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

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Received 31 July 1998; accepted in revised form 23 October 1998

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 ⁶⁷Sr/⁶⁶Sr ratios from mollusk shells and ⁴⁰Ar/³⁹Ar 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 ~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 of Thalassiosira praefraga 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 seismc 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 & Gombo (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; Steinhauff 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 Embyament (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 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 Palaeogene 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 ecologic 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 tychoplanktic ('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 Istmiia, Arachnostoa, and a large unknown diatom (referred to here as genus and species uncertain A, as well as Cocconeis spp., Rhadinomena spp. and Grannataphora 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 benthic 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 tychoplanktic 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
<table>
<thead>
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<th>Abundance</th>
<th>Ecology</th>
<th>Processing Notes</th>
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<td>&lt;10</td>
<td>P+T</td>
<td>shore</td>
</tr>
<tr>
<td>5.4</td>
<td>5.3-5.77.79</td>
<td>&lt;30</td>
<td>B</td>
<td>shore</td>
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<td>5.7-5.78</td>
<td>100</td>
<td>P+T</td>
<td>shore, float</td>
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<td>5.6</td>
<td>6.14-6.15</td>
<td>&lt;50</td>
<td>P</td>
<td>shore</td>
</tr>
<tr>
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<td>6.7-7.77</td>
<td>100</td>
<td>P+T</td>
<td>shore, sieve</td>
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<td>5.8</td>
<td>7.7-7.79</td>
<td>100</td>
<td>P</td>
<td>shore</td>
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<table>
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<td>&lt;50</td>
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<td>6.2</td>
<td>6.2-6.3</td>
<td>&lt;50</td>
<td>P</td>
<td>shore</td>
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**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' = tychoplanktic; and 'B' = benthic. Intervals lacking sufficient data for ecological 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. Black bars represent diatom occurrence with increasing abundance to the right. Five fields-of-view were observed (at 250×) in a raw strewn slide of each sample. Data were collected in six categories: barren (X), <10, <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."

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

<table>
<thead>
<tr>
<th>Depth Range (mbsf)</th>
<th>Datum</th>
<th>Published Age (Ma)</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>Absent</td>
<td>FAD Actinocyclus ingens</td>
<td>16.3 (C5Cn.1n)</td>
<td>H&amp;M</td>
</tr>
<tr>
<td>59.58 - 58.75</td>
<td>FAD Denticulopsis macreolunni</td>
<td>16.6 (C5Cn.3n)</td>
<td>H&amp;M</td>
</tr>
<tr>
<td>88.81 - 91.22</td>
<td>LAD Thalassiosira praefraga</td>
<td>18.4-17.8 (C5En to C5Dr)</td>
<td>Y&amp;A / H&amp;M / H+</td>
</tr>
<tr>
<td>103.39 - 102.24</td>
<td>LAD Asteromphalus symmetricus</td>
<td>18.5 (C5En)</td>
<td>H&amp;M</td>
</tr>
<tr>
<td>146.79-146.83</td>
<td>FCAD Thalassiosira praefraga</td>
<td>20.3 or 20.6 (C6N1)</td>
<td>Y&amp;A / H&amp;M / H+</td>
</tr>
<tr>
<td>Absent</td>
<td>LAD Caveritius eactus</td>
<td>20.5</td>
<td>A+</td>
</tr>
<tr>
<td>Absent</td>
<td>LAD Kisseleviella carina</td>
<td>&lt;25 (at 145 m in CIROS-1)</td>
<td>He</td>
</tr>
<tr>
<td>Absent</td>
<td>LAD Lisitziinia ornata</td>
<td>24.5 (C6C2r)</td>
<td>H&amp;M</td>
</tr>
</tbody>
</table>

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).
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 bio-provinces 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 spumelloides, 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 diatom events 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 maccoliumii. 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).
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 praefraga. 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 magentic 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. praefraga (102.24 to 103.39 mbsf) is reported at 20.3 Ma (Yanagisawa & Akiba, 1998) from the North Pacific region. This age agrees with the 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. praefraga (T. fraga). We use the published age of 20.3 Ma for the first common appearance datum of T. praefraga. 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 diamicrite, which is barren of diatoms. The presence of the Unit 6.1 diamicrite probably causes a truncation of the lower range of T. praefraga, as well as other diatoms characteristic of this interval, such as Fragilariaopsis sp. A. This implies that the age for the FCAD of T. praefraga is younger in CRP-1 than 20.3 Ma.

