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Fossil marine diatom resting spore morpho-genus Gemellodiscus gen. nov. in the North Pacific and Norwegian Sea

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Abstract. A new fossil marine diatom resting spore morpho-genus Gemellodiscus Suto gen. nov. is described using samples from DSDP Site 338 in the Norwegian Sea, Sites 436 and 438 in the northwest Pacific and the onland Newport Beach Section, California. Gemellodiscus is characterized by possessing a valve with setae of several types: bifurcated seta, fused seta and crossed seta. Eleven taxa are described and their stratigraphic ranges are presented: G. incurvus (Bailey) Suto comb. nov., G. pliocenus (Brun) Suto comb. nov., G. cingulus Suto var. cingulus sp. nov., G. cingulus var. longus Suto var. nov., G. bifurcus Suto sp. nov., G. hirtus Suto sp. nov., G. dicollinus Suto sp. nov., G. geminus Suto sp. nov., and G. dimontanus Suto sp. nov.

Key words: Gemellodiscus, fossil resting spore, diatom, ODP, taxonomy

Introduction

Chaetoceros Ehrenberg is one of the largest and most diverse of all marine planktonic diatom genera (VanLandingham, 1968; Rines and Hargraves, 1988; Hasle and Syvertsen, 1996). It plays an important role in marine primary production, especially in nearshore upwelling regions. Most species of the section Hyalochaete are known to form resting spores under various unfavorable conditions, such as nutrient depletion, darkness, and low temperature (e.g., Durbin, 1978; Garrison, 1981; Hargraves and French, 1983; Kuwata and Takahashi, 1990; Kuwata et al., 1993; Oku and Kamatani, 1995, 1997, 1999; McQuoid and Hobson, 1996). The resting spores of Chaetoceros are differentiated from the vegetative frustules by possessing more heavily silicified valves, and occur frequently in nearshore sediments with other fossil diatom valves. However, taxonomic and biostratigraphic studies on these fossil resting spores have been limited, except for some studies such as Gersonde (1980), Lee (1993) and Suto (2003a, b, 2004a).

In this study, a new morpho-genus *Gemellodiscus*, including eleven taxa, is described from the middle Eocene through Recent sediments at DSDP Sites 338

(Norwegian Sea), 438 and 436 (Northwest Pacific) and an onland section at Newport Beach, California (Figure 1) to clarify the systematics of this genus.

Terminology

Some of the characteristic structures common to the new resting spore genus *Gemellodiscus* are shown in Figure 2. General morphological terms are after Anonymous (1975) and Ross *et al.* (1979). New terms used to describe *Gemellodiscus* are defined below.

Epivalve: the first-formed valve of a resting spore. It differs morphologically from the hypovalve, i.e., the frustule is heterovalvate (Figure 2c).

Hypovalve: the second-formed valve of a resting spore. In *Chaetoceros* spores observed by Hargraves (1979), hypovalves possess a submarginal flange, which fits into the epivalve. The hypovalve possesses a single ring of puncta at the base of the mantle, a characteristic feature that clearly distinguishes the hypovalve from the epivalve, which lacks such structures (Suto, 2003a) (Figure 2d).

Heterovalvate: the two valves of a frustule being dissimilar.

Mantle: the marginal part of the valve differentiated

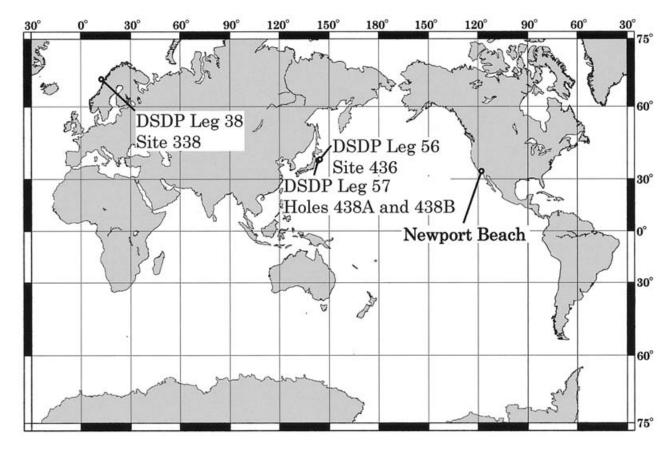


Figure 1. Location of DSDP Sites 338, 436 and 438 and the Newport Beach Section.

by slope, and sometimes also with structures such as spines, perpendicular to the valve face (Figure 2e).

Ring of puncta: a row of perforations at the base of the hypovalve mantle. The ring of puncta can be seen when the frustule is observed under LM, but using SEM the puncta cannot be observed because the epivalve mantle covers the hypovalve mantle (Figure 2f).

Seta: a tubular outgrowth of the valve projecting outside the valve margin, with a structure different from that of the valve. **Bifurcated seta:** a seta bifurcated at or near its base (Figure 2g). **Fused seta:** a nearly straight or strongly curved seta connected to other setae at the base of a paired valve, and then separated for a rather long distance (Figure 2h). **Crossed seta:** a seta crossed and fused with other setae of a paired valve (Figure 2i).

Sheath: a sleeve-like siliceous membrane attached to the resting spore mantle, hyaline or with a series of perforate slots (Figures 2m, n).

Paired valve: two spores connected by the setae which originate on their hypovalves, formed with basal plate of each entirely connected or joined by setae with basal plate of each disconnected (Figure 2k).

Results

Samples and methods in this study are described in Suto (2004b). The results of counting and the stratigraphic distribution of each species are shown in Figures 3–7 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 for the Eocene and Oligocene after Schrader and Fenner (1976).

Gemellodiscus species are similar to the resting spores of extant Chaetoceros species, but the taxonomic relationship between fossil species of Gemellodiscus and resting spores of extant species of Chaetoceros cannot be determined because the vegetative valves of Gemellodiscus species were not preserved as fossils. Accordingly, it is appropriate to use the genus name Gemellodiscus 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 *Gemellodiscus* Suto gen. nov.

Type species.—*Gemellodiscus cingulus* sp. nov.

Description.—Frustule heterovalvate and formed in pairs. Valve oval to elliptical in valve view. In girdle view, epivalve face vaulted, hyaline or covered with numerous knobs or spines, with high mantle. Mantle of epivalve hyaline. Hypovalve face hyaline, vaulted, with two tapered setae, and a mantle. The tapered setae are strong, smooth, and paired. Some bifurcated and fused at the base, but curve back to encircle the girdle (bifurcated seta). Some nearly straight or strongly curved and fused at the base for a rather long distance before bifurcating at an acute angle (fused seta). Some crossed and joined for a rather long distance, polygonal in cross-section (crossed seta). In the case of completely paired spores, two frustules are connected by these setae. Paired valve formed with the entirely connected basal plates of two hypovalves or joined by two setae with a disconnected basal plate. Mantle of hypovalve hyaline, with a single ring of puncta at its base.

Stratigraphic occurrence.—This genus occurs from pre-middle Eocene to the Recent (Figure 3).

Remarks.—This genus includes eleven taxa: G. incurvus (Bailey) Suto comb. nov., G. pliocenus (Brun) Suto comb. nov., G. cingulus Suto var. cingulus sp. nov., G. cingulus var. longus Suto var. nov., G. bifurcus Suto sp. nov., G. hirtus Suto sp. nov., G. caveatus Suto sp. nov., G. micronodosus Suto sp. nov., G. dicollinus Suto sp. nov., G. geminus Suto sp. nov. and G. dimontanus Suto sp. nov. (Figure 2).

In general, *Chaetoceros* spores differ morphologically from vegetative cells by lacking setae. In *Gemellodiscus* species (and some modern *Chaetoceros* spores), however, the valves are held in tandem by fusion of the setae. Although similar in surface structure to a vegetative seta, the seta of a resting spore is more robust and there are only two per spore. In some species, the paired valve may also fuse or coalesce (i.e., *G. cingulus* and *G. bifurcus*). The formation of a paired valve characterizes the fossil morpho-genus

Gemellodiscus of Chaetoceros resting spores.

Etymology.—From Latin gemellus, "twin" and discus, "disc".

Key to species

1a. Two tapered setae on the hypovalve are bifur
cated
1b. Two tapered setae on the hypovalve are fused
1c. Two tapered setae on the hypovalve are crossed
2a. Valve face hyaline
2b. Valve face with numerous spines and knobs
Ĝemellodiscus incurvu
3a. Valve circular in valve view
3b. Valve composed of two flat circles joined to
gether by isthmus G. pliocenu
4a. Bifurcated seta are fused for a short distance
G. cingulus var. cingulu
4b. Bifurcated seta are fused for a long distance
G. cingulus var. longu
5a. Basal plate connected to hypovalve of the paired valve
5b. Basal plate and hypovalve of the paired valve are
unconnected
6a. Valve face hyaline
6b. Valve face with numerous spines and knobs
G. hirtu
7a. Valve face hyaline
7b. Valve face with numerous small spines and knob
G. micronodosu
8a. Epivalve domed
8b. Epivalve center vaulted with numerous knobs
G. dicollinu
9a. Valve face hyaline
9b. Valve face with numerous knobs
G. dimontanu

Gemellodiscus incurvus (Bailey) Suto comb. nov.

Figures 2.A; 8.16, 8.17

Basionym.—Chaetoceros incurvus Bailey, 1854, p. 9, pl. 1, figs. 30?, 31, 32

Reference.—Chaetoceros incurvus Bailey, Mereschkowsky, 1889, p. 484, pl. 16, figs. 1, 2.

Synonymy.—Chaetoceros spores (cf. radicans) of Whiting and Schrader, 1985, pl. 5, fig. 3 nec fig. 2.

