Quaternary Diatom Biostratigraphy and Palaeoenvironments of the CRP-1 Drillcore, Ross Sea, Antarctica

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Abstract - In the first season of drilling, the Cape Roberts Project (CRP) recovered one drillcore (CRP-1) from Roberts Ridge in western McMurdo Sound, Ross Sea, Antarctica. Diatom biostratigraphy places the upper six lithostratigraphic units (Units 1.1, 2.1, 2.2, 2.3, 3.1, and 4.1) of CRP-1 (0.0 to 43.15 mbsf) within the Quaternary. Both non-marine and marine Quaternary diatoms occur in variable abundance in the Quaternary interval of CRP-1. Biostratigraphic data resolve two Quaternary time slices or events within CRP-1. Marine diatom assemblages in Units 4.1 and 3.1 represent sedimentation within the diatom *Actinocyclus ingens* Zone (1.35 to 0.66 Ma). Further refinement of the age of Unit 3.1 places deposition in the interval 1.15 to 0.75 Ma based on the common occurrence of *Thalassiosira elliptipora* and correlation to the Southern Ocean acme of this taxon. The absence of *Actinocyclus ingens* and the presence of *Thalassiosira antarctica* in Unit 2.2 require a younger zonal assignment for this interval, within the diatom *Thalassiosira lentiginosa* Zone (0.66 to 0.0 Ma). A new diatom species, *Rouxia leventerae*, is described from marine assemblages of Units 2.2, 2.3, 3.1, and 4.1.

Lithostratigraphic Unit 3.1 (33.82 to 31.89 mbsf) is a bryozoan-dominated skeletal-carbonate facies. Low abundance of *Fragilariopsis curta* and *Fragilariopsis cylindrus* within this unit combined with the relatively high abundance of species associated with open water indicates deposition in waters that remained ice free for much or all of the year. Diatom assemblages suggest carbonate deposition in Unit 3.1 is linked to a significant early Pleistocene event in McMurdo Sound, when elevated surface-water temperatures inhibited the formation of sea ice.
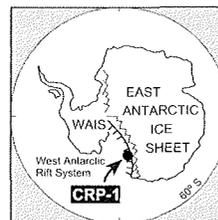
INTRODUCTION

The Cape Roberts Project (CRP) is an international drilling project aimed at the recovery of Palaeogene sediments from McMurdo Sound, Ross Sea, Antarctica. The project name is derived from Cape Roberts, a coastal promontory in northwest McMurdo Sound (see Fig. 1 in Introduction), which serves as a staging point for drilling operations. Two seasons of drilling were initially planned to recover several cores through seaward dipping strata in the Victoria Land Basin on Roberts Ridge, 10 to 15 km east of Cape Roberts. Seismic surveys have indicated 2 000+m of strata are present in this sequence (Cape Roberts Science Team, 1998). The first season of drilling commenced in October 1997 and resulted in the recovery of one core, CRP-1.

Cape Roberts Drillhole 1 (CRP-1) was drilled 16 km northeast of Cape Roberts at a water depth of 153.5 m. The site was chosen in order to drill the youngest seismic reflectors on Roberts Ridge (Cape Roberts Scientific Team, 1998). The hole was drilled to a depth of 148 metres below the sea floor (mbsf), and 113.32 m of core was recovered. Quaternary and Miocene strata are present in this section, and the age of the base of the core is placed at ~21.5 Ma by diatom biostratigraphy, palaeomagnetic stratigraphy, argon-argon dating, and strontium isotope dating (Roberts et al., this volume). Drilling was terminated prematurely

due to a severe storm that removed fast ice to within 1 km of the drill rig and resulted in unstable drilling conditions (Cape Roberts Science Team, 1998).

The upper section of CRP-1 (0.0 to 43.55 mbsf) is interpreted to be Quaternary in age by diatom and foraminifer biostratigraphy, argon-argon dating, strontium isotope dating, and amino acid racemisation ages (Roberts et al., this volume). Sediments in this interval range from "soupy" to consolidated and are not cemented. Recovery of 77% was obtained, even though the drilling system did not allow lining of the core barrel. A wide range of lithologies are present in this interval, but diamicton predominates. Based on lithologic variations, the Quaternary section of CRP-1 is divided into six lithostratigraphic units: Units 1.1, 2.1, 2.2, 2.3, 3.1, and 4.1. Facies interpretations indicate sedimentation in a glaciomarine environment (Cape Roberts Science Team, 1998), with a possible grounded-ice event in Unit 2.3 (Powell et al., this volume).

A distinctive and unusual interval of mixed skeletal carbonate and clastic sediment (muddy packstone) is present from 31.89 to 33.82 mbsf (Lithostratigraphic Unit 3.1). Bryozoans are the dominant carbonate skeletal component of this unit, and it is classified as a bryomol facies (Taviani & Claps, this volume). Siliciclastic sediment in this interval is limited, although significant amounts of ice-rafted detritus occur in some intervals (Cape Roberts Science Team,

1998). The duration of sediment accumulation in Unit 3.1 is not known, but the unit most likely represents a deposition period of several thousands of years. *In situ* macro-invertebrate fauna present in this interval indicate quiet-water carbonate accumulation (>70 m water depth) in a distal glaciomarine environment (Cape Roberts Science Team, 1998; Taviani et al., this volume; Powell et al., this volume).

Recognition or recovery of *in situ* Plio-Pleistocene shelf strata is a valuable addition to the existing stratigraphic record of the Antarctic shelf. Upper Pleistocene sediments are known to occur beneath the West Antarctic Ice Sheet (WAIS) and in a deposit on Ross Island near Cape Barne. Material recovered from beneath the WAIS at Ice Stream B represents an age younger than ~600 Ka (Scherer, 1991; Scherer et al., 1998). The deposit at Cape Barne has been assigned a late Pleistocene age of 120 Ka based on Uranium/Thorium dating of skeletal carbonate material (Stuvier et al., 1981). Planktic diatom occurrence and biostratigraphic age assignment of the deposit at Cape Barne are outlined in the present paper.

Upper Pliocene diatomaceous sediments on the Antarctic shelf were recovered in the CIROS-2 drillcore in McMurdo Sound (Harwood, 1986; Barrett et al., 1992; Ishman & Rieck, 1992; Hambrey & Barrett, 1993; Winter & Harwood, 1997) and on Leg 119 of the Ocean Drilling Program in Prydz Bay. ODP Hole 742A (Leg 119) contains a 60 cm interval of diatomite that is assigned a late Pliocene age (Mahood & Barron, 1996). Pliocene sediments are also known from the Prospect Mesa in Wright Valley, Southern Victoria Land, and are interpreted to represent deposition in a palaeofjord (Webb, 1972; Ishman & Rieck, 1992; Prentice et al., 1993). Volcaniclastic erratics of the Scallop Hill Formation, containing marine microfossils and invertebrates, occur scattered throughout McMurdo Sound and are also thought to represent a late Pliocene age (Speden, 1962; Harwood, 1986; Leckie & Webb, 1979; Webb & Andreason, 1986). Similar volcaniclastic lithologies crop out on Cockburn Island in the Antarctic Peninsula and are dated as early to late Pliocene (Gazdzicki & Webb, 1996; Jonkers, 1998; Jonkers & Kelly, in press).

Initial diatom biostratigraphic age assignments placed the Quaternary section of CRP-1 in the *Fragilariopsis kerguelensis* Zone in the time interval 1.80 to 1.25 Ma (Cape Roberts Science Team, 1998). This paper further documents Quaternary diatom occurrences in CRP-1 and provides revised diatom zonal assignments with biostratigraphic datums correlated to the Berggren et al. (1995) time scale. Non-marine and marine diatom assemblages occurring in the Quaternary sediments of CRP-1 also provide a basis for palaeoenvironmental interpretations in this important "window" into the Pleistocene history of the Ross Sea region.

METHODS

Samples for diatom analysis from the Quaternary interval of the CRP-1 core were collected at irregular intervals due to gaps in recovery and variation in diatom abundance (Tab. 1). High-resolution sample spacing was performed in Lithostratigraphic Units 3.1 and 2.2, where diatoms are abundant. To supplement the samples examined for the initial report, twenty additional samples were taken in key intervals for post-drilling work (indicated with an asterisk on Tab. 1). Smear slides were also prepared from selected intervals (indicated with ¤ on Tab. 1) to further characterise diatom occurrence.

Sample preparations at McMurdo Station involved both raw sample analysis and the use of several techniques to concentrate siliceous microfossils. Selected samples were sieved at 10 µm to concentrate specimens of *Thalassiosira* and other large, biostratigraphically useful taxa. Depending on lithologic characteristics, some samples were treated with hydrogen peroxide (to remove organic material) or hydrochloric acid (to remove carbonate). A few samples were also prepared using heavy-liquid separation, where a small aliquot of sample was placed in a 2.2 specific gravity (SG) sodium polytungstate solution and left to settle for three hours. This procedure removes a large percentage of sand-sized carbonate and quartz grains (~2.6-2.7 SG) from opaline silica diatom valves (~2.0 SG). This technique is further described in Harwood & Rose (1998).

Samples prepared for quantitative diatom abundance counts (Tab. 2a & b) were prepared from a 2 cc sediment volume. These samples were first placed in 50 ml centrifuge tubes and thoroughly disaggregated in de-ionized water using a vortex stirrer. Strewn slides were then made from the suspended material after a short settling time of approximately 30 seconds. All samples were mounted in *Norland Optical Adhesive #61* (Refractive Index 1.56) with the exception of samples at 25.15-.17 mbsf; these samples were mounted in Hyrax (R.I. 1.65+) for photomicrography of non-marine diatoms.

Quantitative diatom abundance was obtained using standard methodology by counting individual, complete or nearly complete valves. A few exceptions are noted for broken valves. Long, pennate diatoms are commonly fragmented, and, consequently, *Thalassiothrix antarctica* group and *Thalassionema nitzschioides* group were counted only when apical ends were identified. Broken *Rouxia* spp. were counted when apical ends including the central area were observed. Broken, identifiable centric diatoms were counted when fragments included both the central area and part of the margin. Non-marine diatoms in CRP-1 commonly occur as articulated frustles and were counted as two valves. Several informal taxonomic designations are used in species assignments, and these taxa are illustrated in the plates.

RESULTS

CRP-1 DIATOM OCCURRENCE

Diatom occurrence and assemblage composition is highly varied within the Quaternary section of CRP-1 (Tabs. 1, 2a & b). Abundance and species counts of selected samples are shown in table 2a and b. Marine

Tab. 1 - Samples collected for diatom analysis in CRP-1 and Quaternary diatom occurrence.

Unit	Sample depth	Occurrence	Graphical Representation	Zone
1.1	8.50-8.51	N rare / M frags rare / rew		
	16.06-16.07	M frags rare / N rare		
2.1	19.13-19.15*	N		
	19.16□	M frags rare		
	19.23□	N rare		
	19.27-19.28	N		
	19.46□	X		
	20.00□	X		
	20.12□	X		
	20.18-20.19	X		
	20.50□	X		
	20.65-20.66	X		
	20.87-20.88	N rare		
	20.99□	N rare		
	20.99-21.00	X		
	21.04□	N rare		
	21.04-21.14	X		
	21.23□	X		
	21.51□	N rare		
	21.51-21.52	X		
	21.54-21.57	X		
	21.58□	X		
	21.93□	X		
	21.99□	X		
	21.99-22.00	X		
2.2	24.46□	X		*T. lentiginosa* Zone
	24.53□	N / M frags rare		
	24.53-24.54	N		
	24.69□	X		
	24.95□	X		
	25.12-25.13	N		
	25.13□	N		
	25.15-25.17*	N		
	25.17□	N		
	25.32-25.34*	N		
	25.36□	N		
	25.58□	X		
	25.60□	N		
	25.89□	X		
	26.05□	X		
	26.08□	X		
	26.08-26.09	X		
	26.12□	X		
	26.12-26.13	X		
	26.15□	N rare		
	26.38-26.40*	N		
	26.47□	N		
	26.95-26.96	M / rew		
	27.00□	M frags rare		
	27.07-27.09*	M frags common / N rare		
	27.13□	M frags rare / N rare		
	27.24-27.26*	N / M		
	27.26□	N / M		
	27.47□	X		
	27.47-27.48	X		
	27.78□	N / M		
	27.81-27.82	M / N / rew		
	27.84-27.86*	M / N		
	28.00□	N / M frags rare		
	28.10□	M		
	28.10-28.11	M / rew		
2.3	30.08□	X		
	30.08-30.09	X		
	30.70□	M frags rare		
	30.70-30.71	X		
	30.94□	X		
	31.00-31.01	X		
	31.10□	M frags rare		
	31.10-31.11	X		
	31.70-31.71	N / M / rew		
3.1.1	31.90-31.93	M		
	32.00-32.02*	M		
	32.05-32.15	M / rew		
	32.17-32.19*	M		
	32.30-32.32*	M		
	32.37-32.40*	M		
	32.49-32.51*	M		
	32.58-32.61	M		
	32.65-32.67*	M		
	32.78-32.80*	M		*A. ingens* Zone
3.1.2	32.95-32.98	M / N rare		
	32.98-33.01	M frags common		
	33.19-33.21*	M frags common		
	33.31-33.34	M / rew		
	33.50-33.53	M / rew		
	33.55-33.57*	M frags common		
	33.68-33.70*	M frags common		
	33.72-33.75	M / rew		
4.1	34.12-34.14*	X		
	34.17-34.18	X		
	34.56-34.57	X		
	34.70-34.72*	X		
	34.80-34.81	M / rew		
	35.46-35.47	M frags rare		
	35.88-35.89	X		
	35.92-35.93	M frags rare		
	37.45-37.46	X		
	37.92-37.93	X		Not Zoned
	38.44-38.45	X		
	38.93-38.94	X		
	39.32-39.33	X		
	39.96-39.97	X		
	40.32-40.33	X		
	40.89-40.90	X		
	41.27-41.28	X		
	41.77-41.78	X		
	42.43-42.44	X		
	43.04-43.05	X		

Note: sample intervals with no demarcation symbol represent original 2 cc samples taken at McMurdo Station. Sample intervals denoted with an asterisk are 2cc samples taken for post-drilling work, and sample intervals marked with "□" denote smear slides samples. In occurrence column, "X" = barren, "N" = non-marine diatoms, "M" = marine diatoms, "rew" = reworking present, and "frags" = only fragments observed. In the graphical representation column, white areas are barren or contain rare fragments, grey intervals contain non-marine diatoms, and black intervals contain marine diatoms.

