

4. MIOCENE TO PLEISTOCENE RADIOLARIAN BIOSTRATIGRAPHY OF NORTH PACIFIC SITES 881, 884, 885, 886, AND 887¹

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ABSTRACT

Ocean Drilling Program Leg 145 recovered sediments from seven sites in the North Pacific, all of which contained radiolarians. The northernmost sites, Site 884 on the eastern flank of the Detroit Seamount (Emperor Chain) and Site 887 on the Patton-Murray Seamount Platform (Gulf of Alaska), contained the oldest radiolarian-bearing sediments of lower Miocene age. Radiolarian sediments from the central (885 and 886) and western (881) North Pacific sites ranged in age from late Miocene to Pleistocene.

Based on their stratigraphic potential, we selected 39 radiolarian species and determined their abundance and preservation (entire radiolarian assemblage) in Leg 145 sediments. The high-latitude North Pacific Miocene through Pleistocene radiolarian population is described and classified in detail, with the identification of a new species, *Dictyophimus bullatus*, and subspecies, *Lychnocanoma nipponica sakaii*. This research provides the critical stratigraphic link in the previously disconnected Miocene and Pliocene siliceous faunal sequences from the western and eastern margins of the North Pacific. Because of the nearly complete sections recovered at the Leg 145 sites, many of which contain excellent paleomagnetic records, it is possible to estimate with a fairly high degree of accuracy the age of specific faunal events in the various regions of the North Pacific. The results of this comprehensive survey of the temporal and spatial distribution of radiolarians in high-latitude North Pacific sediments are compared with those reported previously from the North Pacific and other ocean regions, thereby refining and expanding the siliceous faunal stratigraphy.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 145 traversed the North Pacific, occupying 7 sites and recovering sediments from 25 holes. Because of time constraints, this study is confined to an examination of the siliceous fauna in 7 holes at only 5 of these sites (Table 1; Fig. 1). The radiolarian fauna in sediments from the other two sites (Sites 882 and 883) should be similar to that reported here for Site 884 because of the close proximity of these three sites to one another.

Several previous legs have drilled in North Pacific waters. Investigators (Foreman, 1973; 1975; Ling, 1980; Reynolds, 1980; Sakai, 1980; Schaaf, 1981; Wolfart, 1981; Morley 1985) have reported on the presence, abundance, and ranges of radiolarians recovered from mid-latitude North Pacific sites during Deep Sea Drilling Project (DSDP) Legs 20, 32, 55, 56, 57, 62, 63, and 86. Additional papers (Kling, 1973; Ling, 1973) have described the siliceous fauna from high-latitude North Pacific sites associated with DSDP Legs 18 and 19. Only the sediments collected during Leg 86, however, were retrieved using the advanced hydraulic piston corer (APC), which drastically improves recovery as it greatly minimizes sediment disturbance. Leg 145 marked the first time that ODP had drilled in the high-latitude North Pacific and the first time a scientific drill ship had entered these North Pacific latitudes since 1970.

Radiolarians occur in sediments from all five sites examined as part of this study. The northernmost sites from the western (Site 884) and eastern (Site 887) Pacific contain radiolarians of early Miocene

Table 1. Coordinates and water depths of Leg 145 holes analyzed in this study.

Hole	Latitude	Longitude	Water depth (m)
881A	47°06.14'N	161°29.49'E	5531.1
881C	47°06.13'N	161°29.49'E	5530.8
884B	51°27.03'N	168°20.23'E	3824.8
885A	44°41.30'N	168°16.32'W	5708.5
886C	44°41.38'N	168°14.40'W	5713.3
887A	54°21.92'N	148°26.77'W	3631.2
887C	54°21.93'N	148°26.78'W	3633.6

to Pleistocene age. The siliceous faunal assemblage in sediments from the southern three sites (Sites 881, 885, and 886) range in age from late Miocene to Pleistocene.

Site 881 was situated in the abyssal plain underlying waters of the central portion of the western subarctic gyre. Site 884 sampled sediments from the Meiji Drift along the eastern flank of the Detroit Seamount. Sites 885 and 886 recovered sediments from the central North Pacific at the southern margin of the subarctic gyre. The platform surrounding the Patton-Murray Seamounts in the Gulf of Alaska was the location of the northernmost site (887) drilled during Leg 145.

The continuous coring techniques employed during Leg 145, the nearly complete sections recovered, the excellent magnetic reversal record, and the spatial distribution across the North Pacific of the five sites examined in this study make it possible to construct a detailed inventory of the Miocene through Pleistocene radiolarian population in the high-latitude North Pacific. The excellent magnetostratigraphy acquired for most of these sites presents us with the opportunity to refine and revise the age of species' first (FO) and last (LO) occurrences and compare our results with those reported from the Japanese and California margins as well as from the low-latitude Pacific and Indian oceans.

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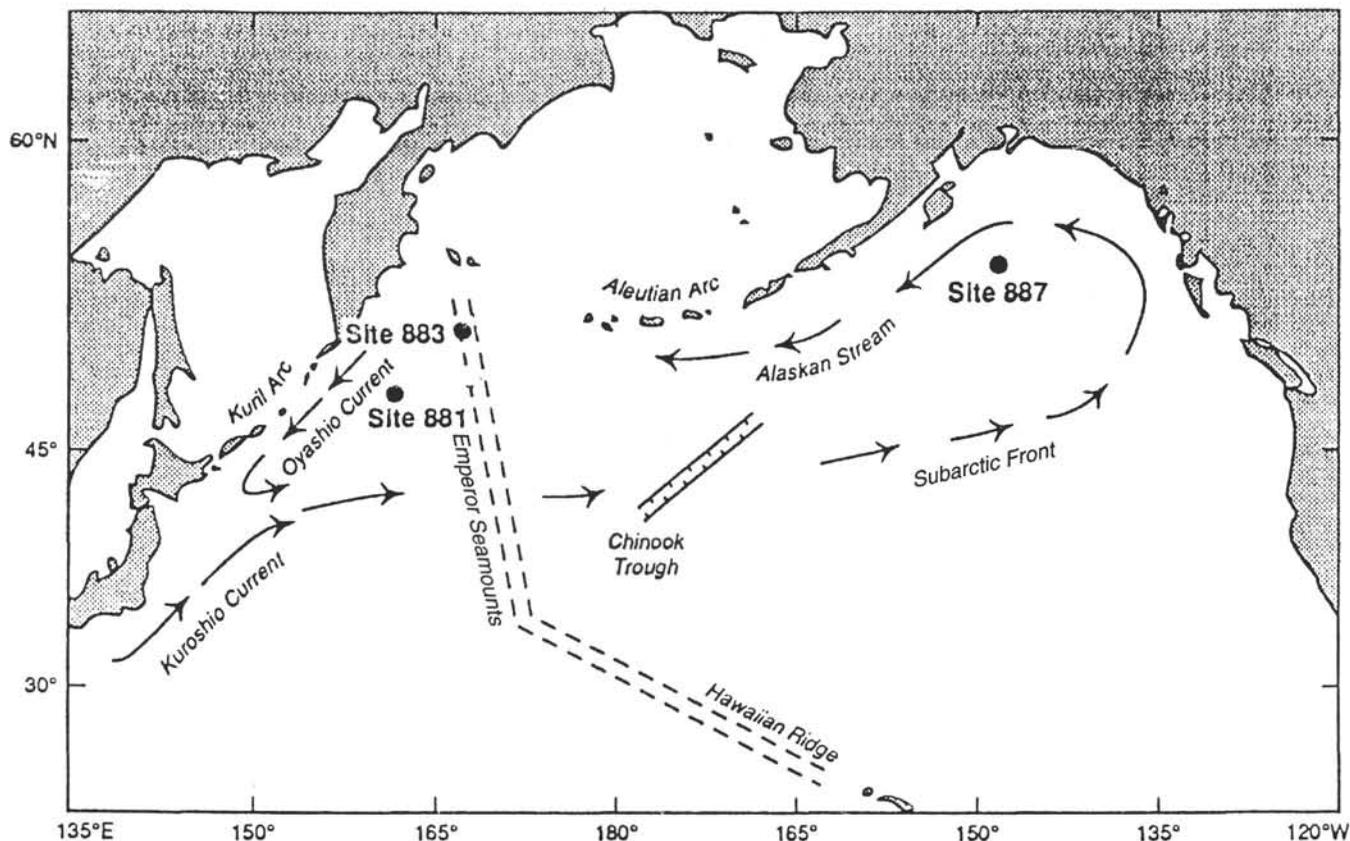


Figure 1. Location of specific Leg 145 sites containing sediments that were analyzed in this study.

METHODS

Sampling, Sample Preparation, and Census Counting

As many as six samples per core were taken for biostratigraphic analysis. All samples were dried, weighed, disaggregated with the aid of hydrogen peroxide and sieved at 63 μm . In most cases, the residue remaining on the sieve was randomly settled on slides following the technique described by Moore (1973). Strawn slides were also made for much of the upper Miocene through lower Pliocene sediment sequence from the five sites so as to reduce the flood of large-sized diatoms, which masked the radiolarians in many samples throughout this time interval.

Abundance values presented on range charts (Tables 2–6) are based on calculations of the number of radiolarians per gram of raw sample. The relative abundance of radiolarians in each sample is determined using the dry sample weight, the area of the beaker in which the sample is randomly settled, and the number of radiolarians per area of slide. Abbreviations for radiolarian abundances are R = rare (0–4999 radiolarians/gram), F = few (5000–9999 radiolarians/gram), C = common (10000–24,999 radiolarians/gram), and A = abundant (>25,000 radiolarians/gram).