Description.—Valve oval to elliptical in valve view, apical axis 12.0-17.0 μm, transapical axis 9.0-10.0 μm. In girdle view, epivalve face vaulted, covered with numerous knobs and spines. Valve with two tapered bifurcated setae, and a mantle. Bifurcated setae hyaline, smooth, emerging from valve apices, fused for

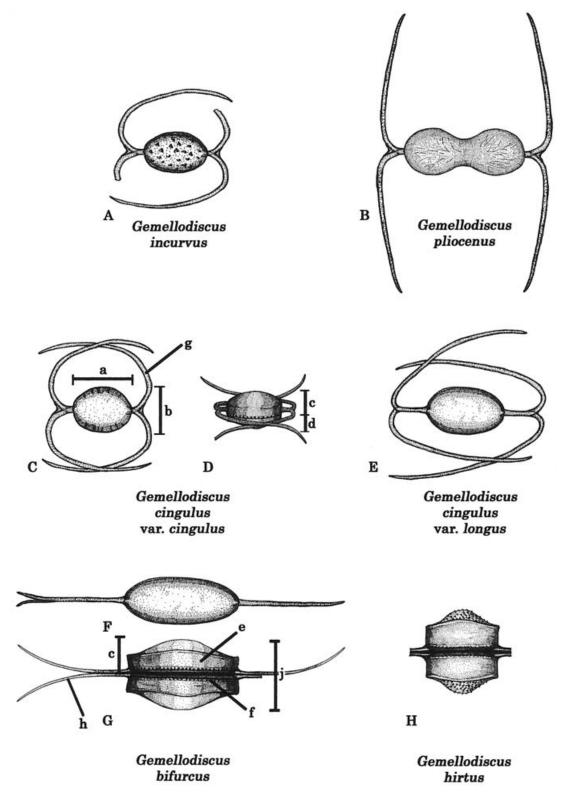


Figure 2. Sketches of *Gemellodiscus* species; **A:** *G. incurvus*, **B:** *G. pliocenus*, **C, D:** *G. cingulus* var. *cingulus*, **E:** *G. cingulus* var. *longus*, **F, G:** *G. bifurcus*, **H:** *G. hirtus*.

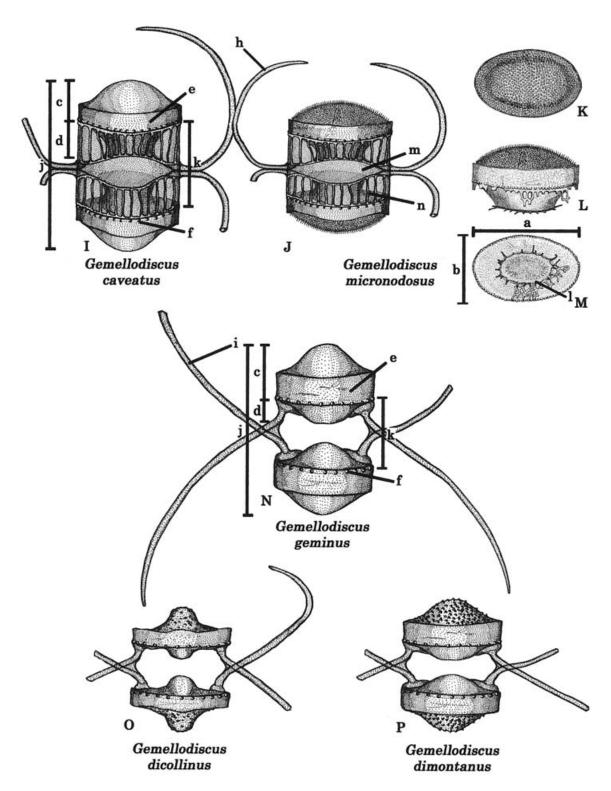


Figure 2. (Continued) I: G. caveatus, J-M: G. micronodosus, N: G. geminus, O: G. dicollinus, P: G. dimontanus, (A, B, C, E, F, K: valve view of epivalve, D, L: girdle view of frustule, G, H, I, J, N, O, P: girdle view of paired valve, M: valve view of hypovalve). Key to structures: a: apical axis, b: transapical axis, c: pervalvar axis of epivalve, d: pervalvar axis of hypovalve, e: mantle, f: a single ring of puncta, g: bifurcated seta, h: fused seta, i: crossed seta, j: paired valve, k: unconnected hypovalves, l: truncated elevation with a basal flat plate, m: hyaline sheath, n: cage-like sheath. All sketches were made using LM.

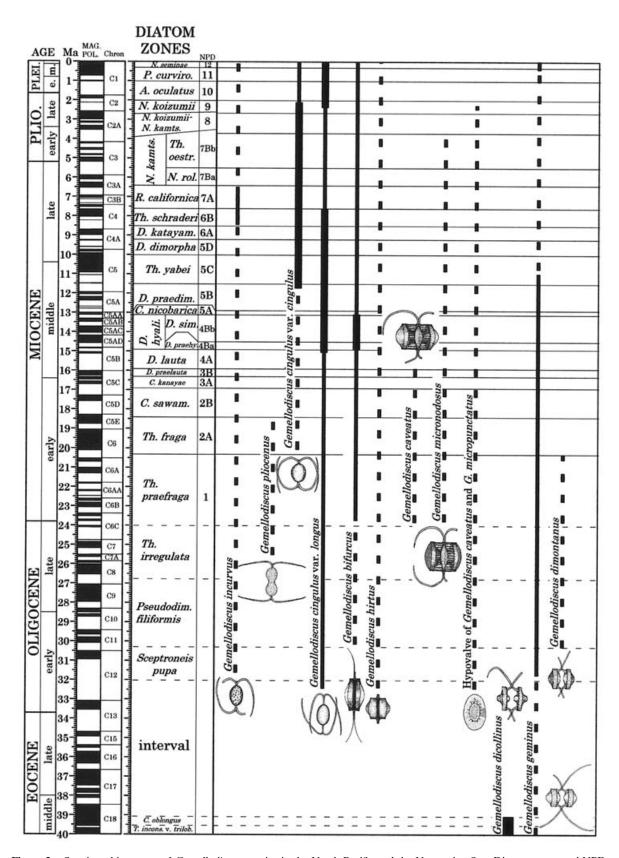


Figure 3. Stratigraphic ranges of *Gemellodiscus* species in the North Pacific and the Norwegian Sea. Diatom zones and NPD codes are after Yanagisawa and Akiba (1998) for the Miocene, Pliocene and Pleistocene, and after Schrader and Fenner (1976) for the Eocene and Oligocene.

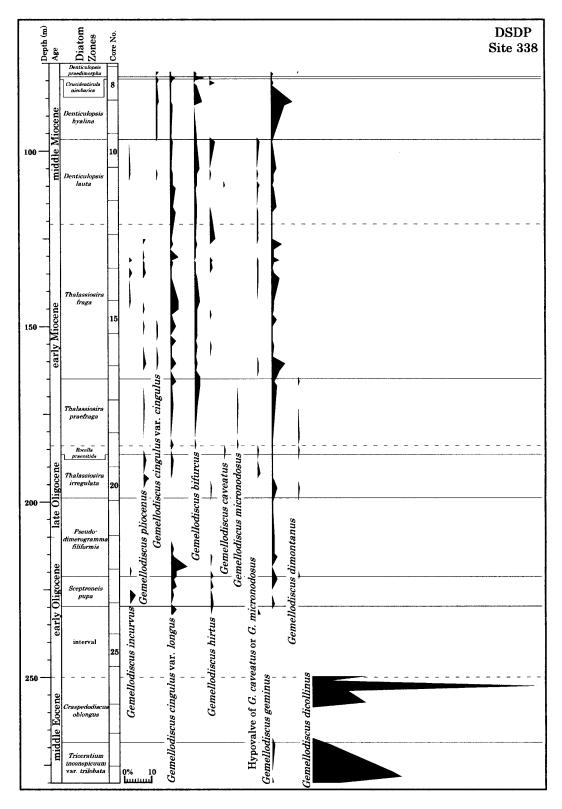
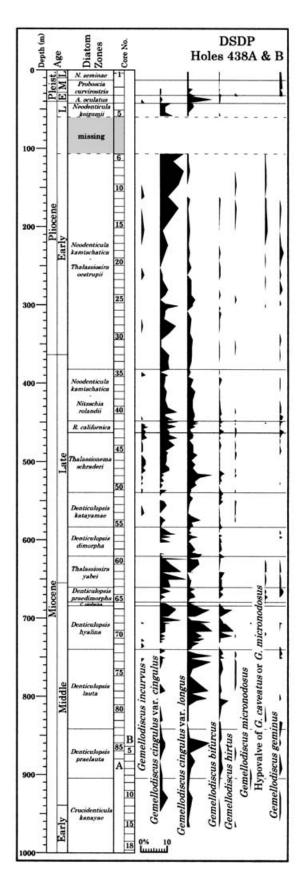


Figure 4. Stratigraphic occurrences of Gemellodiscus species at DSDP Site 338. Diatom zones are after Schrader and Fenner (1976).



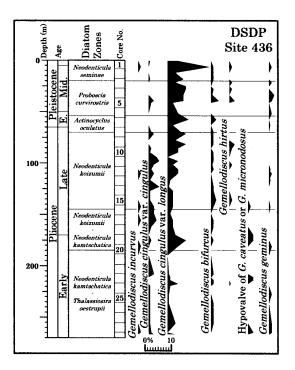


Figure 6. Stratigraphic occurrences of *Gemellodiscus* species at DSDP Site 436. Diatom zones are after Yanagisawa and Akiba (1998).

a short distance, then curved back around the valve away from the apical axis to encircle the girdle. Mantle hyaline. Frustule not observed, hypovalve unknown.

