Title

Thalassionema bifurcum sp. nov., a new stratigraphically important diatom from Pliocene subantarctic sediments

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Abstract

A new diatom species *Thalassionema bifurcum* Kato et Suto is described from Pliocene subantarctic deep-sea sediments (DSDP Site 513 and IODP Site U1371). The stratigraphic occurrence of *Thalassionema bifurcum* is likely to be confined to the early Pliocene and shows remarkably high abundance (often comprising 50% of the total diatom assemblage). It can be easily distinguished from other *Thalassionema* species by its bifurcated apices. Considering the short stratigraphic range and its unique morphological character, this taxon seems to be a useful stratigraphic marker to identify the early Pliocene in Southern Ocean sediments.

Introduction

The diatom genus *Thalassionema* Grunow is needle-shaped and cosmopolitan in all but the high-latitude Arctic and Antarctic seas (Hasle & Syvertsen 1997). Their valve morphologies are highly variable and the genus consists of more than 18 taxa, which have been defined mainly by their valve outlines (Hallegraeff 1986; Moreno-Ruiz & Licea 1995; Tanimura et al. 2007). *Thalassionema* species often show high abundance, are often dominant components of the planktonic diatom flora (e.g., Saijo et al. 1969; Romero & Hensen 2002) and range in age from the Eocene to Recent (e.g., Barron 1985; Baldauf & Barron 1991; Harwood & Maruyama 1992; Gladenkov & Barron 1995; Bianchi & Gersonde 2002; Bart & Iwai 2012).

During a micropaleontological investigation of subantarctic sediment core samples (Deep Sea Drilling Project: DSDP Leg 71 Site 513, **Fig. 1**), many of the observed *Thalassionema* specimens were clearly different in morphology from the previously described species, except for those shown by Suto & Uramoto (2015) as "*Thalassionema* sp. A" from Integrated Ocean Drilling Program (IODP) Expedition 329 Site U1371 (**Fig. 1**). In the present study, therefore, we formally describe *Thalassionema bifurcum* sp. nov. and show its stratigraphic occurrences.

Materials and methods

In this study, we investigated sediment samples obtained from DSDP Leg 71 Site 513 (47º35'S, 24º38'W; water depth 4,383 m; **Fig. 1**), located on the lower flank of the Mid-Atlantic Ridge to the east of the Argentine Basin (Shipboard Scientific Party 1983) in the Atlantic sector of the Southern Ocean.

For light microscope (LM) observations of fossil diatoms, 50 microslides were prepared using selected samples from Core 71-513A-1-1, 20–21 cm (56.70 meters below sea floor; mbsf) to Core 71-513A-6-5, 5–6 cm (164.05 mbsf). Temporal resolutions (i.e., time interval between samples) are ca. 0.1 million years and the ages correspond to late Miocene–Pliocene (ca. 6.5–3 Ma). To determine the fluctuation of several *Thalassionema* species in the diatom assemblages, 400 valves of diatoms were counted at the species level for each sample. The LM observations were carried out using an Olympus BX50 light microscope with a differential interference contrast condenser at magnifications of 600x and 1000x. After counting, the slides were scanned to record the presence of species missed in the original tally. Changes in abundance of the new species are categorized in the following way: dominant (>50% of assemblage), abundant (30–50%), common (15–30%), few (3–15%), rare (<3%), trace (observed only sporadically). In addition, we have measured several morphological indices (valve length and width, and number of areolae in 10 μm) of 114 randomly selected specimens derived from three samples; Core 71-513A-3-1, 20–21 cm (85.20 mbsf), Core 71-513A-3-2, 5–6 cm (86.55 mbsf) and Core 71-513A-3-2, 65–66 cm (87.15 mbsf).