Tab. 2a - Diatom abundance data for selected Quaternary samples of CRP-1.

Lithostratigraphic Unit →	2.1	2.2					2.3	3.1.1										3.1.2					4.1
CRP-1 Sample (mbsf) / Species	19.27-.28	25.12-.13	25.15-.17	26.95-.96	27.81-.82	28.10-.11	31.70-.71	31.90-.93	32.00-.02	32.05-.15	32.17-.19	32.30-.32	32.37-.39	32.49-.51	32.58-.61	32.65-.67	32.78-.80	32.95-.98	33.31-.34	33.50-.53	33.72-.73	33.72-.73(>10)	34.80-.81
Preservation	M	G	G	M	G	P	P	G	G	G	M	M	M	G	G	G	G	P	P	P	M	M	P
Marine Planktic																							
Actinocyclus actinochilus				12	3	18	7	9	7	17	15	14	6	22	28	32	21	12	7	6	4	3	4
Actinocyclus ingens				F	F	F	2	4	3	1	2	7	4	3	8	1	1	1	53	17	13	63	13
Actinocyclus karstenii				P	2	P					1	1	6	2	1	2	2		6	4	14	20	5
Actinoptychus senarius				1																			
Asteromphalus hookeri				P	P					P													
Asteromphalus parvulus										P													
Biddulphia punctata group						P				P													1
Chaetoceros bulbosum				2			1	1	1	1	P	3	3	6	2	1	1	2	2	1	5	1	3
Chaetoceros spp. (spores & veg.)			P	75	61	28	41	154	145	150	154	161	153	154	160	127	134	56	49	62	78	18	80
Corethron criophilum				1	2	4		1		P								P					
Coscinodiscus spp.								P		P										1		1	1
Dactyliozolen antarcticus										1	P		1							1		2	P
Eucampia antarctica (intercalary)				13	14	18	8	47	29	30	38	30	50	42	36	74	44	10	10	18	9	37	14
Eucampia antarctica (terminal)																						1	
Fragilariopsis curta				42	45	32	2	4	9	8	5	7	9	9	4	5	16	22	7	14	15	3	3
Fragilariopsis cylindrus			P	12	26			1		2	3								1	1	4		
Fragilariopsis kerguelensis				14	7	5	2											1	1	2	1		P
Fragilariopsis obliquecostata				9	2	8	1	3	3	7	4	2	4	2	2	5	6	6	14	16	15	3	13
Fragilariopsis ritscheri					P	1		1	3	P	2	2	1	1	P	2	2	2	1	P	4	2	
Fragilariopsis sublinearis				28	12	49	1	5	4	4	7	3	6	4	3	4	5	8	2	8	7	6	4
Hyalodiscus sp. A						2		4	P	2	2	P	1	P	1	P		1	3	5		2	3
Odontella weissflogii					P	P		P		P								1					P
Paralia sulcata	1			1	1	1	2	3	1	1	4	1	1	1	1	3			4	6	6	6	17
Porosira pseudodenticulata					1	P		P		P									2			1	
Rhizosolenia hebetata group				P				1				1							4				
Rhizosolenia styliformis																P							1
Rhizosolenia sp. cf. sima f. silicea																			2				
Rouxia antarctica																				3	5		7
Rouxia leventerae				8	40	52	6	7	26	34	21	23	12	19	11	11	17	27	2	8	12	8	3
Stellarima microtrias				2	P	P	1	1	2	3	1	1	1				1	2	9	8	3	16	13
Stephanopyxis spp.								1						1	1						P	1	3
Thalassionema nitzschioides group				5	5	11	42	19	30	13	18	23	15	13	18	14	21	84	37	48	35	9	32
Thalassiosira antarctica				1	P	P		?															
Thalassiosira elliptipora		F		P	P	1	1	4	2	6	6	4	12	1	4	1	6	5	5	P	4	3	2
Thalassiosira fasciculata												P											
Thalassiosira gracilis				1	P	1		P		P		1							3	1	1		2
Thalassiosira lentiginosa				5	1	2		5	2	1	3	2	2	1	1	P			8	2	2	7	9
Thalassiosira oestrupii					P		1	2						1					11	11	17	28	23
Thalassiosira oliverana											P	P									P	3	2
Thalassiosira ritscheri				P																			
Thalassiosira cf. torokina				P	P	P		1	1	1	1	P	1		P	1	1	1	15	12	7	22	16
Thalassiosira trifulta				3	P	P																	
Thalassiosira tumida				F	P	2	F	1		1	1	P			2	P	1	F	2	2	1	1	
Thalassiothrix antarctica group				3	11	7	2	9	9	5	8	11	8	18	17	14	17	16	27	22	16	13	15
Gen et sp. indet. 1							5	6	15	5	1	3				2	1	22	2	9	10	3	2
Marine / Sea-Ice Benthic																							
Amphora sp.											P			P									
Cocconeis spp.							2	1	F	1	1	1	2	P	P			F	1	3		1	1
Diploneis spp.							2	2	2	4	1			P				F	2	3	2	2	1
Entomoneis kjellmanii				P						1						1							
Grammatophora sp.										P	P												
Navicula directa				1								P							1				
Navicula imperfecta			P	P																			
Navicula glaciei				1																			
Navicula sp. C				4	2	11												3					
Navicula / Trachyneis spp.					2	3		1				P	P		P				3	1	2	5	1
Nitzschia spp.									1			P						1					
Pinnularia quadratarea					F	2	2	1	1									5	2	3		2	
Pleurosigma spp.							F		F	1								F		F			
Trigonium arcticum								P				P									1		

Note: numbers represent occurrence in a count of 300 valves. "P" = whole specimens observed in sample but not recorded in initial count of 300 valves. "F" = identifiable fragments observed. Preservation is rated as Good (G), Moderate (M), or Poor (P).

diatom assemblages are present in intervals within Units 2.2, 3.1, and 4.1. Non-marine diatom assemblages occur in intervals within Units 1.1, 2.1, 2.2, and 3.1. Intervals of mixed marine and non-marine diatom assemblages are present within Units 1.1 and 2.2, and at the base of Unit 2.3 and top of Unit 3.1. A detailed account of diatom occurrence in each lithostratigraphic unit follows. Lithologies for each unit are further described in the CRP-1 Initial Report (Cape Roberts Science Team, 1998) and in Powell et al. (this volume).

Lithostratigraphic Unit 1.1 (0.00 to 19.13 mbsf)
Lithology: diamicton

Two samples were examined from Unit 1.1 at 8.50-.51 and 16.06-.07 mbsf. Rare diatoms recovered at 8.50-.51 mbsf include a mixture of non-marine and marine forms. Marine diatoms present in this interval include *Thalassiosira torokina* and *Stellarima microtrias*, which are commonly filled with marine diatomaceous sediment and are thought to be reworked. Reworking is also indicated

Tab. 2b - For caption see previous page.

Lithostratigraphic Unit	2.1	2.2					2.3	3.1.1											3.1.2					4.1
CRP-1 Sample (mbsf) / Species	19.27-.28	25.12-.13	25.15-.17	26.95-.96	27.81-.82	28.10-.11	31.70-.71	31.90-.93	32.00-.02	32.05-.15	32.17-.19	32.30-.32	32.37-.39	32.49-.51	32.58-.61	32.65-.67	32.78-.80	32.95-.98	33.31-.34	33.50-.53	33.72-.73	33.72-.73(>10)	34.80-.81
Preservation	M	G	G	M	G	P	P	G	G	G	M	M	M	G	G	G	G	P	P	P	M	M	P
Non Marine																							
Achnanthes sp. A		6	5																				
Aulacoseira sp. A								1											1	4	5		
Gomphonema sp. A			2																P				
Hantzschia amphioxys	21	10	7	2	2	3																	
Luticola spp.	57	54	49	10	11	16	14																
Melosira charcotii	19	5	4		1					P								7					2
P. cymatopleura - N. quaternaria	17	33	22	8	18	2	3	P										3					
Navicula peraustralis	90	85	88	10	P	7	65	P															
Navicula shackletoni	13	21	18	3	7	1																	
Nitzschia westii	52	58	58	24	21	11	79	1													1		
Navicula sp. B	1	5	3		1													1			P		
Stauroneis anceps	29	23	44	2	1	1	9																
Reworked																							
Denticulopsis simonsenii				P			1			1									1				2
Denticulopsis maccollumii						1														1			
Fragilariopsis barronii																							1
Kisseleviella carina				P																			
Liostephania cast	P											P											
Thalassiosira inura					P																P		
Thalassiosira vulnifica				P														P					
Trinacria excavata					F	F	F	F							1		F	F	F	F	F		1
Pseudammodochium lingii						P																	
Total Diatom Valves Counted	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300	300

by the presence of the ebridian *Pseudammodochium lingii* (Miocene to Oligocene), and heavily silicified casts of diatom interiors (*Liostephania*). These specimens are likely reworked from Eocene to lower Oligocene intervals, correlative with the lower 200 m of the CIROS-1 drillcore (Harwood, 1989). Only rare marine diatom fragments were encountered in the sample at 16.06-.07 mbsf.

Lithostratigraphic Unit 2.1 (19.13 to 22.00 mbsf)
Lithology: diamicton

This unit is predominately barren of diatoms, with the exception of non-marine diatoms and rare marine diatoms at 19.13-.15 and 19.27-.28 mbsf. Non-marine diatom assemblages at 19.27-.28 mbsf are dominated by *Hantzschia amphioxys*, *Luticola* spp., *Melosira charcotii*, *Pinnularia cymatopleura-Navicula quaternaria*, *Navicula peraustralis*, *Navicula shackletoni*, *Navicula* sp. B, *Nitzschia westii*, and *Stauroneis anceps* (Tab. 2a & b). Rare whole specimens of marine diatoms observed in this interval include *Paralia sulcata* and *Liostephania* silicified casts, which are thought to be recycled from the Palaeogene.

Lithostratigraphic Unit 2.2 (22.00 to 29.49 mbsf)
Lithology: sandy mud and diamicton

Two distinct diatom assemblages occur within Unit 2.2. Non-marine assemblages occur in the upper five metres (22.00 to 26.47 mbsf), and mixed non-marine and marine assemblages occur below this interval (26.95 to 29.49 mbsf). A rich assemblage of non-marine diatoms occurs at 25.12-.13 and 25.15-.17 mbsf (Tab. 2a & b), similar in composition to that recorded in Unit 2.1.

Mixed assemblages of non-marine and marine diatoms are relatively abundant and diverse in several samples in

the interval 26.95 to 28.11 mbsf (Tabs. 1, 2a & b). Samples at 26.95-.96, 27.81-.82, and 28.10-.11 mbsf contain a marine diatom assemblage dominated (~5% or greater) by *Actinocyclus actinochilus*, *Chaetoceros* spp., *Eucampia antarctica*, *Fragilariopsis curta*, *Fragilariopsis cylindrus*, *Fragilariopsis sublinearis*, and *Rouxia leventerae*. Benthic marine and sea-ice diatoms of the genera *Entomoneis*, *Navicula*, *Trachyneis* and *Pinnularia* also occur, although in low abundance. Also present within this mixed interval are the non-marine species noted above in Unit 2.1, and rare reworked diatoms (Tab. 2a & b). Reworked diatoms include species from the Pliocene (*Thalassiosira inura* and *Thalassiosira vulnifica*), middle to upper Miocene (*Denticulopsis maccollumii* and *Denticulopsis simonsenii*), and Oligocene (*Kisseleviella carina*).

Lithostratigraphic Unit 2.3 (29.49 to 31.89 mbsf)
Lithology: diamicton

Diatoms are largely absent from Unit 2.3 (Tab. 1). Rare, marine diatom fragments are noted in samples at 30.70 and 31.10 mbsf, which are most likely reworked. The sample at 31.70-.71 mbsf contains a poorly-preserved, mixed non-marine and marine diatom assemblage dominated (~5% or greater) by *Chaetoceros* spp., *Thalassionema nitzschioides* group, *Luticola* spp., *Navicula peraustralis*, and *Nitzschia westii* (Tab. 2a & b).

Lithostratigraphic Unit 3.1 (31.89 to 33.82 mbsf)
Lithology: muddy packstone and muddy sand

Lithostratigraphic Unit 3.1 is divided here into two biostratigraphic subunits (Tab. 1), designated as bio-stratigraphic Subunit 3.1.1 (upper; 31.89 to 32.82 mbsf)

and Subunit 3.1.2 (lower; 32.83 to 33.82 mbsf). These subunits are designated based on variations in diatom assemblages, diatom preservation, and lithology. Subunit 3.1.1 is carbonate-rich and Subunit 3.1.2 is moderately carbonate-rich to clastic. The two subunits are physically separated by a large, ice-rafted dolerite clast that occurs at 32.83-33.02 mbsf (Cape Roberts Science Team, 1998).

Subunit 3.1.1 is characterised by abundant and well-preserved diatoms (Tabs. 1, 2a & b). Samples between 31.90 and 32.82 mbsf contain rich marine diatom assemblages (Tab. 2a & b). These assemblages are dominated (~5% or greater) by *Actinocyclus actinochilus*, *Chaetoceros* spp., *Eucampia antarctica*, *Rouxia leventerae*, and *Thalassionema nitzschioides* group. Benthic/ sea-ice marine diatoms of the genera *Entomoneis*, *Amphora*, *Cocconeis*, *Diploneis*, *Grammatophora*, *Navicula*, *Pinnularia*, *Pleurosigma*, *Trachyneis*, and *Trigonium* are also present in low abundance in this interval.

Subunit 3.1.2 contains assemblages of poor to moderately preserved diatoms. Most samples in this interval contain only highly fragmented marine diatoms. Rare non-marine diatoms, however, are noted at 32.95-.98 mbsf. The sample at 33.72-.75 mbsf contains relatively well-preserved marine diatoms in moderate abundance (Tab. 2a & b), which is dominated (~5% or greater) by *Actinocyclus karstenii*, *Chaetoceros* spp., *Eucampia antarctica*, *Fragilariopsis obliquecostata*, *Thalassionema nitzschioides* group, *Thalassiosira oestrupii*, and *Thalassiothrix antarctica* group. A similar assemblage of benthic marine diatoms as noted in Subunit 3.1.1 is also present in Subunit 3.1.2, but does not constitute a large percentage of the total assemblages (Tab. 2a & b). Rare specimens of the silicoflagellate genera *Dictyocha* and *Distephanus* are also noted at 33.72-.73 and 33.59 mbsf.

