

Pliocene–Pleistocene radiolarian and diatom biostratigraphy of ODP Hole 709C (equatorial Indian Ocean)

Simon K. Haslett¹, Kevin Kennington², Brian M. Funnell² & Claire L. Kersley³

¹ Faculty of Applied Sciences, Bath College of Higher Education, Newton Park, Newton St. Loe, Bath BA2 9BN, UK

² School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

³ Grafham Carbons, Grafham Water Works, Perry, Huntingdon PE18 0BW, UK

ABSTRACT - Ocean Drilling Program (ODP) Hole 709C was drilled on Madingley Rise in the equatorial Indian Ocean. Thirteen radiolarian and diatom events were identified in the Pliocene to Early Pleistocene section studied. Five radiolarian zones could be recognized: *Anthocyrtidium angulare*, *Pterocanium prismatium*, *Anthocyrtidium jenghisi*, *Stichocorys peregrina*, and *Phormostichoartus doliolum* zones. The LAD of *P. prismatium* was found to be an unreliable indicator of the base of the *A. angulare* zone in Hole 709C and in other upwelling areas. Accordingly, the base of the *A. angulare* zone is redefined here by the FAD of *A. angulare*. The *Phormostichoartus fistula* zone, which normally separates the *S. peregrina* and *P. doliolum* zones, could not be identified due to the scarcity of *P. fistula*. Standard tropical diatom Pliocene–Pleistocene zones and subzones were identified: *Nitzschia reinholdii*, *Rhizosolenia praebergonii*, and *Nitzschia jouseae* zones. The development of oxygen isotope calibrated dates enabled the dating of some radiolarian events: FAD *A. angulare* 1.65 Ma, LAD *Theocorythium vetulum* 2 Ma, LAD *A. jenghisi* 2.27 Ma, FAD *Theocalyptra davisiana* 2.33 Ma, FAD *Theocorythium trachelium* 2.33 Ma, and FAD *Lamprocyrtis neoheteroporos* 2.4 Ma. *J. Micropalaeontol.* 14(2): 135–143, October 1995.

INTRODUCTION

The primary objective behind the drilling of Site 709 in the equatorial Indian Ocean, was to retrieve a continuous Neogene sediment sequence from which carbonate preservation variability throughout time could be assessed. Hole 709C was one of three holes drilled at the Site, with 327.9 m of core recovered at a total recovery rate of 93%, spanning the Eocene through to Recent. The first 20 cores representing the topmost 189.1 m of sediment, achieved almost 100% core recovery (Shipboard Scientific Party, 1988).

Most shipboard and post-cruise micropalaeontological work was carried out on calcareous microfossils: calcareous nannofossils (Fornaciari *et al.*, 1990; Matsuoka & Okada, 1990; Okada, 1990; Rio *et al.*, 1990), and foraminifera (Boersma, 1990; Premoli-Silva & Spezzaferri, 1990; Haslett & Kersley, 1995). Siliceous microfossils were also investigated: radiolaria (Johnson, 1990; Haslett, 1992; Haslett *et al.*, 1994) and diatoms (Mikkelsen, 1990; Fenner & Mikkelsen, 1990; Kennington, 1992). From the three holes drilled at Site 709, Johnson (1990) concentrated on 709A to provide the Pliocene–Pleistocene radiolarian biostratigraphy, whilst using 709C to provide biostratigraphical data for Eocene–Oligocene sediments. Mikkelsen (1990) investigated the Pliocene–Pleistocene diatom biostratigraphy of 709C, but the resolution was low with some samples spaced more than 4 m apart. Fenner & Mikkelsen (1990) studied only Eocene–Oligocene diatoms.

The main purpose of the present study was to provide detailed biostratigraphical information, using radiolarian and diatom datum levels. The 709C radiolarian data are then compared with a recent palaeomagnetically constrained

radiolarian biostratigraphical scheme from the Indian Ocean (Johnson *et al.*, 1989).

At the present time the surface oceanography of the equatorial Indian Ocean is influenced by the seasonal variation of the monsoonal gyre. The seasonal changes involve the complete reversal of the prevailing wind field between the northeast and southwest monsoons. A distinct hydrochemical front, located approximately 10°S (Wyrski, 1973), separates upwelling waters of the reversing gyre to the north from surface waters of the subtropical gyre to the south. North of the hydrochemical front (Site 709 is situated near 4°S), the surface waters possess higher nutrient levels and support correspondingly higher productivity. In the subtropical gyre both nutrient levels and productivity are low. The higher concentration of biogenic opal present in sediment north of 10°S (Leinen *et al.*, 1986) is linked with the higher nutrient and productivity levels of the surface waters. This scenario is probably valid at least as far back as the middle Miocene (Johnson, 1990).

MATERIAL & METHODS

Hole 709C was drilled as part of Ocean Drilling Program (ODP) Leg 115, and is located in the equatorial Indian Ocean, in a small basin near the summit of Madingley Rise, a regional topographic high between the Carlsberg Ridge and the western Mascarene Plateau. Its position is Latitude 03°54.9'S, Longitude 60°33.1'E.

