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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. norwegica Suto, sp. nov., X. nov., X. teneropunctata 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

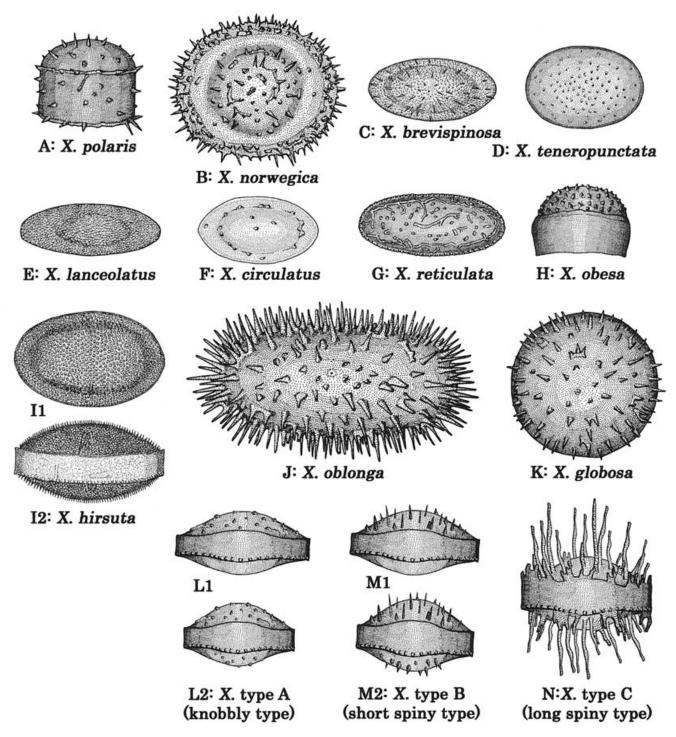


Figure 1. Sketches of valve and girdle view of *Xanthiopyxis* species (A, H, I2, L1, L2, M1, M2, N: girdle view; B, C, D, E, F, G, I1, J, K: valve view). All sketches were made using LM.

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

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

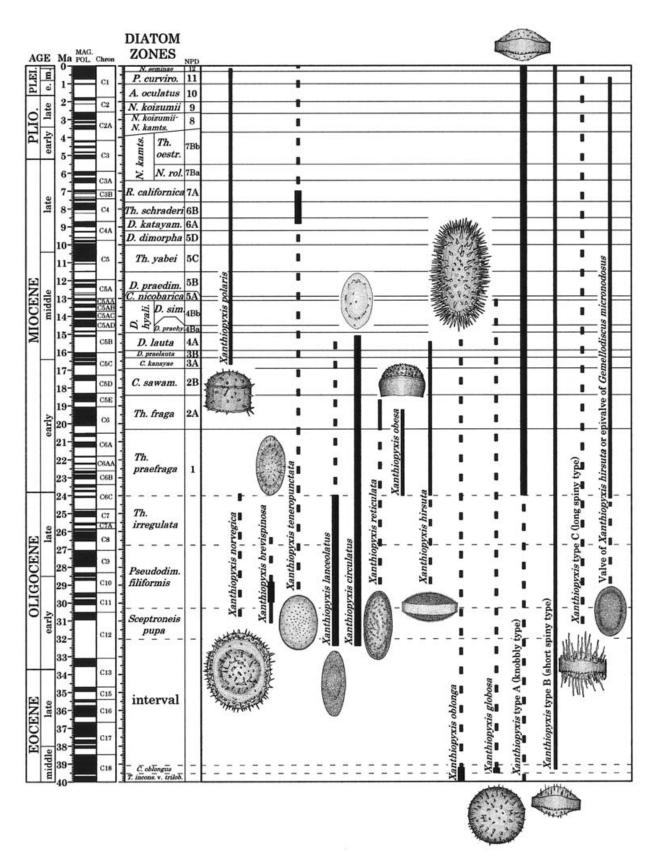


Figure 2. Stratigraphic ranges of *Xanthiopyxis* species. Diatom zones and NPD codes are after Yanagisawa and Akiba (1998) for the Miocene, Pliocene and Pleistocene, and after Schrader and Fenner (1976) for the Eocene and Oligocene.

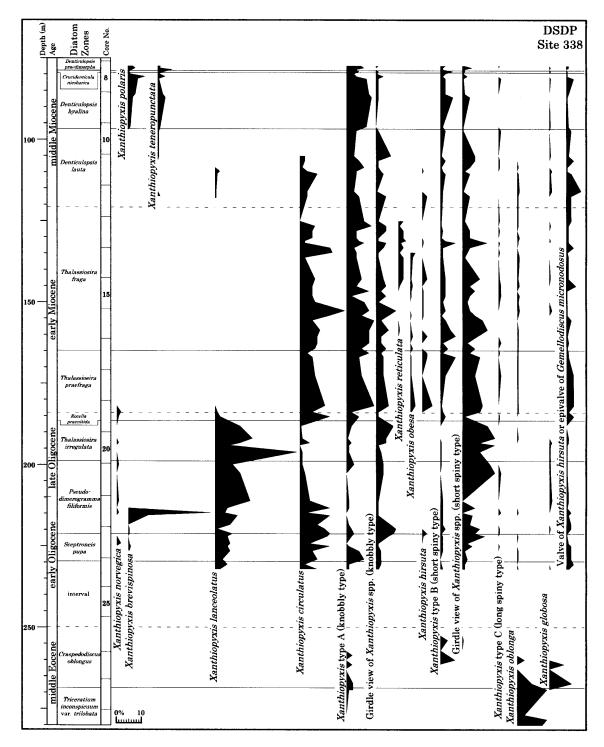


Figure 3. Stratigraphic occurrences of Xanthiopyxis species at DSDP Site 338. Diatom zones are after Schrader and Fenner (1976).

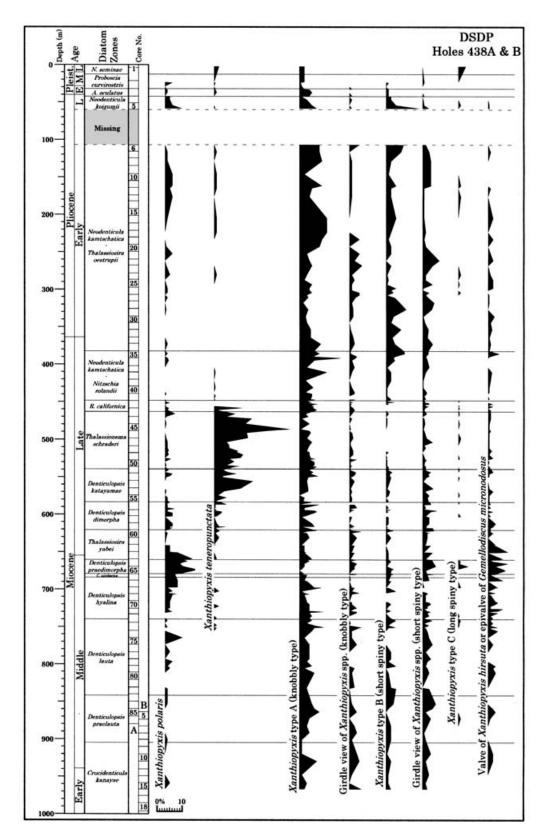


Figure 4. Stratigraphic occurrences of *Xanthiopyxis* species at DSDP Holes 438A and B. Diatom zones are after Yanagisawa and Akiba (1998).