Qualitative scanning electron microscope (SEM) observations of the *Thalassionema* specimens were also carried out using two selected samples: Core 71-513A-3-2, 5–6 cm and Core 71-513A-3-2, 65–66 cm (87.15 mbsf), with a Hitachi High-Technology SEM SU6600 at several magnifications in the Laboratory of Geobiology at Nagoya University, Japan. The sample preparation methods for LM and SEM observation are after Kato & Suto (submitted).

We also observed one additional microslide (Core 329-U1371D-9-1, 92–93 cm) from IODP Expedition 329 Site U1371 (45º58'S, 163º11'W; water depth 5,300 m; **Fig. 1**) in LM, which had been investigated by Suto & Uramoto (2015), to confirm that those *Thalassionema* specimens from Sites 513 and U1371 belong to the same species. Site U1371 is located in the subantarctic region of the South Pacific (**Fig. 1**).

Diatom terminology follows that of Anonymous (1975). Numerical ages and geological epochs used herein according to the Cenozoic geochronologic scale after Gradstein et al. (2012). The terms "the late Miocene" and "early Pliocene" are given according to Gradstein et al. (2004) where Miocene and Pliocene are divided into subepochs.

Results

Observations

Class. Bacillariophyceae

Order. Thalassionematales

Family. Thalassionemataceae

Genus. Thalassionema

Thalassionema bifurcum Kato et Suto sp. nov. (**Figs. 2–37**)

Synonym. Thalassionema sp. A (Suto & Uramoto 2015, Pl. P10, figs. 1–10)

Description. Valve linear, 30–100 μm long, 3.5–6 μm wide (**Fig. 38**). Middle part of the valve slightly inflated. One marginal row of areolae at the valve face/mantle junction, areolae 9–13 in 10 μm throughout the valve (**Fig. 39**). Valve ends isopolar and slightly rounded with compressed apices, forming a somewhat bifurcated shape. In internal view, two rimoportulae on each pole (**Figs. 29–37**), not visible in LM. The labiate processes are oblique (e.g., **Fig. 37**) to parallel (e.g., **Fig. 31**) to the mid-line of the valve.

Holotype. Slide MPC-32999, Micropaleontology Collection, National Science Museum, Tokyo. Holotype specimen (England Finder Q30-3) is from 71-513A-3-1, 20–21 cm (**Figs. 20–21**).

Isotypes. Slides MPC-33000 and -33001, Micropaleontology Collection, National Science Museum, Tokyo. Isotype specimens (England Finder Q31-1 and N29-2) are from 71-513A-3-2, 35–36 cm (**Figs. 8–9**) and 329-U1371D-9-1, 92–93 cm (**Figs. 18–19**).

Type locality. Subantarctic Atlantic, DSDP Leg 71 Site 513 (47º35’S, 24º38’W).

Type level. Early Pliocene.

Remarks. The length and width of the new species are highly variable (**Fig. 38**). The specimens described here include “normal form” (**Figs. 2–11, 18–21**) and “long-slender form” (**Figs. 12–17**). Comparing the typical “long-slender form” and “normal form” might suggest that the “long-slender form” belongs to a different taxon (variety or forma) of *Thalassionema bifurcum* sp. nov. Despite that, they are included in the same taxon in this study, as there is no critical morphological diagnosis that distinguishes the “long-slender form” from the “normal form" and they cannot be clearly separated in the width-length diagram (**Fig. 38**). This new species can easily be separated from other *Thalassionema* taxa by the bifurcated ends (**Table 1**).

Stratigraphic occurrence. At Site 513, the first and last occurrence datums of *Thalassionema bifurcum* sp. nov. are observed at ca. 5.0 and 4.5 Ma, respectively (**Fig. 40**). This taxon shows significantly high abundance (often comprising 50% of the total diatom assemblage, **Fig. 40, Table 2**). On the other hand, the stratigraphic occurrence at Site U1371 ranges from ca. 5.3 Ma to ca. 4.3 Ma, with a distinct peak where it comprises >50% of the total diatom assemblage (**Fig. 40**, **Table 3**).