At Hole 709C the water depth is 3040.8 m with bottom felt (distance from rig floor to sea floor) at 3048.7 m. The total length of cored section was 353.7 m (to 3391.9 m) with 327.9 m of total core recovered. The samples used for Pliocene–Pleistocene radiolarian and diatom slide prepara-

tion range from 3/1/5–7 cm (hydraulic piston core/APC No. 3) to 6/2/5–7 cm (APC 6), spanning a depth in metres below sea-floor from 15.45 mbsf to 45.85 mbsf.

The basic lithology consisted of foraminifera-bearing nannofossil ooze, largely homogenous but with some bioturbation. The sediment varies in colour from very light grey, through light greenish grey to white with some pyrite-stained burrows in sections 1 and 3 of Core 3. Core 5 possesses 26 thin interbedded horizons of very light grey and light greenish grey foraminifera-bearing nannofossil ooze concentrated in sections 2 and 4. Core 6 possesses 35 thin interbedded horizons of very light grey, light grey and very light greenish grey foraminifera-bearing nannofossil ooze distributed throughout the core (Shipboard Scientific Party, 1988).

Samples were provided as <150 µm dried residues (Andrews *et al.*, 1990). Normally, 1 g of sediment was processed. Aliquots of the complete <150 µm fraction were used in the preparation of slides for diatom analysis, whilst a 63–150 µm fraction was used to concentrate radiolaria (Mullineaux & Westberg-Smith, 1986; Haslett & Robinson, 1991). 1 g of sediment from each sample was placed in 10 ml plastic test-tubes. Dilute hydrochloric acid (HCl) was added and agitated until all the carbonate had been dissolved. When the reaction was complete (no more effervescence) the samples were washed with distilled water to dilute and remove the HCl. The samples were then centrifuged and the supernatant decanted. This process was repeated before 10 ml of the deflocculent sodium hexametaphosphate (in solution) was added. The sample was again centrifuged and the supernatant decanted. Further rinsing, centrifuging and decanting was carried out until the sediment was seen to be 'clean'.

A small quantity of sample was withdrawn with one squeeze of a pipette and then released onto a glass coverslip. The coverslips were left to dry on an even surface (i.e. photographic paper, which does not warp when wet). When dry, a pea-sized blob of Naphrax (Northern Biological Supplies, Ipswich) was pipetted onto a labelled glass microscope slide. The slide was inverted and used to pick up the coverslip using the natural tackiness of the mountant. Slides were placed on a warm hotplate to enable the mounting medium to spread evenly and also to expel any air bubbles (without allowing the mountant to boil). When the mounting medium reached the edges of the coverslip, the slides were removed from the hotplate and left to set. Two or three slides were prepared for each sample in case of breakage. These slides were then used for diatom analysis.

To concentrate radiolaria the remaining sediment in the plastic test-tubes were thoroughly washed through a 63 µm sieve. After washing, distilled water was used to channel the remaining 63–150 µm fraction into labelled storage vials or beakers. Slides were prepared as above with the exception that Canada Balsam was used as the mounting agent. In the first instance, slides were examined at regularly spaced core intervals of no more than 2 m apart. Additional slides were then examined to identify radiolarian and diatom datum levels more accurately.

The sample processing method employed here reflects the

essentially non-quantitative approach taken in this particular biostratigraphical study and differs from processing techniques used for palaeoenvironmental analysis.

BIOSTRATIGRAPHY

Radiolaria

Radiolarian zonal schemes relating to the tropical Indian Ocean are few in comparison with those proposed for the tropical Pacific (Nigrini, 1971; Johnson & Knoll, 1975; Riedel & Sanfilippo, 1978; Theyer *et al.*, 1978; Goll, 1980; Nigrini, 1985). Johnson (1990) employed a standard low latitude Cenozoic radiolarian zonation (Sanfilippo *et al.*, 1985), although in many instances this proved unsatisfactory. Partly in response to problems recognized in applying the zonation of Sanfilippo *et al.* (1985) to equatorial Indian Ocean Pliocene–Pleistocene sediments, Johnson *et al.* (1989) proposed a new zonation calibrated by palaeomagnetic age data. The Quaternary part of the zonation is essentially similar to the standard zonation; however, the Late Pliocene has been divided into six zones, which are equivalent to only two zones of the standard zonation.

This biostratigraphical refinement has largely been made possible by taxonomic reviews of the radiolarian genera *Anthocyrtidium* (Nigrini & Caulet, 1988) and *Pterocorys* (Caulet & Nigrini, 1988). Unfortunately, due to the sporadic occurrence of a number of species belonging to these genera, some standard radiolarian events cannot be identified at Site 709 (Johnson, 1990). These events include the LAD (last appearance datum) of *Anthocyrtidium nosicae* Caulet, FAD (first appearance datum) of *A. euryclathrum* Nigrini & Caulet, FAD of *Pterocorys zancleus* (Mueller), LAD of *A. ehrenbergi* (Stohr), and the LAD of *A. prolatum* (Nigrini & Caulet). Johnson (1990) noted that *Theocorythium vetulum* Nigrini was also virtually absent and that members of the *Spongaster* lineage, *S. berminghami* (Campbell & Clark) to *S. pentas* Riedel & Sanfilippo to *S. tetras* Ehrenberg, were very rare or absent. *Pterocanium prismatium* Riedel was also found to be rare.

