

Supplement of

Sea ice and productivity changes over the last glacial cycle in the Adélie Land region, East Antarctica, based on diatom assemblage variability

Lea Pesjak et al. 2023

Correspondence to Lea Pesjak (lea.pesjak@utas.edu.au)

Table S1 Environmental interpretation of diatom species identified within Tan_44, based on water column and sediment studies from coastal Antarctica to Subantarctic Southern Ocean. The three species types identified by both types of studies include: sea ice associated species (blue), open ocean associated species (yellow), and warmer water associated species (orange; Medlin and Priddle 1990). This list includes *Eucampia* index (Terminal/ Intercalary valve ratio). This list suggests there are some differences in interpretation of species habitat depending on the type of study conducted. Reference notes are: 1) Medlin and Priddle (1990); 2) Ligowski, Godlewski and Lukowski (1992); 3) Garrison and Buck (1989); 4) Kopczynska, Weber and El-Sayed (1986); 5) Tanimura et al. (1990); 6) Scott and Thomas (2005); 7) Kopczyńska, Fiala and Jeandel (1998); 8) Ligowski (1983); 9) Garrison, Buck and Fryxell (1987); 10) Beans et al. (2008); 11) Fryxell (1991); 12) Moisan and Fryxell (1993); 13) Doucette and Fryxell (1985); 14) Johansen and Fryxell (1985); 15) Smetacek et al. (1992); 16) Bodungen et al. (1986); 17) Smith and Nelson (1986); 18) Ishikawa et al. (2001); 19) Pichon et al. (1992); 20) Armand et al. (2005); 21) Romero et al. (2005); 22) Zielinski and Gersonde (1997); 23) Kaczmarek et al. (1993); 24) Leventer (1992); 25) Taylor, McMinn and Franklin (1997); 26) Crosta et al. (2005).

ENIRONMENTAL INTERPRETATION

W S Species/ index		WATER COLUMN AND SEA ICE STUDIES		SEDIMENT SURFACE STUDIES	
op si	<i>Actinocyclus actinocilius</i> (Ehrenberg) Simonsen	Sea ice edge; rare in ice; coastal ^{1,2,3}		Sea ice >7 months/yr; sea ice edge; along ice shelves ^{19,20}	
op w	<i>Aspetitia tabularis</i>	Subantarctic, rare near sea ice ¹		Open ocean, warmer water; north of Polar Front ^{21,22}	
op w	<i>Asteromphalus hyalinus</i> Karsten	Coastal, north and south of Polar Front ^{4,5,6}		Open ocean, warmer water; north of Polar Front ²¹	
op w	<i>Asteromphalus parvulus</i> Karsten	Coastal; north and south of Polar Front ^{4,6}		Open ocean, warmer water; north of Polar Front ²¹	
op	<i>Chaetoceros bulbosum</i> (Ehrenberg) Heiden	Open ocean; south of Polar Front; rare in ice ^{7,3}			
op	<i>Chaetoceros dichæta</i> (Ehrenberg)	Open ocean; sea ice; south of Polar Front ^{8,9,4,7}			
op op	<i>Eucampia antarctica</i> (Castracane) Mangin	Open ocean; south of Polar Front; rare in sea ice ^{3,10}			
si si	<i>Eucampia</i> index	Higher index indicates Winter stage (Prydz Bay) i.e. more sea ice ¹¹			
op op	<i>Fragilariopsis kerguelensis</i>	Open ocean; south of Polar Front; rare in sea ice; increases offshore ^{4,3,7}		Coastal to Subtropical Front; increases in glacial intervals ^{22,23}	
op si	<i>Fragilariopsis angulata</i>	Open ocean ¹		Sea ice; along ice shelves (Ross Sea) ^{19,23}	
si si	<i>Fragilariopsis cylindrus</i>	Sea ice; sea ice edge; open ocean; coastal; winter sea ice edge ^{9,12,2}		Open ocean; increases seaward; winter sea ice edge; Polar Front ^{20,22,24}	
si si	<i>Fragilariopsis linearis</i>	Sea ice; ice edge ^{1,12}		Sea ice; coastal ²⁵	
si si	<i>Fragilariopsis obliquecostata</i>	Sea ice ³		Sea ice >7 months/yr; coastal ^{20,22}	
si si	<i>Fragilariopsis obliquecostata</i>	Sea ice; ice edge ^{1,12}		Sea ice; along ice shelves ^{19,20}	
op op	<i>Rhizosolenia antennata</i>	Sea ice; sea ice edge ^{1,12}		Sea ice >7 months/ yr ^{19,20}	
op op	<i>Rhizosolenia styliformis</i> Brightwell	Open ocean ¹⁰		Open ocean; cooler water; sea ice edge ²⁶	
si si	<i>Stellarima microtrias</i> (Ehrenberg) Hasle & Sims	Open ocean; south of 62°S/ south of Polar Front; rare in sea ice ^{4,3}		Open ocean; cooler water; sea ice edge ²⁶	
op op	<i>Thalassiosira lentiginosa</i> (Janish) Fryxell	Sea ice; cold waters ⁶		Sea ice ²⁰	
op op	<i>Thalassiosira oliverana</i>	Open ocean; south of the Polar Front ¹⁴		Open ocean; 0-7°C; between winter sea ice edge and Polar Front; coastal ^{26,22,25}	
op si	<i>Thalassiosira tumida</i> (Janish) Hasle	Open ocean; antarctic and subantarctic ¹		Open ocean; between winter sea ice edge to Polar Front ²⁶	
op op	<i>Thalassiothrix antarctica</i>	Open ocean; ice edge; sea ice; coastal; common south of Polar Front ^{3,17,18,14}		Sea ice >8.5 months/yr ²⁰	
op op	<i>Thalassiothrix longissima</i> Cleve and Grunow	Open ocean; coastal; sea ice edge; south of Polar Front ^{2,10,8,7}		Open ocean; diatom ooze belt ^{19,26}	
op op	<i>Trichotoxon reinboldii</i>	Open ocean; rare in sea ice ³		Open ocean ²⁶	
		Open ocean ¹		Open ocean; cooler water; south of Polar Front ^{26,25}	

