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22. RADIOLARIAN BIOSTRATIGRAPHY IN THE CENTRAL INDIAN OCEAN, LEG 115[1]

David A. Johnson[2]

ABSTRACT

Identifiable radiolarians of stratigraphic importance were recovered at eight of the sites drilled on Leg 115. The assemblages range in age from Holocene to middle Eocene (*Dictyoprora mongolfieri* Zone, about 48 Ma). Faunal preservation is particularly good in two stratigraphic intervals: the Holocene through upper Miocene (0–9 Ma), and the lowermost Oligocene to middle Eocene (35–48 Ma). Fluctuating rates of silica accumulation at these drill sites during the Cenozoic reflect changing tectonic and paleoceanographic conditions. In particular, the gradual closure of the Indonesian and Tethyan seaways and the northward migration of the Indian subcontinent severely restricted zonal circulation and silica accumulation in tropical latitudes during the late Oligocene through middle Miocene. By the late Miocene the Indian subcontinent had moved sufficiently north of the equator to allow trans-Indian zonal circulation patterns to become reestablished, and biosiliceous sedimentation resumed.

The composition of the radiolarian assemblages in the tropical Indian Ocean is closely comparable with that of the "stratotype" sequences in the equatorial Pacific. However, there are some notable exceptions in Indian Ocean assemblages: (1) the scarcity of the genera *Pterocanium* and *Spongaster* in the Neogene; (2) the absence of the stratigraphically important *Podocyrtis* lineage, *P. diamesa* → *P. phyxis* → *P. ampla*, in the middle Eocene; and (3) the scarcity of taxa of the genus *Dorcadospyris*, with the exception of *D. ateuchus*.

The succession of radiolarian events was tabulated for those stratigraphic intervals where the assemblages were well preserved. We identified 55 events in the middle Eocene to earliest Oligocene, and 31 events in the late Miocene to Holocene. The succession of events is closely comparable with that of the tropical Pacific. However, there are exceptions that appear to be real, rather than artifacts of sample preservation, mixing, and core disturbance.

INTRODUCTION AND METHODS

Radiolarians were recovered in eight of the sites occupied during Ocean Drilling Program (ODP) Leg 115 in the western Indian Ocean. The locations and water depths of these sites appear in Table 1.

The upper portions of several of these sites were double- or triple-cored with the advanced hydraulic piston corer (APC). For purposes of this report, radiolarian biostratigraphy is reported only for a composite stratigraphic section at each site. There was insufficient time available to analyze all cores obtained from the duplicate- or triplicate-cored intervals.

Within those stratigraphic intervals where radiolarian preservation was good, four samples per core were prepared and examined. Ordinarily, these samples were obtained from Sections 2, 4, 6, and the core catcher (CC). The sediment was prepared by means of standard techniques (Sanfilippo et al., 1985, p. 633) and was sieved at 63 μm; two strewn slides were prepared for each sample.

For each sample examined, qualitative estimates of radiolarian abundance (C = common; F = few; R = rare; + = very rare; − = absent) and preservation (G = good; M = moderate; P = poor) were made. Raw data tables are included in this report for those sites containing significant stratigraphic intervals with identifiable radiolarians. These tabulations include qualitative assessments of the relative abundance of each taxon in the two strewn slides examined for each sample. The criteria used are:

C = common (>5% of a given assemblage);
F = few (1%–5% of a given assemblage);
R = rare (0.1%–1% of a given assemblage);
+ = very rare (only one or two specimens found); and
− = absent.

Table 1. Location and water depths of sites drilled during Leg 115.

Site	Latitude	Longitude	Water depth (m)
707	07°32.7′S	59°01.0′E	1552
708	05°27.3′S	59°56.6′E	4109
709	03°54.9′S	60°33.1′E	3041
710	04°18.7′S	60°58.8′E	3824
711	02°44.6′S	61°09.8′E	4439
712	04°13.0′S	73°24.4′E	2904
713	04°11.6′S	73°23.7′E	2915
714	05°03.6′N	73°47.2′E	2038

Unlike some other Deep Sea Drilling Project (DSDP) reports (e.g., Westberg and Riedel, 1982), this chapter does not report quantitative abundances of taxa. Even though for some purposes the qualitative approach adopted here may be less than satisfactory, we think it is sufficient for the primary task of this report, namely, identifying significant radiolarian datum levels and their stratigraphic succession.

A complete listing of species names and taxonomic references for all species examined is presented in Appendix A at the end of this chapter. Abbreviated forms of the species names will be used in the text and in Appendixes B and C.

CENOZOIC RADIOLARIAN ZONATION

This report adopts the standard Cenozoic radiolarian zonation that has been developed for tropical latitudes (Sanfilippo et al., 1985, pp. 645–648; Nigrini, 1985). In addition, the recent work of Riedel and Sanfilippo is incorporated (see Saunders et al., 1985, pp. 409–413). They have replaced the late Eocene

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[2] Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, U.S.A.

Thyrsocyrtis bromia Zone with three zones: the *Cryptoprora ornata* Zone of Maurasse and Glass (1976), and two new zones, the *Calocyclas bandyca* Zone and the "*Carpocanistrum*" *azyx* Zone. This replacement allows for increased zonal resolution in the late Eocene, an interval in which many radiolarian extinctions and appearances occurred (Saunders et al., 1985; Sanfilippo et al., 1985).

We have chosen not to include in this report the proposed zonal subdivisions of the Pliocene, which have been suggested by Johnson et al. (1989). Even though a revision is clearly needed because of the scarcity of the *Spongaster* lineage in the Indian Ocean, we have retained here the more familiar zonal names (Sanfilippo et al., 1985) for purposes of designating stratigraphic intervals.

Because of the scarcity of the genus *Spongaster* in the early Pliocene, the base of the *S. pentas* Zone is approximated by the last occurrence (LO) of *Solenosphaera omnitubus*. And because of the absence of *Podocyrtis ampla* in the middle Eocene, the base of the *P. ampla* Zone is approximated by the LO of *Theocotyle conica*.

RADIOLARIANS AT EACH SITE

In this section, the radiolarian findings for each site are summarized. Raw data are presented in Tables 2–6 for those stratigraphic intervals that contain well-preserved assemblages. Using these data tables, listings of radiolarian "events" (first and last appearances) are presented for portions of the Neogene (Appendix B) and Paleogene (Appendix C).

Sites 705 and 706

Sites 705 and 706, located approximately 5 km apart, were drilled on the northeastern flank of the Nazareth Bank. All core-catcher samples were examined from these sites, and each sample proved to be barren of radiolarians.

Site 707

Three holes, all within 0.1 km of each other, were drilled at Site 707, located on the Mascarene Plateau, at the saddle between the Saya de Malha and Seychelles banks. Table 7 lists the intervals that were cored; all were cored with excellent to good core recovery. Radiolarians were examined only in Holes 707A and 707C because the sequences obtained in Hole 707B duplicate those in Hole 707A.

Hole 707A

Cores 115-707A-1H through -3H (0–25.8 mbsf) contain unidentifiable radiolarian fragments. Cores 115-707A-4H through -11H (25.8–102.8 mbsf) contain moderately to well-preserved assemblages of Pliocene and late Miocene age. The occurrences of taxa and zonal age assignments for this interval are presented in Table 2.

Cores 115-707A-12H through -19H (105.3–173.7 mbsf) are barren of identifiable radiolarians.

Samples 115-707A-20X-1, 101 cm, through 115-707A-23X-2, 101 cm (174.7–205.2 mbsf) contain moderately preserved radiolarians diagnostic of the *Theocyrtis tuberosa* Zone of early Oligocene age. Diagnostic taxa include *Lithocyclia angusta, Tristylospyris triceros, Theocyrtis tuberosa, Artophormis gracilis, Didymocyrtis prismatica, Dictyoprora pirum,* and *Cryptoprora ornata.*

Sample 115-707A-23X-4, 101 cm (208.2 mbsf), contains well-preserved radiolarians diagnostic of the *Cryptoprora ornata* Zone of late Eocene age. Key taxa include *Lithocyclia aristotelis, Dictyoprora mongolfieri, Cryptoprora ornata, Sethochytris babylo-*

Table 2. Radiolarians from Hole 707A.

Core, section, interval (cm)	Radiolarian zones	Abundance	Preservation	*Acrobotrys tritubus*	*Amphirhopalum ypsilon*	*Anthocyrtidium jenghisi*	*Anthocyrtidium michelinae*	*Anthocyrtidium prolatum*	*Dendrospyris bursa*	*Diartus hughesi*	*Didymocyrtis antepenultima*	*Didymocyrtis avita*	*Didymocyrtis penultima*	*Didymocyrtis prismatica*	*Didymocyrtis tetrathalamus*	*Lithopera bacca*	*Lychnodictyum audax*	*Phormostichoartus doliolum*	*Phormostichoartus fistula*	*Pterocanium prismatium*	*Siphostichartus corona*	*Solenosphaera omnitubus*	*Stichocorys delmontensis*	*Stichocorys peregrina*
115-707A-4H-2, 101–103	*Spongaster pentas*	R	P		—	R	R					—			F	R	R	—	+	R		—		R
115-707A-4H-4, 101–103		C	M		—	R	F	R				R			R	R	R	R	R	R		—		C
115-707A-4H-CC		F	M		—	R	F					R			F	R	R	F	R	R		—		F
115-707A-5H-2, 102–104		R	M		—	R	R	R				R			R	R	R	R	R	R		—		R
115-707A-5H-4, 101–103		F	M		—	F	R	R				R			—	F	F	F	R	R		—		C
115-707A-5H-5, 101–103		C	M		—	R						R	—		R	F	F	F	R	R		—		C
115-707A-5H-CC		F	M		—	R		R				F	—		R	R	F	F	R	R		—		F
115-707A-6H-2, 101–103		C	M		—							F	—		R	F	F	R	R	R		—		F
115-707A-6H-4, 101–103		C	G		—	R	F	R				R	—		—	R	C	C	R	R		—		C
115-707A-6H-6, 101–103		C	G			F	R	R	R			F	R		—	C	F	F	R	—		—		C
115-707A-6H-CC	*Stichocorys peregrina*	C	G				F					F	R		—	F	F	C	R	—		R	—	C
115-707A-7H-2, 101–103		F	M			R	R					F	R		—	R	F	F	R	—		R	—	F
115-707A-7H-4, 101–103		C	M			F	F					F	R			F	C	F		—		F	—	C
115-707A-7H-6, 101–103		C	G	R			R		R			F	R			C	C	F	R	+		F	—	C
115-707A-7H-CC		C	G				R		R				R			R	C	C		—		R	—	C
115-707A-8H-CC		F	M				F						R			R	F	F	R	—		R	R	C
115-707A-9H-2, 101–103		C	M				F					R	F			F	F	R	R	—	—	R	F	C
115-707A-9H-4, 101–103	*Didymocyrtis penultima*	F	M			R	R		R	—	—		R			F	F	F			—	R	C	F
115-707A-9H-6, 101–103		R	M							—	—		R				R		R			—	F	—
115-707A-9H-CC		C	M						F	—	—		R	R		R	F					—	F	+
115-707A-10H-2, 101–103	*Didymocyrtis antepenultima*	F	M							R	R		+				F		R			—	F	—
115-707A-10H-4, 101–103		R	M						R	R	R		+				R					—	R	—
115-707A-10H-6, 101–103		R	P							R	R		—				R					—	R	—
115-707A-10H-CC		R	P							R	R		—				R	R				—	R	—
115-707A-11H-1, 40–42		R	P							R	R		—				R					—		—
115-707A-11H-CC		R	P							R	R		—	R								—		—

Table 3. Radiolarians from Hole 709A.