Diatoms

Schrader (1974) and Kazarina (1975) were the first workers to propose diatom zonal schemes for the tropical Indian Ocean. However, it is now possible to employ the cosmopolitan low-latitude zonation of Burckle (1972), which was originally proposed for the eastern equatorial Pacific. Barron (1985) updated Burckle's scheme, and this version is used here. A coarse diatom biostratigraphy of 709C was given by Mikkelsen (1990).

RESULTS

Ten radiolarian and three diatom datum levels were identified (Table 1). Range and abundance data for radiolaria are given in Table 2, and for diatoms in Table 3. Preservation of both radiolaria and diatoms is generally good, however certain poorly preserved horizons were encountered, e.g. 5/1/45–47 – 5/2/105–107 and 4/4/145 – 4/5/145–147, which cause difficulty in assigning some datum levels.

Species	Samples
LAD <i>Anthocyrtidium michelinae</i>	<3/1/5–7
LAD <i>Nitzschia reinholdii</i>	<3/1/5–7
LAD <i>Pterocanium prismatium</i>	<3/1/5–7
LAD <i>Rhizosolenia praebergonii</i>	<3/1/5–7
FAD <i>Anthocyrtidium angulare</i>	3/1/5–7 – 3/1/65–67
LAD <i>Theocorythium vetulum</i>	3/2/140–142 – 3/2/145–147
LAD <i>Anthocyrtidium jenghisi</i>	3/4/5–7 – 3/4/75–77
FAD <i>Theocalyptra davisiana</i>	3/4/145–147 – 3/5/75–77
FAD <i>Theocorythium trachelium</i>	3/4/145–147 – 3/5/75–77
FAD <i>Lamprocyrtis neoheteroporos</i>	3/5/75–77 – 3/5/145–147
LAD <i>Thalassiosira convexa</i>	4/1/10–12 – 4/1/50–52
LAD <i>Nitzschia jouseae</i>	4/1/100–102 – 4/1/120–122
LAD <i>Stichocorys peregrina</i>	4/1/105–107 – 4/1/145–147
FAD <i>Rhizosolenia praebergonii</i>	4/1/145–147 – 4/2/5–7
LAD <i>Lychnodictyum audax</i>	5/2/105–107 – 5/2/145–147
LAD <i>Phormostichoartus doliolum</i>	5/2/145–147 – 5/3/35–37
FAD <i>Amphirhopalum ypsilon</i>	5/6/5–7 – 5/CC/5–7
FAD <i>Spongaster tetras</i>	>6/2/5–7

<, above; >, below

Table 1. Position of radiolarian and diatom data in Hole 709C.

Early Pliocene

Spongaster tetras was present in all samples examined; its FAD occurs below the studied section. *Amphirhopalum ypsilon* Haeckel is first encountered in 5/6/5–7, and is present in all subsequent samples. *Phormostichoartus doliolum* (Riedel & Sanfilippo) is common in samples up to its last appearance at 5/3/35–37. *Lychnodictyum audax* Riedel was present in only two samples, 5/6/5–7 and 5/2/145–147.

Late Pliocene

Rhizosolenia praebergonii Mukhina is first encountered in 4/2/5–7. *Stichocorys peregrina* (Riedel) is very common in all samples up to 4/2/145–147, after which it becomes rare, and is last encountered in 4/1/145–147. *Nitzschia jouseae* Burkle and *Thalassiosira convexa* Mukhina, both of which occur consistently, are last encountered in 4/1/120–122 and 4/1/50–52 respectively. The evolutionary transition of *Lamprocyrtis neoheteroporos* Kling (2 segmented) from its ancestor *L. heteroporos* (Hays) (3 segmented) is often difficult to determine; however, undoubted specimens of *L. neoheteroporos* are present in 3/5/75–77, after which it is a common faunal component. *Theocorythium trachelium* (Ehrenberg) was first encountered in 3/4/75–77; however, it occurs rarely and sporadically thereafter, and is often poorly preserved. *Theocalyptra davisiana* (Ehrenberg) is also first encountered in 3/4/75–77, but does not become common until 3/3/65–67. *Anthocyrtidium jenghisi* Streeter is common up to 3/5/75–77, after which it becomes rare, and last appears in 3/4/75–77. *Theocorythium vetulum* is extremely rare throughout the section. Its last appearance occurs in 3/2/145–147.

Pleistocene

Anthocyrtidium angulare Nigrini is first encountered in the youngest sample examined, 3/1/5–7, although it is scarce in this sample (only two specimens seen). *Pterocanium prismatium* was only encountered in two samples, 3/3/65–67

and 3/2/140–142. The LAD of this species normally post-dates the FAD of *A. angulare* (therefore 3/2/140–142 is not taken to represent the LAD of *P. prismatium*). It is likely that the true LAD *P. prismatium* event occurs above 3/1/5–7.