Diatom assemblages in Subunit 3.1.2 differ significantly from those in Subunit 3.1.1. Diatoms are highly fragmented in Subunit 3.1.2, whereas diatom preservation is moderate to good in Subunit 3.1.1. In comparison to Subunit 3.1.1, diatom assemblages in Subunit 3.1.2 are characterised by lower relative abundance of *Chaetoceros* spp., relatively higher numbers of *Thalassiosira oestrupii* and *T.* cf. *torokina*, and by the presence of *Rouxia antarctica* and *Rhizosolenia* sp. cf. *sima* f. *silicea*.

Lithostratigraphic Unit 4.1 (33.82 to 43.15 mbsf)
Lithology: diamicton

Diatoms throughout Unit 4.1 are rare and poorly preserved. Most diatoms occur as isolated fragments, which are thought to be recycled. One sample at 34.80 mbsf, however, contains a poor to moderately preserved assemblage dominated (~5% or greater) by *Chaetoceros* spp., *Paralia sulcata*, *Thalassionema nitzschioides* group, *Thalassiosira oestrupii*, *Thalassiosira* cf. *torokina*, and *Thalassiothrix antarctica* group (Tab. 2a & b). The diatom assemblage in this sample closely resembles that of Subunit 3.1.2.

INTERPRETATION

DIATOM BIOSTRATIGRAPHY

For the purposes of this report, the Southern Ocean diatom zonations of Harwood & Maruyama (1992) and Winter & Harwood (1997) are employed. Southern Ocean diatom occurrences and age ranges are compiled from the following reports: Ciesielski (1983), Gersonde & Burckle (1990), Baldauf & Barron (1991), Fenner (1991), Harwood & Maruyama (1992), Mahood & Barron (1995), Winter (1995), and Gersonde & Bárcena (1998). Diatom age datums from these reports are revised from the Berggren et al. (1985) to the Berggren et al. (1995) time scale (Tab. 3). Age revisions are based on interpolation and do not represent reinterpretation of the palaeomagnetic stratigraphy and age models for each Southern Ocean drillcore. A summary of diatom biostratigraphic information for each unit is given below.

Lithostratigraphic Unit 2

Unit 2.1 cannot be characterised biostratigraphically, due to the absence of marine marker taxa. Stratigraphic position indicates an upper Pleistocene age.

Unit 2.2 is assigned to the *Thalassiosira lentiginosa* Zone, 0.66 to 0.00 Ma (Tab. 1). This zonal assignment is based on the absence of *Actinocyclus ingens* and the presence of *Thalassiosira antarctica*, *Thalassiosira trifulta*, and *Thalassiosira ritscheri*, among other, longer-ranging taxa characteristic of the modern Antarctic continental shelf setting. This unit also contains rare specimens of older diatoms and diatom fragments, but these are interpreted as reworked, based on their low abundance and poor preservation relative to the underlying diatomaceous sediments (*e.g.* Unit 3.1). Webb & Strong (this volume) report significant percentages of reworked foraminifera in Unit 2.2, particularly in the sample at 26.89-.94 mbsf, which contains 39% pre-Quaternary foraminifera. Diatom reworking in this unit, however, is less pervasive and contributes less than 1% of the diatom assemblage in all samples examined (Tab. 2a & b).

The last occurrence (LO) of *Actinocyclus ingens* is a well-known datum from deep-sea sediments in the Southern Ocean. Previously, this extinction was assigned an age of 620 Ka based on palaeomagnetic stratigraphy of cores tied to the Berggren et al. (1985) time scale (Ciesielski, 1983; Baldauf & Barron, 1991; Harwood & Maruyama, 1992). In the present paper, we recalibrate this datum to 662 Ka, which is an interpolated age based on the 50 ky shift to an older age for the base of the Brunhes normal chron. This reversal has been shifted from 730 Ka (Berggren et al., 1985) to 780 Ka (Berggren et al., 1995). In northern waters of the Southern Ocean, Gersonde & Bárcena (1998) calibrate the extinction of *A. ingens* at 650 Ka within isotope Stage 16 based on data from ODP Site 704, which closely matches our interpolated age of 662 Ka.

Burckle (1993) reports a diachronous LO of

Actinocyclus ingens in ODP Leg 113 cores near the Antarctic margin and suggests that this extinction took place at ~900 Ka or earlier. Scherer (1993), however, argues that this evidence is derived from cores with poor diatom preservation and significant disconformities. Recognition of the LO of *A. ingens* in the upper Pleistocene of DSDP Site 274 suggests that this datum is a useful marker in the Ross Sea region (Scherer, 1993) and can be applied to CRP-1.

The extinction of *Rouxia* spp. in the Southern Ocean has also been used as an upper Pleistocene biostratigraphic marker (Donahue, 1970; Abbott, 1974; Akiba, 1982). Abbott (1974) places the LO of *Rouxia* spp. at 0.35 Ma in upper Pleistocene cores from the southeast Indian Ocean, which is revised here to an age of 0.37 Ma based on the Berggren et al. (1995) time scale (Tab. 3). Akiba (1982) records a similar timing for this extinction from cores in the Bellingshausen Sea and designates a *Rouxia isopolica* Zone from 0.66 to 0.35 Ma. Pichon (1985), however, documents a younger extinction of *Rouxia* spp. and places the LO of *Rouxia peragalli* in isotope Stage 6 (~0.15 Ma). Some taxonomic problems also exist among Pleistocene *Rouxia* spp., particularly with the usage of *Rouxia peragalli*, *R. peragalli* f. *yabei*, *R. isopolica*, *R. californica* (see Akiba, 1982). *Rouxia leventerae* is a newly described species in the present paper from CRP-1 Units 2.2, 3.1, and 4.1, which is not present in modern Antarctic shelf waters. It is not known if the extinction of this taxon corresponds with the LO of other *Rouxia* spp. recorded in deep-sea

sections. At the present time, we have not applied the LO datum of *Rouxia* spp. to date the Quaternary shelf section represented in CRP-1. The LO of *Rouxia leventerae*, however, may be shown to be a useful biostratigraphic marker with future recovery of Antarctic shelf sequences.

Unit 2.3 contains one poorly preserved sample at 31.70-.71 mbsf. This sample is assigned to the *Actinocyclus ingens* Zone and contains the same biostratigraphic markers present in Unit 3.1 (see below).

Lithostratigraphic Unit 3

The stratigraphic position of Lithostratigraphic Unit 3.1 was initially interpreted as "lower Quaternary *Fragilariopsis kerguelensis* Zone (1.25 to 1.6 Ma), perhaps extending up into the lower portion of the *Actinocyclus ingens* Zone" (Cape Roberts Science Team, 1998, p. 49), based on a possible occurrence of *Fragilariopsis barronii*. Subsequent analysis indicates an absence of *F. barronii* s.s., as well as all other mid-to-upper Pliocene markers. Herein, we report a revised correlation of Unit 3.1 to the *Actinocyclus ingens* Zone, 1.35 to 0.66 Ma (Tab. 1, Fig. 1). We tentatively correlate all of Unit 3.1 to a time interval within the reported *Thalassiosira elliptipora* acme (1.15 to 0.75 Ma), which represents the upper part of the *Actinocyclus ingens* Zone. This assignment is based on the unusual abundance of *T. elliptipora* valves and fragments in sieved samples (which are not represented in raw strewn counts on Tab. 2a & b). The ages of the LO of *A. ingens*,

Tab. 3 - Biostratigraphic ranges of selected diatom species occurring in CRP-1.

Species	Published ranges*	Revised**	Sources / Notes
Present			
Actinocyclus actinochilus	3.0 Ma to present	3.1 to 0.0 Ma	H (G&B: FO=2.2-2.5 Ma*)
Actinocyclus ingens	16.4 to .62 Ma	16.2 to .66 Ma	H / C / B / GB (G: FO=15.2 Ma*/ GB: LO=.65 Ma**)
Actinocyclus karstenii	11.7 to 1.7-2.8 Ma	12.0 to 1.8-2.9 Ma	H (B: FO=10.0 Ma*)
Asteromphalus parvulus	4.1 Ma to present	4.5 to 0.0 Ma	H
Corethron criophilum	middle Miocene to present		H
Eucampia antarctica	upper Miocene to present		H / B
Fragilariopsis curta	3.5 Ma to present	3.7 to 0.0 Ma	H
Fragilariopsis kerguelensis	3.1 Ma to present	3.2 to 0.0 Ma	H
Fragilariopsis ritscheri	3.4 Ma to present	3.6 to 0.0 Ma	H
Rouxia spp.	? to .35 Ma	? To .37 Ma	A
Thalassionema nitzschioides	upper Miocene to present		H
Thalassiosira elliptipora	2.2 to .65 Ma	2.3 to .70 Ma	M / C (H: FO=1.6 Ma*)
T. elliptipora acme	1.04 to .70	1.15 to .75	F / GB
Thalassiosira fasciculata	4.1* to .75** Ma	4.5 to .75 Ma	H (GB: LO= .75 Ma**)
Thalassiosira gracilis	2.2 Ma to present	2.3 to 0.0 Ma	H
Thalassiosira lentiginosa	3.9 Ma to present	4.2 to 0.0 Ma	H
Thalassiosira oestrupii	5.1 Ma to present	5.6 to 0.0 Ma	H / B
Thalassiosira oliverana	5.8 Ma to present	6.4 to 0.0 Ma	H
Thalassiosira torokina	8.2 to ?	9.0 to ? Ma	H / C /B (H: LO=1.8 Ma*)
Thalassiosira tumida	lower Pliocene to present		H
Absent			
Fragilariopsis barronii	4.1 to 1.25 Ma	4.5 to 1.35 Ma	H / W (GB: LO=1.3 Ma**)
Thalassiosira antarctica	<.62	<.67	S
Thalassiosira inura	4.5 to 1.8 Ma	4.9 to 1.9 Ma	H / W (B: FO=4.7-4.8 Ma*)
Thalassiosira kolbei	3.8 to 1.8 Ma	4.1 to 1.9 Ma	H/W (B: LO=1.75-1.9 Ma*/ GB: LO=2.0 Ma**)
Thalassiosira striata	4.1 to 2.8 Ma	4.5 to 2.9 Ma	H / W
Thalassiosira vulnifica	3.1 to 2.2 Ma	3.2 to 2.3 Ma	H / W / C (B: FO=2.7-2.8 Ma*) (GB: LO=2.5 Ma**)

Note: information compiled from several sources: "A" = Akiba (1982), "C" = Ciesielski (1983), "G" = Gersonde & Burckle (1991), "B" = Baldauf & Barron (1991), "F" = Fenner (1991), "S" = Scherer (1991), "H" = Harwood & Maruyama (1992), "M" = Mahood & Barron (1995), "W" = Winter (1995), and "GB" = Gersonde & Bárcena (1998). Age datums are revised from the Berggren et al. (1985) time scale (column indicated with *) to the Berggren et al. (1995) time scale (column indicated with **). "FO" = first occurrence, and "LO" = last occurrence.
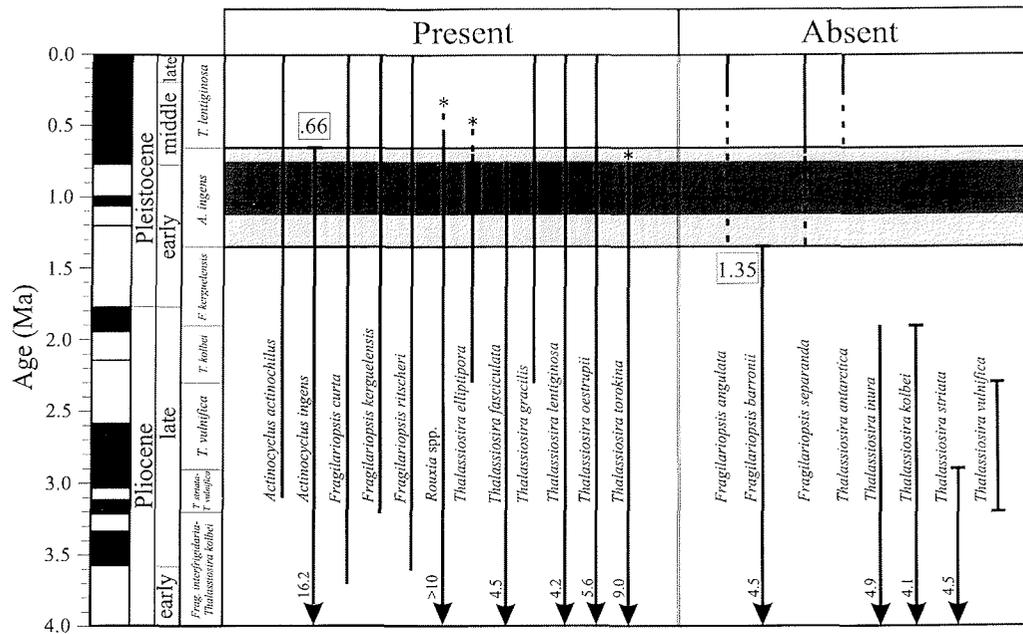
Fig. 1 - Biostratigraphic ranges of selected diatom taxa that are present and absent in CRP-1 Lithostratigraphic Unit 3.1. Ranges truncated by horizontal bars indicate zonal markers. Ranges denoted with an asterisk indicate ranges that are revised from data in the present study. Area of light shading represents interpreted diatom zonal assignment for Unit 3.1. Area of dark shading represents a more restricted age interpretation that corresponds with the documented Southern Ocean acme of *Thalassiosira elliptipora*.

the LO of *F. barronii* (the upper and lower boundaries of the *A. ingens* Zone, respectively), and the range of the *T. elliptipora* acme (Tab. 3) are well established from many palaeomagnetically-calibrated cores in the circum-Antarctic region (Ciesielski, 1983; Gersonde & Burckle, 1990; Baldauf & Barron, 1991; Fenner, 1991; Harwood & Maruyama, 1992; Gersonde & Bárcena, 1998).