Core, section, interval (cm)	Radiolarian zones	Abundance	Preservation	*Acrobotrys tritubus*	*Amphirhopalum ypsilon*	*Anthocyrtidium angulare*	*Anthocyrtidium euryclathrum*	*Anthocyrtidium jenghisi*	*Anthocyrtidium michelinae*	*Anthocyrtidium pliocenica*	*Buccinosphaera invaginata*	*Collosphaera tuberosa*	*Dendrospyris bursa*	*Diartus hughesi*	*Didymocyrtis antepenultima*	*Didymocyrtis avita*	*Didymocyrtis penultima*	*Didymocyrtis tetrathalamus*	*Lamprocyrtis neoheteroporos*	*Lamprocyrtis nigriniae*	*Lithopera bacca*	*Lychnodictyum audax*	*Phormostichoartus doliolum*	*Phormostichoartus fistula*	*Pterocanium prismatium*	*Pterocorys campanula*	*Pterocorys hertwigii*	*Siphostichartus corona*	*Solenosphaera omnitubus*	*Spongaster berminghami*	*Spongaster tetras*	*Stichocorys delmontensis*	*Stichocorys peregrina*	*Stylatractus universus*	*Theocorythium trachelium*
115-709A-1H-2, 75–77	*Buccinosphaera invaginata*	C	G		R	—					R	R						F	—	F					—		R				F			—	C
115-709A-1H-4, 75–77	*Amphirhopalum ypsilon*	C	G		F	—		—	—		—	—						C	—	R					—		R							F	C
115-709A-1H-CC		C	G		C	—	R	—	—									F	—	R					—	R	—				F			R	C
115-709A-2H-2, 75–77	*Anthocyrtidium angulare*	C	G		C	R	R	—	—									C	—	—	F				—	R	—							F	F
115-709A-2H-4, 75–77		C	G		F	R		—	—									C	R		R				—	R	—				F			R	F
115-709A-2H-CC		C	G		R	R		—	R									F	F						—						F			C	F
115-709A-3H-2, 65–70	*Pterocanium prismatium*	C	G		F	—		—	R									R	F		F				R						F		—	C	F
115-709A-3H-2, 65–70		C	G		C	—		R	R	—								C	R		F				R								—	F	—
115-709A-3H-6, 65–70		C	G		C	—		C	R	—								F				—	—	—	F								—		—
115-709A-3H-CC	*Spongaster pentas*	C	G		+			F	R	—								F				—	—	—	F								F	F	—
115-709A-4H-2, 65–70		F	P		R			R	R	+								R				—	—	—									F		—
115-709A-4H-CC		F	P		R			R	R	+											R	F	—	R					—				F	F	—
115-709A-6H-2, 65–70		F	M		—			R	R	R						R						R	F	R					—			—	F		
115-709A-6H-4, 65–70		F	M		—			R	R	R							—					R	F	R				—	—			—	F		
115-709A-6H-CC		C	G		—			R	F	R						F	—					F	C	F	R			—	—			—	C		
115-709A-7H-4, 65–70		C	G					F	F	R						F	+	F				R	C	R	R			—	—			+	C		
115-709A-7H-6, 65–70	*Stichocorys peregrina*	C	G	—				R		R						F	R				F	C	F	F				R	R	R		+	C		
115-709A-7H-CC		C	G	R				R		R							F				C	F	C	F				R	R			R	C	F	
115-709A-8H-4, 65–70		C	G	F				F		C											F	C	F	R				R	R			R	C		
115-709A-8H-CC		C	G	R						F							F				C	R	R	R				R	R			R	C		
115-709A-9H-4, 65–70		C	G	R						R			—			F	F				C	C	C	R				R	F	R		R	C		
115-709A-9H-CC		C	G	R									—				F					F	F	R				F				R	C		
115-709A-10H-2, 65–70		C	G	+						F			—				F				F	F	F					R	F			F	C		
115-709A-10H-4, 65–70	*Didymocyrtis penultima*	C	M	+									R	—			F				F	F	R	R					R			F	R		
115-709A-10H-CC		C	G	R									F	—			C											F	—			C	R		
115-709A-11H-4, 65–70		F	M	+									R	R	—		R					F		F					—			F	R		
115-709A-11H-CC		C	M	—									R	—	—		R				R	F										F	R		
115-709A-12H-2, 65–70		R	M	—									R	+	—		R				R	R										F	R		

Table 4. Radiolarians from Hole 709C.

Core, section, interval (cm)	Radiolarian zones	Abundance	Preservation	*Artophormis barbadensis*	*Artophormis gracilis*	*Calocyclas bandyca*	*Calocyclas hispida*	*Calocyclas turris*	*"Carpocanistrum" azyx*	*Cryptoprora ornata*	*Dictyoprora mongolfieri*	*Dictyoprora pirum*	*Eusyringium fistuligerum*	*Eusyringium lagena*	*Lithochytris vespertilio*	*Lithocyclia angusta*	*Lithocyclia aristotelis*	*Lithocyclia crux*	*Lithocyclia ocellus*	*Lophocyrtis biaurita*	*Lophocyrtis jacchia*	*Lychnocanoma bellum*	*Phormocyrtis striata striata*	*Podocyrtis chalara*	*Podocyrtis dorus*	*Podocyrtis fasciolata*	*Podocyrtis goetheana*	*Podocyrtis mitra*	*Podocyrtis sinuosa*	*Podocyrtis trachodes*	*Sethochytris babylonis*	*Sethochytris triconiscus*	*Theocorys spongoconus*	*Theocotyle conica*	*Theocotyle venezuelensis*	*Theocotylissa ficus*	*Theocyrtis tuberosa*	*Theocyrtis bromia*	*Thyrsocyrtis rhizodon*	*Thyrsocyrtis tetracantha*	*Thyrsocyrtis triacantha*	*Tristylospyris triceros*
115-709C-27X-CC		F	M	—	R							R				R	—																F				F	—				F
115-709C-28X-2, 70–75		F	M	—	R							R				F	—	R															F				F	—				F
115-709C-28X-CC	*Theocyrtis tuberosa*	C	G	—	R							R				F	—																F				C	—				F
115-709C-29X-2, 70–75		F	M	—	R							R				R	—																R				F	—				F
115-709C-29X-4, 70–75		R	M	—	R					—	—	R				R	—				—	—									—		—				F	—				R
115-709C-29X-6, 70–75		F	M	—	F					—	—	R				R	—	R			—	—									—		—				F	—	—			F
115-709C-29X-CC		F	P	—	F					—	—	R				R	—	R			—	—									—		—				F	—	—			F
115-709C-30X-2, 70–75		F	M	R	—	—		—	—	R	C	R				+	R	F			R	R									C						R	—	—	—		F
115-709C-30X-CC		C	G	R	—	—	—	—	—	R	C	R	—			R	C				R	F									C						F	—	—	—		F
115-709C-31X-2, 70–75	C	C	M	R	—	R	—	+	—	F	C	R	—			—	C				F	F									C						—	—	—	—		C
115-709C-31X-4, 70–75		C	M	R	—	R	—	R	—	F	C	R	—			—	F	F			R	F									F						—	—	R	—	—	C
115-709C-31X-CC	*Thyrsocyrtis bromia*	C	M	R	—	F	—	C	R	R	C	R	—			—	R	R			R	F									F						—	F	C	F	—	F
115-709C-32X-2, 70–75		C	M		—	F	—	C	F	R	F	R	—			—	R	F			R	R									F							F	C	C	—	F
115-709C-32X-4, 70–75		C	M		—	F	R	F	R	R	F	R	F			—	R	R			R	F	—	—							R							F	C	C	—	R
115-709C-32X-6, 70–75	B	C	G			—	F	—	R	F	C	R	C				R		R		R	F	+	—							R	—				—		F	C	F	R	F
115-709C-32X-CC		C	M			C	R	C	F	R	F	F	F		—		R		—		R	R	—	—			—	—			F	—				—		C	C	C	+	R
115-709C-32X-2, 70–75		C	G			C	R	C	F	R	C	R	R		—		F	F	—		F	R	—	—			—	—			R	—				—		F	C	C	R	R
115-709C-33X-4, 70–75	*Podocyrtis goetheana*	C	G			—	C	—	—	—	C	+	C		—		F	—	+	—	—	R	R	R			F	—		—	F	—				R		—	R	—	F	R
115-709C-33X-CC	*Podocyrtis chalara*	C	M			—	C	—	—	—	C	—	C		R		—	—	F	—	—	R	R	F			—	—		—	F	F				R		—	C	—	F	—
115-709C-34X-2, 70–75		C	G			—	C	—	—	—	C	—	C		R		—	—	R	—	—	F	R	C			—	R		—	R	F				R		—	C	—	F	—
115-709C-34X-4, 70–75	*Podocyrtis mitra*	F	M			—	C	—	—	—	F	—	F		C		—	—	R	—	—	R	R	R		—	—	F		R	F	F				R		—	C	—	F	—
115-709C-34X-6, 70–75		C	M				F				C		F		F				R	—		R	R	R		—		C		C	C	R				F		—	C	—	F	
115-709C-34X-CC		C	M				C				C		F	—	F				R	—		R	R	—		—		C		C	F	F				F		—	C	—	F	
115-709C-35X-2, 70–75		C	G				C				F		C	—	R				R	—		R	R	—		—		R		F	F	F				R			C		C	
115-709C-35X-4, 70–75		C	G				F				C		C	—	R				R	R		R	R	—		C		F	—	F	F	R				F			C		F	
115-709C-35X-6, 70–75		C	G				C				C		C	—	R				R	R		R	R	—		C		F	—	C	F	R				F			C		F	
115-709C-35X-CC		C	G				C				C		C	R	F				F	R		F	R			R		F	—	F	C	R				R			F		C	
115-709C-36X-2, 70–75	*Podocyrtis ampla*	C	G				F				C		C	R	F				R	R		R	R			C		F	C	F	F	—				R			C		F	
115-709C-36X-CC		C	M				F				C		C	R	F				F	F		R	R		—	C		—	C	—	F	—				R			F		F	
115-709C-37X-2, 70–75		C	G				R				C		R	F	R				R	F		R	R		—	—		—	C	—	R	—				R			C		F	
115-709C-37X-4, 70–75		C	G				C				C		R	F	F				R	F		R	R		—	—			C	—	F	—			—	C			C		F	
115-709C-37X-6, 70–75		C	G				F				C		—	F	C				R	R			R		F				C	—	F	—		—	—	F			C		C	
115-709C-37X-CC	*Thyrsocyrtis triacantha*	C	M				F				F		—	F	C				R	R			R		F				C	—		—		R	R	F			C		C	

Table 5. Radiolarians from Hole 710A.

Core, section, interval (cm)	Radiolarian zones	Abundance	Preservation	*Acrobotrys tritubus*	*Amphirhopalum ypsilon*	*Anthocyrtidium angulare*	*Anthocyrtidium euryclathrum*	*Anthocyrtidium jenghisi*	*Anthocyrtidium michelinae*	*Anthocyrtidium pliocenica*	*Buccinosphaera invaginata*	*Calocycletta caepa*	*Collosphaera orthoconus*	*Collosphaera tuberosa*	*Dendrospyris bursa*	*Diartus hughesi*	*Diartus petterssoni*	*Didymocyrtis antepenultima*	*Didymocyrtis avita*	*Didymocyrtis laticonus*	*Didymocyrtis penultima*	*Didymocyrtis tetrathalamus*	*Lamprocyrtis neoheteroporos*	*Lamprocyrtis nigriniae*	*Lithopera bacca*	*Lychnodictyum audax*	*Phormostichoartus doliolum*	*Phormostichoartus fistula*	*Pterocanium prismatium*	*Pterocorys campanula*	*Pterocorys hertwigii*	*Siphostichartus corona*	*Solenosphaera omnitubus*	*Spongaster berminghami*	*Spongaster tetras*	*Stichocorys delmontensis*	*Stichocorys johnsoni*	*Stichocorys peregrina*	*Stylatractus universus*	*Theocorythium trachelium*
115-710A-1H-2, 70–75	*Collosphaera tuberosa*	C	G		F	—	F	—	—		—		R	R								F	—	R	R				—	F	F				F				—	F
115-710A-1H-4, 70–75	*Amphirhopalum* ypsilon	C	G		C	—	R	—	—		—		—	—								C	—	R	R				—	F	C				R				R	C
115-710A-1H-CC		C	M		F	—	R	—	—		—		—	—								F	—	F	R				—	F	—				R				R	R
115-710A-2H-2, 70–75	*Anthocyrtidium angulare*	C	G		C	R	—	—	—				—	—								C	F	—					—	F	—								F	C
115-710A-2H-4, 70–75		C	G		F	R	—	—	R													C	F	—					—	F	—								R	R
115-710A-2H-6, 70–75	*Pterocanium prismatium*	F	M		F	—	—	—	R													C	F	—					F	F								—	R	R
115-710A-2H-CC		C	G		F	—		—	F													R	F	—		—	—	—	R	F					R			—	R	F
115-710A-3H-2, 70–75		F	G		F	—		F	R	—									—			R	R		F	—	—	—	R	R								—		
115-710A-3H-3, 95–97	*Spongaster pentas*	F	G		F			F	F	—									—			F	R			—	—	—	F	R					F	—		F		
115-710A-3H-CC		C	G		R			F	F	R									R			F				—	—	+	F	F					F	—		C		
115-710A-4H-2, 70–75		C	G		+			F	C	R									R			F				R	F	R	C			—	—			—		C		
115-710A-4H-4, 70–75		C	G	—	—			R	C	F									F			R			C	R	F	R	R			—	—	—		—	—	C		
115-710A-4H-6, 70–75		C	G	—	—			F	F	R									F		—	R				F	C	R	F			—	—	—		—	—	C		
115-710A-4H-CC	*Stichocorys peregrina*	C	G	—	—			R	F	R									F		—				C	R	C	F	+			—	R	R		+	—	C		
115-710A-6H-2, 75–80		C	G	R	—				F	F									C		—					F	C	R	—			F	R			+	R	C		
115-710A-6H-4, 40–50		C	G	R						R									F		R					R	C	R	—			R	F	R		+	R	C		
115-710A-6H-6, 75–80		C	G	R					R	F					—			—	C		F					F	C	R	—			R	R	R		F	F	C		
115-710A-6H-CC		F	M	R						F					—	—		—	F		F					F	R	R	—			R	R			C	R	C		
115-710A-7H-2, 70–75		C	G	R											R	—		—	R		R					F	C	R				R	R	R		F	R	C		
115-710A-7H-4, 70–75	*Didymocyrtis penultina*	C	G	R					R			+			R	—		R	+		F				F		C	R				F	—			C	R	F		
115-710A-7H-6, 70–75		C	M	R						R					R	R		+			C					F	C	R				R	—			C	R	F		
115-710A-7H-CC		F	M	—						R						+		R			F				R	R	F	R				F				F		R		
115-710A-8H-2, 70–75	*Didymocyrtis antepenultima*	C	M	—											F	C	—	C			R					R	R	R								R		—		
115-710A-8H-4, 70–75		F	M									—				R	—	R		R	+				R	F										R		—		
115-710A-8H-6, 70–75		F	P									—				R	—	R		+	—				R	F										R		—		
115-710A-8H-CC		C	G							R		—			R	F	—	C		+	—					F	F	R								F		—		
115-710A-9H-2, 70–75	*Diartus petterssoni*	F	M									—				+	F	—		R	—					F	R	R				R				F		—		
115-710A-9H-4, 70–75		F	P									—				—	R	—		R						F		R								F		—		
115-710A-9H-6, 70–75		F	P									R				—	R	—		R																F		—		

Table 6. Radiolarians from Hole 711A.