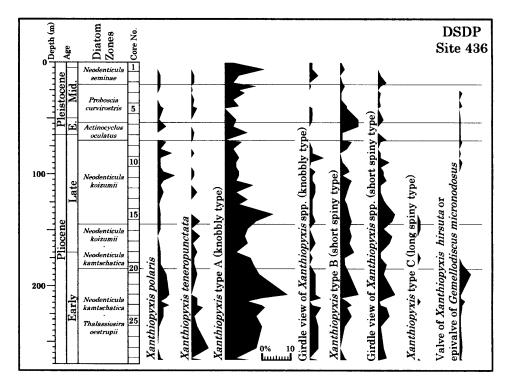


Figure 5. Stratigraphic occurrences of *Xanthiopyxis* species at DSDP Site 436 and in the Newport Beach Section. Diatom zones are after Yanagisawa and Akiba (1998).

6c.	Spines are strong and long
	X. type C (long spiny type)
6d.	Spines are bristly
	Valve oval to broadly elliptic
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 $21.0{\text -}34.5\,\mu\text{m}$, pervalvar axis $17.0{\text -}31.0\,\mu\text{m}$. 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.

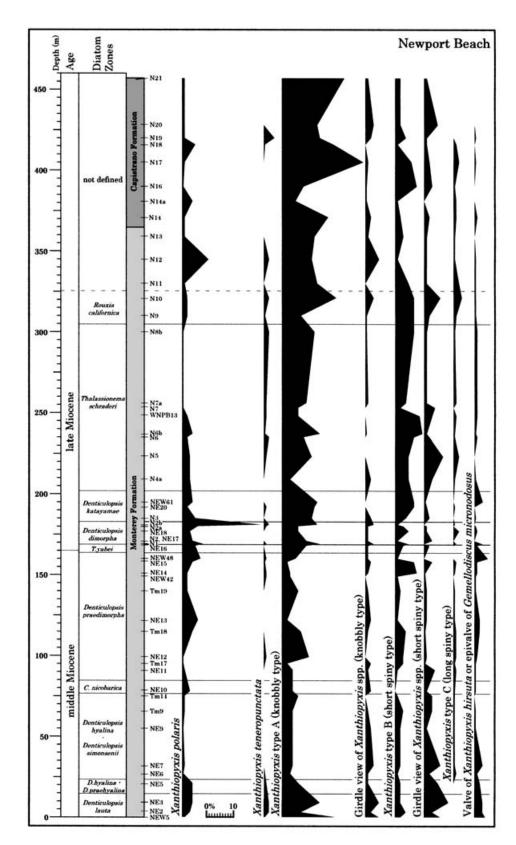


Figure 6. Stratigraphic occurrences of *Xanthiopyxis* species in the Newport Beach Section. Diatom zones are after Yanagisawa and Akiba (1998).

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).

			u Akiba (13	, u	iia c		111 20)11 C S	111		Ong				,0011	C 41				unu i	C1111		,1770	· ·
	Diatom zones	NPD	Core Section, Interval (cm) Leg 38 Site 338	Depth (m)	Preservation	→ Abundance	Xanthiopyxis polaris	X, norvegica	X. brevispinosa	X. teneropunctata	K, lanceolatus	K. circulatus	X. type A (knobbly type)	Girdle view of <i>Xanthiopyxis</i> 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
Н	Denticulopsis	5B	8-1, 140-141	77.40 77.98	G		2			1	<u> </u>		6	1				2	1	+			1	100
	praedimorpha		8-2, 48-49 8-2, 99-100	78.49	G G	A A	3 2			1 6			7 4					1 1	1			+	1	100 100
	C. nicobarica	5A	8-3, 10-11 8-3, 80-81	79.10 79.80	G	A	+			3			5 3	<u>1</u>				5 2	<u> 1</u>			+	+	100
middle Miocene	Denticulopsis hyalina	4B	8-4, 10-11 8-4, 80-81 9-1, 50-51 9-1, 148-149 10-1, 106-107	80.60 81.30 86.00 86.98 96.06	G G G	A A A A	7 4 3 2			3 + 2 3			4 8 9 10 8	3 1 1 1				1 2 2 5	2 + 1 3 +	1		+	+ 3 1 +	100 100 100 100 100
middl	Denticulopsis lauta	4A	10-2, 80-81 11-1, 50-51 11-2, 50-51 11-3, 98-99 11-4, 70-71 11-4, 148-149 12-2, 40-41 12-3, 38-39	97.30 105.00 106.50 108.48 109.70 110.48 115.90 117.38	G G G G G G	A C A A A				+ +	2 1 + +	2 2 1 3 7 3	4 3 5 7 4 4 3 5	1 6 1 1 2 3 +			+	2 + 2 + 1 2 1	+ 5 5 3 1 3 + 3	1 + +	+ + 1 +	+ 1 + 1	2 1 3 + 2 6 2	100 100 100 100 100 100 100 100
early Miocene	Thalassiosira fraga Thalassiosira praefraga	2A	13-1, 148-149 13-2, 148-149 13-3, 148-149 13-5, 70-71 13-6, 70-71 14-1, 20-21 14-2, 20-21 14-3, 20-21 14-3, 20-21 14-3, 20-21 15-3, 100-101 15-5, 100-101 15-5, 138-139 16-1, 10-11 16-3, 10-11 16-3, 10-11 16-5, 10-11 16-5, 10-11 16-5, 10-11 17-2, 119-120 17-3, 110-111 17-4, 79-80 18-1, 148-149	124.98 126.48 127.98 130.20 131.10 133.20 134.70 146.50 145.00 149.88 152.55 154.05 154.05 156.55 160.45 162.50 164.19	000000000000000000000000000000000000000	A A A A A A A A A A A A A A A A A A A				•		6 5 5 2 2 12 13 2 6 5 5 5 6 18 12 5 7 7 6 6 3 5 6 6 6 6 7 7 7 6 6 6 7 7 7 6 6 7 7 7 7	7 10 4 4 4 5 7 3 4 4 4 6 6 4 9 9 9 6 11 9 9 9 6 9 9 9 9 9 9 9 9 9 9	1 4 4 1 1 1 3 1 1 3 4 2 4 1 8 5 2 2 4 2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	2 + 2 2 3 1 2 + 2 2 + +	1 2 1 + + + + + + + 1 1 + + + + + + + +	2 + + + + + + 2 2 2 2 2	+ + 1 + 2 6 1 1 1 2 2 2 2 1 2 4 6 1 3 1 6 1 2 6 1 2 6 1 2 6 1 6 1 6 1 6 1 6 1	1 2 3 3 7 100 3 2 1 7 3 5 5 8 100 6 2 2 5 7 5	+ + + + + 1 1 1 + + 1	+ + + + + + + 1 + + 1 + + + + + + + + +	+ + +	2 1 1 1 1 3 + 1 1 4 + + + + 2 1 1 1 1 3	100 100 100 100 100 100 100 100 100 100
			19-1, 130-131 19-3, 20-21	181.80 183.70	G	A A		1			1	10 5	11 2	5 1		2+	4	+ 1	8 7		+		3 1	100 100
Oligocene	R. praenitida Thalassiosira irregulata		19-4, 10-11 19-5, 148-149 20-2, 30-31 20-3, 20-21 20-3, 90-91 20-4, 148-149	185.10 187.98 191.80 193.20 193.90 195.98	G G G G G	A A C C A		1	-		10 15 10 6 33	12 + 1 4	5 2 + 2 1 1	1 7 4 4 1 2				+ + +	10 13 7 13 7	+	+	1 + +	3 1 1 + +	100 100 100 100 100 100
late	Pseudodimero- gramma filiformis		21-1, 32-33 21-2, 148-149 22-2, 10-11 22-3, 80-81 22-4, 79-80 22-5, 10-11	199.82 202.48 211.00 213.20 214.69 215.50	000000	A R C R		+ + +	34 8		7 10 14 5 4	1 2 4 12 3 12	3 1 1	3 1 1 1 1				+ 1 1 1	11 13 5	1	+	+ + 1 +	+ + 1 + 2 1	100 100 100 100 100 100
cene			22-6, 148-149 23-1, 80-81 23-2, 80-81	218.38 219.60 221.10	G G	C C A			+		6 1 7	7 10 12	1 2 3	6 8 7			,	1 2 +	3 7 5	+		+	2 2 +	100 100 100
early Oligoce	Sceptroneis pupa		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	99999	C C C A R		1	+ 1 +		5 6 5 6 3	11 4 12 5 7	2 1 5 7	5 1 1 2 2			+	1 1 1 1	9 2 4 1 2	+	+ + +		+ 1 2 2 2	100 100 100 100 100
	interval		24-2, 100-101 24-3, 100-101	230.50 232.00	G G	C R					5 2	2 7 bar	1 1 ren ur	2 1 til:				+	1		+	+	3	100 100
middle Eocene	Craspedodiscus oblongus		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	000000	R R R R R R R							1 1	ba	urren			1 1 2	+		1	2		30 30 100 30 30 30 30 30 30
-	Triceratium		28.2, 148.149	268.98	G	R							1								4			30
	inconspicuum var. trilobata		29-1, 130-131 29-2, 120-121 29-3, 148-149	276.80 278.20 279.98	G G	R R R															1 4 1			30 30 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).