Thalassiosira elliptipora has a total range of ~2.2 to 0.70 Ma (Fenner, 1991; Mahood & Barron, 1995). The first occurrence of *T. elliptipora* is not well known and may extend back to ~3.0 Ma (Winter & Harwood, 1997). An acme interval of *T. elliptipora* is recorded during the interval 1.15 Ma and 0.75 Ma in the northern Southern Ocean, where abundance may reach 30% of the total diatom assemblage in individual samples (Fenner, 1991; Gersonde & Bárcena, 1998). Correlating acme zones across broad stretches of ocean is generally a precarious practice, as these events may be environmentally controlled, rather than a function of biotic evolution. However, in this case we feel justified in correlating the CRP-1 carbonate unit to the *T. elliptipora* acme, for reasons listed below.

(1) The *Thalassiosira elliptipora* acme in the deep-sea record is a single, rather than a multiple event such as the *Rocella gelida* acmes during the late Oligocene (Gombos & Ciesielski, 1983) or *Hemidiscus karstenii* and *Actinocyclus ingens* acmes of the Pleistocene (Gersonde & Bárcena, 1998). The *T. elliptipora* acme has been established in numerous sites in the circum-Antarctic, including several sites tied directly to magnetostratigraphy. The top of the acme zone lies just above the Brunhes-Matuyama boundary, dated at 780 Ka (Berggren et al., 1995).

(2) Holoplanktonic diatoms characteristic of the open ocean and deep-sea sediments are abundant in Unit

3.1. Although the diatom assemblage of Unit 3.1 contains significant evidence of neritic diatoms and some evidence of sea-ice-related forms, open-ocean marker taxa are abundant. This indicates that the marker taxa are *in situ* and that the assemblages were freely exchanging with pelagic populations.

(3) The Southern Ocean diatom zonal scheme has previously been successfully applied to sediments from McMurdo Sound (Barrett et al., 1992; Winter & Harwood, 1997), suggesting no significant diachroneity of marker taxa.

(4) The assemblage includes little evidence of reworking of older diatoms and few benthic diatoms, although reworked Pliocene foraminifera are reported (Webb & Strong, this volume). We interpret the diatom assemblage to be predominantly *in situ* with rare reworked specimens.

(5) The age of Unit 3.1, as determined by diatom biostratigraphy (1.15 to 0.75 Ma), is in agreement with strontium isotope dating performed on calcareous fossils (Lavelle, this volume), which indicates an age of between 1.30 and 0.86 Ma, and Ar-Ar dating of volcanic clasts within the unit, which indicates a maximum age of 1.2 Ma (McIntosh, this volume). Using a composite of the above constraints, an age range of 1.15 to 0.86 Ma is suggested for Unit 3.1. Dates derived from amino acid racemisation, however, indicate a younger age (Hart & Webb, this volume).

Several differences in diatom assemblage composition are noted between Subunits 3.1.1 and 3.1.2. *Actinocyclus karstenii*, *A. ingens*, and *Thalassiosira* cf. *torokina* occur in low abundance in Subunit 3.1.1, and *Rouxia antarctica* and *Rhizosolenia* sp. cf. *sima* f. *silicea* are absent. This suggests a difference in age between the two subunits, but

environmental differences may also be responsible. Both subunits are correlated to the Southern Ocean acme of *Thalassiosira elliptipora* within the upper *Actinocyclus ingens* Zone. A possible hiatus between Subunits 3.1.1 and 3.1.2, therefore, must be confined within the time interval 1.15 to 0.75 Ma.

Lithostratigraphic Unit 4

Unit 4.1 is also assigned to the *Actinocyclus ingens* Zone. The sample at 34.80-.81 mbsf contains the same biostratigraphic marker species present in Subunit 3.1.2. Although *Thalassiosira elliptipora* is present in this sample, we do not correlate this unit to the Southern Ocean acme of this taxon. Several specimens of reworked taxa were also observed in this interval, including *Denticulopsis simonsenii*, which has a middle Miocene to early Pliocene range. A single specimen of *Fragilariopsis barronii* is noted, which may be reworked, although we cannot exclude the possibility that it is in place. An age greater than 1.9 Ma can be ruled out, however, based on the absence of *Thalassiosira kolbei*, which is a common component of upper Pliocene assemblages in the Ross Sea (Winter, 1995; Winter & Harwood, 1997) and is present in an upper Pliocene diatomite reported from Prydz Bay (Mahood & Barron, 1996).

QUATERNARY DIATOM PALAEOENVIRONMENTS

Lithostratigraphic Units 2.1 and 2.2

Benthic non-marine diatoms are a common component of Quaternary assemblages of CRP-1. They are particularly common in Lithostratigraphic Units 2.1 and 2.2 and occur in some intervals in the absence of marine diatom flora. Non-marine diatom taxa present in these units are mostly cosmopolitan and are common today in coastal lakes and ponds in Southern Victoria Land (West & West, 1911; Kellogg et al., 1980). They are also known from intervals of Dry Valley Drilling Project (DVDP) cores 4a (Wright Valley), 10 (Taylor Valley), 11 (Taylor Valley), and 15 (McMurdo Sound) and from the CIROS-2 drillcore in Ferrar Fjord (Brady, 1981; Winter, 1995; Winter & Harwood, 1997). One taxon present in CRP-1, *Melosira charcotii*, is known from marine-proximal settings, such as the nearshore and intertidal zone (Peragallo, 1921) and from the "dirty ice" of the McMurdo Ice Shelf (Scherer, 1987), especially near tide cracks in the ice shelf (Scherer, unpublished data). This taxon has also been documented as "*Melosira nummuloides* (?)" in neritic marine sediments of Yan'ou Lake, King George Island (Yang & Chen, 1994).

We consider several possible explanations for the occurrence of relatively abundant and well-preserved non-marine diatoms in Unit 2 of CRP-1:

(1) *in situ* deposition in lakes on a subareally-exposed surface, due to lowered glacio-eustatic sea level, perhaps coupled with tectonic and isostatic controls,

(2) glacial transport of lacustrine sediment from the continent,

(3) fluvial transport from the coast,

(4) eolian transport from the coast, or

(5) episodic or periodic deposition of diatoms from ponds on the surface of an ice shelf - a setting similar to the McMurdo Ice Shelf today.

Lithostratigraphic interpretations do not support subaerial exposure (*i.e.* palaeosol development) within Unit 2 (Powell et al., this volume), thus mechanism (1) does not satisfactorily explain the occurrence of non-marine diatom floras. Introduction of both marine and non-marine floras into the water column can occur in many different environments in the absence of a thick ice shelf. Mixed marine and non-marine diatom sedimentation would most likely result through mechanisms (2), (3), and (4) and may explain mixed assemblages within the lower part Unit 2.2. The absence of marine diatoms, however, accompanying non-marine taxa in most intervals of Unit 2 suggests that marine productivity was suppressed, such as by the presence of an ice shelf, thereby supporting mechanism (5).

Diatom sedimentation of low species richness can take place within ponds on the ice-shelf surface, where valves commonly accumulate in abundance among cyanobacterial mats (Scherer, unpublished data). Surficial sediment accumulation of this type (mechanism 5) on an ice shelf over the Cape Roberts drilling site is postulated in order to explain exclusive non-marine diatom occurrences in Unit 2. Deposition through ice-shelf tide cracks is a possible mechanism of delivering the sediment to the sea floor.

Webb & Strong (this volume) record an agglutinated foraminifer assemblage at 25.40-.43 mbsf (in Unit 2.2) and suggest this assemblage may reflect deposition in hyposaline, ice-front conditions. Samples in this interval also contain a rich assemblage of exclusively non-marine diatoms. Although we suggest these non-marine diatoms are derived from surficial ice-shelf sediments, similar assemblages could also be derived from surficial material on a floating tongue of the MacKay Glacier and associated meltwater sources. Hyposaline, ice-front waters, however, often support neritic marine diatom species (Smith & Nelson, 1985) that have adapted to wide salinity fluctuations associated with sea-ice formation. We therefore interpret the exclusively non-marine diatom assemblages in CRP-1 to result from local cover by a relatively thin ice shelf or ice tongue, which limited light penetration. Due to the resultant suppressed production of marine plankton, deposition under a floating glacier tongue may be hard to distinguish from that under an ice shelf (P.N. Webb, pers. comm.).

Marine diatom assemblages in Unit 2.2 are dominated by *Fragilariopsis* spp.(~30% of the assemblages), including up to 15% *F. curta*, up to 9% *F. cylindrus*, and up to 18% *F. sublinearis* in various samples. *Fragilariopsis curta* and *F. cylindrus* are sea-ice-associated taxa that live both in the sea ice and in the plankton, and often bloom near the ice edge (Hasle, 1969; Hargraves, 1968; Garrison & Buck, 1985; Smith & Nelson, 1985; Garrison et al., 1987; Tanimura et al., 1990). Abundance distributions of these taxa in modern surface sediments show a high preservation potential, and thus are good indicators of sea-ice influence in the fossil record (Gersonde, 1986; Leventer, 1998). The high relative abundance of *F. curta* and *F. cylindrus* in Unit 2.2 is interpreted to indicate an

environment dominated by sea ice during deposition of the marine intervals of this unit.

The pennate diatoms *Entomoneis kjellmanii*, *Pinnularia quadratarea*, *Navicula imperfecta*, and *Navicula glaciei* are present in low total relative abundance in samples at 26.95-.96, 27.81-.82, and 28.10-.11 mbsf, and in several samples of Unit 3.1. These taxa are known to be associated with modern Antarctic sea-ice algal communities (Hargraves, 1968; Krebs, 1983; Leventer, 1998), although they are only rarely preserved or encountered in sediments beneath sea-ice environments (Leventer, 1998). The occurrences of these taxa are presently not applied in the interpretation of the CRP-1 core due to their low abundance in CRP-1 samples and status as poor fossil indicators of sea-ice influence. *Entomoneis kjellmanii* may initially make up a large percentage of the water-column assemblage but, due to dissolution, usually does not survive into the sediment (Leventer, 1998). *Pinnularia quadratarea* may be present in moderate abundance in sea-ice assemblages (Leventer, 1998; Tanimura et al. 1990), but also does not preserve well in surface sediments (Leventer, 1998). *Navicula glaciei* has been documented locally in high abundance in sea-ice tide crack assemblages (Whitaker & Richardson, 1980) and preserves well in underlying sediments (Whitehead & McMinn, 1997), but is not a widespread taxon throughout the sea-ice environment in Antarctica. *Navicula imperfecta* has rarely been reported or identified, presumably due to its low abundance in sea-ice assemblages and in surface sediments.

Chaetoceros spp., which are strongly dominated by vegetative cells in CRP-1 samples, account for up to 25% of the diatom flora in Unit 2.2. Abundant *Chaetoceros* spp. generally indicate high primary productivity, and a dominance of vegetative cells in CRP-1 samples may indicate open water, rather than an ice-edge bloom setting where spores often dominate (Leventer, 1998). Open-ocean taxa, such as *Thalassiothrix antarctica* group, *Thalassionema nitzschioides* group, *Fragilariopsis*

kerguelensis, *Rouxia leventerae*, and *Thalassiosira* spp. account for up to 10% of the diatom flora in Unit 2.2, indicating some sustained contact with the open ocean. The common occurrence of *Fragilariopsis curta* and *F. cylindrus* in Unit 2.2 combined with the presence of open-ocean diatom taxa may indicate seasonal sea ice that breaks out completely in the summer, rather than the fast-ice dominated setting of western McMurdo Sound today.

Lithostratigraphic Unit 3.1

The diatom assemblage of Subunit 3.1.1 is dominated by *Chaetoceros* spp. (>50% in most samples), most of which are vegetative cells. As noted above, *Chaetoceros* spp. often proliferate in the Antarctic in highly productive near-shore settings, especially in areas of the northern Antarctic Peninsula, where their relative abundance can reach more than 90% (Leventer, 1998; Crosta et al., 1997). The controls that influence the modern distribution of *Chaetoceros* spp. in the Southern Ocean, however, are not well understood and are thought to be related to a combination of factors, including temperature, salinity, and productivity (Crosta et al., 1997). Interpretation of high abundance of *Chaetoceros* spp. in Unit 3.1 is therefore difficult, but most likely does not represent an ice edge bloom setting, as is interpreted for highly-stratified waters in the Antarctic Peninsula (Leventer, 1998), based on the low abundance of *Fragilariopsis curta* and *F. cylindrus*.

Other abundant diatom taxa in Subunit 3.1.1 include *Eucampia antarctica* (10-25%), *Rouxia leventerae* (2-12%), *Thalassionema nitzschioides* group (4-10%), *Thalassiothrix antarctica* group (2-6%), and *Thalassiosira* spp. (1-5%). Abundant *Thalassionema*, *Thalassiothrix*, and *Thalassiosira* species are interpreted to indicate an open-water setting (Fenner et al., 1976; Leventer & Dunbar, 1988), all with optimal temperatures typically above 0°C (Fig. 2; Zielinski & Gersonde, 1997).

