11. QUATERNARY RADIOLARIANS FROM THE EQUATORIAL PACIFIC, DEEP SEA DRILLING PROJECT LEG 85[1]

Monique Labracherie, Département de Géologie et Océanographie, Université de Bordeaux I[2]

ABSTRACT

Quaternary radiolarians are common and rather well preserved in the sections recovered from DSDP Holes 571, 572A, and 573. The assemblages from Hole 575C are less abundant and contain high concentrations of reworked specimens. Twelve first occurrences, extinction levels, and transitions, some of which are already known in the equatorial Pacific area, are recognized in the interval between the top of the Olduvai and the present (approximately between the Pliocene/Pleistocene boundary and the Holocene). These radiolarian events are compared and correlated with both the paleomagnetic time scale and the carbonate content determined from an undisturbed section with a high sediment accumulation rate.

INTRODUCTION

Numerous biostratigraphic studies have shown the usefulness of radiolarian species for interpretation of the Quaternary. Nigrini's (1971) Quaternary radiolarian zonation of the tropical Pacific presented the main stratigraphic markers. Later, Johnson and Knoll (1975) proposed age estimates for zonal boundaries of this zonation by correlation with paleomagnetic stratigraphy. Recently, Goll (1980) did not apply Nigrini's zonation to the eastern province of the equatorial Pacific, because of the absence of some biostratigraphic indicator taxa. The presence of radiolarians more typical of eastern equatorial assemblages gave him the opportunity to establish a new biozonation with a high resolution. One of the disadvantages of the fourfold Quaternary zonation proposed by Nigrini (1971) is indeed the relatively long time-range of biozones 3 and 4 (the *Amphirhopalum ypsilon* Interval-Zone and the *Anthocyrtidium angulare* Range-Zone).

Leg 85 coring recovered sediments containing especially diverse and abundant Quaternary radiolarians. Radiolarian assemblages were examined in 4 of 17 holes on Leg 85. These four holes (571, 572A, 573, and 575C) are situated in two regions of the equatorial Pacific: Holes 573 and 575C at approximatively 0°N, 134°W and 5°N, 134°W, respectively, and Holes 572A and 571 at about 1°N, 114°W and 4°N, 114°W, respectively toward the East Pacific Rise (Fig. 1).

All radiolarian datum levels of Johnson and Knoll (1975) and some biohorizons or evolutionary lineages of Goll (1980) are easily recognizable in Leg 85 sediments. They correlate directly with stratigraphies based upon paleomagetism (Weinreich and Theyer, this volume) and/or carbonate content (Pujos, this volume).

PROCEDURES

Cores from Holes 571 and 575C were sampled at 20-cm intervals. In cores from Holes 573 and 572A, only three or four samples per core were analyzed. Sediments were treated with H_2O_2 and HCl and sieved through a 45-μm screen. Strewn slides were also prepared, following the procedures outlined by Riedel and Sanfilippo (1977).

In the Quaternary stratigraphic zonation schemes based on the radiolarian fauna, the definition of limits of species range is somewhat ambiguous because of (1) low abundances of the marker taxa, resulting from their usually strong dilution in the biosiliceous (radiolarian) assemblages, (2) fragility of skeletons of some stratigraphic indicator radiolarians, causing poor preservation and (3) the possibility of reworking.

In this investigation of radiolarians from Leg 85 Quaternary sequences, for each sample, about 500 specimens were counted on one slide, along several horizontal traverses, and the main species found in this geographic area were noted. Six categories were used to indicate the relative abundances of selected taxa (see Tables 1 to 4). The level for each species event was chosen as the lowermost or uppermost sample—bounding an interval of regular presence—in which the taxon occurs; in the ideal cases, these samples show an increased abundance (above the first-occurrence level) and a decreased abundance (below extinction level) of the taxon, respectively.

QUATERNARY ZONATION

The main faunal constituents of Leg 85 radiolarian assemblages are typically equatorial and tropical; but species more specifically associated with the Peru coastal upwelling are present (Romine and Moore, 1981). The low-latitude radiolarian zonation of Nigrini (1971) is applied as a starting point to describe the radiolarians at each site (Table 5). The radiolarian zonal sequence used to characterize these Pleistocene assemblages includes events identified in both central and eastern equatorial provinces of the Pacific Ocean. The paleomagnetism record is used as the basis for the chronostratigraphy, and fluctuations in carbonate content are used for the local correlations.

Site 571

Core 571-1 contains Quaternary assemblages of good to moderate preservation (Table 1). Changes in the preservation of biogenic silica can be correlated with impor-

[1] Mayer, L., Theyer, F., Thomas, E., et al., *Init. Repts. DSDP*, 85: Washington (U.S. Govt. Printing Office).

[2] Address: Département de Géologie et Océanographie, Laboratoire associé au C.N.R.S. no. 197, Université de Bordeaux I, Avenue des Facultés, 33405 Talence Cedex, France.

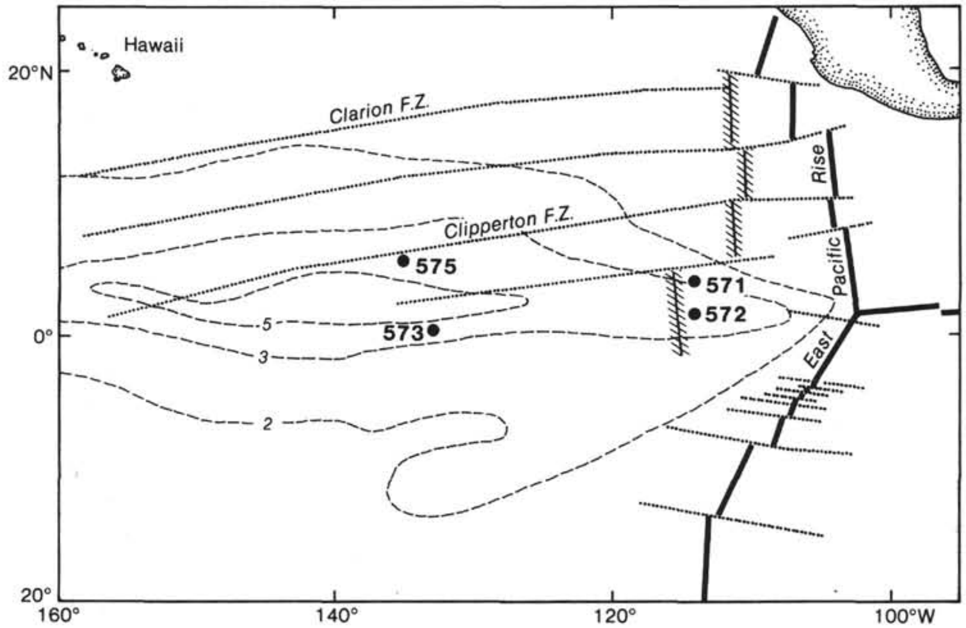

Figure 1. Locations of Sites 571, 572, 573, and 575 (Leg 85) in relation to sediment thickness (broken contours) and fracture zones. Contour intervals are in tenths of seconds of two-way traveltime.

tant fluctuations in the carbonate content. Minima and maxima in the carbonate content at Site 571 are given by Pujos (this volume). Radiolarians from carbonate-rich sediments are abundant, well preserved, and diluted by centric diatoms. Assemblages are generally more poorly preserved within intervals where the carbonate content is minimal. Samples 571-1-2, 41–43 cm, 571-1-3, 18–20 cm, and 571-1-4, 118–120 cm yielded many broken forms, associated sometimes with numerous *Ethmodiscus* fragments, whereas centric diatoms become rare or absent in the fraction greater than 45 μm. Radiolarians are diluted by clay aggregates, which may be trapped inside skeletons.

