

## Lower Miocene Diatom Biostratigraphy of the CRP-1 Drillcore, McMurdo Sound, Antarctica

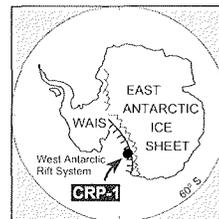
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**Abstract** - Lower Miocene diatoms and other siliceous microfossils in the Cape Roberts Project drillcore (CRP-1), Roberts Ridge, western McMurdo Sound, are documented. Diatom biostratigraphy, along with <sup>87</sup>Sr/<sup>86</sup>Sr ratios from mollusk shells and <sup>40</sup>Ar/<sup>39</sup>Ar data from volcanic materials, constrain the interpretation of the magnetic polarity stratigraphy and allows construction of an age model for CRP-1. Together, these records indicate an age span from to ~21.5 Ma at 147.69 mbsf (the bottom of the hole) to ~17.5 Ma at 43.15 mbsf (top of the lower Miocene interval). Important diatom datums identified in this drillcore are the FAD and LAD of *Thalassiosira praeфрага* and the LAD of *Cavitatus rectus*. Variation in diatom abundance and assemblage composition through the lower Miocene reflects changes in depositional environment. There are intervals of repeated ice cover (floating or grounded) in the lower Miocene section of CRP-1, where diatom production was limited, and intervals where diatoms were growing in open, although at times shallow (<35 m), marine seas. Relative numbers of planktic to benthic diatoms often parallel similar indices of water depth from sedimentologic and sequence stratigraphic interpretations. Approximately 70 diatom taxa, in addition to 2 silicoflagellate and 2 ebridian taxa, are reported. No radiolarians were encountered. Three tentative diatom biostratigraphic zones are introduced, though not formally named in this report. A Ross Sea diatom zonation for the lower Miocene to upper Eocene is under development, for future publication. The forthcoming zonation will incorporate diatom biostratigraphic information from CRP-1 and CRP-2, and earlier stratigraphic drilling in McMurdo Sound, as well as magnetostratigraphically calibrated datums from the Southern Ocean.



### INTRODUCTION

The Cape Roberts Project (CRP) is an international programme aimed at the recovery of Palaeogene sediments from McMurdo Sound, Ross Sea, Antarctica, through stratigraphic drilling. Two seasons of drilling were planned in order to core several holes through seaward dipping strata on Roberts Ridge, 10 to 15 km east of Cape Roberts. 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 Science Team, 1998). The hole was drilled to a depth of 147.69 metres below the sea floor (mbsf), and 113.32 m of core was recovered. 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). Quaternary and Miocene strata are present in this section, and the favoured age model for the lower ~100 m of the drillcore is from ~17.5 Ma to ~21.5 Ma (Roberts et al., this volume).

### ANTARCTIC DIATOM BIOSTRATIGRAPHY

Antarctic diatom biostratigraphy has advanced steadily over the last two decades. Initial description of lower Miocene diatom assemblages from Antarctica and the

Southern Ocean was presented by McCollum (1975), with further discussions by Schrader (1976) and Weaver & Gombos (1981). Neogene and Oligocene diatom assemblages of the Southern Ocean have only recently been calibrated to the magnetic polarity time scale (Gersonde & Burckle, 1990; Baldauf & Barron, 1991; Harwood & Maruyama, 1992; Harwood, 1994).

Prior drilling in the western Ross Sea resulted in the development of a local biostratigraphic framework for the upper Eocene to lower Miocene (Harwood, 1986, 1989; Harwood et al., 1989a). Diatomaceous sediments were recovered during DSDP Leg 28 at sites 270 and 272 (McCollum, 1975; Savage & Ciesielski, 1983; Steinhaff et al., 1987), although diatom diagenesis and transformation to opal C/T (disordered cristobalite/tridymite) rendered the siliceous sediments in these sections largely unusable for diatom studies. Lower to middle Miocene diatom assemblages were also described from reworked diatomite clasts in upper Miocene sediment in the central Ross Embayment (Harwood et al., 1989b; Scherer, 1992). The CRP-1 drillcore adds an important interval to this composite record that was previously not available.

The diatom stratigraphy in deep-sea sediments of the Southern Ocean is well-documented and calibrated to the magnetostratigraphic time scale, but available stratigraphic sections from the Antarctic continental shelf are largely discontinuous and not calibrated to absolute time scales. Some diatom datums used in the Southern Ocean zonal

framework (Baldauf & Barron, 1991; Harwood & Maruyama, 1992) can be applied directly to the Antarctic continental shelf. Other open-ocean taxa, however, are not present or abundant due to biogeographic barriers and, thus, have limited biostratigraphic value in Antarctic shelf sections.

Diatom floras recovered from the continental shelf include a mixture of neritic planktic and benthic littoral taxa, in addition to rarer occurrences of open-ocean floras characteristic of the Southern Ocean. Many fossil neritic and coastal taxa are poorly known, or undescribed. While these taxa may be of biostratigraphic value in future studies, no calibrated reference sections have been available to enable their application in age determination and correlation at this time. The focus of the present study is to establish the ranges of diatoms that have utility as biostratigraphic markers and to provide data on diatom occurrence and abundance that may aid in palaeo-environmental interpretations. A diatom biostratigraphic framework for the Antarctic continental shelf is being developed, and will be formally presented in a later work.

## METHODS

A total of 155 samples from the Miocene interval of the CRP-1 drillcore were collected for diatom analysis. Sample spacing for study of lower Miocene diatoms is variable, but it is less than 1 m for most intervals (Tab. 1). All samples were checked initially by examination of a strewn slide of raw sediment. This was prepared by separation and disaggregation in 50 ml of water and settling for 30 seconds to remove coarse material. A strewn slide was made from the suspended material for a quick check of diatom presence and abundance. If warranted, additional concentration was performed by sieving through a 25 µm sieve, and in some samples, density separation was performed using a Sodium Polytungstate solution of 2.2 specific gravity. Slides were routinely examined at 500x with increase to 1250x magnification for positive identification.

## DIATOM OCCURRENCE IN CRP-1

Marine diatom occurrence is discontinuous throughout the lower Miocene section of CRP-1, with intervals of rich diatom assemblages separated by non-productive intervals of reworked, fragmented diatoms (Fig. 1, Tab. 1). Intervals of abundant *in situ* diatoms occur within the following core depths: 58.75 to 77.06 mbsf; 80.12 mbsf; 85.20 to 102.25 mbsf; 116.48 to 118.57 mbsf; 127.79 to 134.31 mbsf; 141.80 to 142.61 mbsf; and 146.51 to 147.69 mbsf. All other intervals are interpreted to reflect intervals when diatoms were not growing over the CRP-1 site, likely due to cover by floating or grounded ice. Alternatively, extremely rapid sedimentation and water column turbidity would limit diatom production and dilute diatom abundance in the sediment. Poor diatom preservation and the occurrence of <30 diatom fragments in 5 fields of view at 250x are interpreted to reflect intervals of glacial recycling

of marine sediments (Fig. 1, Tab. 1). These diatom-poor assemblages were eroded locally from lateral correlatives of underlying lithostratigraphic units or were reworked from older strata. Intervals where more than 50 fragments were observed in 5 fields-of-view (Fig. 1, Tab. 1) are interpreted to represent open-water productivity and *in situ* diatom sedimentation. There is no evidence for reworking of lower Oligocene or older Paleogene diatoms into the Miocene sequence of CRP-1. The known stratigraphic ranges of diatoms in CRP-1 are presented in figure 2 and table 2.

The Miocene section of CRP-1 includes several ecological associations of marine diatoms. These reflect environmental conditions of variable water depth. A preliminary assessment of diatom assemblage ecology from CRP-1 is shown in table 1. The following characteristic assemblages are noted in order of decreasing water depth: (1) assemblages dominated by pelagic and neritic marine planktic *Coscinodiscus* and *Stephanopyxis* spp., designated 'P' (planktic) on table 1; (2) assemblages with high abundance of *Paralia*, a filamentous tycho planktic ('T') diatom from the benthic environment, which often occurs in high numbers in the plankton; (3) assemblages with high numbers of large benthic diatoms ('B'), such as *Istmia*, *Arachnoidiscus*, and a large unknown diatom (referred to here as genus and species uncertain A, as well as *Cocconeis* spp., *Rhabdonema* spp. and *Grammatophora* spp. The association of 'B+P' is generally a reflection of benthic diatom transport into deep water and mixing with open-marine planktic diatoms.

The distribution of diatoms is discussed, and presented in table 1, in relation to stratigraphic units from the base of the core upwards to the unconformity with overlying Pleistocene sediments at ~43 mbsf. Diatom study of the Pleistocene section of CRP-1 is presented in a companion paper (Bohaty et al., this volume).

*Lithostratigraphic Unit 7.1 (147.69 to 141.60 mbsf) mudstone* - A rich assemblage of mixed benthic and planktic diatoms is present near the top and base of this lithostratigraphic unit. The middle of this lithostratigraphic unit from 145.76 to 143.73 mbsf contains rare diatoms of indeterminate ecology.

*Lithostratigraphic Unit 6.3 (141.60 to 119.28 mbsf), diamictite* - The diatom assemblages within this lithostratigraphic unit are variable in the different samples, ranging between benthic, planktic and barren of diatoms. The upper part of the unit contains a higher concentration of benthic diatoms than the lower section (Tab. 1).

*Lithostratigraphic Unit 6.2 (119.28 to 108.76 mbsf), sandstone* - This lithostratigraphic unit contains a poor assemblage of diatoms and fragments of diatoms, except for the sample at 118.56-118.57 mbsf, where planktic and tycho planktic diatoms occur in higher abundance.

