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Upper Paleocene radiolarians from DSDP Sites 549 and 550, Goban Spur, NE Atlantic

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Abstract
Upper Paleocene-lower Eocene sequences of mainly pelagic sediments in DSDP Sites 549 and 550 of Goban Spur, NE Atlantic, representing time periods of 10 and 6 m.y. respectively, were examined to investigate the biotic response of radiolarians to the PETM. The preservation of radiolarians in the lower Eocene sequences for both sites is poor. Upper Paleocene radiolarian assemblages, representing a time interval of ~59-56 Ma at Site 549 and a much shorter period at Site 550, are generally moderately well-preserved. Fifty four species were identified. Four species occur significantly earlier in the middle high latitude NE Atlantic than in New Zealand, where the sudden appearance during the PETM has been taken as evidence of global pole-ward migration of warm-water radiolarians. Available model shows that the Goban Spur area should belong to the subpolar surface ocean gyre in the early Paleogene. Thus, our investigation questions the validity of the previously used index species of subtropical warm water masses. High-latitude offshore sections across the P/E boundary with well preserved radiolarians are needed to test the hypothesis of pole-ward migration of warm-water radiolarians during this geologically transient global warming period.

Keywords: Upper Paleocene; radiolarians; NE Atlantic; biotic response; PETM
1 Introduction

Biotic responses to the Paleocene – Eocene thermal maximum (PETM) have been extensively studied (e.g., Aubry et al., 1998; Wing et al., 2003) since the associated CIE (Carbon Isotope Excursion) and PETM were first identified in the southern ocean ODP Site 690 (Kennett and Stott, 1991). Radiolarians, the skeletons of which are composed of pure amorphous opaline silica, are extremely diverse and widely distributed marine plankton with a long geologic history (De Wever et al., 2001). Detailed studies of this group across the PETM provide a useful opportunity to investigate the response of siliceous fossils to this geologically transient global warming period, which will contribute to our more general understanding of the biosphere-geosphere interactions in this period.

To investigate the effect of the PETM on radiolarian fauna, the first study was conducted using DSDP/ODP samples by Sanfilippo and Nigrini (1998). They re-examined all of the then available deep-sea sections (DSDP/ODP Legs 1-135) and selected 12 DSDP and ODP sites between 40°N and 30°S containing upper Paleocene-lower Eocene radiolarians. However, no obvious changes in the radiolarian assemblages were reported in this study because there are no continuous sections across the PETM preserved at these sites (Sanfilippo and Nigrini, 1998). Subsequently, radiolarians were reported in upper Paleocene – lower Eocene sections from western Cuba (Sanfilippo and Hull, 1999), but other biostratigraphic evidence shows that the P/E boundary in this section lies within an unconformity. It had been hoped that ODP Leg 165 would provide a good place to examine the paleoenvironmental signals provided by radiolarians during the PETM, but generally very poor preservation of radiolarians made this impossible (Nigrini and Sanfilippo, 2000).

Subsequently, radiolarian assemblages in a well-constrained P/E boundary section from western North Atlantic ODP Hole 1051A were reported (Sanfilippo and Blome, 2001). This section contains the only known record of a well-preserved PETM radiolarian assemblage in the deep-sea. The results show that there is no obvious change in radiolarian composition (number of first and last occurrences of radiolarian taxa) across the PETM interval and only two first occurrences of radiolarian taxa (*Podocyrtis papalis* and *Phormocyrtis turgida*) were identified in the interval of the PETM (Sanfilippo and Blome, 2001).

A recent study provides the only quantitative investigation of radiolarians across the P/E boundary using samples from an onshore section in New Zealand (Hollis, 2006). This section is also the only one that shows a significant faunal change during the PETM with the first occurrences of 13 species in the PETM interval between 157 m and 160.9 m above the K/T boundary (Hollis, 2006; Hollis et al., 2005). The last occurrences of three species in this interval suggest that the faunal turnover is not an artifact of stratigraphic discontinuity (Hollis, 2006). Based on the abrupt appearance of five so-called typical low-latitude species, a pole-ward migration of warm-water radiolarians during the PETM was suggested (Hollis, 2006).

During Deep Sea Drilling Project (DSDP) Leg 80, four sites were drilled on the Goban Spur in the NE Atlantic (Fig. 1). The main objective of this leg was to investigate the development of
the continental margin of Western Europe (de Graciansky et al., 1985). Sites 549 and 550
drilled an expanded sequence within Chron C24r that contains part of the PETM interval and
records a number of events related to it. Hence, abundant research has been conducted
using materials from these sites (e.g., Ali and Hailwood, 1998; Kahn and Aubry, 2004; Knox et
al., 1996; Thomas and Bralower, 2005). However, early Paleogene radiolarians from these
sites have not been studied until now.

In order to investigate the biotic response of radiolarians to the PETM, we examined samples
across the P/E boundary from these two sites (~59-49 Ma for Site 549 and ~57-51 Ma for
Site 550). Unfortunately, the results are disappointing in that the preservation of radiolarians
is very variable. The radiolarian assemblages above and just below the PETM are so poor
that their identification is almost impossible. However, we have found that the upper
Paleocene radiolarians are generally well-preserved and several so-called warm-water
species used by Hollis (2006) to indicate a pole-ward migration of radiolarians during the
PETM occurred significantly earlier in the NE Atlantic than in New Zealand. Thus, the main
objectives of this study are to document late Paleocene radiolarian faunas and events from
Leg 80 and discuss the implications of the significantly earlier occurrence of these so-called
warm-water species in the NE Atlantic compared to New Zealand.