Type locality.—Not given (probably middle Miocene, Hawthorn Formation).

Similar taxa.—This species is very similar to G. cingulus var. cingulus and G. cingulus var. longus, but is distinguished by its epivalve covered with numerous knobs and spines. This species differs from G. pliocenus by its oval to elliptical valve shape.

Stratigraphic occurrence.—This species occurs rarely and sporadically from the lower Oligocene to the Recent (Figure 3)

Remarks.—Specimens illustrated by Bailey (1854) probably from the middle Miocene Hawthorn Formation and that of Mereschkowsky (1889) from the Chincha guano in Peru were described as Chaetoceros incurvus, but these specimens are fossil spores. Therefore, the morpho-genus Gemellodiscus is proposed for the fossil resting spores in this paper, because the respective vegetative cells were dissolved

[←] Figure 5. Stratigraphic occurrences of *Gemellodiscus* species at DSDP Holes 438A and B. Diatom zones are after Yanagisawa and Akiba (1998).

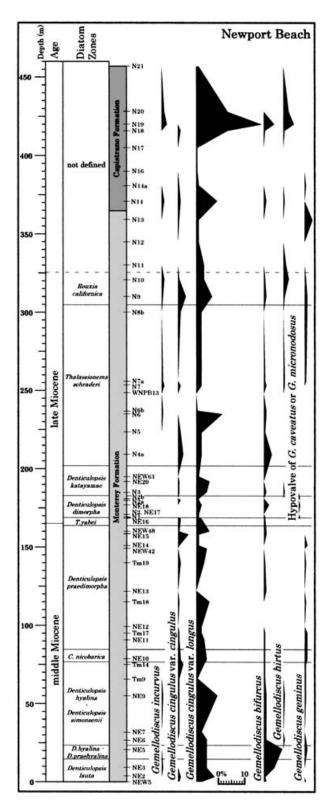


Figure 7. Stratigraphic occurrences of *Gemellodiscus* species in the Newport Beach Section. Diatom zones are after Yanagisawa and Akiba (1998).

Table 1. Occurrences of *Gemellodiscus* 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).

	,,,,,,																		
	Distom zones	NPD	Leg 38 Site 338	Depth (m)	OPreservation	> > Abundance	Gemellodiscus incurvus	G. pliocenus	- G. cingulus var. cingulus	+ G.cingulus var. longus	- + G. bifurcus	G. hirtus	G. caveatus	G. micronodosus	Hypovalve of G. micronodosus	G. dicollinus	G. geminus	G. dimontanus	Total number of resting spore
	Denticulopsis praedimorpha	5B	8-1, 140-141 8-2, 48-49 8-2, 99-100	77.40 77.98 78.49	GG	A A A			1+	++	+						1+	+	100 100
middle Miocene	C. nicobarica Denticulopsis hyalina	5A 4B	8-3, 10-11 8-3, 80-81 8-4, 10-11 8-4, 80-81 9-1, 50-51 9-1, 148-149 10-1, 106-107	79.10 79.80 80.60 81.30 86.00 86.98 96.06	000000	A A A A A			† † † † † †	1 + + 1 +	1 3	2					+ 1 + 8 5		100 100 100 100 100 100 100
midd	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	0000000000000	A A C A A A	+		+	1 + 1 1 1 2 1 2	1 2 1 1 1 + 1	+ +	+		1 + 1 + +		+ 2 1 1 + 1 2 +		100 100 100 100 100 100 100 100
early Miocene	Thalassiosira fraga	2A	13:1. 148-148 13:2. 148-148 13:2. 148-146 13:5. 70-71 13:6. 10-11 13:6. 70-71 14:1. 20-21 14:2. 20-21 14:2. 20-21 14:2. 20-21 15:3. 100-101 15:4. 100-101 15:4. 100-101 15:5. 13:8-101 16:2. 10-11 16:3. 10-11 16:5. 10-11 16:5. 0-11 16:6. 50-51 17:1. 100-101	124.98 126.48 127.98 130.20 131.10 131.70 133.20 134.70 145.00 146.50 148.00 149.88 152.55 154.05 154.05 155.55 156.55 160.45 160.45	00000000000000000000000	A A A A A A A A A A A A A A A A A A A	1 +	1 + + + 1 + + 1	+ + + +	+ 1 3 + 1 + + + 3 3 + 1 2 2 + + 2	+ + + + + + + + 1 2 1 1 1 1 + 1 + + 2	1 + 1			+ + + + + + + + + + + + + + + + + + + +		+ 4 1 1 3 1 + 1 3 1 + + + + + + + + + + + + +		100 100 100 100 100 100 100 100 100 100
	Thalassiosira praefraga	1	17-3, 110-111 17-4, 79-80 18-1, 148-149 19-1, 130-131 19-3, 20-21	165.60 166.79 172.48 181.80 183.70	99999	A A A A		+		2 + 1	2 2 1 +			+			1 2 + + +	+	100 100 100 100 100
late 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	000000	A A C C		1 2 1		1 +		+	+		1		1 + + 1 2	+	100 100 100 100 100 100
	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 22-6, 148-149 23-1, 80-81	211.00 213.20 214.69 215.50 218.38 219.60	00000000	AARCRCCC	+			1 + 1 6 2 2		+					+ + 1 1 2 + + + +		100 100 100 100 100 100 100
early Oligocene	Sceptroneis pupa		23-6, 10-11 24-1, 100-101 24-2, 100-101	230.50	G G G G G G	A C C C A R	2			2 1 2 + 1		1 + 1 +			1		+		100 100 100 100 100 100
	interval	-	26·2, 110·111 26·3, 80·81 26·4, 80·81	249.60 250.80 252.30	G G	R R R		_	barr	en u	ntil				1	6 2 84		_	30 30 100
middle Eocene	Craspedodiscus oblongus		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	253.80 257.08 258.50 259.90 261.30 262.69 267.20	G G G G	R R R R R					bar	en				6			30 30 30 30 30
	Triceratium inconspicuum var. trilobata		28-2, 148-149 29-1, 130-131 29-2, 120-121 29-3, 148-149	276.80 278.20	G G G	R R R										9 11 1	1 +		30 30 30 10

and the correspondence between vegetative cells and resting spores can never be determined in fossil material.

The *Chaetoceros* spores (cf. *radicans*) of Whiting and Schrader (1985) from the upper Miocene to lower

Table 2. Occurrences of *Gemellodiscus* 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).

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			52-3, 36-38	548.9	G	A			7 2				200	2		15-2, 61-62	959	G.	A							100
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Table 3. Occurrences of *Gemellodiscus* 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)	D Preservation	≂Abundance	Gemellodiscus incurvus	G. cingulus var. cingulus	G. cingulus var. longus	G. bifurcus	G. hirtus	Hypovalve of G. arceatus or G. micronodosus	G. geminus	Fotal number of resting spore valves counted
1 3 1	Neodenticula					i	+						
1.8	seminae	1.5, 50.52	6.40	G	С	1		16	1	1		1	100
Pleisto.		2.3, 100.102	12.00	G	R			3	1				100
-	12	3-1, 102-104	18.52	G	R		+	6	1				100
a)		3-3, 100-102	21.50	G	C			3	+	1		1	100
Pleistocene		3-6, 10-12	25.10	Ğ	Ř			7		-		-	100
8	Proboscia	4-1, 50-52	27.50	Ğ	R			7	1	1			100
18	curvirostris	4.5, 50.52	33.50	Ğ	c			6	+			2	100
ᆲ	11	5·2, 148·150				i			3				
딯	11		39.48	G	A		2	6	3	2		1	100
mid.		5-4, 22-24	41.12	G	R	i	1	2				_	100
-		6-4, 100-102	51.50	G	С			4				1	100
Plei.	Actinocyclus	7-2, 54-56	57.54	G	R			8	2				100
	oculatus 10	7-6, 50-52	63.00	G	С			2				+	100
e		8:3, 148,:150	69.48	G	Α.		1_	5	1_				100
1 1		8-5, 18-20	71.18	G	С		2	7	1				100
1 1		9.2, 148.150	77.48	G	Α			3	1				100
		9.5, 95.97	81.35	G	R			7	1	2			100
li		10.1, 148.150	85.48	G	Α		1	4		1			100
1 1		10-4, 98-100	89.48	G	R		+	4	1	+			100
1		11-1, 50-52	94.00	G	R		3		1				100
1	Neodenticula	11-3, 148-150	97.88	G	Α		4	4	1				100
1	koizumii	11-6, 100-102	101.40	Ğ	c		2	2	+	1		i	100
ا و ا	9	12-2, 148-150	105.98	Ğ	č		ī	4	1	-		+	100
8		12-5. 98-100	109.98	G	č	1	2	4	•			1	100
١ž		13-3, 100-102	116.50	G	č	١.	+	1	+			+	100
ate Pliocene		14-1, 100-102	123.00	Ğ	č		4	+	1			т.	100
#						ŀ	-	2					
-		14-4, 48-50	126.98	G	C		+		1				100
		15-3, 141-143	135.91	G	C		+	2	2	1			100
		16-1, 130-132	142.30	G	C	1	2	2	1		+	+	100
	Neodenticula	16-6, 47-49	148.87	G	R		2	1					100
1 1	koizumii -	17-4, 50-52	155.50	G	С	1	3	2	1				100
	Neodenticula	18-2, 45-47	161.95	G	Α		1	2	1				100
l i	kamtschatica	19-1, 50-52	170.00	G	С	l		3			1		100
	8	19-4, 148-150	174.98	G	С		1	7	1		1		100
	•	20-2, 38-40	180.88	G	С	1		4				1	100
П		21.1, 110-112	189.60	G	Ĉ								100
		23-1, 48-50	207.98	Ğ	Ā	l	2	+	1				100
		23.3, 48.50	210.98	Ğ	Â	l	-	1	-		1		100
2	Neodenticula	23.5, 50.52	214.00	Ğ	c	l		i	1		i		100
8	kamtschatica	24-1, 50-52	217.50	G	R			4	1	_			100
🔒	-	24-2, 110-112	217.30	G	R	l	_	1		-			100
14	Thalassiosira					1	+					,	
early Pliocene	oestrupii	25-1, 70-72	227.20	G	R	l	+	+				1	100
%	7Bb	26-1, 60-62	236.47	G	С	İ	+	+	1			.	100
		28.1, 102.104	256.02	G	R	١.	+	3	I			1	100
		29-1, 48-50	264.98	G	R	1	1				1	1	100
ш		29-2, 70-72	266.70	G	R	L	2	3					100

Pliocene marine sediments of the Oregon coast and continental shelf are identified as *G. incurvus*, because the valve face is covered with numerous spines.