W interpretation based on water column studies

S interpretation based on sediment surface studies

si sea ice related species

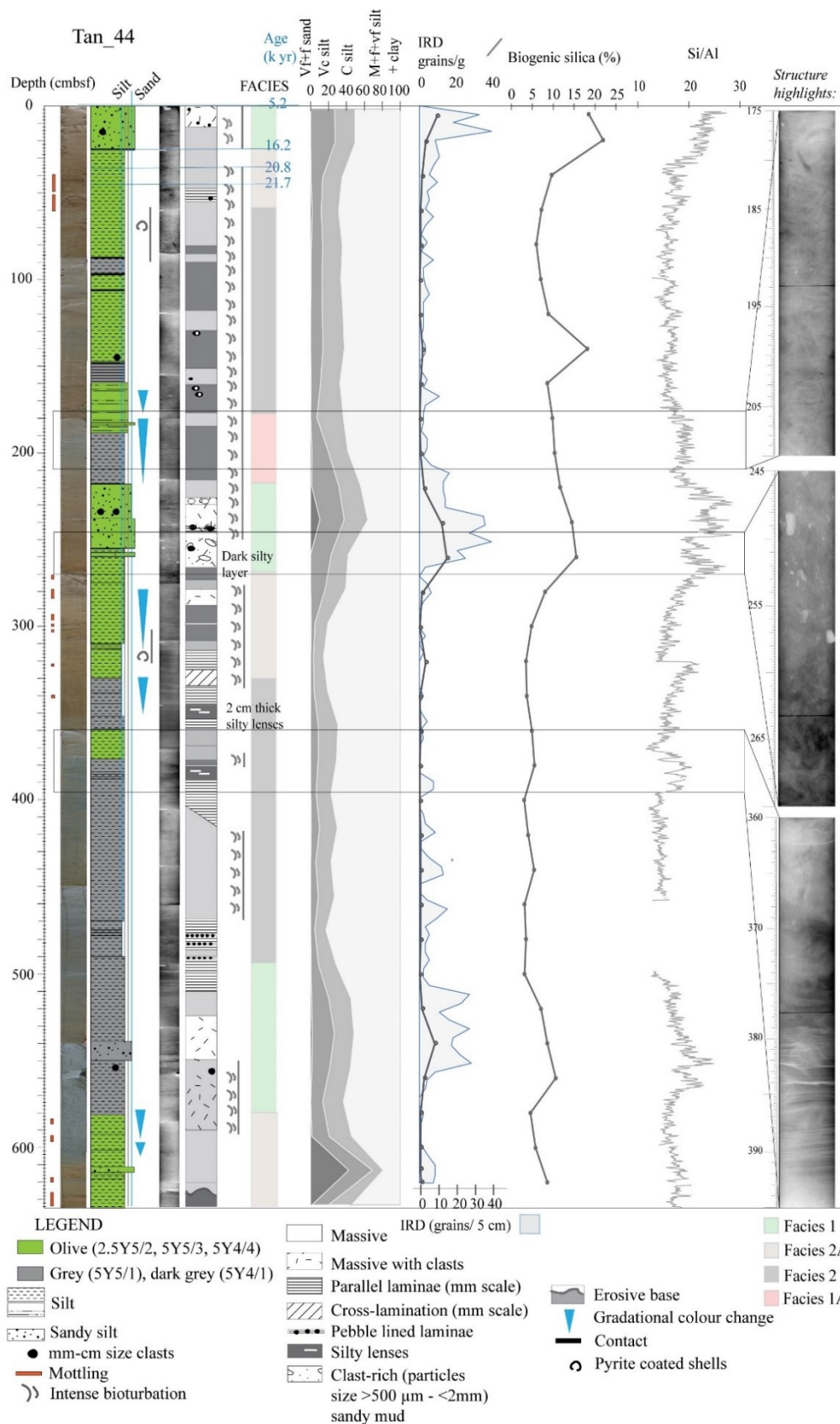


Figure S1 Lithology, structure, grain size, biogenic silica, ice rafted debris (IRD) counted from sieved sections (grains/g) and from X-radiographs (grains/ 5 cm), Si/Al (XRF-derived). Included in this figure is the facies interpretation of core Tan_44. The facies model is based upon primary lithology identified in core logs (olive sandy mud; olive mud; grey mud; and olive-grey mud), Si/Al, biogenic silica and IRD results. Included are X-radiographs of parts of core.

S1 Development of the facies model

S1.1 Methods

Tan_44 lithology was described on the voyage (Williams 2013). The X-radiographs were completed at the National Institute of Water and Atmospheric Research (NIWA; Williams 2013).

S1.1.1 Grain Size

Grain size was determined using a Beckman Coulter 13320 laser diffraction particle size analyser. Sampling for grain size was taken at 20 cm resolution down core. A sample size of 0.5 x 0.5 cm was soaked overnight in a mixture of sodium hydrogen carbonate, sodium carbonate (anhydrous) and water. The sediment in solution was then shaken and placed through a sonic bath for 10 second intervals, several times, to disaggregate clay. This sample was poured into the grain size analyser through a 1.8 mm sieve and analysed for 60 seconds, prior to a 3-minute cleaning routine. The grain size statistics were calculated using GradistatV8 software (Blott & Pye 2001), which uses the Folk and Ward method for size distribution and description.

S1.1.2 X-ray fluorescence (XRF) data: Fe, Ti, Fe/Ti, Ba/Ti, Zr/Rb

The XRF methods are explained in the manuscript under section Si/Al.