The LADs of *Anthocyrtidium michelinae* Caulet, *Rhizosolenia praebergonii* and *Nitzschia reinholdii* Kanaya & Koizumi, which occur consistently throughout the section, also occur above 3/1/5–7.

DISCUSSION

The radiolarian events recognized here can generally be referred to the zonal scheme proposed by Johnson *et al.* (1989). There are two differences however, which lead to a redefined base for the *Anthocyrtidium angulare* zone and to the omission of the *Phormostichoartus fistula* zone. Also, the relative position of the FADs of *Theocorythium trachelium* and *Lamprocyrtis neoheteroporos* in 709A (Johnson, 1990) and 709C (this study) are reversed with respect to Johnson *et al.* (1989). Johnson *et al.* (1989) indicate that these data are diachronous, suggesting that *T. trachelium* migrates into equatorial waters from the south, and that *L. neoheteroporos* originates in equatorial waters subsequently migrating to the south.

Anthocyrtidium angulare Total Range Zone

(Nigrini, 1971; Caulet, 1979; Sanfilippo *et al.*, 1985; Johnson *et al.*, 1989; *emend.* here).

Definition. FAD to LAD of *Anthocyrtidium angulare*.

Remarks. This zone is usually considered an interval chronozone, the base of which is defined by the LAD of *Pterocanium prismatium*. However, in areas of equatorial upwelling *P. prismatium* has a sporadic occurrence and often has a last appearance which predates the FAD of *A. angulare*. This is seen at ODP Sites 677A (Alexandrovich, 1989), 709A (Johnson, 1990), 709C (this study), and 731 (Spaulding *et al.*, 1991). It is clear therefore, that the LAD of *P. prismatium* is an unreliable indicator of the base of the *A. angulare* zone in upwelling areas, and its definition is accordingly emended here.

Pterocanium prismatium Interval Chronozone

(Riedel & Sanfilippo, 1970; *emend.* Riedel & Sanfilippo, 1978; Caulet, 1979; *emend.* Sanfilippo *et al.*, 1985; *emend.* Johnson *et al.*, 1989; *emend.* here).

Definition. LAD of *Anthocyrtidium jenghisi* to FAD of *Anthocyrtidium angulare*.

709C events included in this zone: LAD of *Theocorythium vetulum*.

Remarks. The top of this zone is redefined here as the FAD of *A. angulare*, as the LAD of *P. prismatium* is an unreliable event in upwelling areas.

Anthocyrtidium jenghisi Interval Chronozone

(non NR7 of Caulet, 1979; Johnson *et al.*, 1989).

Definition. LAD of *Stichocorys peregrina* to LAD of *A. jenghisi*.

709C events included in this zone: FAD of *Theocalyptra*

SAMPLES	1	2	3	4	5	6	7	8	9	10	11	12	13	Z
3/1/5-7	C	C	+	C	C	C	-	C						I
3/1/65-67	-	C	-	C	C	C	-	C						II
3/1/120-122		C	+	C	C	C	+	C						
3/1/145-147		C	-	C	C	C	-	C						
3/2/135-137		C	+	C	C	C	-	C	-					
3/2/140-142		C	C	C	C	C	C	C	-					
3/2/145-147		C	C	C	C	C	-	C	C					
3/3/10-12		C	C	C	C	C	-	C	C					
3/3/65-67		C	C	C	C	C	C	C	-					
3/4/5-7		+	+	C	C	C	-	C	-	-				
3/4/75-77		+	+	C	C	C	-	C	-	+				III
3/4/145-147		+	+	C	C	C	-	C	-	+				
3/5/75-77		-	-	C	C	C	-	C	-	C				
3/5/145-147				-	C	C	-	C	-	C				
3/6/145-147					C	C	-	C	-	C				
3/7/50-52					C	C	-	C	-	C	-			
4/1/10-12					C	C	-	C	C	C	R			
4/1/65-67					C	C	-	C	-	C	-			
4/1/105-107					+	C	-	C	-	C	-			
4/1/145-147					C	+	-	C	-	+	+			IV
4/2/65-67					C	+	-	C	-	C	+			
4/2/145-147					C	C	-	C	-	C	C			
4/3/145-147					+	C	-	+	-	+	C			
4/4/145-147					C	C	-	+	-	+	C			
4/5/145-147					+	+	-	+	-	+	+			
4/6/145-147					C	C	-	C	C	C	C			
4/7/60-62					C	C	-	C	-	C	C			
4/CC/10-12					C	C	-	+	-	C	C			
5/1/5-7					+	C	-	+	-	+	C			
5/1/145-147					+	+	-	+	-	+	+			
5/2/65-67					+	+	-	C	-	+	+	-		
5/2/105-107					+	+	-	+	-	+	+	-	-	
5/2/145-147					C	C	-	C	-	C	C	C	-	
5/3/35-37					+	C	-	+	-	C	C	-	C	V
5/3/65-67					+	+	-	+	-	+	+	-	C	
5/3/145-147					C	+	-	+	-	+	C	-	C	
5/4/5-7					+	+	-	+	-	+	C	-	C	
5/5/110-112					C	+	-	+	C	+	C	-	C	
5/6/5-7					C	+	-	C	C	+	C	C	C	
5/CC/5-7					-	C	-	+	+	+	C	-	C	
6/1/10-12					-	C	-	+	-	+	C	-	C	
6/2/5-7						+	-	+	-	+	C	-	C	