Etymology.—Latin incurvus, meaning "curved inside".

Gemellodiscus pliocenus (Brun) Suto comb. nov.

Figures 2.B; 8.18, 8.19

Basionym.—Chaetoceros pliocenus Brun, 1891, p. 15, pl. 19, figs. 1a-c

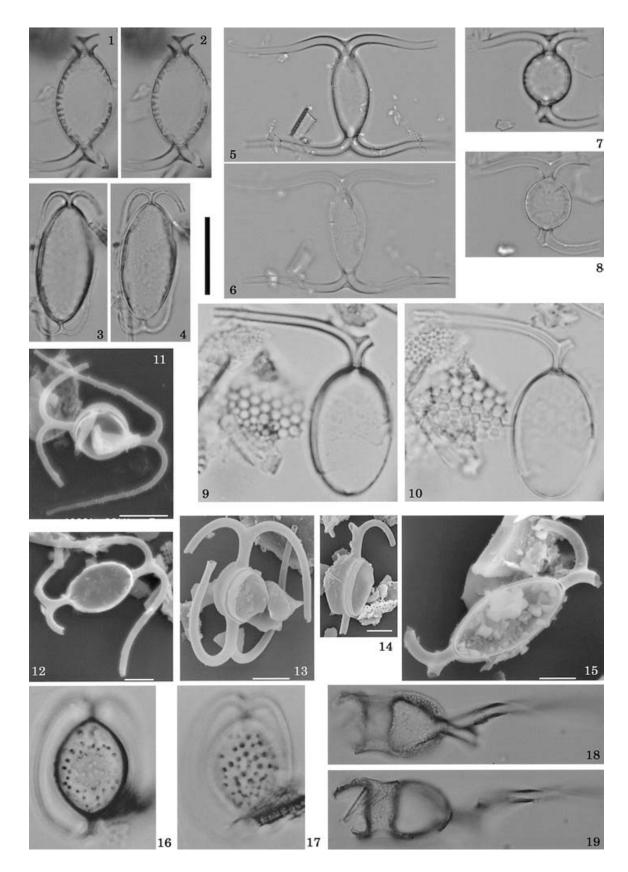
References.—Chaetoceros pliocenus Brun, Sheshukova-Poretzkaya, 1967, p. 207, pl. 24, figs. 10a, b; Dzinoridze et al., 1979, p. 49, fig. 182.

Table 4. Occurrences of *Gemellodiscus* 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).

N21											`																														
No.			sect (W: we	tion estern;			Preservation	Abundance	Gemellodiscus incurvus	G. cingulus var. cingulus	G. cingulus var. longus	G. bifurcus	G. hirtus	Hypovalve of G. micronodosus	G. geminus	Total number of resting spore valves counted																									
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No.			W W W		N14 N13 N12 N11	371 359 345 330	GGGG	C A R A		+	8 1 1 3		1			100 100 100 100																									
Thalassiosira w W W N7a 256 G C 1 1 2 + + + 1 N7a 256 G C 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 2 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 + + 1 N7a 253 G R 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1								Α	_				_			100 100																									
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Synonymy.—Chaetoceros sp. A of Gombos, 1976, p. 592, pl. 24, figs. 1–6; Chaetoceros panduraeformis sensu Barron and Mahood, 1993, p. 38, pl. 5, fig. 14, pl. 6, figs. 6, 7.

Description.—In valve view, epivalve slender, apical axis 12.5–50.0 μm, transapical axis 5.5–20.0 μm, width of isthmus 3.5–14.0 μm. Valve panduriform with broad hyaline isthmus. Valve strongly concave in the isthmus area on each side, with numerous wrinkles extending roughly in fan shape from the junction of the isthmus, with two bifurcated setae, and a mantle. Bifurcated setae hyaline, smooth, emerging from valve apices, fused for a short distance, then curved back around



the valve away from the apical axis to encircle the girdle. Mantle hyaline. Frustule not observed and hypovalve unknown in this study.

Type locality.—Unknown (probably marine pelagic sediment in the *Rouxia californica* Zone at Sendai (Brun, 1891)).

Similar taxa.—This species is characterized by having a valve joined by a broad hyaline isthmus.

Stratigraphic occurrence.—This species occurs rarely but continuously in restricted intervals from the upper Oligocene to the lower Miocene at DSDP Site 338 (Figure 4).

Etymology.—Latin from Greek, pliocenus, i.e., "Pliocene".

Gemellodiscus cingulus Suto var. cingulus sp. nov.

Figures 2.C, D; 8.1-8.10, 8.15

Synonymy.—Chaetoceros cinctus Gran sensu Sheshukova-Poretzkaya, 1967, p. 206, pl. 33, fig. 9; Gleser et al., 1974, pl. 54, figs. 1a, b, pl. 80, fig. 6 nec pl. 48, fig. 7; Chaetoceros incurvus Bailey sensu Sheshukova-Poretzkaya, 1967, p. 207, pl. 8, fig. 8, pl. 33, fig. 10; Chaetoceros didymus Ehrenberg sensu Hanna, 1970, p. 182, figs. 62, 98 nec fig. 97.

Description.—Frustule heterovalvate. Valve oval to elliptical in valve view, apical axis 6.5–17.0 μm, transapical axis 4.5–11.0 μm. In girdle view, epivalve face vaulted, hyaline, with two tapered bifurcated setae, and a mantle. Bifurcated setae hyaline, smooth, emerging from valve apices, fused at the base, then curved back around the valve away from the apical axis to encircle the girdle. Mantle of epivalve hyaline. Hypovalve vaulted, hyaline with mantle. Mantle of hypovalve hyaline with a single ring of puncta at its base.

Holotype.—Slide MPC-02583 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder E38-1N, illustrated in Figures 8.5, 8.6).

Type locality.—DSDP Site 436-11-3, 148–150 cm, northwestern Pacific Ocean.

Similar taxa.—The nominate variety is distinguished from G. cingulus var. longus by its bifurcated

seta fused at the base. This species differs from G. incurvus by its hyaline valve face.

Stratigraphic occurrence.—Lower Miocene to Recent (Figure 3).

Remarks.—The abundance of the nominate variety and G. cingulus var. longus differs through time. In the northwestern Pacific Ocean, the nominate variety occurs less than G. cingulus var. longus in the Pleistocene, but to an equal or greater extent in the Pliocene. The difference in abundance between the two varieties may be due to paleoceanographic changes.

The nominate variety and *G. cingulus* var. *longus* are very similar to the resting spore of the extant species *Chaetoceros cinctus* Gran and *C. radicans* Schütt. *Chaetoceros cinctus* differs from *C. radicans* by its smaller valve size, thinner setae and lack of characteristic spines covering the setae (Stockwell and Hargraves, 1984). The bifurcated setae of *G. cingulus* lack spines, and therefore *G. cingulus* may be a fossil resting spore of *C. cinctus* or more likely the *C. cinctus* lineage.

Etymology.—From Latin cingulus, meaning "belt".

Gemellodiscus cingulus var. longus Suto var. nov.

Figures 2.E; 8.11-8.14; 9.1-9.15

Synonymy.—Chaetoceros cinctus Gran sensu Hajós, 1968, p. 129, pl. 33, figs. 18, 19, pl. 34, fig. 1; Schrader, 1973, pl. 17, figs. 14, 15; Gleser et al., 1974, pl. 48, fig. 7, pl. 80, fig. 6 nec pl. 54, figs. 1a, b; Hasegawa, 1977, p. 81, pl. 23, fig. 16; Shirshov, 1977, pl. 24, fig. 15; Lee, 1993, p. 32, pl. 1, fig. 13; Chaetoceros spores (cf. radicans) of Whiting and Schrader, 1985, pl. 5, fig. 2 nec fig. 3; Chaetoceros sp. B of Lee, 1993, p. 37, pl. 1, fig. 10.

