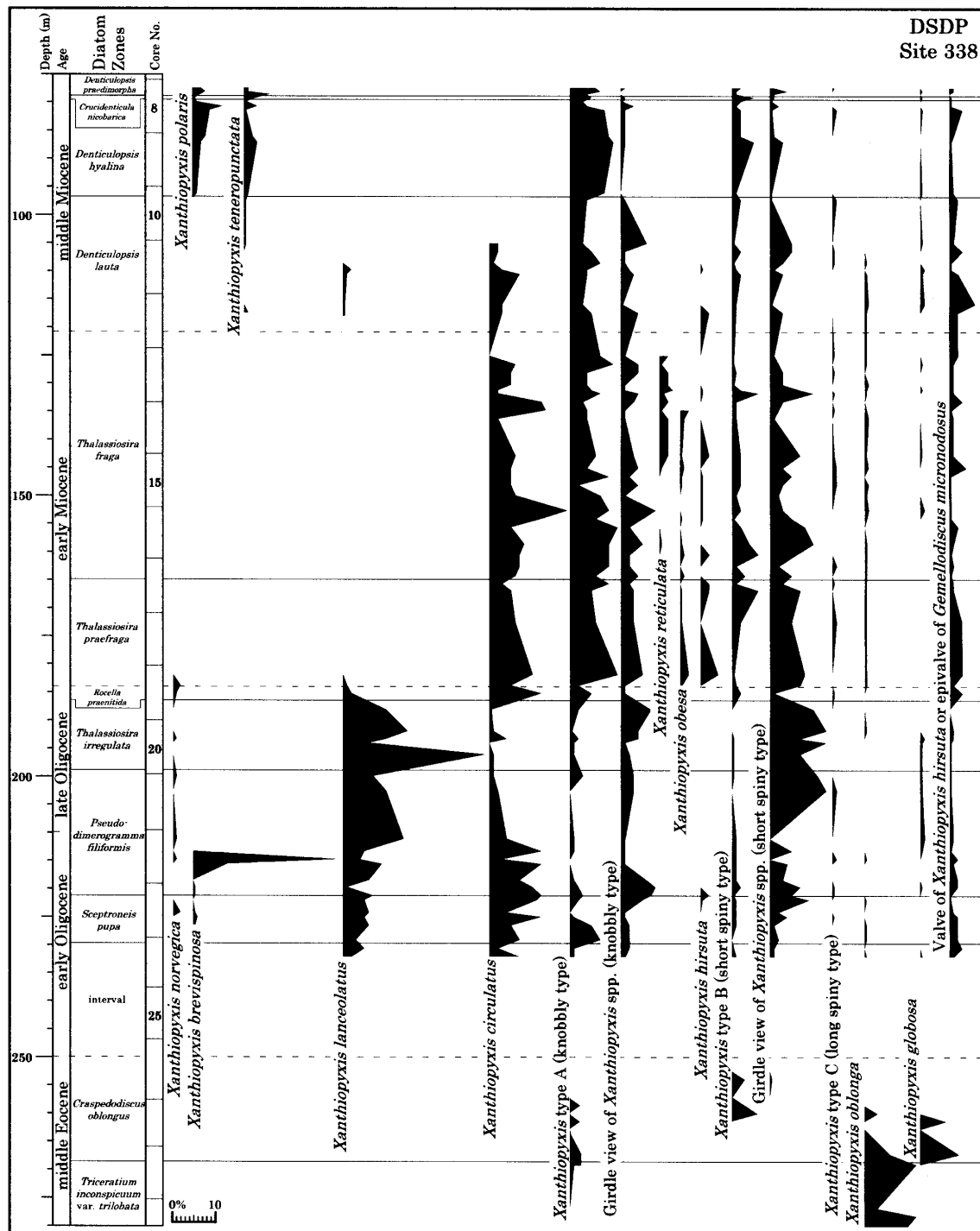


Figure 3. Stratigraphic occurrences of *Xanthiopyxis* species at DSDP Site 338. Diatom zones are after Schrader and Fenner (1976).

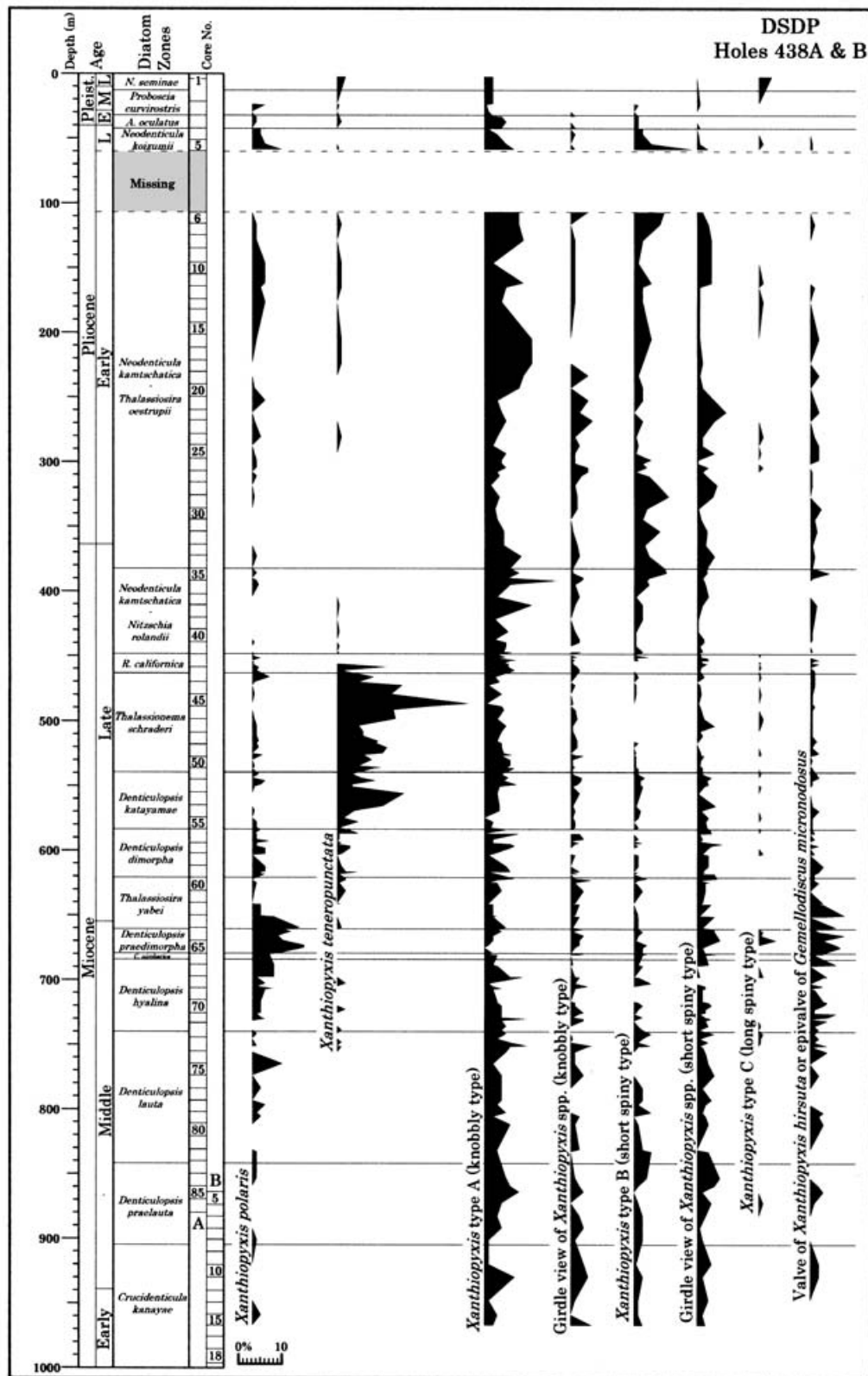


Figure 4. Stratigraphic occurrences of *Xanthiopyxis* species at DSDP Holes 438A and B. Diatom zones are after Yanagisawa and Akiba (1998).

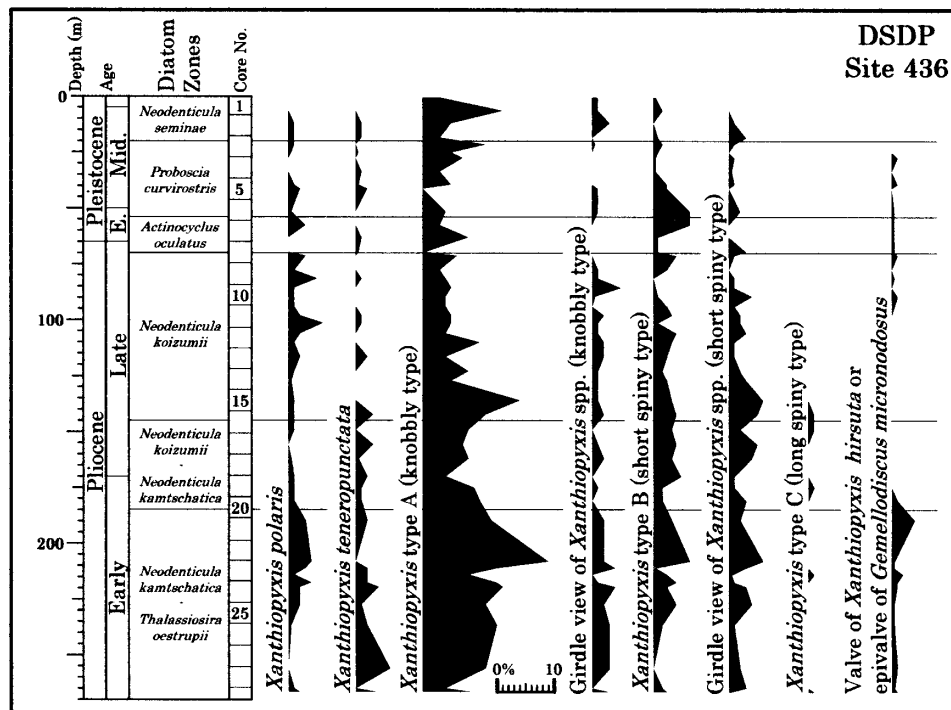


Figure 5. Stratigraphic occurrences of *Xanthiopyxis* species at DSDP Site 436 and in the Newport Beach Section. Diatom zones are after Yanagisawa and Akiba (1998).

- 6c. Spines are strong and long *X. type C* (long spiny type)
 6d. Spines are bristly..... 7
 7a. Valve oval to broadly elliptic *X. oblonga*
 7b. Valve circular *X. globosa*

Xanthiopyxis polaris Gran

Figures 1.A; 7.1–7.17

Basionym.—*Xanthiopyxis polaris* Gran, 1900, p. 51, pl. 3, figs. 16–19.

Synonymy.—*Chaetoceros* spp. of Shirshov, 1977, pl. 15, fig. 15; Spora of Dzinoridze *et al.*, 1978, pl. 15, fig. 18.

Description.—Frustule heterovalvate. Valve circular to oval in valve view, apical axis 4.5–11.5 μm , perivalvar axis 4.5–10 μm . In girdle view, epivalve face strongly vaulted, with numerous short spines and knobs. Mantle of epivalve with numerous short spines and knobs. Hypovalve vaulted or flat, with numerous knobs. Mantle of hypovalve hyaline with a single ring of puncta at its base.

Type locality.—Recent Arctic Ocean.

Similar taxa.—This species is clearly distinguished from other fossil resting spore species by having an epivalve mantle with numerous short spines and

knobs. It differs from *Xanthiopyxis norwegica* by having knobs covering the entire epivalve face.

Stratigraphic occurrence.—This species occurs from the latest early Miocene to the Recent in the North Pacific (Figure 2). At DSDP Site 338, the first occurrence of this species is recorded in the bottom of the middle middle Miocene (Figure 3).

Remarks.—This species occurs abundantly in the North Pacific and is also encountered in the Norwegian Sea. Thus *X. polaris* is probably a cosmopolitan species.

Etymology.—Latin *polaris*, meaning “polar”.

Xanthiopyxis norwegica Suto sp. nov.

Figures 1.B; 8.1–8.15

Description.—Frustule heterovalvate. Valve circular to oval in valve view, apical axis 21.0–34.5 μm , perivalvar axis 17.0–31.0 μm . In girdle view, epivalve face vaulted, central area vaulted with numerous short spines and knobs, intermediate zone hyaline, marginal zone with numerous knobs and spines. Mantle of epivalve with numerous short spines and knobs. Hypovalve hyaline, nearly flat. Mantle of hypovalve hyaline with a single ring of puncta at its base.

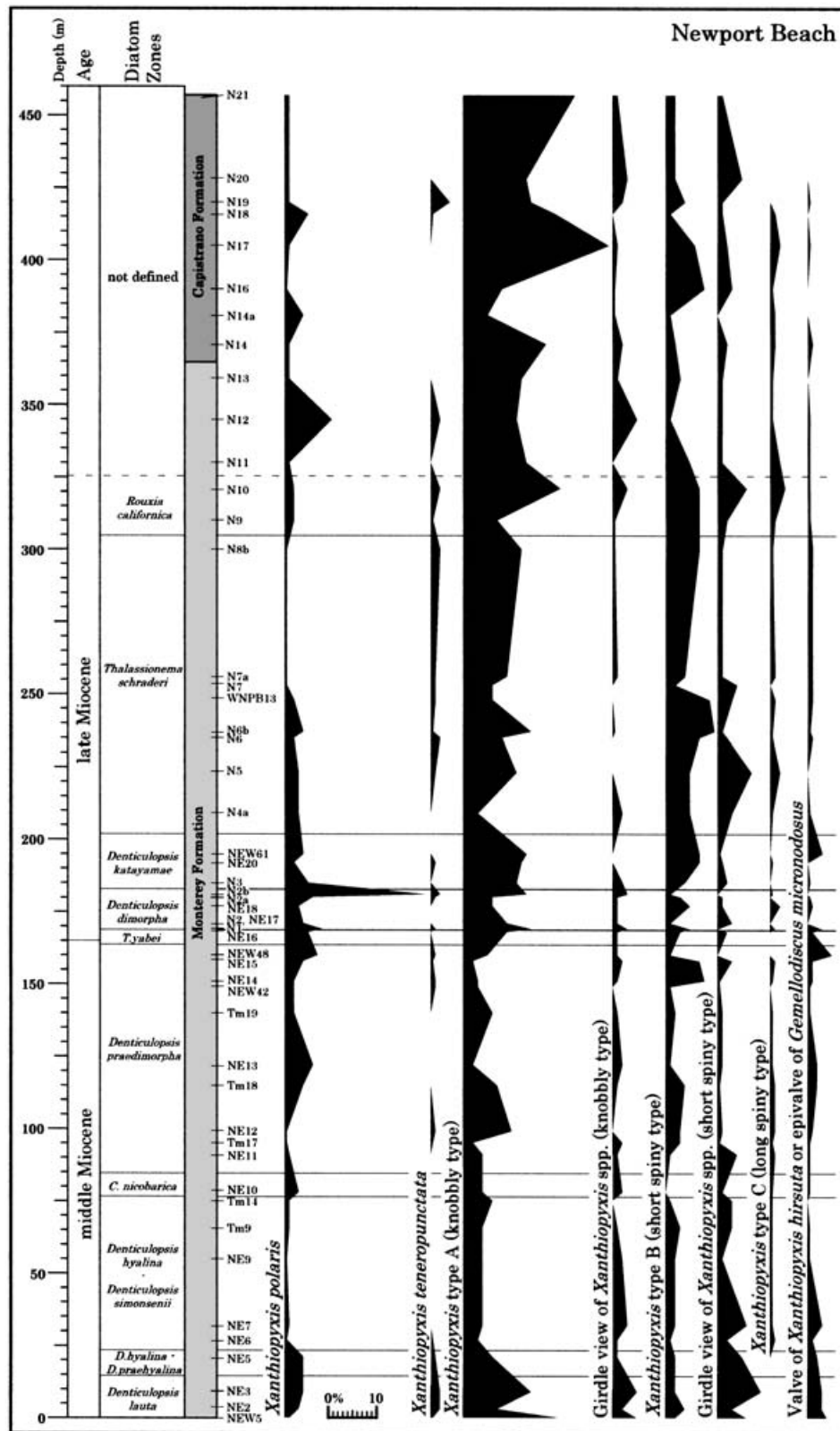


Figure 6. Stratigraphic occurrences of *Xanthiopyxis* species in the Newport Beach Section. Diatom zones are after Yanagisawa and Akiba (1998).