2 Materials and methods
2.1 Sample preparation
This study is based on the paleomagnetic samples used in the study by Ali and Hailwood
(1998). Sixty-four samples from DSDP Site 549 between 274.91 mbsf (meters below sea floor)
and 381.12 mbsf including the well-constrained P/E boundary and 17 samples from Site 550
between 328.38 mbsf and 424.98 mbsf were processed. For the extraction of radiolarians,
the techniques used differ slightly from the traditional method for soft marine sediments
introduced by Sanfilippo et al. (1985). Each sample was first put into a 400 cm³ beaker with
about 200 ml of a solution of 10% hydrogen peroxide and in which about 5g sodium
pyrophosphate had been dissolved to remove organic materials and disaggregate the
sediment. It was then sieved at 400 μm (if lumps remained, the above procedure was
repeated), 180 μm (if radiolarians were abundant) and 63 μm. Several drops of dilute
hydrochloric acid were then put into the residue to remove the calcareous component and it
was again sieved at 63 μm. Finally, the cleaned residue was placed in an oven to dry at about
50°C and then transferred into a plastic bottle for storage.

The cleaned residue was mounted using Norland Optical Adhesive and covered with a 22 ×
38 mm cover slip. All radiolarians were counted for samples for which only one slide can be
prepared. For richer samples, two slides were prepared and examined. To save time, the
following double count method was used. About one thousand specimens were first
counted. The remainder was then searched for rare species. Selected specimens were
mounted on SEM stubs using a thin brush under a binocular microscope, and then coated
with gold. Digital images were captured using a SEM.
The total abundance of radiolarians in each sample was roughly estimated based on the weight of siliceous residue: A (abundant, > 0.1 g), C (common, 0.01 – 0.1 g), F (few, < 0.01 g), B (barren). The following abbreviations are used for species abundance and preservation: A = abundant (> 50 individuals for each species), C = common (5 - 50) and F = few (< five); and W = good (minor dissolution), M = moderate (apparent dissolution with possible identification), P = poor (identification impossible), and S = silicified.

2.2 Age model

The age model for Sites 549 and 550 is based on published biostratigraphic and geomagnetic data (Table 1). Numerical ages assigned to these events were derived from GTS2004 (Gradstein et al., 2005). Linear sedimentation rates were assumed between datum ages.

3. Hiatuses, lithology, and siliceous fossil occurrences

3.1 Site 549

Two holes (549A and 549) were drilled at Site 549 with a water depth of about 2533 m. Lithology at this site has been divided into 11 units (de Graciansky et al., 1985). Our sampled cores belong to lithologic units 2 and 3 of Hole 549 (Table 2).

Samples 549-10-1-41 to -10-3-60 were collected from lithologic unit 2 that mainly consists of nannofossil chalks. Abundant poorly preserved siliceous fossils were extracted from these samples except for sample 549-10-1-41 that generated some moderately preserved radiolarians. Samples 549-10-4-30 to -14-6-86 belong to subunit 3a, which is composed of marly nannofossil chalks in which no siliceous fossils were previously reported (de Graciansky et al., 1985). Siliceous fossils were successfully extracted from samples 549-10-4-30 to -11-2-19 and from 549-13-2-71 to -13-6-107, but the very poor preservation of these samples makes identification impossible. Samples 549-15-1-119 to -16-3-11 belong to subunit 3b that consists of nannofossil chalks. No siliceous fossils were extracted from these samples.

A short hiatus between subunits 3b and 3c removed the topmost part of the CIE recovery (Thomas and Bralower, 2005) based on the orbitally-tuned age model for ODP Site 690 (Röhl et al., 2000). The top of the PETM at Site 549 is located between 335.16 mbsf and 335.55 mbsf corresponding to the lowest occurrence of nannofossil Tribrichiatius contortus (morphotype B) and the highest occurrence of Fasciculithus tympaniformis respectively (Aubry et al., 1996) if we follow the orbital age model. The base of the CIE that has been taken as the P/E boundary and assigned a numerical age of 55.8 Ma (Gradstein et al., 2005) is located at 339.68 mbsf at Site 549 (Thomas and Bralower, 2005). Thus our samples 549-16-4-36 and 549-16-5-35 are located between the onset of the CIE and top of the PETM and consequently, become the most important samples to examine if there are so-called excursion taxa or a sudden acme of a certain group such as those that have been reported in several other marine planktonic protozoans including siliceous diatoms (Sluijs et al., 2007).

Unfortunately, preservation of siliceous fossils in these two samples is very poor and identification of radiolarian taxa is thus impossible.
Samples 549-16-6-83 to -17-6-138 belong to subunit 3c that is composed of siliceous marly nannofossil chalks. Except for those silicified samples, radiolarians are generally well preserved and abundant in this subunit. Samples 549-17-7-7 to -21-2-62 belong to subunit 3d that is composed of siliceous nannofossil chalks. Radiolarian fossils are generally abundant and well preserved between samples -17-7-7 and -19-2-46 except for those samples that are silicified. However, the preservation deteriorates downhole.

