INTRODUCTION

Deep Sea Drilling Project Leg 71 occupied four sites and drilled six holes in the middle- to high-latitude regions of the southwest Atlantic Ocean. Sites 511 and 512 are located on the Falkland Plateau: 511 is at 51°00.28'S, 46°58.30'W (2589 m water depth) in the plateau basin province and 512 at 49°52.19'S, 40°50.71'W (1846 m water depth) on the northeastern margin of the Maurice Ewing Bank (Fig. 1). Sites 513 (47°34.99'S, 24°38.40'W; 4383 m water depth) and 514 (46°02.76', 26°51.29'W; 4318 m water depth) are positioned on the lower western flank of the Mid-Atlantic Ridge system. Hydraulic piston coring (HPC) was successfully used at Sites 512 and 514. Sediments were recovered at all the other sites using conventional coring methods.

As has been the case with previous DSDP Legs into the subantarctic and antarctic regions, bad weather and ice conditions considerably affected or delayed sediment coring, and we were unable to remain at several of the sites for as long as we would have preferred. However, we were very successful in recovering some heretofore uncollected high-latitude sections of Pliocene to Eocene age. The most interesting and scientifically productive intervals include (1) a composite, essentially complete, early Miocene to late Eocene section in Holes 511 and 513A; (2) an excellent middle/late Miocene boundary and middle Eocene section in Hole 512; (3) a very good late Miocene section containing sediments from Magnetic Chronozone 9, 6, and 5 in Hole 513A, and (4) a Pliocene interval with a high sedimentation rate in Hole 514 near the modern position of the Polar Front Zone. Detailed studies of these sections and other DSDP holes in subantarctic and antarctic regions significantly increase our understanding of Cenozoic and Mesozoic high-latitude biostratigraphy and paleoceanographic history.

Radiolarians are generally well preserved, abundant, and diverse in all Cenozoic sediments recovered during Leg 71. In contrast, the Mesozoic section collected at Hole 511 contains only a few sporadic occurrences of radiolarians in Samples 511-23,CC, 511-56,CC, and 511-57,CC. Most specimens are poorly preserved or recrystallized. Sample 511-23,CC contains a Maestrichtian assemblage with Dictyomitra regina, D. lamellicostata, and Amphipyndax sp., whereas Samples 511-56,CC and 511-57,CC yield specimens of the lower Albian to upper Aptian species Thanarla conica and Archaeodictyomitra vulgaris.

BIOSTRATIGRAPHIC FRAMEWORK

The antarctic/subantarctic radiolarian zonation proposed by Chen (1975) is used, with several modifications, to zone Neogene sediments recovered during Leg 71. Since a radiolarian zonation for the Paleogene has not been established in high latitudes and because most Paleogene species identified in Leg 71 samples are endemic to the area, Eocene and Oligocene age determinations are based on the occurrence of secondary marker species whose ranges are established in low-latitude regions (Riedel and Sanfilippo, 1978).

As part of the investigation of Leg 71 radiolarians, my data are supported by detailed radiolarian documentation from other DSDP sites and many Eltanin and Islas Oradas piston cores from the Southern Ocean region. These include DSDP Leg 29, Hole 278; Leg 28, Hole 266; Leg 36, Hole 329; Eltanin Cores 16-4, 36-33, 50-28, 38-8, 14-8, 43-2, 13-17, and 34-5; and Islas Orcadas (IO) Cores 7-49, 7-54, 7-48, 7-55, 7-2, 16-108, and 16-109. Paleomagnetic data are available on these piston cores. Radiolarians in Holes 278, 266, and all Eltanin cores were documented in an earlier study (Weaver, 1976a). Detailed data from these cores will be published separately by Ciesielski and Weaver.

Piston cores provide a more complete record of early Pliocene radiolarian distribution throughout the Gilbert Magnetic Chronozones, thus allowing a high-resolution subdivision of Chen's (1975) Helolotholus vema Zone into the Desmospyris spongiosa, Triceraspis corona-ta, and Stichocorys peregrina zones. The D. spongiosa Zone is defined from the first occurrence of D. spongi-osa to the evolutionary transition from H. praevema to H. vema (~4.25 to 4.0-3.95 Ma). The T. corona Zone is defined from the last occurrence of S. peregrina to the first occurrence of D. spongiosa (~4.5 to 4.25 Ma). Finally, the S. peregrina Zone is defined by the total range of S. peregrina (~6.0 to 4.5 Ma). The base of the S. peregrina Zone is not directly correlated to paleomagnetic stratigraphy. However, in Hole 513A, the first occurrence of S. peregrina coincides with the first appearance of the diatom Thalassiosira praeconvexa, which in low latitudes correlates with the upper reversed interval of Chronzone 6 (Haq et al., 1980).

Radiolarian data from DSDP Leg 29, Hole 278, require a modification of Chen's (1975) late to middle Miocene zones. In Hole 278, Antarctissa conradae ranges below the first occurrence of Actinomma tanyacan-
Figure 1. Location of Leg 71 sites.
thas (Petrushevskaya, 1975; this study). *Antarctissa con-
radae* has a split range that brackets the middle/late Miocene boundary. Therefore, I redefine Chen's (1975) *Actinomma tanyacantha* Zone from the first occurrence of *A. tanyacantha* to the first occurrence of *Theocalyptra bicornis spongorthox*, thus eliminating the *Antarctissa conradae* Zone. The top of the *Actinomma tanyacantha* Zone correlates with upper Magnetic Chronozone 10 or possibly basal 9 (~10.5 to 9.5 Ma) based upon data from Hole 512 and piston cores 10, 51, 54, 49, and 7.48.

