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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

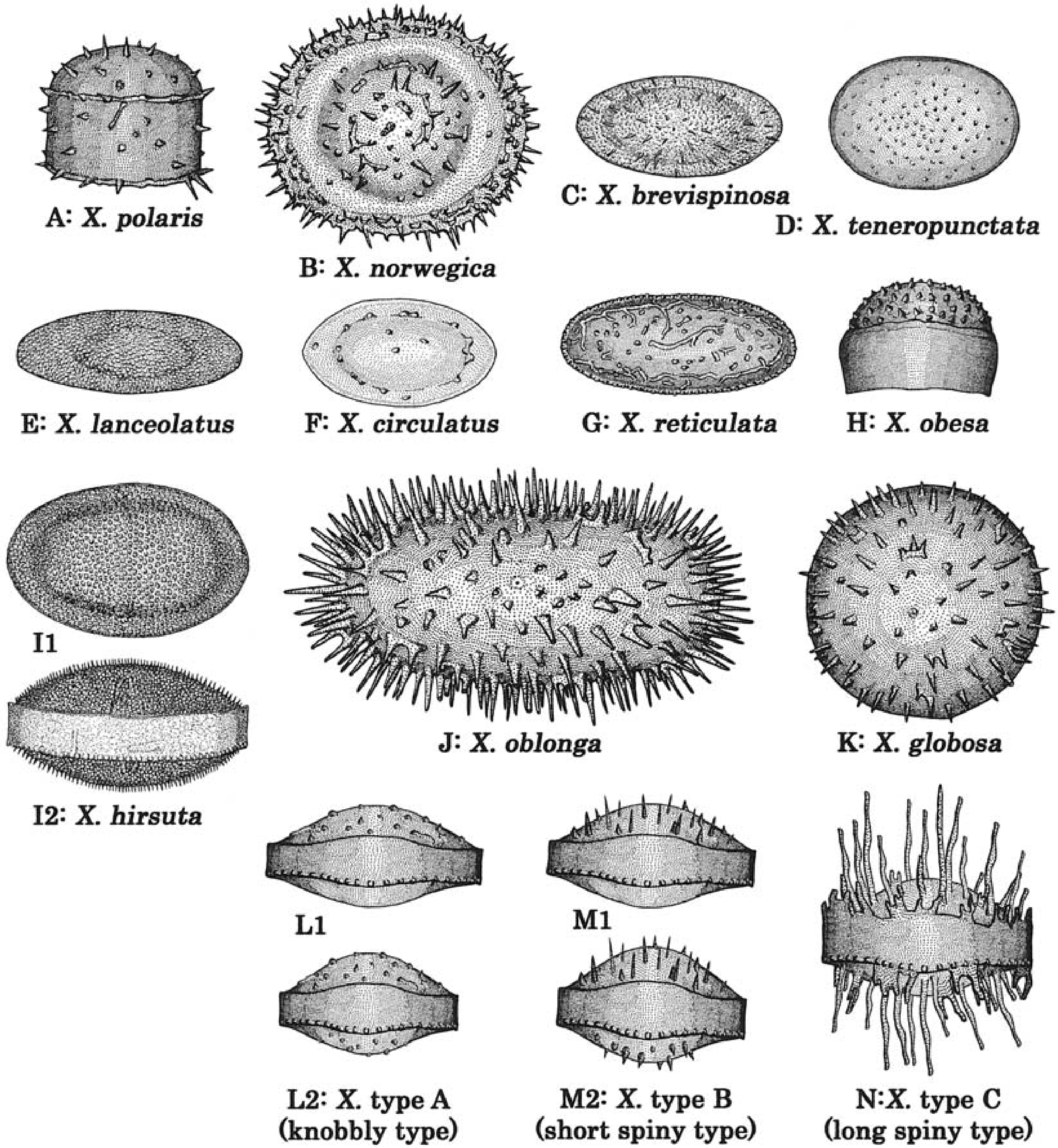


Figure 1. Sketches of valve and girdle view of *Xanthiopyxis* species (A, H, I2, L1, L2, M1, M2, N: girdle view; B, C, D, E, F, G, I1, J, K: valve view). All sketches were made using LM.

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 cockleburs, 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)

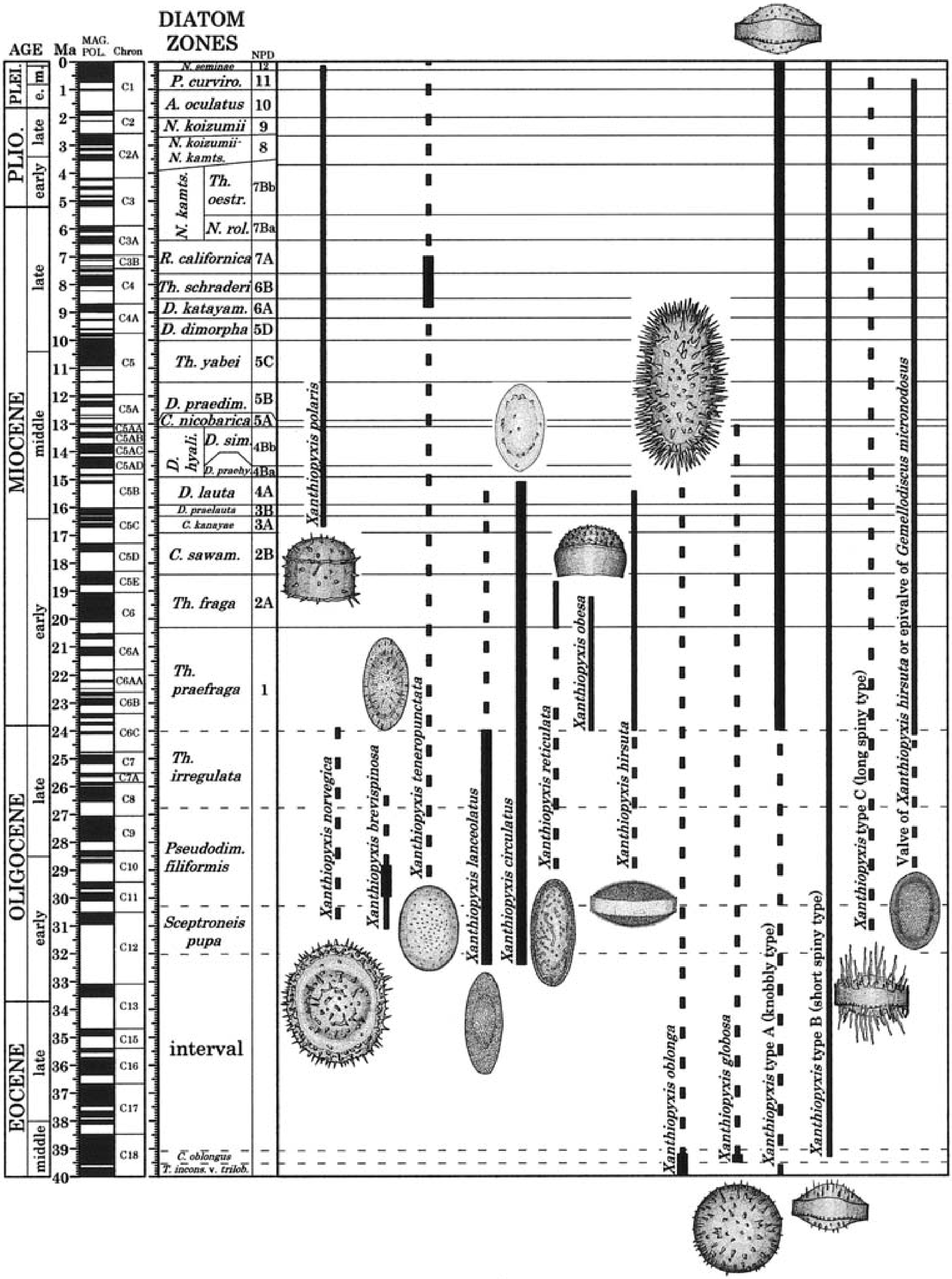


Figure 2. Stratigraphic ranges of *Xanthiopyxis* species. Diatom zones and NPD codes are after Yanagisawa and Akiba (1998) for the Miocene, Pliocene and Pleistocene, and after Schrader and Fenner (1976) for the Eocene and Oligocene.