Radiolarian preservation is indicated for all samples examined on range charts (Tables 2–6) with abbreviations defined as follows: G (good), indicating little sign of dissolution of radiolarians with only minor fragmentation; M (moderate), signifying evidence of moderate dissolution of radiolarians with obvious fragmentation; and P (poor), denoting a high degree of dissolution of radiolarians with few complete specimens.

The relative abundance of individual species given in Tables 2 through 6 is based on systematic examination of a minimum of 500

radiolarians per sample with abbreviations defined as follows: R = rare (2–5 individual per 500); F = few (6–20 individuals per 500); C = common (>20 individuals per 500); + = 1 individual per 500; P = present (present in sample, but outside of area counted); – = specimens sought but not found; +! = older fauna reworked in sediment sample; and ? = dubious identification.

Species Selection

Several criteria were used in the selection of the 39 radiolarian species for this study. All had been identified in at least one of the hundreds of strawn slides prepared during Leg 145. Many of the 39 species are components of various radiolarian zonation schemes constructed for North Pacific siliceous sediments. Most of the selected species also were described by other investigators in their reports of radiolarians in North Pacific sediments recovered during earlier ocean drilling legs (Foreman, 1973, 1975; Kling, 1973; Ling, 1973; Reynolds, 1980; Sakai, 1980; Schaaf, 1981; Wolfart, 1981; Morley, 1985). Some species were also chosen because of their reported dominance in Japanese and Californian siliceous sequences of Miocene age (Nakaseko and Sugano, 1973; Weaver et al., 1981; Funayama, 1988). For the most part, the species selected for this study are relatively easy to identify, with most having distinct stratigraphic ranges.

Zonation

No radiolarian zonation has yet been proposed for high-latitude (>42°N) North Pacific sediments, mainly because of the scarcity of recovered long, continuous siliceous sequences from this region. Sediments from sites drilled in this region during DSDP Legs 18 and 19 were discontinuously sampled and lacked magnetostratigraphy.

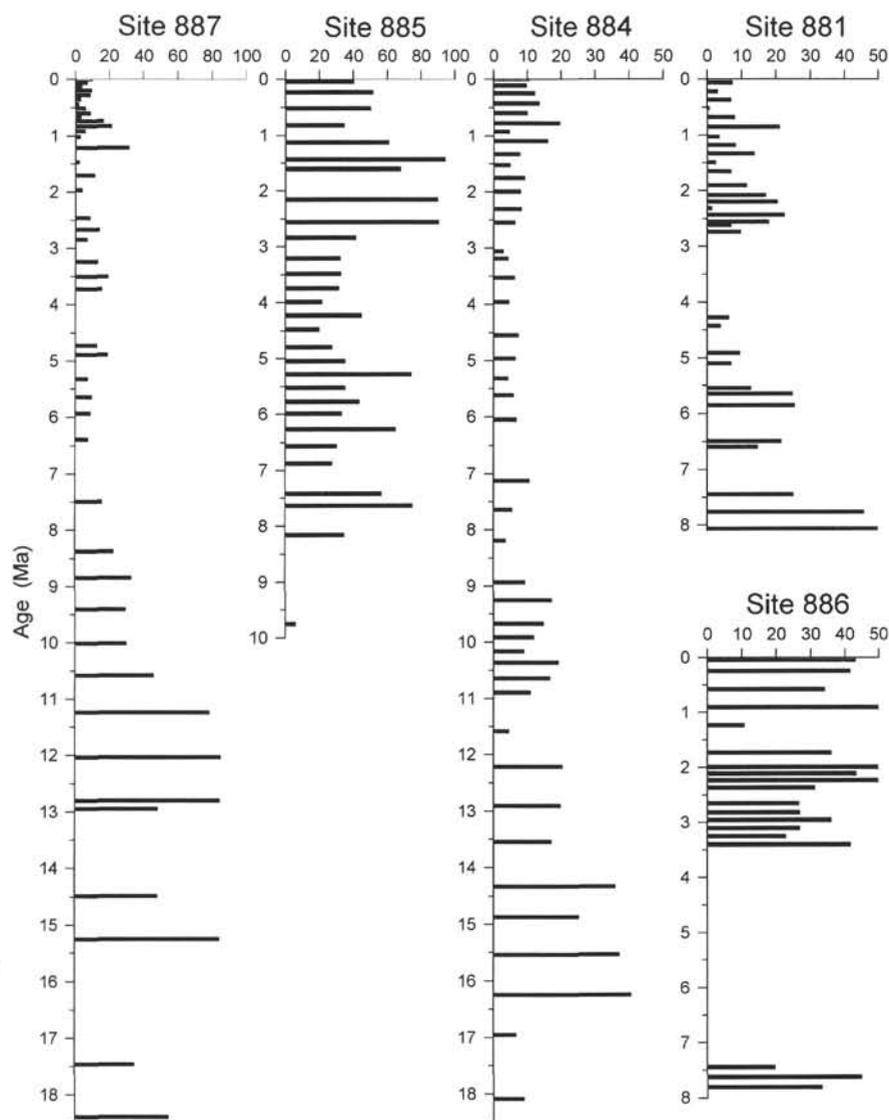


Figure 2. Number of radiolarians per gram of dry weight of sediment at each Leg 145 site examined in this study vs. age (Ma) using Cande and Kent (1992) time scale. Absolute values of radiolarian concentrations were made only for randomly settled samples used in radiolarian survey.

and 887) served as an additional control point for calculating ages of Site 881 samples because the oldest identifiable magnetic event was so great a distance (>125 m) from the bottom of Hole 881C.

The first three cores from Hole 881C contain a radiolarian assemblage characteristic of that described for the North Pacific *Botryostrobus aquilonaris* Zone, with the dominance of *Cycladophora cosma cosma*, *Cycladophora davisiana davisiana*, and *Sphaeropyle langii*, and the LO of *Lychnocanoma nipponica sakaii* (Sample 145-881C-1H-CC) (Table 2). The addition of *Stylocentron acquilonium* and *Stylatractus universus* in sediments from Cores 145-881C-4H through -6H indicates that this assemblage is similar to that reported for the *Stylatractus universus* Zone. The morphological evolution from *Lamprocyrtis neoheteroporos* to *Lamprocyrtis nigrinae* occurs at the base of this interval. The presence of *Eucyrtidium matuyamai* in Samples 145-881C-7H-CC through -13H-CC and the accompanying radiolarian assemblage conform to that representative of the *Eucyrtidium matuyamai* Zone. The termination of the Jaramillo Subchron recorded in Core 145-881C-7H and the identification of the Olduvai Subchron in Cores 145-881C-12H and -13H confirms that this sequence correlates with that defined for the *E. matuyamai* Zone. The LO of both *L. heteroporos* (Sample 145-881C-13H-CC) and *Sphaeropyle robusta* (Sample 145-881C-11H-CC) are recorded at or near the base of this interval.

Because the apparent LO of *Stichocorys peregrina* is much older in Leg 145 sites than in North Pacific sites south of 40°N (~5–6 Ma

vs. ~3 Ma), it is impossible to place radiolarian sequences properly below Core 145-881C-13H in any of the proposed North Pacific radiolarian zonation. The FO of *L. heteroporos* also appears to take place earlier (~6.6 Ma) in sediments from Leg 145 sites compared to mid- and low-latitude Pacific sites, where its FO has been estimated at ~4.4 Ma and ~3.3 Ma, respectively.

Species that experience relatively sharp FOs or LOs in the sediment sequence in Holes 881C and 881D below 2 Ma (~110 mbsf) are *C. davisiana davisiana* (FO between Samples 145-881D-2H-CC and -3H-CC), *S. peregrina* (LO 145-881C-27X-1, 20–21 cm, and -25X-4, 50–51 cm), *Stichocorys delmontensis* (LO between Samples 145-881C-27X-5, 20–21 cm, and -27X-1, 20–21 cm), *Dictyophimus splendens* (LO between Samples 145-881C-29X-3, 20–21 cm, and -30X-1, 21–22 cm), *L. heteroporos* (FO between Samples 145-881C-30X-7, 22–23 cm, and -32X-1, 20–21 cm), *Lychnocanoma nipponica nipponica* (LO between Samples 145-881C-32X-1, 20–21 cm, and -30X-7, 22–23 cm), and *S. acquilonium* (FO between Samples 145-881C-35X-1, 22–23 cm, and -36X-1, 29–30 cm) (Table 2). The switch in dominance from *S. delmontensis* to *S. peregrina* occurs at Sample 145-881C-35X-1, 22–23 cm (Table 2).

Site 884 (Hole 884B)

Site 884, the northernmost site drilled on Leg 145 in the western North Pacific (Table 1), was the deepest hole drilled as part of a depth

transect down the flank of the Detroit Seamount. A thick sediment sequence at the base of this seamount known as the Meiji Tongue (Drift) was sampled at this site. Radiolarians are present throughout the upper 630 m of Hole 884B. Biogenic silica is absent in much of the interval of the core below this depth; and the few radiolarians present in samples below 630 mbsf are poorly preserved. The radiolarians above 630 mbsf at Site 884 range in age from early Miocene to Holocene. Although an excellent magnetic reversal record was recovered from sediments in Hole 884B, several small hiatuses (<1 m.y.) below 435 mbsf in the core make it somewhat difficult to assign the proper event to the recorded reversal. For the upper 535 mbsf, the paleomagnetic event stratigraphy as outlined in "Interpretation 2" of the Shipboard Scientific Party (1993a) was followed. However, below this interval we chose the paleomagnetic events based on diatom stratigraphy (Barron and Gladenkov, this volume). This latter interpretation places the normal polarity interval between 535 and 542.3 mbsf within Subchrons C5AA and C5AB; positions the normal event C5AC between 550 and 559 mbsf; and identifies the terminations of Chrons C5C, C5D, and C5E at 580, 594.2, and 602.8 mbsf, respectively. The oldest three paleomagnetic events were recorded during shipboard measurement of inclination with a cryogenic magnetometer although not listed in Shipboard Scientific Party (1993a) tables. The average sedimentation rate throughout the radiolarian-bearing sequence from the early Miocene to Holocene is quite high (~33 m/m.y.). In most instances, the radiolarian assemblage in one sample from every core was examined except in the uppermost Miocene through lower Pliocene sequences where only one sample from every two cores was studied.