Table 1. Occurrences of *Xanthopyxis* species at DSDP Site 338. Numbers indicate individuals encountered during counts of 100 resting spore valves; + indicates valves encountered after the count; blank indicates absence of any taxa. Diatom zones and NPD codes in the Miocene are after Yanagisawa and Akiba (1998), and diatom zones in the Oligocene and Eocene after Schrader and Fenner (1976).

	Diatom zones	NPD	Core-Section, Interval (cm) Leg 38 Site 338	Depth (m)	Preservation	Abundance	<i>Xanthiopsis polaris</i>	<i>X. norvegica</i>	<i>X. brevispinosa</i>	<i>X. teneropunctata</i>	<i>X. laeoculatus</i>	<i>X. circulatus</i>	<i>X. type A</i> (knobby type)	<i>X. type B</i> (knobby type)	<i>X. reticulata</i>	<i>X. obesa</i>	<i>X. hirsuta</i>	<i>X. type B</i> (short spiny type)	<i>X. type C</i> (long spiny type)	<i>X. oblonga</i>	<i>X. globosa</i>	Valve of <i>X. hirsuta</i> or epilvalve of <i>G. microneodensis</i>	Total number of resting spore valves counted	
middle Miocene	<i>Denticulopsis praedimorpha</i>	5B	8-1, 140-141 8-2, 48-49 8-2, 99-100	77.40 77.98 78.49	G A G A G A	2 3 2		1 1 6				6 7 4	1				2 1 1	1 4 1	+		+	1 1 1	100 100 100	
	<i>C. nicobarica</i>	5A	8-3, 10-11 8-3, 80-81 8-4, 10-11 8-4, 80-81 9-1, 50-51 9-1, 148-149 10-1, 106-107	79.10 79.80 80.60 81.30 86.00 86.98 96.06	G A G A G A G A G A G A G A	+	3 1 7 4 3 2 1		3 +			5 3 4 8 9 10 8	1				5 2 1 2 2 5 1		1	+	+	100 100 100 100 100 100 100		
	<i>Denticulopsis hyalina</i>	4B																						
	<i>Denticulopsis lauta</i>	4A																						
	early Miocene	<i>Thalassiosira fraga</i>	2A	13-1, 148-149 13-2, 148-149 13-3, 148-149 13-5, 70-71 13-6, 10-11 13-6, 70-71 14-1, 20-21 14-2, 20-21 14-3, 20-21 15-1, 30-31 15-2, 100-101 15-3, 100-101 15-4, 100-101 15-5, 138-139 16-1, 10-11 16-2, 10-11 16-3, 10-11 16-5, 10-11 16-6, 50-51 17-1, 100-101 17-2, 119-120	124.98 126.48 127.98 130.20 131.10 131.70 133.20 134.70 136.20 142.80 145.00 146.50 148.00 149.88 152.55 154.05 155.55 158.55 160.45 162.50 164.19	G A G A																		
<i>Thalassiosira praepraga</i>		1	17-3, 110-111 17-4, 79-80 18-1, 148-149 19-1, 130-131 19-3, 20-21	165.60 166.79 172.48 181.80 183.70	G A G A G A G A G A																			
<i>R. praenitida</i>			19-4, 10-11	185.10	G A	+	2	12	5	1								2	1	+			3	100
<i>Thalassiosira irregulata</i>			19-5, 148-149 20-2, 30-31 20-3, 20-21 20-3, 90-91 20-4, 148-149	187.98 191.80 193.20 193.90 195.98	G A G A G C G C G A																			
<i>Pseudodimerogramma filiformis</i>			21-1, 32-33 21-2, 148-149 22-2, 10-11 22-3, 80-81 22-4, 79-80 22-5, 10-11 22-6, 148-149 23-1, 80-81 23-2, 80-81	199.82 202.48 211.00 213.20 214.69 215.50 218.38 219.60 221.10	G A G A G R G C G R G C G C G C G A	+																		
<i>Sceptroneis pupa</i>			23-3, 10-11 23-4, 80-81 23-5, 10-11 23-6, 10-11 24-1, 100-101	221.90 224.10 224.90 226.40 229.00	G C G C G C G R G R																			
interval			24-2, 100-101 24-3, 100-101	230.50 232.00	G C G R																			
middle Eocene		<i>Craspedodiscus oblongus</i>		26-2, 110-111 26-3, 80-81 26-4, 80-81 26-5, 80-81 27-1, 58-59 27-2, 50-51 27-3, 40-41 27-4, 30-31 27-5, 19-20 28-1, 120-121	249.60 250.80 252.30 253.80 257.08 258.50 259.90 261.30 262.69 267.20	G R G R G R G R G R G R G R G R G R G R																		
		<i>Triceratium inconspicuum</i> var. <i>trilobata</i>		28-2, 148-149 29-1, 130-131 29-2, 120-121 29-3, 148-149	268.98 276.80 278.20 279.98	G R G R G R G R																		

Table 2. Occurrences of *Xanthiopyxis* species at DSDP Holes 438A and 438B. Values are for counts of 100 or 200 resting spore valves; + indicates valves encountered after the count; blank indicates absence of any new taxa. Diatom zones and NPD codes are after Yanagisawa and Akiba (1998).

Diatom Zones (NPD)	Core/Section, Interval (cm) Log 57 Site 438	Depth (m)	Preservation	Abundance	<i>Xanthiopyxis polaris</i>	<i>X. longipunctata</i>	<i>X. type A</i>	<i>X. type B</i>	<i>X. type C</i>	Valve of <i>X. hirsuta</i> or equivalent of <i>G. microdonatus</i>	Total number of resting spore valves counted	
<i>N. seminae</i> (NPD 12)	1-2, 80-82	2.31	G	A	2	2					100	
<i>Proboresia curvistris</i> (NPD 11)	2-1, 10-14 2-1, 96-98 2-5, 5-9	23.12 23.97 23.07	G	A	3	+	+		1	1	100	
<i>Actinocyclus oculatus</i> (NPD 10)	3-1, 31-33 3-3, 140-142 3-4, 10-14 3cc	32.82 32.91 37.12 41.65	G	A	+	+	2	1	1	1	100	
<i>Neodenticula koizumii</i> (NPD 9)	4-1, 40-74 4-4, 8-12 5-2, 96-100	42.72 46.6 53.98	G	A	2	3	1	2	+	+	100	
	5cc	58.5	G	A	7	+	7	1	1	1	100	
	6-1, 18-22 7-1, 19-22 8-3, 30-34 10-2, 15-18 11-6, 20-24 12-1, 138-140 13-3, 19-23 16-3, 36-39 18-3, 10-14 19-3, 10-14 20-3, 26-30 21-3, 20-24 22-3, 20-24 23-1, 10-14 24-3, 10-12 25-1, 35-39 25-5, 16-20 26-2, 29-32 26-4, 10-14 26-6, 15-19 27-2, 20-24 27-4, 20-24 28-2, 20-24 29-2, 20-24 30-2, 20-24 31-1, 20-24 32-1, 24-28 33-1, 120-124 34-1, 22-24 35-1, 24-28 35-3, 24-28 35-6, 24-28 36-1, 32-36 36-3, 32-36 37-3, 10-14 38-1, 11-15 39-2, 11-15 40-2, 20-24 40-6, 10-14 41-1, 45-49 41-3, 30-34 41-6, 10-14 41cc	106.7 116.21 128.82 146.17 161.72 164.89 176.21 204.88 223.62 233.12 242.78 252.22 261.72 268.12 280.61 287.37 293.18 298.31 301.12 304.17 307.72 310.72 317.72 326.72 336.22 344.22 353.76 364.22 372.73 382.26 385.86 387.76 391.84 394.84 404.12 410.63 421.63 431.22 437.12 439.47 442.32 446.62 447.12	G	A	1	1	8	4	7	2	2	100
	42-1, 14-18 42-1, 90-91 42-2, 95-96 42-3, 15-16 42-4, 50-54 42-4, 73-74 42-5, 100-101 42-6, 16-20 43-1, 59-63 43-3, 30-34	448.06 449.41 450.96 451.66 453.52 453.74 455.51 456.18 458.61 461.32	G	A	1	1	13	5	4	3	200	
<i>Rouxia californica</i> (NPD 7A)	42-1, 90-91 42-2, 95-96 42-3, 15-16 42-4, 50-54 42-4, 73-74 42-5, 100-101 42-6, 16-20 43-1, 59-63 43-3, 30-34	449.41 450.96 451.66 453.52 453.74 455.51 456.18 458.61 461.32	G	A	2	10	3	7	3	1	200	
	43-6, 82-86 44-1, 60-64 44-3, 10-14 45-1, 54-58 45-6, 30-34 46-1, 18-20 46-3, 18-22 47-1, 10-14 47-4, 110-114 48-1, 14-18 48-3, 46-50 48-6, 25-30 48-7, 30-31 49-3, 10-14 49-6, 10-14 49-7, 10-11 50-1, 20-24 50-3, 20-24 50-6, 20-24 50-7, 10-11 51-1, 16-20	466.34 470.12 472.62 479.56 486.82 488.7 491.7 498.12 503.62 507.66 510.98 515.28 516.81 520.12 524.62 526.11 526.72 529.72 534.22 535.61 536.18	G	A	8	19	5	2	2	5	1	200
<i>Thalassionema schraderi</i> (NPD 6B)	44-1, 60-64 44-3, 10-14 45-1, 54-58 45-6, 30-34 46-1, 18-20 46-3, 18-22 47-1, 10-14 47-4, 110-114 48-1, 14-18 48-3, 46-50 48-6, 25-30 48-7, 30-31 49-3, 10-14 49-6, 10-14 49-7, 10-11 50-1, 20-24 50-3, 20-24 50-6, 20-24 50-7, 10-11 51-1, 16-20	470.12 472.62 479.56 486.82 488.7 491.7 498.12 503.62 507.66 510.98 515.28 516.81 520.12 524.62 526.11 526.72 529.72 534.22 535.61 536.18	G	A	1	10	7	1	2	2	2	200
<i>Denticulopsis katayamae</i> (NPD 6A)	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	3	7	8	1	2	4	1	200
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	11	11	5	5	10	4	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	6	18	9	5	3	7	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	4	7	15	3	8	1	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	1	7	7	1	4	5	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	3	7	8	1	2	4	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	11	11	5	5	10	4	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	6	18	9	5	3	7	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	4	7	15	3	8	1	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	1	7	7	1	4	5	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	3	7	8	1	2	4	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	11	11	5	5	10	4	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	6	18	9	5	3	7	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	4	7	15	3	8	1	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	1	7	7	1	4	5	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	3	7	8	1	2	4	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	11	11	5	5	10	4	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	6	18	9	5	3	7	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	4	7	15	3	8	1	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	1	7	7	1	4	5	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	3	7	8	1	2	4	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	11	11	5	5	10	4	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	6	18	9	5	3	7	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	4	7	15	3	8	1	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	1	7	7	1	4	5	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	3	7	8	1	2	4	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	11	11	5	5	10	4	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	6	18	9	5	3	7	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	4	7	15	3	8	1	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	1	7	7	1	4	5	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	3	7	8	1	2	4	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	11	11	5	5	10	4	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	6	18	9	5	3	7	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	4	7	15	3	8	1	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	1	7	7	1	4	5	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	3	7	8	1	2	4	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	11	11	5	5	10	4	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	6	18	9	5	3	7	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	4	7	15	3	8	1	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	1	7	7	1	4	5	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	3	7	8	1	2	4	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	11	11	5	5	10	4	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	6	18	9	5	3	7	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	4	7	15	3	8	1	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	1	7	7	1	4	5	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	3	7	8	1	2	4	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	11	11	5	5	10	4	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	6	18	9	5	3	7	100	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	4	7	15	3	8	1	200	
	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.08 543.08 545.87 548.87 550.37	G	A	1	7	7	1	4			

Table 3. Occurrences of *Xanthiopyxis* species at DSDP Site 436. Numbers indicate individuals encountered during counts of 100 resting spore valves; + indicates valves encountered after the count; blank indicates absence of any taxa. Diatom zones and NPD codes are after Yanagisawa and Akiba (1998).

	Diatom zones & NPD	Core/Section, Interval (cm) Leg 56 Site 436	Depth (m)	Preservation	Abundance	<i>Xanthiopyxis polaris</i>	<i>X. tenuirostrata</i>	<i>X. type A</i> (knobly type)	Girdle view of <i>Xanthiopyxis</i> spp. (knobly type)	<i>X. type B</i> (short spiny type)	Girdle view of <i>Xanthiopyxis</i> spp. (short spiny type)	<i>X. type C</i> (long spiny type)	Valve of <i>X. hirsuta</i> or epivalve of <i>G. micropaleus</i>	Total number of resting spore valves counted	
l. Plasto	<i>Neodenticula seminae</i> 12	1-1, 49-50	0.49	G R	3	1	3	1	+	+				100	
		1-5, 50-52	6.40	G C	14	1	2							100	
		2-3, 100-102	12.00	G R	1	1	5	3		1				100	
		3-1, 102-104	18.52	G R	1	1	3	3		1	3			100	
m.d. Pliocene	<i>Proboscidea curvirostris</i> 11	3-3, 100-102	21.50	G C	1	11	+	2	1	3				100	
		3-6, 10-12	25.10	G R	+	5		1						100	
		4-1, 50-52	27.50	G R	+	7		+	1				1	100	
		4-5, 50-52	33.50	G C	+	1	3		+	+				100	
e. Pli.	<i>Actinocyclus oculatus</i> 10	5-2, 148-150	39.48	G A	1	5		+	1					100	
		5-4, 22-24	41.12	G R	2	2		1	3				1	100	
		6-4, 100-102	51.50	G C	+	4	1	3	8	2				+	100
		7-2, 54-56	57.54	G R	3	3		8					+	100	
late Pliocene	<i>Neodenticula koizumii</i> 9	7-6, 50-52	63.00	G C	+	1	8		+	1	3		+	100	
		8-3, 148-150	69.48	G A	+	+	+						+	100	
		8-5, 18-20	71.18	G C	3	8	6		5	1				100	
		9-2, 148-150	77.48	G A	1	3	1	3						100	
	9-5, 95-97	81.35	G R	5	1	4		1			+		100		
	10-1, 148-150	85.48	G A	1	5	5		+	1				100		
	10-4, 98-100	89.48	G R	1	4	+							100		
	11-1, 50-52	94.00	G A	+	4		3	1					1	100	
	11-3, 148-150	97.88	G A	2	1	5	2	4	2					100	
	11-6, 100-102	101.40	G C	6	1	5	1	1	2					100	
	12-2, 148-150	105.98	G C	2	4	1	5	3						100	
	12-5, 98-100	109.98	G C	1	1	10	2	4	1					100	
	13-3, 100-102	116.50	G C	2	2	4	2	3						100	
	14-1, 100-102	123.00	G C	1	8	1	2	2						100	
	14-4, 48-50	126.98	G C	+	5	1	3	3						100	
	15-3, 141-143	135.91	G C	1	17	1	4	6						100	
16-1, 130-132	142.30	G C	1	13	1	2	5	5	1				100		
early Pliocene	<i>Neodenticula kamtschatica</i> 8	16-6, 47-49	148.87	G R	3	7	1	4	2	1				100	
		17-4, 50-52	155.50	G C	3	7	1	5	5					100	
		18-2, 45-47	161.95	G A	+	+	8	2	4					100	
		19-1, 50-52	170.00	G C	1	2	4		6	1				100	
	19-4, 148-150	174.98	G C	1	1	9	1	2	1	1				100	
	20-2, 38-40	180.88	G C	1	1	10		2					1	100	
	21-1, 110-112	189.60	G C	3	2	12	2	4	2					4	100
	23-1, 48-50	207.98	G A	4	22	2	8	6					+	100	
	23-3, 48-50	210.98	G A	3	2	13	4	+	3				+	100	
	23-5, 50-52	214.00	G C	1	2	8				1	2			100	
<i>Thalassiosira ostrupii</i> 7Bb	24-1, 50-52	217.50	G A	2	13	1	5	1						2	100
	24-2, 110-112	219.30	G R	2	4	14	4	3	3					1	100
	25-1, 70-72	227.20	G R	2	1	11	2	5	4				+	100	
	26-1, 60-62	236.47	G C	+	2	13	3	2					+	100	
	28-1, 102-104	256.02	G R	1	6	11	3	2					1	100	
	29-1, 48-50	264.98	G R	2	4		3	2				+	100		
	29-2, 70-72	266.70	G R	2	4	9	3	3	3					1	100

Holotype.—Slide MPC-02613 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder O34-2N, illustrated in Figures 8.1, 8.2).

Type locality.—DSDP Site 338-19-4, 10–11 cm, Norwegian Sea.

