

ODP Leg114 시추코아의 미고생물학적 연구

Micropaleontologic and Biostratigraphic study
of Paleogene Radiolarian from ODP Leg114

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제출문

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본 보고서를 "ODP Leg114 시추코아의 미고생물학적 연구"의 최종 보고서로 제출합니다.

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요 약 문

I. 제목

ODP Leg 114 시추코아의 미고생물학적 연구

II. 연구내용 및 결과

본연구에서는 고위도 남대서양 지역에서 실시된 ODP Leg 114 시추코아에 포함된 규질미화석 중 특히 산출상태가 양호한 방산층에 대한 미고생물학적인 연구를 수행함으로써 심해저에 널리 분포하는 규질 퇴적물과 고환경과의 관계를 밝히는데 그 의의가 있다.

현재까지 수행된 방산층을 이용한 생층서 확립은 저위도 지역에서는 신 제삼기 지층까지 Riedel과 Sanfilippo(1978)에 의해 체계화 되었으며, 고위도 지역의 생층서 확립은 Chen(1975)에 의해 이룩되었다. 그러나 시추코아 회수의 어려움으로 고제삼기의 방산층 생층서 연구는 현재까지도 미확립 상태에 있다. 최근에 실시된 ODP Leg 114의 시추코아는 새로운 시추공법을 이용함으로써 심해저로부터 거의 완벽한 고제삼기 코아를 회수함과 아울러 매우 양호한 고지자기 자료를 획득하므로서 고위도 지역에 대한 방산층 생층서 확립의 기회를 제공하였다. 따라서 본 연구의 가장 큰 의의는 미고생물학적으로는 최초로 고제삼기 고위도 지역에 대한 방산층 생층서를 확립하므로서 향후 심해퇴적물에 대한 시대구분의 기틀마련, 심해퇴적물로부터 규질미화석 추출을 위한 실험방법 확립 및 고지자기 자료와 비교 연구하는 것이다.

현미경 분석결과 널리 분포하는 Index species에 의해 팔레오세로부터 올리고세까지 크게 9개의 생분대로 구분할 수 있었다. 방산층의 생분대는 다시 정확성을 기하기 위해 고지자기 자료와 기타 미고생물자료와 비교 연구하므로서 훌륭한 상관관계를 갖는 것으로 확인 되었다. 특히 급격히 변화하는 종의 다양성 및 멸종에 근거를 둔 고해양학적 연구도 병행하여 실시하였으며, 그결과 고제삼기중 크게 3번의 급격한 온도의 변화 및 고해양의 변천과정을 추론할 수 있었다. 이러한 연구결과는 해양연구소의 주요사업인 남극지역의 연구 및 심해저 망간단괴 탐사를 위한 퇴적환경 분석과 시대구분에 크게 기여할 것으로 기대된다.

SUMMARY

I. Title of study

Micropaleontologic and Biostratigraphic study of Paleogene Radiolarian from ODP Leg 114

II. Abstract

Biostratigraphic and paleoenvironmental analyses of Paleogene radiolarians from the high-latitude South Atlantic have been documented based on material collected on Ocean Drilling Program (ODP) Leg 114. The thick and relatively complete Paleogene sequences, and a nearly continuous history of geomagnetic polarity reversals from ODP Leg 114 cores provides an unparalleled opportunity to establish for the first time a Paleogene radiolarian zonation for the high-latitude Southern Ocean.

First and last occurrences of a selected important taxa are employed as boundary criteria for the eight new and one revised radiolarian zones. Numerical ages for these zonal boundary have been determined either by direct calibration to the geomagnetic polarity chrons, where such data is available in the Leg 114 holes, or by comparison with other biozonations, using the standard Cenozoic chronology.

Radiolarians are also useful paleoceanographic indicators and were abundant in the subantarctic South Atlantic sediment during the Paleogene. Distinctive changes in the radiolarian faunas over certain time intervals indicate significant temperature variation and changes in ocean circulation. Based on radiolarian investigation of the Paleogene sections from Leg 114, three major periods of climatic and paleoceanographic evolution are recognized. They are : 1) Middle/Late Eocene boundary, 2) Eocene/Oligocene boundary, and 3) late Early Oligocene. These changes clearly record the transition from relatively warmer conditions of the Eocene to distinctly cooler conditions of the Oligocene.

CONTENTS

LIST of FIGURE -----	(8)
I. ABSTRACT -----	1
II. INTRODUCTION -----	3
III. MATERIALS AND METHODS OF EXAMINATION -----	5
IV. PALEOGENE RADIOLARIAN BIOSTRATIGRAPHY AND ITS CORRELATION WITH OTHER BIOSTRATIGRAPHIC ZONES AND MAGNETOSTRATIGRAPHY -----	8
V. PALEOENVIRONMENTAL INTERPRETATION -----	20
1) Paleocene Oceanographic Evolution -----	20
2) Eocen Oceanographic Evolution -----	21
3) Oligocene Oceanographic Evolution -----	25
VI. CONCLUSION -----	28
VII. SYSTEMATIC MICROPALAEONTOLOGY -----	30
ACKNOWLEDGEMENTS -----	47
REFERENCES -----	48
PLATES -----	57
FIGURE CAPTIONS -----	61

List of Figures

- FIGURE 1: Composite stratigraphic column (top) reveals the ages, lithologies,
and sediment thickness of each site. ----- 64
- FIGURE 2: Paleogene Radiolarian Zones ----- 65
- FIGURE 3: Paleogene radiolarian zones and vertical distribution of taxa
observed from ODP Leg 114 samples. ----- 66
- FIGURE 4: The biostratigraphic correlation of Paleogene radiolarian zones for
holes drilled from Leg 114. ----- 67
- FIGURE 5: Summary of Paleocene biostratigraphic zonations and correlated to
the geomagnetic polarity pattern, Hole 700B. ----- 68
- FIGURE 6: Summary of Early to Late Eocene biostratigraphic zonations
correlated to the geomagnetic polarity pattern, Holes 702A
and 702B. ----- 69
- FIGURE 7: Summary of Late Eocene - Late Oligocene biostratigraphic zonations
correlated to the geomagnetic polarity pattern, Hole 703A.----- 70

FIGURE 8: A. Present-day Southern Ocean circulation (from Pickard and Emery, 1982). ----- 71

B. Schematic cross section of major surface and subsurface water masses of the Southern Ocean (from Gordon, 1971) (Antarctic Convergence is equivalent to the Polar Front). ----- 71

FIGURE 9: Evolution of deep, and intermediate-water circulation during the Cenozoic. ----- 72

FIGURE 10: Reconstruction of the subantarctic sites of Leg 114 for the Late Paleocene and Middle Eocene. ----- 73

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I. Abstract

Biostratigraphic and paleoenvironmental analyses of Paleogene radiolarians from the high-latitude South Atlantic have been documented based on material collected on Ocean Drilling Program (ODP) Leg 114. The thick and relatively complete Paleogene sequences, and a nearly continuous history of geomagnetic polarity reversals from ODP Leg 114 cores provides an unparalleled opportunity to establish for the first time a Paleogene radiolarian zonation for the high-latitude Southern Ocean.

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II. INTRODUCTION

The Antarctic Circumpolar Current is of great oceanographic and climatic importance because it transports probably the largest volume of water of any ocean current. Because of its nearly homogeneous water, produced by vertical instability, the wind-driven Antarctic Circumpolar current is a deep current in contrast to currents in lower latitudes.

However, several fundamental questions remain regarding the evolution of global climatic, glacial, and oceanographic systems since Cretaceous. Only six previous DSDP cruises recovered Subantarctic-Antarctic sequences : Leg 28 (Southeast Indian Ocean and Ross Sea), Leg 29 (Southwest Atlantic), and Leg 90 (Site 594, Southwest Pacific). Most holes of these legs were rotary drilled resulting in drilling disturbance and poor core recovery : other holes were sparsely sampled with large washed intervals in order to reach basement objectives. Recognizing the need and importance of additional high-latitude samples, the Ocean Drilling Program (ODP) drilled Leg 114 in the Subantarctic South Atlantic in 1987 (Figure 1). One of the major successes of Leg 114 was the recovery of a virtually complete Late Cretaceous through the Cenozoic sequence with rich assemblages of microfossils.

Contrary to the Neogene sequence, which has been studied in detail (e.g. Chen, 1975, Petrushevskaya, 1975, Weaver, 1983, Lazarus, 1989, and Abelmann, 1990), no comprehensive Paleogene radiolarian biostratigraphy has been attempted. There are several reasons for this. The most obvious deficiency is the lack of good taxonomic references for the Paleogene radiolaria.

Geologic and geographic distribution data for radiolarians also are lacking, as well as relative abundance data for taxa within assemblages. Furthermore, biostratigraphic ranges of high-latitude radiolarian species are often different from those in low-latitude areas. As expected, ship-board analysis revealed that most of the zonal index species that have been used in the standard zonation from low-latitude regions (Riedel and Sanfilippo, 1978) were absent in Leg 114 samples (Ling, 1988). For these reasons, a Paleogene radiolarian zonation has been established for the Subantarctic South Atlantic sequences in the present study. Nine radiolarian datum levels are used to delineate Paleogene radiolarian biozonation. Wherever possible, these datum levels are then calibrated to geomagnetic polarity zones in order to provide a chronological framework that will facilitate interregional correlation.

Another important factor of paleoceanographic study is testify to temperature variation during certain time interval. Evolution of paleoceanographic systems in the Southern Ocean has been controlled by two factors : plate tectonic events and Antarctic glacial history. In the broad outline, the climatic evolution deduced from paleontological records at different DSDP sites displays world-wide conformity. During the Paleogene, climatic evolution shows important cooling events in the mid- and high-latitudes of the Atlantic and Pacific Oceans, which occurred in a step-like manner rather than continuously (Kennett and Stott, 1990). Radiolarians are useful paleoceanographic indicators and were abundant in the subantarctic South Atlantic sediment. In this study, indications of faunal change at certain intervals may testify to critical paleoceanographic variations during Paleogene time.

III. MATERIALS AND METHODS OF EXAMINATION

A) Materials

During the ODP Leg 114, 12 holes were drilled from seven sites along a west-east transect from the Northeast Georgia Rise to the Meteor Rise, in water depths from 1807 to 4632m. Paleogene sediments were penetrated at all seven sites and are investigated in this study. The localities of these sites are as follows :

site	Latitude	longitude	Water Depth(m)	Location
698	51° 27.51'S	33° 05.96'W	2128	NE Georgia Rise
699	51° 32.531'S	30° 40.619'W	3075	NE Georgia Rise
700	51° 31.992'S	30° 16.69'W	3601	East Georgia Basin
701	51° 59.07'S	23° 12.73'W	4636.7	Islas Orcadas Rise
702	50° 56.786'S	26° 22.117'W	3083	Islas Orcadas Rise
703	47° 03.042'S	07° 53.673'E	1796	Meteor Rise
704	46° 52.757'S	07° 25.250'E	2532.2	Meteor Rise

Radiolarians occur only sparsely at Site 698. At Site 699 through 704, radiolarians are common and well preserved through significant lengths of the cored material.

B) Sample Preparation Procedure

All samples were processed using a standard method employed in the study of radiolarians (Sanfilippo et al., 1985). Approximately one-third of each sample was stored for future reference. The remaining two-thirds were placed in a clean, 250ml of dilute hydrochloric acid (10%) were added to the beaker. This mixture was then heated at about 100°C for one hour on the hot plate. An additional 15ml of hydrochloric acid and hydrogen peroxide were added to the samples again and allowed to continue heating for two additional hours. Samples were washed with distilled water and decanted three times. The samples were screened through a 250 um mesh sieve to remove any large ice-rafted material. The residues were then sieved with a 63um sieve to separate the larger radiolarians and diatoms (greater than 63 um) from the smaller silicoflagellates and ebridians (less than 63 um). The separated residues were placed in clean labeled vials for storage.

C) Slide Preparation Procedure

Two microscope slides were made for each sample. The following procedure was performed to prepare each slide. After shaking, the sample was settled down for 30 seconds and withdrawn with a clean disposal pipette. Two or three drops of sample were spread onto a clean 75×25mm glass slide and heated on a hot plate to drive off the water. A drop of Canada balsam was placed on the slide, and covered with a clean glass coverslip (22×40mm). The slides were placed for two weeks at 70°C in a precision mechanical convection oven.