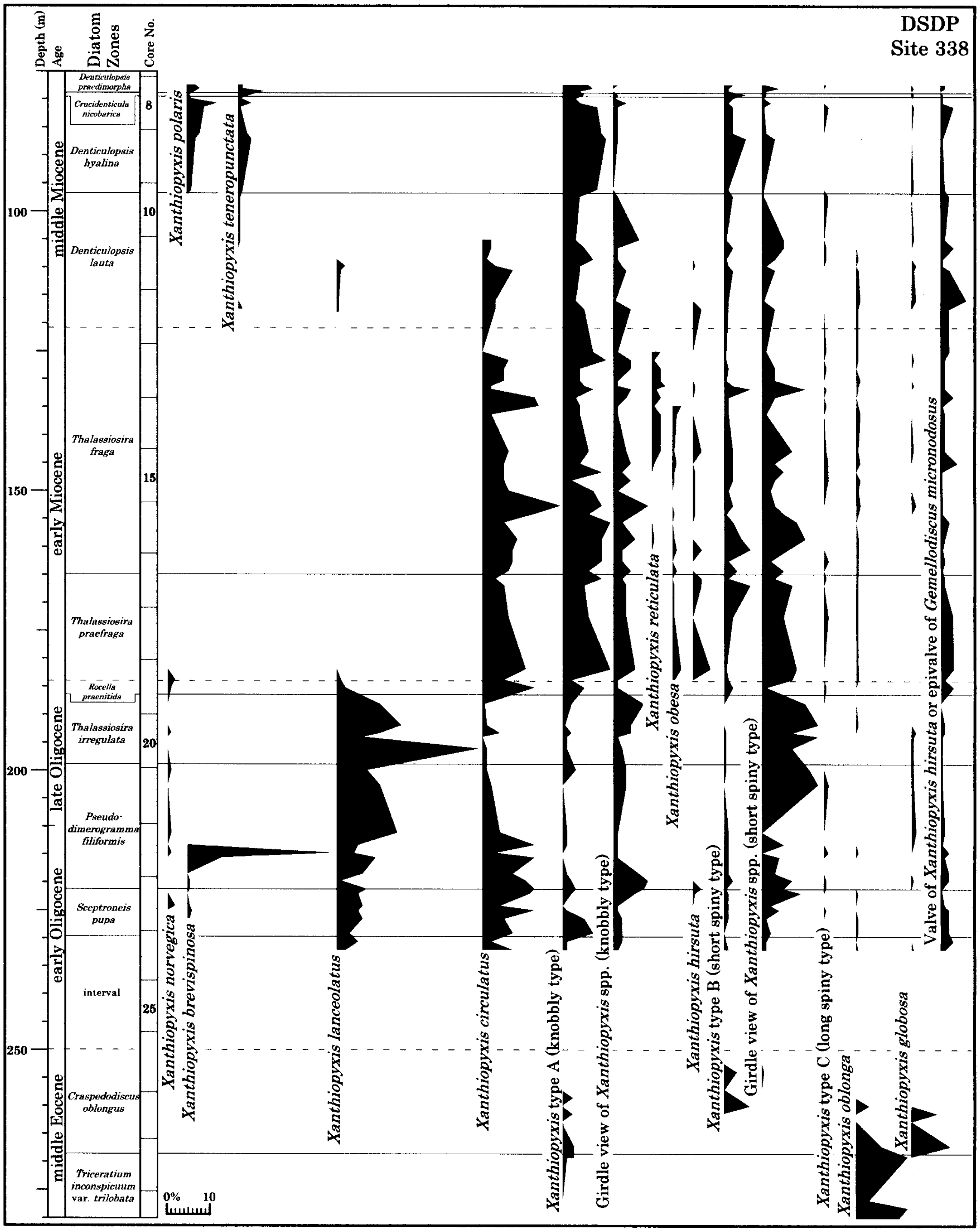


Figure 3. Stratigraphic occurrences of *Xanthiopyxis* species at DSDP Site 338. Diatom zones are after Schrader and Fenner (1976).

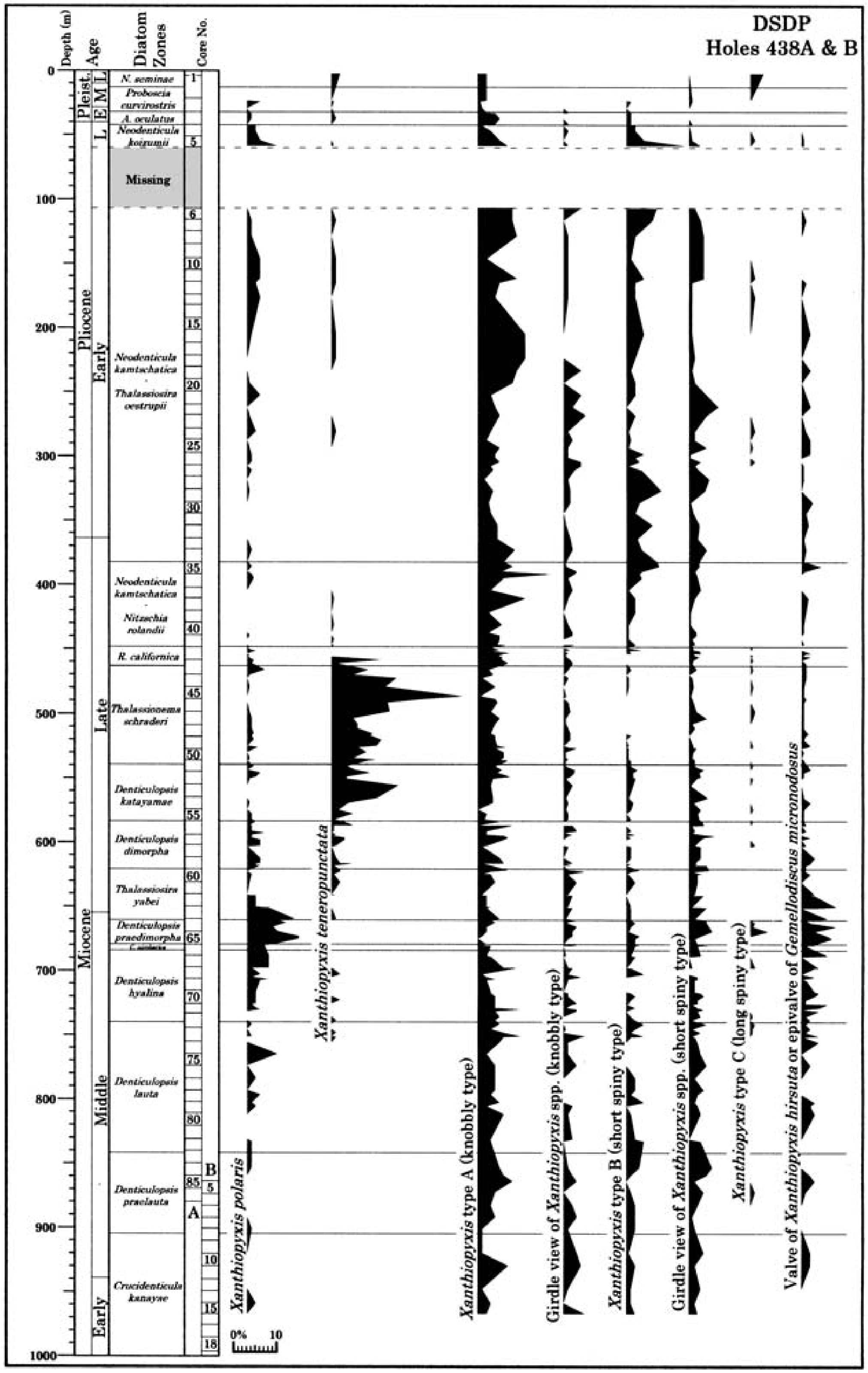


Figure 4. Stratigraphic occurrences of *Xanthiopyxis* species at DSDP Holes 438A and B. Diatom zones are after Yanagisawa and Akiba (1998).

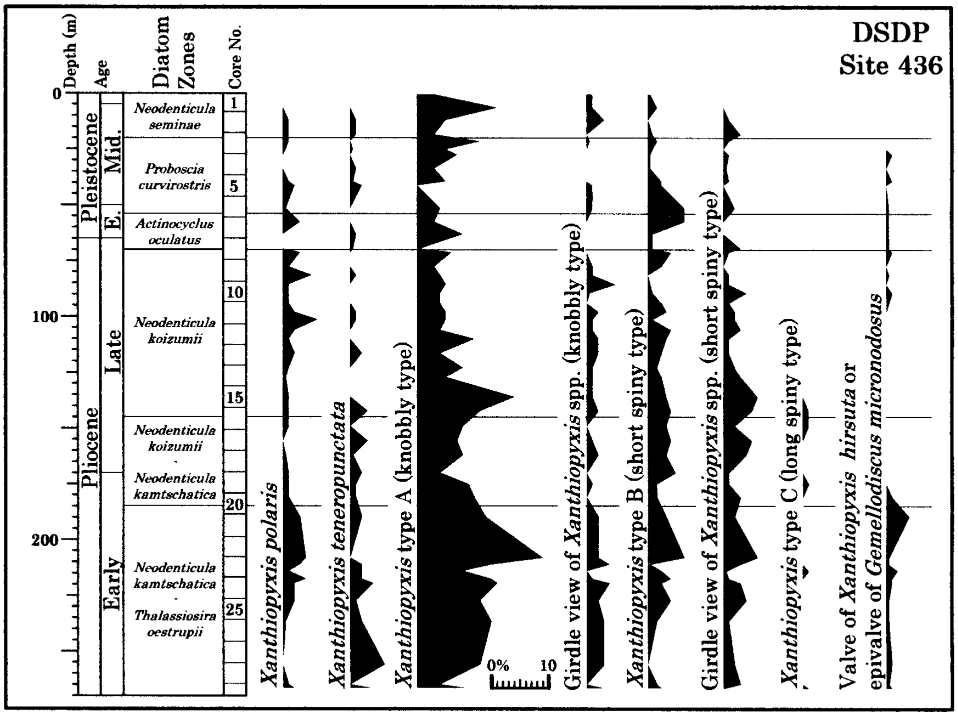


Figure 5. Stratigraphic occurrences of *Xanthiopyxis* species at DSDP Site 436 and in the Newport Beach Section. Diatom zones are after Yanagisawa and Akiba (1998).

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, pervalvar 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, pervalvar 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.