Similar taxa.—This species differs from *Xanthiopyxis polaris* by having knobs on the center and margin of the epivalve face.

Stratigraphic occurrences.—This species occurs rarely and sporadically in the interval from the lower Oligocene to the lowermost Miocene at DSDP Site 338 (Figure 3).

Etymology.—Latin *norwegica*, meaning “Norwegian, of Norway.”

Xanthiopyxis brevispinosa Suto sp. nov.

Figures 1.C; 9.25–9.38

Description.—Frustule heterovalvate. Valve narrowly elliptical to lanceolate in valve view, apical axis 10.0–20.5 μ m, transapical axis 5.5–7.5 μ m. In girdle

Table 4. Occurrences of *Xanthiopyxis* species in the Newport Beach Section. Numbers indicate individuals encountered during counts of 100 resting spore valves; + indicates valves encountered after the count; blank indicates absence of any taxa. Diatom zones and NPD codes are after Yanagisawa and Akiba (1998).

Diatom zones & NPD	Sampled section (W: western; E: eastern)	Sample number	Depth (m)	Preservation	Abundance	<i>Xanthiopyxis polaris</i>	<i>X. tenuirostrata</i>	<i>X. type A</i> (knobly type)	Girdle view of <i>Xanthiopyxis</i> spp. (knobly type)	<i>X. type B</i> (short spiny type)	Girdle view of <i>Xanthiopyxis</i> spp. (short spiny type)	<i>X. type C</i> (long spiny type)	Valve of <i>X. hirsuta</i> or epivalve of <i>G. micropaleus</i>	Total number of resting spore valves counted
not defined	Capistrano Fm.	N21	457	M R	1	23	1	2	1					100
		N20	428	M R	1	13	3	2	5					100
		N19	420	G C	1	4	14	2	4	1			+	100
		N18	416	G A	5	+	19		1	1	1			100
		N17	405	G C	1	30	1	6	2	2	2	+		100
		N16	390	G A	+	8	+	8	3	+				100
		N14a	381	G C	4	5	+	1		1				100
		N14	371	G C	1	17	2	2	2	1	1			100
		N13	359	G A	1	12	1	3	1	+				100
		N12	345	G R	10	2	11	5	1	1	+	+		100
		N11	339	G A	1	13		5	1	2	+			100
late Miocene	Monterey Formation	R. californica 7A	N10	321	G A	2	2	20	3	7	6	3	+	100
			N9	310	G A	2	+	7	+	7	2	1	+	100
		N8b	300	G C	+	2	12	+	7	1	1	+		100
		N7a	256	G C	+	1	9	1	4	1	1			100
		N7	253	G R	+	1	6		2	4				100
		WNPB13	248	G A	2	1	6		9	3	1			100
		N6b	237	G A	4	+	14	+	10	1	+			100
		N6	235	G C	2	2	8		7	2	+			100
		N5	223	G R	3	1	11		5	7	2			100
		N4a	209	M R	3	3	2	5	3	+	+			100
		NEW61	195	G C	4	13		7	+	+	3			100
		NE20	192	G R	2	1	12		7	1	+			100
middle Miocene	Monterey Formation	N3	185	G R	5	11	2	4	2	+				100
		N2b	181	M R	30	2	13	3	1	+				100
		N2a	180	G R	6	1	6	1	3	1	+			100
		NE18	177	G A	3	6	1	5	1	2	1			100
		NE17	171	M R	4	9	1	1	3					100
		N1	169	G C	8	1	14	3	5	1	3			100
		5C	NE16	168	M R	5	9	1	3	2				100
		NEW48	160	G R	7	1	5	1	1					100
		NE15	158	G C	4	+	2	2	7	3	1			100
		NE14	151	G C	2	1	3	1	8	+	+			100
		NEW42	149	G C	2	1	3		1	+	+			100
		Tm19	140	G C	2	6	1	2	1	+	+			100
early Pliocene	Monterey Formation	NE13	122	G R	6	2	2	1	1	+	+			100
		Tm18	115	G C	4	7	1	4	+	1	2			100
		NE12	99	G C	+	1	10	3	3	1	1			100
		Tm17	95	G A	+	2	2	3	+	+	+			100
		NE11	91	G A	1	4	1	1	4	1	+			100
		5A	NE10	78	G C	3	4	2		1	+	+		100
		Tm14	75	G A	1	6		1	3	+	+			100
		Tm9	66	G A	1	4	1	3	3	+	+			100
		NE9	55	G A	+	4	2	2	1	+	+			100
		NE7	32	G A	1	4	3	2	6	+	+			100
		NE6	27	G A	+	3	1	1	2	1	+			100
		NE5	21	G A	4	1	6	1	2	5	2			100
late Pliocene	Monterey Formation	NE3	9	G A	4	2	14	5	2	9				100
		NE2	3	G A	3	2	7	2	4	3				100
		NEW5	0	G A	1	+	20	5	2	6				100

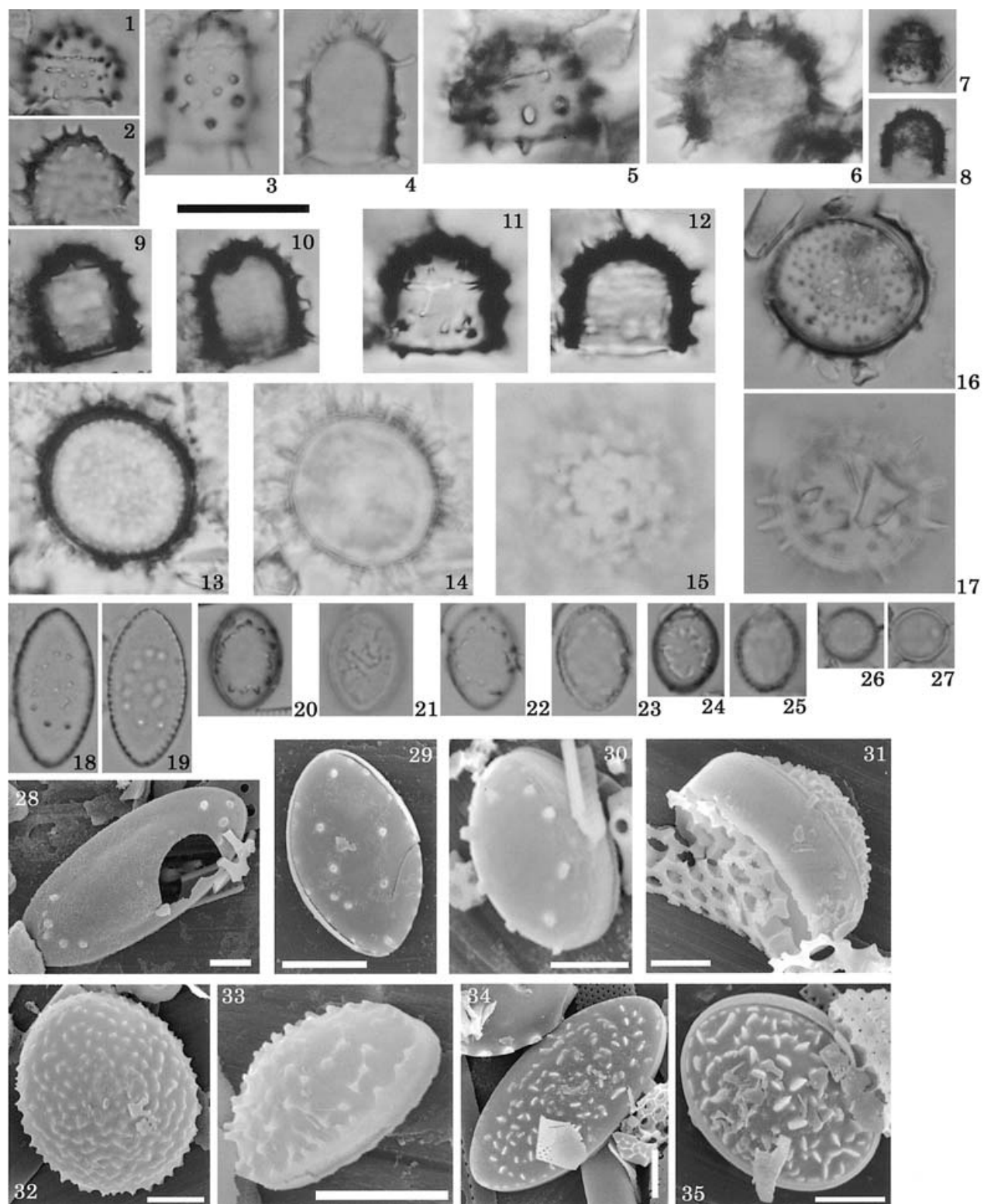
view, epivalve face vaulted, with numerous short strong spines and small knobs. Mantle of epivalve hyaline. Hypovalve vaulted or flat, with numerous short spines and small knobs. Mantle of hypovalve hyaline with a single ring of puncta at its base.

Holotype.—Slide MPC-02615 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder L30-1W, illustrated in Figures 9.33, 9.34).

Type locality.—DSDP Site 338-22-4, 79–80 cm, Norwegian Sea.

Similar taxa.—This species is characterized by having valves with numerous short strong spines and small knobs. This species is similar to *X. lanceolatus* and *X. hirsuta* in possessing numerous short strong spines and small knobs, but this species is distinguished by having a valve possessing both numerous short strong spines and small knobs.

Stratigraphic occurrence.—This species occurs in a very short interval in the upper lower Oligocene at



DSDP Site 338 (Figure 3). This species has peaks in abundance in the *Pseudodimerogramma filiformis* Zone, where it comprises over 30% of the resting spore assemblage.

Etymology.—The Latin word *brevispinosa* means “short-spined”.

***Xanthiopyxis teneropunctata* Suto sp. nov.**

Figures 1.D; 10.41–10.50

Description.—Valve oval to broadly elliptical in valve view, apical axis 5.5–11.5 μm , transapical axis 5.5–10.0 μm . In girdle view, epivalve face vaulted, with numerous weak knobs. Mantle of epivalve hyaline. Frustule not observed, and hypovalve unknown.

Holotype.—Slide MPC-02616 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder N43-1S, illustrated in Figures 10.43, 10.44).

Type locality.—DSDP Site 338-8-2, 99–100 cm, Norwegian Sea.

Similar taxa.—This species is characterized by having a broadly elliptical epivalve with numerous weak knobs. This species is very similar to *X. type A* (knobbly type), *X. circulatus*, *X. reticulata* and *X. obesa* in possessing knobs on the epivalve, but differs by having weak knobs on the epivalve. This species is distinguished from *X. lanceolatus* by having an oval to broadly elliptical valve shape.

Stratigraphic occurrence.—This species occurs from the lower middle Miocene to the upper Pleistocene in the North Pacific (Figures 4–6). At DSDP Hole 438A, this species occurs abundantly from the middle upper Miocene to the upper Miocene, where it comprises over 10% of the resting spore assemblage (Figure 4). At DSDP Site 338, the first occurrence of this species is recorded in the middle Miocene (Figure 3).

Remarks.—This species occurs abundantly in the

North Pacific and is also encountered in the Norwegian Sea. Thus *X. teneropunctata* is probably a cosmopolitan species.

Etymology.—Latin *teneropunctata* means “weakly spotted”.

***Xanthiopyxis lanceolatus* Suto sp. nov.**

Figures 1.E; 9.1–9.24

Description.—Frustule heterovalvate. Valve narrowly elliptical to lanceolate in valve view, apical axis 10.5–42.5 μm , transapical axis 5.5–14.0 μm . In girdle view, epivalve face vaulted, with numerous small weak knobs. Mantle of epivalve hyaline. Hypovalve slightly vaulted or flat, with knobs. Mantle of hypovalve hyaline, with a single ring of puncta at its base.

Holotype.—Slide MPC-02612 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder O40-1C, illustrated in Figures 9.1, 9.2).

Type locality.—DSDP Site 338-20-2, 30–31 cm, Norwegian Sea.

Similar taxa.—This species is characterized by having a narrowly elliptical to lanceolate epivalve with numerous weak knobs. This species is distinguished from *X. teneropunctata* by having a narrowly elliptical to lanceolate valve shape. This species is separable from *X. hirsuta* by its epivalve covered with weak small knobs. This species is similar to *Xanthiopyxis type A* (knobbly type), *X. circulatus*, *X. reticulata* and *X. obesa* in possessing knobs on the epivalve, but differs by having strong rather than weak knobs on the epivalve.

Stratigraphic occurrence.—This species occurs very abundantly in the Oligocene at DSDP Site 338 (Figure 3). In the middle Miocene, only rare occurrences of this species are recognized.

Etymology.—Latin *lanceolatus*, “lanceolate, shaped like the head of a lance.”

◆ **Figure 7. 1–17. *Xanthiopyxis polaris* Gran (LM). Scale bar = 10 μm for each figure.**

1, 2. Girdle view of epivalve, Newport Beach Section, N12. **3, 4.** Girdle view of epivalve, DSDP Site 338-8-1, 140–141 cm. **5, 6.** Girdle view of epivalve, DSDP Hole 438A-79-1, 51–54 cm. **7, 8.** Girdle view of epivalve, DSDP Hole 438A-5-2, 96–100 cm. **9, 10.** Girdle view of epivalve, DSDP Hole 438A-66-2, 82–84 cm. **11, 12.** Girdle view of epivalve, DSDP Hole 438A-42-1, 14–18 cm. **13–15.** Hypovalve view of frustule, DSDP Hole 438A-12-1, 138–140 cm. **16, 17.** Hypovalve view of frustule, DSDP Site 436-12-5, 98–100 cm.

18–30. *Xanthiopyxis circulatus* Suto sp. nov. Scale bar = 10 μm for figures 18–27 (LM); Scale bar = 5 μm for figures 28–30 (SEM). **18, 19.** Valve view of epivalve, DSDP Site 338-14-2, 20–21 cm. **20, 21.** Holotype. Valve view of frustule, DSDP Site 338-12-3, 38–39 cm. **22, 23.** Valve view of epivalve, DSDP Site 338-11-4, 148–149 cm. **24, 25.** Valve view of epivalve, DSDP Site 338-11-4, 70–71 cm. **26, 27.** Valve view of epivalve, DSDP Site 338-14-1, 20–21 cm. **28.** Valve view of epivalve, DSDP Site 338-11-4, 148–149 cm. **29.** Valve view of epivalve, DSDP Site 338-15-2, 100–101 cm. **30.** Valve view of epivalve, DSDP Site 338-11-4, 148–149 cm.

31. *Xanthiopyxis obesa* Suto sp. nov. Scale bar = 5 μm (SEM). **31.** Girdle view of epivalve, DSDP Site 338-18-1, 148–149 cm.

32–35. *Xanthiopyxis type A* (knobbly type). Scale bar = 5 μm for each figure (SEM). **32.** Valve view of epivalve, DSDP Site 338-18-1, 148–149 cm. **33.** Oblique valve view of epivalve, DSDP Site 338-11-4, 148–149 cm. **34.** Valve view of epivalve, DSDP Site 338-18-1, 148–149 cm. **35.** Valve view of epivalve, DSDP Site 338-18-1, 148–149 cm.