The details of preservation and occurrence of radiolarians of Site 549 are listed in Table 2. The stratigraphic ranges of radiolarian species of this site are presented in Fig. 2.

3.2 Site 550

Two holes were drilled at Site 550, the deepest site of the Goban Spur transect with a water depth of 4432 m. Hole 550 contains a thick section of upper Paleocene-lower Eocene marly nannofossil chalk (lithological subunit 2a) and siliceous marly nannofossil chalk and mudstone (lithological subunit 2b). A short hiatus exists between subunits 2a and 2b. Siliceous fossils are generally sparse in the processed samples of Subunit 2a and no identifiable radiolarians are extracted from these samples. Four samples belong to the Subunit 2b were processed, of which three samples contain identifiable radiolarians. The details of preservation and occurrence of radiolarians of Site 550 are listed in Table 3.

4 Did a pole-ward migration of warm-water radiolarians occur during the PETM?

Based on the abrupt appearance of five species in a New Zealand section including *Amphicraspedum murrayanum*, *A. prolixum* s.s., *Bekoma bidartensis*, *Lychnocanium auxilla* (*Lychnocanoma auxilla* in our paper), and *Phormocyrtis cubensis* that were taken as subtropical index species with upper Paleocene FOs at low latitudes, Hollis (2006) concluded that global warming during the PETM promoted pole-ward migration of warm-water radiolarians. This opinion was also adopted by a comprehensive review paper on the PETM (Sluijs et al., 2007). Our investigation at the Goban Spur area, however, questions the validity of these species as index species of tropical-subtropical warm currents.

Except for *Phormocyrtis cubensis* that is not present in our samples, four of these five species taken as typical low-latitude warm water species (Hollis, 2006) show significantly earlier FOs in Site 549 compared with the New Zealand section (Fig. 2; Table 2). During the late Paleocene, Goban Spur was located at similar latitude to Mead Stream (Fig. 3). Modeled result (Huber et al., 2004) shows that both the Goban Spur and the Mead Stream should belong to the subpolar surface ocean gyres in the early Paleogene times. Although there is no direct proxy data of temperature from NE Atlantic and New Zealand in late Paleocene, available proxy data from Bighorn Basin (Paleolatitude ~45° N, Wing et al., 2000), Arctic regions (Sluijs et al., 2006; Tripati et al., 2001; Weijers et al., 2007), and SW Pacific (Bijl et al., 2009) suggest that NE Atlantic is probably not warmer than New Zealand during the late Paleocene. Thus, the occurrence of these four species at the Goban Spur during the late Paleocene indicates that they were probably more cosmopolitan rather than limited to the warm subtropical ocean gyres.
In addition, the PETM is a geologically transient period, which only lasted ~170,000 years (Röhl et al., 2007). If Hollis’s (2006) hypothesis that typical warm water radiolarians migrated into the New Zealand region with the expansion of the subtropical warm pool during the PETM is right, these species should disappear from Mead Stream after the PETM as is observed in dynocyst Apectodinium, a typical subtropical dinoflagellate whose occurrence in high latitudes is limited to the duration of the PETM (e.g., Sluijs et al., 2006). However, except for Amphicraspedum murrayanum which only existed during the PETM at Mead Stream, four of these five species extended above the PETM (Hollis, 2006).

On the other hand, we notice that radiolarians are more poorly preserved in the upper Paleocene at Mead Stream in New Zealand compared with those associated with Eocene strata (Hollis, 2006). Thus, an alternative explanation should be considered, i.e. that the abrupt appearance of these so-called warm-water species is an artifact of severe diagenesis and/or dissolution below the CIE base compared with the section above the CIE base.

Although we doubt the validity of Hollis’ subtropical index fossils, we are not saying that an expansion of subtropical warm pool and consequently, a pole-ward migration of warm water radiolarians is impossible during the PETM. To test this hypothesis, however, we need more knowledge about the biogeographic distribution of radiolarians around the P/E boundary, especially from high latitude sites with well preserved radiolarians.

5. Conclusion
Well preserved radiolarians were extracted from the upper Paleocene at DSDP Sites 549 and 550. They permit sufficient identification and provide important data, which will help fill an informational gap in the radiolarian distribution at middle high latitudes in the North Atlantic. Radiolarian preservation is discontinuous throughout the upper Paleocene-lower Eocene and preservation is generally poor in other sections. Four out of five species taken as typical warm water indicators by Hollis (2006) have significantly earlier FOs at Goban Spur compared with Mead Stream leading us to suggest that the abrupt appearances of these species at Mead Stream are likely an artifact caused by severe diagenesis and/or dissolution. The hypothesis of a pole-ward migration of warm water radiolarians during the PETM remains premature at present and needs to be tested by sampling of high latitude sites that across the PETM with well preserved radiolarians.

6. Species list
Reference to the author, the first definition, the first illustration, the currently adopted species concept and consulted illustration are given. Species listed here are in alphabetical order. All illustrated specimens are deposited at Department of Earth Sciences, The University of Hong Kong and can be located with SEM stub number, followed by specimen number on the stub.