The *T. bicornis spongorthox* Zone of Chen (1975) is redefined from the first occurrence of *T. bicornis spongorthox* to the first occurrence of *S. peregrina* (~10.5-9.5 to 6.0 Ma). Piston core data from 10, 7-49 shows that the upper range of *T. bicornis spongorthox* extends at least into Magnetic Chronozone 8 at ~8.3 Ma. As far as can be discerned, no upper Chronozone 8 to middle Chronozone 6 sections have been collected in piston cores from the Southern Ocean. This major gap in the sedimentary record spans the interval between 6.0 and 8.3 Ma.

Biostratigraphically Important Datums

Radiolarian stratigraphy in Neogene sediments from Leg 71 Holes 512, 513, and 514 and the piston cores previously mentioned permits calibration of several Pliocene to middle Miocene datums to the geologic and paleomagnetic time scales. First-order correlations to paleomagnetic data are available for the Gauss, Gilbert, and Chronozone 11 through basal 8. Second-order correlations are used for the late Miocene interval between 6.1 and 5.4 Ma, where the occurrence of warm-water radiolarians and diatoms permits correlation with established low-latitude datum levels. These biostratigraphic events are:

1. First consistent occurrence (FCO) of *Cycladophora davisi*, upper Gauss Chronozone, 2.8 to 2.6 Ma.
2. Morphotypic last occurrence (Tm) of *Prunopyle titan*, lower Gauss Chronozone, 3.2 Ma. Lower Gauss morphotypes of *P. titan* tend to be considerably smaller (average maximum width 150-180 µm) than those in the Gilbert, where the largest morphotypes occur between 4.0 and 4.25 Ma (average maximum width >210 µm).
3. Evolutionary transition of *Helothis praeveana* to *H. vema*, at or just below the Cochiti Subchronozone, ~3.95 Ma.
4. Morphotypic first occurrence (Bm) of *Lamprocyrtis heteroporos* and *Tholopysir* sp. A, upper Gilbert Chronozone, 3.95 Ma.
5. Tm of *Triceraspis coronata*, just below the Nunivak Subchronozone, ~4.25 Ma.
6. Bm of *Desmospyris spongiosa*, below the Nunivak Subchronozone, 4.3 Ma.
7. Tm of *Amphipyrenium challenger*, just above or within the Sidufjall Subchronozone, 3.45 Ma.
8. Tm of *Stichocorys peregrina*, within the lower Gilbert Chronozone, 4.6 to 4.4 Ma.
9. Tm of *Didymycyrtis didymus*, 5.4 Ma.
10. Tm of *Anthocyrtidium ehrenbergii* and Bm of *Amphipyrenium challenger*, 5.45 Ma.
11. Tm of *Didymycyrtis sp. A* and *Lamprocyrus eleges* group, 5.5 Ma.
12. Bm of *Didymycyrtis didymus* and *Siphocampe* sp. A and the Tm of *Eucyrtidium “sp.”, ~5.6 Ma.
13. Bm of *Didymycyrtis sp. A* and *Lamprocyrus eleges* group, 6.0 to 5.8 Ma.
15. Tm of *Theocalyptra bicornis spongorthox*, 8.3 Ma. This is a maximum age for this datum. It is probably younger, but can only be tied with confidence to paleomagnetic stratigraphy up through basal Chronozone 8.

Two points need to be emphasized concerning late Miocene to early Pliocene radiolarian stratigraphy. We do not have a very good understanding of lower Gilbert Magnetic Chronozone radiolarian distribution throughout the Southern Ocean (4.6 to 5.2 Ma). *Eltanin* Core 34-19, which is used by Keeny (1979) to zone the lower Gilbert, is equivalent to a portion of Magnetic Chronozone 6, on the basis of data from Hole 513A. In addition, we also have very little documentation of radiolarian distributions for the interval between Magnetic Chronozone 8 and 6. A very detailed study of existing core material is underway to try to alleviate these inadequacies.

A preliminary middle Eocene through Oligocene radiolarian datum chart is being prepared from Leg 28, 29, 36, and 71 data. However, before it can be finished a considerable amount of taxonomic work remains to be completed. At least 60 new species are being described from Paleogene sediments recovered in Holes 511, 512, and 513A. These descriptions and the datum chart are being prepared for separate publication.

**RADOLARIAN HOLE SUMMARIES**

**Hole 511**

Radiolarians are common and well preserved in Cores 1 through 20. Cores 21, 23, 56, and 57 contain rare recrystallized or poorly preserved radiolarians. All other cores are barren of siliceous microfossil remains.

**Age Summary**

In the absence of any well-documented high-latitude Paleogene radiolarian zonation, sediments recovered between Cores 2 and 20 are correlated with Riedel and Sanfilippo’s (1978) standard low-latitude zonal scheme using rare secondary radiolarian indices. Table 1 illustrates the distribution and abundance of key radiolarian species identified in Hole 511.

Sample 511-1, CC contains a mixed assemblage of Quaternary, Pliocene, and Oligocene radiolarians indicating substantial disruption of sediments at this level. An unconformity spanning approximately 30 m.y. separates Cores 1 and 2.

Cores 2 through 4 are early Oligocene. They contain *Calocycletta* sp. cf. *C. parva*. This species is believed to be the ancestral form of *C. parva*, which appeared in the late Oligocene in low latitudes. Dinkelmann (1973) reports that this species is restricted to the *Theocyrtis tu-
berosa* Zone, but Moore (1972) believes that it may range into the basal *Dorcadospyris aequus* Zone, or into the early late Oligocene. Therefore, Cores 2 through 4 are dated as early Oligocene to possibly early late Oligocene in age (Table 1).
Table 1. Radiolarians, Site 511.