Core, section, interval (cm)	Radiolarian zones		Abundance	Preservation	*Artophormis barbadensis*	*Artophormis gracilis*	*Calocyclas bandyca*	*Calocyclas hispida*	*Calocyclas turris*	"*Carpocanistrum*" *azyx*	*Cryptoprora ornata*	*Dictyoprora mongolfieri*	*Dictyoprora pirum*	*Eusyringium fistuligerum*	*Eusyringium lagena*	*Lamptonium fabaeforme chaunothorax*	*Lamptonium fabaeforme constrictum*	*Lamptonium fabaeforme fabaeforme*	*Lithochytris vespertilio*	*Lithocyclia augusta*	*Lithocyclia aristotelis*	*Lithocyclia crux*	*Lithocyclia ocellus*	*Lophocyrtis biaurita*	*Lophocyrtis jacchia*	*Lychnocanoma bellum*	*Periphaena tripyramis triangula*	*Phormocyrtis striata striata*	*Podocyrtis chalara*	*Podocyrtis dorus*	*Podocyrtis fasciolata*	*Podocyrtis goetheana*	*Podocyrtis mitra*	*Podocyrtis sinuosa*	*Podocyrtis trachodes*	*Sethochytris babylonis*	*Sethochytris triconiscus*	*Theocotyle conica*	*Theocotyle cryptocephala*	*Theocotyle venezuelensis*	*Theocotylissa ficus*
115-711A-16X-3, 70–75	*Theocyrtis tuberosa*		R	M	—	R	—				—	—	R							R	—	R			—	—										—					
115-711A-16X-4, 70–75			F	P	—	R	—				—	—	R							R	—				—	—										—					
115-711A-16X-6, 70–75			C	M	—	F	—				—	—	R							F	—	R			—	—										—					
115-711A-16X-CC			C	G	R	C	—		—	—	—	—	R	—						R	—	R			—	—										—					
115-711A-17X-2, 70–75	*Thyrsocyrtis bromia*	C	F	P	F	R	—	—	—	—	R	F	R	—						+	R				F	R										R					
115-711A-17X-4, 70–75			C	G	R	—	—	—	—	—	R	R	R	—						+	F	F			F	R										C					
115-711A-17X-6, 70–75			F	M	R	—	—	—	—	—	R	F	R	—						—	R	R			R	R										F					
115-711A-17X-CC			C	G	R	—	—	—	—	—	F	C	F	—						—	R	F			R	R										C					
115-711A-18X-2, 70–75		B	C	G	R	—	C	—	C	C	F	C	R	R						—	F				F							—				R					
115-711A-18X-4, 70–75			C	G	R		F	—	C	C	F	C	R	R						—	R	R			R							—				C					—
115-711A-18X-CC			C	G	R		R	+	C	C	R	C	R	F					—	R					R	R						—				C					—
115-711A-19X-2, 70–75		A	C	G	R		—	R	C	F	R	C	R	R					—	—	R		—		R				—			R				F	—				—
115-711A-19X-4, 70–75			C	G			—	C	F	R	R	F	R	R					—		F		—		R	R		R	—			R	—			F	—				—
115-711A-19X-6, 70–75	*Podocyrtis goetheana*		C	G			—	C	—	—	R	C	—	C					—		R		—		F				—			R	—		—	C	—				F
115-711A-19X-CC	*Podocyrtis chalara*		C	G			—	F	—	—	R	F	—	C					—		—		R		—	R			R		—	—	—	—	—	F	R				F
115-711A-20X-2, 70–75			C	G				F	—	—	R	C	—	F					R		—		R		—	R			R		—	+	—	—	—	F	R				F
115-711A-20X-4, 70–75			C	G				F	—	—	R	C	—	C	—				R		—		C	—	—			F	F		—	—	—	—	F	C	R				F
115-711A-20X-CC	*Podocyrtis mitra*		C	G				C	—	—	—	C		C	—				F		—		R	—					R		—	—	F	—	C	C	C				R
115-711A-21X-2, 70–75			C	G				C			—	C		C	—				F				F	—					—		—		F	—	C	C	F				F
115-711A-21X-4, 70–75			C	G				C			—	F		F	—				F				R	—					—		—		C	—	C	C	F				R
115-711A-21X-CC			C	G				R				C		C	—				R				R	R					—		F		F	R	C	F	R				F
115-711A-22X-2, 70–75			C	G				C				C		F	—				R				F	R					—		R		R	—	F	C	R				F
115-711A-22X-4, 70–75			C	G				C				C		C	—				F				C	R							F		F	—	C	F	+			—	F
115-711A-22X-CC			C	G				F				C		C	R				F				F	R				F		—	C		F	—	—	C	R			—	F
115-711A-23X-2, 70–75	*Podocyrtis ampla*		C	G				C				C		F	R				R				R	R				R		—	R		—	C	—	F	—	—		—	F
115-711A-23X-4, 70–75			C	G				F				C		R	C				F				R	R				R		—	—		—	C	—	F	—	—		—	F
115-711A-23X-6, 70–75			C	G				F				C		R	F				F				R	F				F		—	—		—	C		F	—	—		R	F
115-711A-23X-CC			C	G				F				F		R	F				F				F	R				R		R	—		—	C		C	—	—		R	C
115-711A-24X-2, 70–75	*Thyrsocyrtis triacantha*		C	G				F				C		—	R				F				R	R				R		R	—			C		C		C	—	R	C
115-711A-24X-4, 70–75			C	G				F				C		—	F				F				R	R			R	F		R				C		F		F	—	R	R
115-711A-24X-CC			C	G				C				C		—	F	—	—	—	C				R	R				F		F				C		F		F	—	R	C
115-711A-25X-2, 70–75			C	G				R				F		—	R	—	—	—	F				F	R		R	R	F		R				C		F		R	—	R	R
115-711A-25X-4, 70–75			C	G				R				C			+	—	—	—	F				R	R				F		R				C		F		F	—	R	R
115-711A-25X-CC	*Dictyoprora mongolfieri*		C	G				R				C			—	R	R	F	F				R	—			R	F		R				F		F		R	F	R	R

Table 7. Coring intervals and age ranges for the sites in which radiolarians were recovered.

Hole	Depth (mbsf)	Age range
707A	0–213.3	Holocene–late Eocene
707B	0–124.9	Holocene–middle Miocene
707C	183.8–443.2	early Oligocene–Paleocene
709A	0–203.1	Holocene–earliest Miocene
709B	0–254.8	Holocene–early Oligocene
709C	0–353.7	Holocene–middle Eocene
710A	0–209.7	Holocene–early Oligocene
710B	0–83.4	Holocene–late Miocene
711A	0–249.7	Holocene–middle Eocene
711B	0–98.6	Holocene–early Oligocene
712A	0–115.3	Holocene–middle Miocene
713A	0–191.7	Holocene–middle Eocene
714A	0–233.0	Holocene–late Oligocene
714B	0–122.6	Holocene–middle Miocene

nis, and *Calocyclas turris.* The absence of *Thyrsocyrtis bromia* and *T. tetracantha* is consistent with this zonal determination.

Samples 115-707A-23X-6, 101 cm, through 115-707A-23X-CC (211.2–212.3 mbsf) contain well-preserved radiolarians diagnostic of the *Calocyclas bandyca* Zone of late Eocene age. Key taxa include *T. bromia, T. tetracantha, C. turris, C. ornata, C. azyx, T. rhizodon, C. bandyca, E. fistuligerum, D. mongolfieri, D. pirum, T. triceros,* and *L. jacchia.*

Hole 707C

Hole 707C contains identifiable radiolarians only in Cores 115-707C-3R through -11R (193.5–280.3 mbsf). The *Theocyrtis tuberosa* Zone of early Oligocene age is well represented in Core 115-707C-3R (193.5–203.1 mbsf). Diagnostic taxa in this interval include *T. tuberosa, Lithocyclia angusta,* and *Artophormis gracilis.* Core 115-707C-4R (203.1–212.8 mbsf) obtained zero core recovery, and thus the Eocene/Oligocene boundary interval was not recovered in this hole.

Samples 115-707C-5R-CC through 115-707C-6R-CC (222.5–232.1 mbsf) may be assigned to the *Calocyclas bandyca* Zone of late Eocene age. Diagnostic taxa include *T. bromia, T. tetracantha, C. turris, D. pirum, D. mongolfieri, C. azyx, C. bandyca, L. bellum, L. aristotelis, T. rhizodon, S. babylonis,* and *L. jacchia.*

A short unconformity is apparently present in the interval between Samples 115-707C-6R-CC and 115-707C-7R-2, 78 cm (232.1–234.4 mbsf). Samples 115-707C-7R-2, 78 cm, to 115-707C-11R-CC (234.4–280.3 mbsf) may be assigned to the *Podocyrtis mitra* Zone of middle Eocene age. Diagnostic taxa include *Podocyrtis mitra, P. trachodes, Sethochytris triconiscus, Calocyclas hispida, Lithocyclia ocellus, Podocyrtis helenae, Lithochytris vespertilio,* and *Thyrsocyrtis triacantha.*

All samples below Core 115-707C-11R (280.3 mbsf) are barren of radiolarians.

Site 708

A single hole (708A) was drilled at Site 708, located in the basin separating the Madingley Rise from the Mascarene Plateau, at a water depth of 4109 m. The entire cored interval contains graded calcareous turbidites, ranging in thickness from a few millimeters up to several tens of centimeters. Within the entire interval cored (0–236.2 mbsf) the cumulative thickness of the turbidites is comparable to, and perhaps greater than, that of the intervening pelagic layers. Because of the predominance of turbidites, and the doubtful reliability of detailed stratigraphic studies at this site, only core-catcher samples were examined.

Radiolarians are common and well preserved only in the upper 13 cores at Site 708 (0–120.6 mbsf). Radiolarian fragments in Cores 115-708A-14X through -17X (130.3–159.3 mbsf) are sparse and nondiagnostic. Radiolarians in Cores 115-708A-18X through -25X (168.6–236.2 mbsf) are rare and poorly preserved, and allow only an approximate zonal age determination.

From a preliminary examination of the upper 13 cores, we were able to make the following zonal assignments:

Samples 115-708A-2H-CC through 115-708A-3H-CC (18.6–28.1 mbsf) are of Quaternary age; diagnostic taxa include *T. trachelium, A. ypsilon, D. tetrathalamus, L. nigriniae, S. universus,* and *L. bacca.*

Sample 115-708A-4H-CC (37.6 mbsf) belongs to the *P. prismatium* Zone of late Pliocene age. Diagnostic taxa include *A. ypsilon, P. prismatium, T. trachelium,* and *T. vetulum.*

Samples 115-708A-5H-CC through 115-708A-7H-CC may be assigned to the *S. pentas* Zone of early Pliocene age. Diagnostic taxa include *A. jenghisi, P. prismatium, S. peregrina, A. michelinae, L. audax,* and *P. fistula.*

Samples 115-708A-8H-CC through 115-708A-12X-CC (76.0–111.0 mbsf) may be assigned to the *Stichocorys peregrina* Zone of late Miocene age. Diagnostic taxa in these samples include *S. omnitubus, P. doliolum, S. peregrina, A. jenghisi, D. penultima, P. fistula, A. michelinae, L. audax, S. johnsoni,* and *L. bacca.*

Sample 115-708A-13X-CC may be assigned to the *D. antepenultima* Zone of late Miocene age. Diagnostic taxa include *D. antepenultima, L. audax, S. delmontensis,* and *D. hughesi.*

Samples 115-708A-14X-CC through 115-708A-17X-CC (130.3–159.3 mbsf) are barren of diagnostic radiolarians.