Hole 571 reached only the uppermost levels of the Quaternary. Abundances of some radiolarians are shown in Table 1. Specimens indicative of the uppermost two Quaternary zones of Nigrini's (1971) zonation are common throughout the top meter. These species decrease or disappear below the minima in the carbonate content. The uppermost samples (571-1-5, 21–23 cm through 571-1,CC, 20 cm) containing *Axoprunum angelinum* (= *Stylatractus universus*) can be considered older than 410,000 yrs. (age estimated by Hays and Shackleton [1976] for the extinction level of this species over the whole of its geographic distribution). The date of its last appearance has been differently estimated at 320,000 yrs. ago in the equatorial Pacific (Johnson and Knoll, 1975).

Site 572

Sediments from the upper 26 m of Hole 572A (Cores 572A-1 through 572A-3) represent a continuous record throughout the Quaternary of the eastern equatorial Pacific. Sediments contain well-preserved to moderately well preserved radiolarian assemblages diluted with diatoms. Reworking is minor and occasional (Table 2). The high diversity of assemblages reveals biogeographic correlations with the radiolarian fauna from DSDP sites of the East Pacific Rise and the Galapagos Spreading Center (Goll, 1980); species belonging to the genus *Acrosphaera* are always more scarce, however.

The four Quaternary zones of Nigrini's (1971) tropical zonation can be recognized, but some events described by Goll (1980), using data from Leg 54 sites, are also represented in the assemblages from Hole 572A. Approximately the uppermost 43 cm are from the *Buccinosphaera invaginata* Zone, and the underlying 5 m are from the *Collosphaera tuberosa* Zone. Samples 572A-1-5, 117–119 cm (7.17 m sub-bottom) and 572A-2-3, 118–120 cm (13.70 m) contained the uppermost occurrences of *Axoprunum angelinum* and *Amphispyris roggentheni*, respectively. This latter species, described by Goll (1980), was originally reported in the eastern Pacific, where it became extinct about 650,000 yrs. ago. The transition from *Androspyris anthropiscus* to *A. huxleyi* can be placed between Samples 572A-2-2, 37–39 cm (last occurrence of *A. anthropiscus*) and 572A-1-6, 76–78 cm (first occurrence of *A. huxleyi*). There is a gap between the two events, which occurs between the uppermost occurrences of *A. angelinum* and *A. roggentheni*. Sporadic occurrences of *Androspyris* specimens have been mentioned by Goll (1980), and can explain why it is difficult to place exactly the limit of the *A. anthropiscus*–*A. huxleyi* transition in Hole 572A. Goll (1980) gave it a date of about 500,000 yrs. ago. Samples 572A-2-6, 117–119 cm through 572A-3-2, 142–144 cm have been assigned to the *Anthocyrtidium angulare* Zone. The uppermost occurrence of *Pterocanium prismatium*, between Samples 572A-3-5, 118–120 cm and 572A-3-5, 141–143 cm, places the Pliocene/Pleistocene boundary near 26 m sub-bottom.

Table 1. Ranges and frequency of selected radiolarian species, DSDP Hole 571.

Core-Section (interval in cm)	Preservation	Reworking	Zone	*Buccinosphaera invaginata*	*Collosphaera tuberosa*	*Collosphaera orthoconus*	*Androspyris huxleyi*	*Disolenia* spp.	*Lamprocyrtis nigriniae*	*Pterocorys hertwigii*	*Axoprunum angelinum (S. universus)*	*Lithopera bacca*	*Androspyris anthropiscus*	*Amphispyris roggentheni*	*Anthocyrtidium angulare*	*Lamprocyrtis neoheteroporos*	*Lamprocyrtis heteroporos*	*Theocorythium trachelium* gr.	*Theocorythium vetulum*	*Pterocanium prismatium*	*Amphirhopalum ypsilon*
1-1, 0–2	MG	*		r	R	—	—	F	—	R								F			R
1-1, 20–22	M			—	F	—	—	C	—	r								r			R
1-1, 40–42	MG			r	C	r	—	C	—	r								r			r
1-1, 60–62	G	*		r	F	r	—	C	—	r								—			r
1-1, 81–83	GM		*B. invaginata*	r	R	r	—	F	—	r								—			r
1-1, 101–103	M	*		—	F	r	—	F	—	R								—			R
1-1, 121–123	MG	*		+	R	r	—	F	—	r								—			r
1-2, 1–3	M	*		—	R	—	—	R	—	r								r			r
1-2, 21–23	MG	*		—	—	r	—	R	—	r								r			R
1-2, 41–43	P	*		—	—	—	—	—	—	r								r			—
1-2, 81–83	G			+	—	r	r	F	—	r								—			r
1-2, 102–104	MG	*		!	—	F	r	F	—	r								—			r
1-2, 120–122	MG			—	r	—	—	F	R	r								—			R
1-2, 137–139	P	*	*C. tuberosa*	r!	R	—	—	C	R	—								r			R
1-3, 18–20	P			—	R	—	—	R	—	r								r			r
1-3, 56–58	M			—	+	—	—	F	—	—								R			r
1-3, 98–100	M	*		—	r	r	+	F	—	R								r			r
1-3, 118–120	P	*			R	R	—	C	—	r								—			R
1-4, 3–5	G				—	r	—	F	—	—								r			R
1-4, 36–38	MP				—	—	—	F	—	r	—							—			R
1-4, 98–100	MP	*			—	—	—	F	—	—	—							r			F
1-4, 137–139	P	*			—	—	—	r	+	—	—							r			R
1-5, 4–6	G				—	—	—	r	—	r	—	—	—					F			F
1-5, 21–23	M	*	*A. ypsilon*		—	—	—	r	—	r	r	—	—	—				r			R
1-5, 40–42	M					—	r	R	r	r	r	—	—	—				r			R
1-5, 61–63	M	*				+	—	r	—	r	R	—	—	—				—			R
1-5, 81–83	P					—	—	R	—	—	R	—	—	—				—			R
1,CC (1–3)	MG					—	—	—	—	r	R	r	—	—				r			F
1,CC (17–19)	MG					—	—	—	—	—	R	—	—	—				—			F

Note: Species abundances: — = species sought but not found; + = present (<0.15% of the encountered radiolarians with a constant species numeration, generally about 1 specimen per slide); r = very rare specimens (0.15–0.99%); R = rare specimens (1–2.99%); F = few specimens (3–9.99%); C = common (>10% or more than about 60 specimens per slide); ! = reworking. Preservation of the assemblage: P = poor; M = moderate; G = good. Reworking: * = low.