S1.2 Results

S1.2.1 Lithology

Four lithological units are identified in Tan_44 (Fig. S1), based on visual logs (Williams 2013) and structural features identified in X-radiographs (Fig. S1). Unit 1 is olive sandy mud, comprising olive (2.5Y5/2, 5Y5/3), or grey colour (5Y4/1, 5Y5/1) within 581-493 cm section, and is characterised by a sandy texture, massive structure with dispersed >1 mm sized grains. Unit 2A is olive mud (2.5Y5/2; 5Y4/4) comprising a massive structure, bioturbation, and rare traction structures, i.e., lenses and laminae. Mottling is found at 46-37 cm; 58-54 cm; 584 cm, 594 cm, and 619 cm. Unit 2 is grey mud, comprising grey (5Y5/1) and olive (2.5Y5/2) colour, within section 147-59 cm and is characterised by a finer texture (than Unit 1). The younger Unit 2 (178-59 cm) contains a massive structure with evident bioturbation within the 147-59 cm section, while the older Unit 2 (493-331 cm) contains laminae and pebble-lined laminae. Gradation is observed at the base of the younger unit (at 178-159 cm), and within the lower unit (at 353-331 cm). Unit 1A is olive-grey mud (2.5Y 5/2) comprising a finer texture (than in Unit 1), with a massive structure and evident bioturbation.

S1.2.2 Grain size

A down core grain size pattern exists, formed by the alternation of coarser grained (sandy silt) and finer grained (silt) sediments (Fig. S1). The sandy silt intervals consist of 1-9% very fine to fine sand and, 19-27% very coarse silt. The silt intervals consist of increased medium silt to clay, up to 68% in the upper core, and up to 86% in the lower core. The sandy silt intervals coincide with higher Zr/Rb values and Unit 1. The silt intervals coincide with lower Zr/Rb, and Unit 2, Unit 2A and Unit 1A (Fig S1; Fig. S2).