Radiolarian preservation is good only through the upper 2-m.y. record from Site 884 (Table 3). From 2 to 18 Ma, most samples contain moderate to poorly preserved radiolarians. As was the case with Site 881, high concentrations of large diatoms mask radiolarians from the early Pliocene throughout much of the late Miocene (3.55–9 Ma). Radiolarians, when present in samples below 595 mbsf, are poorly preserved. Concentrations of radiolarians are lower compared with those from the three southern sites occupied on Leg 145, with the only samples containing abundant (>25,000 radiolarians/gram) radiolarians found in the lower middle Miocene (~14–16 Ma) (Table 3; Fig. 2).

The ranges of the 39 species are presented in Table 3. An age was calculated for each sample examined using the magnetostratigraphy and the magnetic time scale of Cande and Kent (1992).

The radiolarian assemblage in the uppermost 14 m (through Sample 145-884B-2H-5, 135–136 cm) in Hole 884B is characteristic of the *Botryostrobus aquilonaris* Zone, with the presence of *Cycladophora davisiana davisiana*, *Cycladophora cosma cosma*, *Lychnocanoma nipponica sakaii*, and *Sphaeropyle langii* (Table 3). *Stylocyrtium acqulionium* and *Stylatractus universus* in Cores 145-884B-3H through -6H indicate that this sequence most likely is representative of the *Stylatractus universus* Zone. The radiolarian *Eucyrtidium matuyamai* is confined to the lower half of Core 145-884B-7H through Core 145-884B-12H, which places this sequence within the *Eucyrtidium matuyamai* Zone (North Pacific radiolarian zonation of Foreman, 1975). The range of the *E. matuyamai* Zone at this site is bracketed by the Jaramillo and Olduvai Subchrons. Although they are not identified in every sample, the LOs of *Sphaeropyle robusta* and *Lamprocyrtis heteroporos* occur within this interval (between Core 145-884B-11H and Sample 145-884B-12X-1, 68–69 cm).

Below this level in Hole 884B, it is not possible to place the radiolarian sequence within any of the existing North Pacific radiolarian zonations because of the apparently older LO of *Stichocorys peregrina* (~5.6 Ma vs. ~3 Ma) and the very rare occurrences of *Lamprocyrtis heteroporos* at this site. Species with clearly delineated FOs and LOs that could be of stratigraphic importance below 2 Ma are *C. davisiana davisiana* (FO between Samples 145-884B-17X-5, 135–136 cm, and -18X-5, 135–136 cm), *Dictyophimus splendens* (LO be-

tween Samples 145-884B-29X-1, 135–136 cm, and -31X-5, 135–136 cm; FO between Samples 145-884B-61X-5, 135–136 cm, and -62X-5, 135–136 cm), *S. acqulionium* (FO between Samples 145-884B-43X-5, 135–136 cm, and -45X-5, 135–136 cm), *Lychnocanoma nipponica magnacornuta* (LO between Samples 145-884B-47X-5, 135–136 cm, and -48X-5, 135–136 cm; FO between Samples 145-884B-57X-5, 137–139 cm, and -58X-5, 135–136 cm), *Cyrtocapsella japonica* (LO between Samples 145-884B-51X-5, 135–136 cm, and -52X-5, 135–136 cm), *Cyrtocapsella cornuta* (LO between Samples 145-884B-56X-5, 135–136 cm, and -57X-5, 137–139 cm), *Cyrtocapsella tetrapera* (LO between Samples 145-884B-56X-5, 135–136 cm, and -57X-5, 137–139 cm), *Eucyrtidium inflatum* (LO between Samples 145-884B-56X-5, 135–136 cm, and -57X-5, 137–139 cm; FO between Samples 145-884B-61X-5, 135–136 cm, and -62X-5, 135–136 cm), *Lithopera renzae* (LO between Samples 145-884B-56X-5, 135–136 cm, and -57X-5, 137–139 cm), *Eucyrtidium asanoi* (LO between Samples 145-884B-59X-5, 135–136 cm, and -60X-5, 135–136 cm; FO between Samples 145-884B-62X-5, 135–136 cm, and -63X-5, 135–136 cm), *Corythospyris?* sp. (LO between Samples 145-884B-61X-5, 135–136 cm, and -62X-5, 135–136 cm; FO between Samples 145-884B-63X-5, 135–136 cm, and -64X-4, 135–36 cm), and *C. cosma cosma* (FO between Samples 145-884B-64X-4, 135–136 cm, and -65X-5, 135–136 cm) (Table 3).

Site 885 (Hole 885A)

Site 885, one of two of the southernmost sites drilled on Leg 145, is located in the central North Pacific. The upper 45.5 m of sediment contain radiolarians of late Miocene to Holocene in age. Radiolarians were examined in samples taken at approximately 1.5-m intervals (one sample/section) from Hole 885A. Although not all present, enough of the magnetic events were identified in Hole 885A material to provide good chronostratigraphic control. In the radiolarian-bearing sequence, the sedimentation rate averages about 5 m/m.y. based on the magnetostratigraphy and biostratigraphy.

Well-preserved radiolarians occur in the upper 17 m (~3.55 m.y.) of this hole (Table 4). Radiolarian preservation is either moderate or moderate to poor in the remaining samples in which radiolarians were present, except for the slide containing the oldest siliceous fauna where radiolarians were poorly preserved. A tremendous influx of diatoms during the late Miocene to early Pliocene makes it difficult to examine radiolarians throughout the time interval between ~3.7–7.2 Ma (Sample 145-885A-3H-3, 115–116 cm, through -5H-4, 115–116 cm). Overall concentrations of radiolarians are high when compared to those at other Leg 145 sites, with highest values (>65,000 radiolarians/gram) occurring in samples of late Pliocene to early Pleistocene age (Table 4; Fig. 2).

Table 4 shows the ranges of the 39 species examined in sediments from Site 885. The calculated age for each sample is based on the magnetostratigraphy, with ages of specific magnetic events taken from Cande and Kent (1992).

The radiolarian assemblage in the upper 1.15 m corresponds to that described for the North Pacific *Botryostrobus aquilonaris* Zone, with the presence of *Botryostrobus aquilonaris*, *Cycladophora davisiana davisiana*, *Cycladophora cosma cosma* and *Sphaeropyle langii* (Table 4). Samples from Sections 145-885A-1H-2 and -1H-3 contain radiolarians similar to those representative of the *Stylatractus universus* Zone, with the addition of *Stylocyrtium acqulionium* and *Stylatractus universus*. The presence of *Eucyrtidium matuyamai* in Sections 145-885A-2H-1 through -2H-3 and the identification of the Jaramillo and Olduvai subchrons bracketing this sequence indicate that this interval corresponds to that of the *Eucyrtidium matuyamai* Zone. Both *Lamprocyrtis heteroporos* and *Sphaeropyle robusta* become extinct approximately midway through this unit.

As with other Leg 145 sites, the older LO of *Stichocorys peregrina* (~5 Ma vs. ~3 Ma) and FO of *L. heteroporos* (~6.6 Ma vs. ~3.3–

4.4 Ma) preclude proper placement of this sequence within previously constructed North Pacific radiolarian zonal schemes. Specific events of stratigraphic potential below 2 Ma in Hole 885A are the FO of *C. davisiana davisiana* (between Samples 145-885A-2H-5, 115–116 cm, and -2H-6, 115–116 cm), the LOs of *S. peregrina* and *Stichocorys delmontensis* (between Samples 145-885A-4H-2, 115–116 cm, and -4H-3, 115–116 cm), the FO of *L. heteroporos* (between Samples 145-885A-5H-2, 115–116 cm, and -5H-3, 115–116 cm), the *S. delmontensis* to *S. peregrina* change in dominance (Sample 145-885A-5H-5, 115–116 cm), the FO of *S. acquilonium* (between Samples 145-885A-5H-6, 115–116 cm, and -6H-1, 115–116 cm) and the LO of *Lychnocanoma nipponica magnacornuta* (between Samples 145-885A-6H-1, 115–116 cm, and -6H-2, 115–116 cm) (Table 4).

Site 886 (Hole 886C)

Site 886, like Site 885, is located in the central portion of the North Pacific. Because of its proximity to Site 885 (within ~2.2 km), these sites contain somewhat similar records, except that Core 145-886C-5H failed to recover any sediment in the lower half (4.5–9.5 m) of the core barrel. Radiolarians are absent in Hole 886C below 54.5 m. The age of the radiolarian-bearing sequence is late Miocene to Holocene. Radiolarians were examined in samples at approximately 1.5-m intervals (one sample/section). The magnetostratigraphy does not have the resolution of that for Site 885, with fewer identifiable magnetic events. The average sedimentation rate, based on both biostratigraphy and magnetostratigraphy for the upper 54 m of Hole 886C, is 6.2 m/m.y.