Etymology. The Latin *bifurcum* means fork, which represents the bifurcated ends of valve.

Discussion

Usefulness of the taxon as a stratigraphic marker

Thalassionema bifurcum sp. nov. is potentially useful as a biostratigraphic marker, because it has a relatively short stratigraphic range and a specific morphological characteristic that enables easy identification in practical stratigraphic analyses. It should be noted that the stratigraphic common occurrence of this taxon is confined to the early Pliocene (**Fig. 40**).

Strictly speaking, however, there is a slight difference in its stratigraphic range between Sites 513 and U1371. As a whole, this taxon shows longer time range in Site U1371 than in Site 513 (**Fig. 40**). It is presumed that the uncertainty in the age models applied to Sites 513 and U1371 are responsible for this age difference. The magnetostratigraphic data of Site 513 (Salloway 1983) are incomplete especially in the Pliocene section, hence, the age control points of Site 513 are a combination of diatom and paleomagnetic polarity datums (Kato & Suto accepted). In addition, the diatom record of Site U1371 includes reworked or contaminated fossils (at least 30 taxa; Suto & Uramoto 2015), which precludes its precise age determination. Therefore, sporadic occurrences of this taxon observed at ca. 3.4–3.0 Ma (Site U1371; **Fig. 40**) seem to be due to reworking.

A continuous biostratigraphic study at other drilling sites, including the correlation between appearance/extinct events of this taxon and paleomagnetic polarity events, should be conducted. When the stratigraphic range of this taxon is defined by precise age determination, the diatom stratigraphy in this region will become a more practical tool.

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Legends

Fig. 1

Map illustrating study sites, DSDP Leg 71 Site 513 and IODP Expedition 329 Site U1371. AP: Antarctic Peninsula, S. America: South America.

Fig. 2–21

Thalassionema bifurcum sp. nov., LM. Two images in different focuses are shown for each specimen. **Figs. 2–3.** Sample 71-513A-3-2, 5–6 cm. **Figs. 4–5.** Sample 71-513A-3-2, 35–36 cm. **Figs. 6–7.** Sample 71-513A-3-2, 5–6 cm. **Figs. 8–9.** Isotype, Slide MPC-33000, Micropaleontology Collection, National Science Museum, Tokyo. Sample 71-513A-3-2, 35–36 cm. **Figs. 10–11.** Sample 71-513A-3-2, 5–6 cm. **Figs. 12–13.** Sample 71-513A-3-2, 5–6 cm. **Figs. 14–15.** Sample 329-U1371D-9-1, 92–93 cm. **Figs. 16–17.** Sample 71-513A-3-2, 5–6 cm. **Figs. 18–19.** Isotype, Slide MPC-33001, Micropaleontology Collection, National Science Museum, Tokyo. Sample 329-U1371D-9-1, 92–93 cm. **Figs. 20–21.** Holotype, Slide MPC-32999, Micropaleontology Collection, National Science Museum, Tokyo. Sample 71-513A-3-1, 20–21 cm.

Fig. 22–28

External view of *Thalassionema bifurcum* sp. nov., SEM. Scale bars = 5 µm. **Figs. 22, 26, 27.** Sample 71-513A-3-2, 5–6 cm. **Figs. 23, 24, 25, 28.** Sample 71-513A-3-2, 65–66 cm

Fig. 29–37

Internal view of *Thalassionema bifurcum* sp. nov., SEM. Sample 71-513A-3-2, 65–66 cm. Scale bars = 5 µm. Arrows indicate the rimoportulae. **Fig. 29.** Whole valve. **Figs. 30–31.** Apices of the valve in Fig. 29. **Fig. 32.** Whole valve. **Figs. 33–34.** Apices of the valve in Fig. 32. **Fig. 35.** Whole valve. **Figs. 36–37.** Apices of the valve in Fig. 35.