	Diatom Zones (NPD)	Core Section, Interval (cm) Leg 57 Site 438	Depth (m)	OPreservation	> Abundance	Xanthiopyxis polaris	X. teneropunctata	X. type A (knobbly type)	(knobbly type)	X. type B (short spiny type) Girdle view of Xanthiopyxis spp.	:	Valve of X. hirsuta or	epivalve of G. micronod	I lotal number of resting spore		Diatom Zones (NPD)	Core Section, Interval (cm) Leg 57 Site 438	Depth (m)	OPreservation	> Abundance	Xanthiopyxis polaris	≅ X. teneropunctata	A. type A. (knobby type) Girdle view of Xanthiopyxis spp.	(knobbly type) X. type B	short s Girdle	(short spiny type) X type C	Valve of X. hirsuta or epivalve of G. micronodosus	, š
	Proboscia	2-1. 10-14 2-1. 96-98 2-5. 5-9 3-1. 31-33 3-3. 140-142 3-4. 10-14	23.12 23.97 29.07 32.82 32.91 37.12	G G G G	A A A A A	3 + 1 1	+ + + 1	2 + 1 2 4 5	1		1			100 100 100 100 100 100		Denticulopsis katayamae (NPD 6A)	54-1, 110-114 54-4, 125-127 55-1, 70-74 55-3, 70-74 55-6, 76-78 56-1, 20-24	565.62 569.26 574.72 577.72 582.27 583.72	G G G G	A A A A A	1 2 2 4	21 8 3 10 1 5	7 1 7 2 1 4 2 3 2 11			1	1 4 1 1 1	200 200 200 200 200 200 200 200
	Neodenticula koizumii (NPD 9)	3ee 4·1. 40·74 4·4. 8·12 5·2. 96·100 5ee 6·1. 18·22	41.65 42.72 46.6 53.98 58.5 106.7	9 9 9 9 9	A A A A	2 2 3 7	+	5 7 8	1 1 4	4 14 7	1 + 1 1 4 2		÷	100 100 100 100 100		Denticulopsis	56·3, 20·24 56·3, 60·62 56·6, 20·24 56·6 57·1, 115·117 57·2, 31·35	586.72 587.11 591.22 592.63 594.16 594.83	9 9 9 9 9 9	A A A A	+ 1 1 4 1	5 + + 1	0 8 2 2 3 2 2 2 6 1		1 2 5 9	! !	1 1 + 0	100 100 100 100 100 100
		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	116.21 128.82 146.17 161.72 164.89 176.21 204.88 223.62 233.12	000000000	A A A A A A	1 3 3 2 3 1	1 1 1 1	8 9 2 9 5 4 11 11 9	1 1 1 1 1	2 1 4 2 2 4 2	4 5 5 1 1 1 1 2		1 2	100 100 100 100 100 100 100 100		dimorpha (NPD 5D)	57-3, 31-35 57-4, 59-61 58-1, 16-20 58-1, 101-103 59-1, 17-21 59-3, 135-137 59-4, 17-21 59-5, 5-6 59-5, 17-21	596.33 598.1 602.68 603.52 612.19 616.36 616.69 618.06 618.19	G G G	A A A A A A	1 3 3 3 2 2 2	3 3 1 1 2 5 1 +	7 4 6 2 1 5 6 2 1 3 2 3		4	1 2 1 1 1 2 3	1 3 2 2 1	100 100 100 100 100 100 100 100 100
	Neodenticula kantschatica (NPD 7B-8)	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°33 26°4. 10°14 26°6. 15°19 27°2. 20°24 20°24 22°24 22°24 22°24 22°24 22°24 22°24 22°24 22°24 22°24 22°24 22°24 22°24 22°24	242.78 252.22 261.72 268.12 280.61 287.37 298.31 301.12 304.17 307.72 310.72	0000000	A A A A A A A A A	+ 3 + 2 + 1 1 1 2	1 +	8 3 4 5 3 2 5 4 4 4 5 3	4 2 5 1 2 1 1 4 4 5 2	2 2 1 2 + 1 + 4 2 3 + 7	2 6 6 10 6 2 1 2 4 + + 4 1 2 7		1 2 1 2 2 2 2 2 +	100 100 100 100 100 100 100 100 100 100		Thalassiosira yabei (NPD 5C)	60·1, 34·38 60·1, 134·136 60·3, 26·27 60·3, 26·27 60·3, 27·29 61cc 62·1, 80·81 62·1, 110·112 63·1, 16·20 63·1, 88·89 63·1, 110·114 64·1, 12·128	621.86 622.85 624.77 624.78 631.08 640.72 641.31 641.61 650.18 650.89	6 6 6 6 6 6 6 6	A A A A A A A A A A	+ 1 1 + 2 2 5 5 11 7	2 2 + + 2 1	7 1 3 5 1 3 4 3 1 1 1 2 2 2 1 3 2 2 5 3 3 3 3	3 2	3 7 1 1	3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	1 1 2 2 3 1 3 8 4	100 100 100 100 100 100 100 100 100 100
438A		29-2, 20-24 30-2, 20-24 31-1, 20-24 32-1, 24-28 33-1, 120-124 34-1, 22-24 35-3, 24-28 35-6, 24-28	326.72 336.22 344.22 353.76 364.22 372.73 382.26 385.86 389.76	000000000	A A A A A A A	2 2		7 5 6 9 9 17 12 16 11	3 3 1 3 4 1 1 6	16 1 6 4 12 5 7 1 14 15 7	11 3 7 6 12 7 7		5 2 3 1 2 1 9	200 200 200 200 200 200 200 200 200	DSDP Hole 438A	Denticulopsis praedimorpha (NPD 58) C. nicobarica (5A)	64·3. 10·14 64·5. 30·32 65·1, 54·56 65·3, 100·103 65·5, 18·21 66·1, 118·122 66·2, 25·27 66·2, 34·36 66·2, 82·84	662.62 665.81 669.55 673.02 675.2 679.7 680.26 680.35	G G G G G G G	A A A A A A A	9 6 7 12 12 6 3 5		4 + 2 2 2 2 1 2 4 3 2 3 3	3 2 3		+ + 3 4 4 4 4 5 5 5 5 5 7 5 5 5 5 7 5 5 5 5 5	2 8 3 6 7 3 3	100 100 100 100 100 100 100 100
DSDP Hole 438/		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 41-1	391.84 394.84 404.12 410.63 421.63 431.22 437.12 439.47 442.32 446.62 447.13	G G G	A A A A A A A	2 3	1 1 1	34 12 6 22 5 11 5 10 10 9	5 2 4 2 2 4 4	7 1 4 4 4 1 1 1 1 1 1 4	5 6 8 4 1 1 5 5 5 2 4 3		3 2 1 1	200 200 200 200 200 200 200 200 200 200		Denticulopsis hyalina (NPD 4B)	67-1, 27-32 67-1, 112-113 68-1, 30-34 68-1, 101-103 68-4, 68-72 68-6, 105-108 68-7, 24-26 69cc 70-1, 16-20 70-1, 78-81 70-3, 49-53	688.3 689.13 697.82 698.02 702.7 705.07 706.75 707.13 716.68 717.3 720.01	G G G G G G	A A A A A A A A	5 5 5 1 3 1 5 3 2 2 2	2	2 3 6 1 9 5 1 1 2 4 4 1 2 1 3 3 4 1 1 4 1 1	1	1 4 2 1 1 4 2 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	1 1 3 3 2 2 2	6 4 3 3 1 3 4 3	100 100 100 100 100 100 100 100 100 100
	Rouxia californica (NPD 7A)	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	448.66 449.41 450.96 451.66 453.52 453.74 455.51 456.18 458.61	6 6 6 6 6 6 6 6 6	A A A A A A	1 2 4	23	9	3 2 1 1 1 3	7 1 2	1 3 1 3 7 8 8 3 4 1 7		1 4 2	200 200 200 200 200 200 200 200 200 200			70-5, 23-27 70-7, 5-7 71-1, 12-16 71-3, 7-11 71-3, 114-116 71-5, 8-12 72-1, 14-18 72-3, 15-17 72-5, 11-13	722.75 725.56 726.14 729.09 730.15 731.6 735.66 738.66	G G G G G	A A A A A A	2 2 1 2 3	2	4 4 4 4 4 4 4 5 4 5 5 4 5 5	3 3 3 3	2 3 1 5 3 1 4 2 1 4 6	3 1 3 5 3 4 + 1	1 1 6 4 1 2	100 100 100 100 100 100 100 100
	Thalassionema schraderi (NPD 6B)	43:3, 30:34 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, 30:30 48:7, 30:31 49:3, 10:14	461.32 466.34 470.12 472.62 479.56 486.82 488.7 491.7 498.12 503.62 507.66 510.98 516.81 520.12	000000000	A A A A A A A A A A	2 8 1 1 2 2 2 3 2 3	2 19 10 30 25 61 43 26 27 10 12 12 19 18 23	5 7 2 8 1 8 9 6 10 8 7 6 8 8	2 2 1 2 3 1 1 2 3 3 3	2 1 1 2	2 5 1 2 3 1 1 2 3 5 2 112 1 2 4 1 1		2 2 1 1 2 1 1 1 1 1 3 2	200 200 200 200 200 200 200 200 200 200		Denticulopsis Isuts (NPD 4A)	73-1, 27-31 73-3, 27-31 73-5, 9-11 73-5, 46-48 74-1, 124-126 75-1, 70-71 76-1, 32-34 77-1, 81-83 78-1, 54-56 78-3, 92-94 79-1, 51-54 79-3, 55-57 80-1, 20-22 82-1, 73-75 82-2, 73-75	745.29 748.29 751.1 751.47 755.75 764.71 773.83 783.82 793.05 796.43 802.53 805.56 811.71 831.24 832.74	66666666666	A A A A A A A A A	7 2 3 1 2	1	3 6 10 8 5 5 2 4 4 4 4 3 3 5 5 2 6 6 3 3 3	5 4 1 1 1 3 3	2 2 5 2 5 1 8 4 2	+ + 1	2 1 4 + 4 2 2 3	100 100 100 100 100 100 100 100 100 100
		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	524.62 526.11 526.72 529.72 534.22 535.61 536.18	000000	A A A A A	5 4 1 1	21 12 13 16 10 21	9 13 8 12 12 10 14	2 6 1 1 2	1 1 1 1 1 2	3 1 3 1 5 3 2 4 4		1 1 1	200 200 200 200 200 200 200 200	ole 438B	Denticulopsis praelauta (NPD 3B)	84-3, 63-65 85-1, 48-50 85-4, 25-27 6-1, 16-19 7-1, 128-130 8-1, 90-92 9-1, 85-87	853.14 859.49 863.76 872.28 882.79 891.81 901.16	999999	A A A A A	1		5 6 8 4 3 4	1 2 3 2 3 1	3 8 1 6 1 5 2 3 2 1 2 5	3 2 5 1 3 1 2	2 3 1	100 100 100 100 100 100 100
	Denticulopsis katayamae (NPD 6A)	51-4, 16-20 51-6, 16-20 52-1, 36-38 52-3, 36-38 52-4, 36-38	540.68 543.68 545.87 548.87 550.37	G G	A A A A	3 6 4 1	7 11 18 7 7	8 11 9 15 7	1 5 5 3	5 3 3	4 1 10 7 8 5 1		1 1	200 200 200 200 200 200	DSDP Hole	Crucidenticula kanayae (NPD 3A)	11-1, 60-62 12-1, 81-82 14cc 15-2, 61-62 16-1, 82-84	919.81 929.52 947.6 959.02 967.13	G G	A A A A	2		1 7 1 1 3 3 2 4	1	2 2 1 4 1 2	5 2 4 2 3	2 2	100 100 100 100 100