Sample 115-708A-18X-CC (168.6 mbsf) is tentatively assigned to the *Cyrtocapsella tetrapera* Zone of early Miocene age. Indicative taxa include *C. virginis, C. serrata,* and *D. prismatica.*

Sample 115-708A-19X-CC (178.2 mbsf) is assigned to the *L. elongata* Zone of earliest Miocene age. Taxa include *L. elongata* and *C. robusta.*

Samples 115-708A-20X-CC through 115-708A-23X-CC (187.9–216.8 mbsf) may be assigned to the *Dorcadospyris ateuchus* Zone of late Oligocene age. Diagnostic taxa include *D. ateuchus, D. papilio, D. prismatica,* and *C. pegetrum.*

Samples 115-708A-24X-CC through 115-708A-25X-CC (226.5–236.2 mbsf) may be assigned to the *Theocyrtis tuberosa* Zone of early Oligocene age. Diagnostic taxa include *L. angusta, D. pirum, A. gracilis,* and *T. spongoconus.*

Site 709

Three holes, all within 0.1 km of each other, were drilled at Site 709, located on the summit of the Madingley Rise, in a water depth of 3041 m. Table 7 lists the intervals cored, all of which had excellent to good core recovery. Radiolarians were examined in selected intervals from each of the three holes in order to form a composite stratigraphic section. The following intervals were sampled: (1) Hole 709A, 0–203.1 mbsf; (2) Hole 709B, 189.4–254.8 mbsf; and (3) Hole 709C, 256.7–353.7 mbsf.

In the discussion that follows, the composite stratigraphic section at this site will be summarized from top to bottom.

Late Miocene to Holocene

Radiolarian assemblages are common and well preserved in this interval, extending between Sample 115-709A-1H-2, 75 cm, and Sample 115-709A-12H-2, 65 cm (2.2–108.8 mbsf). Diagnostic taxa and zonal age assignments are presented in Table 3.

Early Miocene to Middle Miocene

Radiolarians are absent in the interval between Samples 115-709A-12H-4, 65 cm, and 115-709A-19H-CC (111.8–183.9 mbsf), which corresponds to the middle and early Miocene on the basis of calcareous microfossils.

Oligocene

Radiolarians are rare and moderately to poorly preserved in the Oligocene interval of Holes 709A and 709B. For this reason, the biostratigraphic zonal determinations will be summarized briefly in the text rather than tabulated.

Samples 115-709A-20H-2, 65 cm, through 115-709A-20H-6, 65 cm (186.1–192.1 mbsf), and Samples 115-709B-21X-2, 65 cm, through 115-709B-22X-2, 65 cm (189.4–199.0 mbsf), may be assigned to the *Lychnocanoma elongata* Zone of latest Oligocene and earliest Miocene age. Diagnostic taxa include *L. elongata, Dorcadospyris ateuchus,* and *D. papilio.*

Samples 115-709B-22X-4, 65 cm, through 115-709B-25X-CC (202.0–235.5 mbsf) may be assigned to the *Dorcadospyris ateuchus* Zone of late Oligocene age. Diagnostic taxa include *Dorcadospyris ateuchus, D. papilio, Cyclampterium pegetrum, Calocycletta robusta, Artophormis gracilis,* and *Didymocyrtis prismatica.*

Samples 115-709B-26X-2, 65 cm, to 115-709B-27X-CC (237.7–254.8 mbsf), and Samples 115-709C-27X-CC to 115-709C-29X-CC (256.7–276.1 mbsf) may be assigned to the *Theocyrtis tuberosa* Zone of early Oligocene age. Diagnostic taxa within this interval include *Tristylospyris triceros, Theocyrtis tuberosa, Lithocyclia angusta, Artophormis gracilis, Dictyoprora pirum,* and *Didymocyrtis prismatica.*

Radiolarian abundance increases and preservation improves downward within the Oligocene. The assemblages become quite diverse and well preserved as one approaches the Eocene/Oligocene boundary.

Middle and Late Eocene

Samples 115-709C-30X-2, 70 cm, through 115-709C-37X-CC (278.3–353.7 mbsf) contain common and moderately to well-preserved radiolarians that span the Eocene/Oligocene boundary and continue down to the *Thyrsocyrtis triacantha* Zone of middle Eocene age. Diagnostic taxa and zonal age assignments for this interval are presented in Table 4.

The radiolarian occurrences in Core 115-709C-33X indicate that there may be a short unconformity between Sections 2 and 4, or between 307.3 and 310.3 mbsf (see Table 4). The nannofossil assemblages from this interval show significant reworking and cannot be used to verify whether or not the unconformity is present (H. Okada, pers. comm., 20 August 1988).

Site 710

Two holes, located within 0.1 km of each other, were drilled at Site 710, located on the flank of the Madingley Rise, in a water depth of 3824 m. The intervals that were cored are given in Table 7, all with excellent to good core recovery.

Because the site was double-cored, only the assemblages in Hole 710A were examined. However, a few samples in the Pliocene of Hole 710B were checked to confirm the zonal boundary determinations, as Core 115-710B-4H of Hole 710A had no core recovery.

Hole 710A contains common radiolarian assemblages only within the Holocene to late Miocene interval (Cores 115-710A-1H through -9H; 0–86.2 mbsf). Table 5 lists the diagnostic taxa and zonal age assignments for this stratigraphic interval.

Samples 115-710A-10H-2, 70 cm, through 115-710A-14X-4, 70 cm (88.4–130.1 mbsf) are barren of radiolarians.

Samples 115-710A-14X-CC through 115-710A-15X-CC contain rare and poorly preserved specimens that are tentatively assigned to either the *Cyrtocapsella tetrapera* or the *Lychnocanoma elongata* zones of early Miocene age. Taxa in these samples include *Calocycletta robusta, Dorcadospyris ateuchus,* and *Dendrospyris bursa.*

Samples 115-710A-16X-4, 70 cm, through 115-710A-20X-4, 70 cm (147.3–186.0 mbsf), may be assigned to the *Dorcadospyris ateuchus* Zone of late Oligocene age. Diagnostic taxa include *Dorcadospyris ateuchus, D. papilio, Theocorys spongoconus, Lithocyclia angusta, Theocyrtis annosa, Didymocyrtis prismatica,* and *Cyclampterium milowi.*

Samples 115-710A-20X-CC through 115-710A-22X-CC (190.4–209.7 mbsf) may be assigned to the *Theocyrtis tuberosa* Zone of early Oligocene age. Taxa present in these samples include *Theocyrtis tuberosa, Lithocyclia angusta, Tristylospyris triceros, Dictyoprora pirum,* and *Lithocyclia crux.*

Site 711

Two holes, located within 0.1 km of each other, were drilled at Site 711, located near the base of the Madingley Rise in a water depth of 4430 m. The stratigraphic intervals that were cored are listed in Table 7; all had excellent to good core recovery. Because the interval cored in Hole 711B duplicated that of Hole 711A, only samples from Hole 711A were examined for this study.

Radiolarians are common and well preserved only in two stratigraphic intervals at this site: the Quaternary and the earliest Oligocene through middle Eocene.

Quaternary

Sample 115-711A-1H-2, 70 cm, may be assigned to the *B. invaginata* Zone. Diagnostic taxa include *B. invaginata, Collosphaera tuberosa,* and *Amphirhopalum ypsilon.* The middle Brunhes indicator species *Stylatractus universus* is absent.

Sample 115-711A-1H-4, 70 cm, may be assigned to the *A. ypsilon* Zone. Diagnostic taxa include *Theocorythium trachelium, Didymocyrtis tetrathalamus, Amphirhopalum ypsilon, Pterocorys hertwigii,* and rare specimens of *Stylatractus universus.* The late Pleistocene forms *B. invaginata* and *C. tuberosa* and the early Pleistocene form *Anthocyrtidium angulare* are absent.

Sample 115-711A-1H-CC may be assigned to the *Anthocyrtidium angulare* Zone. Taxa in this sample include *A. angulare, A. michelinae, Amphirhopalum ypsilon, Didymocyrtis tetrathalamus, Theocorythium trachelium,* and *Stylatractus universus.*

Pliocene to Early Oligocene

Only one sample in this stratigraphic interval contained identifiable radiolarians. Sample 115-711A-2H-2, 70 cm, contains rare and moderately preserved taxa indicative of the *Pterocanium prismatium* Zone. Forms present include *P. prismatium, T. trachelium,* and common Eocene taxa that are evidently reworked.

All samples between 115-711A-2H-CC and 115-711A-12X-2, 70 cm (17.7–106.7 mbsf), are barren of radiolarians.

Early Oligocene

Samples 115-711A-12X-CC through 115-711A-16X-CC (114.2–153.0 mbsf) contain radiolarians diagnostic of the *Theocyrtis tuberosa* Zone of early Oligocene age. Specimens are rare and poorly preserved at the top of this interval and become increasingly abundant and better preserved as one approaches the Eocene/Oligocene boundary. Diagnostic taxa in this interval include *T. tuberosa, T. triceros, D. pirum, A. gracilis, D. prismatica,* and *L. angusta.*

Late and Middle Eocene

Samples 115-711A-16X-CC through 115-711A-25X-CC (153.0–240.0 mbsf) contain common and well-preserved radiolarian assemblages of late and middle Eocene age. Diagnostic taxa and zonal age assignments are presented in Table 6.

Sites 712 and 713

Sites 712 and 713, located approximately 3 km apart, were drilled on Chagos Bank, in water depths of 2903 m and 2920 m, respectively. The intervals cored are presented in Table 7, all of which had excellent core recovery.

Hole 712A

In Hole 712A, identifiable radiolarians are present only in Cores 115-712A-1R through -4R (0–38.3 mbsf).

Sample 115-712A-1R-CC (9.4 mbsf) may be assigned to the *S. pentas* Zone of Pliocene age. Diagnostic taxa include *P. doliolum, L. audax, S. peregrina, D. avita,* and *P. fistula. Solenosphaera omnitubus* is absent.

Sample 115-712A-2R-CC (19.0 mbsf) may be assigned to the *S. peregrina* Zone of earliest Pliocene age. Diagnostic taxa include *P. doliolum, S. peregrina, S. omnitubus, L. audax,* and *D. penultima.*

Sample 115-712A-3R-CC (28.6 mbsf) may be assigned to the *D. penultima* Zone of late Miocene age. Diagnostic taxa include *S. delmontensis, P. doliolum, L. audax, S. omnitubus, D. penultima,* and *S. corona.*

Sample 115-712A-4R-CC (38.3 mbsf) may be assigned to the *D. antepenultima* Zone of late Miocene age. Diagnostic taxa include *D. antepenultima, D. hughesi, S. johnsoni, P. fistula, L. audax,* and *S. delmontensis.*

Hole 713A

In Hole 713A, identifiable radiolarians of Neogene age are present in Cores 115-713A-1R through -4R (0–30.5 mbsf). Core 115-713A-5R (32.7–40.1 mbsf) is barren of radiolarians. A significant unconformity lies between Cores 115-713A-4R and -5R, on the basis of calcareous nannofossils. Cores 115-713A-6R though-11R contain common radiolarians of middle Eocene age. The following age assignments may be made for those stratigraphic intervals containing radiolarians:

Samples 115-713A-1R-CC through 115-713A-2R-4, 70–75 cm (1.6–3.8 mbsf), contain poorly preserved radiolarians of Quaternary age, including *A. ypsilon, A. michelinae, D. tetrathalamus, T. trachelium, S. universus,* and *A. angulare.*

Sample 115-713A-2R-CC may be assigned to the *S. pentas* Zone of late Pliocene age. Diagnostic taxa include *P. doliolum, A. michelinae, L. audax, S. peregrina,* and *P. fistula. Solenosphaera omnitubus* is absent.

Samples 115-713A-3R-4, 70 cm, through 115-713A-4R-CC (16.4–30.5 mbsf) may be assigned to the *D. penultima* Zone of late Miocene age. Diagnostic taxa include *D. penultima, S. delmontensis, L. audax, S. johnsoni, S. corona, A. michelinae, P. doliolum,* and *A. jenghisi.*

Samples 115-713A-6R-2, 70 cm, through 115-713A-10R-CC (42.3–88.4 mbsf) may be assigned to the *T. triacantha* Zone of middle Eocene age. Diagnostic taxa include *T. triacantha, E. fistuligerum, T. rhizodon, E. lagena, C. hispida, D. mongolfieri, S. babylonis, P. striata striata,* and *L. ocellus.*

Sample 115-713A-11R-3, 70 cm (92.1 mbsf), may be assigned to the *D. mongolfieri* Zone of middle Eocene age. Diagnostic taxa include *T. tensa, P. sinuosa, L. ocellus, C. hispida,* and *D. mongolfieri.*

Site 714

Two holes were drilled at Site 714, located on the eastern shoulder of the Maldives Ridge, in a water depth of 2038 m. Table 7 lists the intervals cored, which had excellent core recovery.