The last occurrence of Cavitus 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 Kiseleviella carina. Yanagisawa and Akiba (1998) reduce this datum to a secondary event at 20.7 Ma, but still below the highest occurrence of Kiseleviella 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 Kiseleviella carina is below the last occurrence of Cavitus 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 Kiseleviella carina Zone of Harwood (1986).

*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.

**STEPHANOPYXIS SPINOSISSIMA INTERVAL ZONE**


*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 PRAEFRAGA RANGE ZONE**


*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/praefraga complex occurs in an interval of reversed polarity (58-65 mbsf) in magnetozone R1.

*Discussion.* Harwood and Maruyama (1992) report the highest occurrence of T. praefraga 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 1J9 (RISP 1J9)**

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 paezferga* 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 *Listrotoma 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 flora 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. 87Sr/86Sr ratios from mollusk shells and 40Ar/39Ar data from volcanic materials (Roberts et al., this volume). Together, these records indicate an age span from ~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/paezferga* 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.

ACKNOWLEDGEMENTS

The CRP-1 drillhole was drilled as a cooperative research program of six nations (Australia, Germany, Italy, New Zealand, United States, United Kingdom) to address the climatic, tectonic, palaeobiologic and geologic history of the Western Ross Sea, Victoria Land Basin and the Transantarctic Mountains. This report on the diatoms was prepared through funds from a U.S. National Science Foundation grant OPP-9420062 to Harwood and Scherer. The authors acknowledge the efforts of the CRP International Steering Committee in organizing this programme. J. Barron, R. Giersch and A. McMinn provided valuable comments to improve this paper.

REFERENCES


Haj6s
Haj6s
Gombos
Desikachiiry
C1eveP.T..
Bcrggrcn
sediments. DSDP Leg 29. In:
Printing Office).

diatomsfrom
Gcbilden
Kreidemergels

Diatiiiiiolo,qica.
Nagacva
Soci6tc
Marines
R.

Inif.

Vergleicli~
38, 40, 41: Biostratigraphy of the equatorial and southern

Drilling Program, Scientific Results, 113, Ocean Drilling Program,
College Station, 791-802.

Leg 113, Weddell Sea (Antarctic Ocean). Proceedings of the Ocean
Drilling Program, Scientific Results, 113, Ocean Drilling Program,
College Station, 761-789.

diatom biostratigraphy of Hole 884 B. Proceedings of the Ocean
Drilling Program, Scientific Results, 145, 21-41.

Gombos A.M. Jr., 1977. Paleogene and Neogene diatoms from the
Falkland Plateau and Malvinas outer basin, Leg 36, Deep Sea

Gombos A.M. Jr. & Ciesielski P.F., 1983. Late Eocene to early Miocene
diatoms from the southwest Atlantic. In: Ludwig W.J., Krenesininkov
Printing Office), 583-654.

Gregory W., 1857. On some new forms of Diatomsae found in the
Firth of Clyde and in Loch Tyne. Trans. Roy. Soc. Edinburgh, 21,
473-542.


Haj6s M., 1968. Die Diatomeen der Miozänen Ablagerungen des
Matarzuvorlandes. Geologica Hungarica, Series Paleontologica,
Fasciculus 37, Budapest, 402 p.

Haj6s M., 1976. Upper Eocene and lower Oligocene Diatomsae, Arcellaononidae, and Silicoflagellatae in southwestern Pacific sediments,


Hanna G.D., 1931. Diatoms and silicoflagellates of the Kreyulencn
Shale. Mining in California, 197-211.

Hargreaves P.E., 1968. Species composition and distribution of net
plankton diatoms in the Pacific sector of the Antarctic Ocean. Ph.D.
Dissertation, The College of William and Mary, Williamsburg,
Virginia, 171 p.

from the MSST-1 drillhole. McMurdo Sound, Antarctica. JSIR


high latitudes: inferred biogeographic barriers and progressive


Antarctic Cenozoic history from the CIROS-I drillhole, McMurdo


Harwood D.M. & Maryanya T., 1992. Middle Eocene to Pleistocene
diatom biostratigraphy of Southern Ocean sediments from Kerguelen Plateau, Leg 120. Proceedings of the Ocean Drilling Project,
Scientific Results, 120(2), 683-733.

W.A., Heezen B., Inokoichi H., Maruyama T., McCarthy K., Wei W.