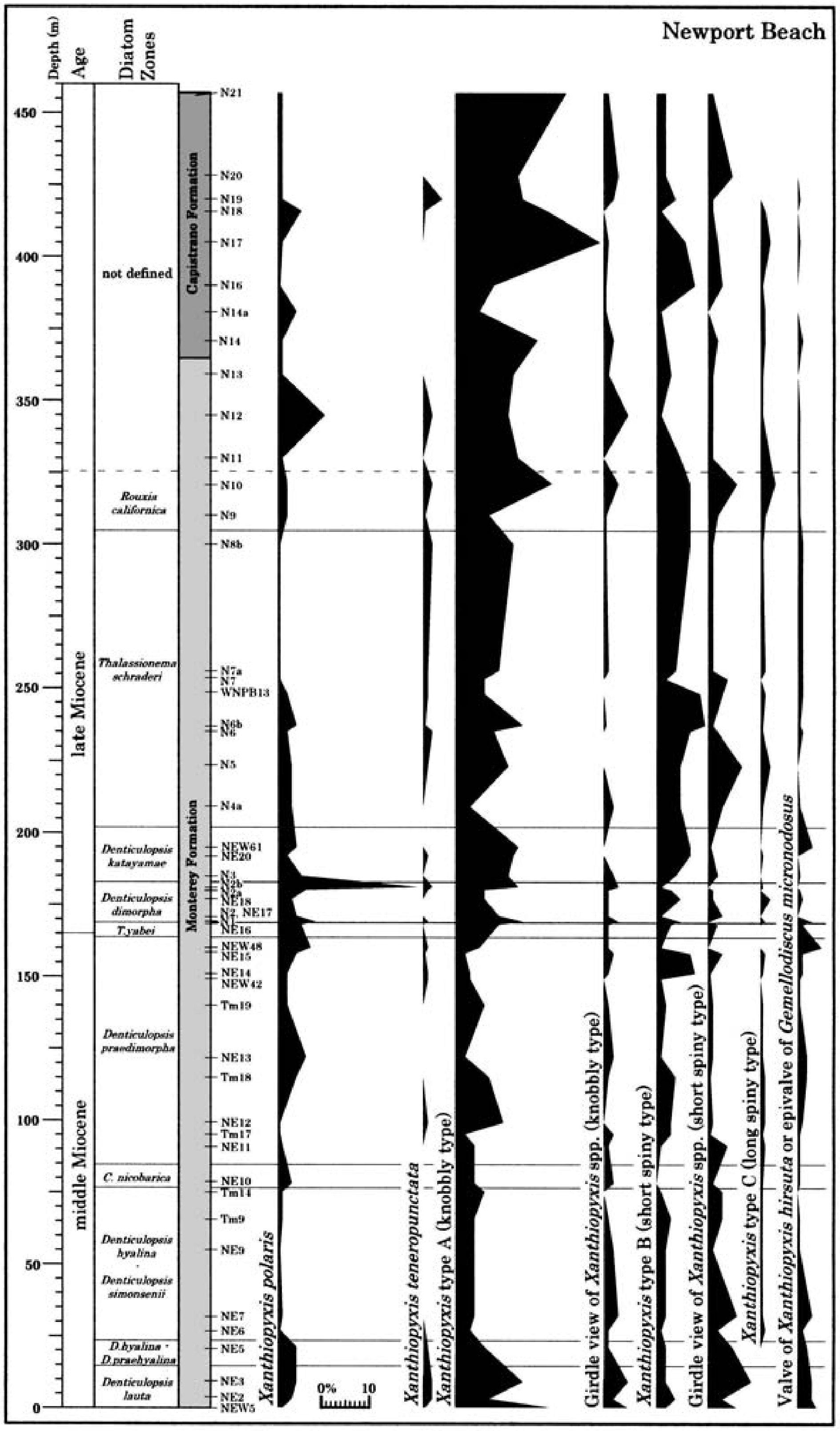


Figure 6. Stratigraphic occurrences of *Xanthiopyxis* species in the Newport Beach Section. Diatom zones are after Yanagisawa and Akiba (1998).

Table 1. Occurrences of *Xanthiopyxis* 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	*Xanthiopyxis polaris*	*X. norvegica*	*X. brevispinosa*	*X. teneropunctata*	*X. lanceolatus*	*X. circulatus*	*X.* type A (knobbly type)	Girdle view of *Xanthiopyxis* spp. (knobbly type)	*X. reticulata*	*X. obesa*	*X. hirsuta*	*X.* type B (short spiny type)	Girdle view of *Xanthiopyxis* spp. (short spiny type)	*X.* type C (long spiny type)	*X. oblonga*	*X. globosa*	Valve of *X. hirsuta* or epivalve of *G. micronodosus*	Total number of resting spore valves counted
middle Miocene	*Denticulopsis praedimorpha*	5B	8-1, 140-141	77.40	G	A	2			1			6	1				2	1	+			1	100
			8-2, 48-49	77.98	G	A	3			1			7					1	4			+	1	100
			8-2, 99-100	78.49	G	A	2			6			4					1	1					100
	C. nicobarica	5A	8-3, 10-11	79.10	G	A	+			3			5	1				5	1			+	+	100
	Denticulopsis hyalina	4B	8-3, 80-81	79.80	G	A	1			+			3	+				2	+				+	100
			8-4, 10-11	80.60	G	A	7			3			4	3				1	2				+	100
			8-4, 80-81	81.30	G	A	4			+			8	1				2	+	1		+	3	100
			9-1, 50-51	86.00	G	A	3			2			9	1				2	1				1	100
			9-1, 148-149	86.98	G	A	2			3			10	1				5	3				+	100
			10-1, 106-107	96.06	G	A	1			1			8					1	+			+	1	100
	Denticulopsis lauta	4A	10-2, 80-81	97.30	G	A				+			4	1				2	+	1			2	100
			11-1, 50-51	105.00	G	A				+		2	3	6				+	5			+	1	100
			11-2, 50-51	106.50	G	C						2	5	1				2	5	+			3	100
			11-3, 98-99	108.48	G	A						1	7	1				+	3	+	+		+	100
			11-4, 70-71	109.70	G	A					2	3	4	2			+	1	1			1	+	100
			11-4, 148-149	110.48	G	A					1	7	4	3				2	3		+	+	2	100
			12-2, 40-41	115.90	G	A					+	3	3	+				1	+		1	1	6	100
			12-3, 38-39	117.38	G	A				1	+	3	5	4			2	1	3		+		2	100
early Miocene	*Thalassiosira fraga*	2A	13-1, 148-149	124.98	G	A							7	1	2			+	1	+	+		2	100
			13-2, 148-149	126.48	G	A						6	10	4	+			+	2		+	+	1	100
			13-3, 148-149	127.98	G	A						5	4	4	2			1	3	+			1	100
			13-5, 70-71	130.20	G	A						5	4	1	2			+	3		1		1	100
			13-6, 10-11	131.10	G	A						2	5	1	3		+	2	7		+	+	1	100
			13-6, 70-71	131.70	G	A						2	7	4	1		+	6	10	+	+		1	100
			14-1, 20-21	133.20	G	A						12	3	3	2	1		1	3				3	100
			14-2, 20-21	134.70	G	A						13	4	1	+	2		1	2	+	+		+	100
			14-3, 20-21	136.20	G	A						2	4	1	2	1		1	1		1		1	100
			15-1, 30-31	142.80	G	A						6	6	3	2	+	2	2	7	+	+	+	1	100
			15-2, 100-101	145.00	G	A						5	4	4	+	1		2	3	1	1		4	100
			15-3, 100-101	146.50	G	A						5	9	2		+	+	2	5	1			+	100
			15-4, 100-101	148.00	G	A						5	2	4		+	+	2	3	1	1		+	100
			15-5, 138-139	149.88	G	A						6	7	1			+	1	2	+	+		+	100
			16-1, 10-11	152.55	G	A						18	9	8			+	2	3		1	1	+	100
			16-2, 10-11	154.05	G	A						12	6	5		+	+	+	5		+		+	100
			16-3, 10-11	155.55	G	A						5	11	2				2	8				2	100
			16-5, 10-11	158.55	G	A						8	9	5	+	+		4	10		+		1	100
			16-6, 50-51	160.45	G	A						7	9	2		1	2	6	6		+		+	100
			17-1, 100-101	162.50	G	A						7	9	2				1	2	1	+		1	100
			17-2, 119-120	164.19	G	A						6	6	4		1		3	5		+		+	100
	Thalassiosira praefraga	1	17-3, 110-111	165.60	G	A						3	9	2			2	1	3	+	+		1	100
			17-4, 79-80	166.79	G	A						5	5	3		+	2	6	7		+		1	100
			18-1, 148-149	172.48	G	A						6	6	3		+		2	5	1	+		3	100
			19-1, 130-131	181.80	G	A						10	11	5		2	4	+	8		+		3	100
			19-3, 20-21	183.70	G	A		1			1	5	2	1		+		1	7		+		1	100
late Oligocene	*R. praenitida*		19-4, 10-11	185.10	G	A		+			2	12	5	1				2	1	+			3	100
	Thalassiosira irregulata		19-5, 148-149	187.98	G	A					10	+	2	7					10					100
			20-2, 30-31	191.80	G	A					15	1	+	4					13		+		1	100
			20-3, 20-21	193.20	G	C		1			10	4	2	4				+	7			1	1	100
			20-3, 90-91	193.90	G	C					6		1	1				+	13			+	+	100
			20-4, 148-149	195.98	G	A					33	1	1	2				+	7			+	+	100
	Pseudodimerogramma filiformis		21-1, 32-33	199.82	G	A		+			7	1	3	3				+	11			+	+	100
			21-2, 148-149	202.48	G	A					10	2		3					13	1		+	+	100
			22-2, 10-11	211.00	G	R		+			14	4	1	1				1				1	1	100
			22-3, 80-81	213.20	G	C					5	12	1	1				1	5			+	+	100
early Oligocene			22-4, 79-80	214.69	G	R		+	34		4	3		1				1		1	+		2	100
			22-5, 10-11	215.50	G	C			8		9	12		1				1	4				1	100
			22-6, 148-149	218.38	G	C					6	7	1	6				1	3				2	100
			23-1, 80-81	219.60	G	C			+		1	10	2	8				2	7	+		+	2	100
			23-2, 80-81	221.10	G	A			+		7	12	3	7			2	+	5	+			+	100
	Sceptroneis pupa		23-3, 10-11	221.90	G	C					5	11	2	5			+	1	9		+		+	100
			23-4, 80-81	224.10	G	C		1	+		6	4		1				1	2				1	100
			23-5, 10-11	224.90	G	C			1		5	12	1	1				1	4	+			2	100
			23-6, 10-11	226.40	G	A			+		6	5	5	2				1	1		+		2	100
			24-1, 100-101	229.00	G	R					3	7	7	2					2		+		2	100
	interval		24-2, 100-101	230.50	G	C					5	2	1	2				+	1				3	100
			24-3, 100-101	232.00	G	R					2	7	1	1				1	1		+	+	1	100
			barren until:																					
middle Eocene			26-2, 110-111	249.60	G	R																		30
	Craspedodiscus oblongus		26-3, 80-81	250.80	G	R																		30
			26-4, 80-81	252.30	G	R																		100
			26-5, 80-81	253.80	G	R												1	+					30
			27-1, 58-59	257.08	G	R																		30
			27-2, 50-51	258.50	G	R							1					1						30
			27-3, 40-41	259.90	G	R												2			1			30
			27-4, 30-31	261.30	G	R							1									2		30
			27-5, 19-20	262.69	barren																			
			28-1, 120-121	267.20	G	R							1								2	3		30
	Triceratium inconspicuum var. *trilobata*		28-2, 148-149	268.98	G	R							1								4			30
			29-1, 130-131	276.80	G	R															1			30
			29-2, 120-121	278.20	G	R															4			30
			29-3, 148-149	279.98	G	R															1			10

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).