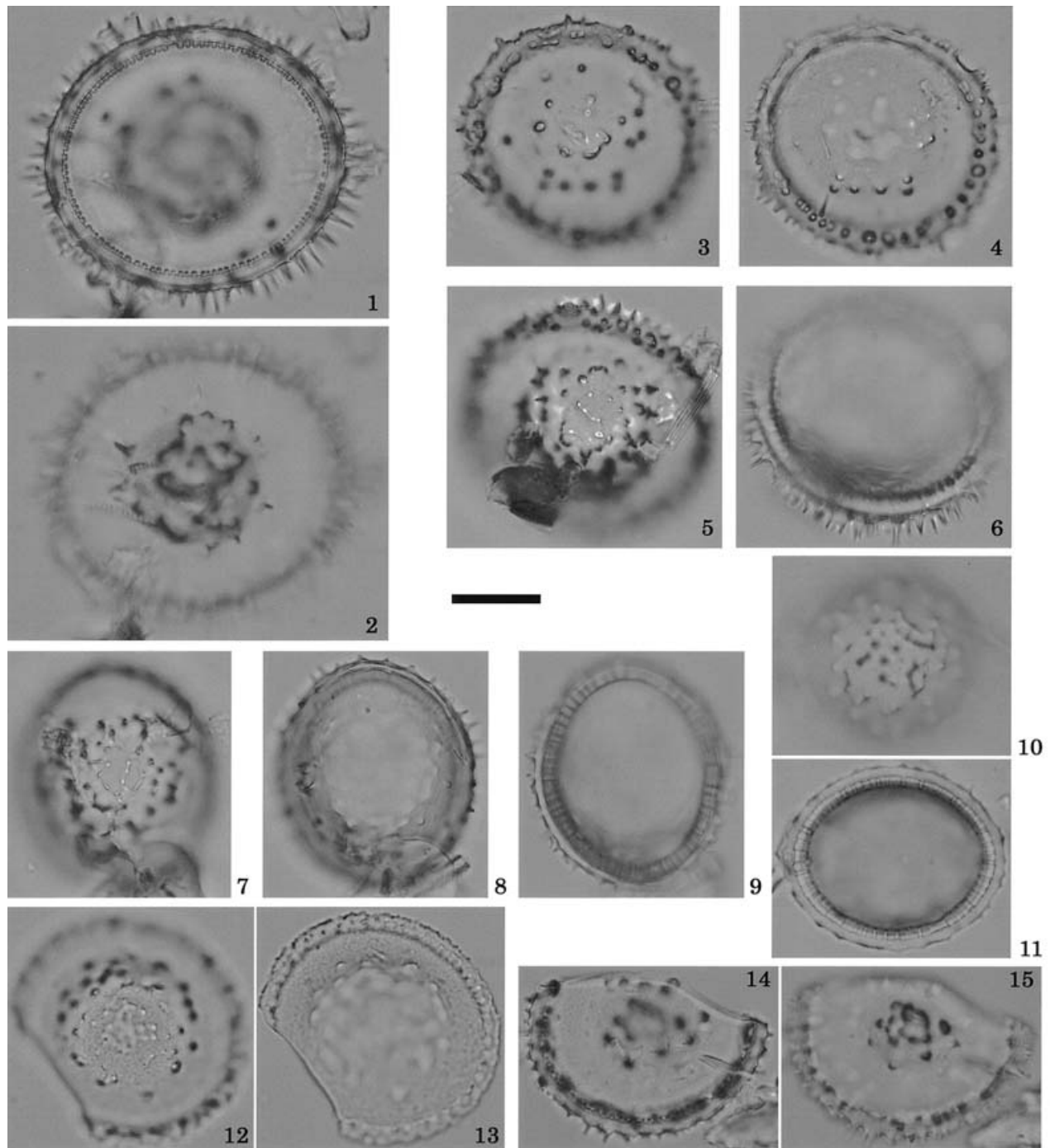


Figure 8. 1–15. *Xanthiopyxis norwegica* Suto sp. nov. Scale bar = 10 μ m for each figure (LM).

1, 2. Holotype. Hypovalve view of frustule, DSDP Site 338-19-4, 10–11 cm. **3, 4.** Valve view of epivalve, DSDP Site 338-20-3, 20–21 cm. **5, 6.** Valve view of epivalve, DSDP Site 338-21-1, 32–33 cm. **7–9.** Valve view of epivalve, DSDP Site 338-19-3, 20–21 cm. **10, 11.** Valve view of epivalve, DSDP Site 338-19-3, 20–21 cm. **12, 13.** Valve view of epivalve, DSDP Site 338-21-1, 32–33 cm. **14, 15.** Hypovalve view of frustule, DSDP Site 338-19-4, 10–11 cm.

***Xanthiopyxis circulatus* Suto sp. nov.**

Figures 1.F; 7.18–7.30

Description.—Frustule heterovalvate. Valve oval to broadly elliptical in valve view, apical axis 4.0–32.5 μm , transapical axis 4.0–14.5 μm . In girdle view, epivalve face vaulted, with numerous knobs. Knobs arranged in a ring in the central area. Inner central part of epivalve hyaline or with some knobs. Mantle of epivalve hyaline. Hypovalve slightly vaulted or flat, with knobs and veins. Mantle of hypovalve hyaline, with a single ring of puncta at its base.

Holotype.—Slide MPC-02610 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder N33-1N, illustrated in Figures 7.20, 7.21).

Type locality.—DSDP Site 338-12-3, 38–39 cm, Norwegian Sea.

Similar taxa.—This species is characterized by knobs on the epivalve arranged in a ring.

Stratigraphic occurrence.—This species occurs very abundantly from the Oligocene to the lower middle Miocene at DSDP Site 338 (Figure 3).

Etymology.—From Latin *circulatus*, “made round”.

***Xanthiopyxis reticulata* Suto sp. nov.**

Figures 1.G; 10.29–10.36

Description.—Valve narrowly to broadly elliptical in valve view, apical axis 10.0–22.5 μm , transapical axis 7.5–10.0 μm . In girdle view, hypovalve face vaulted, with numerous knobs and veins. Veins arranged in a ring in the central area. Inner central part of hypovalve with numerous knobs and veins. Mantle of hypovalve hyaline, with a single ring of puncta at its base. Frustule not observed, and epivalve unknown.

Holotype.—Slide MPC-02611 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder O39-2S, illustrated in Figures 10.29, 10.30).

Type locality.—DSDP Site 338-13-5, 70–71 cm, Norwegian Sea.

Similar taxa.—This species is characterized by veins on the hypovalve arranged in a ring.

Stratigraphic occurrence.—This species occurs in a short interval in the middle lower Miocene at DSDP Site 338 (Figure 3).

Etymology.—From Latin *reticulata*, meaning “net-veined”.

***Xanthiopyxis obesa* Suto sp. nov.**

Figures 1.H; 7.31; 10.37–10.40

Description.—Valve narrowly to broadly elliptical in valve view, apical axis 7.0–10.0 μm , pervalvar axis 6.5–9.5 μm . In girdle view, epivalve face vaulted, with numerous knobs. Mantle of epivalve hyaline, conspicuously expanded. Frustule not observed, and hypovalve unknown.

Holotype.—Slide MPC-02614 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder P39-3N, illustrated in Figures 10.37, 10.38).

Type locality.—DSDP Site 338-14-1, 20–21 cm, Norwegian Sea.

Similar taxa.—This species is characterized by the conspicuously expanded valve mantle.

Stratigraphic occurrence.—This species occurs in a short interval in the lower Miocene at DSDP Site 338 (Figure 3).

Remarks.—It is difficult to identify this species in valve view, therefore the valve in valve view may be counted as “*Xanthiopyxis* type A (knobbly type)”.

Etymology.—The Latin word *obesa* means “fat”.

***Xanthiopyxis hirsuta* Hanna et Grant**

Figures 1.I1, 1.I2; 11.25–11.28; 13.8

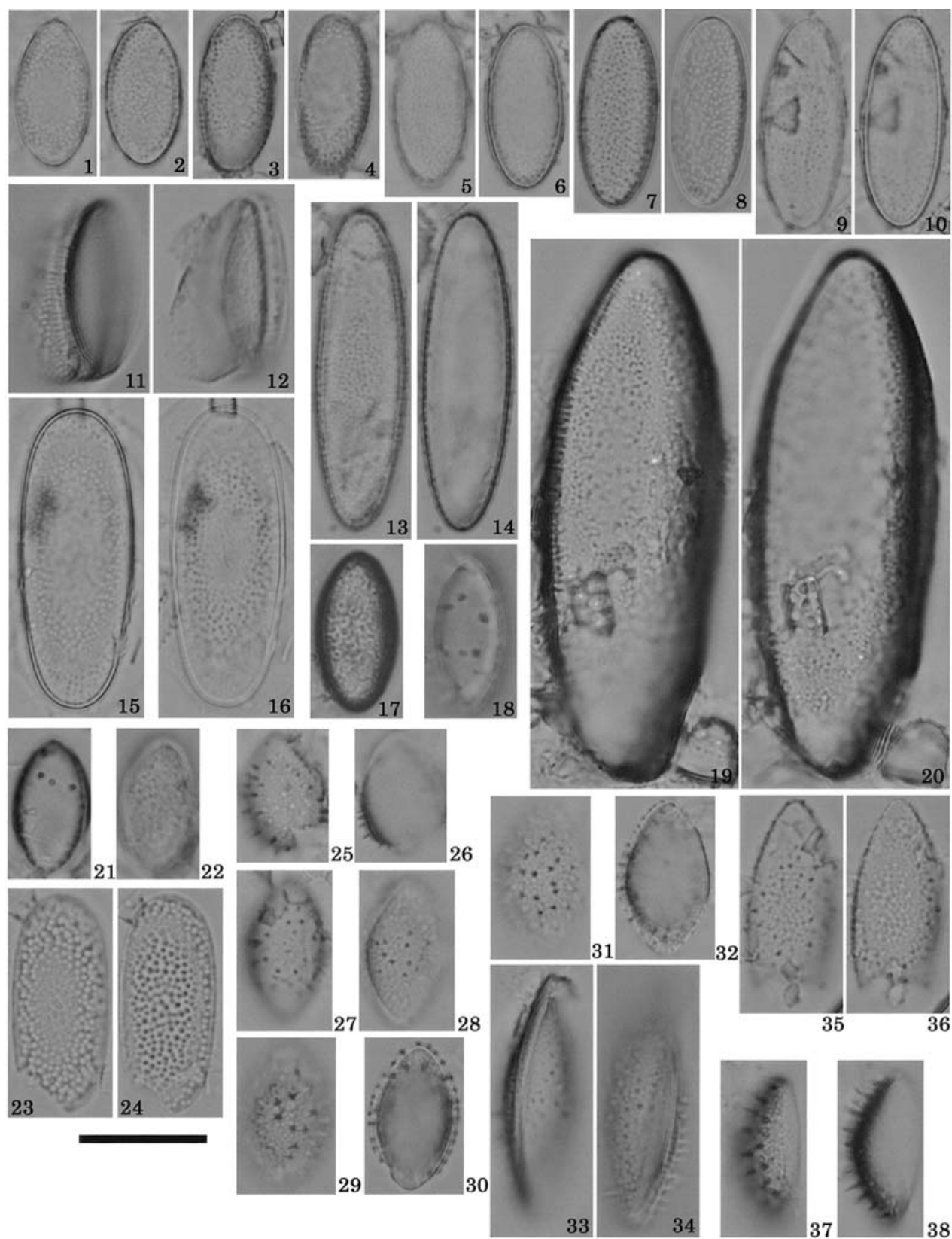
Xanthiopyxis hirsuta Hanna et Grant, 1926, p. 170, pl. 21, fig. 10; Fenner, 1978, p. 536, pl. 35, figs. 7, 8.

Synonymy.—*Xanthiopyxis micropunctatus* Hajós, 1968, p. 117, pl. 28, figs. 1, 2; Indet. sp. of Hajós, 1986, pl. 10, figs. 1–4; Porifera of Hajós, 1986, pl. 34, figs. 17–19.

Description.—Valve oval to broadly elliptical in valve view, apical axis 10–25.5 μm , transapical axis 7.0–20.0 μm , pervalvar axis 5.0–9.0 μm . In girdle view, epivalve vaulted, with numerous small spines. Mantle of epivalve hyaline. Hypovalve vaulted, with numerous small spines. Mantle of hypovalve hyaline with a single ring of puncta.

Type locality.—No. 1990, Museum of California Academy of Science, from Arroyo Hondo, Maria Madre Island (Tres Marias Group), Mexico; collected by Hanna and Jordan, May, 1925; Miocene.

Similar taxa.—This species is characterized by having an oval valve densely covered with numerous small spines. This species is similar to *X. brevispinosa*, but is differentiated by having a valve possessing micro-spines and lacking knobs. This species is distinguished from *X. lanceolatus* by its oval to broad valve shape. This species differs from *X. type B* (short spiny type) and *X. type C* (long spiny type) by its dense micro-spines on the valve face. This species is very similar to *X. microspinosa* Andrews (1976, p. 18, pl. 6, figs. 1–3) by having a valve covered with numerous micro-spines, but is identified by its oval to



narrow valve shape. *X. microspinosa* is found in the middle Miocene sediments of the Choptank Formation, Maryland, and characterized by its broadly lanceolate valve shape, but was not observed in this study.

Stratigraphic occurrence.—This species is found from the lower Oligocene to the middle Miocene at DSDP Site 338 (Figure 3), but was not recorded at DSDP Site 438 and 436, and the Newport Beach Section.

Remarks.—*Xanthiopyxis micropunctatus* Hajós (1968) is synonymized with this species because the valve is densely covered with micro-spines. It is very difficult to tell apart the valve of this species from the epivalve of *Gemellodiscus micronodosus* (Suto, 2004b). It is also difficult to recognize whether or not the valve is an epivalve or hypovalve of this species when it is observed in valve view, because the dense micro-spines make it difficult to recognize the presence of a single ring of puncta at the hypovalve mantle base. Therefore, in this study, valves of this type were counted as “Valve of *X. hirsuta* or epivalve of *G. micronodosus*” when complete frustules of this species did not occur.

Etymology.—The Latin word *hirsuta* means “hirsute, hairy”.

Xanthiopyxis oblonga Ehrenberg

Figures 1.J; 13.10, 13.11; 14.1–14.8

Xanthiopyxis oblonga Ehrenberg, 1844 (1845), p. 273; Forti, 1912, pl. 2, fig. 38; Hanna and Grant, 1926, p. 170, pl. 21, fig. 11; Proschkina-Lavrenko and Sheshukova-Poretzkaya, 1949, p. 86, pl. 84, fig. 3; Kanaya, 1957, p. 116, pl. 8, figs. 12a, b; Sheshukova-Poretzkaya, 1967, p. 180, pl. 24, fig. 5, pl. 26, fig. 2; Hajós, 1968, p. 115, pl. 28, figs. 16, 17, 20, 21; Lohman, 1974, p. 349, pl. 5, fig. 7; Hajós, 1976, p. 826, pl. 17, fig. 11; Schrader and Fenner, 1976, p. 1003, pl. 39, figs. 9, 10, pl. 40, fig. 5?; Hasegawa, 1977, p. 90, pl. 25, figs. 22a–c; Jousé in Dzinoridze *et al.*, 1979, p. 62, fig. 158; Hajós, 1986, pl. 21, figs. 21, 22; Lee, 1993, p. 45, pl. 2, figs. 11, 26, pl. 3, fig. 23 *nec* pl. 2, fig. 2, pl. 3, figs. 13, 17; Harwood and Bohaty, 2000, p. 94, pl. 9, figs. v, w.

Synonymy.—*Xanthiopyxis acrolopha* Forti, 1912, p. 1556, pl. 2, figs.

22, 24, 27, 28, 30–37; Hanna, 1927a, p. 124, pl. 21, figs. 10, 11; Proschkina-Lavrenko and Sheshukova-Poretzkaya, 1949, p. 86, pl. 84, figs. 2a, b; Kanaya, 1959, p. 121, pl. 11, figs. 8a, b; McCollum, 1975, p. 536, pl. 15, figs. 4, 5; Shirshov, 1977, pl. 31, fig. 19; Dzinoridze *et al.*, 1978, pl. 17, fig. 13; Hajós, 1986, pl. 4, fig. 8, pl. 21, figs. 16, 17; Lee, 1993, p. 44, pl. 1, fig. 24; *Xanthiopyxis hystrix* Forti, 1913, p. 1553, pl. 2, figs. 7–9; Proschkina-Lavrenko and Sheshukova-Poretzkaya, 1949, p. 86, pl. 84, figs. 5a, b; Fenner, 1978, p. 536, pl. 36, figs. 1, 2; Hajós, 1986, pl. 4, fig. 9, pl. 16, fig. 7; *Xanthiopyxis cingulata* Ehrenberg *sensu* Forti, 1913, pl. 2, fig. 29; *Xanthiopyxis globosa* Ehrenberg *sensu* Proschkina-Lavrenko and Sheshukova-Poretzkaya, 1949, p. 87, pl. 32, figs. 5a, b *nec* pl. 84, figs. 12a, b; Shirshov, 1977, pl. 33, figs. 9, 11 *nec* pl. 30, fig. 49, pl. 33, fig. 10; Schrader and Schutte, 1981, p. 1192, figs. 9, 10; *Stephanopyxis? limbata* Ehrenberg var. *crista-galli sensu* Kanaya, 1959, p. 70, pl. 30, figs. 1a, b; *Xanthiopyxis cf. acrolopha* Forti *sensu* Hajós, 1976, p. 826, pl. 11, fig. 6, pl. 21, fig. 5 *nec* pl. 17, figs. 4, 10, 12; *Xanthiopyxis oblonga? sensu* Fenner, 1978, pl. 35, fig. 18; *Xanthiopyxis* sp. (*X. globosa?*) *sensu* Dzinoridze *et al.*, 1978, pl. 17, fig. 12.