<table>
<thead>
<tr>
<th>Age</th>
<th>Radiolarian Zones</th>
<th>Core/Section (interval in cm)</th>
<th>Abundance</th>
<th>Preservation</th>
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<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Mixed assemblage</td>
<td></td>
<td>1,CC</td>
<td>C</td>
<td>G</td>
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<tr>
<td>Thysocrits tuberosa to early Doradospyris ateuchus zonal equivalent</td>
<td>2,CC</td>
<td>C</td>
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<td>3,CC</td>
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<td>5,CC</td>
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<td></td>
<td>early Oligocene</td>
<td>6,CC</td>
<td>C</td>
<td>G</td>
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<tr>
<td>T. tuberosa zonal equivalent</td>
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<td>20,CC</td>
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<td>early-middle Eocene</td>
<td>21-1, 71-72</td>
<td>F</td>
<td>P</td>
</tr>
</tbody>
</table>

Note: For abundance, C = common, F = few, R = rare, t = trace (1-2 specimens/slide); for preservation, P = poor, M = moderately well preserved; G = good.

Cores 5 through 17 are dated as early Oligocene and are correlative to the T. tuberosa Zone in low latitudes. This correlation is based on the occurrence of C. acanthocephala throughout this sequence of cores. This species is known only from the early Oligocene or T. tuberosa Zone sediments in low- to middle-latitude regions. Johnson (1974) reports C. acanthocephala in T. tuberosa Zone sediments in the Indian Ocean and Ling (1975) documents its occurrence in the lower half of the T. tuberosa Zone in the Northwest Pacific area. (Core 17, however, is dated as latest Eocene on the basis of foraminiferal, calcareous nannofossil, and palynomorph data.)

Cores 18 to 20 are late Eocene in age and correlate with the Thysocrits bromia Zone in low latitudes. This age determination is based on the occurrence in these cores of Cryptoprora ornata, Lychnocanoma amphitrite, Thysocrits diabolensis, and the ancestral form of T. tuberosa. Core 18 also contains very rare specimens of Thysocrits bromia and T. tetracantha.

Core 21 is tentatively dated as middle to early Eocene because of the co-occurrence of Amphymenium splendiarum and Amphiphraspedum prolixum group along with many recrystallized specimens of Buryella species not identifiable to the specific level.

Paleoenvironmental Interpretation

The presence in Cores 16 through 20 of many specimens of Calocycletta and collossheariid species along with specimens of Cryptoprora ornata, Thysocrits tuberosa (ancestral form), Lychnocanoma amphitrite, Lithocyclia crux, and very rare Thysocrits bromia is indicative of relatively warm, possibly temperate conditions at Hole 511 during the latest Eocene and earliest Oligocene.

However, by Core 12 the specific nature of the overall radiolarian assemblage changes dramatically. Most warm-water species have disappeared and the assemblage becomes dominated by cooler water Spongotheca, Prunopyle, and Eucyrtidium species. This assemblage persists through Core 11 and represents a significant climatic deterioration in the early Oligocene. Cores 11 and 12 appear to document the convergence of temperate and subantarctic waters after the transgression of subantarctic waters over Hole 511 in the early Oligocene.

Cores 2 through 9 contain radiolarians that resemble the early Oligocene assemblage recorded by Chen (1975) in Hole 274 at 60°S latitude near the Ross Sea. This assemblage is characterized by the occurrence of Cyclam-
pterium? longiventer, Calocyclas semipolita, Amphihaploparis sphaera sp., Diplocycles sp. A group, Lithomelissa sphaerocephalus, L. challengerae, Spongomelissa sp., and Eucyrtidium sp. (Table 1).

Chen (1975) records this assemblage in Cores 274-31 through 274-39. Because of their proximity to the Antarctic continent, these radiolarians are considered to be relatively cool-water species. Radiolarians in Cores 511-2 through 511-9 appear to represent the northerly elements of a broad antarctic/subantarctic biofacies that encompassed up to 18 degrees of latitude in the circum-Antarctic seas during the early Oligocene.

In summary, climatic conditions through the late Eocene to early Oligocene at Hole 511 fluctuate from temperate to at least subantarctic.

**Holes 512 and 512A**

Nineteen HPC cores were recovered at Hole 512 and one conventional core at Hole 512A. Very well preserved, abundant, and highly diverse radiolarians are encountered in all cores.

**Miocene**

Samples 512-1-1, 139–141 cm to 512-5, CC are correlated with the Miocene Actinomma tanyacantha Radiolarian Zone (Table 2). This interval spans the late/middle Miocene boundary, based upon foraminiferal data. The paleomagnetic stratigraphy of these sediments is interpreted by Ciesielski (this volume) to represent much of Chronzone 10 and the top of Chronzone 11 or the base of Chronzone 10 and most of Chronzone 11. However, without a more continuous section, it is impossible to say definitively which interpretation is correct.

The radiolarian assemblage encountered in Cores 512-1 through 512-5 is repetitious and is dominated by Dendrosyris haysi, Prunopyle hayesi, Antarctissa coronata, Cornutella profunda, Theocalyptra bicornis, Actinomma antarcticum, and Siphocampe arachnea group. Less abundant species include Cyrtopera lagunella, Actinomma antarcticum, Lychnocana elongata, and Gondwanaria japónica. The only noticeable change in species composition occurs between Sections 512-3-2 and 512-2-2, where Cyrtocapsella japonica is documented (Table 2). The morphotypic top of C. japonica in low latitudes is within the Diatius petterssoni Zone (Johnson and Wick, 1982). They correlate this datum with the Chron 10/11 boundary at approximately 11.2 Ma.