Hasle G.R. & Sims P.A., 1986. The diatom genera Stellorina and
Symbolephora with comments on the genus Actinoptychus. Br.
Phycol. J., 21, 97-114.

& Webb P.N., 1975. Initial reports of the Deep Sea Drilling Project,


Hustedt F., 1930-1933. Die Kieselalgen Deutschlands, Österreichs und
der Schweiz mit Berücksichtigung der übrigen Länder Europas
Kryptogamen-Flora von Deutschland, Österreich und der Schweiz,

Prostrasia. Diatom Research, 6(1), 55-61.

Kanaya T., 1957. Eocene diatom assemblages from the “Kellogg” and

Karsten G., 1905. Das Phytoplankton des Antarktischen Meeres. In:
Churi (ed.), Wissenschaftliche Ergebnisse der deutschen Tierforschung Expedition 1898-1899, Jena (Gustav Fischer), 1-136.

Kim W.H. & Barrow J.A., 1980. Diatom biostratigraphy of the upper
Oligocene to lowermost Miocene San Gregorio Formation, Baja
California, Sur, Mexico, Diatom Research, 1(2), 169-187.

Antarctica, Micropaleontology, 29(3), 267-297.

from the Fisher Massif (Prince Charles Mountains). In: Ricci C.A.
(ed.), The Antarctic Region: Geologic Evolution and Processes,
Plate 3 - Diatoms from CRP-1 drillcore (scale bar equals 10 μm). 1 & 2) Cocconeis sp. cf. C. antiquus var. tenusriata, 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) Diplooneis sp., 141.80 mbsf; 8) Grammatophora marina, 141.80 mbsf; 9) Rhadinonea japonica group, 99.02 mbsf; 10) Rhadinonea sp. B, 141.80 mbsf; 11) Rhadinonea sp., 99.02 mbsf; 12) Grammatophora charcotii, 99.02 mbsf; 13) Rhadinonea sp., 99.02 mbsf; 14) Rhadinonea japonica, 141.80 mbsf; 15) Scheukovia sp., 99.02 mbsf; 16) Rhadinonea sp. cf. R. elegans, 59.58 mbsf; 17) Entepela sp. girdle band, 53.50 mbsf; 18) Rhizonelgia sp. B., 141.80 mbsf; 19) Odontella aurita, 141.80 mbsf.
**Appendix A - Reference to silicic acid 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 given 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 (1972), Schrader (1976), Schrader & Fenner (1976), Gombos (1971), Weaver & Gombos (1981), Gombos & Ciesielski (1983), Harwood (1986), Harwood (1989), Harwood et al. (1989b), Gromov & Butchle (1980), Baldan & L'Anson (1991), and Harwood & Manniya (1992). Lower Miocene diatom flora from the Norwegian Sea are similar to the Antarctic floras. Key references from this region are Schrader & Fenner (1976), Fenner (1978), and Donevandze et al. (1976).

**DIATOMS**

*Cocconeis* *acutus* (Ehrenberg) Ehrenberg; Henday, 1964, p. 95, plate 23, figures 1 and 2; Kanaya, 1957, p. 98, plate 7, figure 117.

*C. cinctus* sp. A of Harwood, 1986, p. 85, plate 1, figures 4 and 5.

*C. cinctus* spp. (Plate 3.1).

*Cocconeis* *parvula* 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* spp. (Plate 3.3-6).

*Cordelion* spp., including setae. (Plate 2.4).

*Cystosira* *lutea* (Shoshukova-Poretskaya) Williams, 1980, p. 266; Akiba et al., 1993, p. 20-22, figures 6-19, 6-20.

*Fragilaria* *nuacea* Shoshukova-Poretskaya, 1902, 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.

*Fragilaria* *nudata* (Schrader) Akiba & Yagisawa in Akiba et al., 1993, p. 28, figures 9-1 to 9-11.

*Fragilaria* *enuciata* (Schrader) Akiba & Yagisawa in Akiba et al., 1993, p. 28, figures 1a, 1b; Kim & Barron, 1986, p. 85, figures 13 and 14.

*Gymnodinium* *rectum* Akiba & Hiramatsu in Akiba et al., 1993, p. 29-30, figures 6-7 to 6-15.

*Phaeocystis* spp., including setae. (Plate 2.4).

*Proboscia* *praebarboi* (Schraer) Jordan & Priddle, 1991, p. 57.

*Proboscia* *praeharboi* (Schrader) Jordan & Priddle, 1991, p. 57.