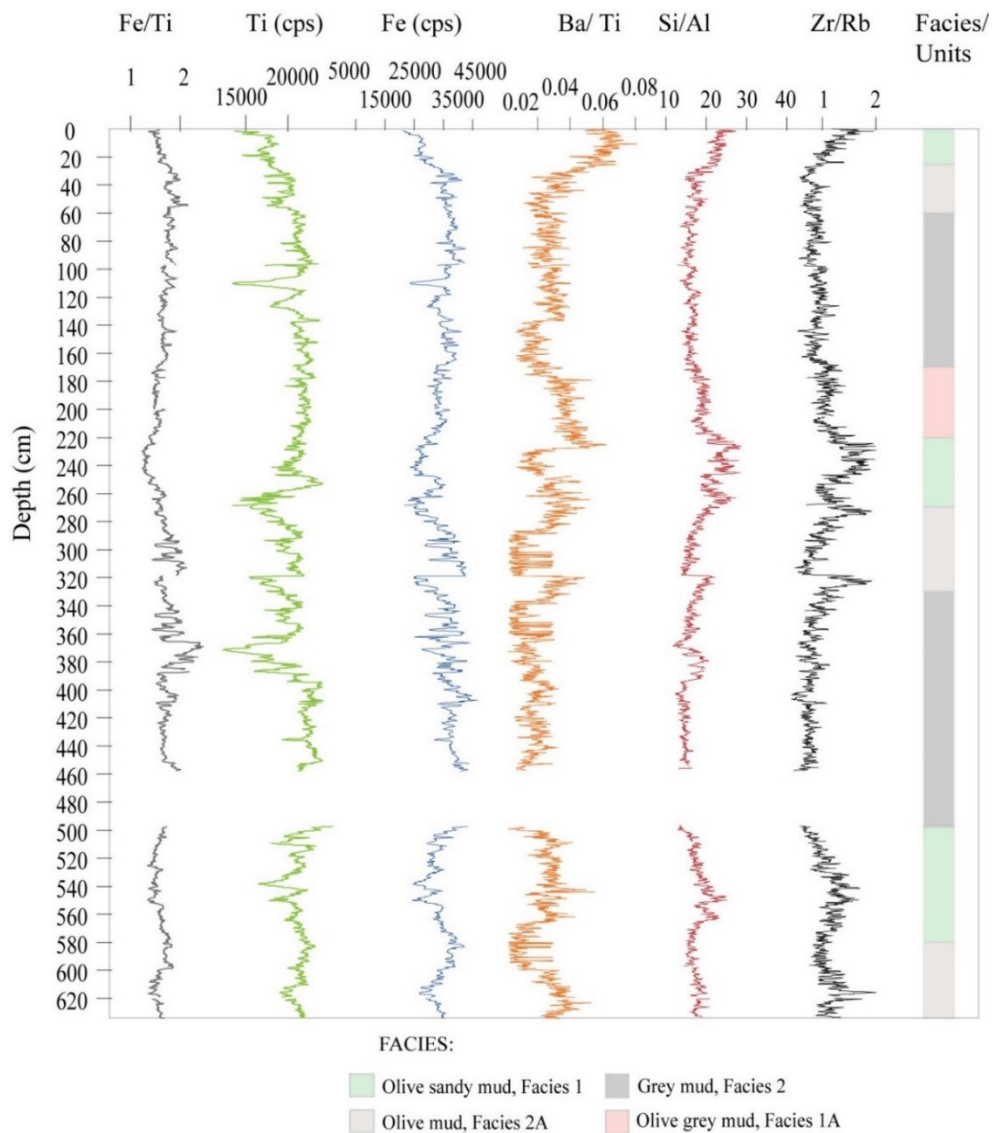


Figure S2 XRF data in Tan_44: Fe/Ti; Fe; Ti; Ba/Ti; Si/Al and Zr/Rb down core values, compared to glacial, interglacial, deglacial and glaciation facies occurrence

S1.2.3 X-ray fluorescence (XRF) data: Fe, Ti, Fe/Ti, Ba/Ti, Zr/Rb

Fe and Ti are generally parallel down core. Fe values range from ~23,000- ~44,000 counts per second (cps) and Ti values range from ~ 6,000-25,000 cps. Lower Fe values (~<33,000) are found in core sections 30-0 cm, 280-220 and 575-500 cm, which coincide with Unit 1 (Fig. S2). Similarly, lower Ti values occur in Unit 1. Fe/Ti

values range from ~1.3- ~2.0, with lower values (<1.5) at 30-0 cm, 285-218 cm, and 580-500 cm, coinciding with Unit 1, and higher values (>1.5) coinciding with Unit 2 and Unit 2A.

Ba/Ti and Zr/Rb are generally parallel down core, aligned with Si/Al (Fig. S2), except within 255-230 cm (Unit 1) section where Ba/Ti decreases significantly. Ba/Ti values range from 0-0.06, with highest values (0-0.06) associated with Unit 1 and Unit 1A, and lower values (0-0.04) associated with Unit 2 and