The occurrence of many known deep-living radiolarian species such as Cyrtopera lagunella, Cornutella profunda, Peripyrimis circumtexta, and S. arachnea group together with common to abundant Thalassiothrix spp. (diatom) throughout Cores 512-1 through 512-5 reflects eutrophic conditions. This association of diatoms and radiolarians is indicative of upwelling conditions (Weaver et al., 1981) and leads to the conclusion that Hole 512 was at or very near the Polar Front Zone between 11.5 and 10 Ma.

**Eocene**

Cores 512-6 through 512-19 and Core 512A-2 contain excellently preserved radiolarians dated as middle Eocene. No Paleogene zones exist at middle to high latitudes and no direct correlation to Riedel and Sanfilippo’s (1978) low-latitude zonation is possible because of the paucity of stratigraphically important, low-latitude, index species. However, an indirect correlation is possible using secondary marker species such as Eusyringium fistuligerum, E. lagena, Lithapium mitra, and Lophocyrtis biaurita (Table 2).

Eusyringium fistuligerum, E. lagena, and Lophocyrtis biaurita range throughout Cores 512-6-19 and 512A-2 (Table 2). Lithapium mitra is found only in Cores 512-9 and 512-17. Based on radiolarian distributions at low latitudes, the highest occurrence of L. biaurita and the lowest occurrence of L. mitra are within the Podocyrtis mitra Zone. This interval is correlative with the NP15–NP16 nannofossil zones. While E. fistuligerum first occurs in low latitudes within the Thyrsocyrtis triacantha Zone, it co-occurs with E. lagena primarily within the Podocyrtis ampla to P. mitra zones. Therefore, based upon the occurrence of these secondary marker species, Cores 512-6-19 and 512A-2 are constrained to the P. mitra to P. ampla zones of Riedel and Sanfilippo, 1978 (Table 2).

The composite middle Eocene radiolarian assemblage at Holes 512 and 512A is dominated by Cyclampterium sp. aff. C. milowii, Lychnocana bellum, L. sp. cf. L. bellum, L. amphitrite, Periphaena decorca, Theocalyptra sa sp. aff. T. ficus, Dictyoprora mongolfieri, Phormocyrtis embolum, Lophocorys sp. aff. L. norvegicensis, and Lophocyrtis biaurita. Numerous other new theopler species were found within this interval and are now being described for publication.

**Holes 513 and 513A**

Radiolarians are common and well preserved throughout all cores recovered at Holes 513 and 513A. Ten cores were taken at Hole 513 and 33 at Hole 513A. Sediments range in age from Quaternary to early Oligocene.

Sample 513-1, CC contains a typical late Quaternary (<400,000 yr.) antarctic radiolarian assemblage that can be assigned to the Antarctissa denticulata Zone. Common species include A. denticulata, A. antarcticum, A. strelkovi, Stylodictyta validispina, Cycadophora davisi, Lithellus nautiloides, Saccospyrus antarctica, and Actinomma antarcticum. The high abundance of A. antarcticum in this sample probably indicates proximity to the Polar Front Zone. Sample 513-3, CC is within the Saturnalis circularis Zone (approximately 0.7 to 1.6 Ma). This core catcher sample contains Quaternary radiolarians restricted to waters south of the Polar Front. Sample 513-4, CC is also in the S. circularis Zone, but it is below the morphotypic top of Clathrocycles bicornis (1.6–1.8 Ma).

Sample 513-5, CC falls within the late Pliocene Eucyrtidium calcitense Zone (1.8–2.4 Ma). Typical late Pliocene antarctic radiolarians dominated by Antarctissa denticulata and Spongotrochus glacialis are present and indicate a position south of the Polar Front. The radiolarians in Sample 513-6, CC correlate to the upper part of the Helotholus vema Zone within the Gauss Magnetic Chronozone. No sediments were recovered from Cores 513-6-7. The early Pliocene Triceraspis coronata Zone is represented in Sample 513-9, CC and 513-10, CC.
Characteristic species include *T. coronata*, *H. praevema*, *C. bicornis*, *Eucrytidium calvertense*, and *Stylactractus universus*.

Sample 513A-1,CC is assigned to the lower part of the early Pliocene *H. vema* Zone. Along with species typical of this zone (Chen, 1975) are found many warm-water species, including *Lamprocyclos martialis*, *Dictycocoryne profunda/truncatum* group, *Tholospyris* sp. A, *Pterocanium trilobum*, *Lamprocyclos heteroporos*, and many collosphaerids. Samples 513A-2,CC to 513A-4,CC are also early Pliocene and fall within the *Triceraspis coronata* Zone (Table 3). *T. coronata* and *H. praevema*
are common constituents in Samples 513A-3, CC and 513A-4, CC. This interval is correlative with Samples 513-9, CC and 513-10, CC. The Stichocorys peregrina Zone is represented in Cores 513A through 8. The Miocene/Pliocene boundary occurs within this zone at an apparent hiatus between Cores 4 and 5 (based on diatom data; Ciesielski, this volume). Diatom data further indicates that the interval between Section 513A-8-3 and an apparent hiatus between Cores 4 and 5 (based on diatom data; Ciesielski, this volume). Diatom data further indicates that Hole 513A was situated north of the Polar Front between approximately 6.3 and 5.6 Ma. Diatoms indicate that Hole 513A was situated north of the Polar Front between approximately 6.3 and 5.6 Ma. A significant transition in the radiolarian fauna is observed between Cores 513A-6 and 5. In Core 5, most warm-water radiolarians have disappeared. Radiolarian abundances are greatly reduced and deeper-living forms such as Siphocampe arachnea group, Cyrtopera lagunula, Cornuella profunda, and Peripyramis circumtexa become progressively more dominant, especially between Sections 513A-5-4 and 513A-5-1. In contrast to Core 6, Core 5 contains a very high concentration of the diatom Thalassiothrix spp. This occurrence, together with the concentration of deep-living radiolarians, strongly suggests increased upwelling and very high productivity in the latest Miocene at Hole 513A. It further signals the late Miocene (~ 5.6-5.4 Ma) northward migration of the Polar Front to a position at or very near Hole 513A. This would be at least a degree or two north of its present position in the Southern Ocean today.