Radiolarians were examined only in Hole 714A, because the sequences obtained in Hole 714B duplicate those in Hole 714A. The following zonal age assignments may be made on the basis of this examination:

Sample 115-714A-1H-CC (2.8 mbsf) may be assigned to the *B. invaginata* Zone of Quaternary age. Diagnostic taxa include *B. invaginata, D. tetrathalamus, L. nigriniae, T. trachelium, A. ypsilon,* and *C. tuberosa.*

Sample 115-714A-2H-CC (12.4 mbsf) may be assigned to the *C. tuberosa* Zone of Quaternary age. Diagnostic taxa include *C. tuberosa, C. orthoconus, S. tetras, P. hertwigii, A. ypsilon,* and *D. tetrathalamus. Stylatractus universus* is absent.

Sample 115-714A-3H-4, 70 cm (17.6 mbsf) may be assigned to the *A. ypsilon* Zone of Quaternary age. Diagnostic taxa include *S. universus, D. tetrathalamus, T. trachelium,* and *A. ypsilon.*

A significant unconformity occurs between Samples 115-714A-3H-4, 70 cm, and 115-714A-3H-CC (17.6–22.0 mbsf).

Samples 115-714A-3H-CC through 115-714A-5H-4, 70 cm (22.0–36.9 mbsf), may be assigned to the *D. antepenultima* Zone of late Miocene age. Diagnostic taxa present include *D. antepenultima, D. hughesi, S. delmontensis, P. doliolum, S. corona, L. audax, C. caepa, D. bursa,* and *S. johnsoni.*

Samples 115-714A-5H-CC through 115-714A-10H-4, 70 cm (41.4–85.0 mbsf), may be assigned to the *D. petterssoni* Zone of late Miocene age. Diagnostic taxa in these samples include *D. petterssoni, D. laticonus, S. delmontensis, C. caepa, L. thornburgi, L. audax, S. corona, L. neotera, P. marylandicus, C. japonica, C. cornuta,* and *C. cristatum.*

Samples 115-714A-10H-CC through 115-714A-14X-4, 70 cm (89.5–123.6 mbsf), may be assigned to the *Dorcadospyris alata* Zone of middle Miocene age. Diagnostic taxa include *D. alata, C. bramlettei, C. caepa, C. cornuta, P. marylandicus, L. audax, S. wolffii, C. virginis,* and *C. costata.*

Samples 115-714A-14X-CC through 115-714A-17X-CC (126.8–155.7 mbsf) may be assigned to the *Calocycletta costata* Zone of middle Miocene age. Diagnostic taxa include *C. virginis, S. wolffii, C. costata, S. delmontensis, E. diaphanes, P. marylandicus, C. cornuta, C. bramlettei,* and *L. elongata.*

Samples 115-714A-18X-4, 70 cm, through 115-714A-18X-CC (160.9–165.3 mbsf) may be assigned to the *Stichocorys wolffii* Zone of early Miocene age. Diagnostic taxa include *C. cornuta, S. wolffii, C. virginis, D. violina, S. delmontensis,* and *L. elongata.*

Samples 115-714A-19X-4, 70 cm, through 115-714A-20X-CC (170.5–184.7 mbsf) may be assigned to the *Stichocorys delmontensis* Zone of early Miocene age. Diagnostic taxa include *S. delmontensis, C. tetrapera, D. violina, C. caepa, E. cienkowskii, E. diaphanes,* and *C. cornuta.*

Sample 115-714A-21X-CC (194.4 mbsf) may be assigned to the *Cyrtocapsella tetrapera* Zone of early Miocene age. Diagnostic taxa include *L. elongata, D. prismatica, C. virginis,* and *A. gracilis.*

Samples 115-714A-22X-4, 70 cm, through 115-714A-23X-CC (199.6–213.8 mbsf) may be assigned to the *Lychnocanoma elongata* Zone of earliest Miocene or latest Oligocene age. Diagnostic taxa include *A. gracilis, C. robusta, D. prismatica, C. pegetrum, D. ateuchus, T. annosa, L. trifolium, E. cienkowskii,* and *D. bursa.*

All samples examined below Sample 115-714A-23X-CC (213.8 mbsf) are barren of radiolarians.

DISCUSSION

Radiolarian Events

This report documents the succession of radiolarian events in two stratigraphic intervals: 31 events are identified in the late Neogene (0–8 Ma), and 55 events in the middle Eocene to earliest Oligocene (35–49 Ma). Within each of these intervals, there are a number of important events that have been identified in drill sites elsewhere, but were not identified in Leg 115 core material because of variations in species abundance and specimen preservation.

In the late Neogene sequences of the central Indian Ocean, Johnson et al. (1989) have identified several datum levels on the basis of the genera *Anthocyrtidium* and *Pterocorys*. These two genera were well represented in Leg 115 material, but a number of the taxa occurred only sporadically. Consequently, the following events that were identified previously (Johnson et al., 1989) are omitted from this report:

Top *Anthocyrtidium nosicaae*
Base *Anthocyrtidium euryclathrum*
Base *Pterocorys zancleus*
Top *Anthocyrtidium ehrenbergi*
Top *Anthocyrtidium prolatum*

A number of other significant late Neogene events were not possible to identify, including the following:

1. *Theocorythium vetulum* was virtually absent from the Pliocene sequences; thus, its upper and lower limits were not identified.
2. Specimens of the *Spongaster* lineage, extending from *S. berminghami* to *S. pentas* to *S. tetras,* were very rare or absent entirely. Thus, they were not satisfactory as a basis for selecting datum levels or defining zonal boundaries. For this reason, the base of the *S. pentas* Zone in the early Pliocene was approximated by the LO of *Solenosphaera omnitubus.*
3. The evolution of *Pterocanium prismatium* in the earliest Pliocene occurred over a long period of time (at least 1 m.y.; see Lazarus, 1985). Moreover, specimens of this taxon are very rare in Leg 115 material. The lower limit of this species was not identified therefore.

In the middle and late Eocene interval, the assemblages are remarkably diverse and well preserved in Holes 709C and 711A. However, the *Podocyrtis* lineage extending from *P. diamesa* to *P. phyxis* to *P. ampla* was totally missing and was not satisfactory, therefore, as a zonal boundary criterion. For this reason, the base of the *P. ampla* Zone was approximated by the LO of *Theocotyle conica.*

The form *Artophormis barbadensis* was notably rare in the late Eocene, and its lower limit could not be identified.

Paleomagnetic Calibrations and Diachroneity

Studies of paleomagnetically dated cores have documented the significance of time-transgressive biostratigraphic events (Johnson and Nigrini, 1985; Barron et al., 1985; Baldauf et al., 1986). One of the objectives of drilling on Leg 115 was to recover a continuous magnetic polarity stratigraphy in the Neogene, and to calibrate microfossil events to the geomagnetic polarity time scale (Berggren et al., 1985). This would allow a more precise assessment of the extent and significance of time-transgressive "events."

Of the Neogene sites drilled on Leg 115, only Site 710 obtained both a reliable paleomagnetic record and radiolarian-rich sediments. The magnetic stratigraphy for this site (Backman et al., in press) allows a precise age-depth curve to be constructed (see Schneider, this volume). Radiolarian events support the polarity designations in at least three significant instances:

1. The LO of *Pterocanium prismatium,* which is near the top of the Olduvai, is identified between 14.7 and 17.7 mbsf in Hole 710A (see Appendix B). Thus, the normal magnetic event in the lower part of Core 115-710A-2H (Backman et al., in press, fig. 1) appears to be the Olduvai.
2. The LO of *Stichocorys peregrina,* at about 2.6 Ma in the uppermost Gauss (Johnson et al., 1989), is identified between 21.4 and 23.1 mbsf in Hole 710A (Appendix B). Thus, the normal magnetic event in the top of Core 115-710A-3H (Backman et al., in press, fig. 1) is the uppermost Gauss. The overlying lower Matuyama, around 2.0–2.4 Ma, may be missing, as suggested by Backman et al. (in press).
3. The FO of *Amphirhopalum ypsilon,* at 3.8 Ma in the upper part of the Gilbert (Johnson et al., 1989), is identified between 31.0 and 34.0 mbsf in Hole 710A (Appendix B). Thus, the long intervals of reversed polarity in Core 115-710A-4H (Backman et al., in press, fig. 1) appear to correspond to the Gilbert.

The polarity stratigraphy of Hole 710A (Schneider, this volume) can be used to assess absolute ages and the synchroneity of several well-defined radiolarian events:

1. The transition from *Stichocorys delmontensis* to *S. peregrina* occurs at 59.7–62.7 mbsf (Appendix B). This level corresponds exactly with the FO of the nannofossil *A. primus*, which has been dated in Site 710 as 6.7 Ma (Backman et al., in press, table 1).
2. The FO of *Solenosphaera omnitubus* also occurs at 59.7–62.7 mbsf (Appendix A) and may therefore be dated as 6.7 Ma.
3. The LO of *Diartus hughesi* occurs at 62.7–65.7 mbsf (Appendix B). This level is between the FO of *A. primus* and the FO of *D. quinqueramus* (6.70 and 7.46 Ma, respectively; see Backman et al., in press, table 1) and thus may be dated as approximately 7.0 Ma in Site 710.
4. The FO of *D. hughesi* occurs at 78.8–81.8 mbsf (Appendix B). This level corresponds with the FO of *D. neohamatus*, which has been dated as 8.96 Ma in Site 710 (Backman et al., in press, table 1).

If we now compare these age estimates with those derived from paleomagnetically dated core material in the equatorial Pacific (Johnson and Nigrini, 1985), we note that two of the events appear to be synchronous and two are diachronous (see Table 8). From these comparisons of ages, it appears that *D. hughesi* and *S. peregrina* appeared somewhat earlier in the equatorial Indian Ocean than in the equatorial Pacific. This pattern is consistent with earlier observations of Johnson and Nigrini (1985). It is clear that faunal and floral diachroneity remains a significant phenomenon to document and to explain.

Paleoceanography

In the western tropical Indian Ocean, the deposition of biogenic silica undergoes a dramatic shift at the middle/late Miocene boundary, about 10–11 Ma. Below this transition, in sediments of Oligocene through middle Miocene age, silica is ab-

Table 8. Comparison of age estimates for Site 710 (Indian Ocean) and Site 573 (Pacific Ocean).

Event	Age (Ma) Site 710	Site 573
Stichocorys delmontensis → *Stichocorys peregrina*	6.7	6.1–6.3
B *Solenosphaera omnitubus*	6.7	6.7–6.8
T *Diartus hughesi*	7.0	7.0–7.1
B *Diartus hughesi*	8.9	7.8–8.1

Note: The letters "T" and "B" signify the morphotypic top and bottom of each species' range.

sent in virtually all Leg 115 sites and is only sparsely present in sites north of the equator (Site 714). Above this transition, in the late Miocene through Holocene, silica is common and radiolarians are well preserved.

In the Atlantic, this pattern is exactly reversed: biogenic silica is common and radiolarians are well preserved in the Neogene and Paleogene, prior to about 11 Ma. In the late Miocene through Pleistocene, however, silica is virtually absent throughout tropical and temperate latitudes (e.g., Riedel and Sanfilippo, 1970; Foreman, 1973; Johnson, 1977, 1983). This event seems to be of oceanwide significance and implies a major shift in the primary productivity and/or dissolution characteristics of much of the Atlantic.

Several oceanographic events of global significance occurred near the middle/late Miocene transition, including the expansion of the Antarctic ice cap (Shackleton and Kennett, 1975) and intensified flow in the Circumpolar Current (Johnson et al., 1983). Because the major wind-driven and thermohaline current systems are inextricably linked (Johnson, 1982), it is difficult to specify a particular triggering event to account for a number of closely occurring transitions observed in the depositional record. Several possibilities, however, may be considered.

1. The gradual closure of the Tethyan Seaway during the Neogene (Norton and Sclater, 1979) is one possible factor that may have been crucial in controlling the silica budgets of the Atlantic and Indian oceans, leading to preferential silica deposition in only one of the two oceans. It is beyond the scope of this paper, however, to suggest the particular threshold conditions and chemical parameters that might account for this striking shift in first-order patterns of silica accumulation in the two oceans.

2. During the Neogene, as Australia migrated northward and Indonesian seaways closed, the Pacific and Indian oceans became less connected in tropical latitudes. One might expect that microfossil assemblages would reflect this closure and geographic separation of the two oceans. One piece of evidence in this direction is that the Eocene radiolarian assemblages of the two oceans are remarkably comparable, and the succession of events (Appendix C) in the Indian Ocean is essentially identical with that of the Pacific (Sanfilippo et al., 1985). Thus, there is no evidence of significantly diachronous events in the Paleogene. In the late Neogene, however, as the closure of the Indonesian seaways progressed, there is evidence for substantial diachroneity of events, up to several million years in some instances (Johnson and Nigrini, 1985).