Except for Sample 145-886C-1H-4, 114–115 cm, preservation of the siliceous fauna in Hole 886C varies between good and moderate throughout the last 4.75 m.y. (~upper 33 m) (Table 5). Below this level, silica dissolution increases with radiolarian preservation only moderate to poor until sediment from Hole 886C becomes barren of radiolarians in the top of Core 145-886C-7H. As at Site 885, radiolarians are masked by high numbers of diatoms, which flood the upper Miocene through early Pliocene samples (~3.55–7.3 Ma). Radiolarian concentrations are high, although not quite as high as at Site 885, with maximum values (>35,000 radiolarians/gram) occurring in upper Pliocene through lower Pleistocene samples (Table 5; Fig. 2).

Ranges of the 39 species in sediments from Site 886 are shown in Table 5. The estimated age of each sample examined is based on the ages of the paleomagnetic events identified in the core using the magnetic time scale of Cande and Kent (1992).

Sediment from the upper 1.14 m contains a radiolarian fauna representative of the North Pacific *Botryostrobus aquilonaris* Zone, including *Cycladophora davisiana davisiana*, *Cycladophora cosma cosma*, *Sphaeropyle langii* and the LO of *Lychnocanoma nipponica sakaii* (Sample 145-886C-1H-1, 114–115 cm) (Table 5). The next two sections (145-886C-1H-2 and -1H-3) contain siliceous fauna typical of the *Stylatractus universus* Zone, with the addition of *Stylatractarium acquilonium* and *Stylatractus universus*. A small hiatus may exist in Hole 886C within the interval from the top of Section 145-886C-1H-4 to the top of Section 145-886C-2H-1, based on the presence of *Eucyrtidium matuyamai* in only one sample and the inability to identify the Brunhes/Matuyama magnetic boundary as well as the onset and termination of the Jaramillo Subchron in records from this hole. The LOs of *Sphaeropyle robusta* and *Lamprocyrtis heteroporos* occur in Sample 145-886C-2H-1, 114–115 cm, above the termination of the Olduvai Subchron.

Species at Site 886 that exhibit distinct FOs and/or LOs that have stratigraphic potential below 2 Ma are *C. davisiana davisiana* (FO between Samples 145-886C-3H-1, 114–115 cm, and -3H-2, 114–115 cm), *Stichocorys peregrina* (LO between Samples 145-886C-4H-5, 114–115 cm, and -4H-CC), *Stichocorys delmontensis* (LO between Samples 145-886C-4H-CC, and -5H-1, 114–115 cm), *S. acquilonium* (FO between Samples 145-886C-6H-4, 114–115 cm, and -6H-5,

114–115 cm), and *Lychnocanoma nipponica magnacornuta* (LO between Samples 145-886C-6H-5, 114–115 cm, and -6H-CC) (Table 5). The change in dominance from *S. delmontensis* to *S. peregrina* occurs at Sample 145-886C-6H-3, 114–115 cm (Table 5).

Site 887 (Holes 887A and 887C)

Gulf of Alaska Site 887, the northernmost site occupied during Leg 145, contains radiolarian-bearing sediment of early Miocene age through Holocene. Analysis of radiolarians for this study was restricted to a maximum of two samples per core from Hole 887A supplemented with samples from Hole 887C to complete several unrecovered portions of the sediment sequence in Hole 887A. The magnetic reversal record at this site is excellent, with all but a few reversals clearly identifiable. The magnetostratigraphy derived from this record (Shipboard Scientific Party, 1993b) agrees with the diatom biostratigraphy (Barron and Gladenkov, this volume). The sedimentation rate in this nearly continuous sequence averages ~15 m/m.y., with much higher rates (~40 m/m.y.) since the onset of the Pleistocene and lower rates (~7 m/m.y.) for the middle and early Miocene. Of the five Leg 145 sites surveyed in this study, evidence of reworking was most obvious at Site 887, especially from the bottom of Cores 145-887A-12H and 145-887C-12H through Cores 145-887A-22H and 145-887C-22H (approximately 110–200 mbsf).

In most samples from the uppermost 90 m (last ~2.6 m.y.), radiolarian preservation is good (Table 6). Preservation of the siliceous fauna decreases throughout the remainder of the sedimentary record, varying between moderate and poor. As was the case at the other four Leg 145 sites examined in this study, radiolarians were diluted in sediments from Site 887 by large quantities of diatoms from the late Miocene through the early Pliocene (~3.55–7.5 Ma). Concentrations of radiolarians are slightly higher than those calculated for the other high-latitude North Pacific Site (884), with highest concentrations (>25,000 radiolarians/gram) confined to samples between 215 mbsf and the bottom of the core (~9–18 Ma) (Table 6; Fig. 2).

Table 6 lists the ranges of the 39 species in sediments from Site 887. Ages of each sample were calculated using the magnetostratigraphy, applying the geochronologic time scale of Cande and Kent (1992).

The first three cores from Hole 887A contain a radiolarian assemblage similar to that described for the North Pacific *Botryostrobus aquilonaris* Zone with the presence of *B. aquilonaris*, *Cycladophora davisiana davisiana*, *Cycladophora cosma cosma*, *Sphaeropyle langii*, and the LO of *Lychnocanoma nipponica sakaii* (Sample 145-887A-1H-3, 52–53 cm) (Table 6). The additional presence of *Stylatractarium acquilonium* and *Stylatractus universus* in sediments from Cores 145-887A-4H through -7H indicates that this sequence is most likely representative of the *Stylatractus universus* Zone. The range of *Eucyrtidium matuyamai*, which defines the North Pacific Zone of the same name, extends from the base of Core 145-887A-7H through Core 145-887A-9H. As with the other Leg 145 sites, the LO of *Sphaeropyle robusta* (Sample 145-887A-8H-6, 54–55 cm) is recorded in sediments within this interval. None of the proposed North Pacific radiolarian zonations could be applied to the radiolarian assemblage in the composite section from Site 887 below Core 145-887A-9H (~2 Ma).

Several species exhibit distinct ranges with abrupt FOs and LOs in the sediment record from Site 887 below the FO of *E. matuyamai* and are potentially useful as stratigraphic markers. These include *C. davisiana davisiana* (FO between Samples 145-887A-11H-3, 54–55 cm, and -12H-3, 54–55 cm), *Dictyophimus splendens* (LO between Samples 145-887A-16X-3, 55–56 cm, and -17X-2, 54–55 cm), *S. acquilonium* (FO between Samples 145-887A-22H-6, 54–55 cm, and -23H-6, 54–55 cm), *Lychnocanoma nipponica magnacornuta* (LO between Samples 145-887A-23H-6, 54–55 cm, and -24H-3, 54–55 cm; FO between Samples 145-887C-27H-3, 55–56 cm, and -27H-6, 55–

56 cm), *Cyrtocapsella japonica* (LO between Samples 145-887A-24H-6, 54–55 cm, and -25H-3, 54–55 cm), *Cyrtocapsella tetrapera* (LO between Samples 145-887A-25H-6, 54–55 cm, and 145-887C-26H-6, 55–56 cm), *Eucyrtidium inflatum* (LO between Samples 145-887A-25H-6, 54–55 cm, and 145-887C-26H-6, 55–56 cm; FO between Samples 145-887A-28H-6, 55–56 cm, and -29H-3, 54–55 cm), *Cyrtocapsella cornuta* (LO between Samples 145-887C-26H-6, 55–56 cm, and -27H-3, 55–56 cm), *Lithopera renzae* (LO between Samples 145-887C-26H-6, 55–56 cm, and -27H-3, 55–56 cm; FO between Samples 145-887A-29H-3, 54–55 cm, and 145-887C-30H-3, 54–55 cm), and *C. cosma cosma* (FO between Samples 145-887A-29H-3, 54–55 cm, and 145-887C-30H-3, 54–55 cm) (Table 6). The switch in dominance from *Stichocorys delmontensis* to *Stichocorys peregrina* is recorded in sediments from Sample 145-887A-22H-6, 54–55 cm (Table 6).

STRATIGRAPHIC AND GEOGRAPHIC RADIOLARIAN RANGES

A chart listing the FOs and LOs of most of the species surveyed in this study is presented in Table 7. Recording "events" of this type is a more basic, first-order method of building a radiolarian biostratigraphy than generating a zonal scheme. We have followed the lead of several other studies of this type (Riedel and Sanfilippo, 1971; Kling, 1973; Foreman, 1975; Reynolds, 1980; Sakai, 1980; Nigrini, 1985) in using this method to summarize the sequence of Miocene to Pleistocene events recorded in North Pacific sediments from each of our Leg 145 Sites. It is a particularly appropriate and prudent approach when one is dealing with unique material from sites that are geographically distant from each other. As more material, particularly Miocene, is recovered from the North Pacific, our events list will be refined and, in time, it will become evident which events are consistently present, isochronous, and easily recognized. It is only then that a satisfactory zonal scheme, applicable over a wide geographical area of the North Pacific, can be erected.

The data presented in this table synthesizes the information contained in the range charts for each of our sites (Tables 2–6), placing these findings within a magnetostratigraphic framework. The high core-recovery rates, overall quality of radiolarian preservation, high sedimentation rates, nearly continuous records, and excellent magnetostratigraphy at these Leg 145 sites make it possible to examine in detail various radiolarian events across a broad latitudinal and longitudinal band. Ages for these biostratigraphic events were calculated using the magnetostratigraphy from each of the sites, with ages for magnetic events taken from Cande and Kent (1992). These estimated ages are based on the assumption of a constant rate of sedimentation between pairs of magnetic reversal events. Ages of biostratigraphic events located between the core top and the earliest magnetic event were determined using a core top age of 0.00 Ma and interpolating between 0.00 Ma and the age of the youngest identifiable magnetic event. Except for the bottom of Site 881 (see radiolarian site summary for Site 881), the ages of biostratigraphic events positioned below the oldest recognized magnetic reversal in a hole were calculated using the sedimentation rate derived from the oldest pair of magnetic events.