C, common; +, present; -, searched for but not found; R, reworked occurrence. Species 1, *Anthocyrtidium angulare*; 2, *Theocalyptra davisiana*; 3, *Theocorythium trachelium*; 4, *Lamprocyrtis neoheteroporos*; 5, *Amphirhopalum ypsilon*; 6, *Spongaster tetras*; 7, *Pterocanium prismatium*; 8, *Anthocyrtidium michelinae*; 9, *Theocorythium vetulum*; 10, *Anthocyrtidium jenghisi*; 11, *Stichocorys peregrina*; 12, *Lychnodictyum audax*; 13, *Phormostichoartus doliolum*. Zone I, *A. angulare* zone; II, *P. prismatium* zone; III, *A. jenghisi* zone; IV, *S. peregrina* zone; V, *P. doliolum* zone.

Table 2. Radiolarian stratigraphy of Hole 709C.

Explanation of Plate 1

Fig. 1, 2. *Stichocorys peregrina* (Riedel), sample 5/3/65-67, mag. $\times 310$. **Fig. 3.** *Theocorythium vetulum* Nigrini, sample 3/3/5-7, mag. $\times 330$. **Fig. 4.** *Theocorythium trachelium* (Ehrenberg), sample 3/3/10-12, mag. $\times 330$. **Fig. 5.** *Anthocyrtidium jenghisi* Streeter, sample 4/CC/10-12, mag. $\times 315$. **Fig. 6.** *Anthocyrtidium michelinae* Caulet, sample 4/7/60-62, mag. $\times 250$. **Fig. 7.** *Phormostichoartus doliolum* (Riedel & Sanfilippo), sample 5/3/65-67, mag. $\times 230$. **Fig. 8.** *Amphirhopalum ypsilon* Haeckel, sample 5/3/65-67, mag. $\times 380$. **Fig. 9.** *Theocalyptra davisiana* (Ehrenberg), sample 3/1/5-7, mag. $\times 170$. **Fig. 10.** *Spongaster tetras* Ehrenberg, sample 5/2/145-147, mag. $\times 320$. **Fig. 11.** *Lamprocyrtis neoheteroporos* Kling, sample 3/3/5-7, mag. $\times 320$. **Fig. 12.** *Hemidiscus cuneiformis* Wallich, sample 3/2/140-142, mag. $\times 1000$. **Fig. 13.** *Diploneis* sp., sample 5/2/145-147, mag. $\times 1200$.