Hole	Diatom Zones (NPD)	Core-Section, Interval (cm) Leg 57 Site 438	Depth (m)	Preservation	Abundance	*Xanthiopyxis polaris*	*X. teneropunctata*	*X.* type A (knobbly type)	Girdle view of *Xanthiopyxis* spp. (knobbly type)	*X.* type B (short spiny type)	Girdle view of *Xanthiopyxis* spp. (short spiny type)	*X.* type C (long spiny type)	Valve of *X. hirsuta* or epivalve of *G. micronodosus*	Total number of resting spore valves counted
DSDP Hole 438A	*N. seminae* (NPD12)	1-2, 80-82	2.31	G	A		2	2				3		100
	Proboscia curvirostris (NPD 11)	2-1, 10-14	23.12	G	A			2			1			100
		2-1, 96-98	23.97	G	A	3	+	+		1	1			100
		2-5, 5-9	29.07	G	A			1						100
	Actinocyclus oculatus (NPD 10)	3-1, 31-33	32.82	G	A	+	+	2	1	1				100
		3-3, 140-142	32.91	G	A	1	+	4		1				100
		3-4, 10-14	37.12	G	A	1	1	5		1				100
		3cc	41.65	G	A	+		4	1	1	1			100
	Neodenticula koizumii (NPD 9)	4-1, 40-74	42.72	G	A	2		1		2				100
		4-4, 8-12	46.6	G	A	2		3	1	2	+			100
		5-2, 96-100	53.98	G	A	3		5		4	1	1	+	100
		5cc	58.5	G	A	7	+	7	1	14	4		+	100
	Neodenticula kamtschatica (NPD 7B-8)	6-1, 18-22	106.7	G	A			8	4	7	2			100
		7-1, 19-22	116.21	G	A	1	1	8		6	4		1	100
		8-3, 30-34	128.82	G	A	1		9	1	2	5			100
		10-2, 15-18	146.17	G	A	3	1	2	1	1	5			100
		11-6, 20-24	161.72	G	A	3	1	9	1	4	5	1		100
		12-1, 138-140	164.89	G	A	2	1	5	1	2	1		1	100
		13-3, 19-23	176.21	G	A	3		4	1	2	1	1		100
		16-3, 36-39	204.88	G	A	1	1	11		4	1		2	100
		18-3, 10-14	223.62	G	A		1	11		2	2			100
		19-3, 10-14	233.12	G	A			9	4	1	1		2	100
		20-3, 26-30	242.78	G	A	+		8		2	2			100
		21-3, 20-24	252.22	G	A	3		3	4	2	6		1	100
		22-3, 20-24	261.72	G	A			4	2		10		2	100
		23-1, 10-14	268.12	G	A	+		5	5	2	6			100
		24-3, 10-12	280.61	G	A	2	1	3	1	+	2	1	1	100
		25-1, 35-39	287.37	G	A		+	2	2	1	2		2	100
		25-5, 16-20	293.18	G	A	+		5	1	+	6	+	2	100
		26-2, 29-33	298.31	G	A	1		4	1	4	+		2	100
		26-4, 10-14	301.12	G	A	1		4	1	2	+			100
		26-6, 15-19	304.17	G	A	1		5	4	3	4	1		100
		27-2, 20-24	307.72	G	A			3	4	+	2		+	100
		27-4, 20-24	310.72	G	A	2		7	5	7	7		1	200
		28-2, 20-24	317.72	G	A			3	2	11	14		1	200
		29-2, 20-24	326.72	G	A	1		7	3	16	11			200
		30-2, 20-24	336.22	G	A			5	3	6	1		5	200
		31-1, 20-24	344.22	G	A			6		4	3		2	200
		32-1, 24-28	353.76	G	A			9	1	12	7		3	200
		33-1, 120-124	364.22	G	A			9	3	5	6		1	200
		34-1, 22-24	372.73	G	A	2		17	4	7	12		2	200
		35-1, 24-28	382.26	G	A			12	1	14	7		1	200
		35-3, 24-28	385.86	G	A	2		16	1	15	7		9	200
		35-6, 24-28	389.76	G	A			11	6	7	4		1	200
		36-1, 32-36	391.84	G	A	2		34	5	6	5			200
		36-3, 32-36	394.84	G	A	3		12	2	7	6			200
		37-3, 10-14	404.12	G	A			6	4	1	8			200
		38-1, 11-15	410.63	G	A		1	22	2	4	4		3	200
		39-2, 11-15	421.63	G	A			5		4	1		2	200
		40-2, 20-24	431.22	G	A		1	11	2	1	1		1	200
		40-6, 10-14	437.12	G	A			5	4	1	5		1	200
		41-1, 45-49	439.47	G	A	1		10	4	1	5			200
		41-3, 30-34	442.32	G	A		1	10		1	2			200
		41-6, 10-14	446.62	G	A			9		4	4		1	200
		41cc	447.13	G	A		1	13	5	4	3			200
	Rouxia californica (NPD 7A)	42-1, 14-18	448.66	G	A	1		7		2	1			200
		42-1, 90-91	449.41	G	A			7			3	1		200
		42-2, 95-96	450.96	G	A	2		10	3	7	3			200
		42-3, 15-16	451.66	G	A	4		6		1	7		1	200
		42-4, 50-54	453.52	G	A			15	2	2	8		4	200
		42-4, 73-74	453.74	G	A			12	1		3		2	200
		42-5, 100-101	455.51	G	A	1		9	1		4	1		200
		42-6, 16-20	456.18	G	A			11	1		7		4	200
		43-1, 59-63	458.61	G	A	3	23	11	3		3	1		200
		43-3, 30-34	461.32	G	A	2	2	14	4		2		2	200
	Thalassionema schraderi (NPD 6B)	43-6, 82-86	466.34	G	A	8	19	5	2	2	5	1	2	200
		44-1, 60-64	470.12	G	A	1	10	7					2	200
		44-3, 10-14	472.62	G	A		30	2	2	1	2		2	200
		45-1, 54-58	479.56	G	A	1	25	8		1	3	1	1	200
		45-6, 30-34	486.82	G	A		61	1	1		1		1	200
		46-1, 18-20	488.7	G	A		43	8			2		2	200
		46-3, 18-22	491.7	G	A		26	9	2		3		1	200
		47-1, 10-14	498.12	G	A	1	27	6	3		5	2	1	200
		47-4, 110-114	503.62	G	A	2	10	10	1		12	1	1	200
		48-1, 14-18	507.66	G	A	2	12	8	1		2		1	200
		48-3, 46-50	510.98	G	A	2	12	7	2		4		1	200
		48-6, 26-30	515.28	G	A	3	19	6	3		1		3	200
		48-7, 30-31	516.81	G	A	2	18	8	3	2			2	200
		49-3, 10-14	520.12	G	A	3	23	8	3		1		1	200
		49-6, 10-14	524.62	G	A		21	9		1	3	1	4	200
		49-7, 10-11	526.11	G	A	5	12	13	2		3	1	2	200
		50-1, 20-24	526.72	G	A	4	13	8	6	1	5			200
		50-3, 20-24	529.72	G	A		16	12	1	1	3		1	200
		50-6, 20-24	534.22	G	A	1	10	12	1	1	2			200
		50-7, 10-11	535.61	G	A	1	21	10	2	1	4		1	200
		51-1, 16-20	536.18	G	A		17	14	1	2	4		1	200
	Denticulopsis katayamae (NPD 6A)	51-4, 16-20	540.68	G	A	3	7	8	1	2	4	1	3	200
		51-6, 16-20	543.68	G	A		11	11	5	5	10		4	200
		52-1, 36-38	545.87	G	A	6	18	9	5	3	7		1	200
		52-3, 36-38	548.87	G	A	4	7	15	3	3	8		1	200
		52-4, 36-38	550.37	G	A	1	7	7	1	4	5	1		200
		53-1, 77-81	555.79	G	A		31	6	4	3	1			200
		54-1, 110-114	565.62	G	A		21	7	1	1	13		1	200
		54-4, 125-127	569.26	G	A	1	8	7	2	3	3		4	200
		55-1, 70-74	574.72	G	A		3		1	2	8	1	1	200
		55-3, 70-74	577.72	G	A	2	10	4	2		6		1	200
		55-6, 76-78	582.27	G	A	2	1	3	2	2	7		1	200
		56-1, 20-24	583.72	G	A	4	5	11			9	1	1	200
	Denticulopsis dimorpha (NPD 5D)	56-3, 20-24	586.72	G	A	+	5	0			5		1	100
		56-3, 60-62	587.11	G	A	1	+	8	2		1			100
		56-6, 20-24	591.22	G	A	1	+	2	3	1	2		1	100
		56cc	592.63	G	A	4		2			1			100
		57-1, 115-117	594.16	G	A	1	1	2	2	2	5			100
		57-2, 31-35	594.83	G	A	1		6	1		9		+	100
		57-3, 31-35	596.33	G	A	1	3	7	+	1	5		2	100
		57-4, 59-61	598.1	G	A	3	3	6			4			100
		58-1, 16-20	602.68	G	A	3	1	2			2	1	1	100
		58-1, 101-103	603.52	G	A			1	1	1	4			100
		59-1, 17-21	612.19	G	A	3	1	5		1	4		3	100
		59-3, 135-137	616.36	G	A	3	2	6	2		2		2	100
		59-4, 17-21	616.69	G	A	2	5	1		1	3		2	100
		59-5, 5-6	618.06	G	A	2	1	3	2		1		1	100
		59-5, 17-21	618.19	G	A	3	+	3			6		1	100
	Thalassiosira yabei (NPD 5C)	60-1, 34-38	621.86	G	A	+	2	7	1	3	7		1	100
		60-1, 134-136	622.85	G	A		2	3	5	1	1		1	100
		60-3, 26-27	624.77	G	A	1	+	1	1		5		2	100
		60-3, 27-29	624.78	G	A	1	+	3	1	+	3		2	100
		61cc	631.08	G	A	+	2	4	3	2	3			100
		62-1, 20-24	640.72	G	A			1	1		2		3	100
		62-1, 80-81	641.31	G	A	+	1	1			1		1	100
		62-1, 110-112	641.61	G	A	2		2	2		5		3	100
		63-1, 16-20	650.18	G	A	2		2	1	1	1		8	100
		63-1, 88-89	650.89	G	A	5		3			6		4	100
		63-1, 110-112	651.11	G	A	5		2	2	1	6			100
		64-1, 10-14	659.62	G	A	11	1	5	+	1	2		6	100
		64-1, 121-128	660.75	G	A	7		3	3	1	6		1	100
	Denticulopsis praedimorpha (NPD 5B)	64-3, 10-14	662.62	G	A	9		4	+	2	6	1	2	100
		64-5, 30-32	665.81	G	A	6		2	3	1	7	+	8	100
		65-1, 54-56	669.55	G	A	7		2	2	+	8	4	3	100
		65-3, 100-103	673.02	G	A	12		1	2	3	4		6	100
		65-5, 18-21	675.2	G	A	12			1	2	2		7	100
		66-1, 118-122	679.7	G	A	6		2		2	3		3	100
		66-2, 25-27	680.26	G	A	3		+	3	3	6		3	100
		66-2, 34-36	680.35	G	A	5		2	2	2	7			100
	C. nicobarica (5A)	66-2, 82-84	680.83	G	A	4		3		2	3		1	100
	Denticulopsis hyalina (NPD 4B)	67-1, 27-32	688.3	G	A	5		2	+	1	4		6	100
		67-1, 112-113	689.13	G	A	5		3		2				100
		68-1, 30-34	697.82	G	A	5		6	1		1	1	4	100
		68-1, 101-103	698.02	G	A	1		9	2	1			3	100
		68-4, 68-72	702.7	G	A	3	2	1	1	4				100
		68-6, 105-108	705.07	G	A	1		2	4		3		3	100
		68-7, 24-26	706.75	G	A	5		4	1		3			100
		69cc	707.13	G	A	3		2	1		2		1	100
		70-1, 16-20	716.68	G	A	2		3			2		3	100
		70-1, 78-81	717.3	G	A	2		3	1	1	4		4	100
		70-3, 49-53	720.01	G	A	2		4	1	2	5		3	100
		70-5, 23-27	722.75	G	A	2	2	4	2	1	3		1	100
		70-7, 5-7	725.56	G	A	2		4	3	+	3		1	100
		71-1, 12-16	726.14	G	A	1		4	2		1		6	100
		71-3, 7-11	729.09	G	A	2		4	+	2	3		4	100
		71-3, 114-116	730.15	G	A	3		10	3	1	5			100
		71-5, 8-12	731.6	G	A			4	3		3		4	100
		72-1, 14-18	735.66	G	A			5		1	4	+	1	100
		72-3, 15-17	738.66	G	A		1	4		2	1		2	100
	Denticulopsis lauta (NPD 4A)	72-5, 11-13	741.62	G	A	1		5		4	6	1	1	100
		73-1, 27-31	745.29	G	A			3	+	2	1	+	2	100
		73-3, 27-31	748.29	G	A	+	1	6		1	4	+	1	100
		73-5, 9-11	751.1	G	A	1		10	5	4	1		4	100
		73-5, 46-48	751.47	G	A		1	6	4	1	2		+	100
		74-1, 124-126	755.75	G	A			5	1		3		4	100
		75-1, 70-71	764.71	G	A	7		2	1		4			100
		76-1, 32-34	773.83	G	A			4	3		6		2	100
		77-1, 81-83	783.82	G	A	2		4		2	2			100
		78-1, 54-56	793.05	G	A			4		2	5			100
		78-3, 92-94	796.43	G	A	3		3		1	3			100
		79-1, 51-54	802.53	G	A	1		5		4	2		3	100
		79-3, 55-57	805.56	G	A	2		2	2		3		2	100
		80-1, 20-22	811.71	G	A			6	1	1	4		3	100
		82-1, 73-75	831.24	G	A			3	2	2				100
		82-2, 73-75	832.74	G	A	1		3		4	4			100
	Denticulopsis praelauta (NPD 3B)	84-3, 63-65	853.14	G	A	1		5	1	3	8			100
		85-1, 48-50	859.49	G	A			6	2	1	6		2	100
		85-4, 25-27	863.76	G	A			8	3		2		3	100
DSDP Hole 438B		6-1, 16-19	872.28	G	A			4		1	5	1	1	100
		7-1, 128-130	882.79	G	A			3	2	2	3			100
		8-1, 90-92	891.81	G	A			4	3	2	1			100
		9-1, 85-87	901.16	G	A	1		1	1	2	2			100
	Crucidenticula kanayae (NPD 3A)	11-1, 60-62	919.81	G	A			1	3	+	5		2	100
		12-1, 81-82	929.52	G	A			7	4	2	2		2	100
		14cc	947.6	G	A			1	1	1	4			100
		15-2, 61-62	959.02	G	A	2		3		1	2			100
		16-1, 82-84	967.13	G	A			2	5	2	3			100