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)	O Preservation	⊅ Abundance	Xanthiopyxis polaris	X. teneropunctata	X. type A (knobbly type)	Girdle view of Xanthiopyxis spp. (knobbly type)	(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
1 5	Neodenticula	1-1, 49-50		G										
Pleisto	seminae	1.5, 50.52	6.40	G	C R	١.		14	1 3	2				100
1 -	12	2-3, 100-102 3-1, 102-104	12.00 18.52	G	R	1	1	5 3	3	1	1			100 100
		3-3, 100-102	21.50	Ğ	C	1		11	+	2	- i -			100
5		3-6. 10-12	25.10	Ğ	Ř	+	+	5		ī	•		i :	100
اقا	Proboscia	4-1, 50-52	27.50	G	R			7		+	1		1	100
1.8	curvirostris	4.5, 50.52	33.50	G	c	i	1	3		+	+		Ι.	100
=	11	5-2, 148-150	39.48	G	Α	1	+	5		3	1		1	100
mid. Pleistocene		5-4, 22-24	41.12	G	R	2	2		1	3				100
		6-4, 100-102	51.50	G	<u>c</u>	+		4	1	8	2		+	100
Plei.	Actinocyclus	7-2, 54-56	57.54	G	R	3		3		8			+	100
	oculatus 10	7-6, 50-52	63.00	G	C	1	1	8		1			+ .	100
اف		8-3, 148, 150 8-5, 18-20	69.48 71.18	G	-A	3	+	+		5	3		+	100
1 1		9-2, 148-150	77.48	G	A	1		3	1	3	1		'	100
1		9-5, 95-97	81.35	Ğ	Ř	5	1	4	i	o o	1		+	100
1 1		10-1, 148-150	85.48	Ğ	A	ĭ	•	5	5	+	î			100
1 1		10-4, 98-100	89.48	Ğ	R	l i		4	+	1	4		1	100
1 1		11-1, 50-52	94.00	G	R	1		4		3	1		+	100
1 1	Neodenticula	11.3, 148.150	97.88	G	Α	2	1	5	2	4	2			100
1	koizumii	11-6, 100-102	101.40	G	С	6	1	5	1	1	2		1	100
1 8	9	12-2, 148-150	105.98	G	С	2		4	1	5	3		1	100
8		12-5, 98-100	109.98	G	С	1		10	2	4	1		[100
ate Pliocene		13-3, 100-102	116.50	G	c	2	2	4	2	3	1		1	100
18		14-1, 100-102	123.00	G	C	1		8	1	2	2		1	100
12		14-4, 48-50	126.98	G	C	†		5 17	1	3	3		i	100
1		15·3, 141·143 16·1, 130·132	135.91 142.30	GG	c	1	3	11	1 2	4 5	6 5	1	1	100 100
1 1	Neodenticula	16-6, 47-49	148.87	G	Ř	i i	<u> </u>	- 11		4	2	1	 	100
1 1	koizumii -	17-4, 50-52	155.50	Ğ	č	1 ^	3	7	1	5	5	•	l	100
		18-2, 45-47	161.95	Ğ	Ã	+	+	8	2	4	4		l	100
	Neodenticula	19-1, 50-52	170.00	G	C	1	2	4		6	1		l	100
1 1	kamtschatica 8	19-4, 148-150	174.98	G	С	1	1	9	1	2	1	1	l	100
\vdash	8	20-2, 38-40	180.88	G	c	1	1	10		2	3		1	100
1 1		21-1, 110-112	189.60	G	Ċ.	3	2	12	2	4	2		4	100
1 1	l	23·1, 48·50 23·3, 48·50	207.98 210.98	G	A	4 3	2	22 13	2	8	6		+	100
1 8	Neodenticula	23-5, 50-52	214.00	G	C	1	2	8	4	3	+	1	2	100
early Pliocene	kamtschatica	24-1, 50-52	217.50	Ğ	R	4	2	13	1	5	ĭ	1	lí	100
#		24-2, 110-112	219.30	Ğ	R	2	4	14	4	3	3		l î	100
اھ ا	Thalassiosira	25.1. 70.72	227.20	Ğ	R	2	î	11	2	5	4		+	100
<u>F</u>	oestrupii	26-1, 60-62	236.47	G	c	+	2	13	3	2	1		+	100
"	7Вь	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 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 μm, transapical axis 5.5–7.5 μm. 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).