An obvious strategy for testing this notion is to examine other microfossil groups in the tropical Indian and Pacific regions to see if there is a pattern of increasingly diachronous events toward the middle and late Neogene, with the gradual closure of Indonesian seaways.

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REFERENCES

Backman, J., Schneider, D., Rio, D., and Okada, H., in press. Neogene low latitude magnetostratigraphy from ODP Site 710 and revised age estimates of Miocene nannofossil datum events. *Geology.*

Baldauf, J. G., Thomas, E., Clement, B., Takayama, T., Weaver, P. E., Backman, J., Jenkins, G., Mudie, P. J., and Westberg-Smith, M. J., 1986. Magnetostratigraphic and biostratigraphic synthesis, Deep Sea Drilling Project Leg 94. *In* Ruddiman, W. F., Kidd, R. B., Thomas, E., et al., *Init. Repts. DSDP,* 94, Pt. 2: Washington (U.S. Govt. Printing Office), 1159–1205.

Barron, J. A., Nigrini, C. A., Pujos, A., Saito, T., Theyer, F., Thomas, E., and Weinreich, N., 1985. Synthesis of biostratigraphy, central equatorial Pacific, Deep Sea Drilling Project Leg 85: refinement of Oligocene to Quaternary biochronology. *In* Mayer, L., Theyer, F., Thomas, E., et al., *Init. Repts. DSDP,* 85: Washington (U.S. Govt. Printing Office), 905–934.

Berggren, W. A., Kent, D. V., and Van Couvering, J. A., 1985. The Neogene: Part 2, Neogene geochronology and chronostratigraphy. *In* Snelling, N. J. (Ed.), *The Chronology of the Geological Record.* Geol. Soc. Mem. (London), 10:211–260.

Bjorklund, K. R., and Goll, R. M., 1979. Internal skeletal structures of *Collosphaera* and *Trisolenia:* a case of repetitive evolution in the Collosphaeridae (Radiolaria). *J. Paleontol.,* 53:1293–1326.

Caulet, J.-P., 1986. Radiolarians from the southwestern Pacific. *In* Kennett, J. P., von der Borch, C. C., et al., *Init. Repts. DSDP,* 90: Washington (U.S. Govt. Printing Office), 835–861.

Caulet, J.-P., and Nigrini, C. A., 1988. The genus *Pterocorys* (Radiolaria) from the tropical late Neogene of the Indian and Pacific Oceans. *Micropaleontology,* 34:217–235.

Foreman, H. P., 1973. Radiolaria of Leg 10 with systematics and ranges for the families Amphipyndacidae, Artostrobiidae, and Theoperidae. *In* Worzel, J. L., Bryant, W., et al., *Init. Repts. DSDP,* 10: Washington (U.S. Govt. Printing Office), 407–474.

Goll, R. M., 1980. Pliocene-Pleistocene radiolarians from the East Pacific Rise and the Galapagos spreading center, Deep Sea Drilling Project Leg 54. *In* Rosendahl, B. R., Hekinian, R., et al., *Init. Repts. DSDP,* 54: Washington (U.S. Govt. Printing Office), 425–453.

Hays, J. D., 1970. Stratigraphy and evolutionary trends of Radiolaria in North Pacific deep sea sediments. *In* Hays, J. D. (Ed.), *Geological Investigations of the North Pacific.* Mem. Geol. Soc. Am., 10:185–218.

Johnson, D. A., 1977. Cenozoic radiolaria from the eastern tropical Atlantic, DSDP Leg 41. *In* Lancelot, Y., Seibold, E., et al., *Init. Repts. DSDP,* 41: Washington (U.S. Govt. Printing Office), 763–789.

________, 1982. Abyssal teleconnections: interactive dynamics of the deep ocean circulation. *Paleogeogr., Paleoclimatol., Paleoecol.,* 38: 93–128.

________, 1983. Cenozoic radiolarians from the Brazil Basin and Rio Grande Rise. *In* Barker, P. F., Carlson, R. L., Johnson, D. A., et al., *Init. Repts. DSDP,* 72: Washington (U.S. Govt. Printing Office), 783–791.

Johnson, D. A., Ledbetter, M. T., and Damuth, J. E., 1983. Neogene sedimentation and erosion in the Amirante Passage, western Indian Ocean. *Deep Sea Res.,* 30:195–219.

Johnson, D. A., and Nigrini, C. A., 1985. Synchronous and time-transgressive Neogene radiolarian datum levels in the equatorial Indian and Pacific Oceans. *Mar. Micropaleontol.,* 9:489–523.

Johnson, D. A., Schneider, D. A., Caulet, J.-P., Nigrini, C. A., and Kent, D. V., 1989. Pliocene-Pleistocene radiolarian events and magnetostratigraphic calibrations for the tropical Indian Ocean. *Mar. Micropaleontol.,* 14:33–66.

Kling, S. A., 1971. Radiolaria. *In* Fischer, A. G., Heezen, B. C., et al., *Init. Repts. DSDP,* 6: Washington (U.S. Govt. Printing Office), 1069–1117.

Knoll, A. H., and Johnson, D. A., 1975. Late Pleistocene evolution of the collosphaerid radiolarian *Buccinosphaera invaginata* Haeckel. *Micropaleontology,* 21:60–68.

Lazarus, D. B., 1985. Evolution of the radiolarian species-complex *Pterocanium*: a preliminary survey. *J. Paleontol.,* 59:183–220.

Mato, C. Y., and Theyer, F., 1980. *Lychnocanoma bandyca* n. sp., a new stratigraphically important late Eocene radiolarian. *In* Sliter, W. V. (Ed.), *Studies in Marine Micropaleontology and Paleoecology: A Memorial Volume to Orville L. Bandy.* Spec. Publ., Cushman Found. Foraminiferal Res., 19:225-229.

Maurasse, F., and Glass, B., 1976. Radiolarian stratigraphy and North American microtektites in Caribbean core RC9-58: implications concerning late Eocene radiolarian chronology and the age of the Eocene/Oligocene boundary. *Trans. Caribb. Geol. Conf., 7th, Guadeloupe, 1974,* pp. 205-212.

Moore, T. C., 1972. Mid-Tertiary evolution of the radiolarian genus *Calocycletta. Micropaleontology,* 18:144-152.

Nigrini, C., 1967. Radiolaria in pelagic sediments from the Indian and Atlantic Oceans. *Bull. Scripps Inst. Oceanogr.,* 11:1-125.

_______, 1971. Radiolarian zones in the Quaternary of the equatorial Pacific Ocean. *In* Funnell, B. M., and Riedel, W. R. (Eds.), *The Micropalaeontology of Oceans:* Cambridge (Cambridge Univ. Press), 443-461.

_______, 1974. Cenozoic radiolaria from the Arabian Sea, DSDP Leg 23. *In* Davies, T., Luyendyk, B. P., et al., *Init. Repts. DSDP,* 26: Washington (U.S. Govt. Printing Office), 1051-1121.

_______, 1977. Tropical Cenozoic Artostrobiidae (Radiolaria). *Micropaleontology,* 23:241-269.

_______, 1985. Radiolarian biostratigraphy in the central equatorial Pacific, Deep Sea Drilling Project Leg 85. *In* Mayer, L., Theyer, F., et al., *Init. Repts. DSDP,* 85: Washington (U.S. Govt. Printing Office), 511-551.

Nigrini, C., and Lombari, G., 1984. *A Guide to Miocene Radiolaria.* Spec. Publ., Cushman Found. Foraminiferal Res., No. 22.

Nigrini, C., and Caulet, J.-P., 1988. The genus *Anthocyrtidium* (Radiolaria) from the tropical late Neogene of the Indian and Pacific oceans. *Micropaleontology,* 34:341-360.

Norton, I. O., and Sclater, J. G., 1979. A model for the evolution of the Indian Ocean and the breakup of Gondwanaland. *J. Geophys. Res.,* 84:6803-6830.

Riedel, W. R., and Sanfilippo, A., 1970. Radiolaria, Leg 4, Deep Sea Drilling Project. *In* Bader, R. G., Gerard, R. D., et al., *Init. Repts. DSDP,* 4: Washington (U.S. Govt. Printing Office), 503-575.

_______, 1971. Cenozoic Radiolaria from the western tropical Pacific, Leg 7. *In* Winterer, E. L., Riedel, W. R., et al., *Init. Repts. DSDP,* 7, Pt. 2: Washington (U.S. Govt. Printing Office), 1529-1672.

_______, 1978. Stratigraphy and evolution of tropical Cenozoic radiolarians. *Micropaleontology,* 24:61-96.

_______, 1986. Morphological characters for a natural classification of Cenozoic Radiolaria, reflecting phylogenies. *Mar. Micropaleontol.,* 11:151-170.

Sanfilippo, A., Burckle, L. H., Martini, E., and Riedel, W. R., 1973. Radiolarians, diatoms, silicoflagellates, and calcareous nannofossils in the Mediterranean Neogene. *Micropaleontology,* 19:209-234.

Sanfilippo, A., and Riedel, W. R., 1973. Cenozoic Radiolaria (exclusive of theoperids, artostrobiids, and amphipyndacids) from the Gulf of Mexico, Deep Sea Drilling Project Leg 10. *In* Worzel, J. L., Bryant, W., et al., *Init. Repts. DSDP,* 10: Washington (U.S. Govt. Printing Office), 475-611.

_______, 1980. A revised generic and suprageneric classification of the artiscins (Radiolaria). *J. Paleontol.,* 54:1008-1011.

_______, 1982. Revision of the radiolarian genera *Theocotyle, Theocotylissa,* and *Thyrsocyrtis. Micropaleontology,* 28:170-188.

Sanfilippo, A., Westberg-Smith, M. J., and Riedel, W. R., 1985. Cenozoic Radiolaria. *In* Bolli, H. M., Saunders, J. B., and Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy:* Cambridge (Cambridge Univ. Press), 631-713.

Saunders, J. B., Bernoulli, D., Müller-Merz, E., Oberhänsli, H., Perch-Nielsen, K., Riedel, W. R., Sanfilippo, A., and Torrini, R., Jr., 1985. Stratigraphy of the late middle Eocene to early Oligocene in the Bath Cliff section, Barbados, West Indies. *Micropaleontology,* 30:390-425.

Shackleton, N. J., and Kennett, J. P., 1975. Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analyses in DSDP Sites 277, 279, and 281. *In* Kennett, J. P., Houtz, R. E., et al., *Init. Repts. DSDP,* 29: Washington (U.S. Govt. Printing Office), 743-755.

Streeter, L., 1988. Two species (one new) of Pliocene-Pleistocene Radiolaria from the central equatorial Indian Ocean. *Micropaleontology,* 34:63-66.

Westberg, M. J., and Riedel, W. R., 1982. Radiolaria from the Middle America Trench off Guatemala. *In* Aubouin, J., Von Huene, R., et al., *Init. Repts. DSDP,* 67: Washington (U.S. Govt. Printing Office), 401-424.

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APPENDIX A: SPECIES LIST

Cited references present descriptions and illustrations of the concept of each species as applied in this study.

Acrobotrys tritubus Riedel; Nigrini and Lombari, 1984, p. N203, pl. 33, figs. 1a, 1b.

Amphirhopalum ypsilon Haeckel; Nigrini, 1971, p. 447, pl. 34, figs. 7a-7c.

Anthocyrtidium angulare Nigrini; Nigrini, 1971, p. 445, pl. 34.1, figs. 3a, 3b.

Anthocyrtidium euryclathrum Nigrini and Caulet; Nigrini and Caulet, 1988, p. 349, pl. 1, figs. 5-7.

Anthocyrtidium jenghisi Streeter; Streeter, 1988, p. 63, pl. 1, figs. 1-4.

Anthocyrtidium michelinae Caulet; Streeter, 1988, pp. 64-65, pl. 1, figs. 5-9; Nigrini and Caulet, 1988, p. 351, pl. 1, figs. 13, 14.

Anthocyrtidium pliocenica (Seguenza); Nigrini and Lombari, 1984, p. N149, pl. 27, figs. 2a, 2b.

Artophormis barbadensis (Ehrenberg); Sanfilippo et al., 1985, p. 666, figs. 12.1a, 12.1b.

Artophormis gracilis Riedel; Sanfilippo et al., 1985, pp. 666-667, figs. 12.2a-12.2c.

Buccinosphaera invaginata Haeckel; Knoll and Johnson, 1975, p. 63, pl. 1, figs. 3-7.

Calocyclas bandyca (Mato and Theyer); Mato and Theyer, 1980, p. 225, pl. 1, figs. 1-6; Saunders et al., 1985, pl. 5, figs. 1, 5-6.

Calocyclas hispida (Ehrenberg); Foreman, 1973, p. 434, pl. 9, fig. 18.

Calocyclas turris Ehrenberg; Riedel and Sanfilippo, 1978, p. 65, pl. 3, figs. 7, 8.