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	*Xanthiopyxis polaris*	*X. teneropunctata*	*X.* type A (knobbly type)	Girdle view of *Xanthiopyxis* spp. (knobbly type)	*X.* type B (short spiny type)	Girdle view of *Xanthiopyxis* spp. (short spiny type)	*X.* type C (long spiny type)	Valve of *X. hirsuta* or epivalve of *G. micronodosus*	Total number of resting spore valves counted
l. Pleisto.	*Neodenticula seminae* 12	1-1, 49-50	0.49	G	R			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		1	3			100
mid. Pleistocene	*Proboscia curvirostris* 11	3-3, 100-102	21.50	G	C	1		11	+	2	1			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
		5-2, 148-150	39.48	G	A	1	+	5		3	1		1	100
		5-4, 22-24	41.12	G	R	2	2		1	3				100
		6-4, 100-102	51.50	G	C	+		4	1	8	2		+	100
e. Plei.	*Actinocyclus oculatus* 10	7-2, 54-56	57.54	G	R	3		3		8			+	100
		7-6, 50-52	63.00	G	C		1	8		1			+	100
		8-3, 148,-150	69.48	G	A		+	+		1	3		+	100
late Pliocene	*Neodenticula koizumii* 9	8-5, 18-20	71.18	G	C	3		6		5	1		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		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	+	1	4		1	100
		11-1, 50-52	94.00	G	R	1		4		3	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		10	2	4	1			100
		13-3, 100-102	116.50	G	C	2	2	4	2	3	1			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	3	11	2	5	5	1		100
	Neodenticula koizumii - *Neodenticula kamtschatica* 8	16-6, 47-49	148.87	G	R	1		8		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	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	3		1	100
early Pliocene	*Neodenticula kamtschatica* - *Thalassiosira oestrupii* 7Bb	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		3	+	1	2	100
		24-1, 50-52	217.50	G	R	4	2	13	1	5	1		1	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	1		+	100
		28-1, 102-104	256.02	G	R		6	11	3		2		1	100
		29-1, 48-50	264.98	G	R	1		4		2	3		+	100
		29-2, 70-72	266.70	G	R	2	4	9	3	3		1	1	100

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	*Xanthiopyxis polaris*	*X. teneropunctata*	*X.* type A (knobbly type)	Girdle view of *Xanthiopyxis* spp. (knobbly type)	*X.* type B (short spiny type)	Girdle view of *Xanthiopyxis* spp. (short spiny type)	*X.* type C (long spiny type)	Valve of *X. hirsuta* or epivalve of *G. micronodosus*	Total number of resting spore valves counted
not defined		W	Capistrano Fm.	N21	457	M	R	1		23	1	2	1			100
		W		N20	428	M	R	1		13	3	2	5			100
		W		N19	420	G	C	1	4	14	2	4	1		+	100
		W		N18	416	G	A	5	+	19		1	1	1		100
		W		N17	405	G	C	1		30	1	6	2	2	+	100
		W		N16	390	G	A	+		8	+	8	3	+		100
		W		N14a	381	G	C	4		5	+	1		1		100
		W		N14	371	G	C	1		17	2	2	2	1	1	100
		W	Monterey Formation	N13	359	G	A	1		12	1	3	1	+		100
		W		N12	345	G	R	10	2	11	5	1	1	+	+	100
		W		N11	330	G	A	1		13		5	1	2	+	100
late Miocene	*R. californica* 7A	W		N10	321	G	A	2	2	20	3	7	6	3	+	100
		W		N9	310	G	A	2	+	7	+	7	2	1	+	100
	Thalassiosira schraderi 6B	W		N8b	300	G	C	+	2	12	+	7	1	+	1	100
		W		N7a	256	G	C	+	1	9	1	4	1	1	1	100
		W		N7	253	G	R	+	1	6		2	4		1	100
		W		WNPB13	248	G	A	2	1	6		9	3	1	1	100
		W		N6b	237	G	A	4	+	14	+	10	1	+	+	100
		W		N6	235	G	C	2	2	8		7	2	+	1	100
		W		N5	223	G	R	3	1	11		5	7	2		100
		W		N4a	209	M	R	3		3	2	5	3	+	+	100
	Denticulopsis katayamae 6A	E		NEW61	195	G	C	4		13		7	+		3	100
		E		NE20	192	G	R	2	1	12		7	1	+		100
		W		N3	185	G	R	5		11	2	4	2		+	100
	Denticulopsis dimorpha 5D	W		N2b	181	M	R	30	2	13	3	1		+		100
		W		N2a	180	G	R	6	1	6	1	3	1		+	100
		E		NE18	177	G	A	3		6	1	5	1	2	1	100
		E		NE17	171	M	R	4		9	1	1	3			100
		W		N1	169	G	C	8	1	14	3	5		1	3	100
	5C	E		NE16	168	M	R	5		9	1	3	2		1	100
middle Miocene	*Denticulopsis praedimorpha* 5B	E		NEW48	160	G	R	7	1	5	1	1			5	100
		E		NE15	158	G	C	4	+	2	2	7	3	1	1	100
		E		NE14	151	G	C	2	1	3	1	8	+	+	1	100
		E		NEW42	149	G	C	2	1	3		1	+		+	100
		E		Tm19	140	G	C	2		6	1	2	1	+	+	100
		E		NE13	122	G	R	6		2	2	1	1	+	2	100
		E		Tm18	115	G	C	4		7	1	4	+	1	2	100
		E		NE12	99	G	C	+	1	10		3	1	1	1	100
		E		Tm17	95	G	A	+	+	2	2	3	+	+	+	100
		E		NE11	91	G	A	1		4	1	1	4	1	+	100
	5A	E		NE10	78	G	C	3		4	2		1	+	+	100
	Denticulopsis hyalina 4Bb	E		Tm14	75	G	A	1		6		1	3	+		100
		E		Tm9	66	G	A	1		4	1	3	3	+	+	100
		E		NE9	55	G	A	+		4	2	2	1	+	+	100
		E		NE7	32	G	A	1		4	3	2	6	+	3	100
		E		NE6	27	G	A	+	+	3	1	1	2	1	1	100
	4Ba	E		NE5	21	G	A	4	1	6	1	2	5		2	100
	Denticulopsis lauta 4A	E		NE3	9	G	A	4	2	14	5	2	9		3	100
		E		NE2	3	G	A	3	2	7	2	4	3		3	100
		E		NEW5	0	G	A	1	+	20	5	2	6		4	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