D) Microscopic Analysis

A random count of 200 specimens was made on each slide for statistical purposes, using a Leitz photomicroscope. The following factors of each sample were considered during microscopic analysis: 1) abundance of taxa; 2) morphological features; 3) preservation of the assemblages; 4) effect of reworking. All photo-micrographs were taken by Kodak Panatomic-X film. Specimens of all observed taxa are illustrated in Plates 1-3. The locations of illustrated specimens in strewn slides are indicated by sample and slide number and England Finder Coordinates.

IV. PALEOGENE RADIOLARIAN BIOSTRATIGRAPHY AND ITS CORRELATION WITH OTHER BIOSTRATIGRAPHIC ZONES AND MAGNETOSTRATIGRAPHY

A zonation of Paleogene radiolaria was established for the first time based on material from ODP Leg 114. This zonation includes eight new zones and one revised zone (Figure 2). The nine zones proposed for this interval are, in ascending order: the *Lithocampe latissima* Zone, *Buryella tetradica* Zone, *Stylosphaera goruna* Zone, *Eucyrtidium parva* Zone, *Lophoconus titanothericeraos* Zone, *Lychnocanoma amphitrite* Zone, *Axoprunum magnum* Zone, *Calocyclus semipolita* Zone, and *Cyrtocapsella robusta* Zone (revised). The zones described here are defined by either the first or last occurrences of a radiolarian species (Figure 3). Figure 4 provides the biostratigraphic correlation of Paleogene radiolarian zones for holes drilled from Leg 114.

In the following discussion, the age assignments of the radiolarian zonal boundaries are discussed based on their geological occurrences and integrated with paleomagnetic stratigraphy (Hailwood and Clement, 1991; Clement and Hailwood, 1991), calcareous nannofossil (Crux, 1991), planktonic foraminifer (Nocchi et al., 1991), diatom (Fenner, 1991), and silicoflagellate (Ciesielski, 1991).

1) *Lithocampe latissima* Zone

Definition: The base of this zone is defined by the first occurrence of *Lithocampe latissima*. The top of this zone coincides with the base of *Buryella tetradica* Zone.

Paleomagnetic Correlation: Due to the absence of radiolarians from earliest Paleocene sediments, only the top of the zone is directly correlated with the paleomagnetic data of Hole 700B to occur within the lower portion of Chron C26R (Figure 5).

Age: Top = 62.6-62.8Ma; Bottom = 63.6-?66/4

Type Section: ODP Leg 114, Hole 700B, sample 114-700B-31R-6, 62-63cm to section 114-700B-32R-cc.

Remarks: The base of this zone has not been recovered from Leg 114 as a result of the absence of siliceous-bearing sediments of earliest Paleocene age. However, the upper boundary of the zone is recognized in Hole 700B. According to Hailwood and Clement (1991), the long reversed-polarity magnetozone in core 114-700B-30R to section 114-700B-31R,cc, correlates with the distinctive long reversed polarity Chron C26R (60.7-63Ma). The last occurrence of *Lithocampe latissima* was observed in sample 114-700B-31R-6, 62-64cm. The top of this zone should, therefore, have an age near the lower portion of Chron C26R, within calcareous nannofossil NP4 Zone, planktonic foraminifers P2 Zone, and silicoflagellate *Corbisema hastata alta* Zone (Figure 5). An additional useful stratigraphic marker for the top of the zone is the first occurrences of *Lithomespilus mendosa* (700B-31R-6, 62-64cm) and *Buryella tetradica* (700B-31R-5, 71-73cm).

2) *Buryella tetradica* Zone

Definition: The base and top of this zone are defined by the first and last occurrences of *Buryella tetradica*.

Paleomagnetic Correlation: Magnetozone is not recorded for the top of this zone from Leg 114. The base of the zone is directly correlated to paleomagnetic data of Hole 700B to occur within the lower portion of Chron C26R (Figure 5).

Age: Top = 59.3-59.6Ma; Bottom = 62.6-62.8Ma

Type Section: ODP Leg 114, Hole 700B, section 114-700B-27R,cc to sample 114-700B-31R-5, 71-73cm.

Other Occurrences: ODP Leg 114, Hole 702B, 114-702B-31-X,cc; Hole 698A, 114-698A-10R,cc to 114-698A-11R,cc.

Remarks: The interval from core 114-700B-27R to sample 114-700B-29R-2, 49-51cm, is assigned to the Late Paleocene by calcareous nannofossils NP8 Zone (Crux, 1991) and planktonic foraminifers P4 Zone (Nocchi et al., 1991). Within this interval, the last occurrence of *Buryella tetradica* is observed in section 114-700B-27R,cc. Thus, the top of this zone can be correlated with middle portion of the calcareous nannofossil NP8 Zone (~59.3-59.6),

within the planktonic foraminifers P4 Zone, diatom *Hemiaculus inaequilaterus* Zone, and silicoflagellate *Naviculopsis constricta* Zone (Figures 5). The base of this zone is approximately synchronous with the first occurrences of *Microciadiocapsa* sp. and *Buryella* sp. (114-700B-31R-5, 71-73cm).

3) *Stylosphaera goruna* Zone

Definition: The base of this zone coincides with the top of the *Buryella tetradica* Zone. The top of the zone is defined by the last occurrence of *Stylosphaera goruna*.

Paleomagnetic Correlation: Magnetozones are not recorded for this interval from Leg 114.

Age: Top = 53.4-58.6Ma; Bottom = 59.3-59.6Ma

Type Section: ODP Leg 114, Hole 700B, Samples 114-700B-26R-2, 54-56cm to 114-700B-27R-2, 7-9cm.

Remarks: Unfortunately, the upper portion of the zone has not been recovered from Leg 114 as a result of the absence of radiolarian-bearing sediments of earliest Eocene age. The only biosiliceous late Early Eocene material recovered from Hole 698A (114-698A-3R,cc) has been dated as calcareous nanofossil NP13 Zone (Crux, 1991) and planktonic foraminifers P8/9

Zone(Nocchi et al., 1991). This sample contains abundant *Eucyrtidium parva* and thus provides a minimum age for the boundary between the *Stylosphaera goruna* Zone and *Eucyrtidium parva* Zone. Based on these data, the top of the *Stylosphaera goruna* Zone should be placed between the middle portion of calcareous nannofossil NP13 Zone (~53.4Ma) and the lower portion of NP9 Zone (~58.6Ma) (Figures 5).

4) *Eucyrtidium parva* Zone

Definition: The base of this zone is defined by the last occurrence of *Stylosphaera goruna*. The top of the zone is defined by the last occurrence of *Eucyrtidium parva*.

Paleomagnetic Correlation: Due to the absence of radiolarians from earliest Eocene sediments, only the top of the zone is directly correlated to the paleomagnetic data of Hole 702B to occur within the middle portion of Chron C20R (Figure 6).

Age: Top = 47.5Ma: Bottom = 53.4-58.6Ma

Type Section: ODP Leg 114, Hole 702B, section 114-702B-15X, cc to sample 114-702-19X-4, 52-54cm.

Other Occurrences: ODP Leg 114, Hole 698A, sample 114-698A-3R-1, 52-54cm to section 114-698A-3, cc.

Remarks: An accurate age determination of this zone is not possible because samples 114-702B-15X-2, 84-86cm to 114-702B-15X-4, 84-86cm are barren of radiolarians. According to Clement and Hailwood (1991), the reversed magnetozone in cores 114-702B-13X to 114-702B-17X represents Chron C20R (46.2-48.8Ma). Available nannofossil data (Crux, 1991) also indicate that sample 114-702B-15X-2, 60-61cm, to section 114-702B-19X,cc, is assigned to the Early to Middle Eocene. The last occurrence of *Eucyrtidium parva* occurs in section 114-702B-15X,cc. Thus, the top of this zone could be placed near the middle portion of foraminifers P11 Zone, and silicoflagellate *Bachmannocena vetula* Zone (Figure 6). The first occurrences of *Lychnocanoma amphitrite* and *Lithomitra docilis* characterize the middle portion of this zone.

5) *Lophoconus titanothericeraos* Zone

Definition: The base and top of this zone are defined by the first and last occurrences of *Lophoconus titanothericeraos*.

Paleomagnetic Correlation: The top of the zone is placed in the lower portion of Chron C18R, the base in the middle portion of Chron C20R (Figure 6).

Age: Top = 43.6Ma: Bottom = 47.5-48Ma

Type Section: ODP Leg 114, Hole 702B, Samples 114-702B-10X-1, 50-52cm to 114-702B-15X-6, 84-86cm.

Other Occurrences: ODP Leg 114, Hole 703A, section 114-703A-23, cc.

Remarks: According to Clement and Hailwood (1991), the reversed magnetozone in cores 114-702B-9X to 114-702B-10X represents Chron C18R (42.7-43.6Ma). The last occurrence of *Lophoconus titanothericeraos* occurs in sample 114-702B-10X-1, 50-52cm. This datum should, therefore, have an age near the lower portion of Chron C18R, within calcareous nannofossil NP16 Zone, planktonic foraminifers P13 Zone, and silicoflagellate *Dictyocha grandis* Zone (Figure 6).

6) *Lychnocanoma amphitrite* Zone

Definition: The base of this zone coincides with the top of the *Lophoconus titanothericeraos* Zone. The top of this zone is defined by the last occurrence of *Lychnocanoma amphitrite*.

Paleomagnetic Correlation: A magnetozone is not recorded for the top of this zone from Leg 114. The base of the zone is directly correlated to paleomagnetic data of Hole 702B to occur within the lower portion of Chron C18R (Figure 6).

Age: Top = 41.8-42.2Ma; Bottom = 43.6Ma

Type Section: ODP Leg 114, Hole 702B, sections 114-702B-6X, cc, to 114-702B-9X, cc.

Remarks: The upper boundary of the zone occurs in an interval of Hole 702B without paleomagnetic control. The only way to determine the age of the upper boundary of *Lychnocanoma amphitrite* Zone was to correlate with the other microfossil biostratigraphy. The section 114-702B-6X,cc is assigned to the Middle Eocene by planktonic foraminifers P14 Zone (Nocchi et al., 1991). The final occurrence of *Lychnocanoma amphitrite* is observed in section 114-702B-6X,cc. Thus, the top of this zone can be correlated to the middle portion of planktonic foraminifers P14 Zone (~41.2-42Ma), and the upper portion of calcareous nannofossil NP16 Zone (Figure 6). The base of *Lychnocanoma amphitrite* Zone coincides approximately with the first occurrence of *Calocyclus crassa* (Section 114-702B-9X,cc).

7) *Axoprunum magnum* Zone

Definition: The base of this zone coincides with the top of *Lychnocanoma amphitrite* zone. The top of the zone is defined by the last occurrence of *Axoprunum magnum*.

Paleomagnetic Correlation: Magnetozones are not recorded for this interval from Leg 114.

Age: Top = 35.2-37.8Ma; Bottom = 41.8-42.4Ma

Type Section: ODP Leg 114, Hole 702B, samples 114-702B-5X-2, 50-52cm to 114-702B-6X-2, 20-22cm for the base of the zone. Hole 703A, samples 114-703A-15X-4, 55-57cm to 114-703-18X-3, 50-52cm for the top of the zone.

Other Occurrences: ODP Leg 114, Hole 702A, samples 114-702A-3H-6, 54-56cm to 114-702A-4H-6, 50-52cm; Hole 701C, sample 114-701C-47X-2, 59-61cm to section 114-701C-47X, cc.