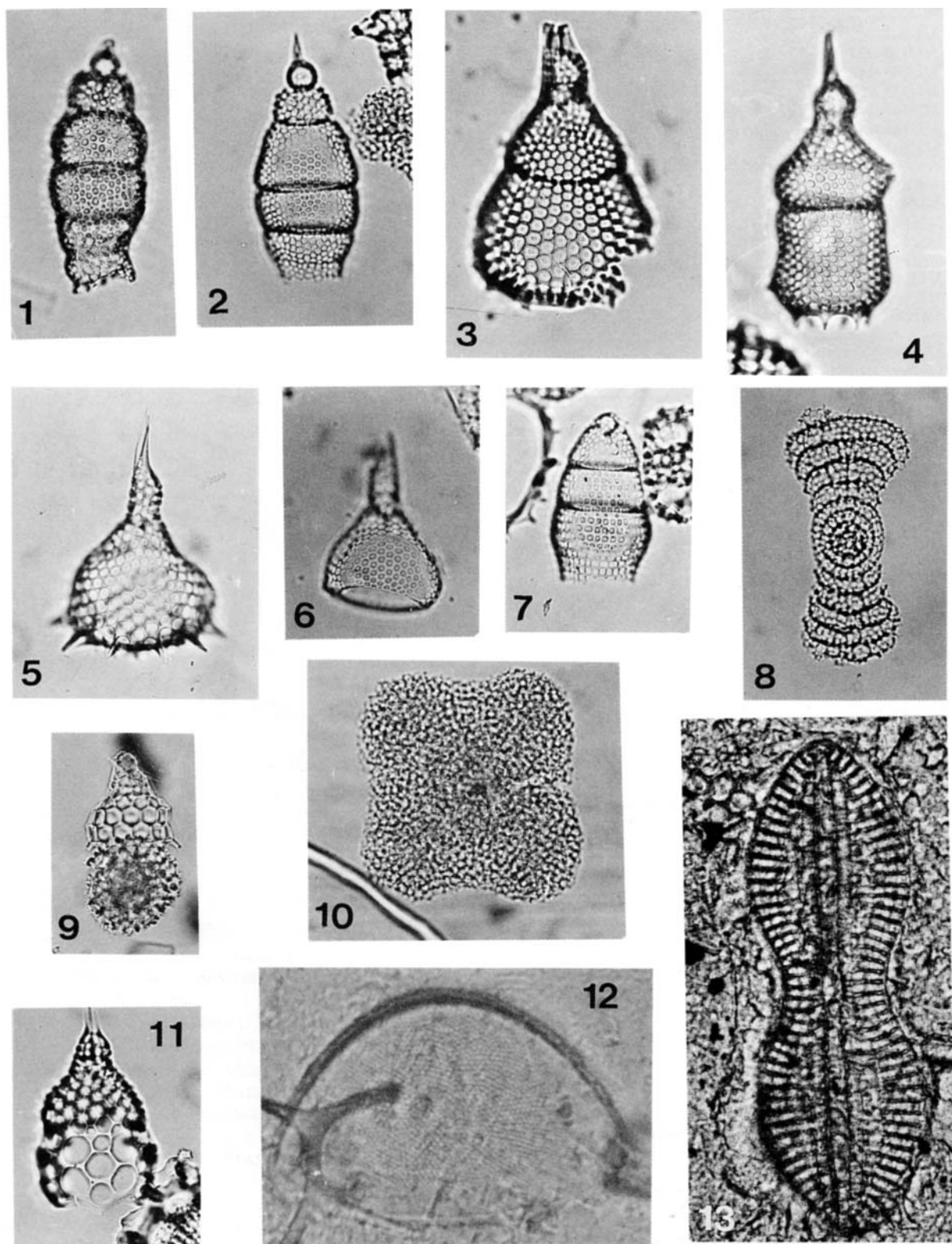


Plate 1

Samples	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Z
3/1/5-7	-	+	+	+	-	-	-	+	-	+	-	+	-			I
3/1/120-122	-	+	-	+	+	-	-	+	-	-	-	+	-			
3/1/145-147	-	+	-	+	+	-	-	+	+	-	-	-	-			
3/2/135-137	-	+	+	-	-	+	+	+	-	-	-	-	-			
3/2/140-142	-	+	+	+	-	+	-	+	-	-	+	-	-			
3/2/145-147	-	+	-	+	+	+	-	-	-	-	-	+	-			
3/3/5-7	-	+	+	+	+	+	-	+	-	-	-	+	-			
3/4/65-67	-	+	+	+	+	+	-	+	+	-	+	-	+			IIc
3/4/90-92		+	+	+	+	+	-	+	+	+	+	-	+			
3/4/145-147		-	+	+	+	+	+	+	-	-	+	+	-			
3/5/145-147		+	+	+	+	-	-	+	+	-	-	+	-			
3/6/145-147		+	-	-	+	-	-	+	+	-	-	-	-			
3/7/145-147		-	-	-	-	-	-	-	-	-	-	-	-			
3/7/50-52		+	-	+	+	-	-	+	+	-	-	-	-			
4/1/10-12		-	-	-	+	-	-	+	+	-	-	+	-	-		
4/1/50-52		-	+	+	-	+	+	+	+	-	-	-	-	+		IIb
4/1/100-102		+	-	+	-	+	-	+	+	-	+	+	-	+	-	
4/1/120-122		+	+	+	+	+	+	+	+	+	-	+	-	+	+	IIa
4/1/145-147		+	+	-	+	-	-	+	+	-	-	+	-	+	+	
4/2/5-7		-	+	+	+	+	+	+	-	-	-	+	-	+	+	
4/2/120-122		+	+	+	+	-	-	+	+	-	+	+	+	+	+	
4/2/145-147		-	+	+	+	-	-	+	+	-	-	+	-	+	-	III
4/3/145-147			-	-	-	-	-	-	+	-	-	-	-	-	-	
4/4/90-92			+	+	+	-	-	-	+	-	-	-	+	+	+	
4/4/120-122			-	+	+	-	-	-	+	-	-	-	-	+	+	
4/4/135-137			-	+	-	-	-	+	+	-	-	-	-	+	-	
4/4/145-147			+	-	-	-	-	-	-	-	-	-	-	+	-	
4/5/145-147			-	-	-	-	-	-	-	-	-	-	-	-	-	
4/6/145-147			+	+	-	-	-	+	+	-	-	+	-	+	+	
4/7/60-62			+	+	-	+	-	+	+	-	-	+	-	+	+	
4/CC/10-12			+	+	-	-	-	+	+	-	-	+	+	+	+	
5/1/5-7			-	+	-	-	-	+	+	+	-	+	-	+	+	
5/1/145-147			-	-	-	-	-	-	-	-	-	-	+	+	+	
5/2/145-147			+	-	-	-	-	+	+	+	-	+	+	+	+	
5/3/145-147			-	-	-	+	-	-	+	-	-	-	-	+	-	
5/CC/5-7			+	+	-	+	-	+	+	-	-	+	-	-	+	
6/1/10-12			+	+	-	+	-	+	+	-	-	+	-	+	+	

+ = present; - = searched for but not found. Species 1 = *Pseudoenotia doliolus*; 2 = *Rhizosolenia praebergonii*; 3 = *Nitzschia reinholdii*; 4 = *N. marina*; 5 = *N. fossilis*; 6 = *Hemidiscus cuneiformis*; 7 = *Diploneis* sp.; 8 = *Coscinodiscus nodulifer*; 9 = *C. kolbei*; 10 = *C. excentricus*; 11 = *Biddulphia alternans*; 12 = *Ethmodiscus* sp.; 13 = *Rhizosolenia* sp.; 14 = *Thalassiosira convexa*; 15 = *Nitzschia jouseae*. Zone I = *Nitzschia reinholdii* zone; II = *Rhizosolenia praebergonii* zone with subzones a, b, c; III = *Nitzschia jouseae* zone.