*Lithostratigraphic Unit 6.1 (108.76 to 103.41 mbsf), diamictite* - Three samples from this lithostratigraphic unit contain only rare fragments of marine diatoms.

*Lithostratigraphic Unit 5.8 (103.41 to 92.19 mbsf), mudstone* - This lithostratigraphic unit contains a rich assemblage of planktic diatoms, although the lowest sample at 103.39-103.40 mbsf is nearly barren. An assemblage of well-preserved diatoms, with relatively abundant

Tab. 1 - Miocene diatom occurrence in CRP-1. Sample intervals are listed with abundance, ecology, and processing techniques.

Units	Sample Interval	Abundance	Ecology	Processing Notes	Units	Sample Interval	Abundance	Ecology	Processing Notes
	43.57-43.58	<10	P+B	strewn	5.8	95.43-95.45	<50	P	strewn
	44.08-44.09	<30	P	strewn; sieve		95.59-95.61	<50	P	strewn
	44.58-44.59	<10	-	strewn		95.93-95.95	<100	P	strewn
	44.93-44.94	<10	-	strewn		96.24-96.25	>100	P	strewn; sieve
	45.04-45.14	<10	-	FT; strewn; sieve; float		96.60-96.62	<100	P	strewn
	45.92-45.93	<10	P	strewn; sieve		97.47-97.49	>100	P	strewn
	47.04-47.05	<10	P	strewn; sieve		98.09-98.11	>100	P	strewn; sieve
	48.06-48.07	X	-	strewn; sieve		98.70-98.72	<100	P	strewn
	48.90-48.91	<10	P	strewn; sieve		98.77-99.78	>100	P	strewn
	50.00-50.01	<10	-	strewn; sieve		99.02-99.12	>100	P	FT; strewn; sieve; float
5.2	51.71-51.72	<10	P	strewn; sieve	99.55-99.57	>100	P	strewn	
	53.01-53.02	<10	P	strewn; sieve	100.05-100.09	>100	P	strewn	
	53.50-53.60	<10	P	FT; strewn; sieve; float	100.27-100.28	>100	P	strewn; sieve	
	55.40-55.41	<30	P	strewn; sieve	100.47-100.49	>100	P	strewn	
	57.37-57.39	<30	P	strewn	101.03-101.05	>100	P	strewn; sieve	
	57.51-57.52	<30	P	strewn; sieve	101.31-101.32	<100	P	smear	
	58.05-58.08	<30	B	strewn	101.49-101.51	>100	P	strewn; sieve	
	58.70-58.72	<50	B	strewn; sieve	102.18-102.20	>100	P	strewn	
	58.75-58.76	<100	B	sieve; float	102.24-102.25	>100	P	strewn; sieve	
	59.58-59.68	<50	B	FT; sieve; float	102.47-102.49	>100	P	strewn; sieve	
5.3	59.98-59.99	<50	B	strewn; sieve	103.39-103.40	<10	-	smear	
	61.68-61.70	<10	-	strewn	103.44-103.47	<10	-	strewn	
	62.11-62.12	<50	-	strewn; sieve	104.55-104.56	<10	-	strewn	
5.4	62.76-62.78	<30	-	strewn	106.44-106.45	<10	-	strewn	
	63.14-63.16	<10	-	strewn	108.78-108.79	<10	-	strewn	
	63.37-63.38	X	-	strewn	110.79-110.80	<30	-	strewn	
	65.80-65.81	<100	P+T	strewn	112.46-112.47	<30	-	strewn	
	66.16-66.17	>100	P	strewn; sieve	114.76-114.77	<10	-	strewn	
	66.64-66.66	<100	P+T	strewn; sieve	115.95-115.96	<50	P	strewn	
	67.42-67.44	<100	P+T	strewn	116.48-116.49	<10	-	strewn; sieve	
	67.56-67.57	>100	P	strewn	118.56-118.57	<50	P+T	strewn; sieve	
	69.73-69.74	>100	P	strewn; sieve	120.40-120.50	<30	P	FT; strewn; sieve; float	
	69.77-69.79	<100	P+T	strewn	120.95-120.96	<30	-	strewn	
5.5	70.23-70.25	<100	P+T	strewn; sieve	122.73-122.74	<30	-	strewn	
	72.58-72.59	<50	P	strewn	123.80 clast	<30	-	smear	
	74.85-74.87	<100	P+T	strewn	123.80 matrix	<30	-	smear	
5.5	74.91-74.92	>100	P	strewn; sieve	125.51-125.52	<30	-	strewn	
	76.18-76.20	>100	P+T	strewn; sieve	126.61-126.63	<30	-	strewn	
	77.00-77.02	<100	P+T	strewn	127.42-127.44	<30	-	strewn	
	77.05-77.06	>100	P	strewn	127.79-127.80	<50	-	strewn	
	77.50-77.52	<10	P+B	strewn	127.79-127.81	<30	-	strewn	
	77.89-77.89	<50	P	strewn; sieve	128.39-128.41	<50	P+B	strewn; sieve	
	78.15-78.25	<30	P	FT; strewn, sieve; float	129.27-129.29	<50	P+B	strewn; sieve	
	78.35-78.37	<30	-	strewn	129.59-129.60	<50	B	strewn	
	78.75-78.77	<30	-	strewn; sieve	130.40-131.42	<50	P+B	strewn; sieve	
	78.61-78.62	<30	B	strewn; sieve	131.41-131.43	<50	P+B	strewn	
5.6	79.43-79.45	<50	P	strewn	131.67-131.68	<50	P	strewn; sieve	
	80.12-80.13	<100	P	strewn	132.59-132.61	<30	P	strewn	
	80.12-80.14	<50	P	strewn	134.18-134.20	<50	P+B	strewn; sieve	
5.7	81.39-81.41	<30	P	strewn	134.30-134.31	<100	P	strewn; sieve	
	81.41-81.42	<30	P	strewn	136.85-136.86	<30	-	strewn	
	81.97-81.99	<50	P	strewn; sieve	138.75-138.76	<50	-	strewn	
	82.38-82.40	<30	P	strewn	139.77-139.78	<10	-	strewn	
	83.24-83.26	<30	P	strewn	141.48-141.49	<10	-	strewn	
	83.29-83.30	<30	P	strewn	141.52-141.54	<10	-	strewn	
	83.61-83.63	<50	P	strewn	141.80-141.92	<100	P+B	FT; strewn; sieve; float	
	84.00-84.01	<50	P	strewn	142.52-142.55	<50	P+B	strewn; sieve	
	84.34-84.36	<50	P	strewn	142.60-142.61	<50	-	strewn	
	84.81-84.83	<50	-	strewn; sieve	142.85-142.91	<50	P+B	strewn; sieve	
5.8	85.21-85.22	<50	P	strewn	143.61-143.3	<50	B	strewn; sieve	
	85.40-85.44	<50	P	strewn; sieve	143.73-143.77	<30	-	strewn	
	85.76-85.78	<50	P+B	strewn	144.01-144.03	<30	-	strewn	
	86.18-86.20	<30	-	strewn	144.38-144.40	<10	-	strewn	
	86.62-86.64	<50	P	strewn	144.80-144.82	<10	-	strewn	
	86.85-86.86	<50	P	strewn	145.18-145.21	<30	P+B	strewn	
	87.06-87.08	<50	P	strewn	145.46-145.50	<10	-	strewn	
	87.54-87.56	<100	P+B	strewn; sieve	145.50-145.51	<30	-	strewn	
	88.81-88.82	<100	P	strewn; sieve	145.68-145.70	<50	B	strewn; sieve	
	91.22-91.23	<100	P	strewn; sieve	145.72-145.76	<30	-	strewn	
5.8	92.26-92.28	<100	P	strewn; sieve	145.95-145.97	<30	P+B	strewn	
	92.70-92.72	<50	P	strewn; sieve	146.34-146.36	<30	P+B	strewn	
	93.14-93.15	<50	P	strewn	146.51-146.52	<50	B	strewn; sieve; float	
	93.24-93.33	<50	P	strewn	146.79-146.83	<100	P+B	strewn; sieve	
	93.88-93.90	<100	P	strewn; sieve	146.80-146.82	<50	P+B	strewn; sieve	
	94.85-94.86	<50	P	strewn	147.19-147.20	<50	P+B	strewn; sieve	
	95.04-95.06	<50	P	strewn; sieve	147.48-147.52	<50	P+B	strewn; sieve	
					147.68-147.69	<100	P	strewn; sieve	

Note: abundance represents the number of diatom fragments observed in five fields-of-view at 250x. Diatom assemblages are classified into general ecological groups, where 'P' = planktic; 'T' = tycho planktic; and 'B' = benthic. Intervals lacking sufficient data for ecologic interpretation are represented by '-.'