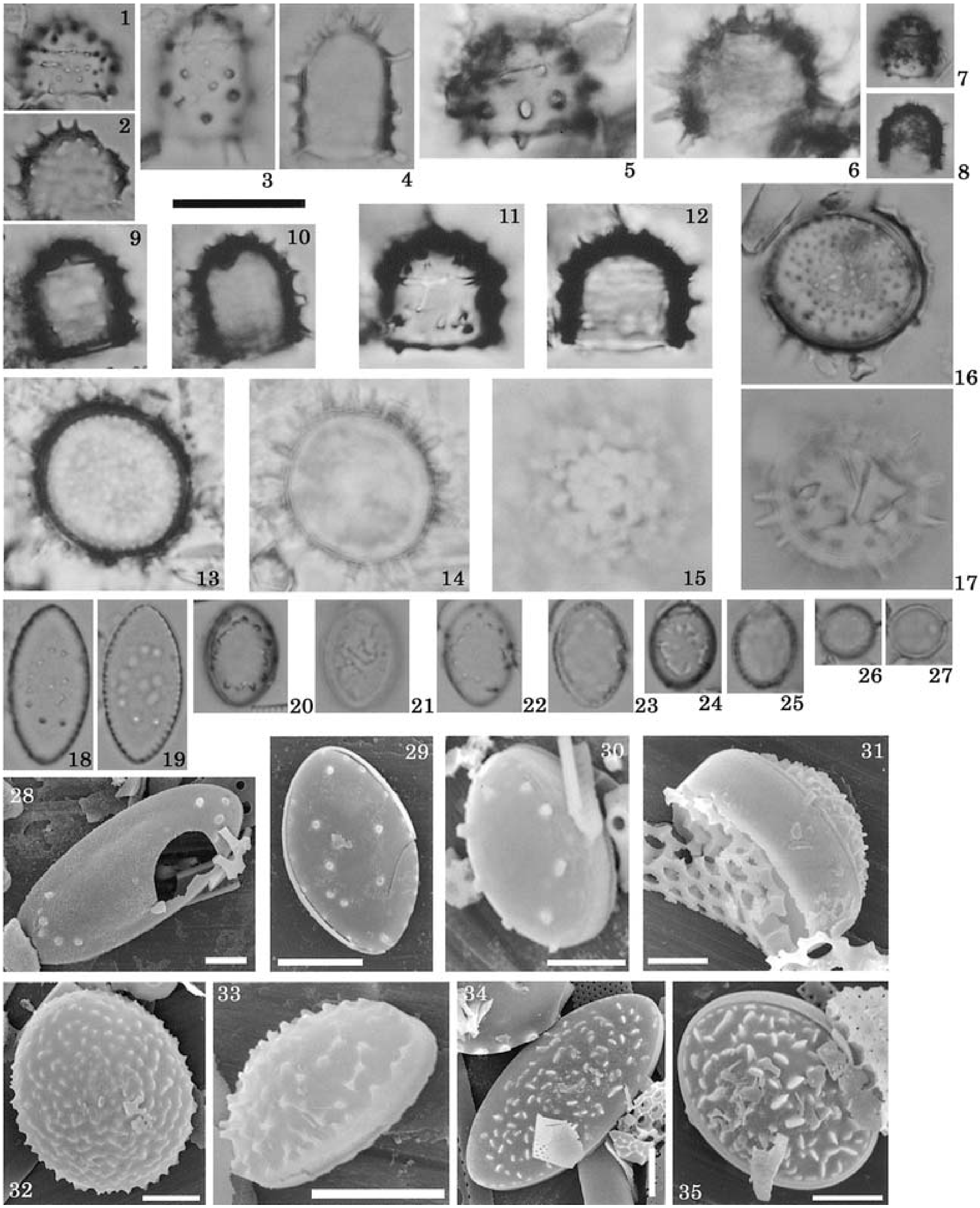
Description.—Frustule heterovalvate. Valve narrowly elliptical to lanceolate in valve view, apical axis 10.0–20.5 μm, transapical axis 5.5–7.5 μm. In girdle view, epivalve face vaulted, with numerous short strong spines and small knobs. Mantle of epivalve hyaline. Hypovalve vaulted or flat, with numerous 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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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.

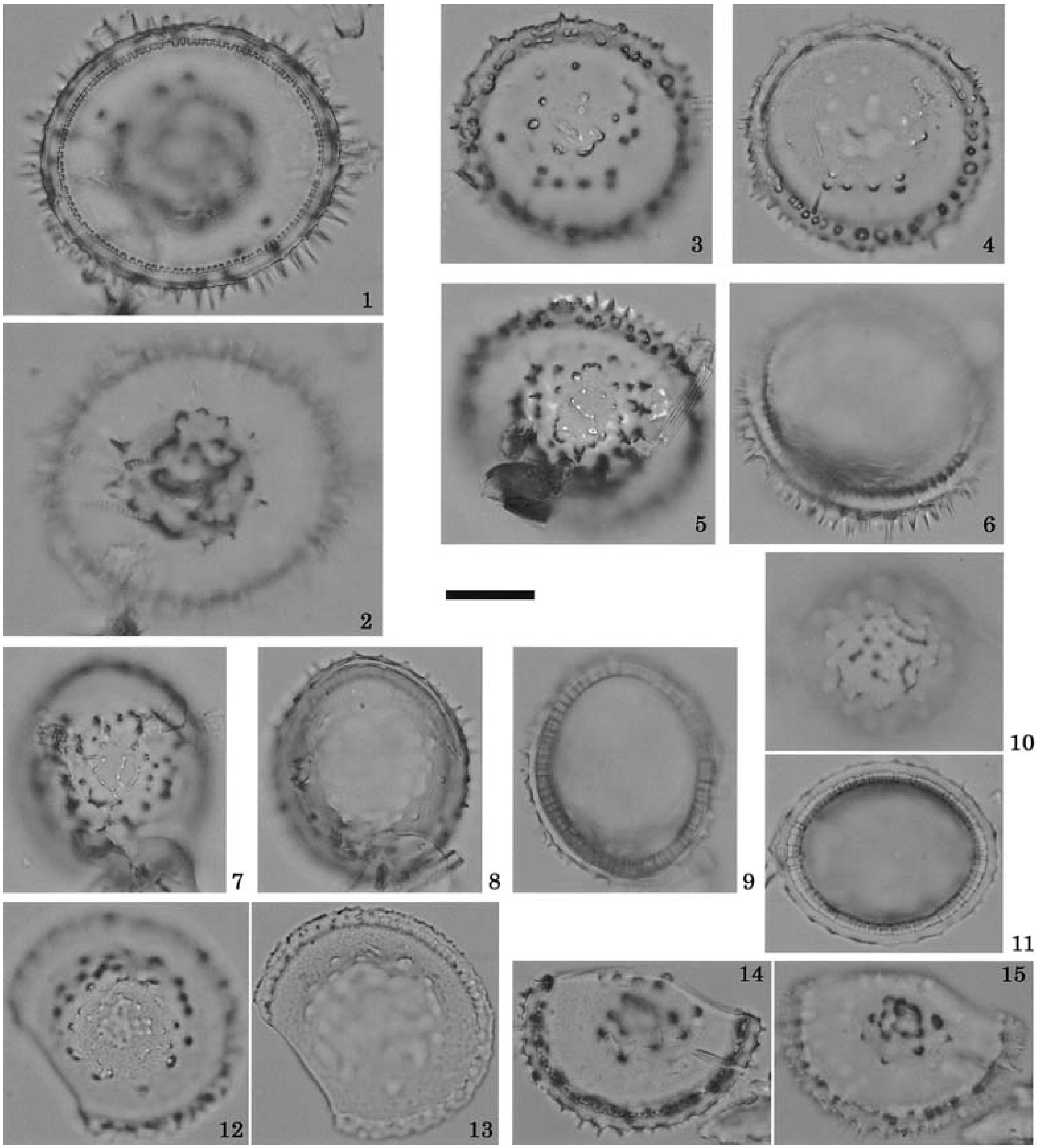


Figure 8. **1–15.** *Xanthiopyxis norwegica* Suto sp. nov. Scale bar = 10 μm for each figure (LM).

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

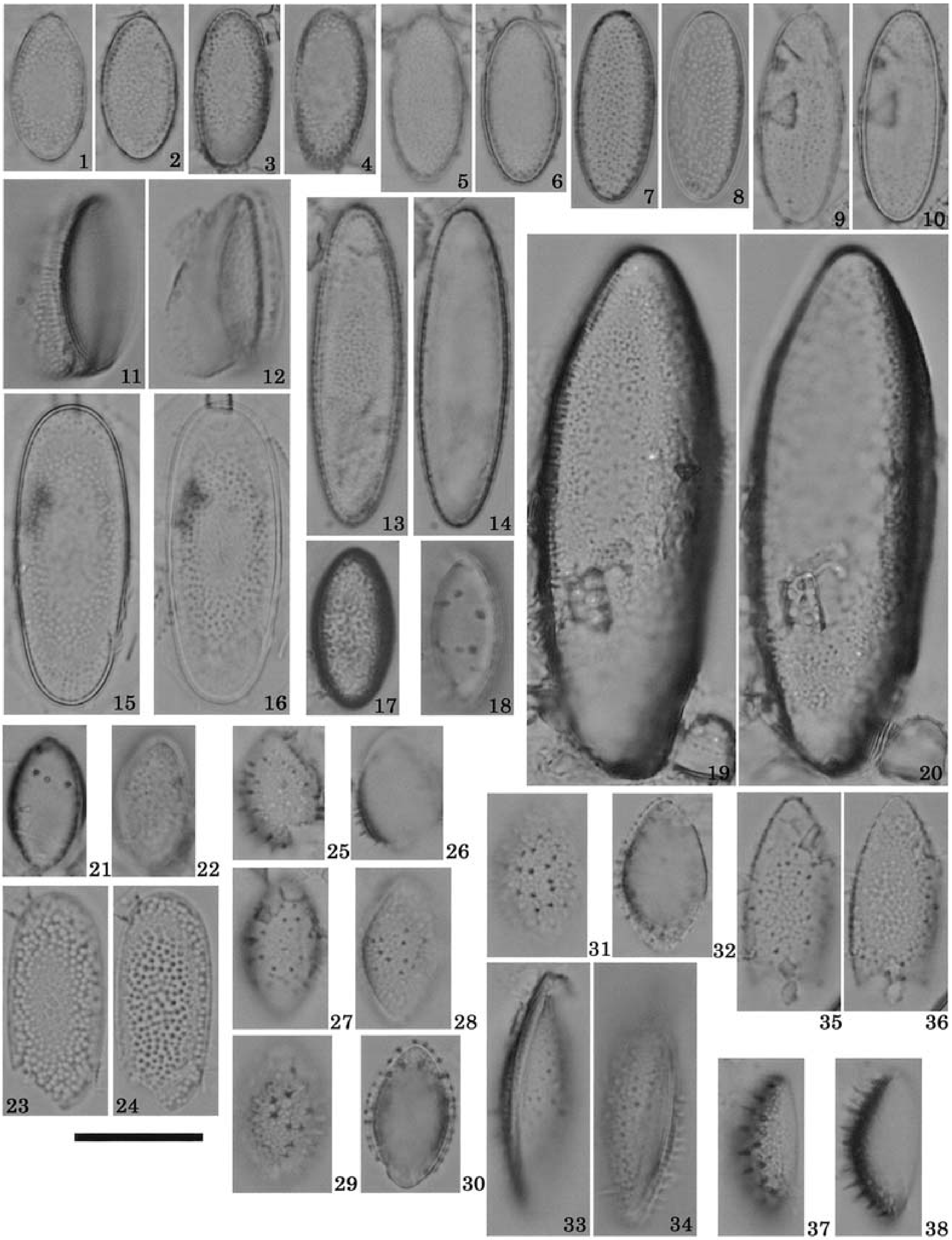
Xanthiopyxis hirsuta Hanna *et* Grant, 1926, p. 170, pl. 21, fig. 10; Fenner, 1978, p. 536, pl. 35, figs. 7, 8.