Distom zones & NPD not defined R. californics 7A Thalassiosira schraderi 6B Denticulopsis	W W W W W W W W W W W W W	Capistrano Fm.	Sample number N21 N20 N19 N18 N16 N14a N13 N13 N12 IN11	Depth (m) 457 428 420 416 405 380 381 371 359	O O O O W W Preservation	O V O W WAbundance	O Xanthiopyxis polaris	X. teneropunctata	T E E (knobbly type)	ο ω Girdle view of Xanthiopyxis spp. (knobbly type)	A to to (short spiny type)	Girdle view of Xanthiopyxis spp. (short spiny type)	X. type C (long spiny type)	Valve of X. hirauta or epivalve of G. micronodosus	SSS valves counted		
R. californics 7A Thalassiosira schraderi 688	W W W W W W W W	Capistrano Fm.	N20 N19 N18 N17 N16 N14a N14 N13	428 420 416 405 390 381 371	M G G G	R R C	1 1 1 5		23 13 14	1 3	2 2 4	1 5			100		
R. californics 7A Thalassiosira schraderi 688	W W W W W W W W	Capistrano Fm.	N20 N19 N18 N17 N16 N14a N14 N13	420 416 405 390 381 371	M G G G	R C A	1 1 5	4	13 14	3	2 4			+			
R. californics 7A Thalassiosira schraderi 688	W W W W W W W	Capistrano F	N18 N17 N16 N14a N14 N13 N12	416 405 390 381 371	G G G	Α	5	4		2		1		+	100		
R. californics 7A Thalassiosira schraderi 68	W W W W W W W	Capistrano	N17 N16 N14a N14 N13 N12	405 390 381 371	G G										100		
R. californics 7A Thalassiosira schraderi 68	W W W W W W	Capistra	N16 N14a N14 N13 N12	390 381 371	G	C		•	19		1	ı	1	1 -	100		
R. californics 7A Thalassiosira schraderi 68	W W W W W	Capie	N14a N14 N13 N12	381 371			1		30	1	6	2	2	+	100		
Thalassiosira schraderi	W W W W W	Ü	N14 N13 N12	371		A	+		8	+	8	3	+		100		
Thalassiosira schraderi	W W W W W		N13 N12		G	С	4		5	+	1		1		100		
Thalassiosira schraderi	W W W W		N12	359	G	C	1		17	2	2	2	1	1	100		
Thalassiosira schraderi	W W W				G	Α	1		12	1	3	1	+		100		
Thalassiosira schraderi	W W W		NII	345	G	R	10	2	11	5	1	1	+	+	100		
Thalassiosira schraderi	w w w			330	G	Α	1		13		5	ı	2	+	100		
Thalassiosira schraderi 6R	w	1	N10	321	G	A	2	2	20	3	7	6	3	+	100		
schraderi 6R	w		N9	310	G	Α	2	+	7	+	7	2	1	+	100		
schraderi 6R		i	N8b	300	G	C.	+	2	12	+	7	1	+	1	100		
schraderi 6R			N7a	256	G	C	+	1	9	1	4	1	1	1	100		
schraderi 6R	w		N7	253	G	R	+	1	6		2	4		1	100		
6B	w		WNPB13	248	G	Α	2	1	6		9	3	1	1	100		
[]	w	}			N6ъ	237	G	Α	4	+	14	+	10	1	+	+	100
	w			N6	235	G	C	2	2	8		7	2	+	1	100	
181	W	1	N5	223	G	R	3	1	11		5	7	2		100		
 	W	1	N4a	209	M	R	3		3	2	5	3	+	+	100		
B Denticulopsis	E	l	NEW61	195	G	C	4		13		7	+		3	100		
katayamae 6A	E	l	NE20	192	G	R	2	1	12		7	1	+		100		
	W	ı	N3	185	G	R	5		- 11	2	4	2		+	100		
	W	۱ ـ	N2b	181	M	R	30	2	13	3	1		+		100		
Denticulopsis	w	<u>.</u> 5	N2a	180	G	R	6	1	6	1	3	1		1 +	100		
dimorpha 5D	E	12	NE18	177	G	A R	3		6	1	5	1	2	1	100		
aD	E	[NE17	171 169	M		8		9	1	1	3	1	3	100		
5C	W E	۳.	NI NE16	168	G M	R	5	1	9	- 3 1	5 3	2	1	1 -	100		
1 50	E	₹ 2	NEW48	160	G	R	7	1	5	-	l i			5	100		
1 1	E	Monterey Formation	NEW48	158	G	C	4	+	2	2	7	3	1	ı	100		
l	E	₽	NE14	151	G	c	2	1	3	1	8	+	+	l i	100		
l I I	E	l -	NEW42	149	G	č	2	i	3		l î	i	•	;	100		
Denticulopsis	E	l	Tm19	140	Ğ	č	2	•	6	1	2	1	+	1	100		
praedimorpha	E	1	NE13	122	Ğ	R	6		2	2	l ĩ	i	+	2	100		
5B	E	1	Tm 18	115	Ğ	C	4		7	ī	4		i	2	100		
ايا	E	1	NE12	99	Ğ	č	1	1	10	•	3	i	1	ī	100		
	E	l	Tm 17	95	Ğ	A	1	;	2	2	3	+	+	1 :	100		
[2]	Ē	l	NEII	91	Ğ	Â	l i		4	ī	ľĭ	4	1	+	100		
engois Penticulonsis	E	1	NE10	78	Ğ	C	3		4	2		1	-	+	100		
1 2	E	1	Tm14	75	G	A	1		6		1	3	+		100		
B Denticulopsis	E	l	Tm9	66	G	A	1		4	1	3	3	+	+	100		
hyalina	E	1	NE9	55	Ğ	A	+		4	2	2	1	+	+	100		
4Bb	E	1	NE7	32	Ğ	A	1		4	3	2	6	+	3	100		
	E	j	NE6	27	G	A	+	+	3	1	1	2	1	1	100		
4Ba	Ē]	NE5	21	G	A	4	1	6	ī	2	5		2	100		
Denticulopsis	E	1	NE3	9	G	A	4	2	14	5	2	9		3	100		
lauta 4A	E	I	NE2	3	G	A	3	2	~	_		•		1 0	100		
Inuta 4A	Е		NEW5	1 0	l c	Α	l i		7 20	2 5	4 2	3 6		3	100		