Very little sediment was recovered in Core 513A-9; however, Sample 513A-9, CC is tentatively dated as late Miocene, although it may be contaminated and unreliable for age analysis. Sections 513A-10 through 513A-11 fall within the Theocalyptra bicorns spongothera Zone (Table 3). The last occurrence of Diartus hughesi

![Table 3. Neogene radiolarians, Hole 513A.](image)
is in Section 513A-10-3 (Table 3). This datum occurs at the top of Chron 9 in low latitudes at approximately 8.6 Ma. (Johnson and Wick, 1982). A radiometric age determination on an ash layer in Section 513A-10-7 yields an age of 8.7 m.y. ± 0.2 (Ciesielski, this volume). These data suggest that Core 513A-10 to Section 513A-11-1 correlates to the late Miocene Magnetic Chron 9. Section 513A-11-3 to Sample 513A-11,CC is middle to early Miocene, based upon the co-occurrence of Cyrtocapsella cornuta and C. tetrapera. Although the radiolarian assemblage is diverse and well preserved, neither low- nor high-latitude index species are present. Chen's (1975) and Riedel and Sanfilippo's (1978) zonations are not applicable. Cores 12 through 14 are early Miocene, based on silicoflagellate data. Radiolarians encountered in this interval are very diverse, as in Core 11, and corresponding bear very little similarity to the early Miocene radiolarians known from low or high latitudes. Apparently these radiolarians represent a somewhat restricted early Miocene temperate biofacies. Radiolarians identified include C. cornuta, C. tetrapera, Sethopilium macropus, Prunopyle hayesi, Lychnocanoma sphaerotherax, Lithomelissa sp. C, Eucyrtidium cienkowski group, and many species of collosphaerids. Many previously undefined species are being described from this interval.

Cores 513A-15 through 33 are dated as Oligocene. Radiolarians in these sediments are well preserved and very diverse but, as reported for the early Miocene assemblage, bear very little resemblance to low-latitude, time-equivalent faunas. Many undescribed species are present. Only four radiolarians reported from low-latitude sediments are observed within this interval: Theocorys spongeocomum, Artophormis gracilis, and two species figured by Riedel and Sanfilippo (1977, plate 14, figs. 19-20, both listed as “theoperids gen. et sp. indet.”).

A significant faunal change occurs between Cores 513A-28 and 27. Samples from Cores 28-33 correlate with Cores 511-2 through 6 or 7 on the Falkland Plateau. This stratigraphic overlap between Holes 511 and 513A provides an apparently complete Oligocene section situated in the cool temperate to subantarctic region of the Southwest Atlantic.

**Hole 514**

Quaternary to Pliocene radiolarians are present in all 35 HPC cores recovered at Hole 514. Abundance and diversity are high and preservation generally good. Hole 514 appears to be stratigraphically uninterrupted down to the Core 26/27 boundary, where an unconformity of approximately 700,000 yr. separates Gauss from upper Gilbert sediments.

Table 4 illustrates the occurrence and abundance of radiolarian species in Hole 514. Based on paleomagnetic stratigraphy, the Quaternary/Pliocene boundary occurs between Cores 4 and 5.

Core 514-1 falls within the *Antarctissa denticulata* Zone, Core 514-2 the *Stylatracus universus* Zone, Cores 514-3 through 5 the *Saturnalis circularis* Zone, Cores 514-6 to 10 the *Eucrytidium calvertense* Zone and Cores 514-11 to 35 the *Helotholus vema* Zone (Table 4). Radiolarian zones and the range correlations of key species to the paleomagnetic time scale agree with the earlier data of Hays (1965) and Hays and Opdyke (1967).

**Polar Front Migration**

One of the primary objectives of Leg 71 was to collect a continuously cored late Cenozoic section near the modern position of the Antarctic Polar Front in order to document its evolution and migration through time.

Radiolarians from Hole 514 record eight separate northward shifts in the Polar Front over this site during the Pliocene and Quaternary. These shifts are:

1. 3.9-4.0 Ma, Gilbert
2. 3.1 Ma, Gauss
3. 2.6-2.7 Ma, Gauss
4. 2.5 Ma, Gauss
5. 1.9-2.4 Ma, Matuyama
6. 1.9-2.4 Ma, Matuyama
7. 1.6 Ma, Matuyama
8. 0.4-0.7 Ma, Brunhes

Details of Polar Front migrations observed from radiolarians in Hole 514 are provided in Ciesielski and Weaver (this volume). Because of the major faunal reorganization at approximately 2.5 Ma (Hays and Opdyke, 1967), Polar Front history must be examined over two intervals, post-Gauss and pre-Matuyama. Post-Gauss Polar Front movements are documented by comparing downhole variations in radiolarians to their modern spatial distributions relative to the Polar Front Zone.

Modern radiolarian biogeography is established using data from Hays (1965), Payne (1977), Nigrini (1967), Lozano and Hays (1976), Hays and Opdyke (1967), Petrushevskaya (1967), and Moore and Nigrini (1978). Latest Quaternary radiolarians indicative of waters north of the modern Polar Front include *Heliodiscus asteriscus*, *Pteroecorys zancleus*, *Eucrytidium acuminatum*, *Dictyocoryne profunda/truncatum* group, *Lamprocyclas marialis*, and *Pterocanium praetextum eucliptum*. The biofacies restricted to the area near and south of Polar Front waters includes *Antarctissa denticulata*, *A. strelkovi*, *Saccospyris antarctica*, *Lithelius nautioides*, *Triceraspis antarctica*, and *Actinomma antarcticum*. Samples with significant numbers of *A. antarcticum* are presumed to record a position at or very near the Polar Front.