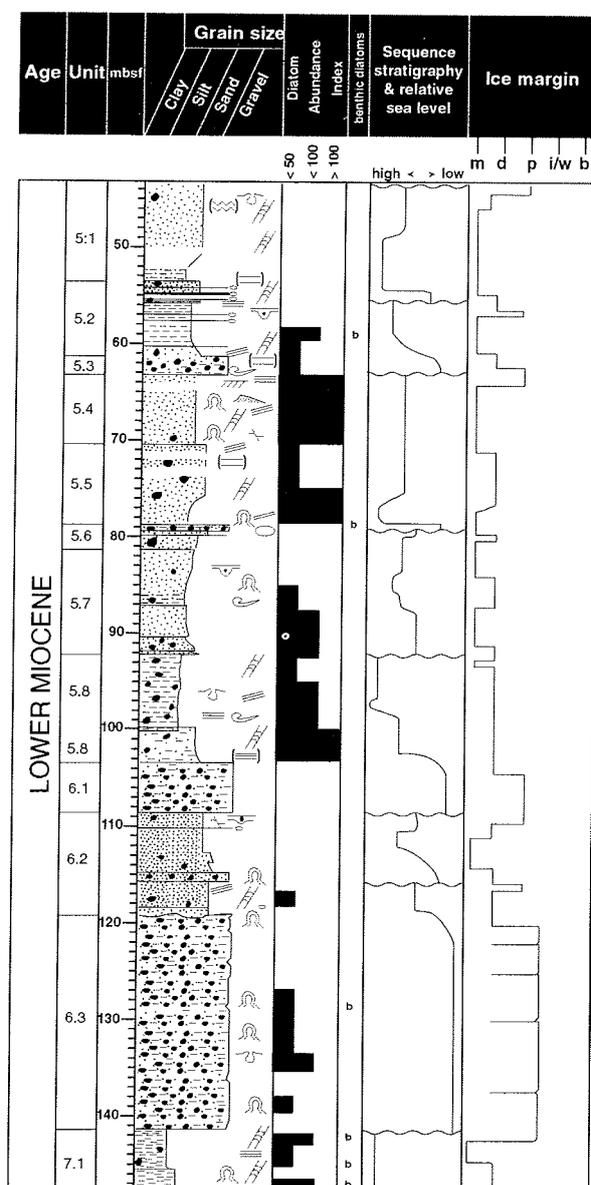


Fig. 1 - Summary log and diatom abundance for Miocene section of CRP-1. Relative diatom abundance is plotted in relation to lithologic descriptions, lithostratigraphic unit designations, and depositional interpretations. Black bars represent diatom occurrence with increasing abundance to the right. Five fields-of-view were observed (at 250x) in a raw strewn slide of each sample. Data were collected in six categories: barren (X), <10, <30, <50, <100, or >100 diatom fragments per five fields-of-view. Only samples equal to or exceeding <50 fragments are depicted; lower abundance categories most likely represent intervals of diatom reworking. Intervals dominated by benthic diatoms are noted with a lower case "b."

*Chaetoceros* frustules, occurs at 91.22-91.23 mbsf.

*Lithostratigraphic Unit 5.7 (92.19 to 81.16 mbsf), siltstone and mudstone* - This lithostratigraphic unit contains an assemblage of planktic diatoms that decrease in abundance upwards.

*Lithostratigraphic Unit 5.6 (81.16 to 78.85 mbsf), sandstone and siltstone* - Three samples were examined from this lithostratigraphic unit. Planktic marine diatoms are present in relatively high abundance, but are highly fragmented.

*Lithostratigraphic Unit 5.5 (78.85 to 70.28 mbsf), sandstone* - This lithostratigraphic unit contains a rich flora of planktic diatoms, which continues into the overlying lithostratigraphic unit. The base of the unit at 78.61-78.62 mbsf was deposited under very shallow water, as indicated by the presence of benthic diatoms and rare planktic diatoms. The assemblages are highly fragmented.

*Lithostratigraphic Unit 5.4 (70.28 to 63.20 mbsf), sandstone* - This lithostratigraphic unit contains a rich flora of planktic and tycho planktic diatoms. The uppermost sample at 63.37-63.38 mbsf is barren of diatoms, except for rare diatom fragments and rare clasts of diatomaceous sediment. Authigenic minerals of dolomite, calcite or siderite are present along with fine grains of mudstone.

*Lithostratigraphic Unit 5.3 (63.20 to 61.51 mbsf), diamictite* - Four samples were examined from this lithostratigraphic unit. The diatoms are highly fragmented and poorly preserved. *Paralia*, *Stephanopyxis* and the ebridian *Pseudammodochium lingii* are present. Pieces of diatomaceous sediment occur as small clasts in the sieved fractions, suggesting a source from existing sediment of a contemporaneous age.

*Lithostratigraphic Unit 5.2 (61.51 to 53.70 mbsf), interbedded siltstone, diamictite and breccia* - The diatoms shift from a benthic assemblage at the base to one reflecting a deeper, open-water environment at 57.51-57.52 mbsf (Tab. 1, Fig. 1). Water depth for the lower interval is estimated at 50 m or less in this environment, the approximate depth where the euphotic zone would illuminate the seafloor. Diatoms are sparse in the upper four samples of this lithostratigraphic unit.

*Lithostratigraphic Unit 5.1 (53.70 to 43.55 mbsf), sandstone and mudstone* - This diatoms of this unit are predominantly fragmented and are thought to be recycled due to low abundance and poor preservation. One sample at 44.08-44.09 mbsf contains a sparse lower Miocene planktic diatom flora that is similar to assemblages present in lower levels of CRP-1.

Tab. 2 - Diatom biostratigraphic datums used in age assignment of the Miocene section of CRP-1.

Depth Range (mbsf)	Datum	Published Age (Ma)	Source
Absent	FAD <i>Actinocyclus ingens</i>	16.3 (C5Cn.1n)	H&M
Absent	FAD <i>Denticulopsis maccollumii</i>	16.6 (C5Cn.3n)	H&M
59.58 - 58.75	LAD <i>Thalassiosira praefraga</i>	18.4-17.8 (C5En to C5Dr)	Y&A / H&M / H+
88.81 - 91.22	LAD <i>Asteromphalus symmetricus</i>	18.5 (C5En)	H&M
103.39 - 102.24	FCAD <i>Thalassiosira praefraga</i>	20.3 or 20.6 (C6N)	Y&A / H&M / H+
146.79-146.83	LAD <i>Cavitatus rectus</i>	~20.5	A+
Absent	LAD <i>Kisseleviella carina</i>	~25 (at 145 m in CIROS-1)	Hc
Absent	LAD <i>Lisitzinia ornata</i>	24.5 (C6Cr)	H&M

Note: ages are revised, by interpolation, to the Berggren et al. (1995) time scale. Datums for each taxon are abbreviated as 'FAD' = First Appearance Datum, 'LAD' = Last Appearance Datum, and 'FCAD' = First Common Appearance Datum. Sources for age information are abbreviated as follows: Hc = Harwood (1989), H&M = Harwood & Maruyama (1992), H+ = Harwood et al. (1992), A+ = Akiba et al. (1993), and Y&A = Yanagisawa & Akiba (1998).

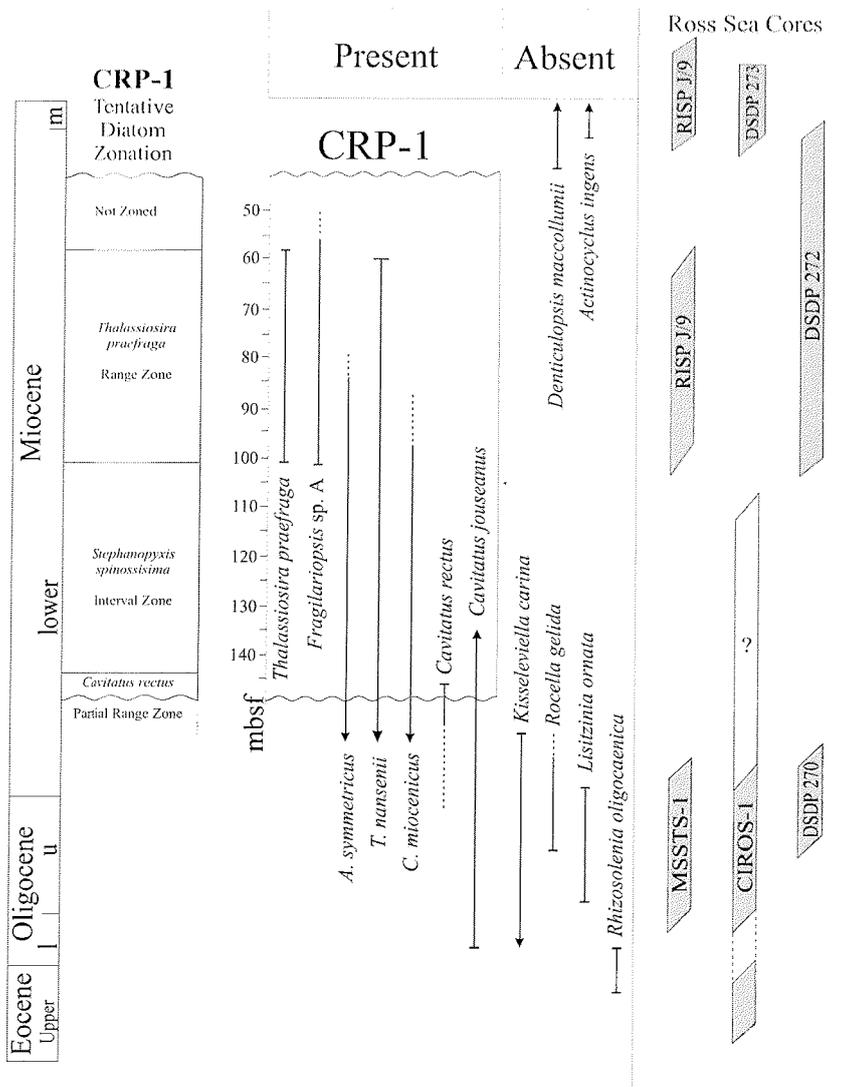


Fig. 2 - Ranges of selected diatom taxa present in and absent from the lower Miocene section of CRP-1, and the tentative Ross Sea diatom zonation proposed for the lower Miocene. Stratigraphic positions of other relevant diatom-bearing sequences in the Ross Embayment are represented with vertical bars.