Unit 2A, and in the 255-230 cm section of Unit 1. Zr/Rb values range from 0.6-1.8, with highest values (~>1) associated with Unit 1 and Unit 1A, and lower values (~<1) associated with Unit 2 and Unit 2A, except in 331-328 cm section of Unit 2A, where slightly higher Zr/Rb values are found.

Table S2 Q-mode principal component factor loadings of each principal component (assemblage; PC 1-3).

	PC 1	PC 2	PC 3
<i>Fragilariopsis kerguelensis</i>	0.258	0.081	-0.282
<i>Actinocyclus actinochilus</i>	-0.636	-0.146	0.628
<i>Eucampia antarctica</i>	-0.935	-0.209	0.000
<i>Fragilariopsis</i> group	-0.200	0.904	-0.039
<i>Actinocyclus ingens</i>	-0.074	-0.218	0.801
<i>Thalassiosira tumida</i>	0.179	0.566	0.010
<i>Thalassiosira oestrupii</i>	0.283	-0.007	0.029
<i>Asteromphalus parvulus</i>	0.068	0.669	-0.093
<i>Asteromphalus hyalinus</i>	0.480	0.257	-0.256
<i>Thalassiosira lentiginosa</i>	0.983	0.100	-0.118
<i>Azpeitia tabularis</i>	0.675	-0.296	-0.048
<i>Thalassiosira oliverana</i>	0.030	0.328	0.525

Table S3 R-mode principal factor analysis: the main components (PC 1-2) loadings down core.