Table 3. Diatom stratigraphy of Hole 709C.

davisiana, FAD of *Theocorythium trachelium*, and FAD of *Lamprocyrtis neoheteroporus*.

Stichocorys peregrina Interval Chronozone

(non *S. peregrina* zone of Riedel & Sanfilippo, 1970; emend. Riedel & Sanfilippo, 1978; Johnson *et al.*, 1989; emend. here).

Definition. LAD of *Phormostichoartus doliolum* to LAD of *S. peregrina*.

709C events included in this zone: LAD of *Lychnodictyum audax*.

Remarks. Johnson *et al.* (1989) define the base of this zone with the LAD of *Phormostichoartus fistula* Nigrini. However, in this study only one undoubted specimen of *P. fistula* was encountered. Therefore, the *P. fistula* Interval Chronozone of Johnson *et al.* (1989) is omitted here and the base of the *S. peregrina* Interval Chronozone is redefined here as the LAD of *P. doliolum*.

Explanation of Plate 2

Fig. 1. *Rhizosolenia* sp., sample 4/5/145-147, mag. ×1200. **Figs 2, 3.** *Rhizosolenia praebergonii* Mukhina, sample 3/3/65-67, mag. ×1200. **Fig. 4.** *Coscinodiscus nodulifer* Schmidt, sample 3/1/120-122, mag. ×1300. **Fig. 5.** *Thalassiosira convexa* Mukhina, sample 4/CC/10-12, mag. ×1180. **Fig. 6.** *Nitzschia jouseae* Burkle, sample 4/2/145-147, mag. ×1300. **Fig. 7.** *Nitzschia fossilis* (Frenguelli), sample 3/1/145-147, mag. ×1100. **Fig. 8.** *Nitzschia reinholdii* Kanaya & Koizumi, sample 4/1/50-52, mag. ×1200. **Fig. 9.** *Nitzschia marina* Grunow, sample 3/1/5-7, mag. ×650.