Fig. 38

Length-width ratio of *Thalassionema bifurcum* sp. nov. The image on upper left: “long-slender form”, image on lower right: “normal form” (see text).

Fig. 39

Comparison between valve length and number of central areolae in 10 µm of *Thalassionema bifurcum* sp. nov.

Fig. 40

Stratigraphic occurrences of *Thalassionema bifurcum* sp. nov. at DSDP Site 513 and IODP Site U1371. Changes in species abundance at Site U1371 are based on Suto & Uramoto (2015). Age models of Sites 513 and U1371 are after Kato & Suto (accepted) and Suto & Uramoto (2015), respectively.

Table 1

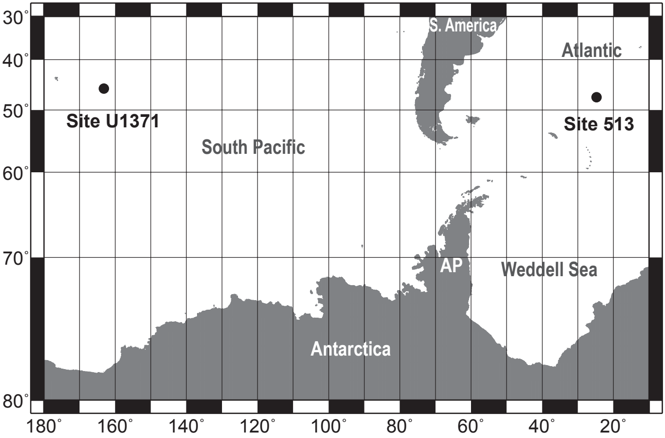
Morphometric features of *Thalassionema* species found in the materials. Morphometric data are quoted from Moreno-Ruiz & Licea (1996) except for those of *Thalassionema bifurcum* sp. nov.

Table 2

Occurrence of *Thalassionema* species in DSDP Site 513. The abundance is shown in percentage. The plus mark (+) indicates presence of species missed in the original tally. G: good, M: moderate, P: poor.

Table 3

Occurrence of *Thalassionema* species in IODP Site U1371. All data presented here are after Suto & Uramoto (2015). The abundance is shown in percentage. The plus mark (+) indicates presence of species missed in the original tally. G: good, M: moderate, P: poor.