*Amphicraspedum murrayanum* Haeckel
Plate 1, figures 3, 4
Amphicraspedum murrayanum Haeckel, 1887, p. 523, pl. 44, fig. 10; Sanfilippo and Riedel, 1973, p. 524, pl. 10, figs. 3-6; pl. 28, fig. 1; Nishimura, 1987, pl. 1, figs. 14, 18; Sanfilippo and Blome, 2001, p. 208, fig. 8a; Hollis, 2006, pl. 1, figs. 18, 19; Jackett et al., 2008, pl. 4, figs. 1, 2.

Amphicraspedum prolixum Sanfilippo and Riedel group
Plate 1, figures 32, 33
Amphicraspedum prolixum Sanfilippo and Riedel group, 1973, p. 524, pl. 10, figs. 7-11; pl. 28, figs. 3, 4; Hollis, 2006, pl. 1, figs. 14, 21, 21; Jackett et al., 2008, pl. 4, figs. 3-5.

Amphisphaera coronata (Ehrenberg)
Plate 1, figure 7
Stylosphaera coronata Ehrenberg, 1873, p. 258; 1875, pl. 25, fig. 4.
Stylosphaera coronata coronata Ehrenberg, Sanfilippo and Riedel, 1973, p. 520, pl. 1, figs. 13-17; pl. 25, fig. 4; Nishimura, 1992, pl. 1, fig. 11, fig. 9. Jackett et al., 2008, pl. 3, fig. 10.
Amphisphaera coronata (Ehrenberg), Hollis, 1997, p. 35, pl. 2, figs. 14-17.

Amphisphaera goruna (Sanfilippo and Riedel)
Plate 1, figure 9
Stylosphaera goruna Sanfilippo and Riedel, 1973, p. 521, pl. 1, figs. 20-22; pl. 25, figs. 9, 10; Nishimura, 1987, pl. 1, fig. 3.
Amphisphaera goruna (Sanfilippo and Riedel), Hollis, 1997, p. 34, pl. 2, figs. 10, 11.

Amphisphaera macrosphaera (Nishimura)
Plate 1, figure 8
Stylosphaera coronata macrosphaera Nishimura, 1992, p. 325, pl. 1, figs. 3, 4; pl. 11, fig. 1.
Amphisphaera macrosphaera (Nishimura), Hollis, 1997, p. 34, pl. 2, figs. 12, 13.

Axoprunum pierinae (Clark and Campbell)
Plate 1, figures 1, 2
Lithatractus pierinae Clark and Campbell, 1942, p. 34, pl. 5, fig. 25.
Axoprunum pierinae (Clark and Campbell) group, Sanfilippo and Riedel, 1973, p. 488, pl. 1, figs. 6-12; pl. 23, fig. 3; Nishimura, 1987, pl. 1, fig. 6.

Bathropyramis magnifica (Clark and Campbell)
Plate 2, figure 11
Sethopyramis magnifica Clark and Campbell, 1942, p. 72, pl. 8, figs. 1, 5, 9.
Bathropyramis magnifica (Clark and Campbell), Jackett et al., 2008, pl. 1, fig. 16.

Bekoma bidartensis Riedel and Sanfilippo
Plate 2, figure 32
Bekoma bidartensis Riedel and Sanfilippo, 1971, p. 1592, pl. 7, figs. 1, 2, 5, 7; Foreman, 1973, p. 432, pl. 3, figs. 20, 21; pl. 10, fig. 6; Nishimura, 1992, pl. 5, figs. 8, 9; Jackett et al., 2008, pl. 1, fig. 12.
**Buryella pentadica** Foreman

Plate 2, figure 12

*Buryella pentadica* Foreman, 1973, p. 433, pl. 8, fig. 8; pl. 9, figs. 15, 16; Nishimura, 1987, pl. 2, fig. 9.

**Buryella tetradica** *tetradica* Foreman

Plate 2, figure 13

*Buryella tetradica* Foreman, 1973, p. 433, pl. 8, figs. 4, 5; pl. 9, figs. 13, 14; Nishimura, 1987, pl. 2, fig. 8; Jackett et al., 2008, pl. 2, fig. 20.

*Buryella tetradica** *tetradica* Foreman, Hollis, 2002, p. 300, pl. 4, figs. 13, 14.

**Buryella tetradica** *tridica* O’Connor

*Buryella tridica* O’Connor, 2001, p. 11, pl. 2, figs. 9a-15; pl. 4, figs. 14-25.

*Buryella tridica* O’Connor, Hollis, 2002, p. 300, pl. 4, fig. 12.

Remarks: The discovery of this variant of *Buryella tetradica* in North Atlantic expands its geographical distribution which has previously been suggested as a possible geographically restricted morphotype in South Pacific by Hollis (2002).

**Carposphaera subbotinae** (Borisenko)

Plate 1, figure 22

*Carposphaera subbotinae* Borisenko, 1958, p. 85, pl. 5, figs. 5-7.

*Carposphaera subbotinae* (Borisenko), Sanfilippo and Riedel, 1973, p. 490, pl. 4, fig. 3; pl. 23, figs. 4, 5; Jackett et al., 2008, pl. 3, fig. 4.

**Cassideus mariae** Nishimura

Plate 1, figure 49; plate 2, figures 1-3

*Cassideus mariae* Nishimura, 1992, p. 333, pl. 4, figs. 1-3.