We also, in the discussion which follows, compare our estimates of the ages of events with those from other published studies, some of which are listed in the right-hand columns of Table 7. The quality of the stratigraphic control varies widely in these reports from high-resolution oxygen isotope stratigraphy (i.e., Hays and Shackleton, 1976; Morley and Shackleton, 1978; Moore et al., 1993; Moore, 1995) to magnetostratigraphy (i.e., Morley, 1985; Johnson et al., 1989; Caulet et al., 1993) to only biostratigraphy (i.e., Kling, 1973; Foreman, 1975; Reynolds, 1980; Sakai, 1980; Wolfart, 1981). Where ages were not estimated for events, we have taken zonal informa-

tion, revising it, if necessary, to reflect most recent correlations with respect to specific epoch boundaries. For the data from northwest Pacific Site 579A, we reexamined the slides as part of this study and updated the magnetostratigraphy to the Cande and Kent (1992) time scale.

When comparing age estimates for specific radiolarian events listed in Table 7 and discussed in the following section, it is important to note several possible reasons for any age differences. One of the most obvious reasons for age differences is that the particular event is diachronous, taking place at different times in various regions. Dissimilar ages could be the result of significant differences in sample density. Degree and quality of stratigraphic control as well as improper identification of biostratigraphic species and magnetostratigraphic events could also create age differences.

The last abundant appearance of *Lychnocanoma nipponica sakaii* (Pl. 6, Figs. 1, 4) is recorded at three sites (881, 886, and 887). Studies of North Pacific piston cores by Robertson (1975), Kruglikova (1976), and Morley et al. (1982) have shown that this event occurs consistently throughout the North Pacific with an estimated age of ~0.05 Ma. Spencer-Cervato et al. (1993), however, in their revision of North Pacific datum levels in twelve DSDP sites, list an age of 0.55 Ma for this event (LO of *Lychnocanium grande*). The APC apparently failed to recover the topmost sediments at Sites 884 and 885, which would account for the presence of *L. nipponica sakaii* within the upper 0.2 m of both Holes 884B and 885A.

The LO of *Stylocystidium acquilonium* (Pl. 3, Figs. 1, 2, 4) occurs at or just above the globally synchronous extinction of *Stylocystis universus* at all five sites. Analysis of high-sedimentation-rate piston cores by Robertson (1975) and Morley et al. (1982) have shown that this event is synchronous in the northwest Pacific with an age of 0.35 Ma. From examination of the sample interval information for our five sites and the presence/absence data in the range charts (Tables 2–6), we arrived at an estimated age of this event in our Leg 145 sites ranging from 0.37 to 0.43 Ma. The timing of this event corresponds with that reported for this species throughout the North Pacific (Kling, 1973; Reynolds, 1980; Sakai, 1980; Weaver et al., 1981).

As in other ocean regions, the LO of *Stylocystis universus* (Pl. 2, Fig. 3) is apparently synchronous throughout the North Pacific, with an estimated age range of 0.5–0.6 Ma based on combining the presence/absence data for this event (Tables 2–6). This age, however, is slightly older than that (0.45 Ma) calculated by correlating the LO of this species with oxygen isotope stratigraphies in piston cores from the Atlantic, Pacific, Indian, and Southern oceans (Hays and Shackleton, 1976; Morley and Shackleton, 1978). It is also older than that reported from eastern equatorial Pacific Leg 138 sites (0.45–0.46 Ma, Moore et al., 1993; Moore, 1995), from northwest Pacific Site 579A (0.47 Ma, this study), from a suite of DSDP North Pacific sites (0.4 Ma, Spencer-Cervato et al., 1993), and from low-latitude Indian Ocean sites (0.47 Ma; Caulet et al., 1993). Our data on the timing of this event with respect to the LO of *S. acquilonium* agrees with that of previous studies of North Pacific sediments (Kling, 1973; Reynolds, 1980; Sakai, 1980; Weaver et al., 1981).

Anthocyrtella (?) callopisma (Pl. 3, Fig. 3) is not present in samples from Gulf of Alaska Site 887 (northernmost site) and occurs only in a few older levels in western North Pacific Site 884. In the three southern sites drilled on Leg 145, the age of the LO of *A. (?) callopisma* occurs between 0.52 and 0.91 Ma. This range can be narrowed by selecting the age of the oldest of the samples in which this species does not occur and the age of the youngest of the samples containing *A. (?) callopisma*. Applying this technique, we arrive at a revised age for this event ranging from 0.58 to 0.68 Ma. This age estimate is slightly younger than the 0.74 Ma age reported by Caulet (1986b) for this event.

The LO of *Eucyrtidium matuyamai* (Pl. 5, Fig. 3) is clearly recorded in four of our five sites. At Sites 884, 885, and 887, the youngest samples containing *E. matuyamai* occur directly below the onset of

Table 7. Radiolarian event chart for North Pacific Sites 881, 884, 885, 886, and 887.