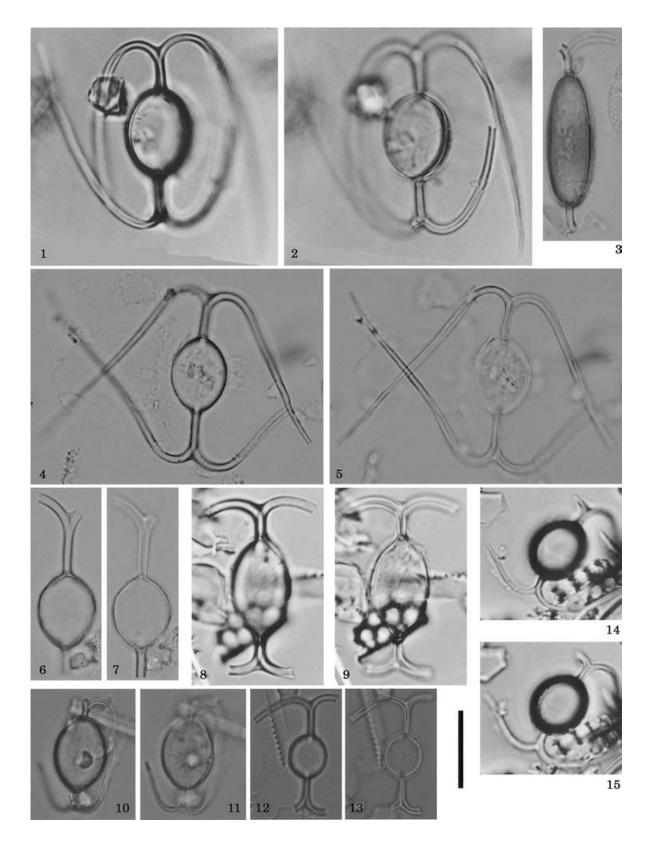
Description.—Frustule heterovalvate. Valve oval to elliptical in valve view, apical axis 5.0–17.5 μm, transapical axis 5.0–9.0 μm. In girdle view, epivalve vaulted, hyaline, with two bifurcated setae, and a mantle. Bifurcated setae hyaline, smooth, emerge from valve apices, fused for a short distance, then curved back around the valve away from the apical axis to encircle the girdle. Mantle of epivalve hyaline. Hypovalve vaulted, hyaline with mantle. Mantle of hypo-

Figure 8. 1–10, 15. Gemellodiscus cingulus var. cingulus Suto sp. nov., LM scale bar = 10 μm for figures 1–10; SEM. Scale bar = 5 μm. **1, 2.** Valve view of epivalve, DSDP Site 436-11-1, 50–52 cm. **3, 4.** Valve view of epivalve, Newport Beach Section, N2b. **5, 6.** Holotype. Valve view of epivalve, DSDP Site 436-14-1, 100–102 cm. **9, 10.** Valve view of epivalve, DSDP Hole 438A-41-6, 20–24 cm. **15.** Inner valve view of epivalve, DSDP Hole 438A-44-3, 10–14 cm.

^{11-14.} Gemellodiscus cingulus var. longus Suto var. nov., SEM. Scale bar = $5 \mu m$ for each figure. 11. Inner valve view of epivalve, DSDP Hole 438A-32-1, 24-28 cm. 12. Inner valve view of epivalve, DSDP 438A-37-3, 10-14 cm. 13. Oblique girdle view of epivalve, DSDP Hole 438A-67-1, 112-113 cm. 14. Oblique girdle view of epivalve, DSDP Hole 438A-67-1, 112-113 cm.

^{16, 17.} Gemellodiscus incurvus (Bailey) Suto comb. nov., LM. Scale bar = $10 \mu m$ for each figure. 16, 17. Valve view of frustule, DSDP Hole 438A-42-4, 50-54 cm.

^{18, 19.} Gemellodiscus pliocenus (Brun) Suto comb. nov., LM. Scale bar $=10~\mu m$ for each figure. 18, 19. Valve view of epivalve, DSDP Site 338-13-1, 148–149 cm.



valve hyaline with a single ring of puncta at its base.

Holotype.—Slide MPC-02582 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder Q27-1S, illustrated in Figures 9.4, 9.5).

Type locality.—Newport Beach section, sample no. NEW 48 of Barron (1976), California.

Similar taxa.—This variety differs from G. cingulus var. cingulus by having bifurcated setae fused for a short distance.

Stratigraphic occurrence.—Lower Oligocene to Recent (Figures 3–7).

Etymology.—Latin longus, "distant".

Gemellodiscus bifurcus Suto sp. nov.

Figures 2.F, G; 10.1-10.25

Synonymy.—Chaetoceros furcellatus Bailey sensu Sheshukova-Poretzkaya, 1967, p. 205, pl. 33, fig. 8; Hajós, 1968, p. 129, pl. 34, fig. 2; Gleser et al., 1974, pl. 58, fig. 3, pl. 88, fig. 4; Shirshov, 1977, pl. 2, fig. 17; Sancetta, 1982, pl. 2, figs. 7, 9; Lee, 1993, p. 33, pl. 1, fig. 11; Chaetoceros sp. IV of Hajós, 1968, p. 130, pl. 34, fig. 10; Chaetoceros septentrionalis Oestrup sensu Sancetta, 1982, pl. 2, fig. 8; Chaetoceros didymus Ehrenberg sensu Whiting and Schrader, 1985, pl. 5, fig. 4.

Description.—Frustule heterovalvate. Valve oval to elliptical in valve view, apical axis 5.0–18.0 μm, pervalvar axis 3.0–7.0 μm. In girdle view, epivalve vaulted, hyaline. Mantle of epivalve hyaline. Hypovalve slightly vaulted, hyaline with two fused setae, and a mantle. Fused setae hyaline, smooth, nearly straight, emerging from apices, curved tubular outgrowth of the valve projecting outside the valve margin, connected to setae of paired valve, separated for a rather long distance, parallel to apical plane. Mantle of hypovalve hyaline with a single ring of puncta at its base. Paired valve formed by completely connected basal plates of two hypovalves.

Holotype.—Slide MPC-02587 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder L31-1W, illustrated in Figures 10.13, 10.14).

Type locality.—DSDP Site 436-3-3, 100–102 cm, northwestern Pacific Ocean.

Similar taxa.—This species is very similar to G. hirtus, but is distinguished from the latter by its hyaline valve face.

Stratigraphic occurrence.—Lower Oligocene to Recent (Figure 3).

Remarks.—This species may be an ancestor of the extant species Chaetoceros furcillatus, often misspelled as C. furcellatus (e.g., Stockwell and Hargraves, 1984), but the relationship between them cannot be determined because the vegetative valves were not preserved as fossils.

Etymology.—Latin bifurcus, meaning "two-pronged".

Gemellodiscus hirtus Suto sp. nov.

Figures 2.H; 10.26-10.31

Description.—Frustule heterovalvate. Valve oval to elliptical in valve view, apical axis 5.0-8.0 μm, pervalvar axis 4.0-6.0 μm. In girdle view, epivalve vaulted, with numerous knobs and spines. Mantle of epivalve hyaline. Hypovalve hyaline, slightly vaulted, with two fused setae, and a mantle. Fused setae hyaline, smooth, nearly straight, emerging from valve apices as curved tubular outgrowths of the valve projecting outside the valve margin, connected to setae of paired valve, separated for a rather long distance, parallel to apical plane. Mantle of hypovalve hyaline with a single ring of puncta at its base. Paired valve formed completely by the connected basal plates of two hypovalves.

Holotype.—Slide MPC-02588 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder S37-3N, illustrated in Figures 10.28, 10.29).

Type locality.—Newport Beach section, sample no. N20 of Barron (1976), California.

Similar taxa.—This species is very similar to G. bifurcus, but differs by possessing a valve face covered with numerous knobs and spines. This species resembles G. incurvus in valve view, but differs by having fused setae.

Stratigraphic occurrence.—Lower Oligocene to Recent (Figure 3).

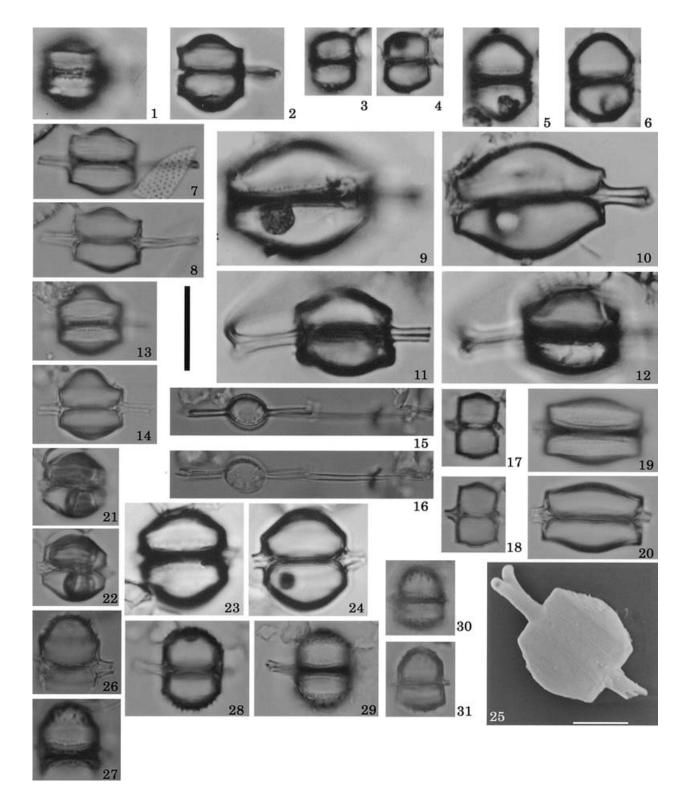
Etymology.—Latin hirtus, meaning "shaggy."

Gemellodiscus caveatus Suto sp. nov.