**Clathrocycloma? catherinea** Nishimura

*Clathrocycloma? catherinea* Nishimura, 1992, pl. 334, pl. 4, figs. 10, 11.

**Cornutella californica** Campbell and Clark

*Cornutella californica* Campbell and Clark, 1944, p. 22, pl. 7, figs. 33, 34, 42, 43; Hollis, 1997, p. 71, pl. 17, figs. 13-15; 2002, pl. 6, figs. 4, 5.

**Cromyomma riedeli** Nishimura

*Cromyomma riedeli* Nishimura, 1992, p. 322, pl. 1, figs. 6, 7; pl. 11, fig. 7

**Dendrospyris golli** Nishimura

Plate 2, figures 33, 34

*Dendrospyris golli* Nishimura, 1992, p. 330, pl. 3, figs. 1, 2; pl. 12, fig. 11.

**Dictyocephalus middouri** s.l. Nishimura
Plate 2, figures 18-20

Dictyocephalus middouri Nishimura, 1992, p. 336, pl. 9, figs. 10-12.

Remarks: specimens examined here include those with three-bladed apical horn.

Dictyophimus? sp. aff. Pterocodon campana Ehrenberg

Pterocodon campana Ehrenberg, 1873, p. 255; 1875, p. 82, pl. 19, fig. 1.

Dictyophimus? sp. aff. Pterocodon campana Ehrenberg, Nishimura, 1992, pl. 10, fig. 15.

Diplocyclas pseudobicorona pseudobicorona Nishimura

Plate 2, figures 6-10

Diplocyclas pseudobicorona pseudobicorona Nishimura, 1992, p. 340, pl. 4, figs. 4-6; pl. 13, fig. 14.

Diplocyclas pseudobicorona teres Nishimura

Plate 2, figures 4, 5

Diplocyclas pseudobicorona teres Nishimura, 1992, p. 340, pl. 4, figs. 8, 9; pl. 13, fig. 20.

Diploplegma? sp. aff. D. somphum Sanfilippo and Riedel

Diploplegma somphum Sanfilippo and Riedel, 1973, p. 491, pl. 4, fig. 5.

Diploplegma? sp. aff. D. somphum Sanfilippo and Riedel, Nishimura, 1992, p. 324, pl. 2, figs. 6, 10; pl. 11, fig. 10.

Dorcadospyris platyacantha (Ehrenberg) group

Plate 2, figures 35, 36

Peralospyris platyacantha Ehrenberg 1873, p. 247; 1875, pl.22, fig. 8.

Dorcadospyris platyacantha (Ehrenberg), Sanfilippo and Riedel, 1973, p. 528, pl. 17, figs. 11-15; pl. 33, fig. 2; Nishimura, 1992, pl. 3, figs. 3, 4; Jackett et al., 2008, pl. 4, fig. 17.

Hexacontium palaeocenicum Sanfilippo and Riedel

Plate 1, figures 15-18

Hexacontium palaeocenicum Sanfilippo and Riedel, 1973, p. 492, pl. 4, fig. 2; pl. 24, fig. 4;

Nishimura, 1987, pl. 1, figs. 8, 11; Jackett et al., 2008, pl. 3, fig. 5.

Hexacontium sp.

Plate 1, figures 19-21

Remarks: This form is different from Hexacontium palaeocenicum with seven external spines.

Lamptonium pennatum Foreman

Plate 2, figures 30, 31

Lamptonium pennatum Foreman, 1973, p. 436, pl. 6, figs. 3-5; pl. 11, fig. 13; Jackett et al., 2008, pl. 1, fig. 10.

Lithelius foremanae Sanfilippo and Riedel
Lithelius foremanae Sanfilippo and Riedel, 1973, p. 522, pl. 7, figs. 1-6; pl. 26, figs. 4, 5; Jackett et al., 2008, pl. 4, fig. 20.

Lithomespilus coronatus Squinabol
Plate 1, figures 10-14
Lithomespilus coronatus Squinabol, 1904, p. 198, pl. 4, fig. 7; Hollis, 1997, p. 37, pl. 4, figs. 1-3.

Lychnocanium carinatum Ehrenberg
Plate 2, figures 21-22
Lychnocanium carinatum Ehrenberg, 1875, p. 78, pl. 8, fig. 5; Nishimura, 1987, pl. 3, figs. 6, 11; Jackett et al., 2008, pl. 1, fig. 25.

Lychnocanoma anacolum Foreman
Lychnocanoma anacolum Foreman, 1973, p. 437, pl. 1, fig. 19; pl. 11, fig. 7; Jackett et al., 2008, pl. 1, fig. 24.

Lychnocanoma auxilla Foreman
Plate 2, figures 23-29
Lychnocanoma auxilla Foreman, 1973, p. 437, pl. 2, fig. 6; pl. 11, figs. 1, 2; Jackett et al., 2008, pl. 1, fig. 20.

Lychnocanoma babylonis (Clark and Campbell) group
Dictyophimus babylonis Clark and Campbell, 1942, p. 67, pl. 9, figs. 32, 36.
Sethochytris babylonis (Clark and Campbell) group, Riedel and Sanfilippo, 1970, p. 528, pl. 9, figs. 1-3.
Lychnocanoma babylonis (Clark and Campbell) group, Foreman, 1973, p. 437, pl. 2, fig. 1.
Lychnocanoma sp. aff. L. babylonis (Clark and Campbell), Nishimura, 1987, pl. 3, figs. 3-5.