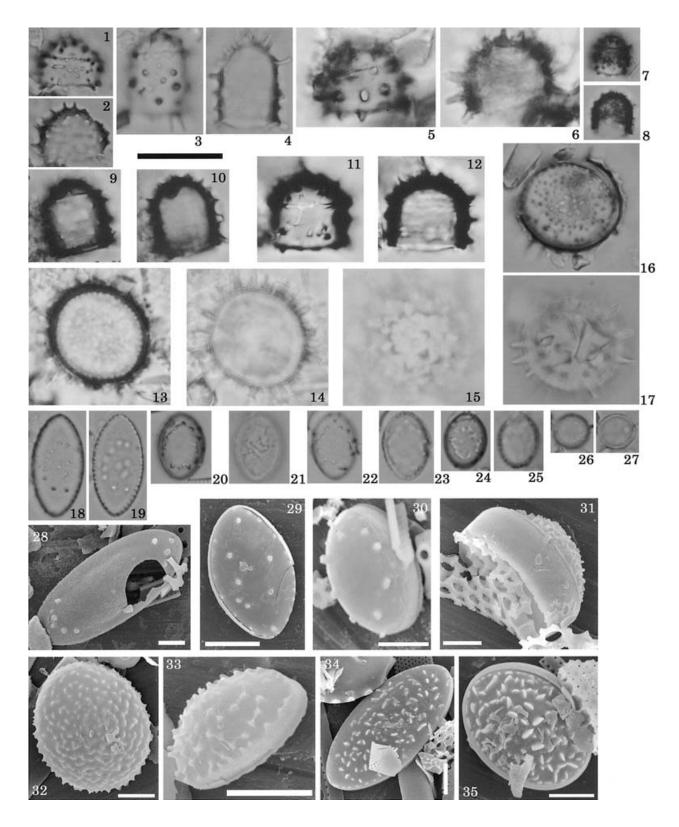
view, epivalve face vaulted, with numerous short strong spines and small knobs. Mantle of epivalve hyaline. Hypovalve vaulted or flat, with numerous short spines and small knobs. Mantle of hypovalve hyaline with a single ring of puncta at its base.

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-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 = $10 \mu m$ for figures 18-27 (LM); Scale bar = $5 \mu m$ for figures 28-30 (SEM). 18, 19. Valve view of epivalve, DSDP Site 338-14-2, $20-21 \mu m$. 20, 21. Holotype. Valve view of frustule, DSDP Site 338-12-3, $38-39 \mu m$. 22, 23. Valve view of epivalve, DSDP Site 338-11-4, $148-149 \mu m$. 24, 25. Valve view of epivalve, DSDP Site 338-11-4, $70-71 \mu m$. 26, 27. Valve view of epivalve, DSDP Site 338-11-4, $20-21 \mu m$. 28. Valve view of epivalve, DSDP Site 338-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 20. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site 238-11-4, $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve, DSDP Site $20-21 \mu m$. 29. Valve view of epivalve

^{31.} Xanthiopyxis obesa Suto sp. nov. Scale bar = $^{1}5 \mu m$ (SEM). 31. Girdle view of epivalve, DSDP Site 338-18-1, 148–149 cm.

^{32–35.} *Xanthiopyxis* type A (knobbly type). Scale bar = $5 \mu m$ 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 338-18-1, $148-149 \ cm$. 35. Valve view of epivalve, DSDP Site 338-18-1, $148-149 \ cm$.