Calocycletta caepa Moore; Moore, 1972, p. 150, pl. 2, figs. 4-7; Nigrini and Lombari, 1984, p. N153, pl. 28, figs. 1a-1d.

Calocycletta costata (Riedel); Riedel and Sanfilippo, 1971, p. 1598, pl. 2H, figs. 12-14.

Calocycletta robusta Moore; Moore, 1972, p. 148, pl. 1, fig. 6.

Calocycletta serrata Moore; Moore, 1972, p. 148, pl. 2, fig. 1.

Calocycletta virginis Haeckel; Sanfilippo et al., 1985, p. 693, figs. 28.1a, 28.1b.

"*Carpocanistrum*" *azyx* Sanfilippo and Riedel; Sanfilippo and Riedel, 1973, p. 530, pl. 35, fig. 9; Sanfilippo et al., 1985, pp. 690-691, figs. 27.1a, 27.1b.

Carpocanopsis cristatum (Carnevale); Riedel and Sanfilippo, 1971, p. 1597, pl. 2G, figs. 1-7.

Collosphaera orthoconus (Haeckel); Bjorklund and Goll, 1979, p. 1317; Goll, 1980, pl. 1, figs. 10-11.

Collosphaera tuberosa Haeckel; Knoll and Johnson, 1975, p. 63, pl. 2, figs. 1-3.

Cryptoprora ornata Ehrenberg; Sanfilippo et al., 1985, p. 693, figs. 27.2a, 27.2b.

Cyrtocapsella cornuta Haeckel; Sanfilippo et al., 1985, p. 670, figs. 16.2a, 16.2b.

Cyrtocapsella tetrapera Haeckel; Sanfilippo et al., 1985, p. 670, figs. 16.1a, 16.1b.

Cyclampterium milowi Riedel and Sanfilippo; Riedel and Sanfilippo, 1971, p. 1595, pl. 3B, fig. 3.

Cyclampterium pegetrum Sanfilippo and Riedel; Riedel and Sanfilippo, 1971, pl. 2D, figs. 13-14.

Dendrospyris bursa Sanfilippo and Riedel; Sanfilippo et al., 1973, p. 217, pl. 2, figs. 9-13.

Diartus hughesi (Campbell and Clark); Sanfilippo et al., 1985, p. 655, fig. 8.11.

Diartus petterssoni (Riedel and Sanfilippo); Sanfilippo et al., 1985, p. 657, figs. 8.10a, 8.10b.
Dictyoprora mongolfieri (Ehrenberg); Sanfilippo et al., 1985, pp. 702–703, figs. 33.1a–33.1d.
Dictyoprora pirum (Ehrenberg); Nigrini, 1977, p. 251, pl. 4, fig. 8.
Didymocyrtis antepenultima Riedel and Sanfilippo; Sanfilippo et al., 1985, p. 657, fig. 8.6.
Didymocyrtis avita (Riedel); Sanfilippo et al., 1985, pp. 657–658, fig. 8.8a.
Didymocyrtis laticonus (Riedel); Sanfilippo et al., 1985, p. 658, figs. 8.5a, 8.5b.
Didymocyrtis penultima (Riedel); Sanfilippo et al., 1985, p. 658, figs. 8.7a, 8.7b.
Didymocyrtis prismatica (Haeckel); Sanfilippo and Riedel, 1980, p. 1010; Riedel and Sanfilippo, 1971, pl. 2C, figs. 11–13, pl. 4, fig. 5.
Didymocyrtis tetrathalamus (Haeckel); Sanfilippo et al., 1985, p. 659; Nigrini, 1967, pl. 2, figs. 4a–4d.
Dorcadospyris alata (Riedel); Riedel and Sanfilippo, 1970, p. 523; Sanfilippo et al., 1985, pp. 661–662, fig. 10.7.
Dorcadospyris ateuchus (Ehrenberg); Sanfilippo et al., 1985, p. 663, figs. 10.4a, 10.4b.
Dorcadospyris papilio (Riedel); Sanfilippo et al., 1985, pp. 663–664, figs. 10.2a, 10.2b.
Eucyrtidium diaphanes Sanfilippo and Riedel; Sanfilippo et al., 1973, p. 221, pl. 5, figs. 12–14.
Eusyringium fistuligerum Ehrenberg; Sanfilippo et al., 1985, pp. 670–671, figs. 17.1a, 17.1b.
Eusyringium lagena (Ehrenberg); Sanfilippo et al., 1985, pp. 672–673, figs. 17.2a–17.2c.
Lamprocyrtis neoheteroporos Kling; Kling, 1973, p. 639, pl. 5, figs. 17–18; pl. 15, figs. 4–5.
Lamprocyrtis nigriniae (Caulet); Sanfilippo et al., 1985, pp. 694–695, figs. 29.1a–29.1c.
Lamptonium fabaeforme chaunothorax Riedel and Sanfilippo; Riedel and Sanfilippo, 1970, p. 524, pl. 5, figs. 8, 9.
Lamptonium fabaeforme constrictum Riedel and Sanfilippo; Sanfilippo et al., 1985, p. 674, fig. 18.4.
Lamptonium fabaeforme fabaeforme (Krasheninnikov); Sanfilippo et al., 1985, p. 674, fig. 18.2.
Lithochytris vespertilio Ehrenberg; Riedel and Sanfilippo, 1970, p. 528, pl. 9, figs. 8, 9.
Lithocyclia angusta (Riedel); Sanfilippo et al., 1985, p. 653, figs. 7.3a–7.3c.
Lithocyclia aristotelis (Ehrenberg) group; Sanfilippo et al., 1985, p. 653, figs. 7.2a–7.2d.
Lithocyclia crux Moore; Sanfilippo et al., 1985, p. 655, figs. 7.4a, 7.4b.
Lithocyclia ocellus Ehrenberg group; Sanfilippo et al., 1985, p. 655, figs. 7.1a, 7.1b; Riedel and Sanfilippo, 1986, pl. III, figs. 4–5.
Lithopera bacca Ehrenberg; Nigrini, 1967, p. 54, pl. 6, fig. 2.
Lithopera thornburgi Sanfilippo and Riedel; Sanfilippo and Riedel, 1970, p. 455, pl. 2, figs. 4–6.
Lophocyrtis biaurita (Ehrenberg); Foreman, 1973, p. 442, pl. 8, figs. 23–26.
Lophocyrtis jacchia (Ehrenberg); Riedel and Sanfilippo, 1978, p. 70, pl. 7, fig. 1; Riedel and Sanfilippo, 1986, pl. VII, fig. 10.
Lychnocanoma bellum (Campbell and Clark); Foreman, 1973, p. 437, pl. 1, fig. 17; Riedel and Sanfilippo, 1986, pl. I, fig. 12.
Lychnocanoma elongata (Vinassa de Regny); Sanfilippo et al., 1985, p. 676, figs. 19.1a, 19.1b.
Lychnodictyum audax Riedel; Sanfilippo et al., 1985, p. 677, fig. 21.2.
Periphaena tripyramis triangula (Sutton); Sanfilippo and Riedel, 1973, p. 523, pl. 9, figs. 10–11.
Phormocyrtis striata striata Brandt; Sanfilippo et al., 1985, p. 679, figs. 20.1a, 20.1b.
Phormostichoartus doliolum (Riedel and Sanfilippo); Nigrini, 1977, pp. 252–253, pl. 1, fig. 14.
Phormostichoartus fistula Nigrini; Nigrini, 1977, p. 253, pl. 1, figs. 11–13.
Phormostichoartus marylandicus (Martin); Nigrini, 1977, p. 253, pl. 2, figs. 1–4.
Podocyrtis ampla Ehrenberg; Riedel and Sanfilippo, 1970, p. 533, pl. 12, figs. 7–8.
Podocyrtis chalara Riedel and Sanfilippo; Sanfilippo et al., 1985, p. 697, fig. 30.11.
Podocyrtis diamesa Riedel and Sanfilippo; Sanfilippo et al., 1985, p. 695, fig. 30.2.
Podocyrtis dorus Sanfilippo and Riedel; Sanfilippo and Riedel, 1973, p. 531, pl. 35, figs. 12–14.
Podocyrtis fasciolata Nigrini; Sanfilippo et al., 1985, p. 697, fig. 30.7.
Podocyrtis goetheana (Haeckel); Sanfilippo et al., 1985, pp. 697–698, fig. 30.12.
Podocyrtis mitra Ehrenberg; Sanfilippo et al., 1985, p. 698, fig. 30.10.
Podocyrtis sinuosa Ehrenberg; Sanfilippo et al., 1985, pp. 698–699, fig. 30.9.
Podocyrtis trachodes Riedel and Sanfilippo; Sanfilippo et al., 1985, p. 699, fig. 30.14.
Pterocanium prismatium Riedel; Sanfilippo et al., 1985, pp. 679–680, figs. 21.1a, 21.1b.
Pterocorys campanula Haeckel; Caulet and Nigrini, 1988, p. 226, pl. 1, figs. 2–5.
Pterocorys hertwigii (Haeckel); Caulet and Nigrini, 1988, p. 228, pl. 1, figs. 11, 12.
Sethochytris babylonis (Clark and Campbell) group; Nigrini, 1974, p. 1068, pl. 1G, figs. 9–14.
Sethochytris triconiscus Haeckel; Sanfilippo et al., 1985, pp. 680–681, figs. 22.1a–22.1d.
Siphostichartus corona (Haeckel); Nigrini, 1977, pp. 257–258, pl. 2, figs. 5–7; Riedel and Sanfilippo, 1986, pl. V, fig. 10.
Solenosphaera omnitubus Riedel and Sanfilippo; Sanfilippo et al., 1985, p. 651, figs. 4.3a, 4.3b.
Spongaster berminghami (Campbell and Clark); Sanfilippo et al., 1985, pp. 660–661, figs. 9.3a, 9.3b.
Spongaster pentas Riedel and Sanfilippo; Sanfilippo et al., 1985, p. 661, figs. 9.2a, 9.2b.
Spongaster tetras Ehrenberg; Sanfilippo et al., 1985, p. 661, figs. 9.1a–9.1c.
Stichocorys delmontensis (Campbell and Clark); Sanfilippo et al., 1985, pp. 681–682, figs. 23.1a, 23.1b.
Stichocorys johnsoni Caulet; Caulet, 1986, p. 851, pl. 6, figs. 5, 6.
Stichocorys peregrina (Riedel); Sanfilippo et al., 1985, p. 682, fig. 23.2.
Stichocorys wolffii Haeckel; Sanfilippo et al., 1985, p. 682, figs. 23.3a, 23.3b.
Stylatractus universus Hays; Hays, 1970, p. 215, pl. 1, figs. 1, 2. This taxon has also been designated as *Axoprunum angelinum* (Campbell and Clark); see Sanfilippo et al., 1985, pp. 651–652, figs. 5.1a, 5.1b.
Theocorys spongoconus Kling; Kling, 1971, p. 1087, pl. 5, fig. 6.
Theocorythium trachelium (Ehrenberg); Nigrini, 1967, p. 79, pl. 8, fig. 2; pl. 9, fig. 2.
Theocorythium vetulum Nigrini; Nigrini, 1971, p. 447, pl. 34.1, figs. 6a–6b.
Theocotyle conica Foreman; Sanfilippo et al., 1985, p. 683, fig. 25.3.
Theocotyle cryptocephala (Ehrenberg); Sanfilippo and Riedel, 1982, p. 178, pl. 2, figs. 4–7; Sanfilippo et al., 1985, p. 685, figs. 25.2a, 25.2b.
Theocotyle venezuelensis Riedel and Sanfilippo; Sanfilippo and Riedel, 1982, p. 179, pl. 2, figs. 8–12; Sanfilippo et al., 1985, pp. 685–686, figs. 25.4a–25.4c.
Theocotylissa ficus (Ehrenberg); Sanfilippo et al., 1985, p. 686, figs. 25.7a, 25.7b.
Theocyrtis annosa (Riedel); Riedel and Sanfilippo, 1970, p. 535, pl. 15, fig. 9.
Theocyrtis tuberosa Riedel; Sanfilippo et al., 1985, pp. 701–702, figs. 32.1a–32.1d.
Thyrsocyrtis bromia Ehrenberg; Sanfilippo and Riedel, 1982, pp. 172–173, pl. 1, figs. 17–20.
Thyrsocyrtis hirsuta (Krasheninnikov); Sanfilippo et al., 1985, p. 687, fig. 26.2.
Thyrsocyrtis rhizodon Ehrenberg; Sanfilippo and Riedel, 1982, pp. 173–174, pl. 1, figs. 14–16.
Thyrsocyrtis robusta Riedel and Sanfilippo; Sanfilippo and Riedel, 1982, p. 174, pl. 1, fig. 5.
Thyrsocyrtis tensa Foreman; Sanfilippo and Riedel, 1982, p. 176, pl. 1, figs. 6–7.
Thyrsocyrtis tetracantha (Ehrenberg); Sanfilippo et al., 1985, p. 690, figs. 26.8a, 26.8b.
Thyrsocyrtis triacantha (Ehrenberg); Sanfilippo et al., 1985, p. 690, figs. 26.7a, 26.7b.
Tristylospyris triceros (Ehrenberg); Sanfilippo et al., 1985, pp. 665–666, figs. 10.3a, 10.3b.