Figures 2.I; 11.1-11.4

Description.—Frustule heterovalvate. Valve oval to elliptical in valve view, apical axis 12.0–34.0 μm, pervalvar axis 6.5–15.0 μm. In girdle view, epivalve

Figure 9. 1–15. *Gemellodiscus cingulus* var. *longus* Suto var. nov., LM. Scale bar = 10 μm for each figure. 1, 2. Valve view, DSDP Hole 438A-25-5, 16–20 cm. 3. Valve view, DSDP Site 338-15-2, 100–101 cm. 4, 5. Holotype. Valve view, Newport Beach Section NEW48. 6, 7. Valve view, DSDP Site 338-8-1, 140–141 cm. 8, 9. Valve view, DSDP Hole 438A-26-4, 10–14 cm. 10, 11. Valve view, DSDP Site 436-3-6, 11–12 cm. 12, 13. Valve view, DSDP Site 436-6-4, 100–102 cm. 14, 15. Valve view, DSDP Hole 438A-26-6, 15–19 cm.



vaulted, hyaline. Mantle of epivalve hyaline. Hypovalve slightly vaulted, with a truncated elevation in the center with a flat plate, marginal zone, two fused setae, outer cage-like sheath and mantle. Flat plate of hypovalve oval to elliptical, slightly concave, with marginal net-like spines connected to the outer cagelike sheath. Fused setae hyaline, smooth, emerging from valve apices of basal plate as curved tubular outgrowths of the valve projecting outside the valve margin, connected to the setae of paired valve. Mantle of hypovalve hyaline with a single ring of puncta at its base. Paired valve formed by two fused setae and hyaline sheath with disconnected basal plate.

Holotype.—Slide MPC-02581 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder O40-1S, illustrated in Figures 11.3, 11.4).

Type locality.—DSDP Site 338-12-2, 40–41 cm, Norwegian Sea.

Similar taxa.—This species resembles G. micro-nodosus, but is distinguished by its hyaline epivalve face.

Stratigraphic occurrence.—This species occurs very rarely and sporadically in the uppermost Oligocene Rocella praenitida Zone and in the middle Miocene Denticulopsis lauta Zone (NPD 4A) at DSDP Site 338 (Figure 4).

Remarks.—It is very difficult to identify the hypovalve of this species vis a vis that of *G. micronodosus* (Figures 13.1–13.14; 14.4), and therefore, this type of hypovalve was counted as "hypovalve of *G. caveatus* and *G. micronodosus*" when only hypovalves occurred. Etymology.—From Latin caveatus, "caged".

Gemellodiscus micronodosus Suto sp. nov.

Figures 2.J-2.M; 12.1-12.14; 14.1

Description.—Frustule heterovalvate. Valve oval to elliptical in valve view, apical axis 12.0–25.5 μm, pervalvar axis 7.0–10.0 μm. In girdle view, epivalve vaulted, with numerous small spines. Mantle of epivalve hyaline. Hypovalve slightly vaulted, with a trun-

cated elevation in the center with a flat plate, marginal zone, two fused setae, outer cage-like sheath and mantle. Flat plate of hypovalve oval to elliptical, slightly concave, with marginal net-like spines connected to the outer cage-like sheath. Fused setae hyaline, smooth, emerging from valve apices of basal plate as curved tubular outgrowths of the valve projecting outside the valve margin, connected to the setae of paired valve. Mantle of hypovalve hyaline with a single ring of puncta at its base. Paired valve formed by two fused setae and hyaline sheath with disconnected basal plate.

Holotype.—Slide MPC-02589 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder O30-2S, illustrated in Figures 12.9, 12.10).

Type locality.—DSDP Site 338-19-3, 20–21 cm, Norwegian Sea.

Similar taxa.—This species differs from G. caveatus by having an epivalve face with numerous small spines.

Stratigraphic occurrence.—The frustule of this species occurs very rarely and sporadically in the lowest Miocene *Denticulopsis praefraga* Zone (NPD 1) at DSDP Site 338 (Figure 4).

Remarks.—The epivalve of this species is very difficult to distinguish from that of Xanthiopyxis hirsuta (Suto, 2004b). Thus, this type of valve was counted as "valve of X. hirsuta and epivalve of G. micronodosus" when an isolated epivalve was encountered. The hypovalves of G. caveatus and G. micronodosus (Figures 13.1–13.14; 14.4) are very similar and therefore, they were counted as "hypovalve of G. caveatus and G. micronodosus".

Etymology.—From the Greek and Latin micro-nodosus, "with minute knobs".

Hypovalves of *Gemellodiscus caveatus* and *G. micronodosus*

Figures 2.M; 13.1-13.14; 14.4

Same type hypovalve.—Xanthiopyxis sp. A of Lee, 1993, p. 46, pl. 2, fig. 14.

[←] Figure 10. 1–25. Gemellodiscus bifurcus Suto sp. nov., LM scale bar = 10 μm for figures 1–24; SEM scale bar = 5 μm for figure 25. 1, 2. Girdle view of frustule, DSDP Hole 438A-62-1, 20–24 cm. 3, 4. Girdle view of frustule, DSDP Hole 438A-70-1, 16–20 cm. 5, 6. Girdle view of frustule, DSDP Hole 438A-70-1, 16–20 cm. 7, 8. Girdle view of frustule, DSDP Site 338-12-2, 40–41 cm. 9, 10. Girdle view of frustule, DSDP Hole 438A-70-1, 16–20 cm. 11, 12. Girdle view of frustule, DSDP Hole 438A-49-3, 10–14 cm. 13, 14. Holotype. Girdle view of frustule, DSDP Site 436-3-3, 100–102 cm. 15, 16. Valve view of frustule, DSDP Site 436-5-2, 148–150 cm. 17, 18. Girdle view of frustule, DSDP Site 338-8-1, 140–141 cm. 19, 20. Girdle view of frustule, DSDP Site 338-11-1, 50–51 cm. 21, 22. Girdle view of frustule, Newport Beach Section N9. 23, 24. Girdle view of frustule, DSDP Hole 438A-42-1, 14–18 cm. 25. Girdle view of frustule, DSDP Hole 438A-67-1, 112–113 cm.

^{26–31.} Gemellodiscus hirtus Suto sp. nov., LM. Scale bar = 10 μm for each figure. 26, 27. Girdle view of epivalve with paired valve, DSDP Site 436-1-5, 50–52 cm. 28, 29. Holotype. Girdle view of frustule, Newport Beach Section N20. 30, 31. Girdle view of frustule, Newport Beach Section N7.

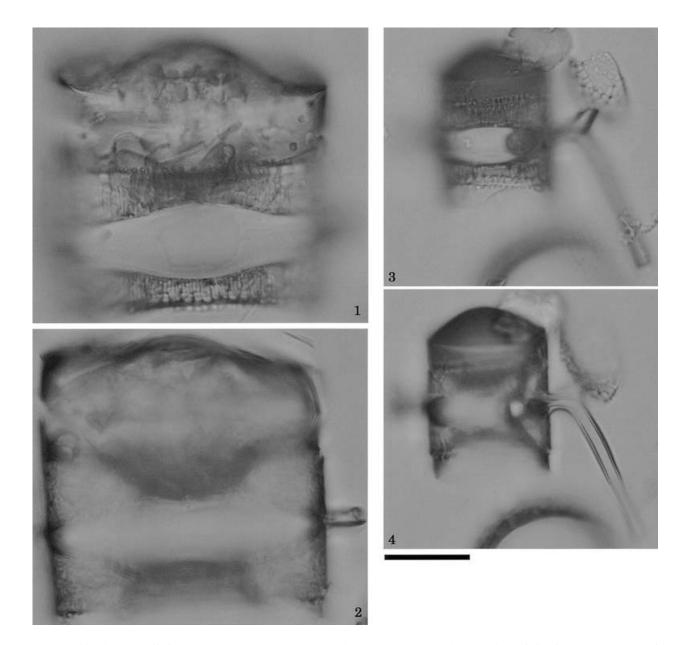
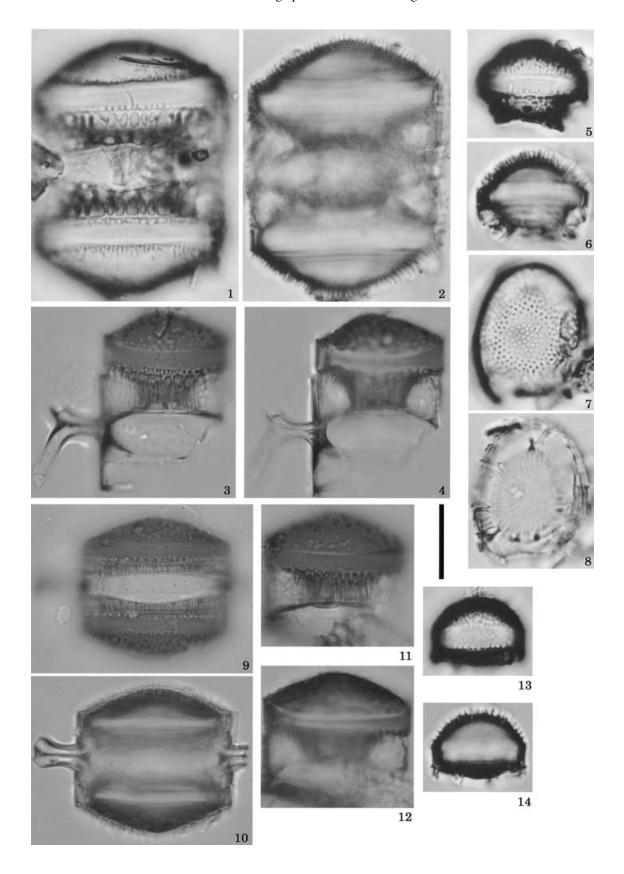
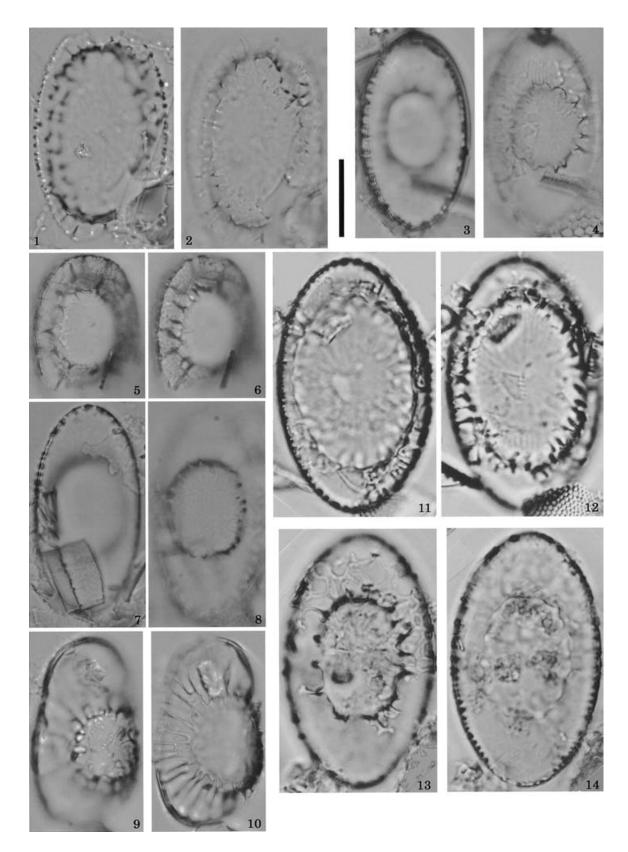