## BIOGEOGRAPHIC CONSIDERATIONS

As with diatom assemblages and distributions from the CIROS-1 (Cenozoic Investigations in the Ross Sea) and MSSTS-1 (McMurdo Sound Sediment and Tectonic Studies) drillcores, there is considerable difficulty in correlating Antarctic shelf sequences to established Southern Ocean diatom biostratigraphic schemes (Harwood & Maruyama, 1992). This is a likely result of local environmental effects such as temperature, salinity, turbidity, proximity to ice and ice cover, as well as regional palaeobiogeographic controls on diatom bioprovinces in the southern high latitudes. Such biogeographic barriers appear to have limited the southward migration of Southern Ocean zonal taxa such as *Lisitzinia ornata*, *Rocella gelida*, *Azpeitia gombosi*, *Coscinodiscus rhombicus*, *Rossiella symmetrica*, *Bogorovia* spp., *Thalassiosira spumellaroides*, *Hemiaulus taurus* and *Nitzschia maleinterpretaria* (Harwood, 1991).

## DIATOM BIOSTRATIGRAPHY

Important Miocene diatom datums recognised in CRP-1 are listed in table 2 and highlighted in table 3.

Diatom occurrence and range in relation to a tentative zonal scheme are summarised in figure 2. These data bracket the interval recovered by CRP-1 and provide a means of correlating CRP-1 to other shelf sections in the Ross Embayment. Interpreted stratigraphic relationships between these sections, based on diatom biostratigraphy, are shown on figure 2. In some instances, the basis for determining the stratigraphic level of first and last diatom occurrences is not well-established at this time, nor is the sequence of datums known from a single continuous section. The sequence of datums will be established through future drilling. Ages listed below and marked by asterisk are revised to conform to the Berggren et al. (1995) time scale, as adjusted by Barron (pers. comm.). This recalibration accounts for the differences in cited ages between this paper and those of Baldauf & Barron (1991) and Harwood & Maruyama (1992).

The absence of *Actinocyclus ingens* in CRP-1 suggests an age older than 16.2\* Ma within magnetic subchron C5Cn.1n (Barron & Baldauf, 1995) at 43.15 mbsf. The top of the lower Miocene section (at 43.15 mbsf) is older than 16.7\* Ma based on the absence of *Denticulopsis maccollumii*. This datum occurs within magnetic subchron C5Cn.3n in ODP Site 748 (Harwood et al., 1992), at an age of 16.7\* Ma according to Berggren et al. (1995). Both of

Tab. 3 - Miocene siliceous microfossil occurrence in CRP-1 - selected taxa.

Lithologic Unit	Sample Depth (mbsf)	Abundance	Preservation	<i>Arachnoidiscus</i> sp. A	<i>Asteromphalus symmetricus</i>	<i>Cavitatus jouseanus</i>	<i>Cavitatus miocenicus</i>	<i>Cavitatus rectus</i>	<i>Cymatosira biharzensis</i>	<i>Dactyliosolen antarcticus</i>	<i>Fragilaropsis</i> sp. A	Gen. et sp. indet. D	<i>Liradiscus</i> sp.	<i>Rhabdonema</i> sp. cf. <i>R. elegans</i>	<i>Rhizosolenia</i> sp. B	<i>Stephanopyxis spinosissima</i>	<i>Stephanopyxis</i> sp. C (MSSTS-1)	"Tigeria" spp.	<i>Thalassiosira praefraga</i> complex	<i>Thalassiosira nansenii</i>	<i>Trinacria racovitzae</i>	<i>Corbisema triacantha</i> (silico.)	<i>Septamocena pappii</i> (silico.)
5.1 to 5.2	53.50-53.60	<10	P	X			X							X			R						
	55.40-55.41	<30	P				X				F			X			R						
5.4	58.75-58.76	<100	M	X							R						R		X				
	59.58-59.68	<50	M	R										R			R						X
5.5	66.16-66.17	>100	M				R			F	R		R					F	R	R			
	67.56-67.57	>100	M				R			X		X						X	R	X	R		
	69.73-69.74	>100	M				R											X	X				
	70.23-70.25	<100	P				X												X				
	74.91-74.92	>100	M				X			X									R	R	F	X	
5.6	76.18-76.20	>100	P				X				R	X						X	R	X	R		
	77.05-77.06	>100	P				X			X	X							X	R	X			
	77.89-77.89	<50	P				X											X	R		X		
	78.15-78.25	<30	P	X			X												X				
	78.61-78.62	<30	M	X							X								X				
5.7	79.43-79.45	<50	M				F			X	R	X						R	F	R	X		
	80.12-80.13	<100	P				X													X			
	81.97-81.99	<50	P				X				X							X		X	X		
	83.61-83.63	<50	P				R														R		
	84.00-84.01	<50	P		X		R			X	R							R	X	X	R		
5.8	85.40-85.44	<50	M				X			X	R	R						R	X	R	X		X
	88.81-88.82	<100	M				R			F	X	X						R	R	R	R		
	91.22-91.23	<100	G		X		X			R	F	X						R	R	R	X		
	93.88-93.90	<100	P				R								X				F	R	X		
	96.24-96.25	>100	M				F				R	R						R	R	R			
	98.09-98.11	>100	M				R				X	X						X	R	R	X		R
	99.02-99.12	>100	M		X	R	R				R			R				R	X	R	R	R	R
	100.27-100.28	>100	M				F				R	X						C	R	F	R	R	R
	101.49-101.51	>100	M		X		R				F	R		X				R	X	R		X	X
	102.24-102.25	>100	M			R	R			R	F	R						X	F	R			
6.2	115.95-115.96	<50	P											X			X	R					
	118.56-118.57	<50	M			R	X			X		X		R			C		R	X			
6.3	129.27-129.29	<50	P				X				X			X	X	X	X	X				X	
	131.67-131.68	<50	P				X	X			X			X		F						X	
	134.30-134.31	<100	P											R		R	R	X		R			
7.1	141.80-141.92	<100	M	X			X	X			F			X	R	R	R	X	X	R		R	
	142.85-142.91	<50	P				X				X		X	X								F	
	145.68-145.70	<50	P				R				R							R	R		X		R
	146.51-146.52	<50	M	X			X						X					F	R		R	X	X
	146.79-146.83	<100	M	X		X	X				F		F	X				R	R		R	X	X
	147.48-147.52	<50	P	X			X	X			R		X	X				X	X				
	147.68-147.69	<100	M		X	R	X	X	X		R		X	X			R	F		X			R

these datums approximate the boundary between the early and middle Miocene. Furthermore, both of these taxa are well-documented in Ross Sea continental shelf sediments.

Similarly, the absence of *Kisseleviella carina* at the bottom of CRP-1 suggests an age younger than ~25 Ma (the LAD of *K. carina*). *Kisseleviella carina* has a highest appearance in CIROS-1 at 145.21 mbsf. This datum suggests the lower Miocene CRP-1 section may be correlative with all or part of the upper ~145 m of the CIROS-1 drillcore.

The diatoms *Thalassiosira fraga* and *T. praefraga* are useful biostratigraphic markers for the lower Miocene. The reported occurrences of *T. fraga* in Antarctic diatom studies should be attributed to *T. praefraga*, as the Antarctic forms do not exhibit the distinctive marginal processes of *T. fraga*. It is possible that the presence of these processes

is either environmentally controlled, or that one form is the resting spore morphology. Alternatively, *T. fraga* may not range into the southern high latitudes and the occurrences there are exclusively *T. praefraga*. Further study is warranted on Southern Ocean and Antarctic shelf deposits to document the biostratigraphic ranges and morphologic variation of these taxa. Until resolution of this situation, these diatoms are reported here as the *T. fraga/T. praefraga* complex. Gersonde (1990) illustrated examples from this group in the Southern Ocean that have two marginal rings of strutted processes, which are denser in arrangement than that indicated in the emended description of *T. fraga* by Akiba & Yanagisawa (1986).

The range of the *Thalassiosira fraga/T. praefraga* complex (synonyms: *Coscinodiscus* sp. 1 of McCollum, 1975; *Thalassiosira fraga* of Gersonde & Burckle, 1990,

of Baldauf & Barron, 1991, of Harwood et al., 1989b, and of Harwood & Maruyama, 1992) provides two key biostratigraphic datums for CRP-1. An age of 18.3\* Ma is suggested for depth 59.68 to 58.75 mbsf based on the Last Appearance Datum (LAD) of *Thalassiosira praeфрага*. The age for this datum is derived from Yanagisawa & Akiba (1998) from the North Pacific, yet they also indicate a discontinuous range for this diatom up to 17.3 Ma. Harwood & Maruyama (1992) record this datum in the Southern Ocean at ODP Hole 751A within the lower part of magnetic subchron C5Dr (Harwood et al., 1992) with an age of 17.8 Ma according to Berggren et al. (1995). Other reports place this datum slightly older within the upper part of C5En (Gersonde & Burckle, 1990; Barron & Baldauf, 1995). This datum defines the boundary between *T. fraga* subzones "b" and "c" of Harwood & Maruyama (1992).