30°
40°
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70°
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180°
160°
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120°
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40°
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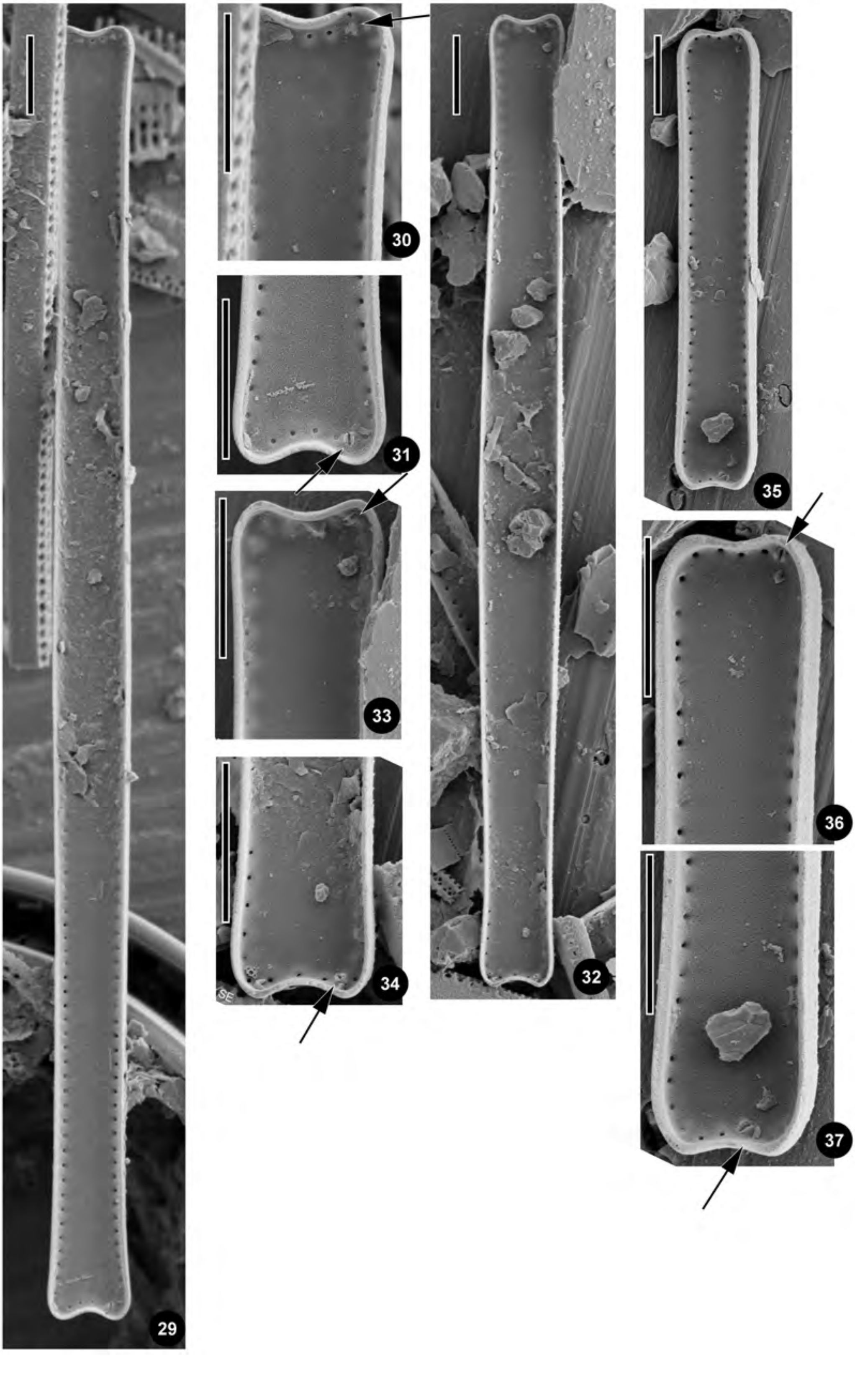
S. America
Atlantic
Site U1371
Site 513
South Pacific
AP
Weddell Sea
Antarctica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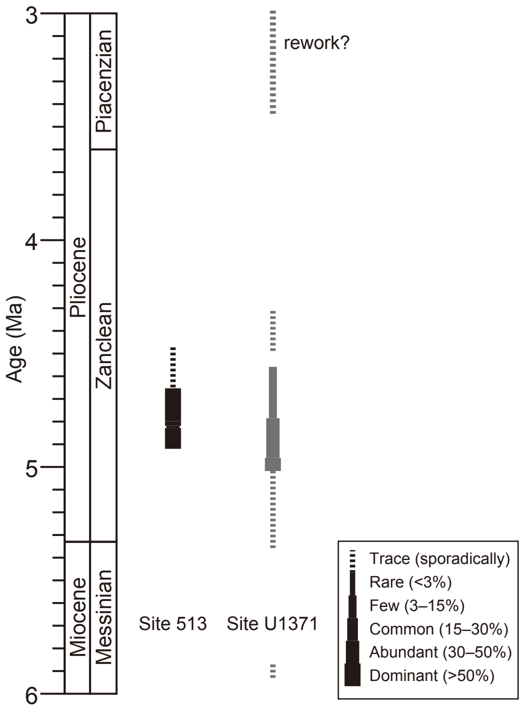

Age (Ma)
3
4
5
6
Pliocene
Miocene
Piacenzian
Zanclean
Messinian
Site 513
Site U1371
rework?
Trace (sporadically)
Rare (<3%)
Few (3–15%)
Common (15–30%)
Abundant (30–50%)
Dominant (>50%)