Radiolarian event	CK92 Age	Hole 881C			Hole 885A			Hole 886C		
		Core, section, interval (cm)	Depth (mbsf)	Age (m.y.)	Core, section, interval (cm)	Depth (mbsf)	Age (m.y.)	Core, section, interval (cm)	Depth (mbsf)	Age (m.y.)
<i>LO L. nipponica</i>		1H-1, 21–22	0.2	0				1H-1, 20–21	0.2	0.04
<i>sakaii</i> n. ssp.		1H-CC	3.8	0.06				1H-1, 114–115	1.14	0.25
<i>LO S. acquilonium</i>		3H-CC	22.8	0.37	1H-1, 115–116	1.15	0.23	1H-1, 114–116	1.14	0.25
		4H-CC	32.3	0.52	1H-2, 115–116	2.65	0.52	1H-2, 114–115	2.64	0.58
<i>LO S. universus</i>		3H-CC	22.8	0.37	1H-1, 115–116	1.15	0.23	1H-2, 114–115	2.64	0.58
		4H-CC	32.3	0.52	1H-2, 115–116	2.65	0.52	1H-3, 114–115	4.14	0.91
<i>LO A (?) callopisma</i>		4H-CC	32.3	0.52	1H-2, 115–116	2.65	0.52	1H-2, 114–115	2.64	0.58
		5H-CC	41.8	0.68	1H-3, 115–116	4.15	0.82	1H-3, 114–115	4.14	0.91
Brunhes/Matayama	0.78	6H-5, 30	48.1	0.78	1H-3, 95	3.95	0.78			
<i>LO E. matuyamai</i>		6H-CC	51.3	0.85	1H-3, 115–116	4.15	0.82	Absent?		
		7H-CC	60.8	1.03	2H-1, 115–116	5.75	1.13			
Jaramillo (term)	0.98	7H-5, 30	57.6	0.98	2H-1, 35	4.95	0.98			
<i>FO L. nigrinae</i>		7H-CC	60.8	1.03	1H-2, 115–116	2.65	0.52	1H-3, 114–115	4.14	0.91
		8H-CC	70.3	1.18	1H-3, 115–116	4.15	0.82	1H-4, 114–115	5.64	1.24
<i>LO P. pitomorphus</i>		9H-CC	79.8	1.34	1H-3, 115–116	4.15	0.82	1H-3, 114–115	4.14	0.91
		10H-CC	89.3	1.5	2H-1, 115–116	5.75	1.13	1H-4, 114–115	5.64	1.24
<i>LO L. neoheteroporos</i>		5H-CC	41.8	0.68	1H-3, 115–116	4.15	0.82	1H-3, 114–115	4.14	0.91
		6H-CC	51.3	0.85	2H-1, 115–116	5.75	1.13	1H-4, 114–115	5.64	1.24
Jaramillo (onset)	1.05	8H-2, 20	62.5	1.05	2H-1, 76	5.36	1.05			
<i>LO S. robusta</i>		10H-CC	89.3	1.5	2H-1, 115–116	5.75	1.13	1H-4, 114–115	5.64	1.24
		11H-CC	98.8	1.66	2H-2, 115–116	7.25	1.44	2H-1, 114–115	7.94	1.74
<i>LO L. heteroporos</i>		12H-CC	108.3	1.91	2H-1, 115–116	5.75	1.13	1H-4, 114–115	5.64	1.24
		13H-CC	117.8	2.11	2H-2, 115–116	7.25	1.44	2H-1, 114–115	7.94	1.74
Olduvai (term)	1.76	12H-5, 20	105	1.76	2H-3, 117	8.77	1.76	2H-1, 123	8.03	1.76
Olduvai (onset)	1.98	13H-2, 10	109.9	1.98	2H-4, 34	9.54	1.98	2H-2, 88	9.18	1.98
<i>FO E. matuyamai</i>		13H-CC	117.8	2.11	2H-3, 115–116	8.75	1.75	Not found		
		14H-CC	127.3	2.23	2H-4, 115–116	10.25	2.16			
<i>FO L. nipponica</i>		15H-CC	136.8	2.3	2H-4, 115–116	10.25	2.16	2H-1, 114–115	7.94	1.74
<i>sakaii</i> n. ssp.		D-1H-1, 20–21	155.2	2.33	2H-5, 115–116	11.75	2.56	2H-2, 114–115	9.44	2
Réunion (term)	2.2	14H-4, 75	123.05	2.2						
Réunion (onset)	2.23	14H-7, 50	127.3	2.23						
<i>FO P. pitomorphus</i>		16H-CC	146.3	2.36	2H-6, 115–116	13.25	2.84	2H-5, 114–115	13.94	2.37
		17H-CC	155.8	2.43	3H-1, 115–116	15.25	3.21	3H-1, 114–115	17.44	2.66
<i>FO L. neoheteroporos</i>		17H-CC	155.8	2.43	2H-6, 115–116	13.25	2.84	3H-1, 114–115	17.44	2.66
		18X-3, 50–51	159.3	2.45	3H-1, 115–116	15.25	3.21	3H-2, 114–115	18.98	2.82
Matuyama/Gauss	2.6	D-1H-6, 125	163.75	2.6	2H-5, 145	11.95	2.6	3H-1, 53	16.83	2.6
<i>FO C. davisiana</i>		D-2H-CC	174	2.92	2H-5, 115–116	11.75	2.56	3H-1, 114–115	17.44	2.66
<i>davisiana</i>		D-3H-CC	183.5	3.2	2H-6, 115–116	13.25	2.84	3H-2, 114–115	18.98	2.82
<i>LO P. fistula</i>		17H-CC	155.8	2.43	3H-5, 115–116	21.25	4.23	3H-2, 114–115	18.98	2.82
		18X-3, 50–51	159.3	2.45	3H-6, 115–116	22.75	4.48	3H-3, 114–115	20.44	2.96
Kaena (term)	3.05	D-3H-3, 120	178.2	3.05						
Kaena (onset)	3.13	D-3H-5, 150	181.5	3.13						
Mammoth (term)	3.22	D-4H-1, 70	184.2	3.22						
Mammoth (onset)	3.33	D-4H-2, 120	186.2	3.33						
Gauss/Gilbert	3.55	D-5H-5, 70	199.7	3.55	3H-2, 145	17.05	3.55	4H-1, 53	26.33	3.55
<i>LO P. crustula</i>		D-5H-CC	202.5	3.67	3H-1, 115–116	15.25	3.21	3H-6, 114–115	24.92	3.41
		D-6H-CC	212	4.07	3H-2, 115–116	16.75	3.49	4H-1, 114–115	26.94	3.66
Cochiti (term)	4.03	D-6H-6, 80	210.8	4.03						
Cochiti (onset)	4.13									
<i>LO D. bullatus</i> n. sp.		D-6H-CC	212	4.07	3H-5, 115–116	21.25	4.23	4H-2, 114–115	28.44	3.92
		25X-1, 20–21	219.2	4.31	3H-6, 115–116	22.75	4.48	4H-3, 114–115	29.94	4.19
C3n.2n (onset)	4.43									
C3n.3n (term)	4.61									
C3n.3n (onset)	4.69									
C3n.4n (term)	4.81									
C3n.4n (onset)	5.05									
<i>LO S. peregrina</i>		25X-4, 50–51	224	4.47	4H-2, 115–116	26.25	5.05	4H-5, 114–115	32.94	4.72
		27X-1, 20–21	238.5	4.96	4H-3, 115–116	27.75	5.29	4H-CC	35.3	5.13
<i>LO S. delmontensis</i>		27X-1, 20–21	238.5	4.96	4H-2, 115–116	26.25	5.05	4H-CC	35.3	5.13
		27X-5, 20–21	244.5	5.16	4H-3, 115–116	27.75	5.29	5H-1, 114–115	36.44	5.34
<i>FO D. bullatus</i> n. sp.		27X-5, 20–21	244.5	5.16	4H-4, 115–116	29.25	5.53	5H-2, 114–115	37.94	5.6
		29X-1, 20–21	257.8	5.61	4H-5, 115–116	30.75	5.78	5H-3, 98–99	39.28	5.84
Gilbert/Epoch 5	5.71				4H-5, 74	30.34	5.71			
C3An.1n (onset)	5.95				4H-6, 66	31.76	5.95			
<i>FO S. langii</i>		29X-3, 20–21	260.8	5.71	4H-6, 115–116	32.25	5.99	5H-2, 114–115	37.94	5.6
		30X-1, 21–22	267.41	5.93	5H-1, 115–116	34.25	6.27	5H-3, 98–99	39.28	5.84
<i>LO D. splendens</i>		29X-3, 20–21	260.8	5.71	4H-6, 115–116	32.25	5.99	5H-3, 98–99	39.28	5.84
		30X-1, 21–22	267.41	5.93	5H-1, 115–116	34.25	6.27	6H-1, 114–115	45.94	7.01
C3An.2n (term)	6.08				5H-1, 14	33.24	6.08			
C3An.2n (onset)	6.38				5H-2, 20	34.8	6.38			
<i>LO T. redondoensis</i>		29X-3, 20–21	260.8	5.71	5H-2, 115–116	35.75	6.57	5H-3, 98–99	39.28	5.84
		30X-1, 21–22	267.41	5.93	5H-3, 115–116	37.25	6.88	6H-1, 114–115	45.94	7.01
<i>FO P. crustula</i>		30X-1, 21–22	267.41	5.93	4H-3, 115–116	27.75	5.29	4H-5, 114–115	32.94	4.72
		30X-7, 22–23	276.42	6.23	4H-4, 115–116	29.25	5.53	4H-CC	35.3	5.13
C3Bn (term)	6.74									
C3Bn (onset)	6.9									
C3Br.1n (term)	6.95									
C3Br.1n (onset)	6.98									
<i>LO L. nipponica</i>		30X-7, 22–23	276.42	6.23	4H-6, 115–116	32.25	5.99	5H-3, 98–99	39.28	5.84
<i>nipponica</i>		32X-1, 20–21	286.7	6.58	5H-1, 115–116	34.25	6.27	6H-1, 114–115	45.94	7.01
<i>FO L. heteroporos</i>		30X-7, 22–23	276.42	6.23	5H-2, 115–116	35.75	6.57	5H-3, 98–99	39.28	5.84
		32X-1, 20–21	286.7	6.58	5H-3, 115–116	37.25	6.88	6H-1, 114–115	45.94	7.01
C4n.1n (term)	7.25				5H-5, 0	39.1	7.25	6H-2, 98	47.28	7.25
C4n.1n (onset)	7.38									
C4n.2n (term)	7.46									

Table 7 (continued).

Radiolarian event	CK92 Age	Hole 881C			Hole 885A			Hole 886C		
		Core, section, interval (cm)	Depth (mbsf)	Age (m.y.)	Core, section, interval (cm)	Depth (mbsf)	Age (m.y.)	Core, section, interval (cm)	Depth (mbsf)	Age (m.y.)
<i>S. delmontensis</i>		35X-1, 22-23	315.62	7.55	5H-5, 115-116	40.25	7.42	6H-3, 112-113	48.92	7.45
→ <i>S. peregrina</i>		36X-1, 29-30	325.39	7.88	5H-6, 115-116	41.75	7.64	6H-4, 114-115	50.44	7.63
LO <i>P. hayesi</i>		35X-1, 22-23	315.62	7.55	5H-5, 115-116	40.25	7.42	6H-3, 112-113	48.92	7.45
		36X-1, 29-30	325.39	7.88	5H-6, 115-116	41.75	7.64	6H-4, 114-115	50.44	7.63
FO <i>S. acquilonium</i>		35X-1, 22-23	315.62	7.55	5H-6, 115-116	41.75	7.64	6H-4, 114-115	50.44	7.63
		36X-1, 29-30	325.39	7.88	6H-1, 115-116	43.75	8.16	6H-5, 114-115	51.94	7.81
LO <i>A. amphistylum</i>					5H-5, 115-116	40.25	7.42	6H-3, 112-113	48.92	7.45
					5H-6, 115-116	41.75	7.64	6H-4, 114-115	50.44	7.63
C4n.2n (onset)	7.89				6H-1, 90	43.5	7.89	6H-6, 35	52.65	7.89
C4An (term)	8.53				6H-2, 0	44.1	8.53	6H-6, 82	53.12	8.53
LO <i>L. nipponica magnacornuta</i>					6H-1, 115-116	43.75	8.16	6H-5, 114-115	51.94	7.81
C4An (onset)	8.86				6H-2, 115-116	45.25	9.76	6H-CC	54.3	10.14
C4Ar.1n (term)	9.07									
C4Ar.1n (onset)	9.15									
C4Ar.2n (term)	9.43									
C4Ar.2n (onset)	9.49									
C5n.1n (term)	9.59									
C5n.1n (onset)	9.74									
C5n.2n (term)	9.78									
LO <i>C. japonica</i>										
C5n.2n (onset)	10.83				6H-6, 123	51.33	10.83			
LO <i>C. tetrapera</i>										
LO <i>E. inflatum</i>										
LO <i>C. cornuta</i>										
LO <i>L. renzae</i>										
C5r.2n (term)	11.38									
C5An.1n (term)	11.85									
C5An.1n (onset)	12									
C5An.2n (term)	12.11									
FO <i>L. nipponica magnacornuta</i>										
C5An.2n (onset)	12.33									
C5Ar.1n (term)	12.62									
C5Ar.1n (onset)	12.65									
C5Ar.2n (term)	12.72									
C5Ar.2n (onset)	12.76									
FO <i>S. delmontensis</i>										
C5AAn (term)	12.94									
C5ABn (onset)	13.48									
LO <i>E. asanoi</i>										
C5ACn (term)	13.67									
C5ACn (onset)	14.06									
C5ADn (term)	14.16									
C5Bn.1n (term)	14.8									
C5Bn.1n (onset)	14.89									
C5Bn.2n (term)	15.04									
C5Bn.2n (onset)	15.16									
FO <i>L. nipponica nipponica</i>										
FO <i>D. splendens</i>										
FO <i>E. inflatum</i>										
LO <i>Corythospyris?</i> sp.										
FO <i>E. asanoi</i>										
C5Cn (term)	16.04									
FO <i>T. redondoensis</i>										
FO <i>L. renzae</i>										
FO <i>Corythospyris?</i> sp.										
LO <i>Cenosphaera</i> sp.										
LO <i>C. cosma cosma</i>										
C5Dn (term)	17.31									
C5Dn (onset)	17.65									
C5En (term)	18.32									

Notes: Left-hand column lists radiolarian event and magnetic reversal. Column second from left (CK92 Age) gives age of magnetic event using Cande and Kent (1992) time scale. Next 15 columns list sample levels that bracket event, depth (mbsf), and age of these levels. Four columns on far right-hand side give age estimates for many of these events derived from information reported from previous studies of radiolarian-bearing sediments in the Pacific: northwest Pacific Site 579 (this study); eastern equatorial Pacific Leg 138 (Moore et al., 1993 [lower half of box when two dates given]; Moore, 1995); central Pacific Leg 85 (Johnson et al., 1989); North Pacific (Spencer-Cervanto et al., 1993). Ages of events revised to conform to Cande and Kent (1992) geochronology.