Site 573

Hole 573 was drilled farther west in the equatorial Pacific, and is the southernmost hole of Leg 85. The magnetostratigraphy provided by the major polarity-reversal events in this hole (Weinreich and Theyer, this volume) places the base of the Quaternary between Samples 573-4-3, 88 cm and 573-4-3, 136 cm, at the top of the Olduvai event (Berggren et al., 1980). A record of fluctuations in calcium carbonate content is also available from this same hole (Pujos, this volume).

On average, radiolarians are moderately well preserved, abundant to common, and somewhat diluted by diatoms, with a very small number of reworked Pliocene and Miocene species. Pliocene radiolarians (especially *Spongaster pentas*) occur in well-preserved Pleistocene assemblages. Older forms are mixed into more poorly preserved assemblages. Relative abundances of radiolarians, and the zonation, are shown in Table 3. Preservation is very good at the top (Cores 573-1 and 573-2). The *Buccinosphaera invaginata* and *Collosphaera tuberosa* zones occupy about the upper 0.70 and 4.5 m, respectively. The first-occurrence level of *C. tuberosa* lies above poorly preserved samples. The *Amphirhopalum ypsilon* Zone is quite thick (about 14 m). Within this broad interval, the last occurrence of *Axoprunum angelinum* (= *Stylatractus universus*) is between Samples 573-2-3, 145–147 cm and 573-2-4, 36–40 cm. The average relative-abundance curve of this taxon seems to indicate that its upper limit could have been truncated, because the progressive final decline (Hays and Shackleton, 1976) was not observed. Only two samples contain *Androspyris anthropiscus*, and the last occurrence of *Amphispyris roggentheni* is between Sample 573-3-2, 35–37 cm and 573-3-2, 85–87 cm. The *Anthocyrtidium angulare* Range Zone is bounded by both the extinction levels of *A. angulare* and *Lamprocyrtis neoheteroporos*, at the top, and the first occurrence of *A. angulare*, just above the uppermost occurrence of *Pterocanium prismatium* at the base. In Hole 573, this last species is very abundant in its uppermost occurrence, which coincides exactly with the top of the Olduvai.

Table 2. Ranges and frequency of selected radiolarian species, DSDP Hole 572A.

Core-Section (interval in cm)	Preservation	Reworking	Zone	*Buccinosphaera invaginata*	*Collosphaera tuberosa*	*Collosphaera orthoconus*	*Androspyris huxleyi*	*Disolenia* spp.	*Lamprocyrtis nigriniae*	*Pterocorys hertwigii*	*Axoprunum angelinum (S. universus)*	*Lithopera bacca*	*Androspyris anthropiscus*	*Amphispyris roggentheni*	*Anthocyrtidium angulare*	*Lamprocyrtis neoheteroporos*	*Lamprocyrtis heteroporos*	*Theocorythium trachelium* gr.	*Theocorythium vetulum*	*Pterocanium prismatium*	*Amphirhopalum ypsilon*
1-1, 2-4	G			r	R	—	—	R	r	R								R			R
1-1, 21-23	M		*B. invaginata*	r	R	r	—	F	r	R								—			R
1-1, 41-43	GM			r	R	—	—	F	r	+								—			r
1-1, 61-63	GM			—	R	—	—	R	r	R								r			r
1-1, 90-101	G			—	R	r	—	R	—	R								r			r
1-1, 141-143	M			—	F	r	—	r	r	r								R			R
1-2, 37-39	G			—	r	—	—	+	r	r								R			r
1-2, 77-79	G			—	—	—	r	r	—	r								r			r
1-2, 117-119	GM			—	r	—	—	R	r	r								—			R
1-3, 37-38	MG		*C. tuberosa*	—	r	—	—	R	r	r								—			r
1-3, 77-79	G			—	+	—	+	R	r	+								R			r
1-3, 118-119	GM			+!	—	—	—	R	—	R								r			R
1-3, 137-139	G			—	R	r	—	R	—	R								r			+
1-4, 36-38	M			—	r	—	—	R	—	r	—							—			R
1-4, 117-119	P	*		—	—	—	—	R	—	r	—							—			R
1-4, 137-139	MP	*		—	—	—	—	R	r	r	—							r			R
1-5, 36-38	G			—	—	—	—	R	—	r	—	—						—			R
1-5, 76-78	G				—	—	—	r	r	r	—	—						r			R
1-5, 117-119	G	*			—	—	—	R	—	R	+	—						R			R
1-5, 137-139	G				—	—	—	r	r	r	r	—	—					—			r
1-6, 36-38	P				—	—	—	r	—	R	R	—	—					—			R
1-6, 76-78	M				—	—	r	R	R	—	r	—	—	—				—			R
1-6, 137-139	G					+!	—	R	—	R	r	r	—	—				+			R
2-1, 37-39	G					—	—	R	—	r	r	r	—	—				r			R
2-1, 117-119	G	*				r	—	r	—	+	r	r	—	—				r			F
2-2, 37-39	M	*	*A. ypsilon*			—	—	+	—	—	R	—	—	—				R			R
2-2, 117-119	MG	*				—	—	—	—	—	r	—	—	—				r			R
2-3, 38-40	MG					—	—	—	—	—	r	—	+	—				R			R
2-3, 118-120	M					—	—	—	—	—	r	r	—	+				R			R
2-3, 141-143	G					—	—	+	—	—	r	—	r	r				R			R
2-4, 77-79	G					—	—	+	—	+	R	r	—	—	—	—		R			r
2-4, 142-144	GM							r	—	r	—	—	—	r	—	—		R			R
2-5, 37-39	G							r	—	r	r	+	—	+	—	—	—	R			R
2-5, 77-79	G							—	—	—	R	R	r	—	—	—	—	R			R
2-5, 142-144	G							r	—	+	r	r	—	+	—	—	—	R			r
2-6, 82-84	GM							—	—	—	R	—	r	+	—	—	—	r			+
2-6, 117-119	GM							—	—	+	r	+	+	—	+	r	—	r	—		R
2-6, 142-144	G							—	—	+	r	r	+	—	R	+	—	—	—		—
3-1, 37-39	G							r	—	—	r	—	+	—	R	r	—	F	—		R
3-1, 82-84	G							r	—	—	r	+	—	r	R	r	—	R	—		R
3-1, 117-119	M							—	—	—	R	r	—	—	r	r	r	r	r		—
3-1, 142-144	G							R	—	—	R	r	—	+	r	+	—	R	R		R
3-2, 37-39	G							+	—	—	r	r	+	—	F	r	—	R	r		R
3-2, 81-83	G							r		—	R	—	—	r	F	—	—	R	+		R
3-2, 142-144	G							r		—	r	r	r	r	R	r	r	R	R		R
3-3, 81-83	G		*A. angulare*					—			F	—	—	—	r	R	—	r	F		F
3-3, 141-143	G							—			F	—	—	—	r	—	r	r	R		R
3-4, 37-39	G							—			F	r	—	—	R	—	r	r	F		R
3-4, 81-83	G							—			F	R	—	—	r	—	r	+	R		r
3-4, 118-120	M							—			F	—	—	—	r	—	F	—	F		r
3-4, 141-143	M							—			R	r	—	r	—	r	R	—	F	—	r
3-5, 37-39	G							r			r	—	r	—	—	—	r	+	F	—	r
3-5, 81-83	G							+			R	r	—	r	—	—	R	—	R	—	R
3-5, 118-120	M							r			R	r	—	—	—	—	R	+	F	—	R
3-5, 141-143	M							R			R	—	+	—	—	?	r	—	F	r	R
3-6, 82-84	M		*P. prismatium*					R			R	—	—	—	—	—	r	—	F	R	r
3-6, 118-120	GM							R			R	—	—	—	—	r!	r	—	F	R	r

Note: Symbols for species abundances, preservation, and reworking as in Table 1; ? = doubtful.