Depth (cm)	PC 1	PC 2
10	0.961	0.262
20	0.946	0.297
30	0.973	0.222
40	0.964	0.121
50	0.972	0.132
60	0.635	0.682
70	0.119	0.990
80	0.185	0.981
90	0.113	0.988
100	0.157	0.982
110	0.470	0.881
120	0.328	0.943
130	0.566	0.816
140	0.506	0.858
150	0.872	0.481
160	0.760	0.639
170	0.621	0.752
180	0.804	0.546
190	0.797	0.592
200	0.803	0.565
210	0.489	0.741
220	0.831	0.329
230	0.939	0.334
240	0.867	0.469
250	0.873	0.477
260	0.940	0.330
270	0.974	0.168
280	0.662	0.740
290	0.672	0.735

Table S4 List of diatom species in Tan_44, including terminal and intercalary valve counts of *Eucampia antarctica*.

DEPTH (cm)	5	20	30	40	50	60	70	80	90	100	110	120
<i>Actinocyclus actinochilus</i>	7	12	12	20	9	51	28	15	75	27	39	46
<i>Actinocyclus ingens</i>	1	1				45	7		4	2	2	4
<i>Asteromphalus hookeri</i>	5	5	3	6	8		1	3	1	2	1	1
<i>Asteromphalus hyalinus</i>	2	5	5	5	4		2					
<i>Asteromphalus parvulus</i>	4	3	3		3			1		3	1	1
<i>Azpeitia tabularis</i>	14	24	22	31	31				4	1	4	4
<i>Chaetoceros bulbosum</i>				10								
<i>Chaetoceros chriophilus</i>												
<i>Chaetoceros adelianum</i>				1								
<i>Chaetoceros dictyota</i>												
<i>Chaetoceros flexuosus</i>												
<i>Cocconeis costata</i>												
<i>Coscinodiscus asteromphalus</i>		2									2	
<i>Coscinodiscus bouvet</i>				1		1						
<i>Coscinodiscus curvatus</i>	1	6		2	5							
<i>Coscinodiscus oculoides</i>			1	1			1		1			1
<i>Coscinodiscus radiatus</i>				1					1			
<i>Coscinodiscus marginatus</i>												
<i>Coscinodiscus vulnificus</i>		1						1	1			
<i>Eucampia antarctica</i> terminal valve	3	13	9	3	7	41	108	43	100	120	59	103
<i>Eucampia antarctica</i> intercalary valve	30	25	13	7	5	61	140	82	226	222	120	127
<i>Eucampia antarctica</i>	33	38	22	10	12	102	248	125	326	342	179	230
<i>Fragilariopsis kerguelensis</i>	42	8	27	83	87		4		12	13	6	9
<i>Fragilariopsis obliquecostata</i>	1								2		3	1
<i>Fragilariopsis sublinearis</i>	1	1									1	2
<i>Fragilariopsis linearis</i>												
<i>Fragilariopsis rhombica</i>												
<i>Fragilariopsis cylindrus</i>												
<i>Fragilariopsis curta</i>												
<i>Fragilariopsis vanheurckii</i>												
<i>Fragilariopsis seriata</i>	1											
<i>Fragilariopsis ritscherii</i>									1			
<i>Fragilariopsis barbieri</i>					1							
<i>Fragilariopsis pseudonana</i>					1							
<i>Porosira glacialis</i>	2			1		1	1	2			1	
<i>Porosira pseudodenticulata</i>							2					
<i>Rhizosolenia styliformis</i>				1				2		1		
<i>Rhizosolenia polydactyla</i>												
<i>Rhizosolenia</i> sp.							1	1	1			
<i>Rhizosolenia hebetata</i>												
<i>Rhizosolenia setigera</i>							1					
<i>Rhizosolenia antennata</i>												
<i>Rhizosolenia</i> (twin process) <i>antennata</i>												1
<i>Proboscia inermis</i>												
<i>Rhizosolenia curvata</i>												
<i>Stellarima microtrias</i>	3	2	1	1	0	6	1	0	8	5	7	3
<i>Thalassiosira gracilis</i>	2	1		1		1	3	1			4	
<i>Thalassiosira lentiginosa</i>	291	307	324	266	319	164	87	53	118	130	157	144
<i>Thalassiosira oestrupii</i>		2	9	13	12	1	2	2	3	1	3	1
<i>Thalassiosira oliveriana</i>	25	24	9	6	12	26	9	4	17	15	10	17
<i>Thalassiosira ritscherii</i>	2				1	1						
<i>Thalassiosira tumida</i>	5	3	4	9	4		1	2	2	3	3	7
<i>Thalassiothrix antarctica</i>		2		11					1			
<i>Thalassiothrix longissima</i>	1				3							
<i>Trichotoxon reinboldii</i>			1	2	1							
<i>Triceratium</i> spp.												
Total counts	444	446	443	482	513	399	399	212	578	545	423	472