Phormocyrtis striata exquisita (Kozlova)
Plate 2, figures 15-16
Phormocyrtis striata exquisita (Kozlova), Foreman, 1973, p. 438, pl. 7, figs. 1-4, 7, 8; pl. 12, fig. 5; Nishimura, 1987, pl. 2, fig. 13; 1992, pl. 9, figs. 4, 5; Jackett et al., 2008, pl. 1, fig. 18.

Podocyrtis sp. aff. P. papalis Ehrenberg
Plate 2, figure 14
Podocyrtis papalis Ehrenberg, 1847, p. 55, fig. 2.
Podocyrtis sp. aff. P. papalis Ehrenberg, Nishimura, 1992, pl. 10, figs. 1-3; pl. 13, fig. 18.

Prunopyle adelstoma Kozlova
Plate 1, figure 37
**Pseudostaurosphaera? sp. aff. P. perelegans** Krasheninnikov

*Pseudostaurosphaera perelegans* Krasheninnikov, 1960, p. 276, pl. 1, fig. 6.

*Pseudostaurosphaera? sp. aff. P. perelegans* Krasheninnikov, Nishimura, 1992, p. 324, pl. 1, fig. 5; pl. 11, fig. 4.

**Pterocodon? ampla** (Brandt)

*Theocyrtis ampla* Brandt, in Wetzel 1935, p. 56, pl. 9, figs. 13–15.

**Pterocodon? ampla** (Brandt), Foreman, 1973, p. 438, pl. 5, figs. 3-5; Jackett et al., 2008, pl. 2, fig. 14.

**Pterocodon poculum** Nishimura

Plate 2, figures 37-39

**Pterocodon poculum** Nishimura, 1992, p. 350, pl. 8, figs. 1-3; pl. 13, fig. 13; Jackett et al., 2008, pl. 1, fig. 13.

**Saturnalis kennetti** Dumitrica

Plate 1, figures 5, 6

**Saturnalis kennetti** Dumitrica, 1985, p. 189, pl. 2, figs. 1, 2; pl. 3, fig. 15; Hollis, 1997, p. 42, pl. 4, fig. 14; 2002, pl. 1, fig. 17.

**Spongodiscus americanus** Kozlova

Plate 1, figures 39-41

**Spongodiscus americanus** Kozlova, Kozlova and Gorbovetz, 1966, p. 88, pl. 14, figs. 1, 2; Sanfilippo and Riedel, 1973, p. 524, pl. 11, figs. 9-13; pl. 27, fig. 11; pl. 28, fig. 9; Jackett et al., 2008, pl. 4, fig. 9.

**Spongodiscus cruciferus** (Clark and Campbell)

Plate 2, figures 40-42

**Spongastericus cruciferus** Clark and Campbell, 1942, p. 50, pl. 1, figs. 1-6, 8, 10, 11, 16-18.

**Spongodiscus cruciferus** (Clark and Campbell), Sanfilippo and Riedel, 1973, p. 524, pl. 11, figs. 14-17; pl. 28, figs. 10, 11; Jackett et al., 2008, pl. 4, fig. 8.

**Spongodiscus quartus bosoculus** Sanfilippo and Riedel

Plate 1, figures 42, 43

**Spongodiscus quartus bosoculus** Sanfilippo and Riedel, 1973, p. 525, pl. 12, figs. 8-10; pl. 29, fig. 7; Nishimura, 1992, pl. 2, fig. 15.

**Spongurus bilobatus** Clark and Campbell group

Plate 1, figures 35-36

**Spongurus bilobatus** Clark and Campbell, 1942, p. 36, pl. 1, figs. 7-9.

**Spongurus cf. bilobatus** Clark and Campbell, Hollis, 1997, p. 47, pl. 7, figs. 15-18.

**Spongurus bilobatus** Clark and Campbell group, Hollis, 2002, p. 291, pl. 2, figs. 11-14.
Spongurus? irregularis Nishimura
Plate 1, figures 29-31

Spongurus? irregularis Nishimura, 1992, pl. 2, figs. 7-9; pl. 12, figs. 3, 7; Jackett et al., 2008, pl. 4, figs. 6, 7.

Spongurus? regularis (Borisenko) group
Plate 1, figures 25-28

Cromyodruppa regularia Borisenko, 1958, p. 88, pl. 5, figs. 13, 14.

Spongurus? regularis (Borisenko) group, Nishimura, 1992, p. 328, pl. 2, figs. 11, 12; pl. 12, figs. 4-6.

Stylosphaera minor Clark and Campbell
Plate 1, figures 3, 4

Stylosphaera minor Clark and Campbell, 1942, p. 27, pl. 5, figs. 1, 2, 12.

Amphisphaera minor (Clark and Campbell), Sanfilippo and Riedel, 1973, p. 486, pl. 1, figs. 1-5;
pl. 22, fig. 4; Nishimura, 1987, pl. 1, fig. 5.

Stylosphaera minor Clark and Campbell, Hollis, 1997, p. 40, pl. 1, figs. 17, 18.