Table 1

Source	Taxa	Length [µm]	Width [µm]	Areolae in 10 µm		Valve outline	Other distinctive characters
				central	terminal		
a	*Thalassionema bifurcum* sp. nov.	30–100	3.5–6	9–13	9–13	linear, slightly convex margin in the middle	isopolar bifurcated apices
b	*T. nitzschioides*	10–84	2.5–4	7–13	7–14	narrow linear, lanceolate margin	isopolar rounded apices exceptionally pointed or capicate
b	*T. nitzschioides* var. *antiqua*	12–153	4–6.5	10–14	10–14	linear margin to very slightly convex	isopolar apices, strongly rounded
b	*T. nitzschioides* var. *capitulata*	34–69	2.8–6	10–12	10–13	margin slightly convex toward the center of valve	thin valves, isopolar elongated apices, slightly capitate
b	*T. nitzschioides* var. *claviformis*	5–94	1.9–7	8–13	9–13	linear lanceolate margin, semiconcave or semiconvex	heteropolar rounded apices, one apex wider thann the other
b	*T. nitzschioides* var. *incurvata*	8–25	2.3–4	10–13	10–13	cancave valve margin in the middle of valve	isopolar apices, strongly rounded
b	*T. nitzschioides* var. *inflata*	16–43	3.3–6.5	9–12	9–13	convex margin in the middle	thin to heavy silicified valves, isopolar short apices, strongly rounded
b	*T. nitzschioides* var. *lanceolata*	26–117	3.5–8.7	9–12	9–12	lanceolate margin	thin to heavy silicified valves, isopolar apices, strongly rounded
b	*T. nitzschioides* var. *parva*	5–10	2.3–4	9–12	9–12	linear margin	isopolar rounded apices
b	*T. nitzschioides* var. *robusta*	24–47	4.5–6	10–12	9–12	semilinear margin, slightly convex	isopolar apices, strongly rounded

a: this study, b: Moreno-Ruiz & Licea (1996).