Remarks: The lower boundary of the zone is recognized in Hole 702B (114-702B-6X-2, 20-22cm) within the upper portion of planktonic foraminifers P14 Zone (Figure 6). The upper portion of the zone has not been recovered from Hole 703A as a result of absence of radiolarians at core 114-703A-14H (118.90-130.45 mbsf). The only way to determine the boundary between *Axoprunum magnum* Zone and *Calocyclus semipolita* Zone was to correlate with the other microfossil biostratigraphy. The interval from cores 114-703A-13H to 114-703A-15H, has been dated as Late Eocene to Early Oligocene by calcareous nannofossil NP19-21 Zones (Crux, 1991). Thus, the top of this zone can be correlated with calcareous nannofossil NP19-21 Zones (~ 35.2-37.8Ma), within planktonic foraminifers P16/17 Zones, silicoflagellate *N. constricta*/*B. paulschulzii* Zones, and diatoms *Cestodiscus antarcticus* Zone (Figure 7).

8) *Calocyclus semipolita* Zone

Definition: The base of this zone coincides with the top of *Axoprunum magnum* zone. The top of the zone is defined by the last occurrence of *Calocyclus semipolita*.

Paleomagnetic Correlation: A magnetozone is not recorded for the base of this zone from Leg 114. The top of the zone is correlated to paleomagnetic data of Hole 703A to occur within the upper portion of Chron C11N (Figure 7).

Age: Top = 31.2Ma; Bottom = 35.2-37.8Ma

Type Section: ODP Leg 114, Hole 703A, Samples 114-703A-10H-5, 50-52cm to 114-703A-15H-2, 55-57cm.

Remarks: The interval from Core 114-703A-11H to Section 114-703A-7H-5, cc, has been dated as Early Oligocene by nannofossils (Crux, 1991). Available paleomagnetic data (Hailwood and Clement, 1991) also indicate that the normal polarity zone in Core 114-703A-11H is correlated with Chron C11N. The last occurrence of *Calocyclus semipolita* occurs in Sample 114-703A-11H-2, 40-42cm. This datum should, therefore, have an age near the upper portion of Chron C11N, within calcareous nannofossil NP23/24 Zones, planktonic foraminifers P21a Zone, and silicoflagellate *N. trispinosa* Zone (Figure 7). The top of this zone approximately coincides with the last occurrences of *Lophocyrtis* (*C.*) sp. and *Heliodiscus linckiaformis*.

9) *Cyrtocapsella robusta* Zone (Revised)

Definition: The base of this zone coincides with the top of the *Calocyclus semipolita* Zone. The top of the zone is defined as the first occurrence of *Cyrtocapsella tetradica*.

Paleomagnetic Correlation: The top of the zone is correlated to paleomagnetic data of Hole 703A to occur within lower portion of Chron C6C, the base in the upper portion of Chron C11N (Figure 7).

Age: Top = 23.3-25.5Ma: Bottom = 31.2Ma

Type Section: ODP Leg 114, Hole 703A, samples 114-703A-6H-2, 60-62cm to 114-703A-10H-3, 50-52cm.

Other Occurrences: ODP Leg 114, Hole 701C, samples 114-701C-29X-2, 50-52cm to 114-701C-41, cc; Hole 699A, samples 114-699A-10H-2, 50-52cm to 114-699A-25X, cc; Hole 704B, sample 114-704B-63X, 40-42cm to section 114-704B-72X, cc.

Remarks: The upper portion of the zone is recognized in Hole 703A. The interval of Core 114-703A-3H and Section 114-703A-5H-2, cc has been assigned an Early Miocene age, whereas Section 114-703A-5H-2, cc has been assigned to the Late Oligocene (Crux, 1991). Paleomagnetic data (Hailwood and Clement, 1991) also indicate that the magnetozone in the lower portion of Core 114-703A-5H correlates to Chron C6C (23.3-25.5Ma). Thus, the Oligocene/Miocene boundary lies between Cores 114-703A-4H and 114-703A-5H. The first occurrence of *Cyrtocapsella tetrapera* was observed in Hole 703A from section 114-703A-5H, cc (Ling, 1988). This species is not observed below sample 114-703A-6H-2, 60-62cm. The top of *Cyrtocapsella robusta* Zone should,

therefore, have an age near the lower portion of Chron C6C, within calcareous nannofossil NP25/NN1 Zones, planktonic foraminifers P22/N4 Zones, silicoflagellate *D. raupii* / *N. niapiculata* Zones and diatoms *Rocella gelida* Zone (Figure 7).

Recently, Abelmann (1990) proposed two new upper Oligocene/lower Miocene radiolarian zones based on material from Hole 689B of ODP Leg 113. These two zones, the *Stylosphaera radiosa* Zone and *C. robusta* Zone, overlap with the upper portion of *C. robusta* Zone of this study. Abelmann stated that the base of *C. robusta* Zone correlated with paleomagnetic data of Hole 689B to occur within Chron C8N. In the present study, the base of *C. robusta* Zone is also directly correlated with paleomagnetic data of Hole 703A to occur within upper portion of Chron C11N. On the basis of this assignment, the base of *C. robusta* Zone from Leg 114 sediments occurs much lower than that of Leg 113 sediments. Thus, the Abelmann's *C. robusta* Zone is herein revised.

V. PALEOENVIRONMENTAL INTERPRETATION

Radiolarians are useful paleoceanographic indicators and were abundant in the Subantarctic South Atlantic sediment during the Paleogene. Distinctive changes in the abundance and diversity of radiolarian faunas over geologic time indicate change in the paleoceanographic system. Based on investigations of radiolaria in the Paleogene section from Leg114, three major periods of climatic and paleoceanographic evolution have been recognized. The results from radiolarian investigations documented here have also been compared with other microfossil data to more completely understand global paleoceanographic and paleoclimatic conditions during Paleogene time.

1) Paleogene Oceanographic Evolution

In the early Late Paleocene, radiolarian assemblages contain some warm-water and cosmopolitan species such as *Buryella tetradica*, *Buryella pentadica*, *Stylosphaera goruna* and *Lithomespilus mendosa*, as reported from the Paleocene sediment in the Gulf of Mexico (Sanfilippo and Riedel, 1973; Hole 94, DSDP Leg 10). Calcareous nannofossils also include a low-diversity but abundant group of discoasters during early Late Paleocene in Hole 700B (Crux, 1991). Abundant discoasters are reliable indicators of warm surface waters, and the occurrence of low-latitude radiolarians in combination with abundant discoasters in the Subantarctic Atlantic suggests warm temperate to cool subtropical conditions during the Late Paleocene. This represents the

beginning of a broad, global warming trend that spanned the Late Paleocene and Early Eocene.

Although the overall diversity among radiolarians increased in the Late Paleocene, differences among radiolarian assemblages from the Subantarctic regions become more pronounced than those from lower latitudes: *Buryella tetradica*, already rare in the Late Paleocene, is missing in the uppermost Late Paleocene, although consistently present from the Early Eocene sediment in the Gulf of Mexico (Foreman, 1973: Hole 94, DSDP Leg 10) and in the North Atlantic (Nishimura, 1987: Hole 603B, DSDP Leg 90). In the low latitudes, the only recognized Paleocene radiolarian zone (*Bekoma bidarfensis*) has been reported from the Late Paleocene sediment in the Gulf of Mexico (Sanfilippo and Riede, 1973; Foreman, 1973: Hole 94, DSDP Leg 10). However, the occurrence of *Bekoma bidarfensis* was not observed in the Subantarctic South Atlantic in this study, suggesting the presence of a latitudinal temperature gradient during the Late Paleocene.

2) Eocene Oceanographic Evolution

Early Eocene: Warmest interval of the Cenozoic

Radiolarians were not observed in the lowermost Eocene sediments of Leg 114. However, calcareous microfossil data indicate that this was perhaps the warmest interval during the entire Cenozoic. A peak in discoaster diversity

and abundance also coincides with the Paleocene/Eocene transition (Crux, 1991). Calcareous ooze accumulates today under conditions of warm, less-fertile surface water. Thus, Southern Ocean upwelling may have declined during this time.

One of the major questions currently confronting paleoceanographers is to explain the exceptional warmth of Cenozoic oceans and the subsequent transition to colder climates. Modern deep ocean circulation is primarily driven by the process of deep and intermediate water formation at high latitudes. The formation of cold deep waters in the Antarctic is the direct result of freezing conditions at these latitudes (see Figure 16). In the Paleogene, when the global climate was warm, the production of deep waters may have occurred through different processes and at different locations than occurs at present. In the absence of very cold polar regions, deep and intermediate waters might still have formed by cooling at high latitudes (Schnitker, 1980; Barrera et al., 1987; Katz and Miller, 1991). An alternative interpretation for the source of deep-water is given by Barron et al. (1981), Hay (1988), and Kennett and Stott (1990). These authors suggested that dense, warm, and salty deep waters were formed at low-latitudes as a result of excess evaporation. These deep waters would have been different from the present deep waters, which are cold, rich in dissolved oxygen, and strongly undersaturated in CaCO_3 at their formation. Thus, Kennett and Stott (1990) concluded that during the Eocene and perhaps the Late Paleocene, the Ocean was two-layered, formed at high-latitude (Figure 17). Under such conditions, production of cool intermediate water at high southern latitudes

may have ceased briefly at the Paleocene/Eocene boundary as a result of extremely warm climates and an infusion of warm waters from low latitudes.

Hence, high surface water temperatures could have led to the prevalence of low-latitude radiolarians such as *Lithmitra docilis*, *Lychnocanoma amphirite*, *Lophocyrtis biaurita*, and *Eusyringium fistuligerum* around the Antarctic. Those species were earlier reported from the Gulf of Mexico (Foreman, 1973) and from siliceous Eocene deposits in central California (Blueford, 1988). Radiolarian data also support warm temperatures during the Early to Middle Eocene, a warming trend that persisted until the Middle/Late Eocene boundary, when radiolarian diversity and abundance declined (see Table 20).

Middle/Late Eocene boundary: Beginning of climatic cooling

The diversity of radiolarians steadily declined from the Middle Eocene to Late Eocene but remained relatively high during most of the Middle Eocene in Hole 702B. However, the abundance of radiolarians sharply declined near the Middle/Late Eocene boundary. Evidence for these changes include the last occurrences of low-latitude radiolarians such as *Lychnocanoma amphirite*, *Lophocyrtis biaurita*, *Lophoconus titanothericeraos*, and *Eusyringium fistuligerum*.

The end of the Middle Eocene is also marked by worldwide extinction of many planktonic microfossils, which suggests drastic changes during the

Middle to Late Eocene in both surface and bottom ocean waters. The geographic distribution patterns of calcareous nannofossils and planktonic foraminifer assemblages indicate an environmental change at the Middle/Late Eocene boundary, which may be due to the cooling of high-latitude surface water (Berggren et al., 1985; Premoli-Silva and Boersma, 1988).

Eocene/Oligocene boundary: Gradual climatic deterioration

The Eocene/Oligocene boundary is one of the most important paleoceanic events within the Cenozoic. Dramatic changes in deep-water circulation near the Eocene/Oligocene boundary are inferred from a variety of paleontological data. The most widely accepted interpretation of a major cooling event is the thermal isolation of Antarctica, the initiation and growth of the Antarctic ice sheets, and the formation of cold bottom-water circulation (Shackleton and Kennett, 1975; Benson, 1975; Benson et al., 1984; Miller and Fairbanks, 1985; Murphy and Kennett, 1986).

In the present study, radiolarian assemblages at the Eocene/Oligocene boundary are represented by cold-water species (e.g. *Calocyclus semipolita* and *Eucyrtidium* sp. A) with co-occurrences of cosmopolitan species such as *Lophocyrtis* (*Cyclampterium*) sp., and *Heliodiscus linckiaformis*. These changes clearly document the transition from relatively warmer conditions of the Eocene to distinctly cooler conditions of the Oligocene. These species were also reported in the Early Oligocene sediments from the high and

mid-latitude Southern Oceans (Chen, 1975; Petrushevskaya, 1975; Weaver, 1983). This cooling trend did not end until late Early Oligocene, when radiolarians became less diverse and lower in abundance.

3) Oligocene Oceanographic Evolution

During the Late Cretaceous, Paleocene and Early Eocene, a system of linked bathymetric highs extended from South America to Africa to and obstructed oceanic exchange. The Falkland-Agulhas ridge system remained relatively shallow through much of the Paleogene, restricting meridional deep-water exchange. However, during the Eocene, a brerach began forming in the Falkland-Agulhas ridge system as the Islas Orcadas Rise and Meteor Rise began rifting apart (Figure 18), ultimately froming a 4000m-deep gap by the Early Oligocene (Ciesielski, Kristoffersen, et al., 1988). The Meteor and Islas Orcadas Rises show an apparent difference in the thickness of the Oligocene biogenic sedimentation, with a thinner sequence on the Meteor Rise (see Figure 5). This may indicate either that the investigated part of the Meteor Rise is a slightly younger feature or that the two rises were located under different productivity regimes during the Late Paleogene.