Table 3. Ranges and frequency of selected radiolarian species, DSDP Hole 573.

Core-Section (interval in cm)	Preservation	Reworking	Zone	*Buccinosphaera invaginata*	*Collosphaera tuberosa*	*Collosphaera orthoconus*	*Androspyris huxleyi*	*Disolenia* spp.	*Lamprocyrtis nigriniae*	*Pterocorys hertwigii*	*Axoprunum angelinum* (*S. universus*)	*Lithopera bacca*	*Androspyris anthropiscus*	*Amphispyris roggentheni*	*Anthocyrtidium angulare*	*Lamprocyrtis neoheteroporos*	*Lamprocyrtis heteroporos*	*Theocorythium trachelium* gr.	*Theocorythium vetulum*	*Pterocanium prismatium*	*Amphirhopalum ypsilon*
1-1, 30–33	G		*B. invaginata*	r	R	—	—	C	r	F								r			r
1-1, 70–72	G	•		r	R	r	—	F	r	F								—			r
1-1, 110–113	GM		*C. tuberosa*	—	r	r	—	F	r	F								r			r
1-2, 20–22	G			—	r	—	—	r	—	R								R			R
2-1, 145–147	G			—	r	r	—	F	r	R								R			r
2-2, 38–40	M				R	R	—	r	r	F	—							r			R
2-2, 95–97	M				+	+	—	R	r	R	—							—			R
2-2, 145–157	P	•	*A. ypsilon*		—	—	—	r	r	R	—							—			F
2-3, 38–40	P				—	—	—	F	r	R	—	—						—			R
2-3, 95–97	M				—	—	—	R	r	R	—	—	—					—			R
2-3, 145–147	PM				—	—	—	R	R	R	—	—	—					—			R
2-4, 36–40	M						—	—	r	r	R	—	—					—			R
2-4, 95–97	G	•					?	R	R	R	R	r	—					r			R
2-4, 145–147	M						—	R	r	F	r	—	—					—			R
2-5, 36–40	M						—	R	r	F	r	r	—					—			r
2-5, 95–97	MG						—	r	r	R	R	—	—					r			F
2-5, 143–145	M							r	—	r	R	r	—					—			F
2-6, 36–38	P	•						r	r	R	r	—	—	—				—			R
2-6, 95–97	M							R	r	R	R	—	—	—				r			F
2-6, 138–140	G							r	+	R	r	—	+	—				r			F
2-7, 36–38	P	•						r	r	R	r	—	—	—				—			R
3-1, 8–10	MP	•						r	+	R	r	—	+	—				r			F
3-1, 68–70	M							r	r	F	r	—	—	—				R			F
3-1, 125–127	P							—	r	R	r	—	—	—				R			F
3-1, 146–147	M	•						—	+	r	R	—	+	—	—			R			F
3-2, 35–37	GM							r	r	—	R	—	—	—	—			F			R
3-2, 85–87	GM							r	—	—	R	—	—	r	—	—		F			F
3-2, 135–137	M	•						r	r	—	R	—	—	—	—	—		F			R
3-3, 35–37	MG							R	+	—	r	—	—	—	—	—		F			F
3-3, 85–87	MG							r	r	—	R	r	—	r	—	—	—	F			R
3-3, 135–137	MG							r	r	—	R	R	—	r	—	—	—	F			R
3-4, 35–37	P							R	—	—	r	—	—	—	—	—	—	R			R
3-4, 85–87	M							—	r	—	r	R	—	r	—	—	—	F			R
3-4, 135–137	GM	•						—	r	—	r	—	—	r	r	—	—	F	—		F
3-5, 6–8	GM							r	—	—	r	r	—	—	—	—	—	F	—		F
3-5, 35–37	G							—	—	—	r	—	—	—	—	r	—	F	—		F
3-5, 85–87	G		*A. angulare*					R	+	—	R	r	—	r	F	—	r	F	—		R
3-5, 135–137	MG							R	—	—	R	R	—	r	F	R	—	F	—		F
3-6, 36–37	G							r	—	—	R	R	—	r	F	r	R	F	—		r
3-6, 85–87	G							—	—	—	r	r	—	—	F	r	—	R	r		F
3-6, 135–137	MG							—	—	—	R	r	—	—	C	r	—	R	r	—	F
4-1, 103–105	M	•						r	—	—	R	r	—	—	F	F	+	+	r	—	R
4-1, 144–146	M	•						+	—	—	R	r	—	—	F	R	—	r	R	—	R
4-2, 36–37	G							r	—	—	R	r	—	+	F	R	r	r	r	—	R
4-2, 135–137	G							—	—	—	R	r	—	r	R	R	r	—	r	—	R
4-3, 3–10	G	•						—	—	—	r	r	—	+	R	—	r	—	r	—	R
4-3, 35–37	G							r	—	—	R	—	—	—	r	—	r	R	r	—	R
4-3, 87–89	G		*P. prismatium*					R	—	—	r	—	—	—	—	—	—	—	r	F	—

Note: Symbols for species abundances, preservation, and reworking as in Table 2.

Site 575

Hole 575C, at 6°N near the Clipperton Fracture Zone, is the northernmost site of Leg 85. Magnetic stratigraphy was established (Weinreich and Theyer, this volume) and the Pliocene/Pleistocene boundary placed between Samples 575C-1-3, 106 cm and 575C-1-3, 116 cm. Hole 575C reached the uppermost level of the Pliocene at 4.11 m sub-bottom. Percentages of calcium carbonate were not determined. Pleistocene sedimentation appears to have been strongly influenced by bottom currents. The rate of sediment accumulation was lower in this hole, even though it was drilled in the high-productivity area, and the sediments contain very high proportions of reworked Tertiary radiolarians throughout the entire section. Reworking is especially important near the Pliocene/Pleistocene and Brunhes/Matuyama boundaries; it dominates the younger assemblages in the upper part of the Brunhes, except those of some uppermost levels. Preservation of Pleistocene radiolarians is regularly poor

Table 4. Ranges and frequency of selected radiolarian species, DSDP Hole 575C.