Description.—Valve oblong, broadly elliptical in valve view, apical axis 31–70 µm, transapical axis 18–40 µm. In girdle view, valve strongly vaulted, with numerous strong bristles. Mantle unknown. Frustule not observed.

Similar taxa.—This species is characterized by its large-sized valve covered with strong bristles. This species is very similar to *X. globosa* in having a valve possessing numerous strong bristles, but is differentiated clearly by its oblong valve shape. This species also resembles *X. type B* and *X. type C* in possessing numerous spines on the valve face, but differs from them by having strong bristles on the valve face.

Stratigraphic occurrence.—Abundant occurrences of this species are recognized in the Eocene, after which it becomes rare, and more sporadic from the lower Oligocene to the middle Miocene at DSDP Site 338 (Figure 3).

Remarks.—This oblong *Xanthiopyxis* species seems to be one of the most common species from the middle Eocene to the middle Miocene.

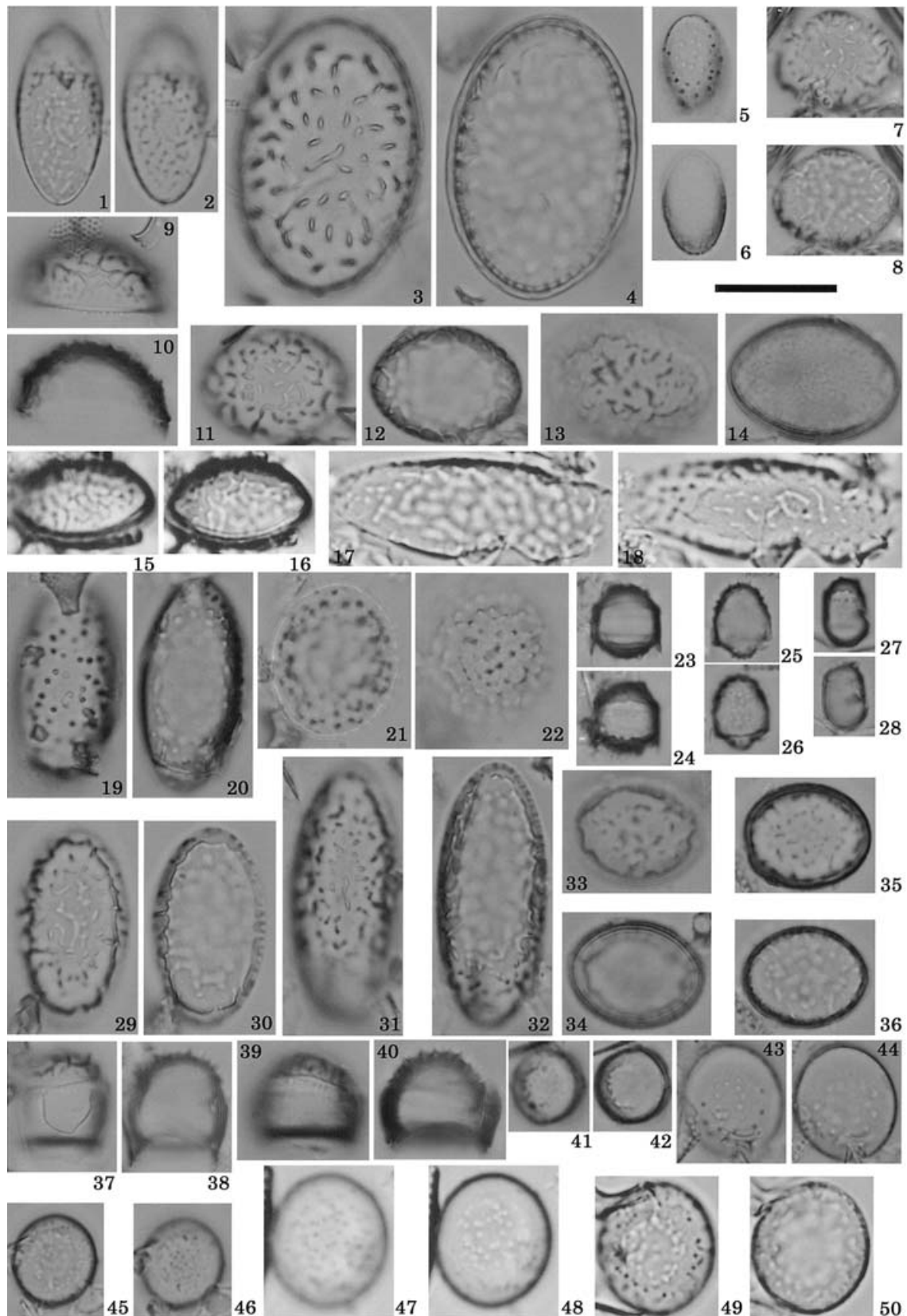
The synonymized species *X. acrolopha* was collected from the Miocene Marmorito Formation in

◀ **Figure 9.** 1–24. *Xanthiopyxis lanceolatus* Suto sp. nov. Scale bar = 10 µm for each figure (LM).

1, 2. Holotype. Valve view of epivalve, DSDP Site 338-20-1, 30–31 cm. 3, 4. Valve view of epivalve, DSDP Site 338-19-3, 20–21 cm. 5, 6. Valve view of epivalve, DSDP Site 338-19-5, 148–149 cm. 7, 8. Valve view of epivalve, DSDP Site 338-19-5, 148–149 cm. 9, 10. Valve view of epivalve, DSDP Site 338-20-2, 30–31 cm. 11, 12. Oblique girdle view of epivalve, DSDP Site 338-20-4, 148–149 cm. 13, 14. Valve view of epivalve, DSDP Site 338-20-2, 30–31 cm. 15, 16. Valve view of epivalve, DSDP Site 338-11-4, 70–71 cm. 17, 18. Valve view of frustule, DSDP Site 338-21-1, 32–33 cm. 19, 20. Valve view of epivalve, DSDP Site 338-23-6, 10–11 cm. 21, 22. Valve view of frustule, DSDP Site 338-20-3, 20–21 cm. 23, 24. Valve view of epivalve, DSDP Site 338-11-4, 70–71 cm.

25–38. *Xanthiopyxis brevispinosa* Suto sp. nov. Scale bar = 10 µm for each figure (LM).

25, 26. Valve view of epivalve, DSDP Site 338-22-4, 79–80 cm. 27, 28. Valve view of epivalve, DSDP Site 338-22-4, 79–80 cm. 29, 30. Valve view of hypovalve, DSDP Site 338-22-4, 79–80 cm. 31, 32. Valve view of hypovalve, DSDP Site 338-22-4, 79–80 cm. 33, 34. Holotype. Oblique valve view of frustule, DSDP Site 338-22-4, 79–80 cm. 35, 36. Valve view of hypovalve, DSDP Site 338-22-4, 79–80 cm. 37, 38. Oblique valve view of frustule, DSDP Site 338-22-4, 79–80 cm.



Italy (Forti, 1912), the lower Miocene shales of Phoenix Canyon in California (Hanna, 1927a), the Miocene Onnagawa Formation in Japan (Kanaya, 1959), the lower Oligocene sediments in the Southern Ocean (McCollum, 1975) and the middle Miocene sediments in the Norwegian Sea (Dzinoridze *et al.*, 1978).

Xanthiopyxis cingulata of Forti (1913) and *X. hystrix sensu* Forti (1913), Proschkina-Lavrenko and Sheshukova-Poretzkaya (1949), Fenner (1978) and Hajós (1986) are also identified as *X. oblonga* because these specimens possess a large valve covered with strong bristles.

Xanthiopyxis globosa Ehrenberg *sensu* Proschkina-Lavrenko and Sheshukova-Poretzkaya (1949), Shirshov (1977), and Schrader and Schuette (1981), *Stephanopyxis? limbata* Ehrenberg var. *crista-galli sensu* Kanaya (1959), *Xanthiopyxis oblonga? sensu* Fenner (1978) and *Xanthiopyxis* sp. (*X. globosa?*) *sensu* Dzinoridze *et al.* (1978) are identified as *X. oblonga* because of their oblong valve covered with strong bristles.

As a result of these studies, it is clear that *X. oblonga* occurs from the Eocene through the middle Miocene and that this species is a cosmopolitan species.

Xanthiopyxis cf. *acrolopha* Forti *sensu* Hajós (1976, pl. 17, figs. 4, 10, 12), *X. acrolopha sensu* Fenner (1978, pl. 35, figs. 25, 26), *X. oblonga sensu* Fenner (1978, p. 536, pl. 35, fig. 9), and *X. oblonga sensu* Homann (1991, p. 143, pl. 57, figs. 5–7, 9–12) do not belong to *X. oblonga* because they lack numerous strong bristles on their valve face. *Xanthiopyxis oblonga sensu* Kanaya (1959, p. 121, pl. 11, figs. 9, 10), Gleser *et al.* (1974, pl. 36, fig. 7) and Lee (1993, pl. 2, fig. 21, pl. 3, figs. 13, 17) are identified as *X. globosa* by their circular valve shape.

Etymology.—Latin *oblonga*, meaning “oblong”.

Xanthiopyxis globosa Ehrenberg

Figures 1.K; 14.9–14.14

Xanthiopyxis globosa Ehrenberg, 1844 (1845), p. 273; Forti, 1912, p. 1557, pl. 2, figs. 39–49; Hanna, 1932, p. 224, pl. 18, fig. 3; Proschkina-Lavrenko and Sheshukova-Poretzkaya, 1949, p. 87, pl. 84, figs. 12a, b *nec* pl. 32, figs. 5a, b; Jousé, 1963, p. 117, fig. 105; McCollum, 1975, p. 536, pl. 15, figs. 6–9; Schrader and Fenner, 1976, pl. 40, figs. 15, 17; Shirshov, 1977, pl. 30, fig. 49, pl. 33, fig. 10 *nec* figs. 9, 11; Dzinoridze *et al.*, 1978, pl. 17, fig. 2; Fenner, 1978, p. 536, pl. 37, figs. 1, 2; Jousé in Dzinoridze *et al.*, 1979, p. 62, fig. 159; Hajós, 1986, pl. 16, figs. 12, 13, pl. 43, fig. 7; Homann, 1991, p. 142, pl. 57, figs. 8, 13.

Synonymy.—*Xanthiopyxis oblonga sensu* Kanaya, 1959, p. 121, pl. 11, figs. 9, 10; Gleser *et al.*, 1974, pl. 36, fig. 7; Lee, 1993, pl. 2, fig. 21, pl. 3, figs. 13, 17 *nec* pl. 2, figs. 11, 26, pl. 3, fig. 23.

Description.—Valve circular to oval in valve view, apical axis 20–35 µm. In girdle view, valve strongly vaulted, with numerous strong bristles. Mantle unknown. Frustule not observed.

Similar taxa.—This species is very similar to *X. oblonga* in having a valve possessing numerous strong bristles, but is clearly differentiated by its oval valve shape.

Stratigraphic occurrence.—This species occurs abundantly in the Eocene but it becomes rare and its occurrence more sporadic from the early Oligocene to the middle Miocene (Figure 2).

Remarks.—The type specimens of *Xanthiopyxis globosa* were collected from the middle Miocene Marmorito Formation in Italy (Forti, 1912). It has also been reported from the lower Miocene Temblor Formation in California (Hanna, 1932), lower Oligocene sediments in the Southern Ocean (McCollum, 1975), lower Oligocene sediments in the Norwegian Sea

◆ **Figure 10.** 1–28. *Xanthiopyxis* type A (knobbly type). Scale bar = 10 µm for each figure (LM).

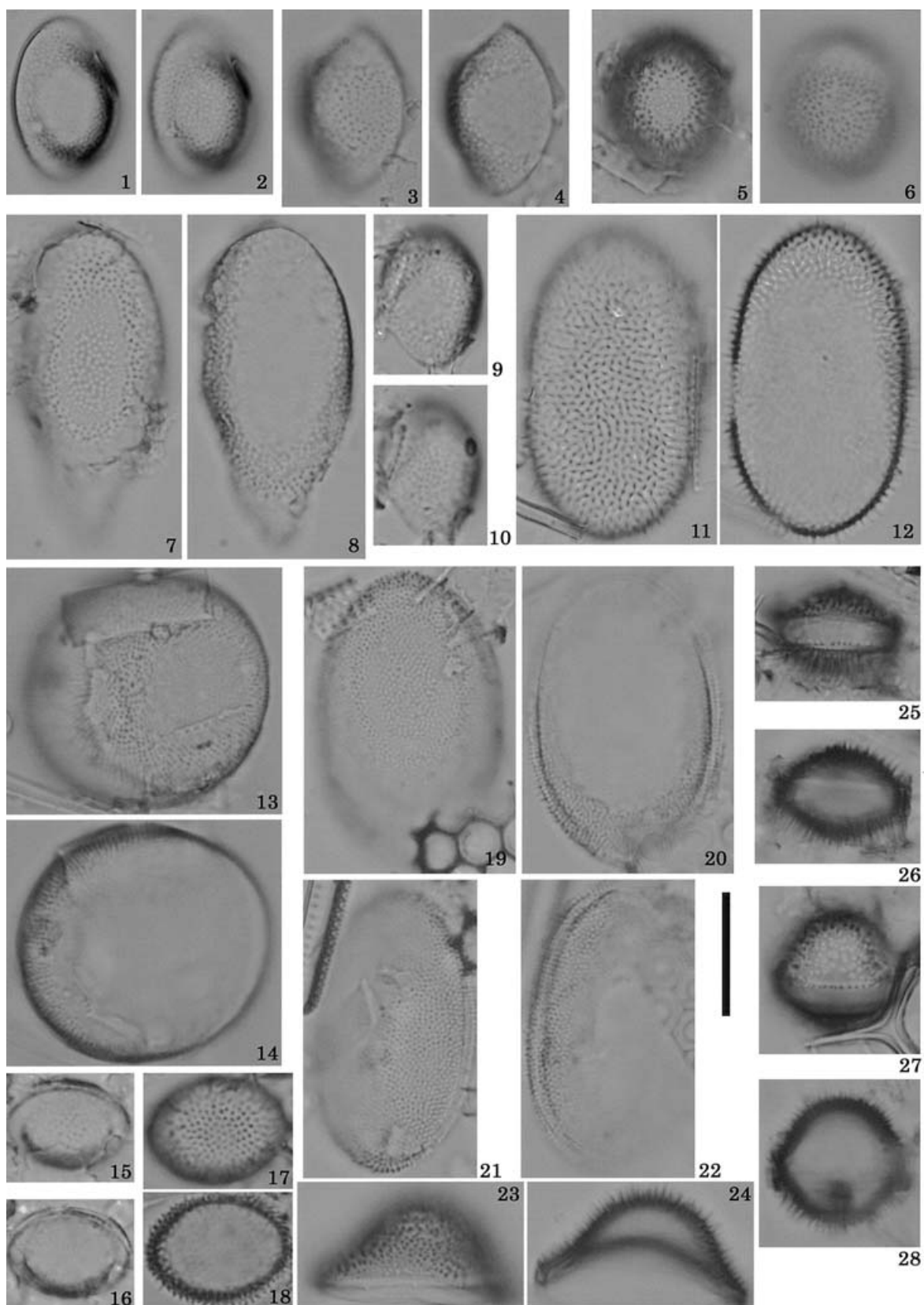
1, 2. Valve view of epivalve, DSDP Site 436-13-3, 100–102 cm. 3, 4. Valve view of epivalve, DSDP Site 338-11-4, 70–71 cm. 5, 6. Valve view of epivalve, DSDP Hole 438A-5-2, 96–100 cm. 7, 8. Valve view of epivalve, DSDP Site 338-13-1, 148–149 cm. 9, 10. Girdle view of epivalve, DSDP Site 338-13-1, 148–149 cm. 11, 12. Valve view of epivalve, DSDP Site 338-14-3, 20–21 cm. 13, 14. Valve view of epivalve, DSDP Site 338-17-1, 100–101 cm. 15, 16. Valve view of epivalve, DSDP Hole 438A-71-1, 12–16 cm. 17, 18. Valve view of epivalve, DSDP Site 338-21-1, 32–33 cm. 19, 20. Valve view of epivalve, DSDP Site 338-14-1, 20–21 cm. 21, 22. Valve view of epivalve, DSDP Site 436-20-2, 38–40 cm. 23, 24. Girdle view of frustule, DSDP Site 436-23-3, 48–50 cm. 25, 26. Girdle view of frustule, DSDP Site 338-15-3, 100–101 cm. 27, 28. Girdle view of frustule, DSDP Site 338-15-3, 100–101 cm.