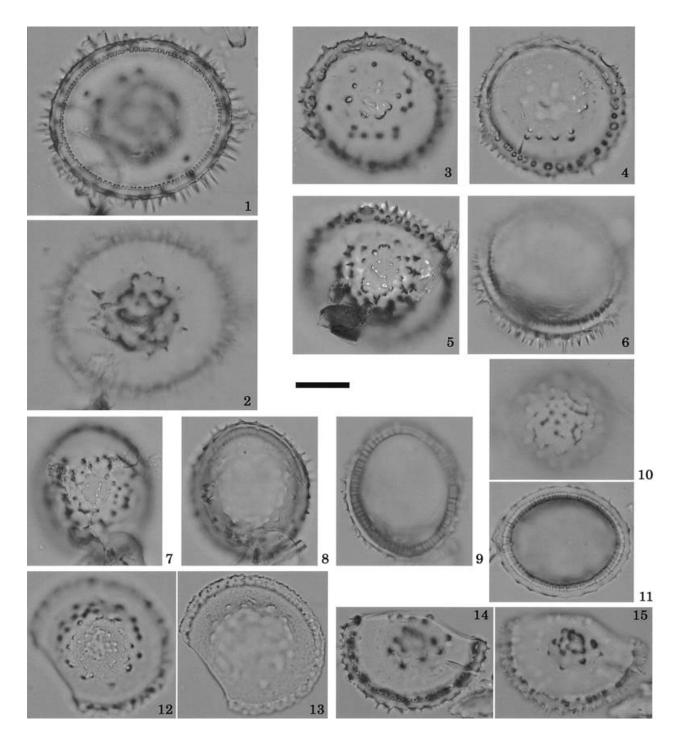


Figure 8. 1–15. *Xanthiopyxis norwegica* Suto sp. nov. Scale bar = 10 µm for each figure (LM).
1, 2. Holotype. Hypovalve view of frustule, DSDP Site 338-19-4, 10–11 cm. 3, 4. Valve view of epivalve, DSDP Site 338-20-3, 20–21 cm. 5, 6. Valve view of epivalve, DSDP Site 338-21-1, 32–33 cm. 7–9. Valve view 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 $4.0-32.5~\mu m$, transapical axis $4.0-14.5~\mu m$. 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 "netveined".

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 $7.0{\text -}10.0$ μm, pervalvar axis $6.5{\text -}9.5$ 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

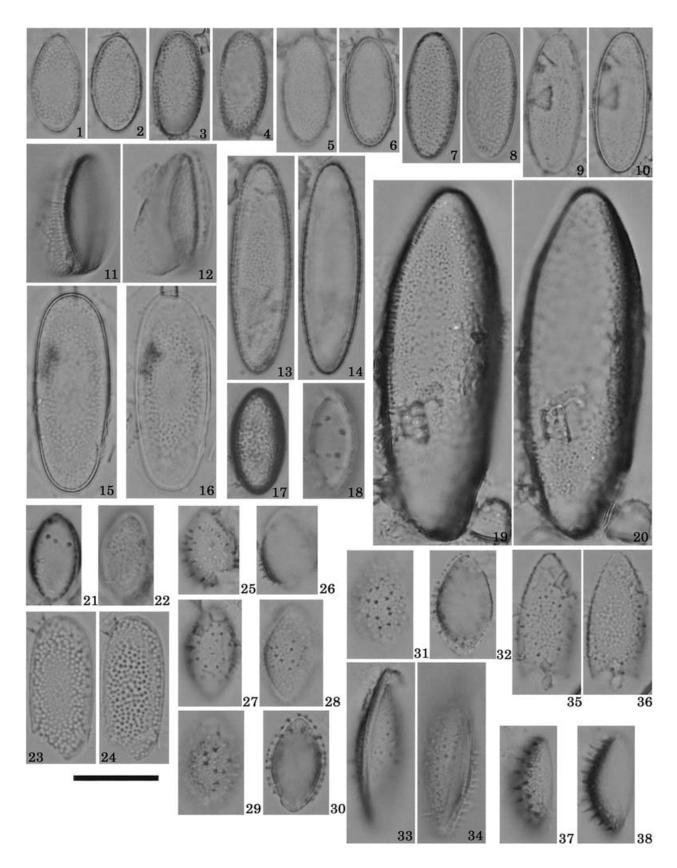
Xanthiopyxis hirsuta Hanna et Grant, 1926, p. 170, pl. 21, fig. 10; Fenner, 1978, p. 536, pl. 35, figs. 7, 8.

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 $10-25.5 \, \mu m$, transapical axis $7.0-20.0 \, \mu m$, pervalvar axis $5.0-9.0 \, \mu m$. 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 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.

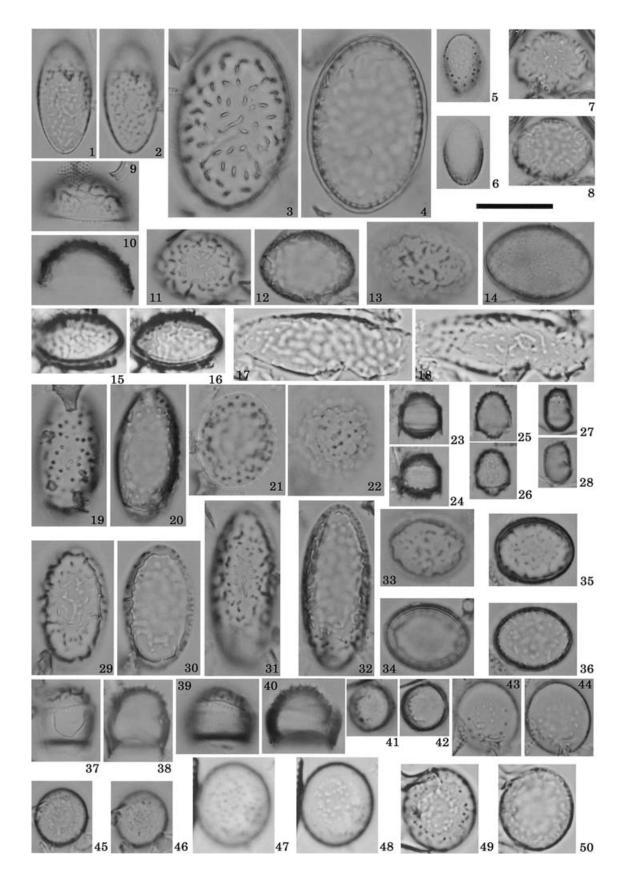
The synonymized species X. acrolopha was collected from the Miocene Marmorito Formation in

Figure 9. 1–24. *Xanthiopyxis lanceolatus* Suto sp. nov. Scale bar = $10 \mu m$ 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 338-20-4, 148–149 cm. 13, 14. Valve view of epivalve, DSDP Site 338-20-4, 148–149 cm. 13, 14. Valve view of epivalve, DSDP Site 338-20-4, 148–149 cm. 13, 14. 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 = $10 \mu m$ 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).