Stylotrochus alveatus Sanfilippo and Riedel
Plate 1, figures 46, 47

Amphisphaera minor (Clark and Campbell), Sanfilippo and Riedel, 1973, p. 525, pl. 13, figs. 4, 5; pl. 30, figs. 3, 4.

Stylotrochus nitidus Sanfilippo and Riedel
Plate 1, figure 38

Stylotrochus nitidus Sanfilippo and Riedel, 1973, p. 525, pl. 13, figs. 9-14; pl. 30, figs. 7-10;
Nishimura, 1987, pl. 1, fig. 12; Nishimura, 1992, pl. 2, fig. 1; pl. 12, fig. 8; Jackett et al., 2008, pl. 4, fig. 13.

Thecosphaera larnacium Sanfilippo and Riedel
Plate 1, figure 24

Thecosphaera larnacium Sanfilippo and Riedel, 1973, p. 521, pl. 3, figs. 4-6; pl. 25, figs. 13, 14;
Jackett et al., 2008, pl. 3, figs 1, 2.

Thecosphaerella ptomatus Sanfilippo and Riedel
Plate 1, figure 23

Thecosphaerella ptomatus Sanfilippo and Riedel, 1973, p. 521, pl. 3, figs. 14-18; pl. 26, fig. 2;
Jackett et al., 2008, pl. 3, fig. 6.

Thecosphaerella rotunda (Borisenko)

Thecosphaera rotunda Borisenko, 1960, p. 222, pl. 1, fig. 3; pl. 3, figs. 2, 3.

Thecosphaerella rotunda (Borisenko), Sanfilippo and Riedel, 1973, pl. 3, figs. 7-11; pl. 26, fig. 3.

Theocorys acroria Foreman
Plate 2, figure 17

Theocorys acroria Foreman, 1973, p. 439, pl. 5, figs. 11–13; pl. 12, fig. 2; Jackett et al., 2008, pl. 2, fig. 24.

Velicucullus? palaeocenica Nishimura
Plate 1, figure 48

Xiphospira circularis (Clark and Campbell)
Plate 1, figures 44, 45
Porodiscus circularis Clark and Campbell, 1942, p. 42, pl. 2, figs. 2, 6, 10.
Xiphodictya amphixiphos (Clark and Campbell), 1942, p. 43, pl. 2, fig. 4.
Circodiscus circularis (Clark and Campbell), Jackett et al., 2008, pl. 4, figs. 10, 12.
Xiphospira circularis (Clark and Campbell), Sanfilippo and Riedel, 1973, p. 526, pl. 14, figs. 5-12: pl. 31, figs. 4-7; Nishimura, 1992, pl. 2, fig. 13; pl. 12, fig. 9.

Acknowledgement
Alan Baxter, Lily Chiu Mei Li, and Yuanyuan Sun (The University of Hong Kong) are thanked for their technical help. ODP East Coast Repository (Lamont Doherty Earth Observatory) staff Paula Weiss and Drew Patrick were very helpful during collection of the samples (in the summer of 1997). We are very grateful to Christopher J. Hollis and Annika Sanfilippo for their careful and constructive reviews.
References


Ehrenberg, C.G., 1873. Grossere Felsproben des Polycystinen-Mergels von Barbados mit
weiteren Erlauterungen. Königliche Preussische Akademie der Wissenschaften zu
Berlin, Monatsberichte, Jahre 1873: 213-263.

Ehrenberg, C.G., 1875. Fortsetzung der mikrogeologischen Studien als Gesammt-Uebersicht
der mikroskopischen Paläontologie gleichartig analysirter Gebirgsarten der Erde, mit
specieller Rücksicht auf den Polycystinen-Mergel von Barbados. Königliche

Foreman, H.P., 1973. Radiolari of Leg 10 with systematics and ranges for the families
Amphipyndacidae, Artostrobiidae, and Theoperidae. In: J.L. Worzel et al. (Editors),


Haeckel, E., 1887. Report on the Radiolaria collected by H.M.S. Challenger during the years
1873-1876. Report on the Scientific Results of the Voyage of the H.M.S. Challenger,
Zoology, 18: 1-1803.

Hollis, C., 2002. Biostratigraphy and paleoceanographic significance of Paleocene
radiolarians from offshore eastern New Zealand. Marine Micropaleontology, 46:
265-316.

Hollis, C., 2006. Radiolarian faunal turnover through the Paleocene-Eocene transition, Mead

Institute of Geological & Nuclear Sciences Monograph, 17: 1-152.

Hollis, C.J., Dickens, G.R., Field, B.D., Jones, C.M. and Strong, C.P., 2005. The
Paleocene-Eocene transition at Mead Stream, New Zealand: a southern Pacific
record of early Cenozoic global change. Palaeogeography Palaeoclimatology

Huber, M., Brinkhuis, H., Stickley, C.E., Doos, K., Sluijs, A., Warnaar, J., Schellenberg, S.A. and
warm by subtropical waters? Paleoceanography, 19: PA4026.

Paleocene-early Eocene radiolarian biozonation based on unitary associations:


of NW Europe: an indirect correlation by means of volcanic ash layers. Journal of the
Geological Society of London, 141: 993-999.

Paleogene in northwest Europe. Geological Society Special Publication, Volume 101,


Table Captions

1. Stratigraphic depth (mbsf) of the biostratigraphic, chemostratigraphic, and magnetostratigraphic tie-points used to construct the age model.