Identifying Polar Front movements in pre-Matuyama sediments presents a more difficult problem because of the increase in radiolarian species that are now extinct and about the paleoecology of which we know very little. However, detailed analyses of Pliocene radiolarian biogeography have identified several species with a restricted regional distribution that is almost certainly controlled by the position of the Pliocene Polar Front Zone. Data from Chen (1975), Weaver (1976a), Keany (1979), Hays and Opdyke (1967), and Hays (1965) are used to select those species.

Pre-Matuyama Pliocene radiolarians used to discern waters north of the Polar Front include *Lamprocyclis heteroporos*, *Tholospyris* sp. A, *Lamprocyclas marialis*, *Dictyocoryne profunda/truncatum* group, and col-
lospherids (with very large pores). Species used to establish a position at or south of the Polar Front are Desmospyris spongiosa, Helotholus vema, Antarctissa den
ticulata, and A. strelkovi. The spatial distribution of these two radiolarian groups is similar to the two major radiolarian biofacies in modern antarctic and subantarctic waters.

LIST OF SPECIES

The following list provides a bibliography of references along with some observations of radiolarian taxa identified in Leg 71 sediments. In most cases the original author is cited along with an additional reference that contains information on the current concept of the species. Additionally, several new species are described and illustrated.

**Actinomma antarcticum** (Haeckel) Nigrini, 1967, p. 26, pl. 2, figs. 1a-d; Hays (1965), pp. 165-167, pl. 1, fig. 1.

**Actinomma tayacanich** Chen, 1975, pp. 450-452, pl. 11, figs. 5-6.

**Amphicapsidium prolixum** Sanfilippo and Riedel, 1973, p. 524, pl. 10, figs. 7-11.

**Amphirhopalum ypsilon** Haeckel, 1887, p. 522; Nigrini, 1967, p. 83, pl. 20, figs. 1-9. Plate 4, Figure 6.

**Amphyrhopalum pseudoinßatum** n. sp. (Plate 5, Figures 8-9).


**Amphyrhopalum tridactylus** Sanfilippo and Riedel, 1971, pi. 3D, figs. 10-11; Sanfilippo and Riedel, 1973, p. 530, pi. 7, fig. 6.

**Amphyrhopalum antepenultimus** (Ommatartus antepenultimus) (= Ommatartus antepenultimus) Riedel and Sanfilippo, 1978, p. 71, fig. 6. Plate 5, Figure 2.

**Amphyrhopalum didymus** Haeckel, 1884, p. 83, pi. 173-175, pl. 2, fig. 1; Weaver, 1976a, p. 579, pl. 7, fig. 4. Plate 5, Figure 4.

**Amphyrhopalum mongollicus** (Ehrenberg) Riedel and Sanfilippo, 1971, p. 742, pi. 5, figs. 10-11. Plate 5, Figure 3.

**Amphyrhopalum sp. aff. D. didymus** (Ehrenberg, 1844).

**Amphyrhopalum diartus** Haeckel, 1884, p. 83, pi. 173-175, pl. 2, fig. 1; Weaver, 1976a, p. 579, pl. 1, fig. 12; Chen, 1975, p. 456, pl. 15, figs. 1-2. Plate 2, Figures 6-8.

**Dictyopora profunda** (Haeckel) Riedel and Sanfilippo, 1978, p. 76, pi. 9, fig. 13.

**Dictyopora sp. A.** Similar to Ommatartus sp. A. Foreman, 1975, p. 618, pl. 8, figs. 20-23, but much more heavily silicified. Plate 6, Figure 5.

**Dictyopora antepenultimus** (= Ommatartus antepenultimus) Riedel and Sanfilippo, 1978, p. 71, pl. 6. Plate 5, Figure 2.

**Dictyopora didymus** Haeckel, 1884, p. 83; Riedel et al., 1974, p. 706, pl. 55, figs. 3-5; Zachariasse et al., 1978, p. 105, pl. 2, figs. 10-11. High-latitude forms of this Dictyopora species encountered in Hole 513A sediments are similar to those referred to as Ommatartus didymus by Riedel et al., 1974. These forms have large multiple polar caps. Sanfilippo et al., 1973, have suggested that D. didymus is a cold-water form of Diartus Hughes. If this is true, then Dictyopora didymus persisted at high latitudes for a considerable time after Diartus Hughes became extinct in low-latitude regions. Plate 6, Figures 7-8.

**Dictyopora sp. aff. D. didymus** (Ehrenberg, 1844).

**Diartus Hughes** (= Ommatartus Hughes) (Campbell and Clark) Riedel and Sanfilippo, 1978, p. 71, fig. 7. Plate 5, Figure 4.

**Diplocyclas sp.** A group Chen, 1975, p. 460, pl. 7, figs. 4-5. Eucyrtidium acuminatum Ehrenberg, 1844, p. 84; Nigrini, 1967, p. 81, pl. 8, figs. 3A, B.

**Eucyrtidium calvertense** (Ehrenberg, 1844). Sanfilippo and Riedel, 1973, p. 524, pl. 10, figs. 7-11.

**Eucyrtidium pseudoinßatum** (Ommatartus pseudoinßatum) Riedel et al., 1974. These forms have large multiple polar caps. Sanfilippo et al., 1973, have suggested that D. didymus is a cold-water form of Diartus Hughes. If this is true, then Dictyopora didymus persisted at high latitudes for a considerable time after Diartus Hughes became extinct in low-latitude regions. Plate 6, Figures 7-8.