Table 2

	Core, section, interval (cm)	Depth (mbsf)	Age (Ma)	Preservation	***Thalassionema bifurcum* sp. nov.**	*Thalassionema nitzschioides* (Grunow) Mereschkowsky	*Thalassionema nitzschioides* var. *antiqua* (Schrader) Moreno-Ruiz	*Thalassionema nitzschioides* var. *capitulata* (Castracane) Moreno-Ruiz	*Thalassionema nitzschioides* var. *claviformis* (Schrader) Moreno-Ruiz	*Thalassionema nitzschioides* var. *incurvata* Heiden et Kolbe	*Thalassionema nitzschioides* var. *inflata* Heiden et Kolbe	*Thalassionema nitzschioides* var. *lanceolata* (Grunow) Peragallo et Peragallo	*Thalassionema nitzschioides* var. *parva* (Heiden) emend. Moreno-Ruiz	*Thalassionema nitzschioides* var. *robusta* (Schrader) emend. Moreno-Ruiz	*Thalassionema* spp.
Pliocene	71-513A-														
	1-1, 20–21	56.7	3.44	M		3					4	1			
	1-2, 5–6	58.05	3.50	M		1					0				
	1-2, 65–66	58.65	3.53	G		3		1			2				
	1-3, 5–6	59.55	3.57	M		1					1		0		
	1-3, 35–36	59.85	3.58	M		6		1			5	0			
	1-3, 65–66	60.15	3.60	M		3					2			1	
	1-3, 81–82	60.31	3.60	G		4		1			2				
	2-1, 5–6	66.05	3.87	M		4		1			3		0		
	2-1, 95–96	66.95	3.91	M		5		1			6		1		
	2-2, 35–36	67.85	3.98	M		1		0			2		1		
	2-2, 65–66	68.15	4.01	M		17		2			13	1	1		
	2-3, 5–6	69.05	4.10	M		7		1		1	15		0	1	
	2-3, 35–36	69.35	4.13	M		15		1			19		2		
	2-3, 95–96	69.95	4.20	M		20		1		0	20		2		
	2-4, 5–6	70.55	4.26	M		12		1		0	17		1		
	2-4, 35–36	70.85	4.29	P		14		0		0	10		1		
	2-4, 95–96	71.45	4.36	P		13		1		0	6				
	2-5, 5–6	72.05	4.42	M		14		5			17		1		+
	2-5, 65–66	72.65	4.46	P		10		3			8		0		
	2-6, 5–6	73.55	4.48	P	+	7		3			5	3			
	2-7, 5–6	75.05	4.52	M	+	2		1			49	20			
	3-1, 20–21	85.20	4.78	M	63	3				0	3		0		12
	3-2, 5–6	86.55	4.81	M	81	1			1		4		1		6
	3-2, 35–36	86.85	4.82	M	38	9		2		0	8		1		20
	3-2, 65–66	87.15	4.83	M	67	5		1		0	2		0		14
	4-1, 5–6	94.55	5.02	M		28	0	12		4	21		9		
	4-2, 5–6	96.05	5.06	G		32		6		6	17		33		
	4-3, 5–6	97.55	5.10	M		28		7		6	19		25		0
	4-4, 5–6	99.05	5.14	M		20		1		2	10		5		0
	4-5, 5–6	100.55	5.18	M		20		1	0	2	16		7		
	4-6, 5–6	102.05	5.22	P		14		1		7	28		3		
	4-7, 5–6	103.55	5.26	M		20		2		2	15		7		
	5-1, 5–6	104.05	5.27	M		24		1	2	11	13		17		
	5-2, 5–6	105.55	5.31	M		22			3	23	9		21		
Miocene	5-3, 5–6	107.05	5.35	M		10	0		3	2	3		8		
	5-4, 5–6	108.55	5.39	G		35		1	0	4	23		9		
	5-5, 5–6	110.05	6.06	M		27		1	1	7	14		18		
	5-5, 65–66	110.65	6.09	M		19		1	4	5	7		23		0
	5-6, 5–6	111.55	6.14	G		21		0	2	5	15		12		
	5-6, 65–66	112.15	6.17	P		20		0	1	9	12		16		0
	5-7, 5–6	113.05	6.21	P		19		0	1	3	33		5		
	6-1, 5–6	113.55	6.24	M		8		+			3		3		
	6-1, 65–66	114.15	6.27	P		6			1	2	0		5		
	6-2, 5–6	115.05	6.32	M		8		2	1	3	1		5		
	6-2, 65–66	115.65	6.35	M		9	0	1	1	7	3		7		
	6-3, 5–6	116.55	6.39	M		7		0	1	2	1		5		
	6-3, 65–66	117.15	6.42	M		45		9		18	3		9		
	6-4, 5–6	118.05	6.47	M		22		13	0	8	1		15		
	6-4, 65–66	118.65	6.50	M		15		3		4	1		6		
	6-5, 5–6	119.55	6.55	M		11		3	1	5	3		27		