DEPTH (cm)	130	140	150	160	170	180	190	200	210	220	230	240
<i>Actinocyclus actinochilus</i>	46	37	26	29	32	17	24	35	29	20	19	31
<i>Actinocyclus ingens</i>	2	1	1							1		1
<i>Asteromphalus hookeri</i>	2	6	1	8	7	1		2			3	1
<i>Asteromphalus hyalinus</i>		3	16	7	11	1	7	4	3	1	4	9
<i>Asteromphalus parvulus</i>	4	4	1	6	10	6		10	2	2	6	6
<i>Azpeitia tabularis</i>	5		1	3			1	5	4	3	9	4
<i>Chaetoceros bulbosum</i>					4	1						1
<i>Chaetoceros chriophilus</i>					1			1				
<i>Chaetoceros adelianum</i>												
<i>Chaetoceros dictyota</i>		2						20				
<i>Chaetoceros flexuosus</i>				2			1	4				
<i>Cocconeis costata</i>												2
<i>Coscinodiscus asteromphalus</i>						1					1	1
<i>Coscinodiscus bouvet</i>												
<i>Coscinodiscus curvatulus</i>				2	2	1	1	1				2
<i>Coscinodiscus oculoides</i>		3			1	3			1			
<i>Coscinodiscus radiatus</i>												
<i>Coscinodiscus marginatus</i>										1		
<i>Coscinodiscus vulnificus</i>				1					1			
<i>Eucampia antarctica</i> terminal valve	42	58	20	19	35	8	22	20	35	14	11	17
<i>Eucampia antarctica</i> intercalary valve	102	111	65	104	125	73	92	73	163	32	34	79
<i>Eucampia antarctica</i>	144	169	85	123	160	81	114	93	198	46	45	96
<i>Fragilariopsis kerguelensis</i>	11		24	35	58	46	23	42	126	92	15	8
<i>Fragilariopsis obliquecostata</i>	2	1		26	28	31	31	32	7	6	3	5
<i>Fragilariopsis sublinearis</i>	2							1	3			
<i>Fragilariopsis linearis</i>										3		
<i>Fragilariopsis rhombica</i>										2	1	
<i>Fragilariopsis cylindrus</i>												
<i>Fragilariopsis curta</i>												
<i>Fragilariopsis vanheurckii</i>												
<i>Fragilariopsis seriata</i>												
<i>Fragilariopsis ritscherii</i>												
<i>Fragilariopsis barbieri</i>												
<i>Fragilariopsis pseudonana</i>												
<i>Porosira glacialis</i>	1	1	1		1			2				
<i>Porosira pseudodenticulata</i>												
<i>Rhizosolenia styliformis</i>	3	5	3	5	5	4	7	7	2	2	1	2
<i>Rhizosolenia polydactyla</i>					1						1	
<i>Rhizosolenia</i> sp.		2										
<i>Rhizosolenia hebetata</i>					1							
<i>Rhizosolenia setigera</i>												
<i>Rhizosolenia antennata</i>					1							
<i>Rhizosolenia (twin process) antennata</i>				1	2			1	2	1	1	
<i>Proboscia inermis</i>								1				
<i>Rhizosolenia curvata</i>		1										
<i>Stellarima microtrias</i>	5	2	3	3	6	5	6	3	0	0	0	1
<i>Thalassiosira gracilis</i>	2		3								1	4
<i>Thalassiosira lentiginosa</i>	162	164	284	227	194	180	249	202	179	165	293	325
<i>Thalassiosira oestrupii</i>	6	8		8	3	3	6	2	4	3	3	14
<i>Thalassiosira oliveriana</i>	10	11	16	9	16	11	23	26	22	5	19	47
<i>Thalassiosira ritscherii</i>							1	4	1		1	
<i>Thalassiosira tumida</i>	7	1	3	12	11	5	10	12	3	3	10	23
<i>Thalassiothrix antarctica</i>												
<i>Thalassiothrix longissima</i>												
<i>Trichotoxon reinboldii</i>												
<i>Triceratium spp</i>												
Total counts	414	421	468	507	555	397	504	510	587	356	436	583