Early Oligocene: Further cooling

Radiolarian faunal changes in the late Early Oligocene age are manifested by the successive disappearances of Late Eocene and Earliest Oligocene

radiolarians such as *Lophocyrtis* (*Cyclampterium*) sp., *Calocyclus semipolita* and *Heliodiscus linckiaformis* at or near the top of the *Calocyclus semipolita* Zone. The top of the *C. semipolita* Zone is a disconformity at Hole 701C and the gravel bed at this depth in Hole 699A is probably evidence of a coeval disconformity. However, radiolarian diversity and abundance also sharply declined in Hole 703A during the Late Early Oligocene. Therefore, the observed faunal changes are either the result of a hiatus or a temperature change over this time interval.

Decreases in the diversity of planktonic foraminifera (Nocchi et al., 1991) and calcareous nannofossil assemblages (Crux, 1991) characterize the Early Oligocene in contrast to the warmer Late Eocene. The presence of the warm-water discoasters in the Paleocene and Eocene and the subsequent absence of these in the Oligocene also indicates a cooling trend.

Late Oligocene: Coldest interval

Siliceous biogenic sediments began to dominate, beginning in Late Oligocene time, which reflects further developments of cold Antarctic surface waters. Kennett and Stott (1990) have proposed two significantly different ocean models for the Paleogene (see Figure 9), each consisting of different deep-water structure. These models are clearly oversimplistic and generalized, but have been presented as a base for further investigations.

However, results of this study show that Early Oligocene radiolarian assemblages are characterized by lower-diversity and cosmopolitan

distribution indicating conformance with the two-layer (Eocene) model. In contrast, Late Oligocene assemblages are characterized by distinct belts of radiolaria arranged latitudinally consistent with the Oligocene model of Kennett and Stott (1990). Thus my data suggest that the two-layer (Eocene) model of Kennett and Stott either needs to be extended for the Early Oligocene to account for widespread distribution of radiolarian assemblages or, conversely, a new mechanism should be derived to explain fossil abundances other than by land-proximal upwellings.

VI. CONCLUSIONS

The major results of this examination of the Paleogene radiolarians in Leg 114 samples are:

- (1) Biostratigraphic and paleoenvironmental analyses of Paleogene radiolarians have been carried out on material collected on Leg 114.
- (2) Nine Paleogene radiolarian zones have been established for the Subantarctic South Atlantic. The boundaries separating these zones have been calibrated to geomagnetic polarity chrons in order to provide a chronological framework that facilitates interregional correlation.
- (3) The newly proposed radiolarian zones can be correlated tentatively with the Paleogene biostratigraphic zones, based on calcareous and other siliceous microfossil groups.
- (4) Although some low-latitude radiolarian species were found during the present investigation, dating of Leg 114 sediments by low-latitude radiolarian biostratigraphy was unsuccessful due to the absence of zonal index fossils.

(5) Three major periods of paleoceanographic evolution were recognized from paleogene sections on Leg 114. They are: 1) Early/Middle Eocene boundary, 2) Eocene/Oligocene boundary, and 3) Late Early Oligocene. The results presented here are also compared with other microfossil data to better understand global paleoceanographic and paleoclimatic conditions during Paleogene time.

VII. SYSTEMATIC MICROPALAEONTOLOGY

Below are brief statements of the characteristic features of species used to define and to recognize the Paleogene radiolarian zones. Genera are arranged alphabetically within families, and species alphabetically within genera. The classification of Riedel (1967a, 1967b) is generally followed wherever possible. Species abundances and ranges are indicated. For those species which have uncertain ranges as a result of intermittent coring, barren sediments, or scarcity, occurrences rather than specific ranges are given.

Subclass *Radiolaria* Müller 1858

Order POLYCYSTINA Ehrenberg, 1838, emend. Riedel, 1967b

Suborder SPUMELLARIA

Family ACTINOMMIDAE Haeckel, 1862, emend. Riedel, 1967b

Genus *AXOPRUNUM* Haeckel

Axoprunum HAECKEL, 1887, p.298. Type species (designated by Campbell, 1954, p.D68): *Axoprunum stauraxonium* Haeckel (1887, p.298, pl.48, fig.4).

Axoprunum magnum n. sp.

Pl. I. Figs.1,2

cf. *Axoprunum liostylum* PETRUSHEVSKAYA, 1975, P.571, pl.2, fig.22.

Description: Cortical shell ellipsoidal, thick-walled, rough surface, with 12-16 regularly arranged pores of equal dimensions across a diameter. It is difficult to observe the inner medullary shell, which is about 1/3 in size of the outer medullary shell. The outer medullary shell has faint subhexagonal, unequal sized pores and is connected to the cortical shell by six bars. Two thick, unequal polar spines are somewhat variable in form and size, but are commonly robust and pointed: the long one is about 2/3 of the length of the cortical shell; the short one is about 1/2 of the length of the cortical shell.

Measurement: Diameter of the cortical shell, 170-200um; of the outer medullary shell, 35-45um; of the pores of cortical shell, 11-14um. Length of the polar spines: long one, 160-175um and short one, 85-95um. Measurement based on 15 specimens from 702A-4H-2, 50-52cm and 703A-15H-6, 55-57cm.

Remarks: *Axoprunum magnum* is easily differentiated from other *Axoprunum* group by its relatively large size, and typical robust pointed polar spines. This species is similar to *Axoprunum liostylum*, which has been reported by Petrushevskaya in the Eocene to Early Oligocene samples at DSDP Leg 29 from southeastern Indian Ocean and Tasman Sea. *Axoprunum magnum* differs from *A. liostylum* in having larger dimensions and more regularly arranged pores on the cortical shell. The species name, *magnum* derived from *magnus*, means large, which is derived from the large cortical shell of this species.

Abundance: Few to common

Occurrence: Late Eocene

Genus *STYLOSPHAERA* Ehrenberg

Stylosphaera EHRENBERG, 1847a, p.54. Type species (designated by Frizzell and Middour, 1951): *Stylosphaera hispida* Ehrenberg (1854a, p.246; 1854b, pl.36, fig.26).

Stylosphaera goruna Sanfilippo and Riedel

Pl. I, Figs.3,4

Drupptractus cf. *coronatus* (SQUINABOL), DUMITRICA, 1973, p.787, pl.6, figs.4,6; pl.12, fig. 1.

Stylosphaera goruna SANFILIPPO and RIEDEL, 1973, p.521, pl. 1, figs. 20-22
NISHIMURA, 1987, p. 729, pl.1, fig.3.

Remarks: *Stylosphaera goruna* is characterized by possessing two or more strong spines on each half-ellipsoid and irregularly arranged subcircular pores. This species was reported by Sanfilippo and Riedel (1973) from the Paleocene of Site 94 in the Gulf of Mexico. Nishimura (1987) also reported it from the Paleocene of Site 603 in the western North Atlantic. Dumitrica (1973) assigned this species to *Drupptractus* on the basis of Paleocene specimens from Site 208, DSDP Leg 21.

Abundance: Few to Common

Occurrence: Early to Late Paleocene

Family SPONGODISCIDAE Haeckel, 1862, emend. Riedel, 1967b.

Genus AMPHYMENIUM Haeckel

Amphymenium HAECKEL, 1881, p.460. Type species (designated by Campbell, 1954, p.D86): *Amphymenium zygartus* Haeckel (1887, p. 520, pl.44, fig.7).

Amphymenium connicinum n. sp.

Pl. I, Figs. 5,6

Description: Shell generally cylindrical, nearly four times longer than wide, with two equal, rounded axial lobes. The bipolar arms may be thicker than the central part of the skeleton. The base of arms and central part of the skeleton are surrounded by a well developed patagium.

Measurement: Length of shell, 280-330um; width of arm, 35-50um; greatest breadth, 60-75um. Measurement based on 15 specimens from 703A-9H-4, 36-38 and 702B-5X-6, 52-54cm.

Remarks: This species is similar to *Amphymenium* sp. reported by Ling (1973, p.780, pl.1, figs. 11,12) from the Miocene of Site 183 in the North Pacific.

It differs from *Amphymenium* sp. (Ling) in the absence of thorns at the end of both arms. *Amphymenium connicinum* also has a distinct patagium. The species name, *connicinum*, means symmetrical, which is derived from the shell morphology of this species.

Abundance: Rare to Rew

Occurrence: Late Paleocene to Oligocene

Genus *SPONGOCORE* Haeckel

Spongocore Haeckel, 1887, p.345. Type species (designated by Campbell, 1954, p. D74): *Spongocore velata* Haeckel (1887, p. 346).

Spongocore spongiosa n. sp.

Pl. I, Fig.7

Description: Shell generally spatulate, thick-walled, nearly two times longer than wide. The central structure is quite indistinct because of heavy spongy meshwork of skeleton. Spongy terminations of arms flatly rounded, and in many specimens bearing few spines or thorns.

Measurement: Length of shell, 335-385um; width of arm, 65-85um; greatest breadth, 110-135um. Measurement based on 15 specimens from 698A-3R-1, 53-54cm.

Remarks: This species occurs intermittently throughout the Middle Eocene to Earliest Oligocene sediments of Leg 114. Abundant and well-preserved *Spongocore spongiosa* co-occur with *Lychnocanoma amphitrite*, *Eucyrtidium parva*, and *Phormocyrtis s. striata* in Hole 698A. Thus, this species can be considered as one of the biostratigraphically important species of Early

Eocene for the high-latitude Southern Ocean. The species name, *spongiosa*, is derived from heavy spongy meshwork of this species.

Abundance: Few to Common

Occurrence: Middle Eocene to Earliest Oligocene

Suborder NASSELLARIA

Family ACANTHODESMIIDAE Haeckel

Genus *GIRAFFOSPYRIS* Haeckel, emend. Goll, 1969.

Dendrospyris Haeckel, 1881, p.441 : 1887, p.1038. Type species (designated by Campbell, 1954): *Ceratospyris stylophora* Ehrenberg (1873, p.220: 1875, pl.20, fig.10).

Giraffospyris Haeckel, 1881, p.442: emend Goll, 1969, p.329. Type species (designated by Campbell, 1954): *Ceratospyris heptaceros* Ehrenberg, 1873 (p. 219: 1875, pl.20, fig.2).

Giraffospyris didiceros (Ehrenberg)

Pl. I, Figs. 8,9

Ceratospyris didiceros EHRENBERG, 1873, p.228 : 1875, pl.21, fig.6.

Dendrospyris didiceros (Ehrenberg)group, PETRUSHEVSKAYA and KOZLOVA, 1972,
p.637, pl.40, fig.12. -LING, 1973, pl.4, fig.16.

Giraffospyris didiceros (Ehrenberg)GOLL, 1969, pl332, pl.60, figs.
5-7,9. -RIEDEL and SANFILIPPO, 1970, pl.5, figs. 3-5. -JOHNSON, 1974, p.547,
pl.3, fig.7. -CHEN, 1975, p.456, pl.3, fig.4.

Remarks: The genus *Giraffospyris* is followed here rather than *Dendrospyris* because most complete specimens appear to have three horns (one apical and two frontal).

Giraffospyris didiceros was well described and illustrated by Goll (1969).

Abundance: Few to Common

Occurrence: Late Paleocene to Oligocene

Family PTEROCORYTHIDAE Haeckel, 1881, emend. Riedel, 1967a

Genus SETHOCYRTIS Haeckel

Sethocyrtis Haeckel, 1887, p. 1298. Type species (designated by Campbell, 1954, p.D128): *Sethocyrtis oxycepalus* Haeckel (1887, p.1298)

Sethocyrtis ovalis n. sp.