Core-Section (interval in cm)	Preservation	Reworking	Zone	*Buccinosphaera invaginata*	*Collosphaera tuberosa*	*Collosphaera orthoconus*	*Androspyris huxleyi*	*Disolenia* spp.	*Lamprocyrtis nigriniae*	*Pterocorys hertwigii*	*Axoprunum angelinum* (*S. universus*)	*Lithopera bacca*	*Androspyris anthropiscus*	*Amphispyris roggentheni*	*Anthocyrtidium angulare*	*Lamprocyrtis neoheteroporos*	*Lamprocyrtis heteroporos*	*Theocorythium trachelium* gr.	*Theocorythium vetulum*	*Pterocanium prismatium*	*Amphirhopalum ypsilon*
1-1, 5-7	M	*	*B. invaginata*	+	r	—	—	F	—	—								—			+
1-1, 25-27	M	*		+	R	—	—	r	—	—								—			—
1-1, 45-47	M	**	*C. tuberosa*	—	r	r	—	r	—	—	—	—						—			r
1-1, 65-67	P	***		—	+	—	—	r	r	—	—	—						—			r
1-1, 85-87	P	***	*A. ypsilon*		?	—	?	r	—	—	—	—						r			—
1-1, 105-107	P	***			?	R	—	—	+	—	—	—						r			r
1-1, 125-127	M	***			—	r	—	—	+	—	r	r						R			R
1-1, 145-147	P	***			—	—	—	—	—	—	r	r						r			F
1-2, 15-17	MP	**				r	—	—	—	—	r	—						r			F
1-2, 35-37	MP	*				r	—	—	—	—	r	—						—			F
1-2, 55-57	M	*				—	—	—	—	—	+	—	—	—				—			R
1-2, 85-87	M	*									r	—	—	—				r			F
1-2, 95-97	M	***									r	—	—	—				F			F
1-2, 115-117	MG	**									+	+	—	+	—			F			r
1-2, 135-137	M	*									+	—	—	+	—	—		r			r
1-2, 145-147	MG	**									—	r	—	r	—	r		R			r
1-3, 5-7	P	**									+	r	—	r	—	r	—	r			r
1-3, 25-27	P	**	*A. angulare*								—	—	—	r	r	r	—	—	—		+
1-3, 45-47	MG	***									r	r	—	r	R	R	—	r	—		F
1-3, 65-67	MG	***									r	r	—	—	R	r	r	r	—	—	r
1-3, 85-87	P	***									r	—	—	r	r	—	r	r	r	—	+
1-3, 105-107	P	***									r	—	—	—	—	+	r	—	r	—	—
1-3, 115-117	P	***	*P. prismatium*								r	r	—	—	r	—	r	r	—	r	—

Note: Species abundances are estimated. Symbols for abundance, preservation, and reworking as in Table 2. (Additional symbols for reworking: ** = moderate; *** = high.)

to moderate, and may explain the discontinuous occurrences. All stratigraphic indicator species are scarce, but the different radiolarian zones or events could be observed (Table 4). *Buccinosphaera invaginata* is confined to a thin surface layer about 25 cm thick, and *Collosphaera tuberosa* occurs within the topmost meter. The genus *Acrosphaera* is exceptionally abundant at the top of the Quaternary sequence. The *Anthocyrtidium angulare* Zone occupies a short interval, and the first and the last occurrences of *A. angulare* are recorded in poorly preserved samples. The extinction level of *Pterocanium prismatium* coincides with the upper boundary of the Olduvai event.

CORRELATIONS AND DISCUSSION

Discussion of the correlations of sequences here proceeds from the base (Pliocene/Pleistocene boundary) to the top (the present). Hole 573 was chosen as the reference Quaternary section for Leg 85 because levels of lowermost and uppermost occurrence can be compared with both the paleomagnetism record (Weinreich and Theyer, this volume) and the calcium carbonate curve (Pujos, this volume). Moreover, Hole 573 yielded an almost undisturbed succession having a high sediment accumulation rate (Figs. 2 and 3).

The Pliocene/Pleistocene boundary is placed near the top of the Olduvai polarity event according to Berggren et al. (1980); it is very close to the extinction level of *Pterocanium prismatium* (about 1.65 Ma). It seems necessary, however, to discuss the exact characteristics of the upper limit of the *Pterocanium prismatium* Zone emended by Riedel and Sanfilippo (1977). Goll (1980) mentioned that the last appearance of *P. prismatium* was diachronous in the equatorial Pacific; that is, there was a gap between this event and the first appearance of *Lamprocyrtis nigriniae*, and consequently there is no radiolarian biohorizon for the Pliocene/Pleistocene boundary.

In Holes 573 and 575C the upper limit of *Pterocanium prismatium* coincides with the Pliocene/Pleistocene boundary and the first occurrence of *Anthocyrtidium angulare*. These events mark also the top of carbonate-dissolution cycle M17, which has been correlated with the top of the Olduvai (Hays et al., 1969 and Gardner, 1982). The last occurrence of *Theocorythium vetulum* is higher in the section. In Hole 572A *P. prismatium* becomes extinct at the top of carbonate stage M17, but there is a gap between this extinction level and the first occurrence of *A. angulare*, which lies higher in the sequence.

Farther east (Goll, 1980), *A. angulare* is even scarcer, and its lower limit is higher in the Pleistocene sequence. This may reflect a true diachronism in the appearance of this species. Interpretation of its morphologic limits becomes more difficult toward the eastern regions of the

Table 5. Radiolarian zones and events, Holes 571, 572A, 573, and 575C.

Age	Radiolarian zone (Nigrini, 1971)	Radiolarian "event"	Hole 571	Hole 572A	Hole 573	Hole 575C
			Core-Section (interval in cm)			
Quaternary	*B. invaginata* *C. tuberosa*	FO *B. invaginata*	1-1, 121–123 1-2, 1–3	1-1, 41–43 1-1, 61–63	1-1, 70–73 1-1, 110–113	1-1, 25–27 1-1, 35–37
	C. tuberosa *A. ypsilon*	FO *C. tuberosa*	1-3, 118–120 1-4, 3–5	1-4, 36–38 1-4, 117–119	2-2, 95–97 2-2, 145–147	1-1, 65–67 1-1, 85–87
	A. ypsilon	LO *A. angelinum* (= *S. universus)*	1-5, 21–23 1-5, 40–42	1-5, 76–78 1-5, 117–119	2-3, 145–147 2-4, 36–40	1-1, 105–107 1-1, 125–127
	A. ypsilon	LO *L. bacca*	1-5, 81–83 1,CC (1–3)	1-6, 76–78 1-6, 137–139	2-4, 36–40 2-4, 95–97	1-1, 105–107 1-1, 125–127
	A. ypsilon	*A. anthropiscus* → *A. huxleyi*	Not reached	1-6, 137–139 2-2, 117–119	Upper to 2-6, 138–140	Species sought but not found
	A. ypsilon	LO *A. roggentheni*	Not reached	2-3, 118–120 2-3, 141–143	3-2, 35–37 3-2, 85–87	1-2, 95–97 1-2, 115–117
	A. ypsilon *A. angulare*	LO *A. angulare*	Not reached	2-6, 82–84 2-6, 117–119	3-5, 35–37 3-5, 85–87	1-3, 5–7 1-3, 25–27
	A. angulare	LO *L. neoheteroporos*	Not reached	2-6, 82–84 2-6, 117–119	3-5, 85–87 3-5, 135–137	1-2, 135–137 1-2, 145–147
	A. angulare	FO acme *T. trachelium* LO *T. vetulum*	Not reached	3-1, 82–84 3-1, 117–119	3-6, 35–37 3-6, 85–87	1-3, 5–7 1-3, 85–87
	A. angulare	*L. heteroporos* → *L. neoheteroporos*	Not reached	3-3, 81–83 3-3, 141–143	3-6, 135–137 4-1, 103–105	1-3, 65–67 1-3, 85–87
	A. angulare	FO *A. angulare*	Not reached	3-4, 118–120 3-4, 141–143	4-3, 35–37 4-3, 87–89	1-3, 85–87 1-3, 105–107
Pliocene	*P. prismatium*	LO *P. prismatium*	Not reached	3-5, 118–120 3-5, 141–143	4-3, 35–37 4-3, 87–89	1-3, 105–107 1-3, 115–117

Note: FO = first occurrence; LO = last occurrence.