APPENDIX B. LATE NEOGENE RADIOLARIAN EVENTS IN HOLES 709A AND 710A.

Events	Hole 709A	Hole 710A
[B *B. invaginata*]	1H-2 (2.2) to 1H-4 (5.2)	—
T *S. universus*	1H-2 (2.2) to 1H-4 (5.2)	1H-2 (2.2) to 1H-4 (5.2)
[B *C. tuberosa*]	1H-2 (2.2) to 1H-4 (5.2)	1H-2 (2.2) to 1H-4 (5.2)
B *P. hertwigii*	1H-4 (5.2) to 1H-CC (10.1)	1H-4 (5.2) to 1H-CC (9.5)
[T *A. angulare*]	1H-CC (10.1) to 2H-2 (12.4)	1H-CC (9.5) to 2H-2 (11.7)
B *L. nigriniae*	1H-CC (10.1) to 2H-2 (11.2)	1H-CC (9.5) to 2H-2 (11.7)
T *L. neoheteroporos*	2H-2 (12.4) to 2H-4 (15.4)	1H-CC (9.5) to 2H-2 (11.7)
T *A. michelinae*	2H-4 (15.4) to 2H-CC (19.7)	2H-2 (11.7) to 2H-2 (14.7)
[T *P. prismatium*]	2H-CC (19.7) to 3H-2 (21.9)	2H-4 (14.7) to 2H-6 (17.7)
B *A. angulare*	2H-CC (19.7) to 3H-2 (21.9)	2H-4 (14.7) to 2H-6 (17.7)
T *A. jenghisi*	3H-2 (21.9) to 3H-4 (24.9)	2H-CC (19.2) to 2H-CC (21.4)
B *T. trachelium*	3H-2 (21.9) to 3H-4 (24.9)	2H-CC (19.2) to 3H-2 (21.4)
[T *S. peregrina*]	3H-6 (27.9) to 3H-CC (29.4)	3H-2 (21.4) to 3H-3 (23.1)
T *A. pliocenica*	3H-CC (29.4) to 4H-2 (31.6)	3H-3 (23.1) to 3H-CC (28.8)
T *P. fistula*	4H-2 (31.6) to 4H-CC (39.1)	3H-3 (23.1) to 3H-CC (28.8)
T *L. audax*	4H-2 (31.6) to 4H-CC (39.1)	3H-CC (28.8) to 4H-2 (31.0)
T *P. doliolum*	4H-CC (39.1) to 6H-2 (50.9)	3H-CC (28.8) to 4H-2 (31.0)
B *A. ypsilon*	4H-CC (39.1) to 6H-2 (50.9)	4H-2 (31.0) to 4H-4 (34.0)
[*S. berminghami* → *S. pentas*]	—	—
T *S. delmontensis*	6H-CC (58.3) to 7H-4 (63.5)	4H-6 (37.8) to 4H-CC (38.3)
T *S. omnitubus*	7H-4 (63.5) to 7H-6 (66.5)	4H-6 (37.0) to 4H-CC (38.3)
T *S. corona*	7H-4 (63.5) to 7H-6 (66.5)	4H-CC (38.3) to 6H-2 (50.2)
T *A. tritubus*	7H-6 (66.5) to 7H-CC (68.0)	4H-CC (38.3) to 6H-2 (50.2)
T *S. johnsoni*	—	4H-CC (38.3) to 6H-2 (50.2)
T *D. bursa*	10H-2 (89.5) to 10H-4 (92.5)	6H-CC (57.5 to 7H-2 (59.7)
[*S. delmontensis* → *S. peregrina*]	10H-2 (89.5) to 10H-4 (92.5)	7H-2 (59.7) to 7H-4 (62.7)
B *S. omnitubus*	10H-4 (92.5) to 10H-CC (96.9)	7H-2 (59.7) to 7H-4 (62.7)
[T *D. hughesi*]	10H-CC (96.9) to 11H-4 (102.1)	7H-4 (62.7) to 7H-6 (65.7)
B *A. tritubus*	11H-4 (102.1) to 11H-CC (106.6)	7H-6 (65.7) to 7H-CC (67.1)
T *D. petterssoni*	—	8H-CC (76.6) to 9H-2 (78.8)
[*D. petterssoni* → *D. hughesi*]	—	8H-CC (76.6) to 9H-2 (78.8)
B *D. hughesi*	—	9H-2 (78.8) to 9H-4 (81.8)

Notes: The letters "T" and "B" signify the morphotypic top and bottom of each species' range. Events in brackets, [ ], define zonal boundaries (Sanfilippo et al., 1985). Columns under hole numbers list the core and section numbers, and the sub-bottom depths (mbsf; in parentheses), between which each event occurs. Complete species names are given in the Species List (Appendix A).

APPENDIX C. PALEOGENE RADIOLARIAN EVENTS IN HOLES 709C AND 711A.

Events	Hole 709C	Hole 711A
B *T. spongoconus*	29X-2 (268.6) to 29X-4 (271.6)	—
T *D. mongolfieri*	29X-CC (276.1) to 30X-2 (278.3)	16X-CC (153.0) to 17X-2 (155.2)
T *S. babylonis*	29X-CC (276.1) to 30X-2 (278.3)	16X-CC (153.0) to 17X-2 (155.2)
A. barbadensis → *A. gracilis*	29X-CC (276.1) to 30X-2 (278.3)	16X-CC (153.0) to 17X-2 (155.2)
T *L. bellum*	29X-CC (276.1) to 30X-2 (278.3)	16X-CC (153.0) to 17X-2 (155.2)
[*L. aristotelis* → *L. angusta*]	29X-CC (276.1) to 30X-2 (278.3)	16X-CC (153.0) to 17X-2 (155.2)
T *L. jacchia*	29X-CC (276.1) to 30X-2 (278.3)	16X-CC (153.0) to 17X-2 (155.2)
T *C. ornata*	29X-CC (276.1) to 30X-2 (278.3)	16X-CC (153.0) to 17X-2 (155.2)
B *T. tuberosa*	30X-CC (285.8) to 31X-2 (288.0)	17X-4 (158.2) to 17X-6 (161.2)
T *C. bandyca*	30X-CC (285.8) to 31-2 (288.0)	17X-CC (162.7) to 18X-2 (164.9)
T *C. turris*	31X-2 (288.0) to 31X-4 (291.0)	17X-CC (162.7) to 18X-2 (164.9)
T *T. rhizodon*	31X-2 (288.0) to 31X-4 (291.0)	17X-CC (162.7) to 18X-2 (164.9)
T *T. bromia*	31X-4 (291.0) to 31X-CC (295.4)	17X-CC (162.7) to 18X-2 (164.9)
[T *T. tetracantha*]	31X-4 (291.0) to 31X-CC (295.4)	17X-CC (162.7) to 18X-2 (164.9)
T *C. azyx*	31X-4 (291.0) to 31X-CC (295.4)	17X-CC (162.7) to 18X-2 (164.9)
T *E. fistuligerum*	32X-2 (297.6) to 323X-4 (300.6)	17X-CC (162.7) to 18X-2 (164.9)
T *C. hispida*	32X-2 (297.6) to 32X-4 (300.6)	18X-4 (167.9) to 18X-CC (172.4)
T *T. triacantha*	32X-4 (297.6) to 32X-6 (300.6)	18X-4 (167.9) to 18X-CC (172.4)
T *P. goetheana*	33X-2 (307.3) to 33X-4 (310.3)	18X-CC (172.4) to 19X-2 (174.6)
[B *C. bandyca*]	33X-2 (307.3) to 33X-4 (310.3)	18X-CC (172.4) to 19X-2 (174.6)
B *C. turris*	33X-2 (307.3) to 33X-4 (310.3)	19X-4 (177.6) to 19X-6 (180.6)
[B *C. azyx*]	33X-2 (307.3) to 33X-4 (310.3)	19X-4 (177.6) to 19X-6 (180.6)
T *T. ficus*	33X-2 (307.3) to 33X-4 (310.3)	19X-4 (177.6) to 19X-6 (180.6)
B *T. bromia*	33X-2 (307.3) to 33X-4 (310.3)	19X-4 (177.6) to 19X-6 (180.6)
T *P. chalara*	33X-2 (307.3) to 33X-4 (310.3)	19X-6 (180.6) to 19X-CC (182.1)
B *T. tetracantha*	33X-2 (307.3) to 33X-4 (310.3)	19X-6 (180.6) to 19X-CC (182.1)
B *D. pirum*	33X-4 (310.3) to 33X-CC (314.8)	19X-4 (177.6) to 19X-6 (180.6)
T *S. triconiscus*	33X-4 (310.3) to 33X-CC (314.8)	19X-6 (180.6) to 19X-CC (182.1)
L. ocellus → *L. aristotelis*	33X-4 (310.3) to 33X-CC (314.8)	19X-6 (180.6) to 19X-CC (182.1)
B *T. triceros*	33X-4 (310.3) to 33X-CC (314.8)	19X-6 (180.6) to 19X-CC (182.1)
[B *P. goetheana*]	33X-4 (310.3) to 33X-CC (314.8)	19X-6 (180.6) to 19X-CC (182.1)
T *L. vespertilio*	33X-4 (310.3) to 33X-CC (314.8)	19X-CC (182.1) to 20X-2 (184.3)
T *P. trachodes*	34X-2 (317.0) to 34X-4 (320.0)	20X-2 (184.3) to 20X-4 (187.3)
T *P. striata striata*	34X-2 (317.0) to 34X-4 (320.0)	20X-2 (184.3) to 20X-4 (187.3)
[*P. mitra* → *P. chalara*]	34X-2 (317.0) to 34X-4 (320.0)	20X-4 (187.3) to 20X-CC (191.7)
B *C. ornata*	33X-2 (307.3) to 33X-4 (310.3)	20X-4 (187.3) to 20X-CC (191.7)
T *L. biaurita*	35X-2 (326.6) to 35X-4 (329.6)	21X-4 (196.9) to 21X-CC (201.4)
T *P. fasciolata*	35X-2 (326.6) to 35X-4 (329.6)	21X-4 (196.9) to 21X-CC (201.4)
T *E. lagena*	35X-6 (332.6) to 35X-CC (334.1)	22X-4 (206.6) to 22X-CC (211.1)

Appendix C (continued).

Events	Hole 709C	Hole 711A
B *S. triconiscus*	35X-CC (334.1) to 36X-2 (336.3)	22X-CC (211.1) to 23X-2 (213.3)
[*P. sinuosa* → *P. mitra*]	35X-CC (334.1) to 36X-2 (336.3)	22X-CC (211.1) to 23X-2 (213.3)
B *P. trachodes*	36X-2 (336.3) to 36X-CC (343.9)	22X-4 (206.6) to 22X-CC (211.1)
E. lagena → *E. fistuligerum*	36X-CC (343.9) to 37X-2 (346.1)	23X-2 (213.3) to 23X-4 (216.3)
B *P. fasciolata*	36X-CC (343.9) to 37X-2 (346.1)	23X-2 (213.3) to 23X-4 (216.3)
T *P. dorus*	37X-4 (349.1) to 37X-6 (352.1)	23X-6 (219.3) to 23X-CC (220.7)
T *T. venezuelensis*	37X-6 (352.1) to 23X-6 (219.3)	23X-4 (216.3) to 37X-CC (353.7)
[*P. phyxis* → *P. ampla*]	—	—
T. conica	37X-6 (352.1) to 37X-CC (353.7)	23X-CC (220.7) to 24X-2 (222.9)
T *T. hirsuta*	—	24X-CC (230.3) to 25X-2 (232.5)
T *T. robusta*	—	25X-2 (232.5) to 25X-4 (235.5)
T *L. fabaeformae constrictum*	—	25X-4 (235.5) to 25X-CC (240.0)
T *L. fabaeformae chaunothorax*	—	25X-4 (235.5) to 25X-CC (240.0)
T. tensa → *T. triacantha*	—	25X-4 (235.5) to 25X-CC (240.0)
[B *E. lagena*]	— 25X-CC (240.0)	25X-4 (235.5) to
T *L. fabaeformae fabaeformae*	—	25X-4 (235.5) to 25X-CC (240.0)

Notes: The letters "T" and "B" signify the morphotypic top and bottom of each species' range. Events in brackets, [ ], define zonal boundaries (Saunders et al., 1985; Sanfilippo et al., 1985). Columns under hole numbers list the core and section numbers, and the sub-bottom depths (mbsf; in parentheses), between which each event occurs. Complete species names are given in the Species List (Appendix A).