2. Abundance, preservation, and occurrence of radiolarians in the upper Paleocene-lower Eocene in DSDP Site 549.

3. Abundance, preservation, and occurrence of radiolarians in the upper Paleocene-lower Eocene in DSDP Site 550.
Figure Captions

1. Modern map showing the location of DSDP Sites 549 and 550, Goban Spur.
2. Stratigraphic ranges of radiolarian species in DSDP Site 549.
3. Paleogeographic reconstruction of the late Paleocene (~56 Ma) showing the location of DSDP Leg 80 and Mead Stream (generated from http://www.serg.unicam.it/Reconstructions.htm).
Plates

All illustrations are scanning electron micrographs of upper Paleocene radiolarians from DSDP Site 549. All illustrated specimens can be located with SEM stub number, followed by specimen number on the stub. All scale bars equal 100 μm.

1. Axoprunum pierinae (Clark and Campbell). 549-17-1-82-A, 3.
5. Saturnalis kennetti Dumitrica. 549-17-2-99, 55.
12. Lithomespilus coronatus Squinabol. 549-17-6-138, 12.
17. Hexacontium palaeocenicum Sanfilippo and Riedel. 549-17-3-79-A, 22.
19. Hexacontium sp.. 549-17-1-82-B, 2.
20. Hexacontium sp.. 549-17-2-99, 41.
21. Hexacontium sp.. 549-17-3-79-B, 1.
26. Spongurus? regularis (Borisenko) group. 549-17-6-138, 47.
27. Spongurus? regularis (Borisenko) group. 549-17-3-79-A, 28.
28. Spongurus? regularis (Borisenko) group. 549-17-3-79-A, 50.
30. Spongurus? irregularis Nishimura. 549-17-6-138, 42.
32. Amphicraspedum prolixum Sanfilippo and Riedel group. 549-17-6-138, 54.
34. Amphicraspedum murrayanum Haeckel. 549-17-3-79-A, 1.
36. Spongurus bilobatus Clark and Campbell. 549-17-6-138, 51.
37. Prunopyle adelstoma Kozlova and Gobovets. 549-17-2-99, 70.
38. Stylotrochus nitidus Sanfilippo and Riedel. 549-17-3-79-A, 7.
1. Spongodiscus americanus Kozlova. 549-17-3-79-B, 56.
4. Spongodiscus quartus bosoculus Sanfilippo and Riedel. 549-17-3-79-B, 22.
5. Xiphospira circularis (Clark and Campbell). 549-17-3-79-B, 28.
7. Stylo trochus alveatus Sanfilippo and Riedel. 549-17-2-99, 34.
8. Stylo trochus alveatus Sanfilippo and Riedel. 549-17-3-79-B, 19.

Plate 2

All illustrations are scanning electron micrographs of upper Paleocene radiolarians from DSDP Site 549. All illustrated specimens can be located with SEM stub number, followed by specimen number on the stub. All scale bars equal 100 μm.

1. Cassideus mariae Nishimura. 549-17-1-82-B, 18.
2. Cassideus mariae Nishimura. 549-17-2-99, 16.
5. Diplocyclas pseudobicorona teres Nishimura. 549-17-2-99, 73.
15. Phormocyrtis striata exquisita (Kozlova). 549-17-3-79-A, 47.
20. Dictyocephalus middouri s.l. Nishimura. 549-17-3-79-B, 32.
23. Lychnocanoma auxilla Foreman. 549-17-2-99, 8.
33. *Dendrospyris golli* Nishimura. 549-17-1-82-A, 11.
34. *Dendrospyris golli* Nishimura. 549-17-2-99, 106.
38. *Pterocodon poculum* Nishimura. 549-17-3-79-A, 58.
42. *Spongodiscus cruciferus* (Clark and Campbell). 549-17-3-79-B, 59.
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**Table 2**

**Sampled Site**

**Sample Date**

**Depth**

**Absolute Age**

**Lithologic Unit**

**Preservation**

**Radiolarian Abundance**

**Nannofossil Assemblage**

- *Unit 3*
  - Sub Unit 3a
    - Sub Unit 3b
  - Unit 2
  - Sub Unit 2a
  - Sub Unit 2b
  - Unit 1
  - Sub Unit 1a
  - Sub Unit 1b
  - Sub Unit 1c

**Notes:**

- *Sub unit 1c*
  - Sub unit 1d
  - Sub unit 1e

**Nannofossil Assemblage:**

- *Sub unit 2a*
  - Sub unit 2b
  - Sub unit 2c

**Nannofossil Assemblage:**

- *Sub unit 3a*
  - Sub unit 3b
  - Sub unit 3c

**Nannofossil Assemblage:**

- *Unit 2*
  - Sub Unit 2a
  - Sub Unit 2b
  - Unit 1
  - Sub Unit 1a
  - Sub Unit 1b
  - Sub Unit 1c

**Nannofossil Assemblage:**

- *Unit 1*
  - Sub Unit 1a
  - Sub Unit 1b
  - Sub Unit 1c

**Nannofossil Assemblage:**
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**Core no. Hole 249**

- Depth of cores: 274.5, 280.5, 300, 312.5, 322, 331.5, 341, 360.5, 360, 399.5, 399.5, 388.5, 388.5