DEPTH (cm)	250	260	270	280	290	300	310	320	330	340	350
<i>Actinocyclus actinochilus</i>	15	34	3	31	37	5	9	1	1		
<i>Actinocyclus ingens</i>	1			13	7		12				
<i>Asteromphalus hookeri</i>	7	3	1	4	3		2				
<i>Asteromphalus hyalinus</i>	10	5	9	1	1		2				
<i>Asteromphalus parvulus</i>	2	1	3		1						
<i>Aspeitia tabularis</i>	20	27		2			1				
<i>Chaetoceros bulbosum</i>											
<i>Chaetoceros chriophilus</i>											
<i>Chaetoceros adelianum</i>											
<i>Chaetoceros dichæta</i>											
<i>Chaetoceros flexuosus</i>											
<i>Cocconeis costata</i>	1										
<i>Coscinodiscus asteromphalus</i>		1		1			1				
<i>Coscinodiscus bouvet</i>											
<i>Coscinodiscus curvatulus</i>	1	8	1	1						1	1
<i>Coscinodiscus oculoides</i>	1				2						
<i>Coscinodiscus radiatus</i>				1	2						
<i>Coscinodiscus marginatus</i>					2		2			1	
<i>Coscinodiscus vulnificus</i>											
<i>Eucampia antarctica</i> terminal valve		7	2		21	9	4	1			2
<i>Eucampia antarctica</i> intercalary valve	87	71	11	137	118	37	61	3	2	1	2
<i>Eucampia antarctica</i>	87	78	13	137	139	46	65	4	2	1	4
<i>Fragilariopsis kerguelensis</i>	9	63	74	28	8		10				
<i>Fragilariopsis obliquecostata</i>			1	3	4						
<i>Fragilariopsis sublinearis</i>				6	2						
<i>Fragilariopsis linearis</i>		2		2							
<i>Fragilariopsis rhombica</i>											
<i>Fragilariopsis cylindrus</i>			3		5						
<i>Fragilariopsis curta</i>							1				
<i>Fragilariopsis vanheurckii</i>							1				
<i>Fragilariopsis seriata</i>											
<i>Fragilariopsis ritscherii</i>											
<i>Fragilariopsis barbieri</i>											
<i>Fragilariopsis pseudonana</i>											
<i>Porosira glacialis</i>				1							
<i>Porosira pseudodenticulata</i>											
<i>Rhizosolenia styliformis</i>				2	2		1				
<i>Rhizosolenia polydactyla</i>											
<i>Rhizosolenia</i> sp.											
<i>Rhizosolenia hebetata</i>											
<i>Rhizosolenia setigera</i>				2	2	2					
<i>Rhizosolenia antennata</i>											
<i>Rhizosolenia</i> (twin process) <i>antennata</i>											
<i>Proboscia inermis</i>		1									
<i>Rhizosolenia curvata</i>											
<i>Stellarima microtrias</i>	2	5	16	5	2	2	1	0	0	0	0
<i>Thalassiosira gracilis</i>	2	1			3	1					
<i>Thalassiosira lentiginosa</i>	292	481	358	191	208	28	122	5	11	1	2
<i>Thalassiosira oestrupii</i>	2	7	3	4	2	2	3		1		
<i>Thalassiosira oliveriana</i>	10	3	1	18	10	2	9	0	1	5	0
<i>Thalassiosira ritscherii</i>				1	1		2				
<i>Thalassiosira tumida</i>	11	10			4	1	4				
<i>Thalassiothrix antarctica</i>		3									
<i>Thalassiothrix longissima</i>		3									
<i>Trichotoxon reinboldii</i>		1									
<i>Triceratium spp</i>					1						1
Total counts	473	737	486	454	448	89	248	10	16	9	8

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