29–36. *Xanthiopyxis reticulata* Suto sp. nov. Scale bar = 10 µm for each figure (LM). 29, 30. Holotype. Valve view of hypovalve, DSDP Site 338-13-5, 70–71 cm. 31, 32. Valve view of hypovalve, DSDP Site 338-14-1, 20–21 cm. 33, 34. Valve view of hypovalve, DSDP Site 338-13-1, 148–149 cm. 35, 36. Valve view of hypovalve, DSDP Site 338-14-2, 20–21 cm.

37–40. *Xanthiopyxis obesa* Suto sp. nov. Scale bar = 10 µm for each figure (LM).

37, 38. Holotype. Girdle view of epivalve, DSDP Site 338-14-1, 20–21 cm. 39, 40. Girdle view of epivalve, DSDP Site 338-14-2, 20–21 cm.

41–50. *Xanthiopyxis teneropunctata* Suto sp. nov. Scale bar = 10 µm for each figure (LM). 41, 42. Valve view of epivalve, DSDP Site 436-23-3, 48–50 cm. 43, 44. Holotype. Valve view of epivalve, DSDP Site 338-8-2, 99–100 cm. 45, 46. Valve view of epivalve, DSDP Site 436-21-1, 110–112 cm. 47, 48. Valve view of epivalve, DSDP Hole 438A-44-3, 10–14 cm. 49, 50. Valve view of epivalve, DSDP Hole 438A-37-3, 10–14 cm.



(Schrader and Fenner, 1976) and middle Miocene sediments in the Norwegian Sea (Dzinoridze *et al.*, 1978). These studies indicate that *Xanthiopyxis globosa* occur from the early Oligocene through the middle Miocene and is a cosmopolitan species.

Xanthiopyxis globosa sensu Hanna (1970, p. 195, fig. 74) and Hasegawa (1977, p. 100, pl. 23, figs. 15a, b) are identified as *X.* type C by having long spines on the valve. *Xanthiopyxis globosa sensu* Lee (1993, p. 45, pl. 3, fig. 22) is assigned to *X.* type B because it has strong bristles rather than spines. *Xanthiopyxis globosa* Ehrenberg *sensu* Proschkina-Lavrenko and Sheshukova-Poretzkaya (1949, p. 87, pl. 32, figs. 5a, b), Shirshov (1977, pl. 33, figs. 9, 11) and Schrader and Schuette (1981, p. 1192, figs. 9, 10), and *Xanthiopyxis* sp. (*X. globosa?*) *sensu* Dzinoridze *et al.* (1978) are all identified as *X. oblonga* because of their oblong valve shape with strong bristles.

Etymology.—Latin *globosa*, meaning “globose”.

Xanthiopyxis type A (knobbly type)

Figures 1.L1, 1.L2; 7.32–7.35; 10.1–10.28

Synonyms.—*Xanthiopyxis* sp. 1 of Kanaya, 1959, p. 122, pl. 11, fig. 11; Schrader and Fenner, 1976, p. 1003, pl. 40, figs. 3, 7; Fenner 1978, p. 537, pl. 35, fig. 6; *Xanthiopyxis* sp. 2 of Kanaya, 1959, p. 122, pl. 11, fig. 12; *Chaetoceros* sp. of Dzinoridze *et al.*, 1978, pl. 9, fig. 14 *nec* figs. 13, 15; *Xanthiopyxis* sp. 3 of Fenner, 1978, p. 537, pl. 35, figs. 10–14, pl. 36, fig. 11; *Xanthiopyxis mexicana* Kanaya, 1957, p. 116, pl. 8, fig. 14; *Chaetoceros* (?)–*Hemiaulus* (?) resting spore of Schrader and Fenner, 1976, figs. 12, 13; *Xanthiopyxis ovalis* Lohman *sensu* Dzinoridze *et al.*, 1978, pl. 17, fig. 1; Fenner, 1978, p. 536, figs. 20–22; Resting spore C of Barron and Mahood, 1993, p. 44, pl. 5, fig. 18; *Chaetoceros* spore of Gladenkov and Barron, 1995, fig. 17.

Description.—Frustule heterovalvate. Valve oval to narrowly or broadly elliptical in valve view. In girdle view, epivalve face vaulted, with numerous knobs and short veins. Mantle of epivalve hyaline. Hypovalve slightly vaulted or flat, or vaulted in the center, hyaline or with knobs and veins. Mantle of hypovalve hyaline, with a single ring of puncta at its base.

Similar taxa.—This species type is characterized by knobs and veins on the epivalve and the hyaline mantle of the epivalve.

Remarks.—This species occurs abundantly in all of the cores and onland sections studied. The valves of these specimens belong to several *Xanthiopyxis* species, but it is very difficult to determine which ones when their frustules are not observed. Therefore, these valves must be counted as “*Xanthiopyxis* type A (knobbly type)”, when only epivalve or hypovalve is observed during the counting process.

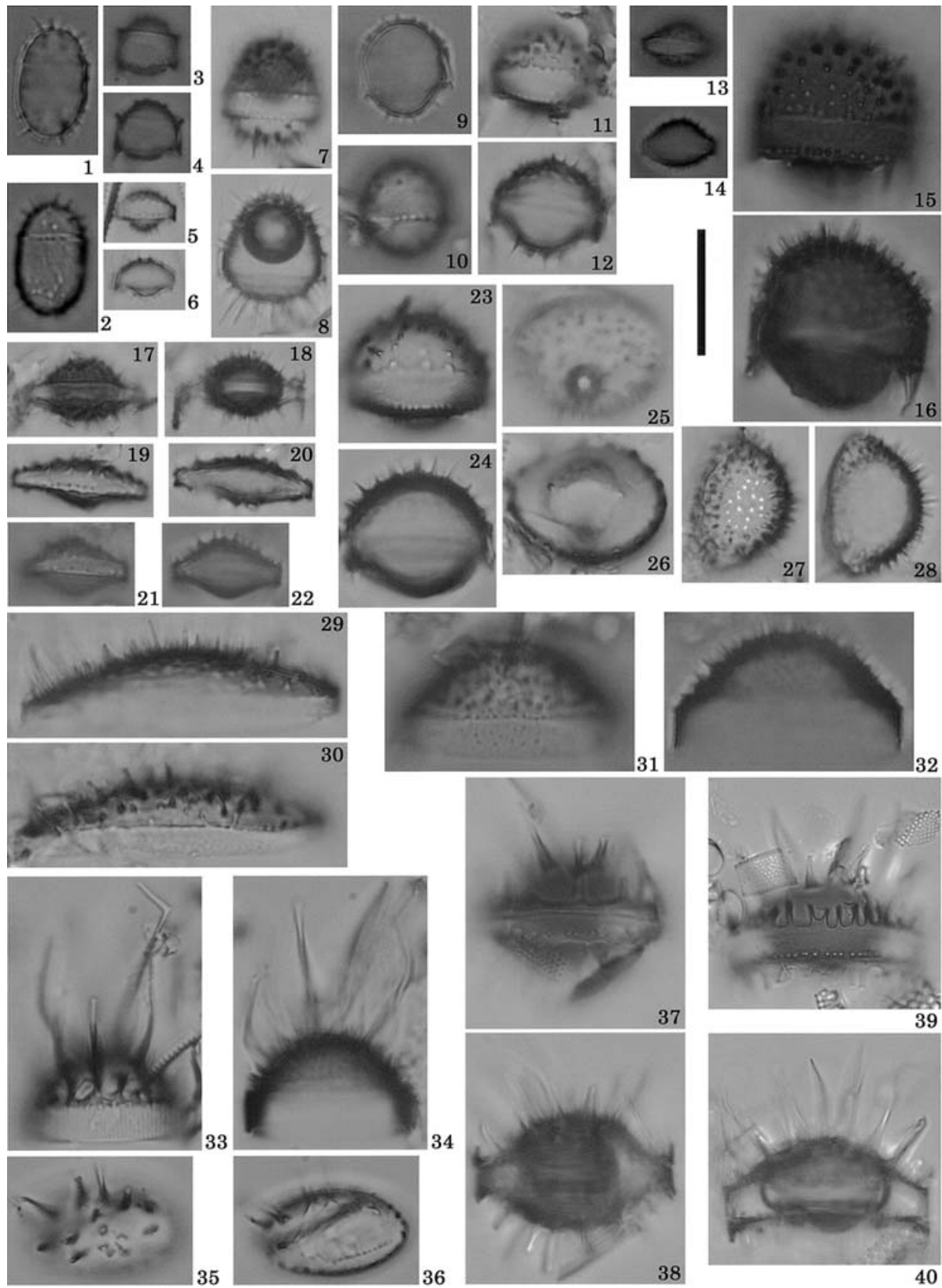
Xanthiopyxis type B (short spiny type)

Figures 1.M1, 1.M2; 12.1–12.32; 13.1–13.7

Synonyms.—*Chaetoceros weissflogii* Schütt *sensu* Brockmann, 1928, p. 57, fig. 3; *Omphalotheca* sp. of Hanna, 1930, p. 192, pl. 14, fig. 11; *Xanthiopyxis ovalis* Lohman, 1938, p. 91, pl. 20, fig. 6, pl. 22, fig. 12; Kanaya, 1957, p. 117, pl. 8, fig. 13; Hajós, 1968, p. 116, pl. 28, figs. 3, 5, 6; Hanna, 1970, p. 196, figs. 64, 70; Lohman, 1974, p. 350, pl. 5, fig. 11; Schrader and Fenner, 1976, p. 1003, pl. 40, fig. 1; Hajós, 1986, pl. 48, fig. 8; Lee, 1986, pl. 1, fig. 17; *Chaetoceros* sp. of Frenguelli, 1949, pl. 4, figs. 16, 17, 19, 20, 32; Schrader, 1973, pl. 17, figs. 5–7, 9–11; Shirshov, 1977, pl. 5, fig. 23; *Chaetoceros tiltilensis* Frenguelli, 1949, p. 140, pl. 4, figs. 28–31; *Chaetoceros wighamii* Brightwell *sensu* Frenguelli, 1949, p. 142, pl. 4, fig. 13; Makarova, 1962, p. 44, pl. 2, figs. 8–10; *Xanthiopyxis* sp. 3 of Kanaya, 1959, p. 123, pl. 11, fig. 13; *Xanthiopyxis* sp. 4 of Kanaya, 1959, p. 123, pl. 11, fig. 14; *Xanthiopyxis* sp. 5 of Kanaya, 1959, p. 123, pl. 11, figs. 15a, b; *Chaetoceros aculeatus* Makarova, 1962, p. 54, pl. 5, figs. 15, 16; *Chaetoceros affinis* Lauder *sensu* Makarova, 1962, p. 51, pl. 4, figs. 2–6, pl. 5, figs. 30, 31; Jousé, 1963, p. 106, fig. 67; Gleser *et al.*, 1974, pl. 54, fig. 2; *Chaetoceros crinitus* Schütt *sensu* Makarova, 1962, p. 46, pl. 1, fig. 9, pl. 2, fig. 15, pl. 5, figs. 22, 23; *Chaetoceros cylindrosporus* Makarova, 1962, p. 55, pl. 1, figs. 15, 16, pl. 2, figs. 22–24, pl. 5, figs. 26, 27; *Chaetoceros holsaticus* Schütt *sensu* Makarova, 1962, p. 48, pl. 1, fig. 19, pl. 3, figs. 1–3; Hajós, 1968, p. 128, pl. 33, figs. 10, 11, 14, 15; *Chaetoceros ingolfianus* Ostenfeld *sensu* Makarova, 1962, p. 46, pl. 1, figs. 10–12; *Chaetoceros muelleri* Lemmermann *sensu* Makarova, 1962, p. 44, pl. 1, fig. 1, pl. 2, figs. 1–4; *Chaetocerotus Aulsenii* Ostenfeld *sensu* Makarova, 1962, p. 46, pl. 1, figs. 4–8, pl. 2, figs. 11–14, pl. 5, figs. 18–21, 28, 29; *Chaetoceros rigidus* Ostenfeld *sensu* Makarova, 1962, p. 44, pl. 2, figs. 5–7; *Chaetoceros robustus* Makarova, 1962, p. 52, pl. 1, figs. 20–22, pl. 5, figs. 6–8; *Chaetoceros scabrosus* Proschkina-Lavrenko *sensu* Makarova, 1962, p. 50, pl. 3, figs. 11, 12; *Chaetoceros simplex* Ostenfeld *sensu* Makarova, 1962, p. 44, pl. 1, figs. 2, 3; *Chaetoceros subtilis* Cleve *sensu* Makarova, 1962, p. 48, pl. 1, figs. 13, 14, pl. 2, figs. 19–21, pl. 5, figs. 24, 25; *Chaetoceros subtortilis* Proschkina-Lavrenko *sensu* Makarova, 1962, p. 52, pl. 2, figs. 16–18; *Xanthiopyxis rotunda* Hajós, 1975, p. 927, figs. 8a, b; *Chaetoceros* (?)–*Hemiaulus* (?) resting spore of Schrader and Fenner, 1976, figs. 19–21;

◀ **Figure 11.** 1–24. Epi/hypovalve of *Xanthiopyxis hirsuta* or epivalve of *Gemellodiscus micronodosus*. Scale bar = 10 µm for each figure (LM). **1, 2.** Valve view, DSDP Site 436-10-4, 98–100 cm. **3, 4.** Valve view, DSDP Site 436-20-2, 38–40 cm. **5, 6.** Valve view, Newport Beach Section, NE6. **7, 8.** Valve view, Newport Beach Section, WNP13. **9, 10.** Valve view, Newport Beach Section, N2b. **11, 12.** Valve view, DSDP Site 338-17-2, 119–120 cm. **13, 14.** Valve view, DSDP Site 338-8-1, 140–141 cm. **15, 16.** Valve view, DSDP Site 436-23-3, 48–50 cm. **17, 18.** Valve view, DSDP Site 338-14-1, 20–21 cm. **19, 20.** Valve view, DSDP Site 338-9-1, 50–51 cm. **21, 22.** Valve view, DSDP Site 338-9-1, 50–51 cm. **23, 24.** Girdle view, DSDP Site 338-12-2, 40–41 cm.

25, 26. *Xanthiopyxis hirsuta* Hanna and Grant. Scale bar = 10 µm for each figure (LM). **25, 26.** Girdle view of frustule, Newport Beach Section, NE2. **27, 28.** Girdle view of frustule, Newport Beach Section, NE2.



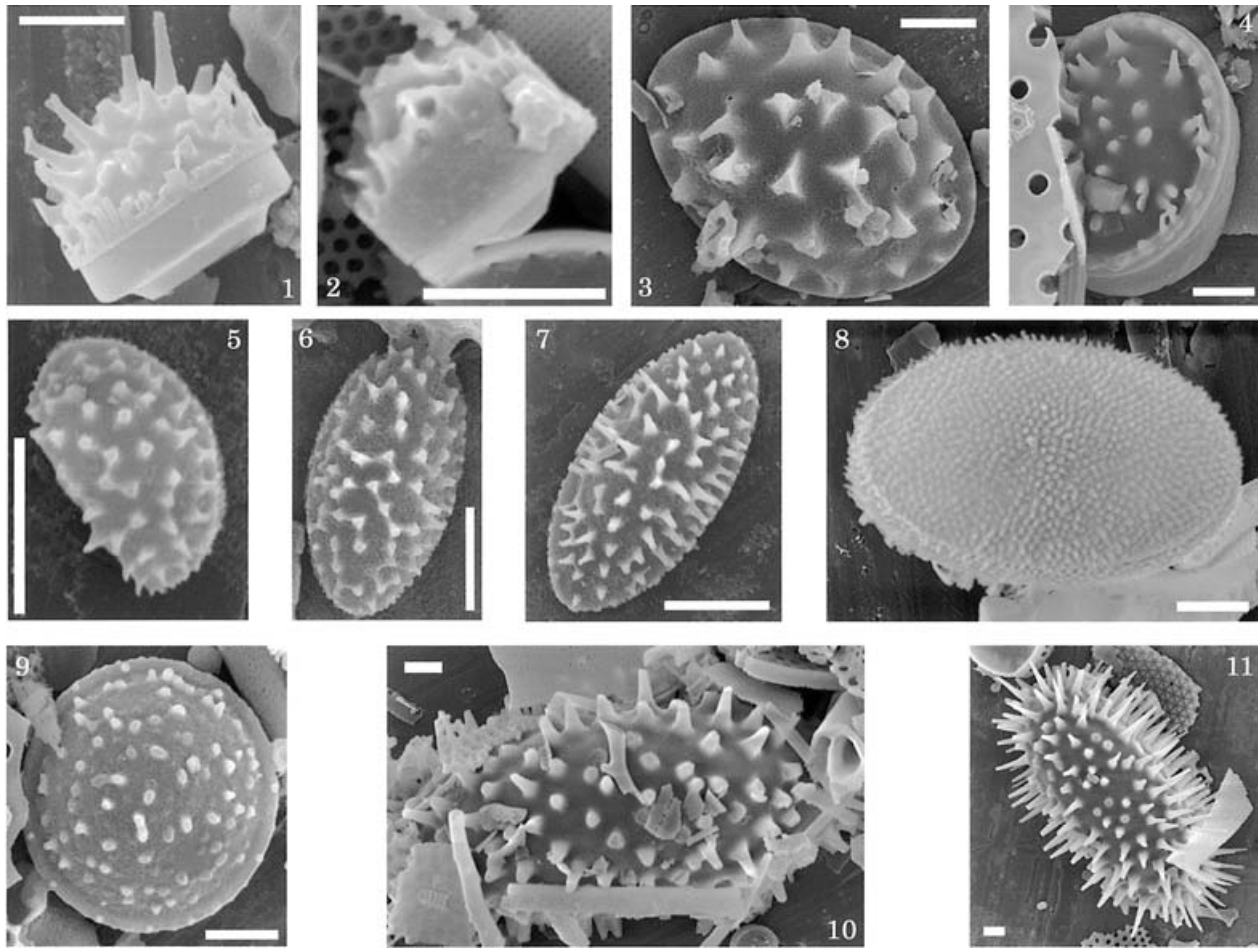


Figure 13. 1–7. *Xanthiopyxis* type B (short spiny type). Scale bar = 5 μm for each figure (SEM).