Pacific; this explains why Goll has not used the range of *A. angulare* in his stratigraphy of the easternmost Pacific. Unfortunately, the first occurrence of *Collosphaera huxleyi*, reported by Goll (1980) as marker for the base of the Pleistocene, cannot be useful in this part of the equatorial Pacific, because its occurrences are too sporadic.

Johnson and Knoll (1975) dated the last appearance of *A. angulare* at about 940,000 yrs. ago, whereas Goll (1980) has estimated that this species became extinct about 900,000 yrs. ago. The last occurrence in Hole 573 occurs just below the Jaramillo polarity event and marks carbonate-dissolution cycle M5. The extinction occurs at a level similar to that in the other holes, in higher latitudes (Hole 575C) as well as toward the eastern region (Hole 572A); it indicates a date somewhat earlier than the first estimates (approximately 1.05 Ma, calculated on the basis of magnetic reversals). This extinction event may be a reliable boundary marker in the equatorial Pacific.

Significant changes occur among the radiolarian assemblages within the *A. angulare* Zone of Nigrini (1971), and they could be useful to informally divide it into upper and lower parts. The first occurrence of *Theocorythium trachelium* could be an eventual marker for the Pliocene/Pleistocene boundary in the equatorial Pacific, but this species occurs in very low numbers in the lowermost Pleistocene. Other workers have reported its extension below the Pliocene/Pleistocene boundary (Johnson, 1974). On the other hand, Nigrini (1971) and Riedel and Westberg (1982) did not find any specimens of *T. trachelium* in the *P. prismatium* Zone. At Leg 85 sites, *T. trachelium* does show an increased abundance (acme), coincident with the extinction level of *Theocorythium vetulum*. This occurs within carbonate-dissolution cycle M7 in both Hole 573 and Hole 572A, and may be used to divide the *Anthocyrdium angulare* Zone into separate parts. The lower part is distinguished by the presence of *T. vetulum*, associated with infrequent *T. trachelium* and *A. angulare*. The evolution from *Lamprocyrtis heteroporos* to *L. neoheteroporos* occurs in this subdivision. The upper part is bounded at the bottom by the lowest occurrence of abundant *T. trachelium*, and is identified by the presence of *L. neoheteroporos* and very common *A. angulare* and *T. trachelium* specimens. The highest occurrence of *L. neoheteroporos* falls very close to the extinction level of *A. angulare*. In Hole 575C the expression of these events is probably masked by the much lower sedimentation rate and the reworking.

Goll has used the extinction level of *Amphispyris roggentheni* in his zonation of the easternmost equatorial Pacific. The occurrence in Holes 572A, 573, and 575C are the first reported for the central Pacific. In both the east and the central region, this species is always scarce and sporadic; to be certain of its presence, one must study several slides. I consider that in both Hole 573 and Hole 575C the extinction level of *A. roggentheni* occurs just below the Brunhes/Matuyama boundary, and that in Holes 573 and 572A it marks the transition between carbonate-dissolution cycles M1 and B17. This extinction may be a reliable marker in the equatorial Pa-

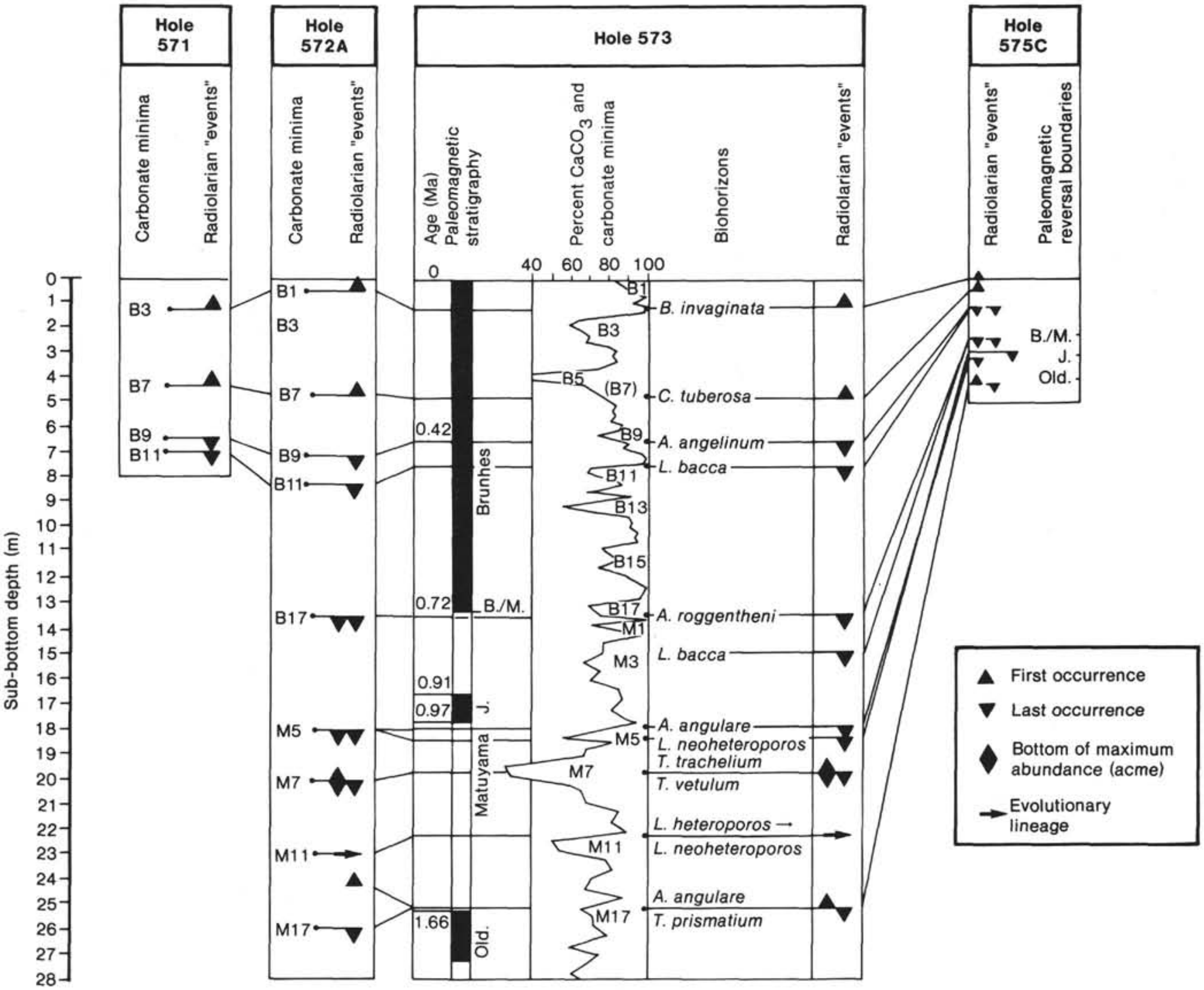

Figure 2. Pleistocene radiolarian biohorizons (events), calcium carbonate fluctuations, and paleomagnetics, Hole 573. Carbonate-minima data from Pujos (this volume). Paleomagnetic stratigraphy from Weinreich and Theyer (this volume). Correlations between four holes of Leg 85.