**Eucyrtidium sp. aff. D. didymus** (Ehrenberg, 1844).

**Eucyrtidium acuminatum** Ehrenberg, 1844, p. 84; Nigrini, 1967, p. 81, pl. 8, figs. 3A, B.

**Eucyrtidium sp.** Chen, 1975, p. 459, pl. 3, figs. 3-5; Weaver, 1976a, p. 581, pl. 1, fig. 9. Plate 5, Figure 2.

**Eucyrtidium elongatum** group Haeckel, 1884, p. 1493, pl. 80, fig. 9; Weaver, 1976a, p. 581, pl. 4, figs. 3-5; Sanfilippo and Riedel, 1978, p. 79, figs. 7-9. Plate 5, Figure 6.

**Eucyrtidium pseudoinßatum** n. sp. (Plate 5, Figures 8-9).

**Eucyrtidium sp. aff. D. didymus** (Ehrenberg, 1844).

**Eucyrtidium elongatum** group Haeckel, 1884, p. 1493, pl. 80, fig. 9; Weaver, 1976a, p. 581, pl. 4, figs. 3-5; Weaver, 1976a, p. 581, pl. 1, fig. 9. Plate 5, Figure 6.

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**Eucyrtidium sp.** Chen, 1975, p. 459, pl. 3, figs. 3-5; Weaver, 1976a, p. 581, pl. 1, fig. 9. Plate 5, Figure 6.
Table 4. Radiolarians, Site 514.

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<th>Core/Section</th>
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<th>Preservation</th>
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<th>Clathrocyprioides cristatus</th>
<th>Collophora sp.</th>
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Note: For abundance, C = common, F = few, R = rare, t = trace (1-2 specimens/slide); for preservation, P = poor M = moderately well preserved, G = good.

from *E. inflatum* in having a greater number of longitudinal furrows, smaller pore diameter, and a maximum width which is attained in the mid to upper first abdominal segment. *E. inflatum* Kling attains a maximum width in the lowermost abdomen or at the division of the abdomen and fourth segment.

**Measurements.** Total length of shell, 145-175 µm; cephalis, 15-22 µm; thorax, 30-38 µm; abdomen, 50-75 µm; all postabdominal segments, 32-52 µm; maximum shell width, 90-110 µm; diameter of pores, 2-6 µm. Measurements based on 25 specimens from DSDP Samples 278-10-2, 43-45 cm, 278-10-3, 48-50 cm, and 278-10-4, 54-56 cm.

**Abundance.** rare to few.

**Occurrence.** late Miocene.

**Type locality.** DSDP Sample 278-10-3, 48-50 cm.

**Holotype.** Plate 5, Figures 8-9.

*Eusyeringium fistuligerum* (Ehrenberg) Riedel and Sanfilippo, 1978, p. 68, pl. 5, figs. 6-7.

*Eusyeringium lagena* (Ehrenberg) Riedel and Sanfilippo, 1978, p. 68, pl. 5, fig. 8.

*Eucyrtidium* sp. Chen, 1975, p. 461, pl. 7, figs. 6-8.


*Gondwanaria japonica* (Nakaseko) Petrushevskaya, 1975, p. 584, pl. 8, fig. 15; pl. 9, figs. 2-7; pl. 12, fig. 1.

*Gondwanaria* sp.
Table 4. (Continued).

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<tr>
<th>Radiolarian Zones</th>
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<tr>
<td><strong>Antarctissa denticulata</strong> Zone</td>
<td><strong>Styliatractus universus</strong> Zone</td>
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<tr>
<td><strong>Saturnalis circularis</strong> Zone</td>
<td><strong>Eucyridium calvertense</strong> Zone</td>
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<td><strong>Helotholus vema</strong> Zone</td>
<td><strong>Eucyridium calvertense</strong> Zone</td>
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**Helotholus praevema** n. sp. (Plate 3, Figs. 1–15).

**Description.** Shell consists of two segments. Cephalis spherical, with numerous circular to subcircular pores and 1 or 2 apical spines. Cephalis width, one-half to two-thirds thorax. Collar structure is distinct. Thorax variable, predominantly subcylindrical, sometimes cup-shaped, with numerous circular to elliptical pores. Commonly pores are irregularly spaced or exhibit crude longitudinal alignment. In well-preserved specimens, supplementary spines protrude from thoracic wall as apparent extensions of the internal structure. Internal structure consists of the elements A, D, V, L₁, and L₂ spines, all arising from a common point in plane of collar structure. An axial spine (Ax) projects downward into thoracic cavity from this point. No distinct median bar (Mb) observed; point of convergence of internal spines could be perceived as short Mb. Where primary interval spines are fused to thoracic wall, it is drawn into shell, forming grooves on surface.

**Discussion.** The internal structure of *Helotholus praevema* closely resembles that of *H. histricosa* Jorgensen. *H. praevema* might become confused with *Antarctissa strekovi*, but it differs from this species in having a distinct collar structure. The internal structure also differs from *A. strekovi* and *H. histricosa* sensu Riedel, 1958, in that these species have a distinct Mb (see fig. 51.6, Petrushhevskaya, 1967, p. 89, and Riedel, 1958, p. 235, figs. 6–7). *H. praevema* evolved to *H. vema* just prior to the Cochiti Subchron. This species transition during the early Pliocene involves (1) almost two fold increase in thoracic width, (2) a gradual invagination of the cephalis into the thorax (Kellogg, 1975), (3) the formation of up to 12 large subcircular to elliptical pores on the flat
Prunopyle hayesi
Chen, 1975, p. 454, pi. 9, figs. 3-5; Weaver, 1976a, p. 580, pl. 1, figs. 10-11. Plate 3, Figures 2-4.

Lamprocyclas aegles group (Ehrenberg) Petrushevskaya and Kozlova, 1972, p. 544, pl. 36, fig. 13. Plate 4, Figures 4-5.