Table 3

	Core, section, interval (cm)	Depth CSF-A (m)	Age (Ma)	Preservation	***Thalassionema bifurcum* sp. nov.**	Slender *Thalassionema nitzschioides* (Grunow) Mereschkowsky	Fat *Thalassionema nitzschioides* (Grunow) Mereschkowsky	*Thalassionema* spp.
Pleistocene	329-U1371D-							
	1-1, 66–67	0.67	0.37	P		2	3	
	1-2, 112–113	2.63	0.45	P		4	1	
	1-3, 66–67	3.67	0.49	P		+	+	
	1-4, 112–113	5.63	0.58	P		2	1	
	1-5, 41–42	6.42	0.61	P		+	1	
	2-1, 133–137	8.73	0.70	P		1	+	
	2-2, 67–68	9.58	0.74	P		2	1	
	2-3, 67–68	11.08	0.80	P		2		
	2-4, 67–68	12.58	0.86	P		6	1	
	2-5, 67–68	14.08	0.92	P		2	+	
	2-6, 29–30	15.20	0.97	M		4	+	
	3-1, 112–113	18.03	1.09	G		2		
	3-2, 112–113	19.53	1.15	M		3	+	
	3-3, 112–113	21.03	1.21	M		1	2	
	3-4, 112–113	22.53	1.26	M		12	5	
	3-5, 112–113	24.03	1.30	M		10	2	
	3-6, 112–113	25.53	1.38	G		4	+	
	3-7, 31–32	26.22	1.42	G		5	+	
	4-1, 106–107	27.47	1.51	M		23	3	
	4-2, 106–107	28.97	1.61	G		26	10	
	4-3, 106–107	30.47	1.68	G		16	6	
	4-4, 20–21	31.11	1.68	G		11	1	
	4-5, 20–21	32.61	1.78	G		1	+	
	4-6, 20–21	34.11	1.96	G		13	1	
	5-2, 112–113	35.37	2.11	G		9	1	
	5-3, 112–113	36.87	2.27	M		21	2	
	5-4, 112–113	39.63	2.51	G		32	4	
	5-5, 112–113	41.13	2.56	G		45	7	
Pliocene	6-2, 81–82	44.27	2.63	M		15	1	
	6-3, 81–82	45.92	2.67	M		36	2	
	6-4, 81–82	49.22	2.75	G		13	3	
	6-5, 81–82	50.72	2.82	P		11	+	
	6-6, 81–82	52.22	2.92	M	+	11	3	
	7-1, 43–44	53.78	3.03	P	1	7	+	
	7-2, 43–44	55.28	3.13	M	1	10	1	
	7-3, 43–44	56.84	3.23	M	+	11	1	
	7-4, 15–16	58.20	3.33	G	+	16	1	
	7-5, 15–16	59.70	3.43	G	+	8	2	
	7-6, 30–31	61.13	4.14	G		35	3	
	8-1, 82–83	63.14	4.32	G	+	22	3	+
	8-2, 82–83	64.72	4.50	G	+	14	2	+
	8-3, 82–83	66.73	4.67	P	4	13	4	1
	8-4, 82–83	68.23	4.70	G	6	23	4	+
	8-5, 82–83	69.73	4.73	G	11	19	3	
	8-6, 82–83	71.23	4.84	G	16	12	+	
	9-1, 92–93	73.03	5.08	G	51	8	1	
	9-2, 92–93	74.53	5.28	M	+	89		
Miocene	9-3 , 92–93	76.33	5.52	G		32	1	
	9-4, 92–93	77.83	5.72	G		19	+	
	9-5, 58–59	79.16	5.90	G	+	38	1	
	9-6, 58–59	80.66	6.10	G		42	+	
	9-7, 58–59	81.74	6.25	G	+	51	+	+
	10-1, 80–81	83.10	6.43	G		45	1	
	10-2, 80–81	84.35	6.60	G		41	1	
	10-3, 80–81	85.71	6.78	G		42	1	
	10-4, 80–81	87.21	6.98	G		8	+	1
	10-5, 80–81	88.71	7.18	G		27	2	1
	10-6, 80–81	90.21	7.38	G		62	3	+
	11-1, 51–52	91.81	7.60	G		53	5	
	11-2, 17–18	93.14	7.77	G		36	3	
	11-3, 17–18	94.75	7.99	G		17	4	
	11-4, 17–18	96.08	8.17	G		67	2	
	11-5, 17–18	97.58	8.37	G		34	2	
	11-6, 17–18	99.08	8.57	G		39	2	
	11-7, 17–18	100.84	9.12	G		42	3	
	12-1, 96–97	103.37	10.07	P		24		
	12-2, 45–46	104.36	10.24	P		1	2	