The First Common Appearance Datum (FCAD) of *T. praeфрага* (102.24 to 103.39 mbsf) is reported at 20.3 Ma (Yanagisawa & Akiba, 1998) from the North Pacific region. This agrees with a first occurrence in the lower part of magnetic subchron C6n or the upper part of C6r from Antarctic drillholes (Gersonde & Burckle, 1991; Baldauf & Barron, 1991; Harwood & Maruyama, 1992; Harwood et al., 1992). We reinterpret the magnetostratigraphic interpretations of Harwood et al. (1992) for ODP Sites 747 and 748 guided by the above ages for *T. praeфрага* (*T. fraga*). We use the published age of 20.3 Ma for the first common appearance datum of *T. praeфрага*. In CRP-1, it first appears as a common element of the diatom assemblage of lithostratigraphic Unit 5.8, at 102.49 mbsf, above lithostratigraphic Unit 6.1, a diamictite, which is barren of diatoms. The presence of the Unit 6.1 diamictite probably causes a truncation of the lower range of *T. praeфрага*, as well as other diatoms characteristic of this interval, such as *Fragilariopsis* sp. A. This implies that the age for the FCAD of *T. praeфрага* is younger in CRP-1 than 20.3 Ma.

The last occurrence of *Cavitatus rectus* is a useful datum for the lower Miocene of Japan (Akiba et al., 1993), where a zone is proposed based on this datum at ~20.5 Ma, but at a stratigraphic level beneath the highest occurrence of *Kisseleviella carina*. Yanagisawa & Akiba (1998) reduce this datum to a secondary event at 20.7 Ma, but still below the highest occurrence of *Kisseleviella carina*. The stratigraphic relationship of these two taxa appears to be reversed both in the CRP-1 and CIROS-1 drillcores, where the last occurrence of *Kisseleviella carina* is below the last occurrence of *Cavitatus rectus*.

A tentative diatom zone for the Ross Sea is suggested for the interval below 141.80 mbsf in CRP-1 (Fig. 2). Three zones are bounded by diatom events and zones proposed for the Antarctic continental shelf from drillcores (Harwood, 1986; Harwood et al., 1989a) and reworked sediment clasts (Harwood et al., 1989b; Scherer, 1992). Many, but not all of the selected diatom events are supported by data from the Southern Ocean. Two of the biostratigraphic zones proposed here are interval zones, and this is not optimal. A zonation based on first occurrences is more desirable and will develop as more is known of the ranges of lower Miocene taxa. A working zonation is

described below. Zonal names and associated datums are not formally described. A formal Ross Sea zonation will be presented following continued drillcore recovery Cape Roberts, following CRP-2.

#### CAVITATUS RECTUS PARTIAL RANGE ZONE

*Base.* Not defined at this time, but it lies at or above the *Kisseleviella carina* Zone of Harwood (1986).

*Top.* Highest occurrence of *Cavitatus rectus*.

*Age range in CRP-1.* This zone ranges up to 146.79 mbsf which is assigned an age of ~21.5 Ma (Roberts et al., this volume).

#### STEPHANOPYXIS SPINOSISSIMA INTERVAL ZONE

*Base in CRP-1.* Highest occurrence of *Cavitatus rectus*.

*Top in CRP-1.* Lowest occurrence of the *Thalassiosira fraga/praeфрага* complex.

*Age range in CRP-1.* This zone ranges from ~21.5 Ma at 146.79 mbsf up to ~20 Ma at 102.25 mbsf (Roberts et al., this volume). This age range is based on the occurrence of diatom index taxa in sediments above and below the interval zone, which itself contains few calibrated age markers. The *S. spinosissima* Interval Zone is characterized by heavily silicified neritic diatoms including *S. spinosissima*. It is unlikely that this zone can be used for correlation well beyond CRP-1.

#### THALASSIOSIRA PRAEΦRAGA RANGE ZONE

*Base.* Lowest occurrence of *Thalassiosira praeфрага*.

*Top.* Highest occurrence of *Thalassiosira praeфрага*.

*Age range in CRP-1.* This zone ranges from ~20 Ma at 102.25 mbsf to between 18.0 and 18.8 Ma at 58.75 mbsf (Roberts et al., this volume); the highest occurrence of the *T. fraga/praeфрага* complex occurs in an interval of reversed polarity (58-65 mbsf) in magnetozone R1.

*Discussion.* Harwood & Maruyama (1992) report the highest occurrence of *T. praeфрага* in the lower part of subchron C5Dr but other reports place this datum slightly older in the upper part of C5En (Gersonde & Burckle, 1990; Barron & Baldauf, 1995).

The interval between 58.75 and 43.15 mbsf is not zoned at present.

#### CORRELATION TO OTHER DIATOM-BEARING ANTARCTIC SHELF SEQUENCES

##### ROSS ICE SHELF PROJECT, SITE J/9 (RISP J/9)

The diatom assemblages from CRP-1 resemble diatom floras recovered from diatomaceous sediment clasts within the RISP Site J-9 (82°22'S; 68°38'W) cores beneath the Ross Ice Shelf (Harwood et al., 1989b; Scherer, 1992). Lower Miocene sediment clasts contain between 72 to

92% diatoms, with little terrigenous debris, reflecting the widespread distribution of diatoms during the early Miocene in the Ross Sea. Diatoms were clearly abundant at this time around the Antarctic margin, yet little is known about these assemblages because lower Miocene reference sections are limited.

#### DEEP SEA DRILLING PROJECT (DSDP) LEG 28

McCollum (1975) described many of the diatom taxa encountered in the present study from strata recovered during DSDP Leg 28. Steinhauff et al. (1987) correlated the drillcores from Site 270 and 272, noting differences in the diatom assemblages, specifically the presence of *Kisseleviella carina* in DSDP Site 270 and its absence in DSDP Site 272.

A gap of 3 my is inferred between these sites within the early Miocene (Steinhauff et al., 1987). Only one sample examined from DSDP Site 270, Core Interval 13-3, 110-112 cm, contained diatoms (Steinhauff et al., 1987) due to diagenetic alteration of diatomaceous sediments to opal C-T and opal Q (chert) in other intervals. The intervals in DSDP Site 272 that are correlative to the lower Miocene of CRP-1 are similarly altered to opal C-T in Unit 2B and to opal Q in Unit 2C (Hayes et al., 1975). The distribution of *Kisseleviella carina* in Core Section 13-3 of DSDP Site 270 and its absence in both DSDP Site 272 and CRP-1 indicate the gap between the DSDP drillholes may be represented, in part, within CRP-1. The range of *Thalassiosira praeprae* enables a good correlation between DSDP Hole 272 (Cores 20 to 29) (Savage & Ciesielski, 1983) and CRP-1 (~102 to 59 mbsf).

#### MSSTS-1

The lower Miocene interval in CRP-1 is probably above the interval recovered by the MSSTS-1 drillcore, as indicated by the absence of diatoms *Pterotheca reticulata*, *Kisseleviella carina* and *Lisitzinia ornata* (Fig. 2).

#### CIROS-1

The diatom record from the upper ~145 m of the CIROS-1 drillcore (Harwood, 1989) is similar to the lower Miocene interval of CRP-1. Both of these intervals are stratigraphically above the highest occurrence of *Kisseleviella carina* and *Pterotheca reticulata*. Re-examination of the diatom record from the upper Oligocene and lower Miocene interval of CIROS-1 is needed, preferably in parallel with the detailed documentation of the diatom floras from CRP-1. A younger age of the upper 145 m of CIROS-1 than inferred by Reick (1989) and Harwood et al. (1989a) will resolve the disagreement in age of diatoms datums noted between the MSSTS-1 and CIROS-1 drillcores. An age of ~18.6-19.4 Ma based on strontium isotope ratios from biogenic carbonate from ~45 mbsf in CIROS-1 (M. Lavelle, pers comm.) initially suggested the younger age and potential for overlap between CRP-1 and upper CIROS-1 drillcore.

## CONCLUSIONS

The documentation of diatom occurrence and abundance is presented here to aid environmental reconstruction through the lower Miocene interval of CRP-1. The diatoms reflect variation in environment through ice cover to open sea. Variation in diatom abundance and assemblage composition through the lower Miocene reflects changes in depositional environment. Several intervals of repeated ice cover (floating or grounded) are interpreted for the lower Miocene section of CRP-1, where diatom production was limited, and intervals where diatoms were growing in open, although at times shallow (<50 m), marine seas.

Several biostratigraphic events provide initial age control for this drillcore, which is now dated by correlation to the magnetic polarity time scale,  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios from mollusk shells and  $^{40}\text{Ar}/^{39}\text{Ar}$  data from volcanic materials (Roberts et al., this volume). Together, these records indicate an age span from to ~21.5 Ma at 147.69 mbsf (the bottom of the hole) to ~17.5 Ma at 43.15 mbsf (top of the lower Miocene interval). Important diatom datums identified in this drillcore are the FAD and LAD of the *Thalassiosira fraga/praeprae* complex and the LAD of *Cavitatus rectus*. Detailed documentation of the diatom assemblages in the future, guided by this age model, will enable the CRP-1 sequence to stand as a reference section for the lower Miocene of the Antarctic continental shelf.