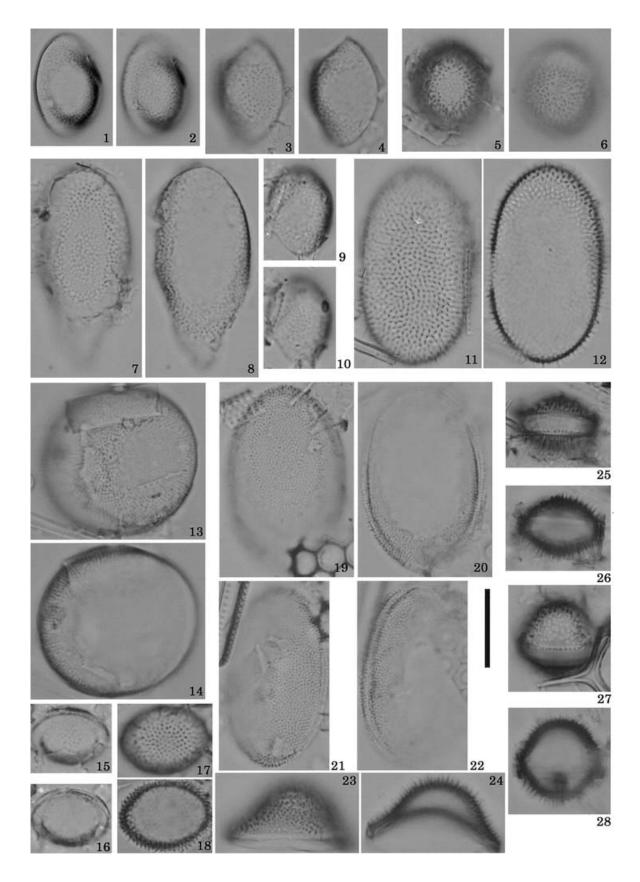
^{1, 2.} Valve view of epivalve, DSDP Site 436-13-3, 100–102 cm. **3, 4.** Valve view of epivalve, DSDP Site 338-11-4, 70–71 cm. **5, 6.** Valve view of epivalve, DSDP Hole 438A-5-2, 96–100 cm. **7, 8.** Valve view of epivalve, DSDP Site 338-13-1, 148–149 cm. **9, 10.** Girdle view of epivalve, DSDP 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 = $10 \mu m$ 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, pl. 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.

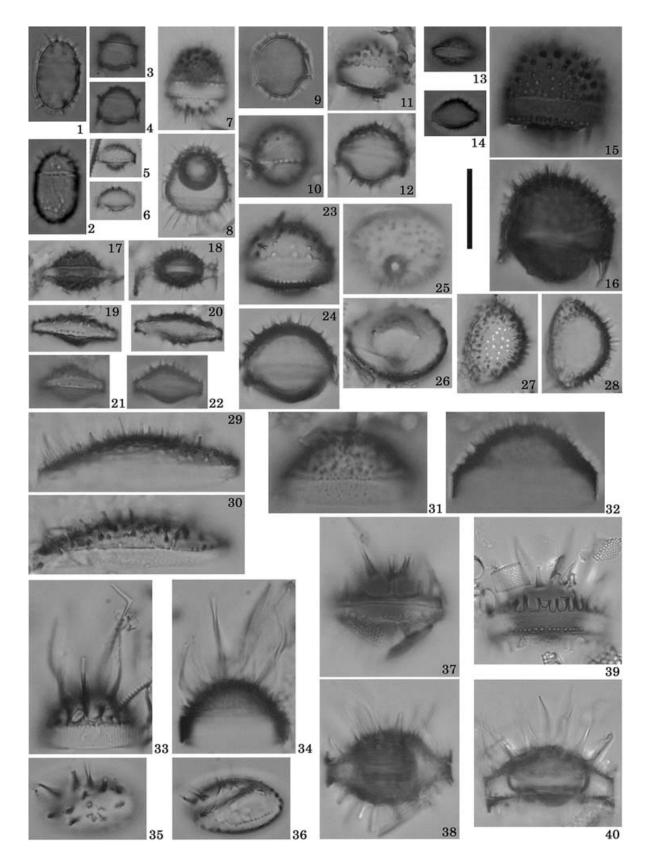
Xanthiopyxis type B (short spiny type)

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.



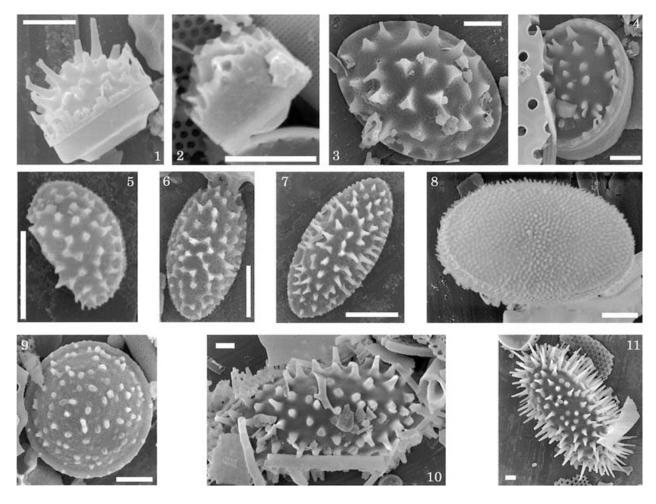


Figure 13. 1–7. Xanthiopyxis type B (short spiny type). Scale bar = $5 \mu m$ for each figure (SEM).

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.

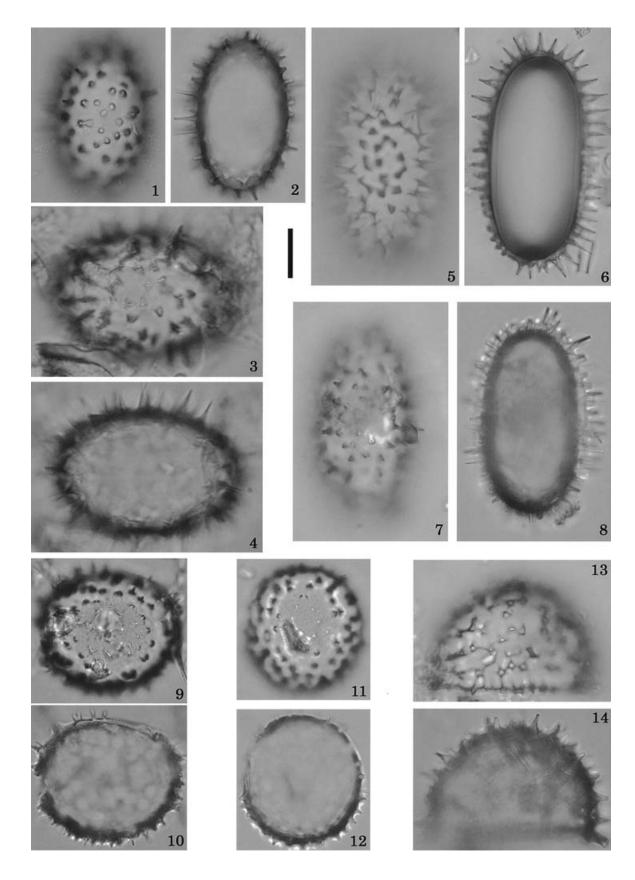
- **8.** *Xanthiopyxis hirsuta* Hanna and Grant. Scale bar = $5 \mu m$ (SEM).
- 8. Valve view of frustule, DSDP Site 338-18-1, 148-149 cm.
- 9. Xanthiopyxis globosa Ehrenberg. Scale bar = 5 μm (SEM).
- **9.** Valve view of epivalve, DSDP Site 338-17-1, 100-101 cm.
- 10, 11. *Xanthiopyxis oblonga* Ehrenberg. Scale bar = $5 \mu m$ 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, N7a. 31, 32. 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 = $10 \mu m$ 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, 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 = $10 \mu m$ 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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