cific near the Brunhes/Matuyama boundary, although the scarcity of the species will have to be taken into account when attempting correlations. The timing of this extinction and the possibility of a west–east diachronism will also have to be addressed by further work, because Goll (1980) has estimated this event to be about 650,000 yrs. old in the eastern Pacific. In that region Goll (1980) has reported the highest (last) occurrence of *Lithopera bacca* just below the highest (last) occurrence of *A. roggentheni. L. bacca* always occurred rather infrequently. A first (i.e., older) highest occurrence level lies at or very close to the extinction level of *A. roggentheni*. However, *L. bacca* recurs in a short interval in the Brunhes. The second (younger) highest occurrence lies just below the highest occurrence of *Axoprunum angelinum*.

The date of the extinction level of *Axoprunum angelinum* (= *Stylatractus universus* Hays) has been estimated in two ways, using (1) a constant accumulation rate between the Brunhes/Matuyama boundary and the present and (2) an astronomical base for the time control. In accord with Hays et al. (1969), the upper limit is synchronous with the top of carbonate maximum peak B10 in the three holes where the carbonate content has been recorded (Pujos, this volume).

This limit occurs in an interval where the radiolarian assemblages are always well preserved. In correlations between carbonate and oxygen-isotope stratigraphies (Berggren et al., 1980; Gardner, 1982), the transition between carbonate stages B9 and B10 has been correlated with the boundary of isotopic stages 11 to 12. The age of 421,000 yrs. can be considered as the definitive estimate of the age of this isotopic stage boundary (Morley and Hays, 1981). If one uses this age for the upper limit of *Axoprunum angelinum*, and if one considers the surface level as representing the Recent sedimentation, it becomes evident that an assumption of a constant accumulation rate between 720,000 yrs. ago and the present is untenable.

The first appearance of *Collosphaera tuberosa* and *Buccinosphaera invaginata* correspond to dates presum-

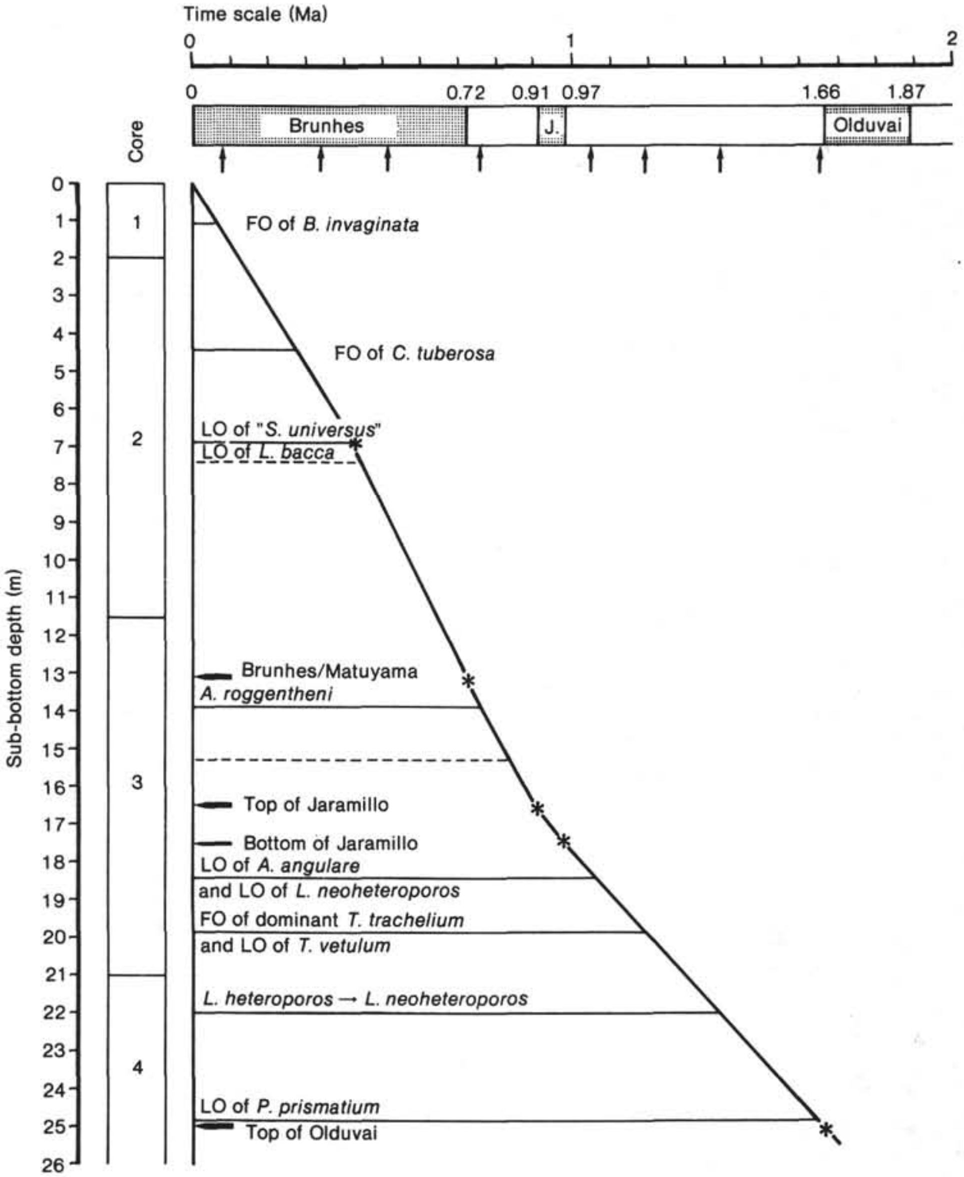

Figure 3. Calibration of Pleistocene radiolarian events, Hole 573. Ages are obtained by extrapolating the sediment accumulation rates between the paleomagnetic boundaries determined by Weinreich and Theyer (this volume) and the estimated date of last occurrence of "*S. universus*," based on time scale of Morley and Hays (1981). FO = first occurrence; LO = last occurrence; asterisks = data points used to construct sedimentation rate curve.

ably later than those reported by Johnson and Knoll (1975). The first occurrence of *C. tuberosa* often falls above rather poorly preserved samples, and coincides in all cases with the top of carbonate stage B7, which has been correlated (Berggren et al., 1980) with the base of ^{18}O Stage 8 and dated at about 279,000 yrs. (Morley and Hays, 1981). The distribution of *Buccinosphaera invaginata* coincides with the two upper carbonate stages in Holes 571 and 573. In Hole 572A, calcium carbonate fluctuations seem more complicated.