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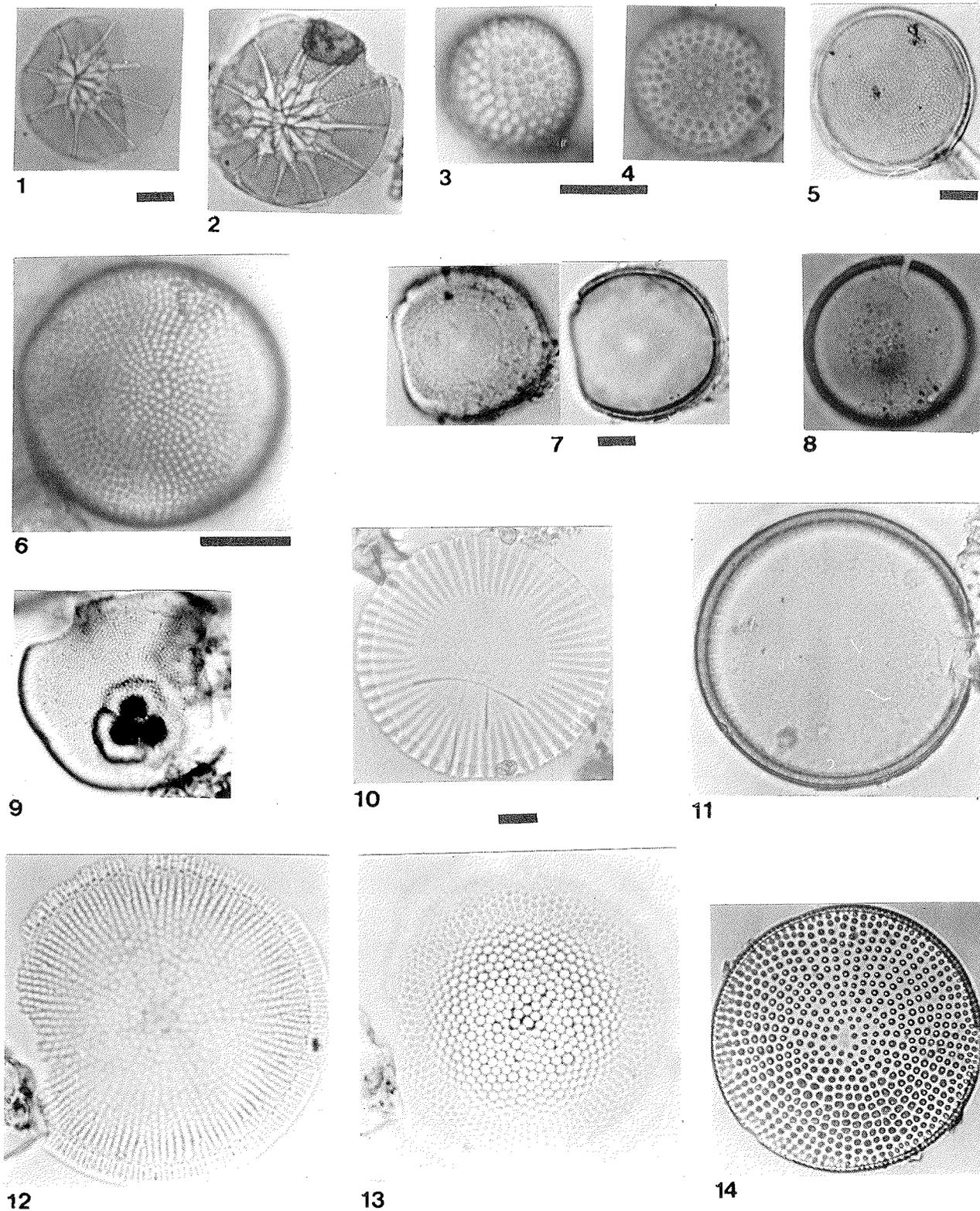


Plate 1 – Diatoms from CRP-1 drillcore (scale bar equals 10  $\mu$ m). 1 & 2) *Asteromphalus* sp. aff. *A. symmetricus*, 99.02 mbsf; 3 & 4) *Thalassiosira fraga/praefraga* complex, 99.02 mbsf; 5 & 6) *Thalassiosira nansenii*, (5) 59.58 mbsf and (6) 99.02 mbsf; 7) *Hyalodiscus* sp. A, 141.80 mbsf; 8) *Melosira* sp., 141.80 mbsf; 9) *Porosira* sp. A, 141.80 mbsf; 10) *Paralia clavigera*, 53.50 mbsf; 11) *Paralia sol* var. *marginalis*, 59.58 mbsf; 12) *Coscinodiscus oculoides*, 53.50 mbsf; 13) *Coscinodiscus* sp. A, 99.02 mbsf.

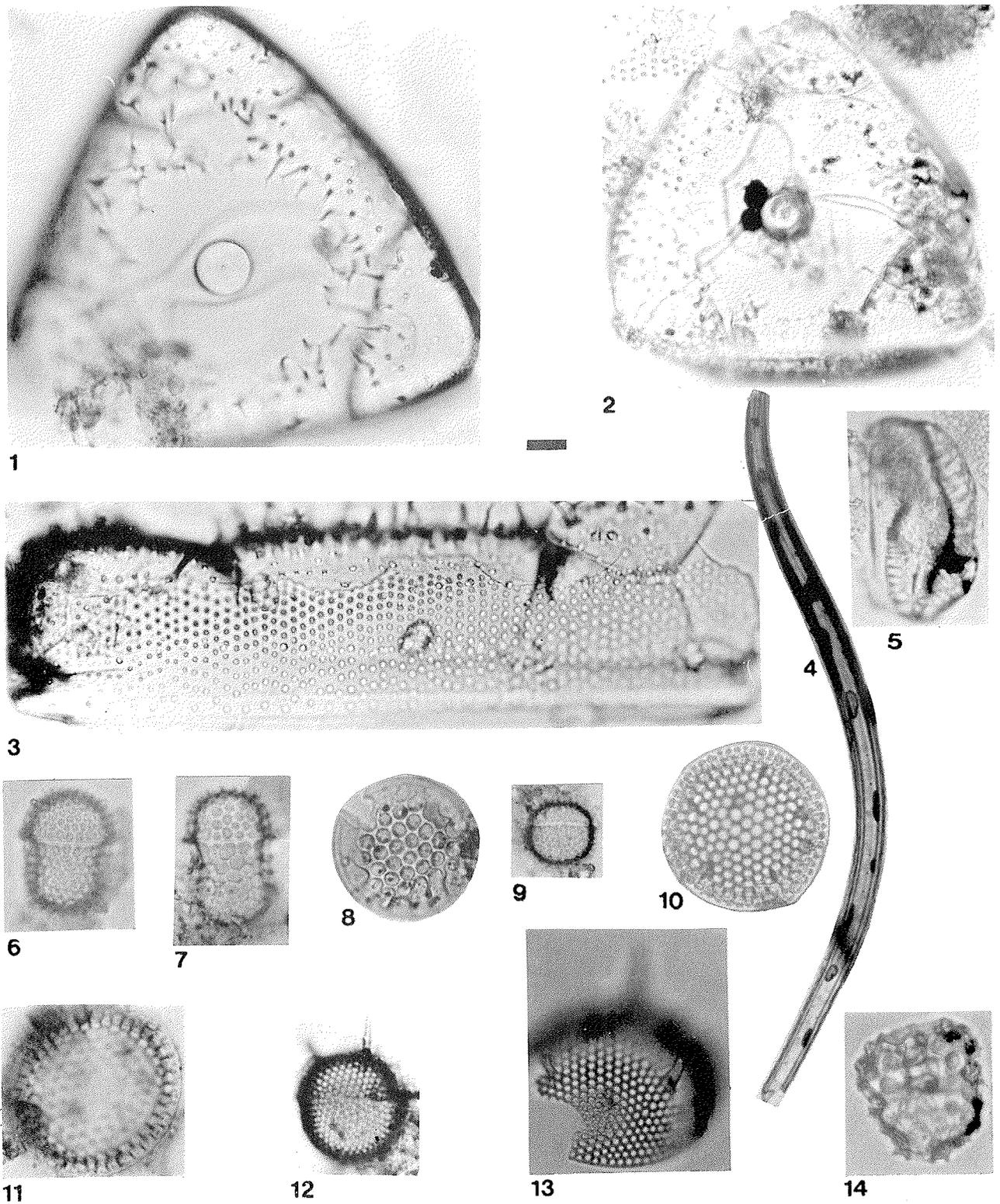


Plate 2 - Diatoms from CRP-1 drillcore (scale bar equals 10  $\mu$ m). 1-3) Genus and species uncertain A, 59.58 mbsf; 4) *Chaetoceros* setae, 99.02 mbsf; 5) *Xanthiopyxis* sp. A, 99.02 mbsf; 6 & 7) *Stephanopyxis turris*, 53.50 mbsf; 8) *Stephanopyxis* sp. resting spore, 99.02 mbsf; 9) *Stephanopyxis* sp. A, 53.50 mbsf; 10) *Stephanopyxis* sp., 59.58 mbsf; 11) *Stephanopyxis* sp. B, 59.58 mbsf; 12 & 13) *Stephanopyxis* sp. C, 59.58 mbsf; 14) *Pseudammodochium lingii* (ebroidian), 99.02 mbsf.