Fragilariopsis spp. constitute 2-6% of the diatom

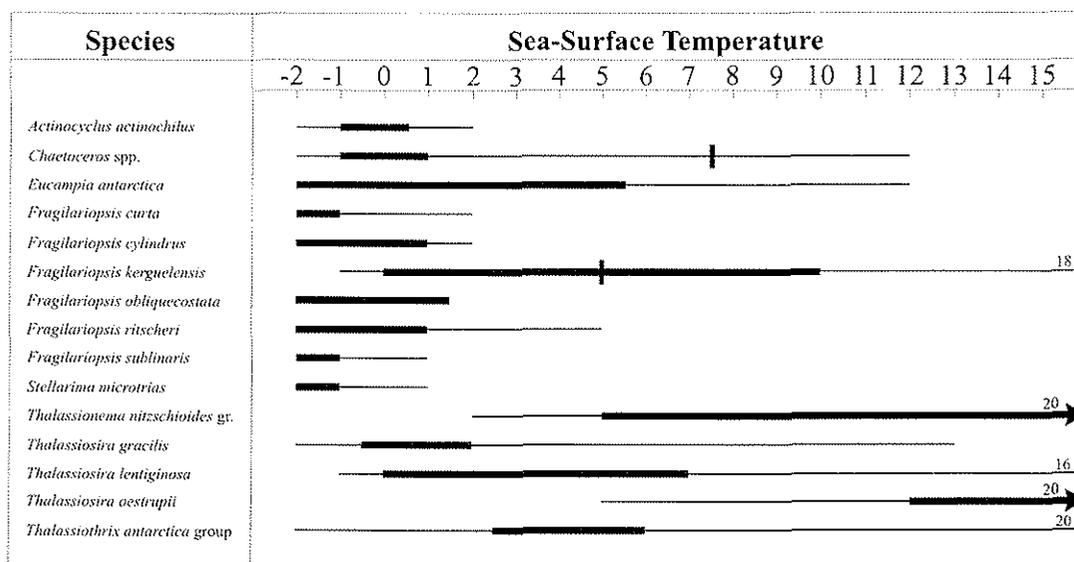| Species | Sea-Surface Temperature |

Fig. 2 - Ecologic data of selected modern diatom taxa from the Weddell Sea. Data is from Zielinski & Gersonde (1997) and is derived from surface-sediment assemblage composition related to mean summer sea-surface temperatures. Thin lines represent the total temperature range under which a species was observed, and thick lines represent temperature range of maximum occurrence. Vertical bars indicate temperature of maximum growth rate in culture as determined by Jacques (1983).

assemblages in Subunit 3.1.1. Sea-ice-related taxa *Fragilariopsis curta* and *F. cylindrus* occur in low abundance, with *F. curta* rarely more than 3% of the total assemblage and *F. cylindrus* absent in most samples. Today, McMurdo Sound is heavily influenced by the formation of sea ice, and *F. curta* and *F. cylindrus* contribute large percentages to diatom assemblages preserved in surface sediments (Leventer & Dunbar, 1987, 1988). Surface sediments in coastal areas of the western Ross Sea dominated by fast sea ice typically contain 20% *F. curta* (Cunningham & Leventer, 1998). Low abundance of *F. curta* and *F. cylindrus* in Subunit 3.1.1 suggests an absence of sea ice throughout the diatom growing season. A reduction in duration of sea-ice cover suggests that summer surface-water temperatures were higher than present day, although taxa associated with cold-water, ice-marginal environments, such as *Actinocyclus actinochilus* and *Fragilariopsis obliquecostata* (Pichon, 1985; Gersonde, 1986), also occur in Subunit 3.1.1 samples.

Subunit 3.1.2 contains a diatom assemblage similar to that in Subunit 3.1.1, but significant differences distinguish the two intervals. In Subunit 3.1.2, diatom preservation is notably poorer, and *Fragilariopsis* taxa are more common (12-16%). *Chaetoceros* spp. are also less abundant (about 20%), and *Thalassionema nitzschioides* group, *Thalassiothrix antarctica* group, and *Thalassiosira* spp. account for as much as 35% of the diatom flora. *Thalassiosira oestrupii* occurs in the lower part of Subunit 3.1.2 in abundances that range from ~3-7%. This taxon is common in Southern Ocean surface sediments that have overlying surface-water temperatures greater than 5°C (Fig. 2; Zielinski & Gersonde, 1997). Other studies have also indicated that *T. oestrupii* is affiliated with northern, subantarctic waters (Hasle, 1969; Hargraves, 1968; DeFelice & Wise, 1981; Crosta et al., 1998), but *T. oestrupii* has been also reported, in low abundance, in water temperatures below 5°C (Hasle, 1969; Fenner et al., 1976; Pichon, 1985). We interpret the presence of significant numbers of *T. oestrupii* to indicate a strong open-water influence during deposition of Subunit 3.1.2, but palaeo-temperatures of greater than 5°C cannot confidently be estimated, due to the reported occurrence of this taxon in colder waters.

Overall, similar palaeoenvironmental conditions are interpreted for both Subunits 3.1.1 and 3.1.2. The low abundance of sea-ice-related taxa, combined with relatively high species richness of *Fragilariopsis* spp., *Thalassiosira* spp., *Thalassionema nitzschioides* group, and *Thalassiothrix antarctica* group, indicate open-water conditions in an environment that remained ice free in the summer months and possibly during much of the year.

Lithostratigraphic Unit 4.1

One sample from Unit 4.1 with a moderately preserved diatom assemblage is recorded at 34.80-.81 mbsf. Planktic species account for nearly 95% of the assemblage, including 27% *Chaetoceros* spp., 7% *Fragilariopsis* spp., 11% *Thalassionema nitzschioides* group, and 18% *Thalassiosira* spp. *Thalassiosira oestrupii* dominates the *Thalassiosira* species (7.7%) in this sample and is interpreted to represent a strong open-water influence. This occurrence, combined

with the presence of several other taxa associated with open water, dictates a similar palaeoenvironmental interpretation for Unit 4.1 as Subunit 3.1.2, although the diamicton lithologies of Unit 4.1 are interpreted to represent significant glacial influence (Powell et al., this volume). This sample may represent a brief, open-water event, or, alternatively, it may contain a reworked assemblage from an older unit that is not present in the CRP-1 section due to erosion.

BIOSTRATIGRAPHIC COMPARISON WITH ROSS SEA QUATERNARY DEPOSITS

CRP-1 Lithostratigraphic Units 4.1 through 2.2 represent one of very few *in situ* Pleistocene continental shelf deposits known from Antarctica. Biostratigraphic comparison with other deposits is not possible at the present time. A deposit of similar lithology to Lithostratigraphic Unit 3.1 of CRP-1 is known at Cape Barne, Ross Island. The Cape Barne exposure is a marine deposit that contains abundant skeletal carbonate mixed with siliciclastic material. It has been proposed that this sediment was transported from a sub-shelf setting while frozen onto the bottom of an ice shelf (Debenham, 1919; Stuiver et al., 1981; Ward & Webb, 1986), and, therefore, does not represent *in situ* deposition. Uranium/Thorium dating of carbonate material indicates an age of ~120 Ka ±6 000 yrs. for this deposit (Stuvier et al., 1981), suggesting initial deposition of fossil material deposition during isotope Stage 5e, prior to subsequent glacial redistribution.

Diatoms are abundant and well-preserved in samples from the Cape Barne deposit. Planktic diatom occurrence from four Cape Barne samples is listed in table 4. The samples are dominated by *Actinocyclus actinochilus, Chaetoceros* spp., *Eucampia antarctica, Fragilariopsis angulata, F. curta, F. kerguelensis, F. obliquecostata, Stellarima microtrias, Thalassiosira gracilis, T. lentiginosa, T. oliverana,* and *T. tumida.* All planktic diatoms observed in these samples represent modern species. We assign this assemblage to the *Thalassiosira lentiginosa* Zone (0.66 to 0.0 Ma) based on the absence of *Actinocyclus ingens* (Fig. 3).

The Cape Barne deposit and Lithostratigraphic Unit 2.2 of CRP-1 are both placed in the *Thalassiosira lentiginosa* Zone, but the Cape Barne deposit represents the younger of the two deposits, based on the presence of *Fragilariopsis separanda* and *F. angulata* and the absence of *Rouxia leventerae* in the Cape Barne section. Both deposits, however, contain *Thalassiosira antarctica.* The absence of *Rouxia leventerae* in the Cape Barne deposit and its presence in CRP-1 Unit 2.2 may further constrain the ages of these units when the LO of *R. leventerae* is better known from future drilling on the Antarctic shelf.

DISCUSSION

Palaeoenvironmental interpretations of CRP-1 Lithostratigraphic Unit 3.1 are not a reflection of the biostratigraphic range of *Fragilariopsis curta*. The range

Tab. 4 - Planktic diatom occurrence in Cape Barne deposit samples.

Species	CB1	CB2B	CB2C	CB2D
Actinocyclus actinochilus	x	x	x	x
Asteromphalus hookeri			x	
Asteromphalus parvulus			x	x
Bidulphia punctata		x	x	
Chaetoceros spp.	x	x	x	x
Coscinodiscus spp.		x		
Dactyliosolen antarcticus		x	x	
Eucampia antarctica (intercalary)	x	x	x	x
Eucampia antarctica (terminal)	x	x	x	x
Fragilariopsis angulata	x	x	x	x
Fragilariopsis curta	x	x	x	x
Fragilariopsis cylindrus	x	x	x	
Fragilariopsis kerguelensis	x	x	x	x
Fragilariopsis obliquecostata	x	x	x	x
Fragilariopsis ritscheri	x	x	x	x
Fragilariopsis separanda	x	x	x	x
Fragilariopsis sublinearis		x		x
Fragilariopsis vanheurkii		?		
Hyalodiscus sp. A		x	x	
Melosira charcotii	x	x	x	x
Odontella weisflogii		x	x	
Paralia sulcata	x	x	x	
Porosira pseudodenticulata		x	x	x
Stellarima microtrias	x	x	x	x
Stephanopyxis spp.				x
Thalassionema nitzschioides group	x	x	x	x
T. nitzschioides v. *parva*	x			
Thalassiosira antarctica		x	x	x
Thalassiosira gracilis	x	x	x	x
Thalassiosira lentiginosa	x	x	x	x
Thalassiosira oestrupii			x	
Thalassiosira oliverana	x	x	x	x
Thalassiosira ritscheri		x		x
Thalassiosira tumida	x	x	x	x
Thalassiothrix antarctica group			x	
Gen et sp. indet. 1		x		

of *F. curta* extends back to ~3.5 Ma (Harwood & Maruyama, 1992; Winter & Harwood, 1997), and it appears as a dominant element of the Antarctic shelf assemblage sometime during the late Pliocene or early Pleistocene.

The low abundance of *F. curta* in Unit 3.1, however, illustrates that this taxon, and its associated sea-ice habitat, was not a persistent feature of some areas of the Antarctic shelf through the entire Pleistocene. The occurrence and abundance of *F. curta* may provide a means of tracking sea-ice extent in shelf sequences through the upper Pliocene and Pleistocene (Harwood et al., 1994; Zielinski & Gersonde, 1997).

The recovery of Unit 3.1 in CRP-1 suggests that many similar units representing significant Late Neogene climatic events will be recognised with future drilling of Antarctic shelf sequences. Mahood & Barron (1996) document a 60 cm diatomite section in Prydz Bay that is assigned an upper Pliocene age (2.2 to 1.8 Ma), within the diatom *Thalassiosira kolbei* Zone (see Fig. 1). The diatom assemblage present in this interval contains low numbers of *Fragilariopsis curta* and *F. cylindrus*, and may represent a similar open-water palaeoenvironmental setting as that of Unit 3.1.

Webb & Strong (this volume) suggest that deposition of CRP-1 Unit 3.1 may represent local changes in the glacial environment, without significant local or regional changes in sea-surface temperature. Planktic foraminifera that are presently confined to more northerly biogeographic provinces are not recorded in Unit 3.1, leading Webb & Strong (this volume) to argue against elevated surface water temperatures during deposition. Diatom assemblages, however, indicate that Unit 3.1 represents a period of reduced sea-ice formation and elevated surface water temperatures. Surface waters in McMurdo Sound may have been as little as 1-2°C above modern surface-water temperatures, which would be sufficient to prevent significant formation of sea ice. The occurrence of relatively high numbers of *T. oestrupii* and other open-marine diatom taxa may further suggest a summer temperature rise of
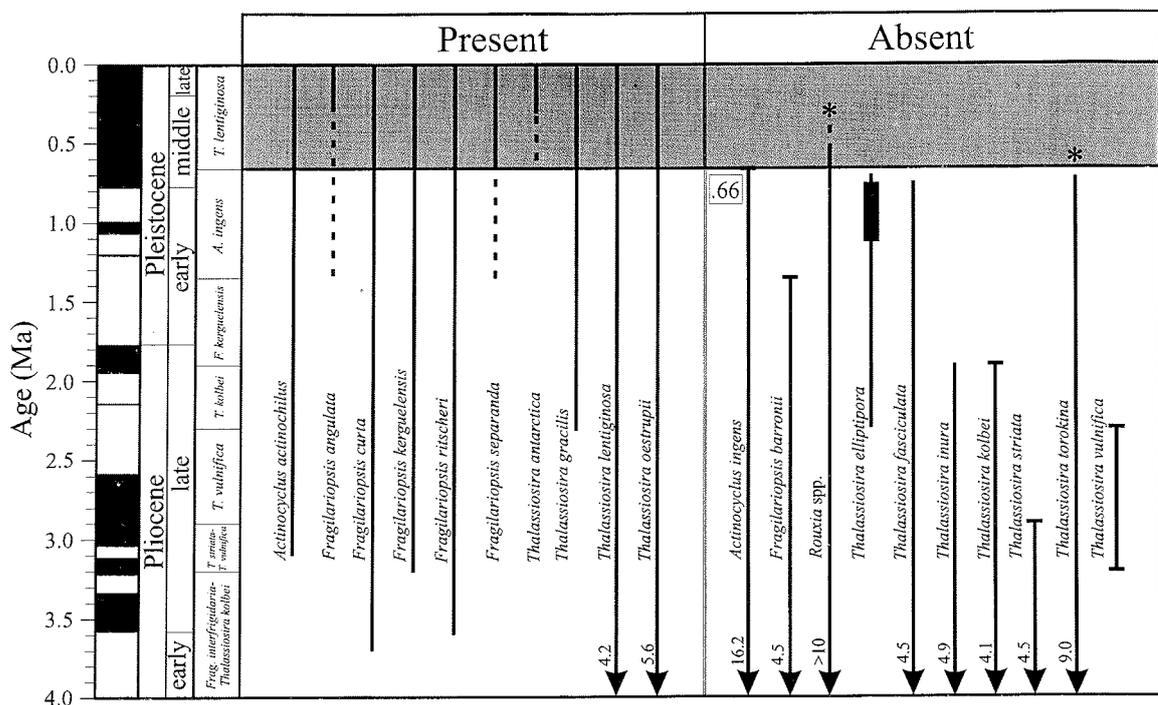

Fig. 3 - Biostratigraphic ranges of selected diatom taxa that are present and absent in the Cape Barne deposit, Ross Island. Ranges truncated by horizontal bars indicate zonal markers. Area of shading represents interpreted diatom zonal assignment for the Cape Barne deposit.

≥3°C (above present day) in a very shallow mixed layer. In light of the diatom data, we argue that a 1-3°C temperature increase in the uppermost waters might not be reflected in planktic foraminiferal assemblages or other faunal elements present in Unit 3.1.