The first appearance of *B. invaginata* is estimated here at about 65,000 to 72,000 yrs. ago—that is, later than the date determined by Goll (1980). We might have to reconsider the use of these two species for datum levels, because their preservation threshold is very low.

SUMMARY

Quaternary radiolarians from 4 of the 17 Leg 85 holes were studied intensively. Twelve datum levels, biohorizons, or evolutionary lineages were compared and calibrated using the magnetostratigraphy and carbonate-dissolution cycles of the last 1.7 m.y.

Radiolarians that become extinct in the section representing this interval are *Pterocanium prismatium* (just above the Olduvai event), *Anthocyrtidium angulare* and *Lamprocyrtis neoheteroporos* (just below the Jaramillo event), and *Amphispyris roggentheni* (just below the Brunhes/Matuyama boundary).

Throughout the Matuyama, the evolutionary lineage from *Lamprocyrtis heteroporos* to *Lamprocyrtis neohet-*

eroporos occurs at the top of carbonate-dissolution cycle M11, and the last occurrence of *Theocorythium vetulum* is synchronous with the first occurrence of maximum abundance of *Theocorythium trachelium*, which marks carbonate minimum M7.

Within sediments interpreted as belonging to the Brunhes, *Lithopera bacca* and *Axoprunum angelinum (= Stylatractus universus)* bracket carbonate-maximum peak B10. The upper limit of *A. angelinum* is now well known, although it had previously been variously dated between 320,000 and 440,000 yrs.; according to Hays et al. (1969), this extinction occurs near the boundary between carbonate cycles B9 and B10. The use of species belonging to the genus *Collosphaera* is somewhat unreliable because of their low preservation threshold. But the occurrence of *Buccinosphaera invaginata* demonstrates that sediments are younger than carbonate minimum B3.

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APPENDIX

Species List with Bibliography for Taxa Cited[3]

Androspyris anthropiscus Haeckel

Androspyris anthropiscus Haeckel, 1887, p. 1093, pl. 83, fig. 8; Goll, 1980, p. 436, pl. 4, figs. 2–3.

Androspyris huxleyi (Haeckel)

Lamprospyris huxleyi Haeckel, 1887, p. 1094, pl. 89, fig. 14.
Androspyris huxleyi (Haeckel) Goll, 1980, p. 436. pl. 4, figs. 4–5.

Amphirhopalum ypsilon Haeckel

Amphirhopalum ypsilon Haeckel, 1887, p. 522; Nigrini, 1971, p. 447, pl. 34.1, figs. 7a–c.

Amphispyris roggentheni Goll

Amphispyris roggentheni Goll, 1980, p. 437, pl. 6, figs. 1, 3, 4, pl. 7, figs. 4–6.

Anthocyrtidium angulare Nigrini

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

[3] See References for full bibliographic data on sources given here.

***Axoprunum angelinum* (Campbell and Clark)**

Stylosphaera angelina Campbell and Clark, 1944, p. 12, pl. 1, figs. 14–20.
Stylatractus universus Hays, 1970, p. 215, pl. 1, figs. 1–2.
Axoprunum angelinum (Campbell and Clark) Kling, 1973, p. 634, pl. 1, figs. 13–16, pl. 6, figs. 14–18.

***Buccinosphaera invaginata* Haeckel**

Buccinosphaera invaginata Haeckel, 1887, p. 99, pl. 5, fig. 11; Nigrini, 1971, p. 445, pl. 34.1, fig. 2: Knoll and Johnson, 1975, p. 63, pl. 1, figs. 3–6.

***Collosphaera orthoconus* (Haeckel)**

Conosphaera orthoconus Haeckel, 1887, p. 221, pl. 12, fig. 2.
Collosphaera sp. A, Knoll and Johnson, 1975, p. 103, pl. 1, fig. 1.
Collosphaera orthoconus (Haeckel) Goll, 1980, p. 436, pl. 1, figs. 10–11.

***Collosphaera tuberosa* Haeckel**

Collosphaera tuberosa Haeckel, 1887, p. 97; Nigrini, 1971, p. 445, pl. 34.1, fig. 1; Strelkov and Reshetnyak, 1971, pp. 336–337, pl. 4, figs. 24–25; Knoll and Johnson, 1975, p. 63, pl. 2, figs. 1–3.

***Cycladophora* (?) *davisiana* Ehrenberg**

Cycladophora davisiana Ehrenberg, 1872, p. 297; Petrushevskaya, 1968, p. 120, figs. 69–70; Morley, 1980, pl. 1.

***Disolenia* spp.**

Different species belonging to the genus *Disolenia*.

***Lamprocyrtis heteroporos* (Hays)**

Lamprocyclas heteroporos Hays, 1965, p. 179, pl. 3, fig. 1.
Lamprocyrtis heteroporos (Hays) Kling, 1973, p. 639, pl. 5, figs. 19–21, pl. 15, fig. 6.

***Lamprocyrtis neoheteroporos* Kling**

Lamprocyrtis neoheteroporos Kling, 1973, p. 639, pl. 5, figs. 17–18, pl. 15, figs. 4–5.

***Lamprocyrtis nigriniae* (Caulet)**

Conarachnium nigriniae Caulet, 1971, p. 3, pl. 3, figs. 1–4, pl. 4, figs. 1–4.
Lamprocyrtis haysi Kling, 1973, p. 639, pl. 5, figs. 15–16, pl. 15, figs. 1–3.
Lamprocyrtis nigriniae (Caulet) Kling, 1973, p. 217, pl. 1, fig. 17.

***Lithopera bacca* Ehrenberg**

Lithopera bacca Ehrenberg, 1872, p. 314; Riedel and Sanfilippo, 1978, p. 70, pl. 6, fig. 9.

***Pterocanium prismatium* Riedel**

Pterocanium prismatium Riedel, 1957, p. 87, pl. 3, figs. 4–5; Riedel and Sanfilippo, 1978, p. 72, pl. 9, fig. 1.

***Pterocorys hertwigii* (Haeckel)**

Eucyrtidium hertwigii (Haeckel), 1887, p. 1491, pl. 80, fig. 12.
Pterocorys hertwigii (Haeckel) Caulet, 1979, pl. 3, fig. 4.

***Theocorythium trachelium* (Ehrenberg)**

Eucyrtidium trachelius Ehrenberg, 1872, p. 312.
Theocorythium trachelium (Ehrenberg) Nigrini, 1967, p. 77, pl. 8, figs. 1–2, pl. 9, figs. 1–2, Riedel and Sanfilippo, 1978, p. 76, pl. 9, fig. 17.

***Theocorythium vetulum* Nigrini**

Theocorythium vetulum Nigrini, 1971, p. 447, pl. 34.1, figs. 6a–b.