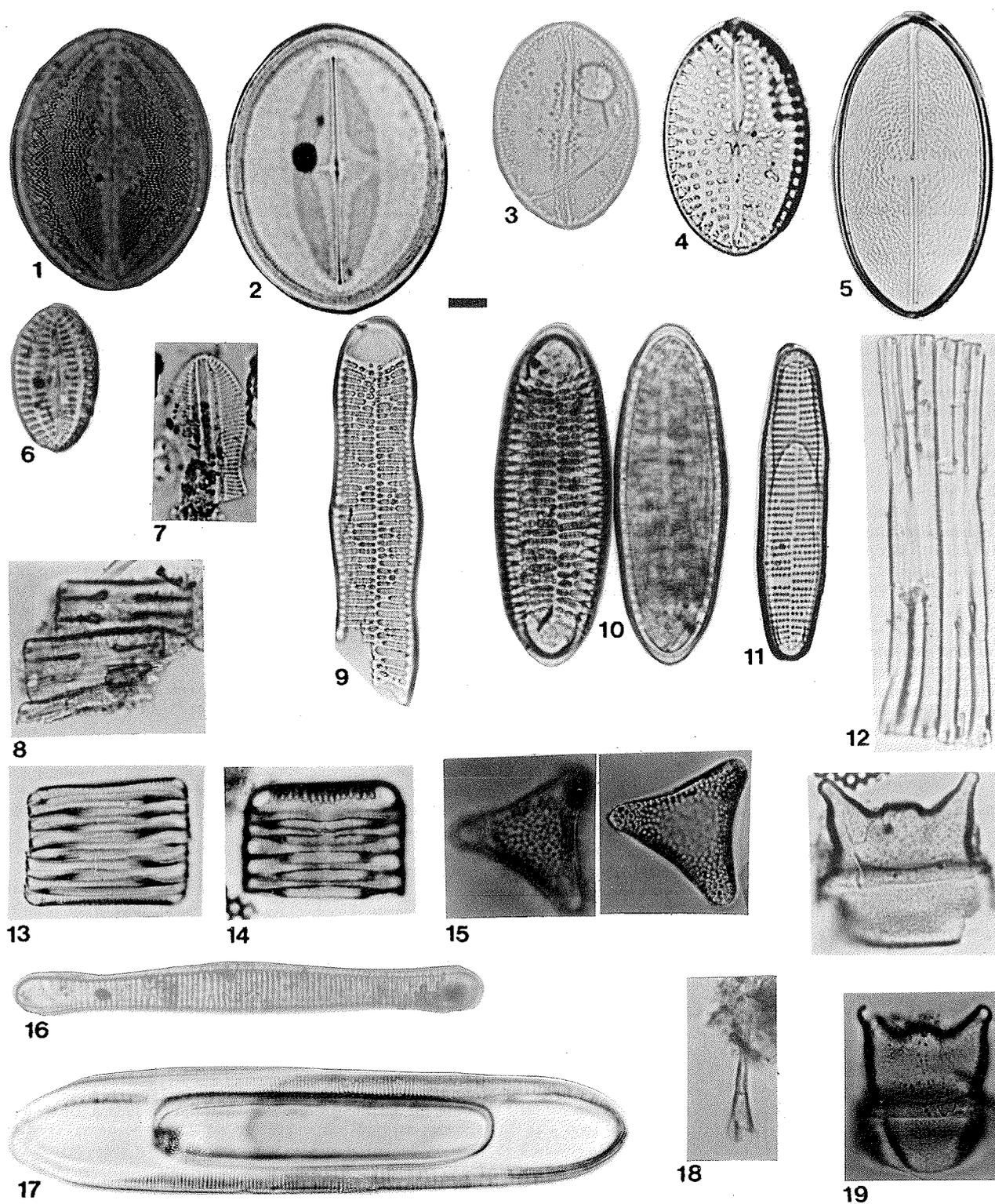


Plate 3 – Diatoms from CRP-1 drillcore (scale bar equals 10  $\mu\text{m}$ ). 1 & 2) *Cocconeis* sp. cf. *C. antiquus* var. *tenuistriata*, 141.80 mbsf; 3) *Cocconeis* sp., 53.50 mbsf; 4) *Cocconeis* sp., 146.51 mbsf; 5) *Cocconeis* sp., 146.51 mbsf; 6) *Cocconeis* sp., 141.80 mbsf; 7) *Diploneis* sp., 141.80 mbsf; 8) *Grammatophora marina*, 141.80 mbsf; 9) *Rhabdonema japonica* group, 99.02 mbsf; 10) *Rhabdonema* sp. B, 141.80 mbsf; 11) *Rhabdonema* sp., 99.02 mbsf; 12) *Grammatophora charcotii*, 99.02 mbsf; 13) *Rhabdonema* sp., 99.02 mbsf; 14) *Rhabdonema japonica*, 141.80 mbsf; 15) *Sheshukovia* sp., 99.02 mbsf; 16) *Rhabdonema* sp. cf. *R. elegans*, 59.58 mbsf; 17) *Entopyla* sp. girdle band, 53.50 mbsf; 18) *Rhizosolenia* sp. B., 141.80 mbsf; 19) *Odontella aurita*, 141.80 mbsf.

## Appendix A - Reference to siliceous microfossils encountered in the CRP-1 drillhole.

The following list is presented as a guide to illustrations of the diatoms present in CRP-1 and to locations where longer lists of synonyms can be found. Citations are in preference for occurrences from within the Southern Ocean and the Ross Embayment. Publications of greatest use for the identification of Antarctic lower Miocene diatoms are McCollum (1975), Schrader (1976), Schrader & Fenner (1976), Gombos (1977), Weaver & Gombos (1981), Gombos & Ciesielski (1983), Harwood (1986), Harwood (1989), Harwood et al. (1989b), Gersonde & Burckle (1990), Baldauf & Barron (1991), and Harwood & Maruyama (1992). Lower Miocene diatom floras from the Norwegian Sea are similar to the Antarctic floras. Key references from this region are Schrader & Fenner (1976), Fenner (1978), and Dzinoridze et al. (1978).

## DIATOMS

- Achnoptychus senarius* (Ehrenberg) Ehrenberg; Hendey, 1964, p. 95, plate 23, figures 1 and 2; Kanaya, 1957, p. 98, plate 7, figure 117.
- Achnoidiscus* sp. A of Harwood, 1986, p. 85, plate 1, figures 4 and 5.
- Achnoidiscus* spp.
- Asteromphalus symmetricus* Schrader & Fenner, 1976, p. 966, plate 21, figures 7, 10-12; Harwood, 1986, p. 85, plate 1, figures 1 and 2; Harwood et al., 1989b, plate 2, figure 4; Harwood & Maruyama, 1992, p. 701, plate 4, figure 18.
- Asteromphalus* sp. cf. *A. symmetricus* in Harwood et al., 1989b, plate 4, figure 3 (Plate 1.1 & 2).
- Auliscus* sp.
- Biddulphia* sp.
- Cavitatus jouseanus* (Sheshukova-Poretzkaya) Williams, 1989, p. 260; Akiba et al., 1993, p. 20-22, figures 6-19, 6-20.
- Synedra jouseana* Sheshukova-Poretzkaya, 1962, p. 208, figure 4; Gombos 1977, p. 599, plate 12, figures 5-7; Schrader, 1973a, p. 710, plate 23, figures 21-23, 25 and 38.
- Cavitatus miocenicus* (Schrader) Akiba & Yanagisawa in Akiba et al., 1993, p. 28, figures 9-1 to 9-11.
- Synedra miocenicica* Schrader, 1976, p. 636, plate 1, figures 1, 1a, 1b; Kim & Barron, 1986, plate 5, figures 13 and 14.
- Cavitatus rectus* Akiba & Hiramatsu in Akiba et al., 1993, p. 29-30, figures 6-7 to 6-15.
- Chaetoceros* spp., including setae. (Plate 2.4).
- Cocconeis antiqua* var. *tenuistriata* Van Heurck, 1909, p. 16, plate 2, figure 27; Harwood, 1986, p. 85, plate 6, figures 1 and 2. (Plate 3.1 & 2).
- Cocconeis costata* group Gregory 1857; Krebs, 1983, p. 285, plate 1, figure 8; Harwood, 1986, p. 85, plate 6, figures 5, 10, 11 and 16.
- Cocconeis* sp. A of Harwood, 1986, p. 85, plate 6, figure 6.
- Cocconeis* sp. D of Harwood, 1986, p. 85, plate 6, figure 9.
- Cocconeis* spp. (Plate 3.3-6)
- Corethron* sp., including spines
- Coscinodiscus oculoides* Karsten, 1905, p. 81; Van Heurck, 1909, p. 49, plate 12, figure 167 (Plate 1.12).
- Coscinodiscus oculisiridus* (Bailey, 1856) Cleve, 1883, p. 147; Harwood, 1986, p. 85, plate 2, figures 1-3.
- Coscinodiscus radiatus* Ehrenberg, 1839, p. 18., plate 3, figure 1 a-c.
- Coscinodiscus* sp. A of Harwood, 1986, p. 85, plate 5, figures 1, 7 and 8 (Plate 1.13).
- Cymatosira biharensis* Pantocsek; Harwood, 1989, p. 78, plate 4, figure 33.
- Dactyliosolen antarcticus* Castracane; Harwood, 1986, p. 85, plate 5, figure 17; Harwood & Maruyama, 1992, p. 702, plate 18, figure 12.
- Diploneis* spp. (Plate 3.7)
- Endietya hungarica* Hajos, 1968, p. 83, plate 9, figures 7; plate 10, figures 1 and 2.
- Coscinodiscus* sp. "robustus", Harwood, 1986, p. 85, plate 5, figures 15 and 16.
- Entopyla australis* var. *gigantea* (Greville) Fricke; Wornardt, 1967, p. 89, figures 177-180; Harwood, 1986, p. 85, plate 7, figure 30 (Plate 3.17).
- Fragilariopsis* sp. A refer to the description and discussion of this taxon in Harwood et al., 1989b, p. 105, plate 3, figures 12-14, under the name *Nitzschia* sp. A.
- Gen. et sp. indet. D** of Harwood, 1989, p. 82, plate 4, figures 26-28.
- Genus and species uncertain A. (Plate 2.1-3)
- Grammatophora charcotii* Peragallo; Harwood, 1989, p. 79.
- Grammatophora* sp. Harwood, 1986, p. 86, plate 7, figures 26 and 27. (Plate 3.12)
- Grammatophora marina* (Lyngbye) Kutzing; Hargraves, 1968, p. 65, figure 15 (Plate 3.8).
- Hyalodiscus radiatus* var. *maximus* (Petit) Cleve & Grunow; Harwood, 1986, p. 86, plate 4, figure 16.
- Hyalodiscus* sp. A. (Plate 1.7).
- Isthmia* sp.
- Liradiscus ovalis* Greville; Hajos, 1976, p. 826, plate 17, figures 1 and 2; Harwood, 1989, p. 79, plate 3, figure 36.
- Compare with McCollum's *Liradiscus* sp. and in Harwood et al., 1989b, plate 3, figure 15.
- Melosira* sp. (Plate 1.8).
- Odontella aurita* (Lyngbye) Agardh, Harwood, 1989, p. 79, plate 4, figure 4. (Plate 3.19).
- Paralia (Ellerbeckia) clavigera* Grunow in Van Heurck; Wornardt, 1967, p. 15, figures 1 and 2; Harwood, 1986, p. 86, plate 2, figure 11 (Plate 1.10).
- Paralia sol* var. *marginalis* Peragallo, 1921, p. 90, plate 5, figure 2 (Plate 1.11).
- Paralia sulcata* (Ehrenberg) Cleve; Hustedt, 1930-1933, p. 276, figures 118-120.
- Pinnularia** spp.
- Pleurosigma* sp.
- Porosira* sp. A. (Plate 1.9).
- Proboscia praebarboi* (Schrader) Jordan & Priddle, 1991, p. 57.
- Rhizosolenia praebarboi* Schrader, 1973b, p. 709-710, plate 24, figures 1-3; Gombos & Ciesielski, 1983, p. 604, plate 24, figure 10; Akiba & Yanagisawa, 1986, p. 497, plate 42, figures 8 and 9; plate 43, figures 1-9.
- Rhabdonema japonicum* group Tempere & Brun; Harwood, 1986, p. 86, plate 7, figure 3. (Plate 3.9 & 14).