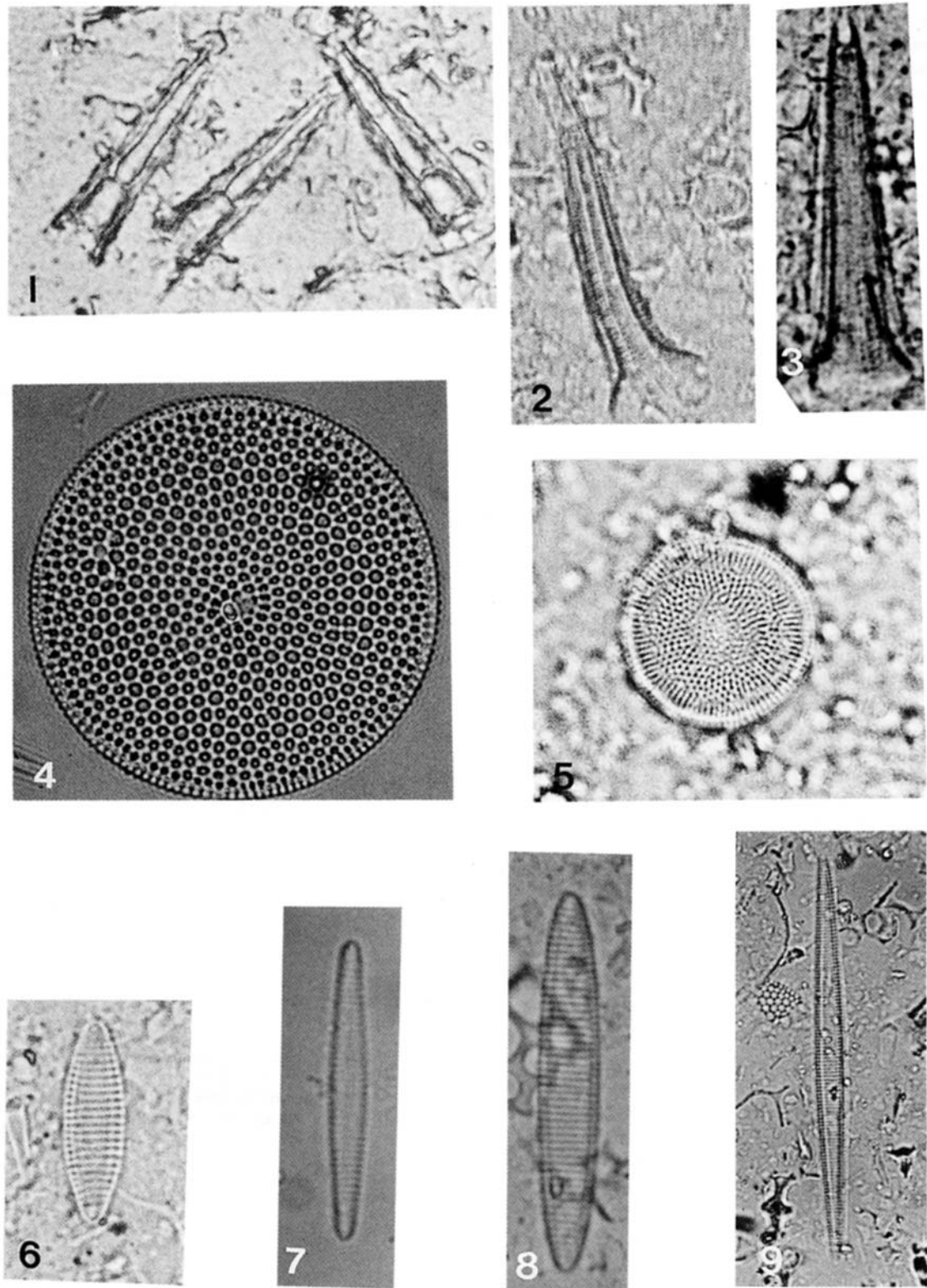


Plate 2

***Phormostichoartus doliolum* Interval Chronozone**(Johnson *et al.*, 1989).

Definition. LAD of *Anthocyrtidium prolatum* to LAD of *P. doliolum*.

709C events included in this zone: FAD of *Amphirhopalum ypsilon*.

The variations between the zonal scheme proposed by Johnson *et al.* (1989) and the scheme derived from the present study, can be attributed to oceanographical differences of the respective locations. Whereas Hole 709C is located 4°S in an area subject to equatorial upwelling, the three cores examined by Johnson *et al.* (1989) containing equivalent aged sediments, were all taken south of the hydrochemical front (Wyrski, 1973). As already mentioned, this front separates high and low productivity areas respectively to the north and south of 10°S.

The diatom results from the present study support and refine those found by Mikkelsen (1990) with only one exception. Mikkelsen's study of 709C located the FAD of *Pseudoeunotia doliolus* at 3/3/92–93 – 3/4/92–93. In the present study, however, this species was not encountered. The proximity of the FAD of *P. doliolus* in Mikkelsen's study to the top of the section under examination here is very close. Other species found at this point are poorly preserved and perhaps this accounts for the absence of *P. doliolus*. A further possible explanation may be attributable to the similarity of *P. doliolus* and *Nitzschia fossilis* (Frenguelli). With the poor preservational state and the similarity of these two species, it is plausible that an identification error may have been made.

In addition to biostratigraphically useful fossils, the presence of other diatom species were also noted. *Nitzschia marina* Grunow, *Hemidiscus cuneiformis* Wallich, *Coscinodiscus nodulifer* Schmidt, *C. kolbei* Jouse, *C. excentricus* Ehrenberg, *Ethmodiscus* sp., and *Rhizosolenia* sp. occurred throughout the studied section, but *Diploneis* sp. and *Biddulphia alternans* Van Heurck exhibit restricted ranges.

CONCLUSION

From Johnson (1990), Mikkelsen (1990) and the present study, it appears that Site 709 is unsuitable as a high resolution biostratigraphical reference section for siliceous microfossils. This is owing to a number of reasons. The poor preservation at certain horizons limits the precision with which biodatums can be identified. The scarcity and/or absence of some important stratigraphical marker species such as *Pterocanium prismatium*, *Pterocorys zancleus*, *Theocorythium vetulum*, *Anthocyrtidium ehrenbergi* (as noted by Johnson, 1990), *A. pliocenica* (Seguenza), *Phormostichoartus fistula* and *Pseudoeunotia doliolus* (present study), is limiting. (*Spongaster tetras* which was recorded as very rare or absent in 709A (Johnson, 1990), was found to be more abundant in 709C).

Nevertheless, Site 709 is still very useful in terms of calcareous biostratigraphy and palaeoceanographical studies of both calcareous and siliceous microfossils. This is particularly so as oxygen isotope calibrated dates are being

Species	Sample	Depth*	Age(Ma)
FAD <i>Anthocyrtidium angulare</i>	3/1/5–7	15.45	1.65
LAD <i>Theocorythium vetulum</i>	3/2/145–147	18.35	2.00
LAD <i>Anthocyrtidium jenghisi</i>	3/4/75–77	20.65	2.27
FAD <i>Theocalyptra davisiana</i>	3/4/145–147	21.35	2.33
FAD <i>Theocorythium trachelium</i>	3/4/145–147	21.35	2.33
FAD <i>Lamprocyrtis neoheteroporos</i>	3/5/75–77	22.15	2.40

*depth (mbsf) as recorded by the Shipboard Scientific Party (1988).

Table 4. Ages for some radiolarian datum levels identified in Hole 709C. Based on Shackleton & Hall (1990) oxygen isotope data.

developed for Hole 709C from data presented by Shackleton & Hall (1990). Dates derived from oxygen isotope and calcareous microfossil data, downhole to sample 3/7/10–12, are assigned in Table 4.

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