Lamprocyclas maritalis Haeckel; Nigrini, 1976, p. 74, pl. 7, fig. 5. Plate 4, Figure 8.

Lamprocystis hannai (Campbell and Clark) K ling, 1973, p. 638, pl. 5, figs. 12-14; pl. 12, figs. 10-14.

Lamprocystis heteroporos (Hays) Kling, 1973, p. 639, pl. 5, figs. 19-21; pl. 15, fig. 6. Plate 4, Figure 1.

Lithapium mitra (Ehrenberg) Riedel and Sanfilippo, 1978, p. 69, pl. 6, figs. 1-2.

Lithelius nautiloides Popofsky; Chen, 1975, p. 455, pl. 24, fig. 7.

Lithocyclus crux Moore; Riedel and Sanfilippo, 1978, p. 70, pl. 6, fig. 7.

Lithomelissa challengerae F. M. Weaver 1976, p. 582, pl. 1, fig. 5. Plate 1, Figure 8.

Lithocyclia crux Moore; Riedel and Sanfilippo, 1978, p. 70, pi. 7, figs. 2-3.

Lithelius nautiloides Popofsky; Chen, 1975, p. 455, pi. 24, figs. 7-8.

Stichocorys delmontensis (Campbell and Clark) Kling, 1973, p. 638, pi. 17, fig. 6; Riedel, 1958, p. 451, pi. 1, fig. 9; Kling, 1973, p. 638, pi. 11, figs. 8-10.

Stichocorys peregrina (Riedel) Sanfilippo and Riedel, 1970, p. 451, pi. 1, fig. 9; Kling, 1973, p. 638, pi. 11, figs. 8-10.


Stichophila sp.

Styloclitica validispina Jorgensen; Petrushevskaya, 1968, p. 30, pl. 17, figs. 4-5. Plate 1, Figure 9.

Stylactatus neptunus Haeckel, 1887, p. 328, pl. 17, fig. 6; Riedel, 1958, p. 226, pl. 1, fig. 9.


Theocorys bicornis Popofsky; Chen, 1975, p. 462, pl. 13, figs. 1-2.

Theocorys bicornis spongotorax Chen, 1975, p. 462, pl. 12, figs. 1-3; Weaver, 1976a, p. 582, pl. 2, figs. 1-4; pl. 6, figs. 2-4. Plate 5, Figure 7.

Theocorys spongicus Kling, 1971, p. 1087, pl. 5, fig. 6; Riedel and Sanfilippo, 1978, p. 76, pl. 9, fig. 16.

Theocorys redondoensis (Campbell and Clark) Kling, 1973, p. 638, pl. 11, figs. 26-28; Weaver et al., 1981, p. 82, pl. 2, figs. 1-2. Plate 2, Figure 4.

Theocorys spongicus Kling, 1971, p. 1087, pl. 5, fig. 6; Riedel and Sanfilippo, 1978, p. 76, pl. 9, fig. 16.

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Thiocorys spongicus Kling, 1971, p. 1087, pl. 5, fig. 6; Riedel and Sanfilippo, 1978, p. 76, pl. 9, fig. 16.

Theocorys redondoensis (Campbell and Clark) Kling, 1973, p. 638, pl. 11, figs. 26-28; Weaver et al., 1981, p. 82, pl. 2, figs. 1-2. Plate 2, Figure 4.

Thiocorys sp. aff. T. fuscus (Ehrenberg, 1873).

Theocorys diabolaensis Clark and Campbell, 1942, p. 90, fig. 13; Chen, 1975, p. 459, pl. 5, figs. 4-7.

Theocorys tuberosa Riedel, 1959, p. 298, pl. 2, figs. 10-11; Riedel and Sanfilippo, 1978, p. 78, pl. 1, fig. 10. The specimens of T. tuberosa identified in Hole 511 are similar to the ancestral form of the species.

Tholosypsis sp. A. Lattice shell crown-shaped; sagittal stricture slight. Apical spine short, often broken. Sagittal ring appears to be D-shaped; joined to front, and back of the shell. Lattice shell smooth, constricted along sagittal ring; perforated by small circular to subcircular, closely spaced lattice pores. Three short bladed feet, broad and fenestrated proximally, tapering quickly.
distally. In some specimens, lattice shell extends below base and joins proximal ends of feet. Laticework between the feet contains numerous pores of irregular size and shape. Maximum width, 85-114 µm; maximum length, 70-96 µm; length of feet, 20-33 µm. Plate 4, Figures 2-3.

**References**


________, 1976b. Late Miocene and Pliocene radiolarian paleobiogeography and biostratigraphy of the Southern Ocean [Ph.D. dissert.]. Florida State University, Tallahassee.


Plate 3. Cenozoic radiolarians. 1. Helotholus praevema n. sp., × 180, Eltanin Core 50-28, 380 cm. 2-4. Helotholus vema, (2-3) Eltanin Core 50-28, 380 cm. (2, × 155, plan view; 3, × 120), (4) × 135, Eltanin Core 38-8, 400 cm. 5-15. Helotholus praevema, (5-7) Eltanin Core 50-28 (5, 411 cm, × 170; 6, 380 cm, × 180, transitional form; 7, 300 cm, × 170), (8-10) Eltanin Core 38-8 (8, 460 cm, × 160; 9, 420 cm, × 165, holotype; 10, 460 cm, × 170), (11) Eltanin Core 34-17, 580 cm, × 175, (12-14) Eltanin Core 38-8 (12, 500 cm, × 175; 13, 520 cm, × 175; 14, 540 cm, × 170), (15) Eltanin Core 34-17, 592 cm, × 160.
CENOZOIC RADIOLARIANS OF THE FALKLAND PLATEAU