Another possibility that may explain the interpreted reduction in sea-ice cover during deposition of Unit 3.1 is the long-term development of a coastal polynya above Roberts Ridge. We consider this an unlikely scenario, because we would expect a cold water polynya system to be variable from season to season, with periodic sea-ice development. Low abundance of sea-ice-related diatoms throughout Unit 3.1 suggest stable, nearly sea-ice-free conditions for at least several thousand years.

The diatom record on the Antarctic shelf is a function of many factors, including ice cover, light level, and diatom ecology. Diatom productivity is prevented with thick ice cover or complete darkness. Periods of open water or sea-ice variability in the winter, therefore, will not be recorded in diatom record. Interpretations of CRP-1 diatoms are directly tied to the summer growing season, which may have been extended during deposition of Unit 3.1 (compared to the present day) due to sea-ice absence. Although winter conditions cannot be directly interpreted, inferred sea-ice absence in the summer is tied to conditions of late winter and early spring when significant sea-ice formation and thickening occurs.

CONCLUSIONS

The age of CRP-1 Lithostratigraphic Unit 3.1 is well-established with diatom biostratigraphy and is in agreement with independent dating methods. This interval from 31.70 to 34.81 mbsf is assigned to the diatom *Actinocyclus ingens* Zone. The precise duration of sediment accumulation through this interval is unknown, but it is unlikely that more than 400 000 years is represented by this section, based on the documented Southern Ocean acme of *Thalassiosira elliptipora* (1.15 to 0.75 Ma). Slight differences in diatom assemblages between Subunits 3.1.1 and 3.1.2 may indicate a hiatus in deposition at 32.83 to 33.02 mbsf, where a large dropstone separates these subunits. Well-preserved diatom assemblages in Subunit 3.1.1 suggest accumulation rates were particularly high; thus, the interval from 31.70 to 32.82 mbsf could represent as little as a few thousand years. Rates of accumulation, however, could not have exceeded minimum turbidity requirements of sea-floor suspension feeders (Taviani et al., this volume), suggesting that the amount of time represented by Unit 3.1 is on the order of thousands of years rather than hundreds.

Marine diatom assemblages in Unit 2.2 are placed within the *Thalassiosira lentiginosa* Zone and represent a sea-ice dominated environment with seasonally open water, similar to present-day McMurdo Sound. Exclusively non-marine diatom intervals in Units 2.1, 2.2, and 2.3 are interpreted to represent deposition beneath an ice shelf. These occurrences, alternatively, may represent cover by an ice tongue or input from fluvial sources in situations when marine productivity (light penetration) was limited. .

Lithostratigraphic Unit 3.1 represents an open-water, glaciomarine setting with occasional input of ice-rafted detritus. Marine diatom assemblages in this unit contain a low relative percentage of diatoms known to be closely associated with the sea-ice environment and a high relative percentage of taxa associated with open water. We interpret these assemblages to indicate a significant reduction in the presence or duration of annual sea-ice cover, and an associated rise in summer surface-water temperatures of at least 1-2°C, as compared to present-day McMurdo Sound (-2 to 0°C). The co-occurrence of taxa associated with the open-ocean circumpolar belt and those associated with colder, ice-marginal areas may reflect the mixed and variable environment created by open water in close proximity to the coast.

Diatom assemblages in Unit 3.1 suggest sea ice was either absent, or developed only briefly during the austral summer. The duration of sea-ice cover in the winter was also most likely reduced, although the winter record during May through mid-August cannot be directly addressed using diatoms. Sea-ice absence through the period when sufficient light was available to stimulate diatom growth, however, suggests a much different environment than is present in McMurdo Sound today. Slight elevations in surface-water temperature (1-2°C) through the year would have a significant impact on the sea-ice formation, and are invoked to explain the inferred reduction in sea-ice cover during deposition of Unit 3.1.

Despite remaining uncertainties regarding palaeoenvironmental interpretations of Lithostratigraphic Unit 3.1 of CRP-1, it is clear that this sedimentary unit represents a significant event in climate evolution of Antarctica.

SYSTEMATIC PALAEONTOLOGY

Notes for only a few taxa are given below. For full systematic treatment and illustrations of taxa recorded in the present study, the reader is referred to the following sources: West & West (1911), Hargraves (1968), McCollum (1975), Fenner et al. (1976), Gombos (1976), Kellogg et al. (1980), Akiba (1982), Krebs (1983), Ciesielski (1983), Johansen & Fryxell (1985), Medlin & Priddle (1990), Gersonde & Burckle (1990), Fenner (1991), Baldauf & Barron (1991), Harwood & Maruyama (1992), Zielinski (1993), Winter (1995), Mahood & Barron (1996), and Gersonde & Bárcena (1998).

Achnanthes sp. A
(Plate 6.16)

Aulacoseira sp. A
(Plate 5.14 to 16)

Eucampia antarctica (Castracane) Mangin

Eucampia antarctica (Castracane) Mangin, 1914, p. 480, figures 7-8.
Eucampia balaustium Castracane, 1886, p. 97-99, Pl. 18, figures 5-6.

Remarks. Nearly 100% of *Eucampia antarctica* valves observed in CRP-1 Quaternary samples are intercalary valves. Cape Barne samples, however, contain high percentages of terminal valves. It is not clear at the present time whether these differences are due to environmental factors or age (biostratigraphic) differences. Fryxell (1991) suggests winter stage formation of *Eucampia antarctica* and duration of seasonal ice cover determine relative terminal *vs* intercalary valve percentages preserved in surface sediments. Surface sediments collected in Prydz Bay contain relatively high terminal to intercalary valve ratios, whereas surface sediments collected on the northern Kerguelen Plateau contain relatively low terminal to intercalary valve ratios (Fryxell, 1991; Tab. 1). Terminal to intercalary valve ratios may prove to be a useful palaeoenvironmental tool.

Gomphonema sp. A
(Plate 6.14 & 15)

Hyalodiscus sp. A
(Plate 5.5)

Navicula glaciei Van Heurck
(Plate 4.6)

Navicula glaciei Van Heurck, 1909, p. 11, plate 1, figure 13.
Navicula gelida var. *parvula* in Heiden & Kolbe, 1928, p. 605, plate 2, figure 53; Hargraves, 1968, p. 71-72, figures 127-129.

Remarks. Hargraves (1968) records this taxon exclusively in pack-ice samples. It is also reported in high abundance in wave-protected coves of Arthur Harbor, Antarctic Peninsula (Krebs, 1983) and in sea-ice tide crack assemblages near Signey Island, South Orkney Islands (Whitaker & Richardson, 1980).

Navicula imperfecta Cleve
(Plate 4.11)

Navicula imperfecta Cleve, 1883, p. 466.
Navicula imperfecta var. *antarctica* Heiden & Kolbe, 1928, p. 602.

Remarks. Hargraves (1968) notes that *Navicula imperfecta* is characteristic of pack-ice assemblages.

Navicula sp. B
(Plate 6.9)

Navicula sp. C
(Plate 4.4)

Rhizosolenia sp. cf. sima f. silicea
(Plate 5.1 & 2)

cf. *Rhizosolenia sima* f. *silicea* Sundström, 1986, p. 62-66, figures 29 (Plate 6) & 150 to 153 (Plate 21).
Rhizosolenia sp. D of Harwood & Maruyama, 1992, p. 705, plate 18, figures 7 to 10; Mahood & Barron,

1996, p. 292, plate 1, figures 4a to 5b, plate 7, figure 3.
Remarks. This heavily-silicified form was informally designated as *Rhizosolenia* sp. D by Harwood & Maruyama (1992) and may be synonymous with *R. sima* f. *silicea* Sundström (L. Armand, pers. comm.). Sundström (1986) suggests that *Rhizosolenia sima* f. *silicea* may be a resting spore of *Rhizosolenia sima* s.s., but was unable to confirm that hypothesis. It is also possible that several fossil and modern *Rhizosolenia* species produce heavily-silicified frustles, some or all of which may be resting spores. Positive identification of *Rhizosolenia sima* f. *silicea* in our samples would require analysis of copulae and areolar structure in the SEM. Our specimens only preserve the heavily silicified apical process, further limiting positive identification. Consequently, we refer to the taxon informally as *R.* sp. cf. *sima* f. *silicea*. This form appears to be a consistent component of Plio-Pleistocene Southern Ocean diatom assemblages.

Rouxia leventerae Bohaty, Scherer and Harwood n. sp.
(Plate 1.1 to 6)

Description. Valve isopolar and linear-lanceolate. Pole shape cuneate to cuspate. Simple raphe is present with straight endings. Parallel, transapical, uniseriate striae are present around the margin of the valve. Striae are 12-14 in 10 μm and possess 1-2 pores. Commonly, 2 pores are present in striae parallel to raphe bars and one pore is present parallel to central area and around poles. Also, 1-3 pores are commonly present on either side of the central raphe endings, parallel to the raphe bars (Plate 1.1). Central area is hyaline, and a few specimens display two rows of vestigial "dimpling" in the central area (Plate 1.4). Pole fields are hyaline and triangular in shape.
Dimensions. Holotype: 65 μm (length) x 7 mm (width). Measured specimens range from 5-7 μm in width to 55-90 μm in length.
Holotype. Plate 1.1 (phase contrast) and 1.2 (differential interference contrast).
Type Level and Locality. CRP-1 drillcore, 27.81-.82 mbsf, Lithostratigraphic Unit 2.2, *Thalassiosira lentiginosa* Zone.
Type specimen. Holotype deposited in the California Academy of Sciences microfossil collection, slide number CAS 219083.
Remarks. Rouxia leventerae is morphologically similar to *Rouxia isopolica* Schrader (1976). *Rouxia leventerae,* however, does not possess two rows of pores in the central area. These pores are distinctive on holotype and paratype specimens of *R. isopolica* (Schrader, 1976; Plate 5.14, 15 & 20) but are not explicit in the description (also see Harwood & Maruyama, 1992, Plate 17, Fig. 13). *Rouxia leventerae* is most likely derived from the same lineage as *Rouxia isopolica,* which is common in lower to upper Pliocene sediments of the Kerguelen Plateau (Harwood & Maruyama, 1992).
Occurrence. Rouxia leventerae is presently known only from the CRP-1 drillcore, western McMurdo Sound, in Lithostratigraphic Units 4.1, 3.1, 2.3, and 2.2. These units are assigned a middle to late Pleistocene age within

the diatom *Actinocyclus ingens* and *Thalassiosira lentiginosa* zones, and most likely represent an absolute age of less than 1.2 Ma based on diatom biostratigraphic datums, strontium isotope dating of calcareous invertebrates (Lavelle, this volume), and Ar-Ar dating of volcanic material (McIntosh, this volume).

Derivation of Name. Named in honor of Dr. Amy Leventer whose contributions have added significantly to the understanding of modern Antarctic diatom ecology and the associated fossil record.

Thalassiosira elliptipora (Donahue) Fenner *ex* Mahood and Barron
(Plate 2.2, 4 & 7)

Thalassiosira elliptipora (Donahue) Fenner ex Mahood & Barron, 1996, p. 292 and 294, plate 4, figure 3, plate 5, figures 4a to 7c, plate 8, figure 6.
Thalassiosira elliptipora (Donahue) Fenner, 1991, p. 108, plate 1, figure 3, plate 3, figure 2.
Coscinodiscus elliptipora Donahue, 1970, p. 183, plate 4, figures e and i-m; Abbott, 1974, p. 311, plate 4, figures A to D.

Remarks. A wide variation in morphology of *Thalassiosira elliptipora* is noted in the present study, as recognised in previous studies (Gombos, 1976; Fenner, 1991; Mahood & Barron, 1996). Valve diameter, coarseness of areolation, and degree of pore elongation vary significantly within many Quaternary samples of CRP-1. Specimens with elongated areolae present only near the margin (Plate 2.2 & 7) dominate Unit 3.1 samples. *Thalassiosira elliptipora* is less common in Unit 2.2, but these morphologies generally possess elongated areolae across the entire valve face (Plate 2.4). SEM study of this taxon indicates the "segmented" margin seen in the light microscope (Plate 2.2) results from T-shaped external labiate processes (Mahood & Barron, 1996). Specimens with elongated areolae across the entire valve face generally do not display this type of marginal structure in the LM. This may result from preservational factors where the margin is easily broken off (Mahood & Barron, 1996) or from morphological differences in margin structure between these different forms. Further SEM study will be required to determine if current taxonomic concepts of *T. elliptipora* include more than one taxon.

Thalassiosira cf. *torokina*
(Plate 3.1 & 2)

cf. *Thalassiosira torokina* Brady, 1977, p. 123, figures 1 to 5; Mahood & Barron, 1996, p. 296, plate 6, figures 1a to 3c, plate 8, figure 8.

Remarks. An extension of the biostratigraphic range of the *Thalassiosira torokina* lineage is documented in the present study. These specimens are recorded as *Thalassiosira* cf. *torokina* and are highly domed and 20-50 µm in diameter. These morphologies also possess 6-8 marginal striae in 10 µm, 5-15 central strutted processes,

and a single marginal labiate process perpendicular to margin.

Mahood & Barron (1996) provide an extended description of upper Pliocene specimens of *Thalassiosira torokina*. These forms are very similar to *T.* cf. *torokina* noted here, but commonly possess more central strutted processes. Upper Miocene to lower Pliocene specimens from the Kerguelen Plateau, however, differ significantly from upper Pliocene and Pleistocene morphologies (Bohaty, unpublished data). *Thalassiosira torokina* from upper Miocene to lower Pliocene sediments of the Kerguelen Plateau are large in diameter, have a broad, flat to slightly domed valve face, and have massive cluster of central strutted processes (see Scherer, 1991, Plate 2, Fig. 4, for a similar form). Similar upper Miocene to lower Pliocene morphologies were described by Brady (1977, Fig. 3) in the initial description of *T. torokina* from DVDP holes 10 and 11. Mahood & Barron (1996) describe *T. torokina* as 37-45 µm in diameter with 10-19 central processes, where Brady (1977) describes *T. torokina* as 50-60 µm in diameter with 12-30 central processes. If these Miocene to Pleistocene taxa represent the same lineage, *T. torokina* appears to have become more domed and possess fewer central strutted processes through time. Further SEM study and comparisons are needed to determine if these observations are consistent through time and if splitting of this group into varietal forms may be warranted.

Gen. et sp. indet. 1
(Plate 1.9 & 10)

Remarks. Small, pennate forms, probably in the *Nitzschia* lineage, identified as "Gen et sp. indet. 1" in the present study, are abundant in CRP-1 Lithostratigraphic Units 3.1 and 4.1. SEM observations are needed to determine the generic classification of this group.