Pl. I, Figs. 10, 11

Description: Shell of two segments with thick-walled segments. Cephalis small, separated from thorax by a slight change in contour, with small subcircular pores, bearing two spines. Thorax conical in the upper part and inflated conical in the lower part. Thoracic pores circular to subcircular, arranged in transeverse rows.

Measurement: Length of the cephalis, 15-20 μ m; of the thorax, 125-140 μ m; of the apical horn, 35-56 μ m. Maximum width of the thorax, 115-135 μ m; of the mouth, 45-56 μ m. Measurement based on 15 specimens from Hole 702B-16X-2, 84-86cm.

Remarks: This species is similar to *Sethocyrtis* sp. Chen (1975), but differs in that *Sethocyrtis ovalis* is smaller and has more regularly arranged small pores on the thorax. The species name, *ovalis*, means *oval*, which derived from the shell morphology of this species.

Abundance: Few to Common

Occurrence: Early to Middle Eocene

Family THEOPERIDAE Haeckel, 1881, emend. Riedel, 1967b

Genus *BURYELLA* Foreman

Buryella Foreman, 1973, p.433.

Buryella tetradica Foreman

Pl. I, Figs.12,13

Lithocampium sp A. RIEDEL and SANFILIPPO, 1971, pl.7, fig.12.

Buryella tetradica Foreman, 1973, p.433, pl.8, figs.4,5; pl.9, figs. 13,14.-RIEDEL and SANFILIPPO, 1978, p.80, pl.3, fig.5; 1986, p.160, pl.5, fig.14.-NISHMURA, 1987, p.721, pl.2, fig.8.- WESTBERG, SANFILIPPO, and RIEDEL., 1987, p.31, pl.1, fig.9.

Remarks: This species is distinguished from its ancestor, *B. pentadica*, by its four-segmented shell. Third segment is usually largest.

Abundance: Common

Occurrence: Middle to Late Paleocene

Genus *CALOCYCLAS* Ehrenberg

Calocyclus Ehrenberg, 1847b, p.54 : Haeckel, 1887, pl. 1381. Type species (designated by Campbell, 1954): *Calocyclus turris* Ehrenberg (1873, p.218; 1876, pl.18, fig.7)

Calocyclus semipolita Clark and Campbell

Pl. II, Figs.1,2

Calocyclus semipolita CLARK and CAMPBELL, 1942, p.83, figs. 12,14,17-19,22,23; 1945, p.44, pl.6, figs. 14,16,17-CHEN, 1975, p.459, pl.6, figs. 3-5 - PETRUSHEVSKAYA, 1973, p.580, pl.8, fig.8 ; pl.41, figs.6,7.

Calocyclus cf. semipolita ABELMANN, 1990,p.697, pl.7, fig.4.

Remarks: *Calocyclus semipolita* was originally described from the Eocene radiolarian faunas of Mt. Diablo, California by Clark and Campbell (1942). According to the original description by Clark and Campbell, *Calocyclus semipolita* shows terminal teeth or feet on an open-ended abdomen and has a stout long apical horn not seen in the Leg 114 samples. The species was recently reported by Caulet (1989) from the Early Oligocene of Site 738 in the Kerguelen-Heard Plateau of eastern Antarctic. Lazarus (1989) also reported this taxon from the Early Oligocene of Sites 748 and 749 in the Raggatt Basin of eastern Antarctic.

Abundance: Common to Abundant

Occurrence: Late Eocene to Middle Oligocene

Calocyclus crassa n. sp.

Pl. II, Figs.3,4

Description: Shell of three segments, thick-walled with rough surface. Cephalis hemispherical with long stout apical horn approximately equal in

length of the thorax. Thorax inflated with circular to subcircular pores, arranged in longitudinal rows, 8-10 on a half-equator, 6-8 in a vertical series. Abdomen thick-walled, usually longer than that of thorax, and tapering distally. Lumbar stricture distinct and marked externally. Abdominal pores larger and less regularly arranged than those of thorax. Mouth usually wide open with a ragged termination.

Measurement: Diameter of cephalis, 20-25um; length of thorax, 85-95um; of abdomen 170-190um; of apical horn, 100-120um. Measurements based on 10 specimens from 702B-9-2, 50-52cm and 702B-8-6, 20-22cm.

Remarks: This species characterized by the pronounced lumbar stricture and long stout apical horn. *Calocyclus crassa* is probably the ancestral form of *C. semipolita*. Progressive increase in the size of the abdomen and concomitant reduction in the development of the apical horn marks the transition between these taxa in the Late Eocene. The species name, *crassa*, means thick, which is derived from the shell morphology of this species.

Abundance: Few to Common

Occurrence: Middle to Late Eocene

Genus CYRTOCAPSELLA Haeckel

Cyrtocapsella Haeckel, 1887, p.1512. Type species (designated by Campbell, 1954, p.143): *Cyrtocapsella tetrapera* Haeckel (1887, p.1512, pl.78, fig.5).

Cyrtocapsella robusta Abelman

Pl. II, Figs. 5, 6

Theocorys longithorax, PETRUSHEVSKAYA, 1975, p. 580, pl. 8, figs. 17, 18 : pl. 22, fig. 2.

Cyrtocapsella robusta ABELMANN, 1990, p. 696, pl. 5, fig. 11(only).

Remarks: The genus *Cyrtocapsella* is followed here rather than *Theocorys* because most complete specimens appear to have a closed abdomen. Recently, Abelman (1990) reported this species from the Late Oligocene samples of Hole 698B in the Weddell Sea of the ODP Leg 113. However, it should be noted that Abelman (1990) did not separate between Early to Middle Oligocene form of *Calocyclus crassa* and the Late Oligocene form of *Cyrtocapsella robusta*. Lazarus (1989) also reported the occurrence of this taxon from the Oligocene of Sites 748 and 749 in the Raggart Basin of eastern Antarctic. The synonymous *Theocorys longithorax* was described by Petrushevskaya (1975) from the Oligocene sediments of Site 280 in the southeastern Indian Ocean.

Abundance: Few to Common

Occurrence: Middle Oligocene to Early Miocene

Genus EUCYRTIDIUM Ehrenberg

Eucyrtidium Ehrenberg, 1847b, p. 43. Type species (designated by Frizzell and Middour 1951): *Lithocampe acuminata* Ehrenberg (1854, p. 84; 1854b, pl. 22, fig. 27).

Eucyrtidium parva n. sp.

Pl. II, Figs. 7, 8

Description: Shell small, generally spindle-shaped, thick-walled, with a rough surface. Cephalis hemispherical, without pores. No apical spine or tube. Thorax conical, rather thick-walled, with small subcircular to circular pores aligned two transverse rows. Abdomen and three to four post-abdominal segments, thick-walled, of approximately equal length, expanding distally to a maximum breadth at about second post-abdominal segment; then narrowing toward last segment. Pores circular to subcircular, aligned in both longitudinal and transverse rows.

Measurement: Length of the shell, 140-160 μ m; of cephalis, 18-22 μ m; of thorax, 22-28 μ m; of widest segment, 85-90 μ m. Measurement based on 15 specimens from 698A-3R-1, 52-54cm and 702B-16X-2, 30-32cm.

Remarks: *Eucyrtidium parva* is characterized by its small, spindle-shaped shell and distinct lumbar strictures. Johnson (1974, pl.3, fig. 12) reported similar species without description under *Theoperid* in the Eocene samples at DSDP Leg 22 from the eastern Indian Ocean. The species name, *parva*, derived from *parvus*, means small.

Abundance: Abundant

Occurrence: Paleocene to Middle Eocene

Genus *LITHOCAMPE* Ehrenberg

Lithocampe Ehrenberg, 1873, pl.128; Haeckel, 1887, p.1501. Type species (designated by Campbell, 1954, p.D140): *Lithocampe radricula* Ehrenberg (1873, pl.22, fig.23a).

Lithocampe latissima n. sp.

Pl. II, Figs.9,10

Description: Shell large, of five to six segments, generally spindle-shaped, thick-walled with rough exterior. Cephalis simple, with a stout apical horn which is usually twice as long than the cephalis. Collar stricture visible externally. Thorax conical, rather thick-walled, with small circular to subcircular pores, arranged in longitudinal rows, 5-7 on a half-equator, 2-3 in a vertical series. Abdominal and post-abdominal segments, thick-walled, of variable length, usually expanding distally to a maximum width and length at first post-abdominal segment, and then narrowing toward final segment. Pores circular to subcircular, arranged in longitudinal rows: larger than thoracic pores, 8-10 on a half-equator, 4-6 in vertical series. Termination either ragged, or in fully developed specimens, the abdomen narrows distally to a poreless peristome with smooth margin.

Measurement: The length of overall shell, 310-380 μ m; of the apical horn, 30-56 μ m; of the thorax, 68-75 μ m. The width of widest abdominal segment, 168-195 μ m. Measurement based on 20 specimens from 700B-31R-6, 62-64 μ m, and 700B-32R-6, 32-34 μ m.

Remarks: This species is similar to *Lithocampe* sp. A illustrated by Dumitrica (1973, p.789, pl.4, fig.7; pl. 10, fig.3; pl.11, fig.3) in the Paleocene sediments from Site 208, of the DSDP, Leg 21. *Lithocampe latissima* is distinguished by the large multi-segmented shell (usually lesser than 6) and stout apical horn. The species name, *latissima*, means the widest derived from the shell morphology of this species.

Abundance: Common to Abundant

Occurrence: Early Paleocene

Genus *LOPHOCONUS* Haeckel

Lophoconus Haeckel, 1887, p.1403. Type species (designated by Frizzel and Middour, 1951): *Eucyrtidium antilope* Ehreberg (1872, p.308; 1873, pl.9, fig.18).

Lophoconus titanothericeraos Clark and Campbell

Pl. II, Fig.11

Lophoconus titanothericeraos CLARK and CAMPBELL, 1943, p.89, pl.8, figs. 24-26, 28, 30-37; 1945, p.47, pl.6, figs.31, 32. -CHEN, 1975, p.461, pl.2, fig.9 - BLUEFORD, 1988, p.246, pl.2, figs.11, 12.

Remarks: Specimens found in the present study are in good agreement with the original description of Clark and Campbell (1942), except that the abdomen of

the subantarctic forms from Leg 114 tend to be more constricted at the lumbar stricture. Lazarus (1989) reported the occurrence of this taxon from the Middle to Late Eocene of Sites 748, 749 and 750 in the Raggartt Basin of eastern Antarctic.

Abundance: Common to Abundant

Occurrence: Middle Eocene

Genus *LYCHNOCANOMA* Haeckel

Lychnocanoma Haeckel, 1887, p.1229. Type species (designated by Campbell, 1954, p.D124): *Lychnocanoma clavigerum* Haeckel (1887, p.1229).

Lychnocanoma amphirite Foreman

Pl. II, Figs.12,13

Lychnocanoma amphirite FOREMAN, 1973, p.437, pl.11, fig.10. -CHEN, 1975, p.469, pl.2, fig.7. -RIEDEL and SANFILIPPO, 1978, p.87, pl.2, figs. 2-3 ; 1986, P.153, pl.1, fig.13.

Remarks: Specimens found in the present study are in good agreement with the original description and figures by Foreman (1973) from the Eocene samples of the DSDP, Leg 10.

Abundance: Common to Abundant

Occurrence: Middle Eocene

Lychnocanoma hexagonum n. sp.

Pl. II, Fig. 14

Description: Cephalis subspherical, with a few, small circular to subcircular pores, bearing a short apical horn. Collar stricture pronounced. Thorax long, slightly inflated, rough and thick-walled. Thoracic pores large, hexagonally framed, arranged in longitudinal rows. Three bladed feet (usually broken) equal in length, slightly diverted and curved inward.

Measurement: Diameter of cephalis (excluding horn) 28-30um; length of thorax 98-120um; of feet 25-30um. Maximum width of thorax 125-145um; pore diameter 12-15um. Measurement based on 15 specimens from 699A-10H-2, 50-52cm.