Figure 11. 1–4. *Gemellodiscus caveatus* Suto sp. nov., LM. Scale bar = 10 µm for each figure. **1, 2.** Girdle view of one frustule with one hypovalve, DSDP Site 338-11-4, 70–71 cm. **3, 4.** Holotype. Girdle view of one frustule with one hypovalve, DSDP Site 338-12-2, 40–41 cm.

[⇒] Figure 12. 1–14. *Gemellodiscus micronodosus* Suto sp. nov., LM. Scale bar = 10 µm for each figure. 1, 2. Girdle view of paired frustule, DSDP Hole 438A-64-1, 10–14 cm. 3, 4. Girdle view of frustule, DSDP Site 338-18-1, 148–149 cm. 5, 6. Girdle view of frustule, DSDP Hole 438A-62-1, 20–24 cm. 7, 8. Valve view of frustule, DSDP Hole 438A-63-1, 16–20 cm. 9, 10. Holotype. Girdle view of paired frustule, DSDP Site 338-19-3, 20–21 cm. 11, 12. Girdle view of frustule, DSDP Site 338-18-1, 148–149 cm. 13, 14. Girdle view of frustule, DSDP Hole 438A-66-1, 119–122 cm.





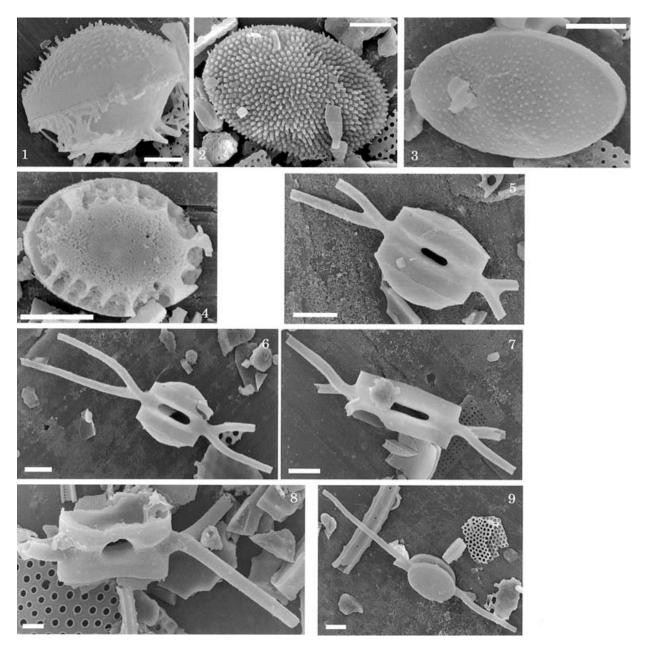


Figure 14. 1. Gemellodiscus micronodosus Suto sp. nov., SEM. Scale bar = $5 \mu m$. 1. Girdle view of frustule, DSDP Site 338-18-1, 148-149 cm.

^{2–3.} Valve of *Xanthiopyxis hirsuta* and epivalve of *G. micronodosus*, SEM. Scale bar = $5 \mu m$ for each figure. **2.** Valve view, DSDP Site 338-18-1, 148–149 cm. **3.** Valve view, DSDP Site 338-18-1, 148–149 cm.

^{4.} Hypovalve of G. caveatus or G. micronodosus 4. Valve view of hypovalve, DSDP Site 338-11-4, 148-149 cm.

^{5–9.} *Gemellodiscus geminus* Suto sp. nov., SEM. Scale bar = 5 μm for each figure. **5.** Girdle view of frustule, DSDP Site 338-17-1, 100–101 cm. **6.** Girdle view of frustule, DSDP Site 338-17-1, 100–101 cm. **7.** Girdle view of paired valve, DSDP Site 338-15-2, 100–101 cm. **8.** Oblique valve view of paired valve, DSDP Site 338-20-3, 90–91 cm. **9.** Oblique valve view of frustule, DSDP Site 338-15-2, 100–101 cm.

[←] Figure 13. 1–14. Hypovalve of *Gemellodiscus caveatus* and *G. micronodosus*, LM. Scale bar = 10 μm for each figure. 1, 2. Valve view of hypovalve, Newport Beach Section N2b. 3, 4. Valve view of hypovalve, DSDP Site 338-15-4, 100–101 cm. 5, 6. Valve view of hypovalve, DSDP Site 338-12-3, 38–39 cm. 7, 8. Valve view of hypovalve, DSDP Site 338-17-1, 100–101 cm. 9, 10. Oblique valve view of hypovalve, Newport Beach section NEW42. 11, 12. Valve view of hypovalve, DSDP Hole 438A-26-4, 10–14 cm. 13, 14. Valve view of hypovalve, DSDP Hole 438A-42-2, 95–96 cm.

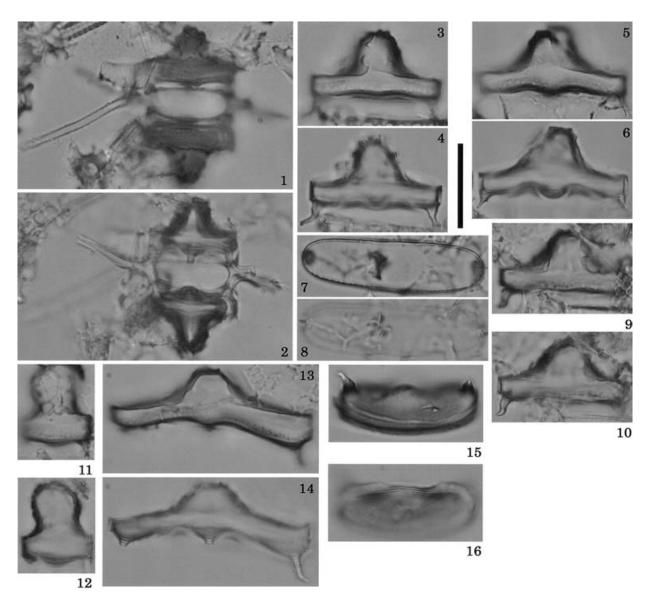
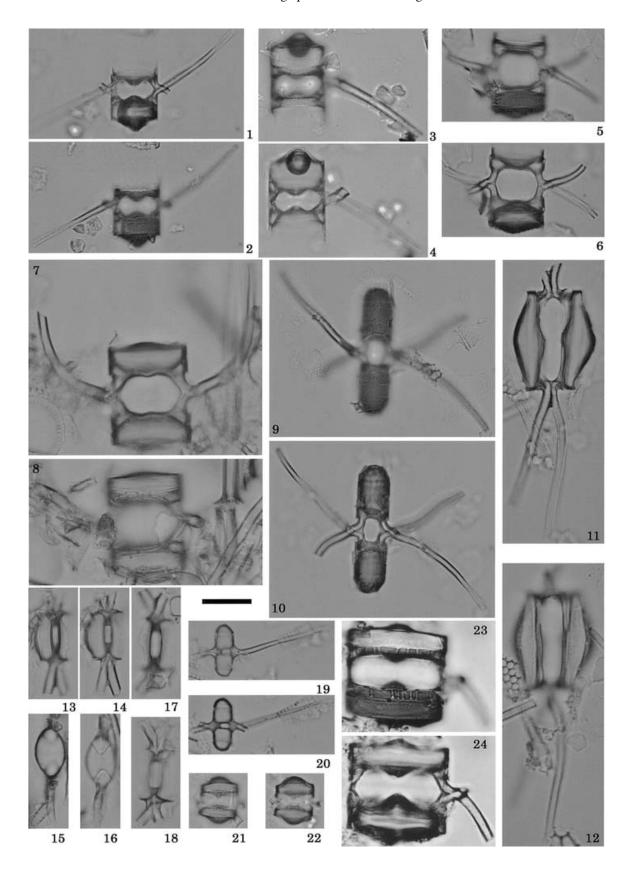


Figure 15. 1–24. *Gemellodiscus dicollinus* Suto sp. nov., LM. Scale bar = $10 \mu m$ for each figure. 1, 2. Holotype. Girdle view of paired frustule, DSDP Site 338-26-4, 80–81 cm. 3, 4. Girdle view of frustule, DSDP Site 338-26-4, 80–81 cm. 5, 6. Girdle view of frustule, DSDP Site 338-26-4, 80–81 cm. 9, 10. Girdle view of frustule, DSDP Site 338-26-4, 80–81 cm. 11, 12. Girdle view of frustule, DSDP Site 338-26-4, 80–81 cm. 13, 14. Girdle view of frustule, DSDP Site 338-26-4, 80–81 cm. 15, 16. Oblique valve view of frustule, DSDP Site 338-38-2, 148–149 cm.