ACKNOWLEDGEMENTS

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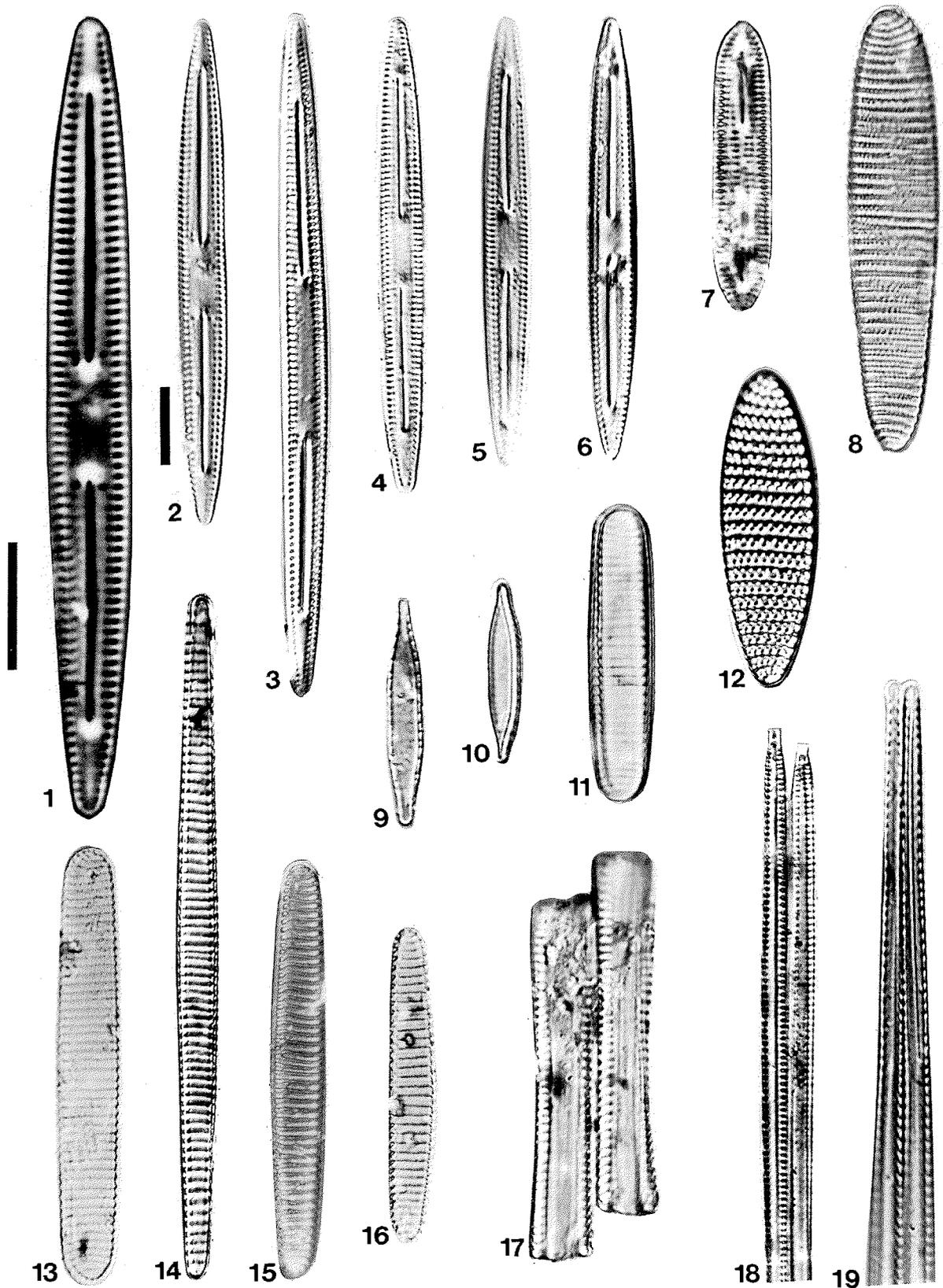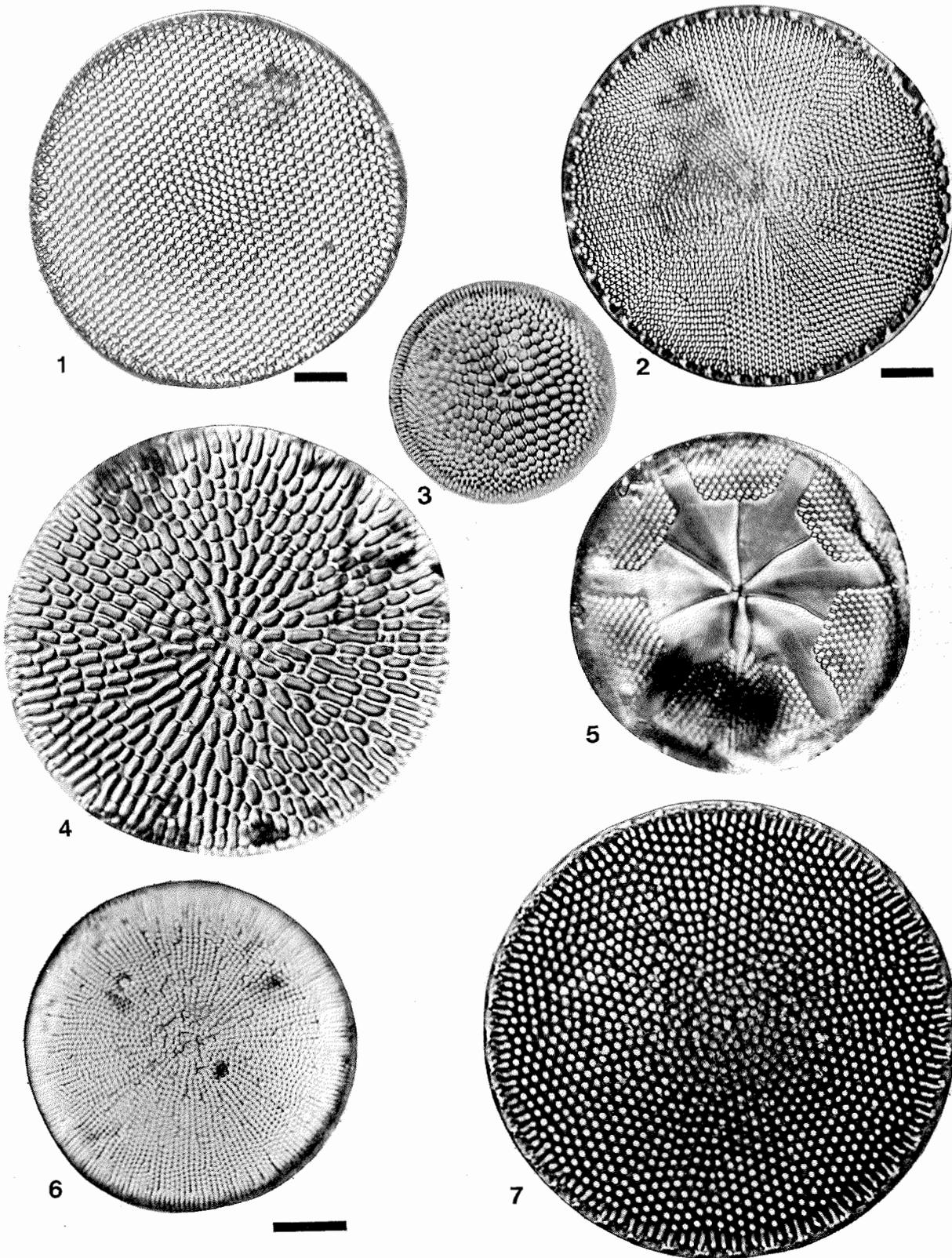
Plate 2 - Scale bars for 1 and 2) represent 10 μm, and scale bar at bottom for 3 to 7) represents 10 μm. *1) Thalassiosira tumida* (Janisch) Hasle (Sample 33.72-.73 mbsf); *2, 4, & 7) Thalassiosira elliptipora* (Donahue) Fenner *ex* Mahood and Barron (2. Sample 33.72-.73 mbsf; 4. Sample 27.81-.82 mbsf; 7. Sample 32.05-.15 mbsf); *3) Thalassiosira oestrupii* (Ostenfeld) Proshkina-Lavrenko (Sample 33.72-.73 mbsf); *5) Asteromphalus hookeri* Ehrenberg (Sample 27.81-.82 mbsf); *6) Stellarima microtrias* (Ehrenberg) Hasle and Sims (Sample 32.00-.02 mbsf).
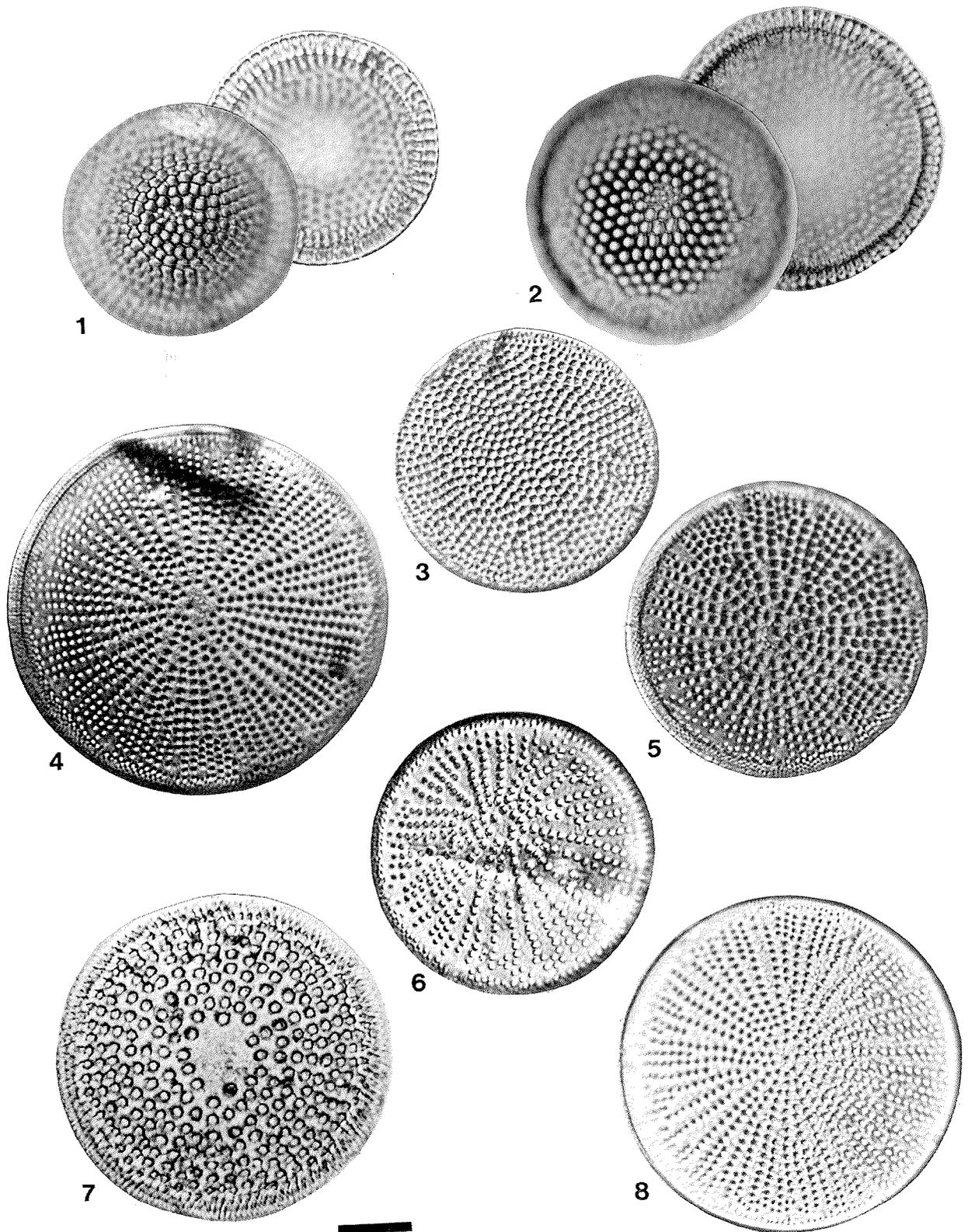
Plate 3 - Scale bar at bottom for 1 to 8) represents 10 μm. *1 & 2) Thalassiosira* cf. *torokina* Brady (1. Sample 33.72-.73 mbsf; 2. Sample 32.05-.15 mbsf); *3) Thalassiosira lentiginosa* (Janisch) Fryxell (Sample 26.95-.96 mbsf); *4 & 5) Actinocyclus karstenii* Van Heurck (4. Sample 33.72-.73 mbsf; *5)* Sample 33.72-.73 mbsf); *6 & 8) Actinocyclus actinochilus* (Ehrenberg) Simonsen (6. Sample 26.95-.96 mbsf; 8. Sample 32.05-.15 mbsf); *7) Actinocyclus ingens* Rattray (Sample 33.50-.53 mbsf).
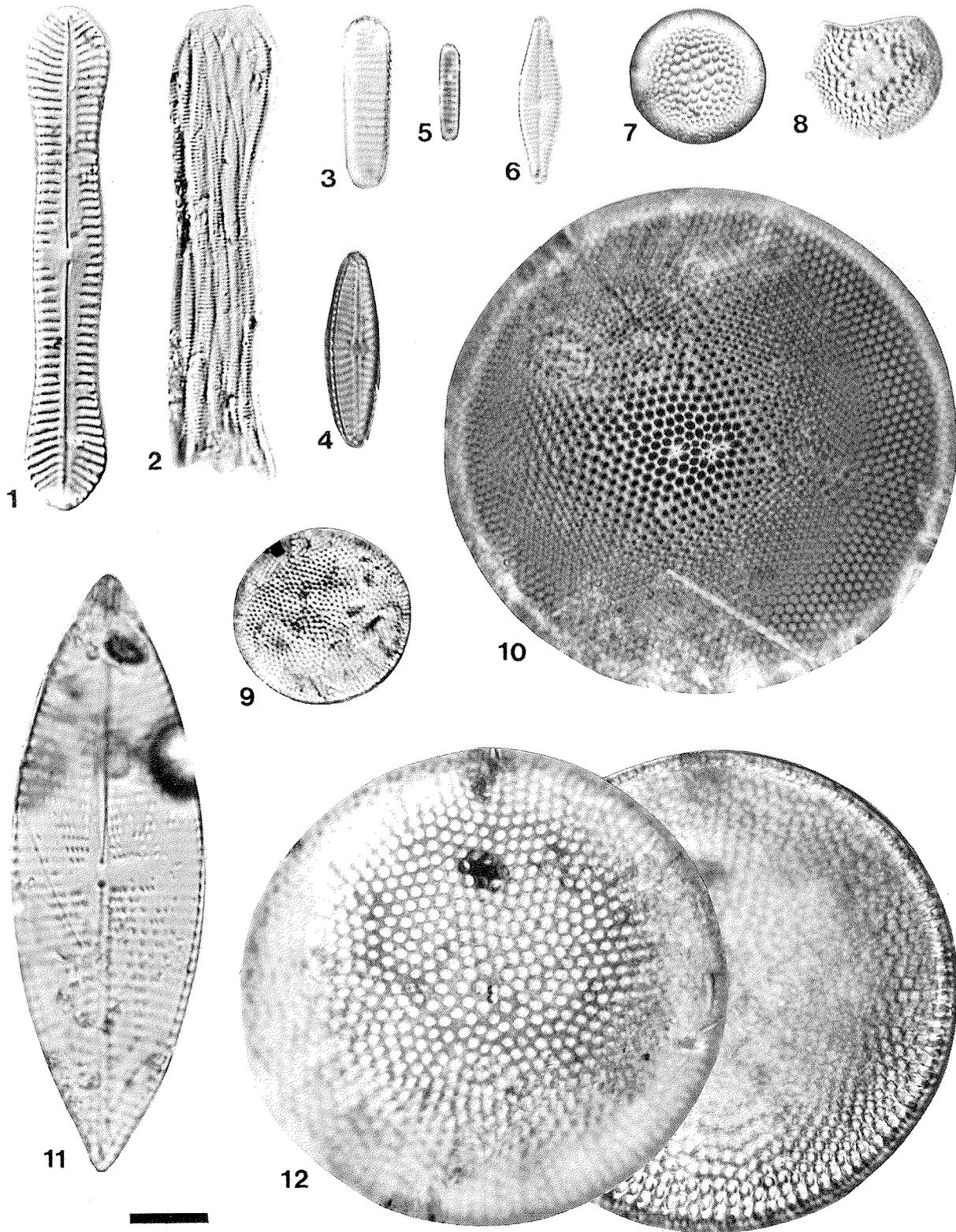
Plate 4 - Scale bar at bottom for 1 to 12) represents 10 μm. *1) Pinnularia quadratarea* (Schmidt) Cleve (Sample 27.81-.82 mbsf); *2) Entomoneis kjellmanii* Cleve (Sample 27.81-.82 mbsf); *3) Fragilariopsis curta* (Van Heurck) Hasle (Sample 27.81-.82 mbsf); *4) Navicula* sp. C (Sample 27.81-.82 mbsf); *5) Fragilariopsis cylindrus* (Grunow) Hasle (Sample 27.81-.82 mbsf); *6) Navicula glaciei* Van Heurck (Sample 27.81-.82 mbsf); *7) Thalassiosira gracilis* var. *expecta* (Van Landingham) Fryxell and Hasle (Sample 28.10-.11 mbsf); *8) Thalassiosira inura* Gersonde (reworked specimen, Sample 27.81-.82 mbsf); *9) Thalassiosira antarctica* Comber (Sample 27.81-.82 mbsf); *10) Thalassiosira ritscheri* (Hustedt) Hasle (phase contrast, Sample 27.81-.82 mbsf); *11) Navicula imperfecta* Cleve (Sample 27.81-.82 mbsf); *12) Thalassiosira trifulta* Fryxell (Sample 27.81-.82 mbsf).