Remarks: This species is similar in size and shape to *Lychnocanium bellum* Clark and Campbell (1942, p.72, pl.9, figs. 35,39) described from the Eocene sediments of California. However, Leg 114 specimens are characterized by the rougher thorax with large pores (12-15um) compared to *Lychnocanium bellum* (8-9um). In addition, *Lychnocanoma* sp. has pores on the cephalis, a feature distinctly missing in the *Lychnocanium bellum*. The species name, *hexagonum*, means hexagonal, which is derived from the hexagonally framed thoracic pores of this species

Abundance: Common

Occurrence: Middle to Late Oligocene

ACKNOWLEDGEMENTS

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PLATE 1

(Magnification $\times 200$ unless otherwise indicated)

- Figure 1,2 *Axoprunum magnum* n. sp.
1. 702A-4-2, 50-52cm, R-2 (M22/3)
2. 703A-18-1, 50-52cm, R-3 (O40-1)
- Figure 3,4 *Stylosphaera goruna* Sanfilippo and Riedel
3. 700B-31-5, 71-73cm, R-3 (L38/2)
4. 700B-31-2, 20-22cm, R-3 (K47-1)
- Figure 5,6 *Amphicraspedum prolixum* Sanfilippo and Riedel
5. 698A-3-1, 52-54cm, R-2 (W33/1)
6. 698A-3-1, 52-54cm, R-2 (O35/4)
- Figure 7 *Spongocore spongiosa* n. sp.
7. 698A-3-1, 52-54cm, R-2 (P34/4)
- Figure 8,9 *Giraffospyris didiceros* (Ehrenberg)
8. 698A-3, cc, R-2 (N13/2)
9. 703A-8-2, 70-72cm, R-3 (J33/2)
- Figure 10,11 *Sethocyrtis ovalis* n. sp.
10. 702B-18-6, 60-62cm, R-3 (L21/3)
11. 702B-16-4, 30-32cm, R-1 (N42/1)
- Figure 12,13 *Buryella tetradica* Foreman
12. 700B-29-1, 49-51cm, R-3 (L37/2)
13. 700B-29-1, 49-51cm, R-3(C43/1)

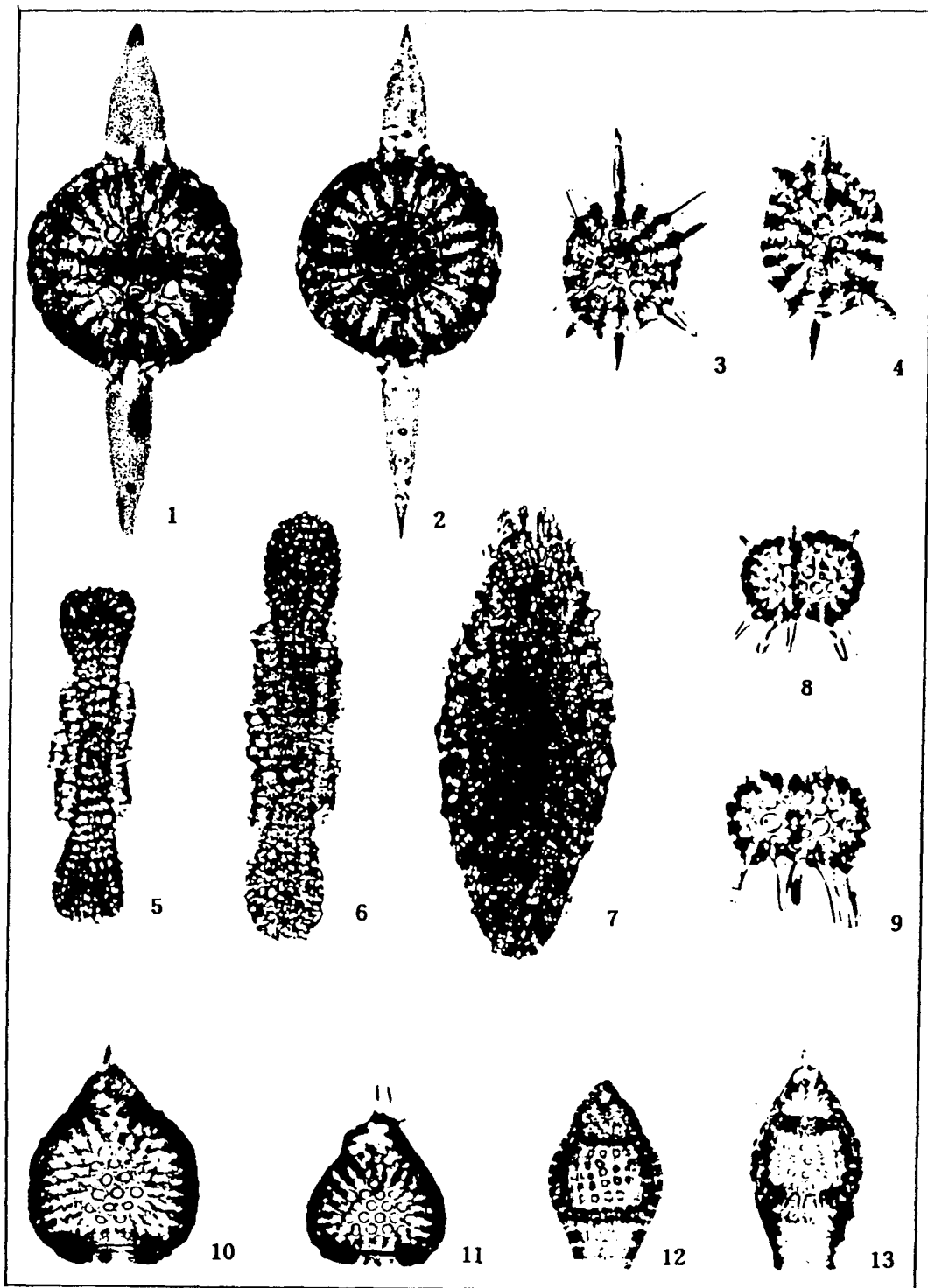


PLATE 2

(Magnification $\times 200$ unless otherwise indicated)

- Figure 1,2 *Calocyclus semipolita* Clark and Campbell
1. 699A-27-6, 77-79cm, R-3 (D28/1)
2. 699A-33-4, 50-52cm, R-1 (O12/3)
- Figure 3,4 *Calocyclus crassa* n. sp.
3. 702B-9-2, 50-52cm, R-2 (J25/3)
4. 702B-8-6, 20-22cm, R-2 (Q27/2)
- Figure 5,6 *Cyrtocapsella robusta* Abelmann
5. 699A-12-2, 50-52cm, R-3 (N20/2)
6. 699A-12-4, 50-52cm, R-3 (V35/1)
- figure 7,8 *Eucyrtidium parva* n. sp.
7. 702B-17-2, 60-62cm, R-3 (M31/2)
8. 700B-32-1, 47-49cm, R-3 (F14/2)
- Figure 9,10 *Lithocampe latissima* n. sp.
9. 700B-31-6, 62-64cm, R-3 (U47/1)
10. 700B-31-6, 62-64cm, R-3 (F16/3)
- Figure 11 *Lophoconus titanothericeraos* Clark and Campbell
11. 702B-12-2, 50-52cm, R-1 (E25/1)s
- Figure 12,13 *Lychnocanoma amphitrite* Foreman
12. 702B-9-2, 50-52cm, R-2 (H23/2)
13. 702B-8-2, 48-50cm, R-2 (N30/3)
- Figure 14 *Lychnocanoma hexagonum* n. sp.
14. 699A-10-4, 48-50, R-3 (S42/1)

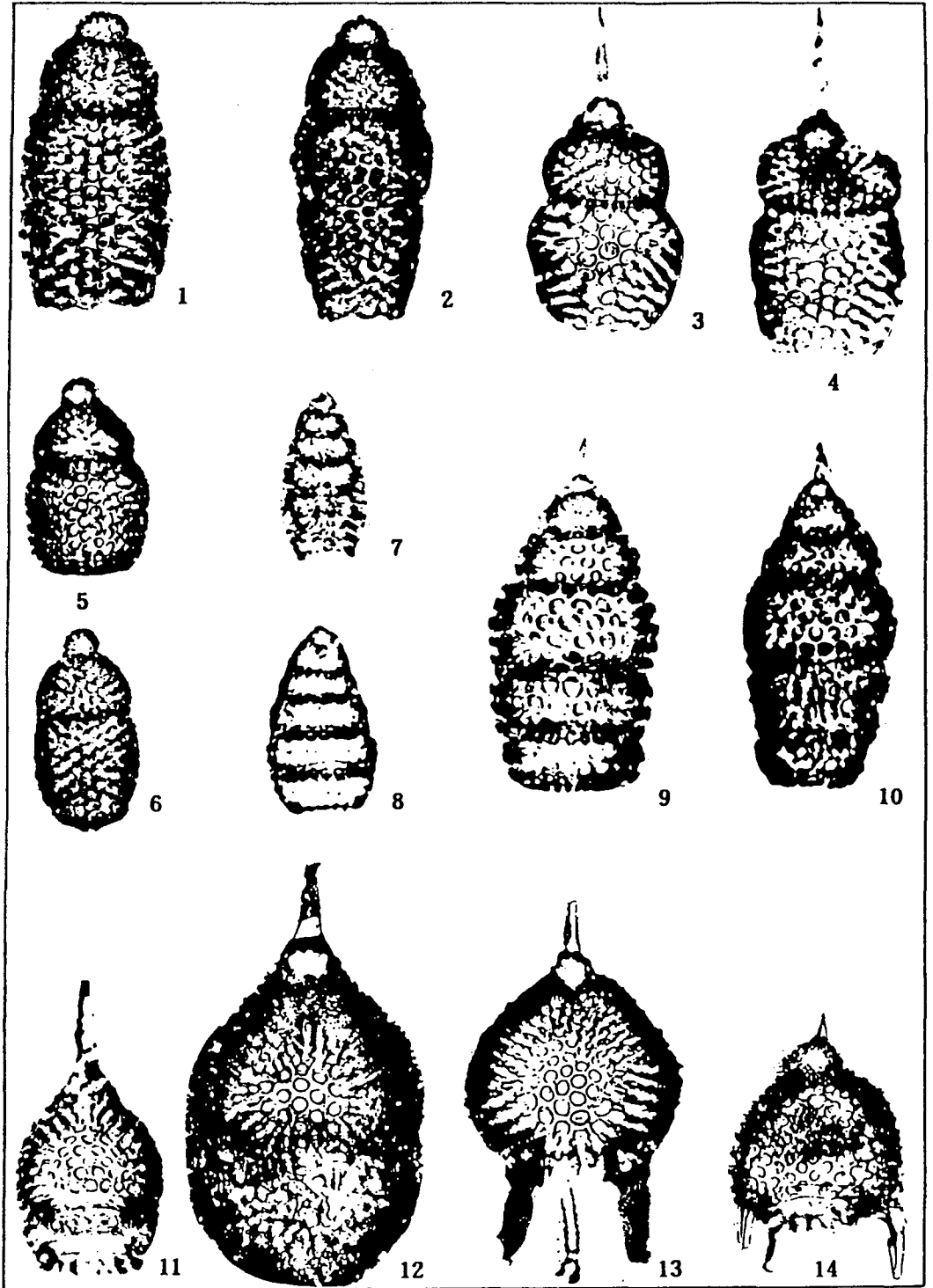


FIGURE CAPTIONS

FIGURE 1: Composite stratigraphic column (top) reveals the ages, lithologies, and sediment thickness of each site. A schematic cross section (bottom) shows the site locations along the bathymetry of the transect (modified after Cieisielski, Kristofferson, et al., 1988).

FIGURE 2: Paleogene Radiolarian Zones

FIGURE 3: Paleogene radiolarian zones and vertical distribution of taxa observed from ODP Leg 114 samples.

FIGURE 4: The biostratigraphic correlation of Paleogene radiolarian zones for holes drilled from Leg 114 (Solid lines indicate the correlation of radiolarian zones of each site).

FIGURE 5: Summary of Paleocene biostratigraphic zonations and correlated to the geomagnetic polarity pattern, Hole 700B. Geomagnetic stratigraphy according to Hailwood and Clement (1991). Calcareous nannofossil zones according to Crux (1991), planktonic foraminifer zones according to Nocchi et al. (1991), diatom zones according to Fenner (1991), silicoflagellate zones according to Cieisielski (1991), and radiolarian zones defined in the present study.