Table 7 (continued).

Radiolarian event	Hole 884B			Hole 887A			Pacific Leg 86, Hole 579A	Pacific Leg 138	Pacific Leg 85	North Pacific
	Core, section, interval (cm)	Depth (mbsf)	Age (m.y.)	Core, section, interval (cm)	Depth (mbsf)	Age (m.y.)				
<i>LO L. nipponica sakaii</i> n. ssp.				1H-1, 12-13	0.12	0				0.55
<i>LO S. acquilonium</i>	2H-5, 135-136	13.85	0.25	1H-3, 52-53	3.52	0.06				
	3H-5, 135-136	23.35	0.43	3H-3, 132-133	20.52	0.35				
<i>LO S. universus</i>	3H-5, 135-136	23.35	0.43	4H-1, 12-13	25.82	0.44	0.47	0.45		0.4
	4H-5, 135-136	32.85	0.6	4H-1, 12-13	25.82	0.44		0.46		
<i>LO A (?) callopisma</i>	Too rare			4H-3, 132-133	30.02	0.51				
				Absent						
Brunhes/Matayama	5H-5, 150	42.5	0.78	6H-1, 85	45.55	0.78		0.78		
<i>LO E. matuyamai</i>	6H-5, 135-136	51.85	0.93	7H-3, 54-56	57.74	1.02				1.05
	7H-5, 135-136	61.35	1.1	7H-6, 54-56	62.24	1.22				
Jaramillo (term)	7H-1, 60	54 - 55.1	0.98	7H-1, 140	55.6	0.98		0.91		
<i>FO L. nigrinae</i>	Absent			Absent			1.06	1.35	1.23	0.85
								1.33		
<i>LO P. pitomorphus</i>	5H-5, 135-136	42.35	0.78	5H-6, 55-56	43.25	0.74				
	6H-5, 135-136	51.85	0.93	6H-3, 54-55	48.24	0.83				
<i>LO L. neoheteroporos</i>	Absent			Absent			0.93	1.07		0.55
Jaramillo (onset)	7H-3, 90	59.4	1.05	7H-4, 25	58.95	1.05		1.07		
<i>LO S. robusta</i>	10H-CC	86.3	1.72	8H-3, 54-55	67.24	1.48				
	12X-1, 68-69	87.98	1.76	8H-6, 54-55	71.74	1.71				
<i>LO L. heteroporos</i>	10H-CC	86.3	1.72	Absent			1.37	1.79		
	12X-1, 68-69	87.98	1.76							
Olduvai (term)										
Olduvai (onset)	13X-3, 60	96.9	1.98					1.77		
<i>FO E. matuyamai</i>	12X-1, 68-69	87.98	1.76	9H-3, 54-55	76.74	1.97		1.95		
	13X-3, 134-135	97.64	2	10H-3, 54-55	86.24	2.46				2
<i>FO L. nipponica sakaii</i> n. ssp.	10H-CC	86.3	1.72	9H-3, 54-55	76.74	1.97				
	12X-1, 68-69	87.98	1.76	10H-3, 54-55	86.24	2.46				
Réunion (term)	14X-3, 110	107.1	2.2							
Réunion (onset)	14X-4, 70	108.2	2.23							
<i>FO P. pitomorphus</i>	13X-3, 134-135	97.64	2	12H-6, 54-55	109.74	3.51				
	14X-5, 133-134	110.3	2.29	13H-3, 54-55	114.74	3.75				
<i>FO L. neoheteroporos</i>	Absent			Absent			2.25	3.25		
Matuyama/Gauss	15X-7, 30	121.9	2.6	10H-4, 20	88.9	2.6				
<i>FO C. davisiana davisiana</i>	17X-5, 135-136	139.15	2.9	11H-3, 54-55	95.74	2.85	2.82	2.71		2.8
	18X-5, 135-136	148.85	3.06	12H-3, 54-55	105.24	3.27				
<i>LO P. fistula</i>	17X-5, 135-136	139.15	2.9	13H-3, 54-55	114.74	3.75			4.41	3.4
	18X-5, 135-136	148.85	3.06	14H-3, 54-55	124.24	4.11			4.39	
Kaena (term)	18X-4, 60	148.1	3.05	11H-6, 140	101.1	3.05			3.054	
Kaena (onset)	19X-1, 125	152.35	3.13	12H-1, 14	101.85	3.13			3.127	
Mammoth (term)	19X-6, 100	159.6	3.22	12H-2, 100	104.2	3.22			3.221	
Mammoth (onset)				12H-4, 35	106.55	3.33			3.325	
Gauss/Gilbert	21X-6, 120	179.2	3.55	12H-6, 115	110.35	3.55				
<i>LO P. crustula</i>	Absent			Absent						
Cochiti (term)	26X-1, 95	219.65	4.03	14H-1, 40	121.1	4.03			4.188	
Cochiti (onset)	26X-4, 100	224.2	4.13	14H-3, 150	125.2	4.13			4.32	
<i>LO D. bullatus</i> n. sp.	Absent			Absent						
C3n.2n (onset)				15X-4, 0	134.7	4.43			4.604	
C3n.3n (term)	29X-4, 0	252.1	4.61						4.782	
C3n.3n (onset)	30X-1, 110	258.4	4.69	16X-1, 100	142.2	4.69			4.88	
C3n.4n (term)	30X-7, 50	266.8	4.81	17X-1, 70	145.8	4.81			4.981	
C3n.4n (onset)	31X-1, 70	276.7	5.05	17X-4, 35	149.95	5.05			5.228	
<i>LO S. peregrina</i>	33X-4, 135-136	292.4	5.34	20X-3, 54-55	177.64	5.94	2.97	2.69	2.78	2.9
	35X-1, 135-135	307.1	5.62	21X-3, 54-55	186.74	6.39				
<i>LO S. delmontensis</i>	39X-5, 135-136	351.3	6.45	21X-3, 54-55	186.74	6.39				
	41X-5, 135-136	370.5	6.99	22H-2, 54-55	195.44	7.04				
<i>FO D. bullatus</i> n. sp.	Absent			Absent						
Gilbert/Epoch 5	35X-4, 135	311.55	5.71	(19X-4, 110)	169.5	5.71		5.875		
C3An.1n (onset)	37X-1, 0	325	5.95	(20X-3, 90)	178	5.95		6.122		
<i>FO S. langii</i>	29X-1, 135-136	249	4.56	16X-3, 55-56	143.25	4.73				4.95
	31X-5, 135-136	274.4	4.99	17X-2, 54-55	147.14	4.89				
<i>LO D. splendens</i>	29X-1, 135-136	249	4.56	16X-3, 55-56	143.25	4.73				
	31X-5, 135-136	274.4	4.99	17X-2, 54-55	147.14	4.89				
C3An.2n (term)	38X-1, 20	334.5	6.08	(20X-6, 90)	182.5	6.08			6.256	
C3An.2n (onset)	39X-3, 110	348	6.38						6.555	
<i>LO T. redondoensis</i>	29X-1, 135-136	249	4.56	17X-2, 54-55	147.14	4.89				
	31X-5, 135-136	274.4	4.99	18X-3, 54-55	158.34	5.33				
<i>FO P. crustula</i>	Absent			Absent						
C3Bn (term)	41X-1, 120	364.3	6.74							
C3Bn (onset)	41X-4, 0	367.6	6.9							
C3Br.1n (term)	41X-5, 0	369.1	6.95							
C3Br.1n (onset)	41X-5, 120	370.25	6.98							
<i>LO L. nipponica nipponica</i>	49X-5, 135-136	447.6	9.26	24H-6, 54-55	220.44	9.44				
	50X-5, 135-136	457.2	9.74	25H-3, 54-55	225.44	10.01				
<i>FO L. heteroporos</i>	Too rare			Too rare					3.29	4.6
C4n.1n (term)	42X-2, 0	374.2	7.25						7.406	
C4n.1n (onset)	42X-5, 95	379.65	7.38	(22H-5, 60)	200	7.38			7.533	
C4n.2n (term)	42X-6, 130	381.5	7.46	(22H-6, 10)	201	7.46			7.618	

Table 7 (continued).