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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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 Schuette, 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.

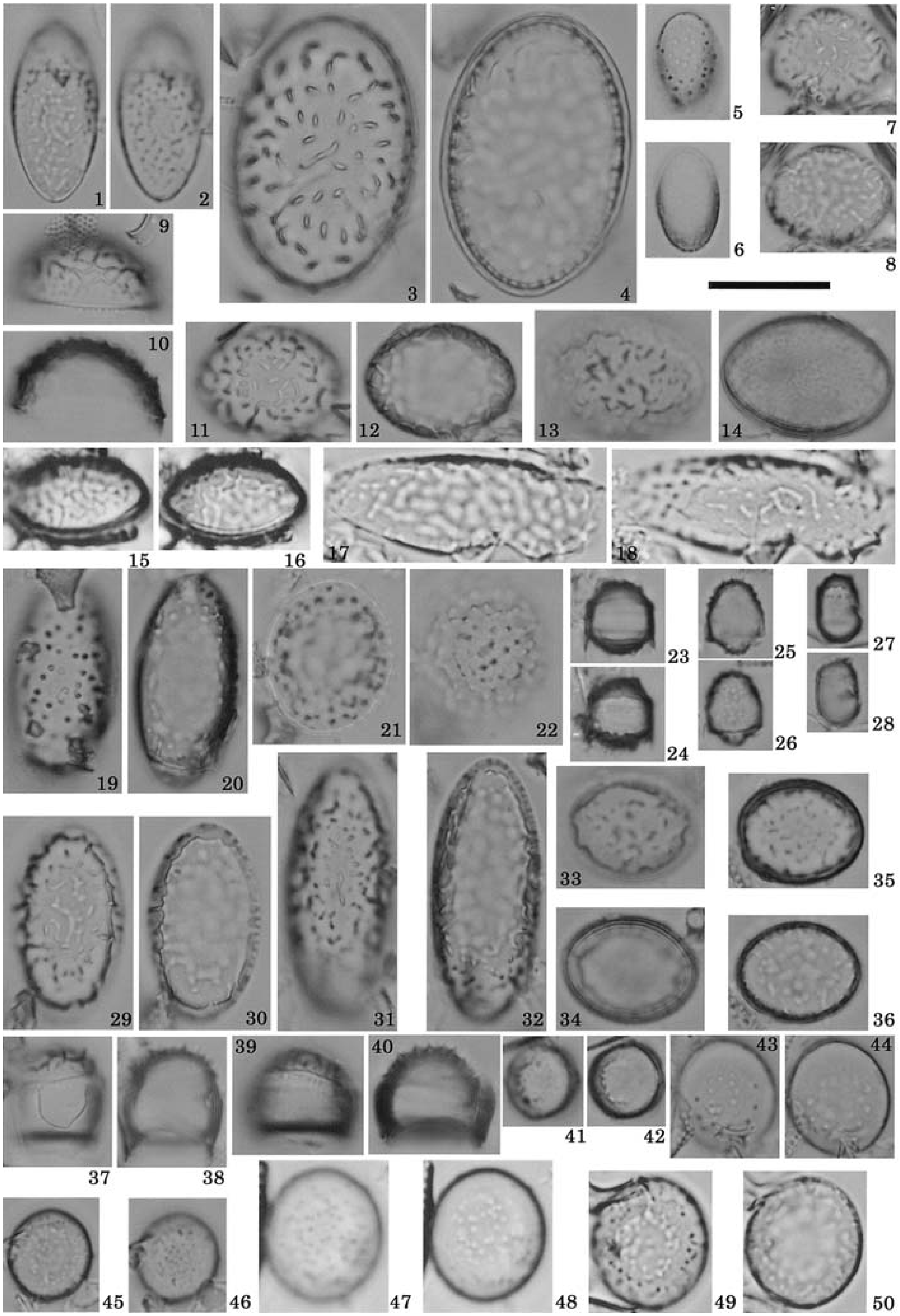
The synonymized species *X. acrolopha* was collected from the Miocene Marmorito Formation in

← **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.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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).

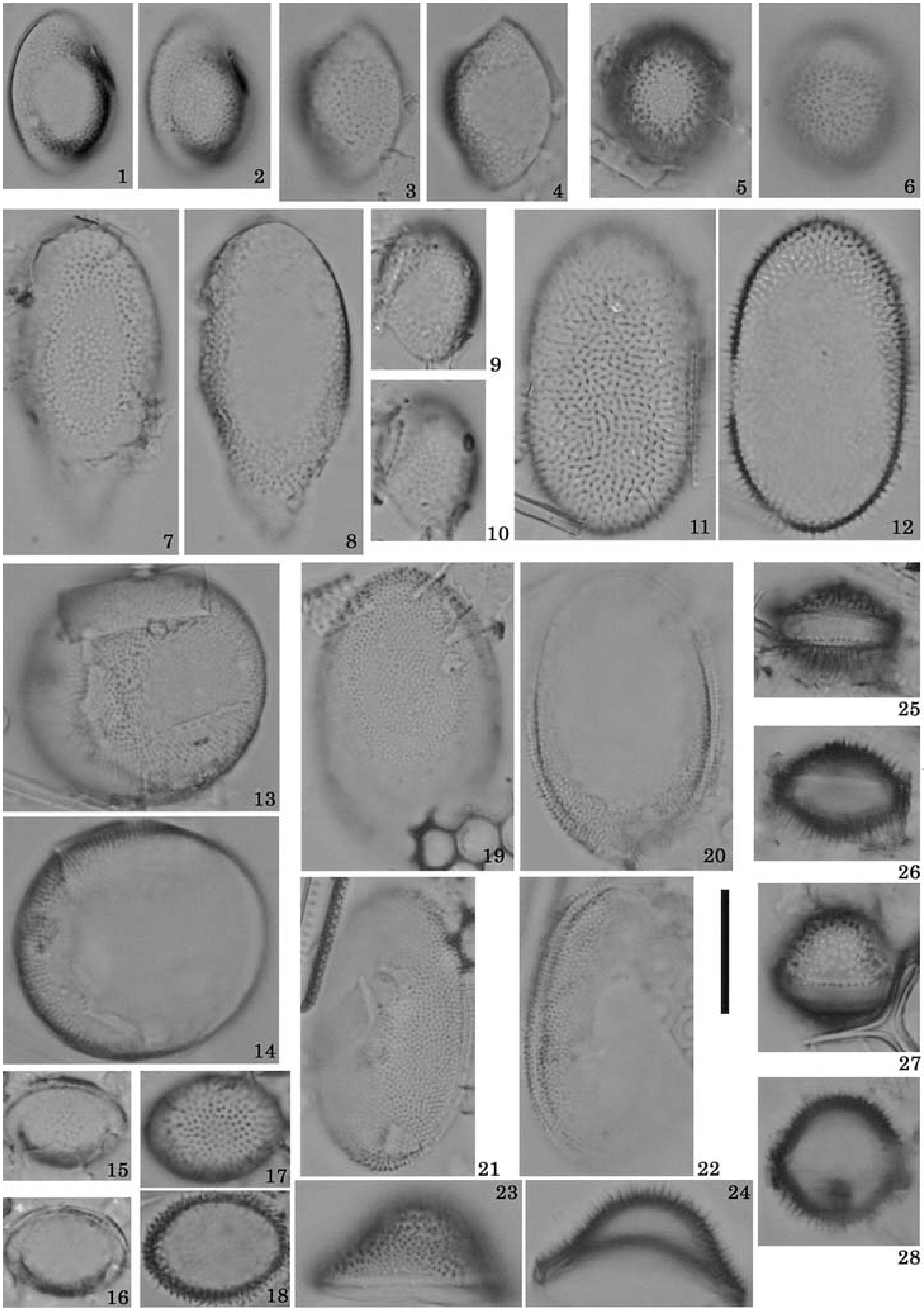
1, 2. Valve view of epivalve, DSDP Site 436-13-3, 100–102 cm. **3, 4.** Valve view of epivalve, DSDP Site 338-11-4, 70–71 cm. **5, 6.** Valve view of epivalve, DSDP Hole 438A-5-2, 96–100 cm. **7, 8.** Valve view of epivalve, DSDP Site 338-13-1, 148–149 cm. **9, 10.** Girdle view of epivalve, DSDP Site 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.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(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.