Striped boxes indicate the range of uncertain age assignment for a zonal boundaries. Horizontal dashed lines indicate placement of stratigraphic hiatus.

FIGURE 6: Summary of Early to Late Eocene biostratigraphic zonations correlated to the geomagnetic polarity pattern, Holes 702A and 702B. Geomagnetic stratigraphy according to Clement and Hailwood (1991). Calcareous nannofossil zones according to Crux (1991), planktonic foraminifer zones according to Nocchi et al.(1991), silicoflagellate zones according to Ciesielski (1991), and radiolarian zones as defined in the present study. Striped boxes indicate the range of uncertain age assignment for a zonal boundary. Horizontal dashed lines indicate placement of stratigraphic hiatus.

FIGURE 7: Summary of Late Eocene - Late Oligocene biostratigraphic zonations correlated to the geomagnetic polarity pattern, Hole 703A. Geomagnetic stratigraphy according to Hailwood and Clement (1991). Calcareous nannofossil zones according to Crux (1991), planktonic foraminifer zones according to Nocchi et al. (1991), silicoflagellate zones according to Ciesielski (1991), and radiolarian zones as defined in the present study. Striped boxes indicate the range of uncertain age assignment for a zonal boundary. Horizontal dashed lines indicate placement of stratigraphic hiatus.

FIGURE 8: A. Present-day Southern Ocean circulation (from Pickard and Emery, 1982).

B. Schematic cross section of major surface and subsurface water masses of the Southern Ocean (from Gordon, 1971) (Antarctic Convergence is equivalent to the Polar Front).

FIGURE 9: Evolution of deep, and intermediate-water circulation during the Cenozoic. Proteus, the ocean of the Eocene, was dominated by halothermal circulation; Proto-Oceanus, the ocean of the Oligocene, exhibited mixed halothermal and thermohaline circulation; whereas the modern ocean, Oceanus, is a psychrospheric ocean dominated by thermohaline circulation.

AABW : Antarctic Bottom Water

AAIW : Antarctic Intermediate Water

NADW : North Atlantic Deep Water

WSDW : Warm Saline Deep Water

MED : Mediterranean

(From Kennett and Stott, 1990).

FIGURE 10: Reconstruction of the subantarctic sites of Leg 114 for the Late Paleocene and Middle Eocene. Spreading-center location based on magnetic anomaly locations (Ciesielski, Kristoffersen, et al., 1988).

FIGURE 1

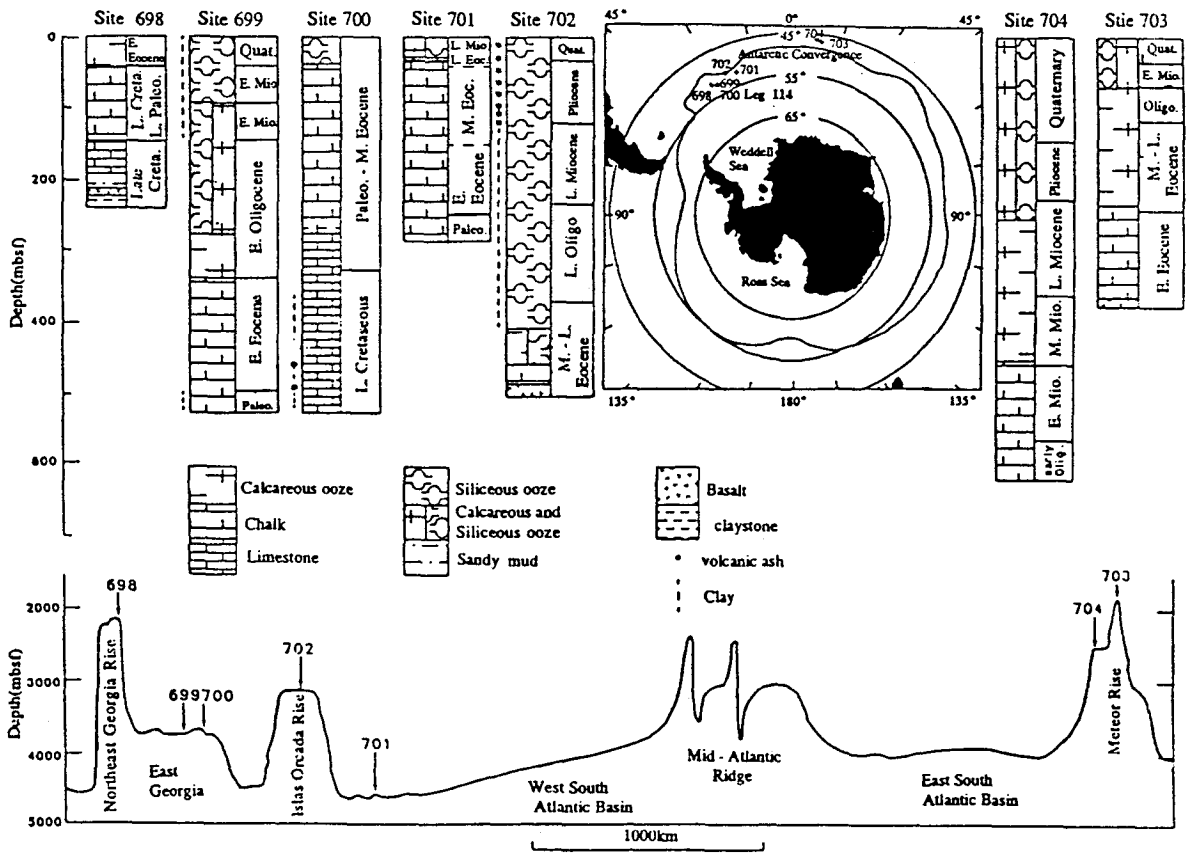


FIGURE 2










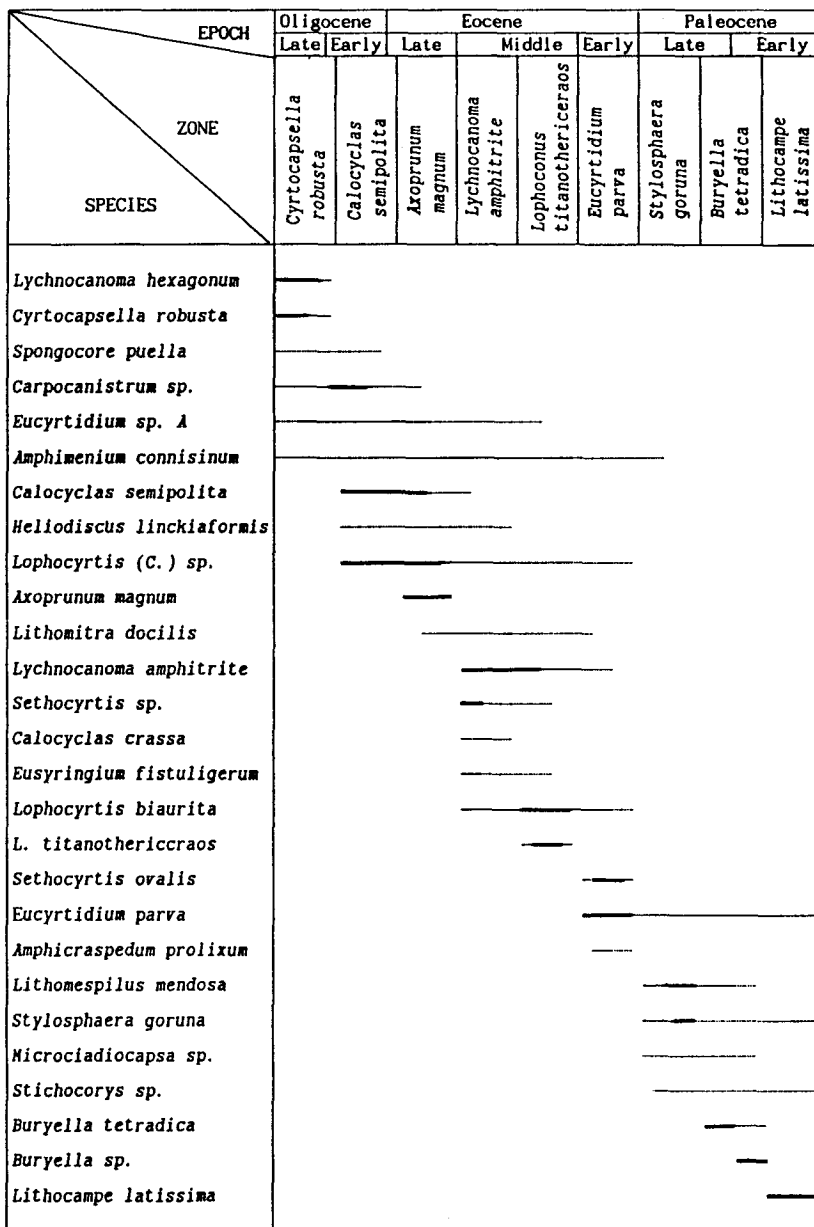
AGE		PALEOGENE RADIOLARIAN ZONES	
Oligocene	Late	<i>Cyrtocapsella robusta</i>	
	Early	<i>Calocyclus semipolita</i>	
Eocene	Late	<i>Axoprunum magnum</i>	
	Middle	<i>Lychnocanoma amphitrite</i>	
		<i>Lophoconus titanothericeraos</i>	
	Early	<i>Eucyrtidium parva</i>	
Paleocene	Late	<i>Stylosphaera goruna</i>	
	Early	<i>Buryella tetradica</i>	
		<i>Lithocampe latissima</i>	