## Appendix A - continued.

- Rhabdonema* sp. cf. *R. elegans* Tempere & Bruun in Bruun & Tempere, 1889; Harwood, 1989, p. 80.  
Gen. et sp. uncertain #11 Harwood, 1986, p. 87, plate 5, figures 11 and 12; Laiba & Pushina, 1997, figure 3, #9. (Plate 3.16).
- Rhabdonema* sp. p. (Plate 3.11 & 13).
- Rhabdonema* sp. A of Harwood, 1989, p. 80, plate 6, figures 7 and 8.
- Rhabdonema* sp. B (Plate 3.10).
- Rhaphoneis* sp. of Harwood, 1986, plate 7, figures 40 and 41.
- Rhizosolenia hebetata* group Bailey, 1856, p. 5, plate 1, figures 18 and 19; Harwood & Maruyama, 1992, p. 705, plate 11, figure 7.
- Rhizosolenia* sp. A of Harwood, 1989, p. 80, plate 3, figure 26.
- Rhizosolenia* sp. B. (Plate 3.18).
- Sheshukovia* sp. (Plate 3.15).
- Stellarima microtrias* Hasle & Sims, 1986; Harwood et al., 1989b, plate 2, figure 6.  
*Coscinodiscus fitreatus* Karsten, in Harwood, 1986, p. 85, plate 4, figures 17, 18 and 21.
- Stephanopyxis grunowii* Grove & Sturt, in Schmidt et al. 1874-1959, plate 130, figures 1-4 and 6; Hanna 1927, p. 33, plate 4, figure 2; Hajos, 1976, plate 4, figures 1 and 2; Gombos 1977, p. 597, plate 28, figures 3-5; plate 31, figures 1, 2 and 7; plate 32, figures 1-3; Harwood, 1989, p. 81, plate 2, figures 5 and 6.
- Stephanopyxis* sp. C of Harwood, 1986, p. 87, plate 4, figures 12 and 13.
- Stephanopyxis spinosissima* Grunow, 1884, p. 90-91; Grunow in Schmidt et al., 1874-1959, plate 123, figure 18; Schrader & Fenner, 1976, p. 1000, plate 31, figure 5.  
*Stephanopyxis* sp. A of Harwood, 1986, p. 87, plate 4, figure 2.
- Stephanopyxis* sp. of Harwood et al., 1989b, plate 4, figure 6. Resting spore. (Plate 2.8).
- Stephanopyxis* sp. A. (Plate 2.9).
- Stephanopyxis* sp. B. (Plate 2.11).
- Stephanopyxis* sp. C. (Plate 2.12 & 13).
- Stephanopyxis turris* group (Greville & Arnott) Ralfs, in Pritchard, 1861; Schrader & Fenner, 1976, p. 1000, plate 30, figures 1-10 and 14; plate 37, figures 17-19.
- Stictodiscus hardmanianus* Greville; Harwood, 1986, p. 87, plate 1, figures 8 and 9; Harwood, 1989, p. 81, plate 1, figure 6; Desikachary & Sreelatha, 1989, p. 236, plate 102, figures 6-7, plate 104, figures 2, 4, 6-7.
- "*Tigeria*" group. Not formally named to date, but likely represents an undescribed genus. We herein use an informal generic name of "*Tigeria*" for forms previously referred to as *Synedra* / *Fragilaria* sp. A of Harwood, 1989, p. 81.. *Synedra*? sp. 1 Brady in Harwood et al., 1989b, plate 3, figure 21; *Synedra*? sp. 2 Brady in Harwood et al., 1989b, plate 3, figure 22; *Tetracyclus* sp. in Harwood, 1986, plate 7, figures 34, 38, 39 and 41.
- Thalassiosira praeфрага* Gladenkov & Barron, 1995, p. 30, plate 2, figures 3-6 and 9.  
*Thalassiosira fraga* Schrader, in Harwood et al., 1989b, plate 2, figure 3.  
*Coscinodiscus* sp. 1 of McCollum, p. 526, plate 8, figure 3. (Plate 1.3 & 4).
- Thalassiosira nansenii* Scherer, in Scherer and Koç, 1996, p. 89, plate 4, figures 1-5.  
*Thalassiosira* aff. *irregulata* Schrader, in Harwood et al., 1989b, plate 4, figure 4. (Plate 1.5 & 6).
- Thalassiothrix / Thalassionema* spp.
- Trigonium arcticum* group (Brightwell) Cleve.
- Trinacria excavata* Heiberg; Gombos & Ciesielski 1983, p. 605, plate 17, figure 8; Harwood, 1986a, p. 87, plate 2, figure 13.
- Trinacria racovitzae* Van Heurck, 1909, p. 37-38, plate 9, figures 119, 120 and 126-131; Harwood, 1986, p. 87, plate 5, figures 2-6.
- Trinacria* spp.
- Xanthopyxis* sp. A of Harwood et al., 1989b, plate 4, figure 9. (Plate 2.5).

## SILICOFLAGELLATES

*Corbisematriacantha* (Ehrenberg) Hanna, 1931, p. 198, plate D, figure 1.  
*Dictyochoa triacantha* Ehrenberg, 1844, p. 80; Lemmermann, 1901, p. 258, plate 10, figure 10.

*Septamesocena pappii* (Bachmann) Desikachary & Prema, 1996, p. 181-182, plate 45, figure 5.  
*Mesocena pappii* Bachmann, 1962, p. 380, plate 1, figures 1-9.

## CHRYSOPHYCEAN CYSTS

The cysts of Chrysophycean algae are not distinguished here, but recorded here as a group. Illustration of this assemblage was given by Harwood (1986, Plate 7).

## EBRIDIANS

*Pseudammodochium lingii* Bohaty & Harwood, in press, plate 5, figure 1; plate 8, figures 1-10.  
*Pseudammodochium* sp. cf. *P. dictyoides* Hovasse, Ling, 1984, figure 2, #5, #6 and #13; Harwood, 1986, p. 87, plate 2, figures 16 and 17; Harwood et al., 1989b, p. 82, plate 4, figure 13. (Plate 2.14).

*Pseudammodochium sphericum* Hovasse, 1932, p. 463, figure 16; Perch-Nielsen, 1975, p. 881, plate 1, figures 17 and 18; Bohaty & Harwood, in press, plate 5, figure 6; plate 10, figures 7-8.

*Appendix B* – Examination of Cape Roberts core CRP-1 for Radiolaria.

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**Summary**

Intact radiolarians were not encountered in core CRP-1. Rare fragments of possible spumellarian radiolarians were observed in a single smear slide at 58.33 cm.

**Report**

Table 3 lists the material examined. This consists of 58 smear slides from 8.5 m core depth to 145.92 m core depth and eight core samples from 21.65 m to 146.81 m core depth. These latter were selected for pilot study from a suite of 29 core samples. The smear slides examined were prepared from the <63 µm fraction of foraminiferal sample residues. Although this fraction is smaller than most intact radiolarians, the slides were used to identify intervals of likely radiolarian occurrence in the core sample suite. The absence of any definite radiolarian fragments indicated that treatment of all core samples was not warranted. Instead a pilot study of eight samples was undertaken. A 5–18 g split (av. 10 g) was taken from each of the eight core samples and processed by heating in a 50 ml solution of 10% hydrogen peroxide and 2 ml of dry sodium pyrophosphate, wet-sieving through a 63 µm stainless-steel screen, and drying at 50°C. The dry residue was examined under a stereo microscope. All smear slides and core sample residues contain common to abundant detrital grains, most contain rare to common sponge spicules, and several contain rare to few diatoms. Neither slides nor residues contain definite radiolarians. One smear slide at 58.33 m contains few sponge spicules, rare diatoms and fragments of siliceous meshwork that may be part of a spumellarian radiolarian test. Examination of an adjacent core sample at 58.25 mbsf revealed a poorer siliceous assemblage and no radiolarians. It appears that depositional depth of this cored interval was too shallow for anything other than the sporadic accumulation of fragmented radiolarian remains.