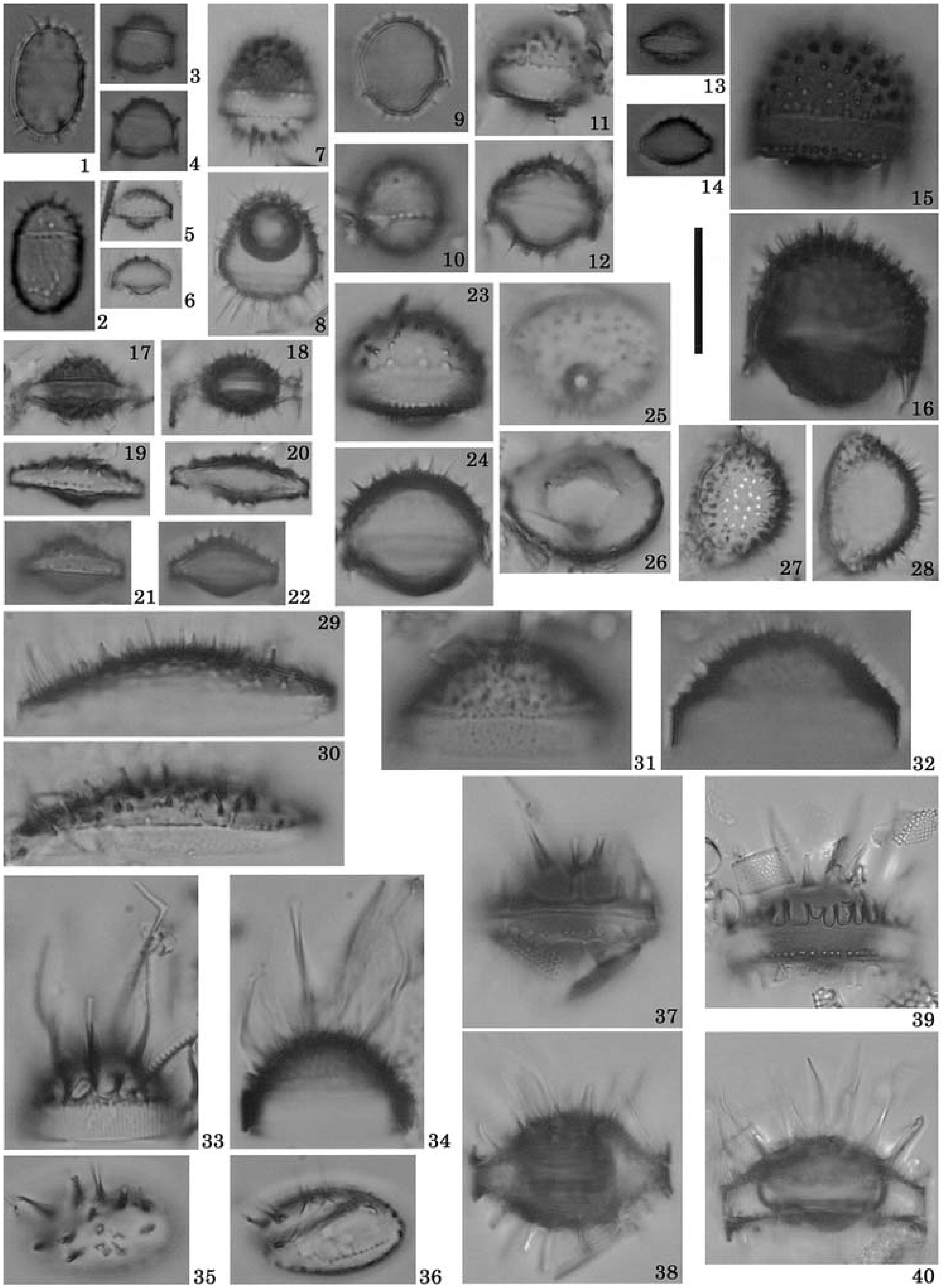
Xanthiopyxis type B (short spiny type)

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; *Chaetocerotype 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, WNBP13. **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.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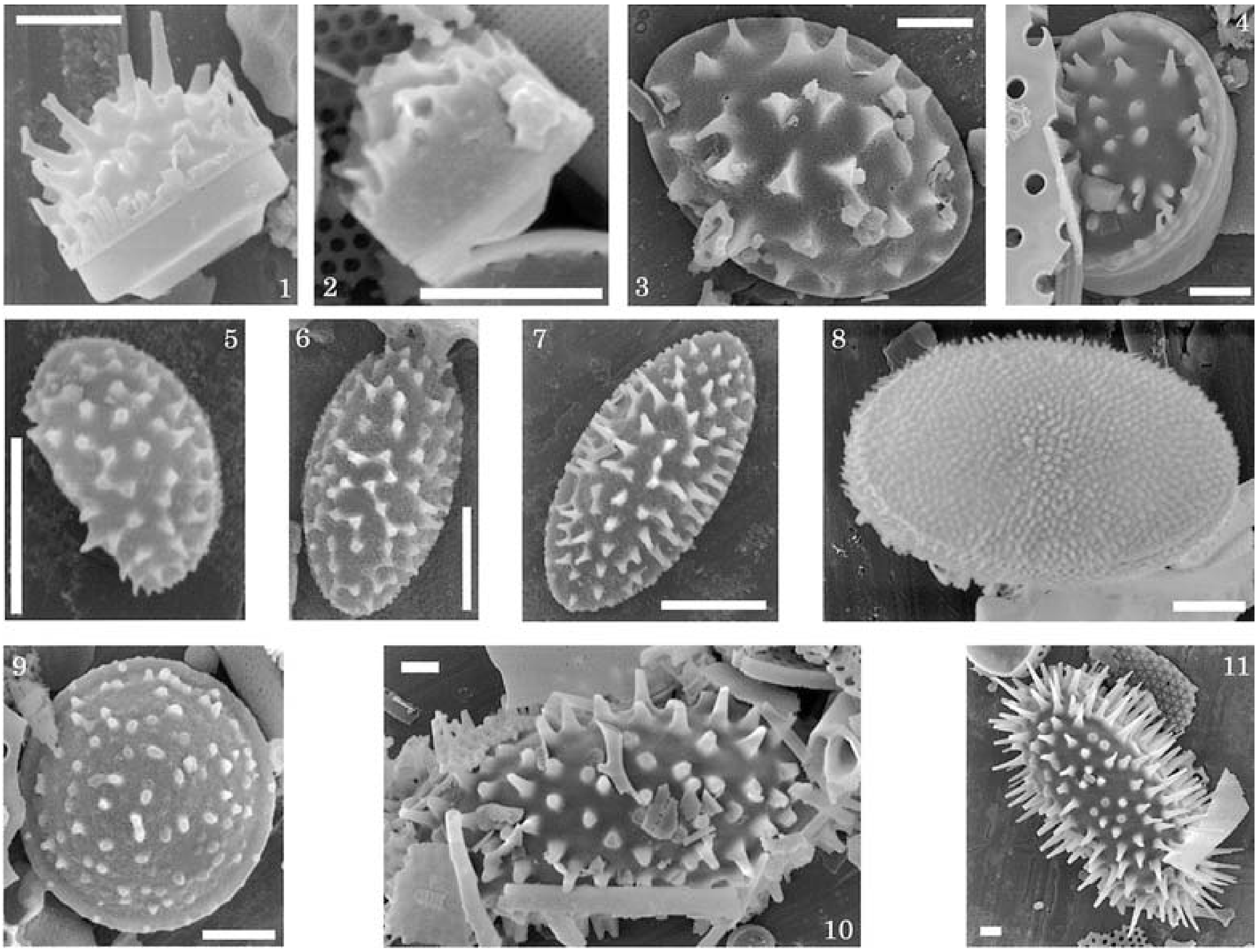


Figure 13. 1–7. *Xanthiopyxis* type B (short spiny type). Scale bar = 5 μm for each figure (SEM).

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).

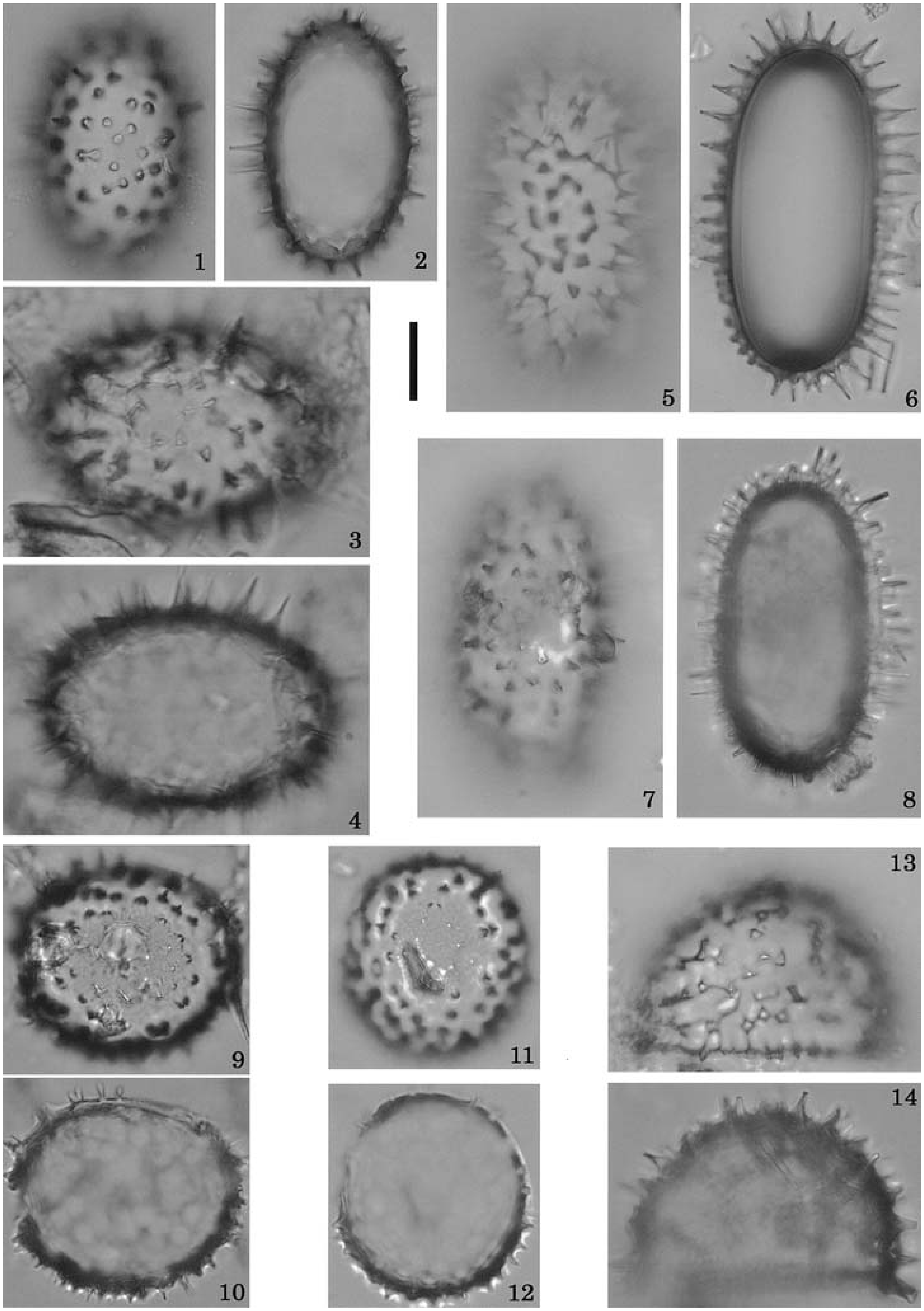
10. Girdle view of frustule, DSDP Site 338-18-1, 148–149 cm. **11.** Girdle view of frustule, DSDP Site 338-17-1, 100–101 cm.

← **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.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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 vanheurckii* 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.I1; 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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