1. Girdle view of frustule, DSDP Site 338-10-1, 106–107 cm. 2. Girdle view of frustule, DSDP Site 338-18-1, 148–149 cm. 3. Valve view of epivalve, DSDP Site 338-10-1, 106–107 cm. 4. Valve view of hypovalve, DSDP Site 338-11-4, 148–149 cm. 5. Valve view of epivalve, DSDP Site 338-17-1, 100–101 cm. 6. Valve view of epivalve, DSDP Site 338-17-1, 100–101 cm. 7. Valve view of epivalve, DSDP Site 338-15-2, 100–101 cm.

8. *Xanthiopyxis hirsuta* Hanna and Grant. Scale bar = 5 μm (SEM).

8. Valve view of frustule, DSDP Site 338-18-1, 148–149 cm.

9. *Xanthiopyxis globosa* Ehrenberg. Scale bar = 5 μm (SEM).

9. Valve view of epivalve, DSDP Site 338-17-1, 100–101 cm.

10, 11. *Xanthiopyxis oblonga* Ehrenberg. Scale bar = 5 μm for each figure (SEM).

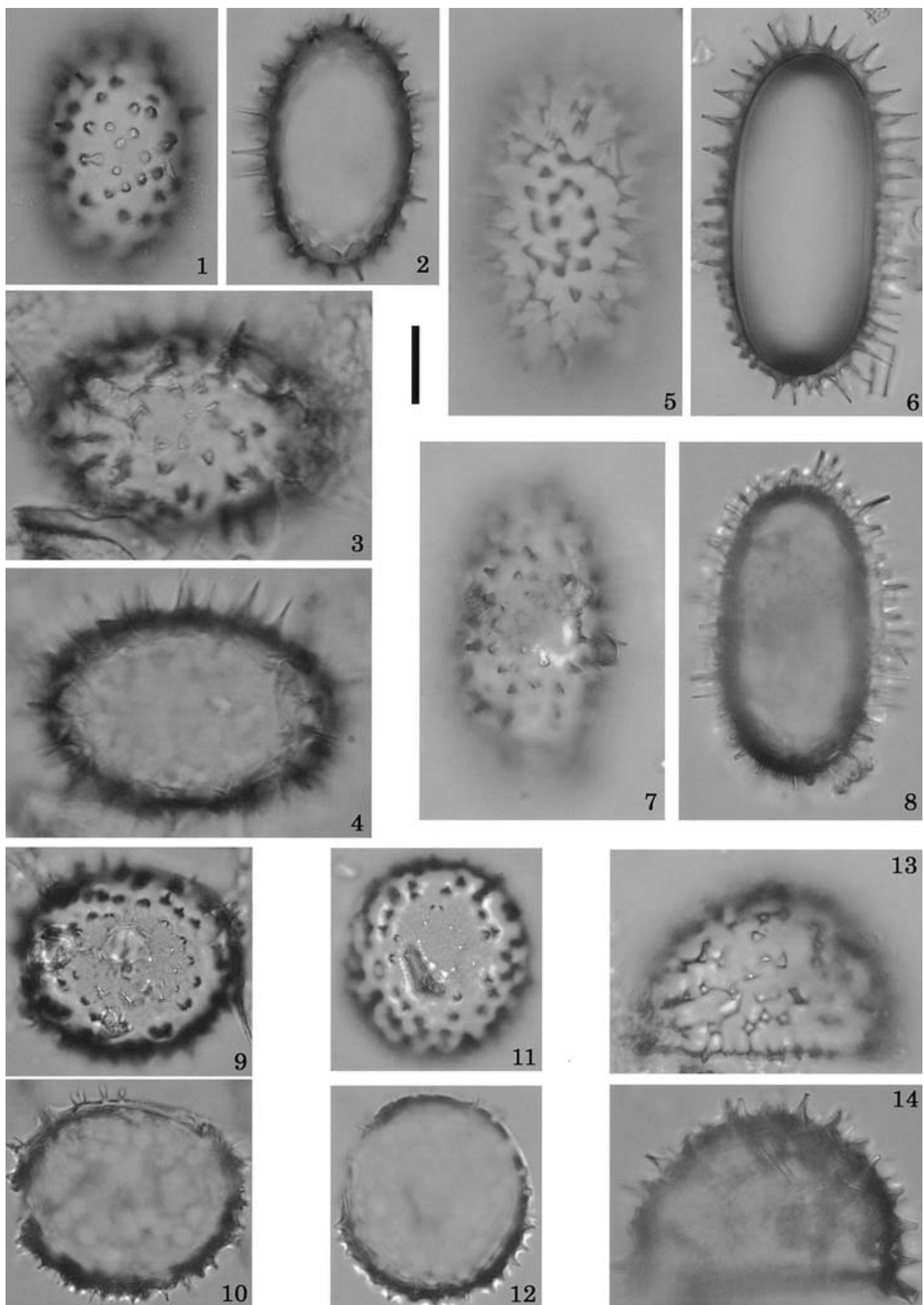
10. Girdle view of frustule, DSDP Site 338-18-1, 148–149 cm. 11. Girdle view of frustule, DSDP Site 338-17-1, 100–101 cm.

◀ **Figure 12.** 1–32. *Xanthiopyxis* type B (short spiny type). Scale bar = 10 μm for each figure (LM).

1, 2. Girdle view of frustule, DSDP Site 436-3-1, 102–104 cm. 3, 4. Girdle view of frustule, DSDP Site 436-6-4, 100–102 cm. 5, 6. Girdle view of frustule, Newport Beach Section, NE3. 7, 8. Girdle view of frustule, DSDP Site 338-8-1, 140–141 cm. 9, 10. Girdle view of frustule, DSDP Site 436-2-3, 100–102 cm. 11, 12. Girdle view of frustule, Newport Beach Section, N6b. 13, 14. Girdle view of frustule, DSDP Site 436-8-3, 148–150 cm. 15, 16. Girdle view of frustule, DSDP Site 436-8-5, 18–20 cm. 17, 18. Girdle view of frustule, DSDP Site 436-11-3, 148–150 cm. 19, 20. Girdle view of frustule, DSDP Site 436-20-2, 38–40 cm. 21, 22. Girdle view of frustule, DSDP Site 436-8-3, 148–150 cm. 23, 24. Girdle view of frustule, Newport Beach Section, N7a. 25, 26. Valve view of frustule, Newport Beach Section, N20. 27, 28. Oblique valve view of epivalve, Newport Beach Section, Tm17. 29, 30. Girdle view of epivalve, Newport Beach Section, N7a. 31, 32. Girdle view of epivalve, DSDP Site 436-5-2, 148–150 cm.

33–40. *Xanthiopyxis* type C (long spiny type). Scale bar = 10 μm for each figure (LM).

33, 34. Girdle view of epivalve, DSDP Site 338-15-2, 100–101 cm. 35, 36. Valve view of epivalve, Newport Beach Section, N5. 37, 38. Girdle view of frustule, DSDP Site 338-15-4, 100–101 cm. 39, 40. Girdle view of frustule, DSDP Site 338-19-1, 130–131 cm.



Chaetoceros compressus Lauder *sensu* Shirshov, 1977, pl. 24, figs. 13, 14; *Chaetoceros* species indet. of Schrader and Gersonde, 1978, pl. 2, figs. 5–7; *Chaetoceros* spore (3) of Fenner, 1978, p. 513, pl. 37, fig. 8; *Chaetoceros* spore (b) of Fenner, 1978, p. 513, pl. 34, fig. 30; Resting spore of Fenner, 1978, pl. 34, fig. 32, pl. 37, fig. 9; *Chaetoceros* spore of Schrader, 1978, p. 859, pl. 18, figs. 1, 2, 5–15, 18; Whiting and Schrader, 1985, pl. 5, figs. 9–11; *Xanthiopyxis* sp. of Hajós, 1986, pl. 22, fig. 14; *Xanthiopyxis* sp. 1 of Baldauf and Barron, 1987, p. 8, pl. 4, fig. 6; *Xanthiopyxis* type A of Harwood *et al.*, 1989, pl. 4, fig. 5; *Chaetoceros amanita* Cleve-Euler *sensu* Lee, 1993, p. 32, pl. 1, figs. 7, 9; *Chaetoceros coronatus* Gran *sensu* Lee, 1993, p. 33, pl. 1, fig. 6, pl. 3, fig. 15; *Chaetoceros costatus* Pavillard *sensu* Lee, 1993, p. 33, pl. 1, figs. 8, 12; *Chaetoceros vanheurcki* Gran *sensu* Lee, 1993, p. 36, pl. 3, fig. 11; *Chaetoceros lauderi* Ralfs in Lauder *sensu* Lee, 1993, p. 34, pl. 1, fig. 1, pl. 2, figs. 4, 7.

Description.—Frustule heterovalvate. Valve oval to narrowly or broadly elliptical in valve view. In girdle view, epivalve face vaulted, with numerous short strong spines. Mantle of epivalve hyaline. Hypovalve slightly vaulted or flat, or vaulted in the center, hyaline or with numerous strong spines. Mantle of hypovalve hyaline, with a single ring of puncta at its base.

Similar taxa.—These specimens are characterized by short strong spines.

Remarks.—These specimens occur abundantly in all of the cores and onland sections studied. The valves of this type are those of several *Xanthiopyxis* species, but these valves are difficult or impossible to classify correctly when their frustules are not observed. Therefore these valves must be counted as “*Xanthiopyxis* type B (short spiny type)”, when only the epivalve or hypovalve is observed during the counting process.

Xanthiopyxis type C (long spiny type)

Figures 1.N; 12.33–12.40

Synonyms.—*Chaetoceros* sp. of Frenguelli, 1949, pl. 4, fig. 22; Hajós, 1968, p. 131, pl. 33, figs. 13, 16, pl. 34, figs. 8, 9a, b, 17; *Chaetoceros longicornis* Makarova, 1962, p. 52, pl. 1, figs. 17, 18, pl. 2, figs. 25–30; *Chaetoceros seiracanthus* Gran *sensu* Makarova, 1962, p. 48, pl. 3, figs. 4, 5; *Chaetoceros* spore of Schrader, 1978, p. 859, pl. 18, figs. 3, 4; *Chaetoceros* sp. I of Hajós, 1968, p. 130, pl. 34, fig. 3; *Chaetoceros* sp. II of Hajós, 1968, p. 130, pl. 34, fig. 7; *Chaetoceros* sp. III of Hajós, 1968, p. 130, pl. 34, figs. 4–6, 11; *Stephanogonia striolata* Pantocsek *sensu* Fenner, 1978, pl. 34, fig. 34; *Periptera* sp. (*Chaetoceros* sp.?) of Hajós, 1986, pl. 58, fig. 8; *Chaetoceros* sp. 1 of Homann, 1991, p. 75, pl. 9, figs. 2–6; *Dicladia* sp. of Barron and Mahood, 1993, p. 38, pl. 3, fig. 8.

Description.—Frustule heterovalvate. Valve oval to narrowly or broadly elliptical in valve view. In girdle view, epivalve face vaulted, with numerous long strong spines. Mantle of epivalve hyaline. Hypovalve slightly vaulted or flat, or vaulted in the center, hyaline or with numerous strong spines. Mantle of hypovalve hyaline, with a single ring of puncta at its base.

Similar taxa.—These specimens are characterized by long strong spines.

Remarks.—These specimens occur rarely in all of the cores and onland sections. These valves belong to several *Xanthiopyxis* species, but it is impossible to identify which ones when their frustules are not observed. Therefore these valves were counted as “*Xanthiopyxis* type C (long spiny type)”, when only the epivalve or hypovalve is observed during the counting process.

Valve of *Xanthiopyxis hirsuta* and epivalve of *Gemellodiscus micronodosus*

Figures 1.II; 11.1–11.24

Description.—Epi- or hypovalve of *Xanthiopyxis hirsuta* and epivalve of *Gemellodiscus micronodosus* (Suto, 2004b). In valve view, valve oval to broadly elliptical. In girdle view, valve vaulted, with numerous small spines, and with a mantle.

Remarks.—It is difficult to identify these specimens as either the valve of *X. hirsuta* or the epivalve of *G. micronodosus* because these valves are very similar to each other. Therefore, in this study, these valves were counted as “Valve of *X. hirsuta* or epivalve of *G. micronodosus*” when the frustule of this type did not occur.

Discussion

Several previously described *Xanthiopyxis* species were not observed in this study, and therefore are not listed above. It cannot be decided whether these species are fossil resting spores of *Chaetoceros* or not by the original descriptions and illustrations of these species. *Xanthiopyxis granti* Hanna is a late Cretaceous diatom characterized by a very slender valve

◆ **Figure 14.** 1–8. *Xanthiopyxis oblonga* Ehrenberg. Scale bar = 10 µm for each figure (LM).

1, 2. Valve view of epivalve, DSDP Site 338-14-2, 20–21 cm. 3, 4. Valve view of epivalve, DSDP Site 338-23-3, 10–11 cm. 5, 6. Valve view of epivalve, DSDP Site 338-11-1, 50–51 cm. 7, 8. Valve view of epivalve, DSDP Site 338-15-2, 100–101 cm.

9–14. *Xanthiopyxis globosa* Ehrenberg. Scale bar = 10 µm for each figure (LM).

9, 10. Valve view of epivalve, DSDP Site 338-21-1, 32–33 cm. 11, 12. Valve view of epivalve, DSDP Site 338-21-1, 148–149 cm.

13, 14. Girdle view of epivalve, DSDP Site 338-15-5, 138–139 cm.

shape (Hanna, 1927b; Hanna, 1934; Nikolaev *et al.*, 2001). This species may not be a resting spore of *Chaetoceros* because the valves in the illustrations of Hanna (1927b, 1934) and Nikolaev *et al.* (2001) possess a porous canal. *Xanthiopyxis cingulata* Ehrenberg is characterized by having a large valve size (15–40 μm) and valve mantle with spines (Ehrenberg, 1854; Hanna and Grant, 1926; Lohman, 1974). The circular valve of *X. umbonatus* possesses numerous spines in the valve center and was collected from upper Eocene to upper Miocene sediments (Greville, 1866; Sheshukova-Poretzkaya, 1967; Hanna, 1970; Fenner, 1978). *Xanthiopyxis cingulata* and *X. umbonatus* may be resting spores of *Chaetoceros*, but this cannot be determined in this study because the illustrations do not show the characteristic single ring of puncta on the mantle. *Xanthiopyxis microspinosa* Andrews has a broadly lanceolate valve with numerous small short spines and was reported from the middle Miocene Choptank Formation in Maryland (Andrews, 1976) and the middle Miocene deposits in the Szurdokpüspöki diatomite quarry, Hungary (Hajós, 1986).

Several extant *Chaetoceros* species form resting spores possessing numerous spines or knobs over the entire valve face (i.e., *C. teres* Cleve, *C. lauderi* Ralfs, *C. vanheurckii* Gran, *C. siamensis* Ostenfeld, *C. hispidum* Brightwell, *C. affinis* Lauder, *C. holsaticus* Schütt, *C. seiracanthus* Gran, and *C. costatus* Pavillard). These resting spores are too similar to distinguish from each other when seen without their vegetative cells. The resting spores of these *Chaetoceros* species, therefore, may not be identified in fossil records. In this study, these resting spores are informally described as *Xanthiopyxis* type A, *X.* type B and *X.* type C (Figure 1.L–1.N).