[→] Figure 16. 1–24. Gemellodiscus geminus Suto sp. nov., LM. Scale bar = 10 μm for each figure. 1, 2. Girdle view of frustule and paired valve, DSDP Site 436-12-5, 98–100 cm. 3, 4. Girdle view of frustule and paired valve, DSDP Site 436-12-5, 98–100 cm. 5, 6. Girdle view of frustule and paired valve, DSDP Site 338-15-3, 100–101 cm. 7, 8. Holotype. Girdle view of paired frustule, DSDP Site 338-11-4, 70–71 cm. 9, 10. Girdle view of paired frustule, DSDP Site 338-19-1, 130–131 cm. 11, 12. Girdle view of paired frustule, DSDP Site 338-22-2, 10–11 cm. 13, 14. Girdle view of frustule and paired valve, DSDP Site 338-8-3, 80–81 cm. 15, 16. Valve view of frustule, DSDP Site 338-9-1, 50–51 cm. 17, 18. Girdle view of paired valve, DSDP Site 338-9-1, 50–51 cm. 21, 22. Girdle view of paired frustule, DSDP Site 338-9-1, 50–51 cm. 21, 22. Girdle view of paired frustule, DSDP Hole 438A-27-4, 20–24 cm.



Description.—In valve view, hypovalve oval to broadly elliptical. In girdle view, hypovalve slightly vaulted, with a truncated elevation in the center, a flat plate and mantle. The flat plate of hypovalve oval to elliptical, slightly concave, with marginal net-like spines. Mantle of hypovalve hyaline with a single ring of puncta at its base.

Stratigraphic occurrence.—This type of hypovalve occurs from the lower Oligocene to the upper Pliocene (Figure 3).

Remarks.—Xanthiopyxis sp. A of Lee (1993) is assignable to this hypovalve, because the specimen possesses sharp spines surrounding the central hyaline zone.

Gemellodiscus dicollinus Suto sp. nov.

Figures 2.O; 15.1-15.16

Synonymy.—Resting spore of Schrader and Fenner, 1976, pl. 45, fig. 16.

Description.—Frustule heterovalvate. Valve oval to elliptical in valve view, apical axis 8.0– $24.0~\mu m$, pervalvar axis 6.0– $10.0~\mu m$. In girdle view, epivalve vaulted or inflated in the center, with numerous knobs. Mantle of epivalve hyaline. Hypovalve slightly vaulted in the center, with two crossed setae, and mantle. Crossed setae hyaline, smooth, emerging from valve apices of hypovalve as nearly straight or strongly curved tubular outgrowths of the valve projecting outside the valve margin, crossed and fused with the setae of paired valve for a rather long distance, polygonal in cross-section. Mantle of hypovalve hyaline with a single ring of puncta at its base. Paired valve formed by two crossed setae with disconnected basal plate.

Holotype.—Slide MPC-02584 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder N40-4N, illustrated in Figures 15.1, 15.2).

Type locality.—DSDP Site 338-26-4, 80–81 cm, Norwegian Sea.

Similar taxa.—This species is very similar to G. dimontanus and G. geminus but differs from them by having an epivalve vaulted in the center with numerous knobs.

Stratigraphic occurrence.—This species occurs very abundantly in the middle Eocene at DSDP Site 338 (Figure 4).

Remarks.—Chaetoceros sp. A of Harwood et al. (2000, fig. 7p) and Chaetoceros spp. of Iwai and Winter (2002, pl. 23, fig. 6), both of which were found in the Pliocene and Pleistocene sediments in the Antarctic, are very similar to G. dicollinus in the in-

flated epivalve with knobs. They may be related to this morpho-genus, but were not examined in this study.

Etymology.—From the Latin dicollinus, meaning "two-hilled".

Gemellodiscus geminus Suto sp. nov.

Figures 2N; 14.5-14.9; 16.1-16.24

Synonymy.—Chaetoceros didymus Ehrenberg sensu Makarova, 1962, p. 50, pl. 4, figs. 7–14; Hanna, 1970, p. 182, fig. 97 nec figs. 62, 98; Shirshov, 1977, pl. 24, figs. 10, 11; Harwood and Bohaty, 2000, p. 91, pl. 2, figs. j, k; Chaetoceros sp. V of Hajós, 1968, p. 131, pl. 34, fig. 14; Chaetoceros debilis Cleve sensu Schrader, 1973, pl. 17, figs. 12, 13; Chaetoceros sp. of Schrader and Fenner, 1976, p. 968, pl. 6, fig. 15, pl. 38, figs. 5, 7 nec fig. 6; Barron and Mahood, 1993, p. 38, pl. 6, figs. 3, 4.

Description.—Frustule heterovalvate. Valve oval to elliptical in valve view, apical axis 3.5–21.0 μm, pervalvar axis 2.0–10.0 μm. In girdle view, epivalve hyaline, vaulted. Mantle of epivalve hyaline. Hypovalve vaulted, with two crossed setae, and mantle. Crossed setae hyaline, smooth, emerging from valve apices of hypovalve as nearly straight or strongly curved tubular outgrowths of the valve projecting outside the valve margin, crossed and fused with the setae of paired valve for a rather long distance, polygonal in cross-section, parallel to apical plane. Mantle of hypovalve hyaline with a single ring of puncta at its base. Paired valve formed by two crossed setae with disconnected basal plate.

Holotype.—Slide MPC-02585 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder H30-2C, illustrated in Figures 16.7, 16.8).

Type locality.—DSDP Site 338-11-4, 70–71 cm, Norwegian Sea.

Similar taxa.—This species differs from G. dimontanus and G. dicollinus by its hyaline epivalve.

Stratigraphic occurrence.—Middle Eocene to Recent (Figure 3).

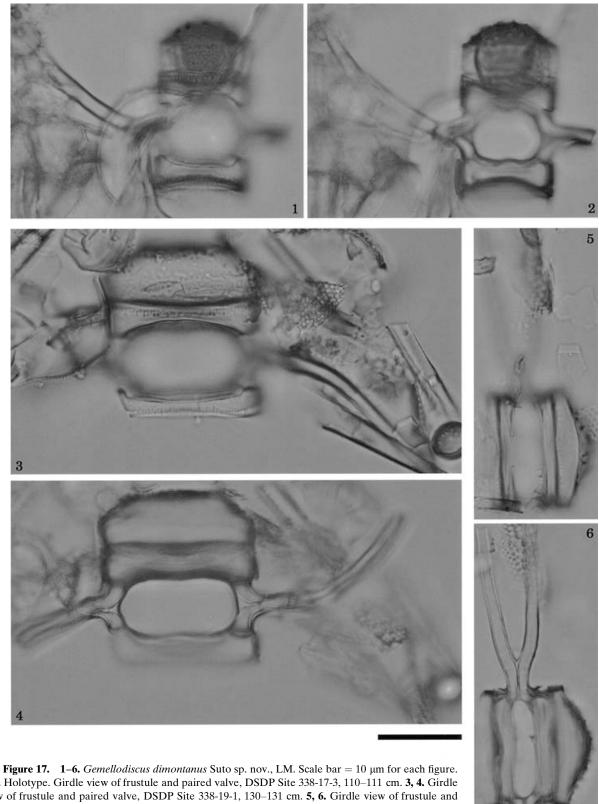
Remarks.—This species may be an ancestor of the extant species Chaetoceros didymus Ehrenberg because of their similarity (e.g., Stockwell and Hargraves, 1984), but the relationship between them cannot be determined because the vegetative valves were not preserved as fossils. Therefore, the morphogenus Gemellodiscus is used in this study.

Etymology.—From Latin geminus, meaning "twin".

Gemellodiscus dimontanus Suto sp. nov.

Figures 2P; 17.1-17.6

Synonym.—Chaetoceros sp. of Dzinoridze et al., 1978, pl. 9, figs. 13–15.



1, 2. Holotype. Girdle view of frustule and paired valve, DSDP Site 338-17-3, 110-111 cm. 3, 4. Girdle view of frustule and paired valve, DSDP Site 338-19-1, 130–131 cm. **5, 6.** Girdle view of frustule and paired valve, DSDP Site 338-19-4, 10–11 cm.

Description.—Frustule heterovalvate. Valve oval to elliptical in valve view, apical axis 11.0–19.0 μm, pervalvar axis 5.0–7.5 μm. In girdle view, epivalve vaulted, covered with numerous knobs. Mantle of epivalve hyaline. Hypovalve vaulted, with two crossed setae, and mantle. Crossed setae hyaline, smooth, emerging from valve apices of hypovalve as nearly straight or strongly curved tubular outgrowths of the valve projecting outside the valve margin, crossed and fused with the setae of paired valve for a rather long distance, polygonal in cross-section, parallel to apical plane. Mantle of hypovalve hyaline with a single ring of puncta at its base. Paired valve formed by two crossed setae with disconnected basal plate.

Holotype.—Slide MPC-02586 (Micropaleontology Collection, National Science Museum, Tokyo, England Finder L32-1W, illustrated in Figures 17.1, 17.2).

Type locality.—DSDP Site 338-17-3, 110–111 cm, Norwegian Sea.

Similar taxa.—This species is very similar to G. geminus, but differs by having an epivalve covered with numerous knobs. This species differs from G. dicollinus by having an inflated, rather vaulted epivalve.

Stratigraphic occurrence.—This species occurs rarely and sporadically in the interval from lower Oligocene to lower Miocene at DSDP Site 338 (Figure 4).

Etymology.—From Latin *dimontanus*, meaning "possessing two mountains".

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