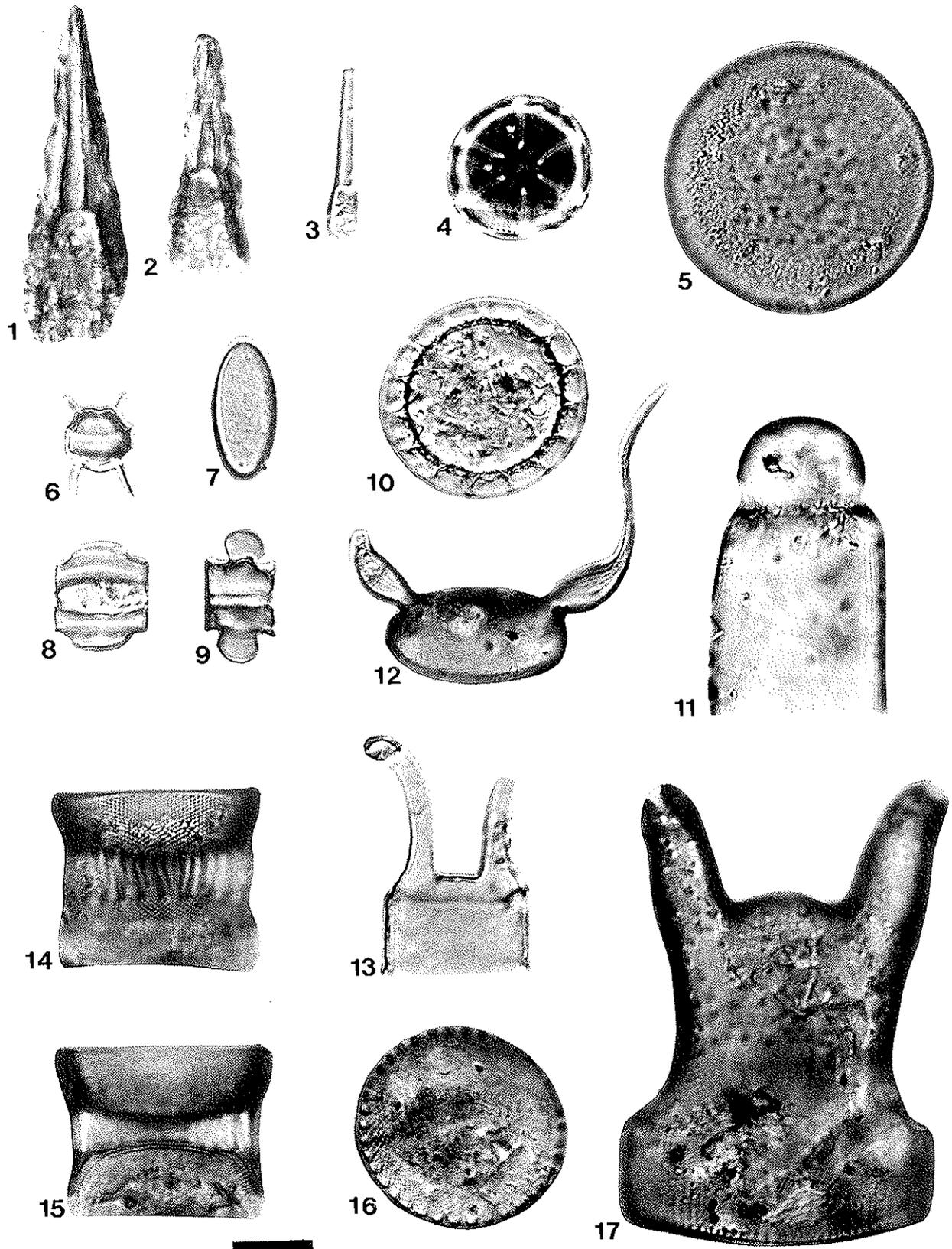
Plate 5 - Scale bar at bottom for 1 to 17) represents 10 μm. *1 & 2) Rhizosolenia* sp. cf. *sima* f. *silicea* Sundström (1. Sample 33.31-.34 mbsf; 2. Sample 33.31-.34 mbsf); *3) Rhizosolenia hebetata* group (Sample 31.90-.93 mbsf); *4)* Gen. et sp. indet. (phase contrast, Sample 27.81-.82 mbsf); *5) Hyalodiscus* sp. A (Sample 32.37-.40 mbsf); *6 to 9 & 13) Chaetoceros* spp. (6. Sample 32.00-.02 mbsf; 7. Sample 32.00-.02 mbsf; 8. Sample 32.00-.02 mbsf; 9. Sample 31.70-.71 mbsf; 13. Sample 27.81-.82 mbsf); *10 & 11) Corethron criophilum* Castracane (10. Sample 27.81-.82 mbsf; 11. Sample 27.81-.82 mbsf); *12) Chaetoceros bulbosum* (Ehrenberg) Heiden (Sample 27.81-.82 mbsf); *14 to 16) Aulacoseira* sp. A. (14. high focus, Sample 33.72-.73 mbsf; 15. middle focus, Sample 33.72-.73 mbsf; 16. Sample 33.72-.73 mbsf); *17) Biddulphia punctata* Greville (Sample 32.05-.15 mbsf).
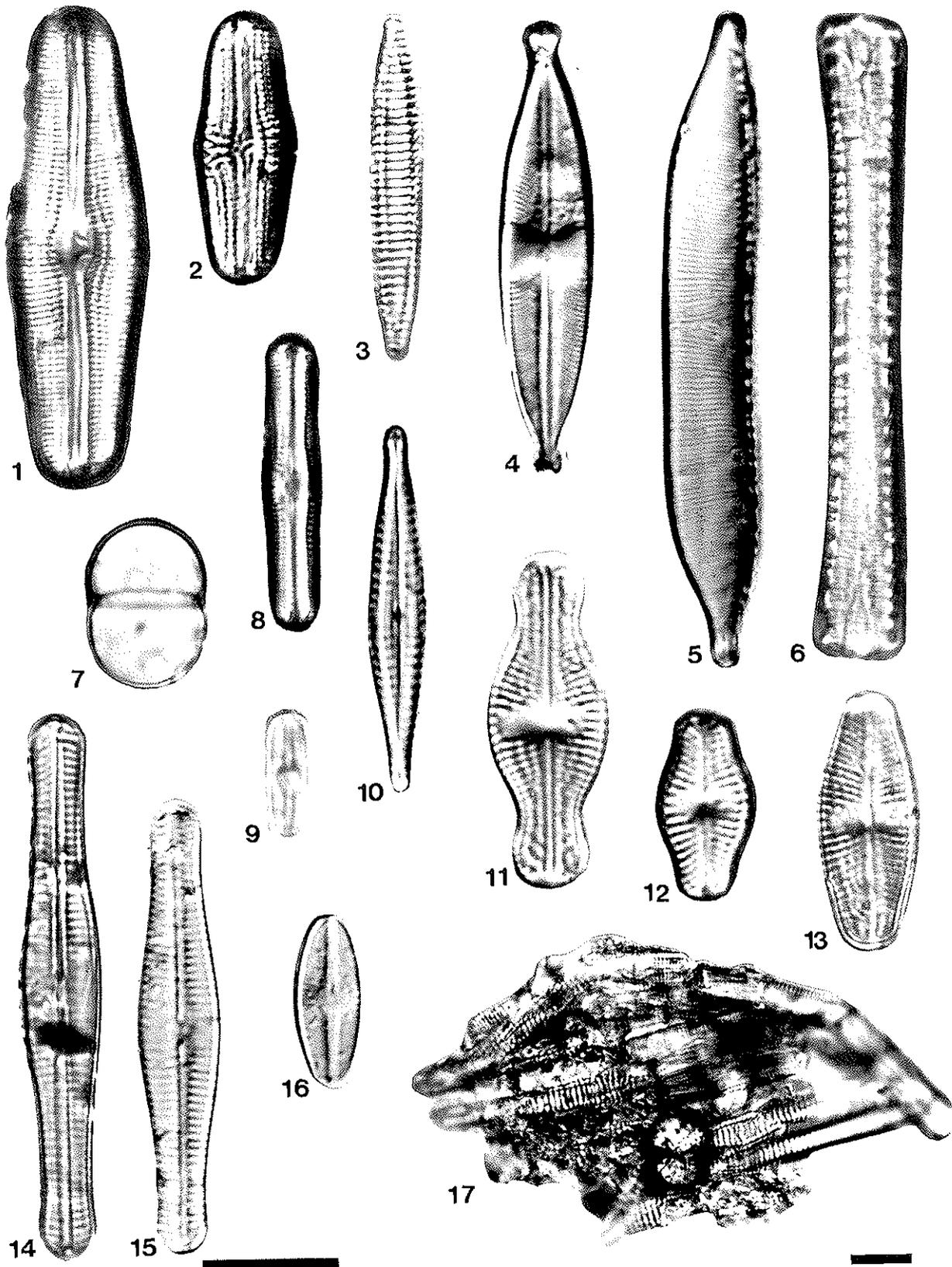
Plate 6 - Scale bar at bottom left for 1 to 16) represents 10 µm, and scale bar at bottom right for 17) represents 10 µm. *1 & 2) Navicula peraustralis* West and West (1. Sample 25.15-.17 mbsf; 2. Sample 25.15-.17 mbsf); *3) Nitzschia westii* Kellogg and Kellogg (Sample 25.15-.17 mbsf); *4) Stauroneis anceps* Ehrenberg (Sample 25.15-.17 mbsf); *5 & 6) Hantzschia amphioxys* (Ehrenberg) Grunow (5. Sample 25.15-.17 mbsf; 6. girdle view, Sample 25.15-.17 mbsf); *7) Melosira charcotii* Peragallo (Sample 27.81-.82 mbsf); *8) Navicula quaternaria* Kellogg and Kellogg (Sample 25.15-.17 mbsf); *9) Navicula* sp. B (Sample 25.15-.17 mbsf); *10) Navicula shackletoni* West and West (Sample 33.72-.73 mbsf); *11-13) Luticola* spp. (11. Sample 25.15-.17 mbsf; 12. Sample 25.15-.17 mbsf; 13. Sample 25.15-.17 mbsf); *14 & 15) Gomphonema* sp. A. (14. Sample 25.15-.17 mbsf; 15. Sample 25.15-.17 mbsf); *16) Achnanthes* sp. A. (Sample 25.15-.17 mbsf); *17)* Non-marine biosiliceous clast containing *Melosira charcotii, Navicula peraustralis,* and *Nitzschia westii* (Sample 25.15-.17 mbsf).