**Rhopalodiscus sp.** (Plate 3, 14)

**Rhopalodiscus sp.** B (Plate 3, 14).

**Rhizosolenia heberti** group Bailey, 1856, p. 5, plate 1, figures 18 and 19; Harwood & Munnanya, 1992, p. 705, plate 11, figure 7.


**Rhizosolenia sp.** B (Plate 3, 18).

Sedaphytomon sp. (Plate 3, 15).

**Stelligarvia unicostata** Hasle & Sims, 1986; Harwood et al., 1989b, plate 3, figure 6.

**Cosmocladus nematodes** Karsten, in Harwood, 1986, p. 85, plate 4, figures 17, 18 and 21.

**Stephanopyxis gracilis** Grove & Sturt, in Schmidt et al., 1974-1999, plate 130, figures 1-4 and 6; Hamra 1986, p. 9, plate 2, figure 1; Hajo, 1976, plate 4, figures 1 and 2; Gombos 1977, p. 597, plate 28, figures 3-5; plate 31, figures 12 and 7; plate 32, figures 1-3; Harwood, 1986, p. 81, plate 2, figures 5 and 6.

**Stephanopyxis sp.** C of Harwood, 1986, p. 87, plate 4, figures 12 and 13.


**Stephanopyxis sp.** A of Harwood, 1986, p. 87, plate 4, figure 2.

**Stephanopyxis sp.** of Harwood et al., 1989b, plate 3, 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 turril group** (Greville & Arooi) Ralfs, in Pritchard, 1861; Schrader & Fenner, 1976, p. 1000, plate 30, figures 1-10 and 14; plate 37, figures 17-19.

**Stedophyca hardimanius** Greville; Harwood, 1986, p. 87, plate 1, figures 8 and 9; Harwood, 1989, p. 81, plate 1, figure 6; Desikachary & Sreekatha, 1980, 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 *Syedra* / *Frugitaria* sp. A of Harwood, 1989, p. 81, *Syedra* sp. 1 Brady in Harwood et al., 1989b, plate 3, figure 21; *Syedra* sp. 2 Brady in Harwood et al., 1989b, plate 3, figure 23; *Tetrasicyclus* sp. in Harwood, 1986, plate 7, figures 34, 38, 39 and 41.


**Thalassiosira fraga** Schrader, in Harwood et al., 1989b, plate 7, figure 3; *Coccosphaera* sp. 1 of McCollum, p. 576, plate 8, figure 3 (Plate 1, 3 & 4).

**Thalassiosira naasenii** Schrader, in Schrader & Koop, 1996, p. 89, plate 4, figures 1-5.

**Thalassiosira aff. irregularata** Schrader, in Harwood et al., 1989b, plate 4, figure 4. (Plate 1, 5 & 6).

**Thalassiosira / Thalassionema spp.**

**Trigonion articum** group (Brightwell) Cleve.

**Trinacria excavata** Heiberg; Gombos & Ciesielski, 1983, p. 605, plate 17, figure 8; Harwood, 1986a, p. 87, plate 2, figure 13.


**Trinacria spp.**

**Xanthophyis sp.** A of Harwood et al., 1989b, plate 4, figure 9. (Plate 2, 5).

**SILICOFLAGELLATES**

**Carpospectives circualis** (Ehrenberg) Hamra, 1931, p. 198, plate D, figure 1.

**Dierckeia trirhapha** Ehrenberg, 1844, p. 80; Lennge, 1901, p. 258, plate 10, figure 10.


**Mesococcus pappii** Buchmann, 1962, p. 380, plate 1, figures 1-9.

**CHRYSO PHYCEAN 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**

**Pseudammodochidium lingul** Bohaty & Harwood, in press, plate 5, figure 1; plate 8, figures 1-10.

**Pseudammodochidium** sp. cf. *P. dicitoides* 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).

**Pseudammodochidium sphricum** 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 radiolaria were observed in a single smear slide at 58.33 m.

Report

Table 3 lists the material examined. This consists of 58 smear slides from 8.3 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 46-63 μm fraction of foraminiferal sample residues. Although this fraction is smaller than most intact radiolaria, the slides were used to identify in threads 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 (ac. 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 radiolaria. 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 mPgb revealed a poorer siliceous assemblage and no radiolaria. It appears that depositional depth of this cored interval was too shallow for anything other than the sporadic accumulation of fragmented radiolarian remains.