Although detailed descriptions of the morphology of extant *Chaetoceros* vegetative frustules are generally available (e.g., Cupp, 1943; Rines and Hargraves, 1988; Hasle and Syvertsen, 1996), our knowledge of extant resting spore morphologies is poor, because it is difficult to see some of the resting spores in valve view. Therefore, more detailed studies on extant and fossil resting spore morphology are needed in order to clarify the correlation between extant vegetative cells and fossil resting spores. Studying live *Chaetoceros* species (in culture or wild material) in the act of resting spore production is the only way to identify with certainty the vegetative cell-resting spore pair for each species. Then, fossil resting spores of similar morphology can be assigned to lineages containing extant members.

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References

- Akiba, F., 1986: Middle Miocene to Quaternary diatom biostratigraphy in the Nankai Trough and Japan Trench, and modified Lower Miocene through Quaternary diatom zones for middle-to-high latitudes of the North Pacific. *In*, Kagami, H. *et al.*, *Initial Reports of the Deep Sea Drilling Project*, vol. 87, p. 393–481. U. S. Govt. Printing Office, Washington, D. C.
- Andrews, G.W., 1976: Miocene marine diatoms from the Choptank Formation, Calvert County, Maryland. *Geological Survey Professional Paper*, vol. 910, p. 1–26.
- Baldauf, J.G. and Barron, J.A., 1987: Oligocene marine diatoms recovered in dredge samples from the Navarin Basin Province, Bering Sea. *U. S. Geological Survey Bulletin*, vol. 1765, p. 1–17.
- Barron, J.A. and Mahood, A.D., 1993: Exceptionally well-preserved early Oligocene diatoms from glacial sediments of Prydz Bay, East Antarctica. *Micropaleontology*, vol. 39, p. 29–45.
- Brockmann, C., 1928: Die Diatomeen im marinen Quartär Hollands. *Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft*, vol. 41, p. 117–187.
- Cupp, E.E., 1943: *Marine Plankton Diatoms of the West Coast of North America*, 237 p. University of California Press, Berkeley.
- Dzinoridze, R.N., Jousé, A.P., Koroleva-Golikova, G.S., Kozlova, G.E., Nagaeva, G.S., Petrushevskaya, M. G. and Strelnikova, N. I., 1978: Diatom and radiolarian Cenozoic stratigraphy, Norwegian Basin; DSDP LEG 38. *In*, Supko, P. R. *et al.*, *Initial Reports of the Deep Sea Drilling Project*, supplement to vol. 38, p. 289–385. U. S. Govt. Printing Office, Washington, D. C.
- Dzinoridze, R.N., Jousé, A.P. and Strelnikova, N. I., 1979: Description of diatoms. *In*, Jousé, A. P. ed., *The History of the Microplankton of the Norwegian Sea (Based on DSDP Material)*, vol. 23, p. 32–70. (in Russian)

- Edwards, L. E., 1991: Dinoflagellates. In, Lipps, J. H. ed., *Fossil Prokaryotes and Protists*, p. 105–130. Blackwell Scientific Publications, Oxford.
- Ehrenberg, C. G., 1844 (1845): Über zwei neue Lager von Gebirgsmassen aus Infusorien als Meeresabsatz in Nord-Amerika und eine Vergleichung derselben mit den organischen Kreidegebilden in Europa und Afrika. *Deutsche Akademie Wissenschaften zu Berlin, Berichte 1844*, p. 253–275.
- Ehrenberg, C. G., 1854: *Mikrogeologie. Das Erden und Felsen schaffende Wirken des unsichtbar kleinen selbständigen Lebens auf der Erde*, 374 p, 40 plates. Leopold Voss, Leipzig.
- Fenner, J., 1978: Cenozoic diatom biostratigraphy of the equatorial and Southern Atlantic Ocean. In, Supko, P. R. et al., *Initial Reports of the Deep Sea Drilling Project*, supplement to vol. 39, p. 491–623. U. S. Govt. Printing Office, Washington, D. C.
- Forti, A., 1912: Contribuzioni diatomologiche XII. Metodo di classificazione delle Bacillariee Immobili fondato sull'affinità morfologica dei frustoli e in relazione con l'evoluzione dell'auxospora. *Atti del Reale Istituto Veneto di Scienze Lettere ed Arti*, vol. 71, p. 678–731.
- Forti, A., 1913: Contribuzioni diatomologiche XIII. Diagnoses Diatomacearum quarundam fossilium italicarum. *Atti del Reale Istituto Veneto di Scienze Lettere ed Arti*, vol. 72, p. 1535–1700.
- Frenguelli, J., 1949: Diatomeas fósiles de los yacimientos chilenos de Tiltit y Mejillones. *Darwinia*, vol. 9, p. 97–157.
- Gladenkov, A. Y. and Barron, J. A., 1995: Oligocene and early middle Miocene diatom biostratigraphy of Hole 884B. In, Rea, D. K. et al., *Proceedings of the Ocean Drilling Program, Scientific Results*, vol. 145, p. 21–41. College Station, TX (Ocean Drilling Program).
- Gleser, S. I., Jousé, A. P., Makarova, I. V., Proshkina-Lavrenko, A. I. and Sheshukova-Poretzkaya, V. S. (eds.), 1974: *The Diatoms of the USSR, Fossil and Recent*, vol. 1, p. 1–400. Nauka, Leningrad. (in Russian)
- Gran, H. H., 1900: Diatomaceae from the ice-floes and plankton of the Arctic Ocean. In, Nansen, F., ed., *Norwegian North Polar Expedition 1893–1896, Scientific Results*, vol. 4, p. 1–74. Jacob Dybwad, Christiania (Oslo).
- Greuter, W., McNeill, J., Barrie, R., Burdet, H. M., Demoulin, V., Filgueiras, T. S., Nicolson, D. H., Silva, P. C., Skog, J. E., Trehane, P., Turland, N. J. and Hawksworth, D. L., 2000: *International Code of Botanical Nomenclature (Saint Louis Code) Adopted by the Sixteenth International Botanical Congress, St. Louis, Missouri. Regnum Vegetabile*, vol. 138, p. 1–474.
- Greville, R. K., 1866: Descriptions of new and rare diatoms, Series XVIII. *Transactions of the Microscopical Society of London, New Series*, vol. 14, p. 193–204.
- Hajós, M., 1968: Die Diatomeen der miozänen Ablagerungen des Matravorlandes. *Geologica Hungarica*, vol. 37, p. 1–401.
- Hajós, M., 1975: Late Cretaceous Archaeomonadaceae, Diatomaceae, and Silicoflagellatae from the South Pacific Ocean, Deep Sea Drilling Project, Leg 29, Site 275. In, Kennett, J. P. et al., *Initial Reports of the Deep Sea Drilling Project*, vol. 29, p. 913–1009. U. S. Govt. Printing Office, Washington, D. C.
- Hajós, M., 1976: Upper Eocene and lower Oligocene Diatomaceae, Archaeomonadaceae, and Silicoflagellatae in Southwestern Pacific sediments, DSDP Leg 29. In, Hollister, C. D. et al., *Initial Reports of the Deep Sea Drilling Project*, vol. 35, p. 817–883. U. S. Govt. Printing Office, Washington, D. C.
- Hajós, M., 1986: Stratigraphy of Hungary's Miocene diatomaceous earth deposits. *Geologica Hungarica*, vol. 49, p. 1–339.
- Hanna, G. D., 1927a: The lowest known Tertiary diatoms in California. *Journal of Paleontology*, vol. 1, p. 103–126.
- Hanna, G. D., 1927b: Cretaceous diatoms from California. *Occasional Papers of the California Academy of Sciences*, vol. 12, p. 5–49.
- Hanna, G. D., 1930: A review of the genus *Rouxia*. *Journal of Paleontology*, vol. 4, p. 179–188.
- Hanna, G. D., 1932: The diatoms of Sharktooth Hill, Kern County, California. *Proceedings of the California Academy of Sciences*, vol. 20, p. 161–263.
- Hanna, G. D., 1934: Additional notes on diatoms from the Cretaceous of California. *Journal of Paleontology*, vol. 8, p. 352–355.
- Hanna, G. D., 1970: Fossil diatoms from the Pribilof Islands, Bering Sea, Alaska. *Proceedings of the California Academy of Sciences*, vol. 37, p. 167–234.
- Hanna, G. D. and Grant, W. M., 1926: Miocene marine diatoms from Maria Madre Island, Mexico. *Proceedings of the California Academy of Sciences*, vol. 15, p. 115–193.
- Harwood, D. M. and Bohaty, S. M., 2000: Marine diatom assemblages from Eocene and younger erratics, McMurdo Sound, Antarctica. In, Stilwell, J. D. and Feldmann, R. M., eds., *Paleobiology and Paleoenvironments of Eocene Rocks, McMurdo Sound, East Antarctica*, Antarctic Research Series, vol. 76, p. 73–98.
- Harwood, D. M., Scherer, R. P. and Webb, P.-N., 1989: Multiple Miocene marine productivity events in West Antarctica as recorded in Upper Miocene sediments beneath the Ross Ice Shelf (Site J-9). *Marine Micropaleontology*, vol. 15, p. 91–115.
- Hasegawa, Y., 1977: Late Miocene diatoms from the Nakayama Formation in the Sado Island, Niigata Prefecture, Japan. *Publications from the Sado Museum*, vol. 7, p. 77–101. (in Japanese)
- Hasle, G. R. and Syvertsen, E. E., 1996: Marine diatoms. In, Tomas, C. R., ed., *Identifying Marine Diatoms and Dinoflagellates*, p. 5–385. Academic Press, San Diego.
- Homann, M., 1991: Die Diatomeen der Fur-Formation (Alttertiär) aus dem Limfjord-Gebiet, Nordjütland/Dänemark. *Geologisches Jahrbuch*, vol. A, p. 1–170.
- Jousé, A. P., 1963: Tip Bacillariophyta. Obschaya chast'. Sistematicheskaya chast': klass Centricae. In, Orlov, Yu. A., ed., *Osnovy Paleontologii, [Tom 14], Vodorosli*. Izdatel'stvo Akademii Nauk SSSR, Moskva (Moscow), p. 55–151. (in Russian)
- Kanaya, T., 1957: Eocene diatom assemblages from the Kellogg and "Sidney" Shales, Mt. Diablo area, California. *Science Reports of the Tohoku University, Second Series (Geology)*, vol. 28, p. 27–124.
- Kanaya, T., 1959: Miocene diatom assemblages from the Onagawa Formation and their distribution in the correlative formation in Northeast Japan. *Science Reports of the Tohoku University, Second Series (Geology)*, vol. 30, p. 1–130.
- Lee, Y. G., 1986: Micropaleontological study of Neogene strata of southeastern Korea and adjacent sea floor. *Journal of*

- Paleontological Society of Korea*, vol. 2, p. 83–113.
- Lee, Y.G., 1993: The marine diatom genus *Chaetoceros* Ehrenberg flora and some resting spores of the Neogene Yeonil Group in the Pohang Basin, Korea. *Journal of the Paleontological Society of Korea*, vol. 9, p. 24–52.
- Lohman, K.E., 1938: Pliocene diatoms from the Kettleman Hills, California. *Geological Survey Professional Papers*, vol. 189-C, p. 81–102.
- Lohman, K.E., 1974: Lower middle Miocene marine diatoms from Trinidad. *Verhandlungen der Naturforschenden Gesellschaft in Basel*, vol. 84, p. 326–360.
- Makarova, I.V., 1962: Ad cognitionem sporarum fossilium specierum generis *Chaetoceros* Ehr. *Notulae Systemticae e Sectione Cryptogamica Instituti Botanici Nomine V. L. Komarovii Academiae Scientiarum URSS*, vol. 15, p. 41–57.
- McCollum, D.W., 1975: Diatom stratigraphy of the Southern Ocean. In, Hayes, D.E. et al., *Initial Reports of the Deep Sea Drilling Project*, vol. 28, p. 515–571. U. S. Govt. Printing Office, Washington, D. C.
- Mills, F.W., 1933–35: *An Index to the Genera and Species of the Diatomaceae and their Synonyms, 1816–1932*, 1726 p. Wheldon and Wesley, London.
- Nikolaev, V.A., Kociolek, J.P., Fourtanier, E., Barron, J.A. and Harwood, D.M., 2001: Late Cretaceous diatoms (Bacillariophyceae) from the Marca Shale Member of the Moreno Formation, California. *Occasional Papers of the California Academy of Sciences*, vol. 152, p. 1–119.
- Proshkina-Lavrenko, A. I. and Sheshukova-Poretzkaya, V.S., 1949: Diatomovyi Analiz. Kniga 2. Opredelitel' Iskopaemykh i Sovremennykh Diatomovykh Vodoroslei, Por-yadok Centrales i Mediales. *Botanicheskii Institut im V. L. Komarova Akademii Nauk SSSR. Gosudarstvennoye Izdatel'stvo Geologicheskoi Literatury, Moskva-Leningrad*, vol. 2, p. 1–238.
- Rines, J.E.B. and Hargraves, P.E., 1988: The *Chaetoceros* Ehrenberg (Bacillariophyceae) flora of Narragansett Bay, Rhode Island, U.S.A. *Bibliotheca Phycologica*, vol. 79, p. 1–196.
- Schrader, H.J., 1973: Cenozoic diatoms from the Northeast Pacific, Leg 18. In, Kulm, L.P. et al., *Initial Reports of the Deep Sea Drilling Project*, vol. 18, p. 673–797. U. S. Govt. Printing Office, Washington, D. C.
- Schrader, H.J., 1978: Quaternary through Neogene history of the Black Sea, deduced from the palaeoecology of diatoms, silicoflagellates, ebridians, and chrysomonads. In, Ross, D. A. et al., *Initial Reports of the Deep Sea Drilling Project*, vol. 42, p. 789–901. U. S. Govt. Printing Office, Washington, D. C.
- Schrader, H.J. and Fenner, J., 1976: Norwegian Sea Cenozoic diatom biostratigraphy and taxonomy. In, Talwani, M. et al., *Initial Reports of the Deep Sea Drilling Project*, vol. 38, p. 921–1099. U. S. Govt. Printing Office, Washington, D. C.
- Schrader, H.J. and Gersonde, R., 1978: Diatoms and silicoflagellates. In, Zachariasse, W. J. et al., *Micropaleontological counting methods and techniques – an exercise on an eight meter section of the lower Pliocene of Capo Rossello, Sicily*, *Bulletin of Utrecht Micropaleontology*, vol. 17, p. 129–176.
- Schrader, H.J. and Schuette, G., 1981: Marine Diatoms. *The Oceanic Lithosphere*, vol. 7, p. 1179–1232.
- Sheshukova-Poretzkaya, V.S., 1967: *Neogene Marine Diatoms of Sakhalin and Kamtschatka*, 482 p. Nauka, Leningrad. (in Russian)
- Shirshov, P.P., 1977: *Atlas of Microorganisms in Bottom Sediments of the Oceans*, 32 p. Nauka, Moscow.
- Suto, I., 2003a: Taxonomy of the marine diatom resting spore genera *Dicladia* Ehrenberg, *Monocladia* gen. nov. and *Syndendrium* Ehrenberg and their stratigraphic significance in Miocene strata. *Diatom Research*, vol. 18, p. 331–356.
- Suto, I., 2003b: *Periptera tetracornusa* sp. nov., a new middle Miocene diatom resting spore species from the North Pacific. *Diatom*, vol. 19, p. 1–7.
- Suto, I., 2004a: Taxonomy of the diatom resting spore form genus *Liradiscus* Greville and its stratigraphic significance. *Micropaleontology*, vol. 50, p. 59–79.
- Suto, I., 2004b: Fossil marine diatom resting spore morpho-genus *Gemellodiscus* gen. nov. in the North Pacific and Norwegian Sea. *Paleontological Research*, vol. 8, p. 255–282.
- Whiting, M.C. and Schrader, H., 1985: Late Miocene to early Pliocene marine diatom and silicoflagellate floras from the Oregon coast and continental shelf. *Micropaleontology*, vol. 31, p. 249–270.
- Yanagisawa, Y. and Akiba, F., 1998: Refined Neogene diatom biostratigraphy for the northwest Pacific around Japan, with an introduction of code numbers for selected diatom biohorizons. *Journal of the Geological Society of Japan*, vol. 104, p. 395–414.