FIGURE 3



— Abundant — Common - - - Present

FIGURE 5

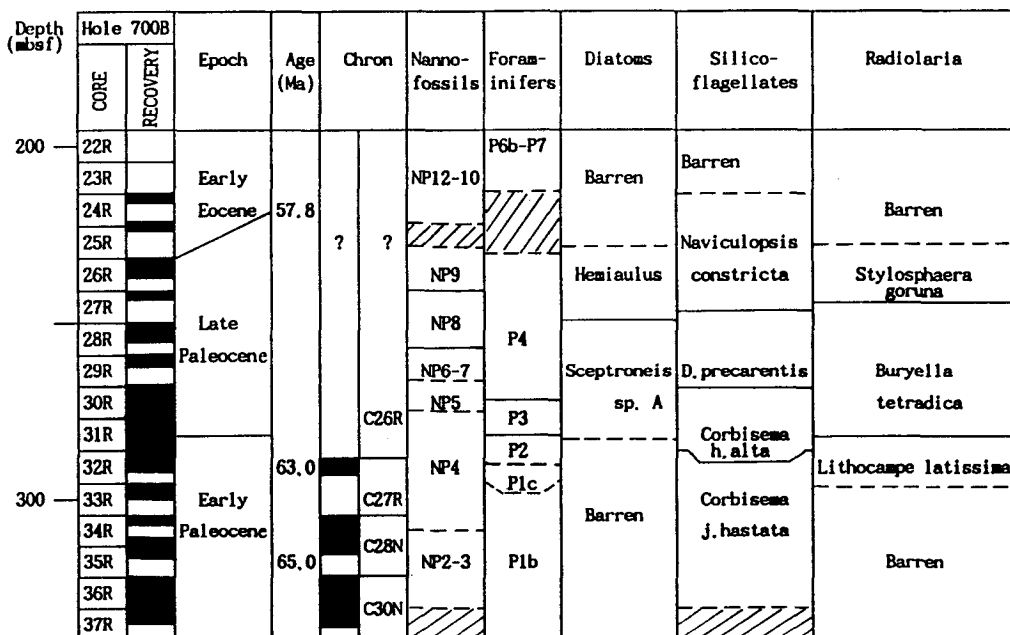


FIGURE 6

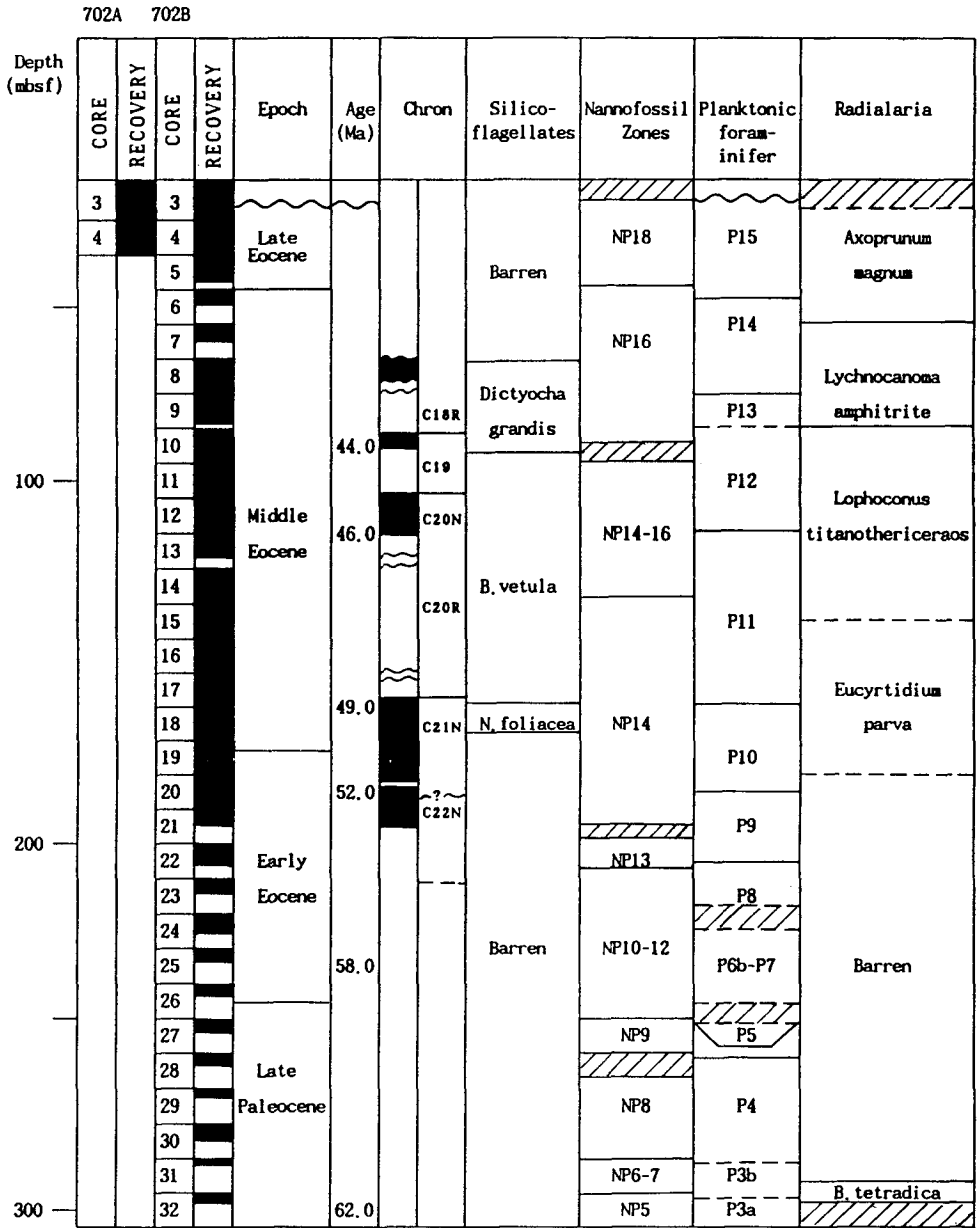


FIGURE 7

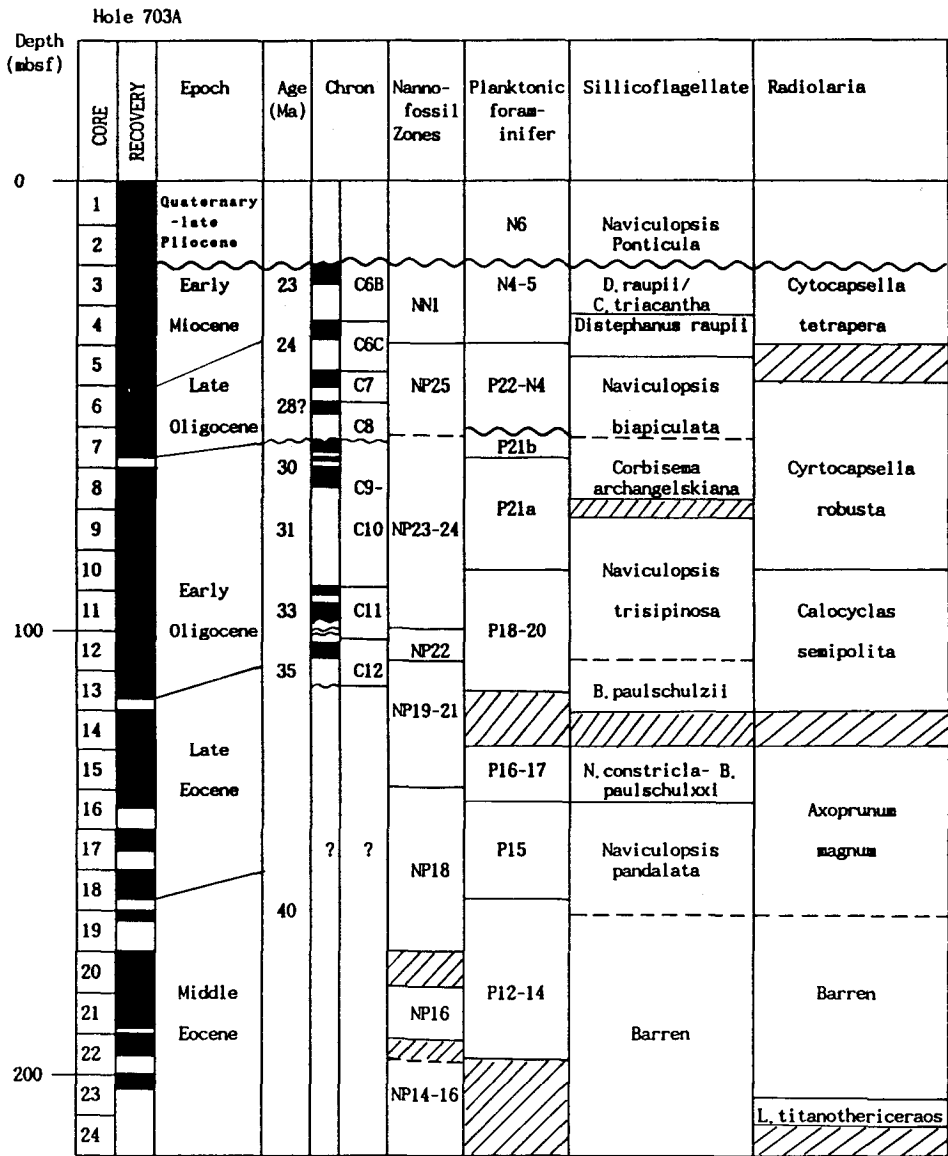
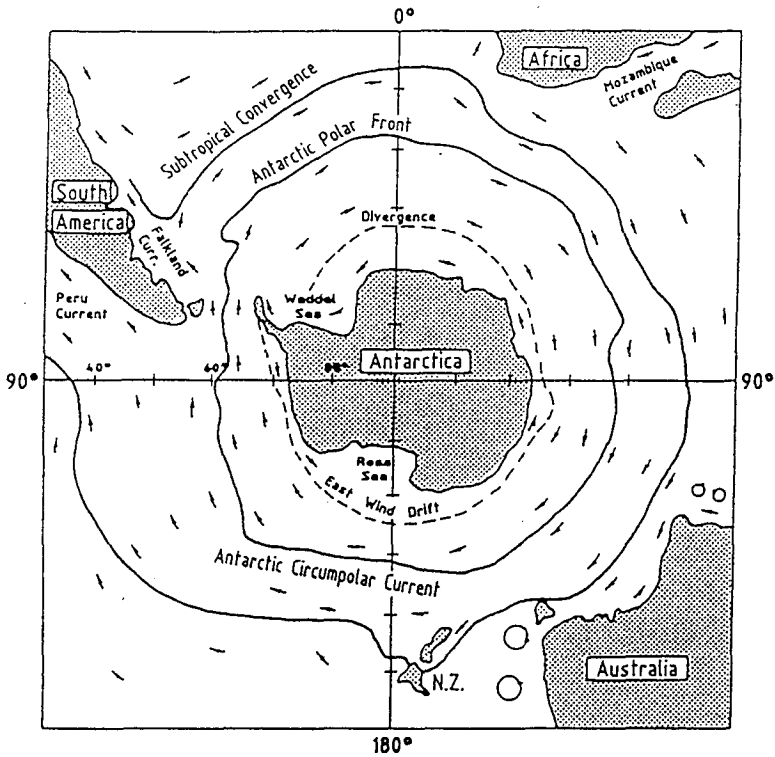
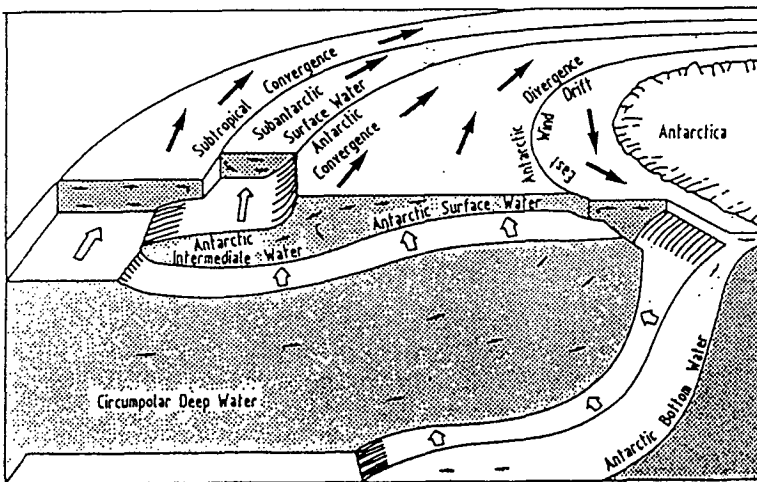


FIGURE 8



A



B

FIGURE 9

ATLANTIC

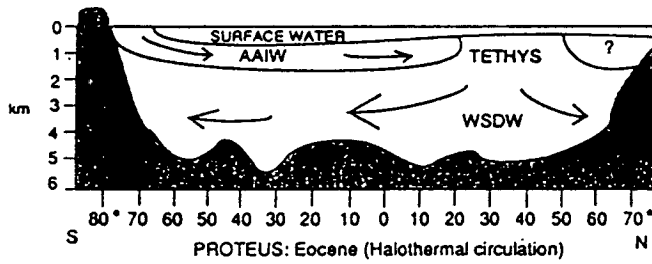
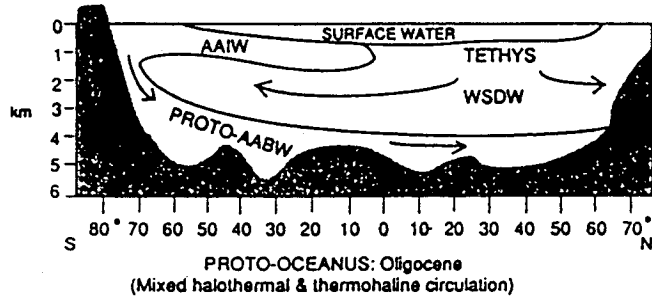
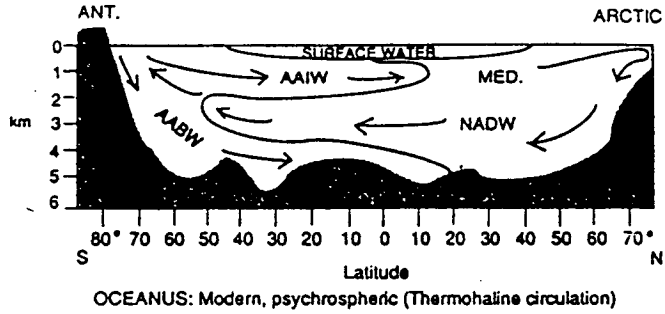


FIGURE 10