Radiolarian event	Hole 884B			Hole 887A			Pacific Leg 86, Hole 579A	Pacific Leg 138	Pacific Leg 85	North Pacific
	Core, section, interval (cm)	Depth (mbsf)	Age (m.y.)	Core, section, interval (cm)	Depth (mbsf)	Age (m.y.)				
<i>S. delmontensis</i>	Not found			22H-6, 54-55	201.44	7.5		6.73	6.58	6.5-8.4
→ <i>S. peregrina</i>				23H-6, 54-55	210.94	8.38		6.69		
LO <i>P. hayesi</i>	43X-5, 135-136	389.8	7.65	22H-6, 54-55	201.44	7.5				
	45X-5, 135-136	409.1	8.2	23H-6, 54-55	210.94	8.38				
FO <i>S. acquilonium</i>	43X-5, 135-136	389.8	7.65	22H-6, 54-55	201.44	7.5				4.95
	45X-5, 135-136	409.1	8.2	23H-6, 54-55	210.94	8.38				
LO <i>A. amphistylum</i>	43X-5, 135-136	389.8	7.65	23H-6, 54-55	210.94	8.38				
	45X-5, 135-136	409.1	8.2	24H-3, 54-55	215.94	8.85				
C4n.2n (onset)	44X-6, 70	400.2	7.89	(23H-3, 10)	206	7.89		8.027		
C4An (term)	46X-5, 115	418.45	8.53	(24H-1, 0)	212.4	8.53		8.631		
LO <i>L. nipponica</i>	47X-5, 135-136	428.3	8.71	23H-6, 54-55	210.94	8.38				
<i>magnacornuta</i>	48X-5, 135-136	438	8.94	24H-3, 54-55	215.94	8.85				
C4An (onset)	48X-4, 105	436.15	8.86	(24H-3, 60)	216	8.86		8.945		
C4Ar.1n (term)	49X-1, 45	440.65	9.07					9.142		
C4Ar.1n (onset)	49X-4, 50	445.2	9.15					9.218		
C4Ar.2n (term)	50X-1, 130	451.1	9.43	(24H-6, 45)	220.35	9.43		9.482		
C4Ar.2n (onset)	50X-3, 30	453.1	9.49	(24H-6, 135)	221.25	9.49		9.543		
C5n.1n (term)	50X-3, 70	453.5	9.59	(24H-7, 50)	221.9	9.59		9.639		
C5n.1n (onset)	50X-6, 0	457.3	9.74	(25H-2, 5)	223.45	9.74				
C5n.2n (term)	50X-7, 50	458.75	9.78	(25H-2, 25)	223.65	9.78				
LO <i>C. japonica</i>	51X-5, 135-136	466.7	9.97	24H-6, 54-55	220.44	9.44		10.1	9.7	11.15
	52X-5, 135-136	476.2	10.2	25H-3, 54-55	225.44	10.01		10.1		
C5n.2n (onset)	55X-3, 25	502.5	10.83	(26X-1, 60)	232	10.83		10.839		
LO <i>C. tetrapera</i>	49X-5, 135-136	447.6	9.26	25H-6, 54-55	229.94	10.57			12	12.05
	50X-5, 135-136	457.2	9.74	C-26H-6, 55-56	234.35	11.24				
LO <i>E. inflatum</i>	56X-5, 135-136	514.8	11.52	25H-6, 54-55	229.94	10.57				12.55
	57X-5, 137-139	524.5	12.24	C-26H-6, 55-56	234.35	11.24				
LO <i>C. cornuta</i>	56X-5, 135-136	514.8	11.52	C-26H-6, 55-56	234.35	11.24		11.89	12	12.4
	57X-5, 137-139	524.5	12.24	C-27H-3, 55-56	239.35	11.89				
LO <i>L. renzae</i>	56X-5, 135-136	514.8	11.52	C-26H-6, 55-56	234.35	11.24		11.83	12	12.55
	57X-5, 137-139	524.5	12.24	C-27H-3, 55-56	239.35	11.89				
C5r.2n (term)				C-26H-6, 135	235.15	11.38		11.373		
C5An.1n (term)	57X-3, 60	520.7	11.85	C-27H-2, 95	238.25	11.85		11.841		
C5An.1n (onset)	57X-4, 50	522.1	12	C-27H-3, 70	239.5	12				
C5An.2n (term)	57X-4, 140	523	12.11	C-27H-3, 125	240.05	12.11				
FO <i>L. nipponica</i>	57X-5, 137-139	524.5	12.24	C-27H-3, 55-56	239.35	11.89				
<i>magnacornuta</i>	58X-5, 135-136	534.1	12.88	C-27H-6, 55-56	243.85	12.73				
C5An.2n (onset)	57X-6, 90	525.5	12.33	C-27H-4, 135	241.65	12.33				
C5Ar.1n (term)	58X-2, 30	528.5	12.62							
C5Ar.1n (onset)	58X-3, 30	530	12.65							
C5Ar.2n (term)	58X-3, 130	531	12.72							
C5Ar.2n (onset)	58X-4, 130	532.5	12.76							
FO <i>S. delmontensis</i>	58X-5, 135-136	534.1	12.88	28H-3, 54-55	254.24	14.49				
	59X-5, 135-136	543.8	13.52	28H-6, 55-56	258.75	15.26				
C5AAn (term)	58X-6, 80	535	12.94							
C5ABn (onset)	59X-4, 140	542.3	13.48							
LO <i>E. asanoi</i>	59X-5, 135-136	543.8	13.52	28H-3, 54-55	254.24	14.49				
	60X-5, 135-136	553.5	13.82	28H-6, 55-56	258.75	15.26				
C5ACn (term)	60X-3, 90	550	13.67	(27H-6, 30)	249	13.67				
C5ACn (onset)	61X-3, 40	559	14.06	(28H-1, 70)	251.4	14.06				
C5ADn (term)				(28H-2, 20)	252.4	14.16				
C5Bn.1n (term)				(28H-4, 80)	256	14.8				
C5Bn.1n (onset)				(28H-5, 30)	257	14.89				
C5Bn.2n (term)				(28H-5, 80)	257.5	15.04				
C5Bn.2n (onset)				(28H-6, 0)	258.2	15.16				
FO <i>L. nipponica</i>	57X-5, 137-139	524.5	12.24	28H-6, 55-56	258.75	15.26				
<i>nipponica</i>	58X-5, 135-136	534.1	12.88	29H-3, 54-55	263.74	16.27				
FO <i>D. splendens</i>	61X-5, 135-136	563	14.44	28H-6, 55-56	258.75	15.26				
	62X-5, 135-136	572.7	15.35	29H-3, 54-55	263.74	16.27				
FO <i>E. inflatum</i>	61X-5, 135-136	563	14.44	28H-6, 55-56	258.75	15.26				13.25
	62X-5, 135-136	572.7	15.35	29H-3, 54-55	263.74	16.27				
LO <i>Corythospyris?</i>	61X-5, 135-136	563	14.44	28H-6, 55-56	258.75	15.26				
sp.	62X-5, 135-136	572.7	15.35	29H-3, 54-55	263.74	16.27				
FO <i>E. asanoi</i>	62X-5, 135-136	572.7	15.35	28H-6, 55-56	258.75	15.26				
	63X-5, 135-136	582.2	16.24	29H-3, 54-55	263.74	16.27				
C5Cn (term)	63X-4, 70	580	16.04	(29H-2, 130)	263	16.04				
FO <i>T. redondoensis</i>	63X-5, 135-136	582.2	16.24	28H-6, 55-56	258.75	15.26				
	64X-4, 135-136	590.3	16.96	29H-3, 54-55	263.74	16.27				
FO <i>L. renzae</i>	61X-5, 135-136	563	14.44	29H-3, 54-55	263.74	16.27				
	62X-5, 135-136	572.7	15.35	C-30H-3, 54-55	267.84	17.51				
FO <i>Corythospyris?</i>	63X-5, 135-136	582.2	16.24	29H-3, 54-55	263.74	16.27				
sp.	64X-4, 135-136	590.3	16.96	C-30H-3, 54-55	267.84	17.51				
LO <i>Cenospaera</i> sp.	63X-5, 135-136	582.2	16.24	29H-3, 54-55	263.74	16.27				
	64X-4, 135-136	590.3	16.96	C-30H-3, 54-55	267.84	17.51				
LO <i>C. cosma cosma</i>	64X-4, 135-136	590.3	16.96	29H-3, 54-55	263.74	16.27				
	65X-5, 135-136	601.5	18.09	C-30H-3, 54-55	267.84	17.51				
C5Dn (term)	65X-1, 10	594.2	17.31	(29H-5, 80)	267	17.31				
C5Dn (onset)	65X-4, 40	599	17.65	C-30H-3, 110	268.4	17.65				
C5En (term)	65X-6, 120	602.8	18.32	C-30H-6, 15	271.95	18.32				

the Jaramillo Subchron (1.05 Ma). At Site 881, the youngest sample in which *E. matuyamai* is present falls just above the onset of the Jaramillo. If we combine the presence/absence data shown in the range charts for these four sites (Tables 2–4, 6), we arrive at an estimate of 1.0 Ma for the age of this event. At Site 886, the entire Jaramillo Subchron was not detected in Hole 886C, which may explain why *E. matuyamai* was found in only a single sample from this hole. The timing of this event recorded at the Leg 145 sites agrees with that reported previously in western North Pacific sediments (Foreman, 1975; Kellogg and Hays, 1975; Reynolds, 1980; Sakai, 1980; Morley, 1985), in eastern North Pacific sequences (Kling, 1973; Wolfart, 1981) and in California sections (Weaver et al., 1981). It is also similar to the average age for LO of *E. matuyamai* in North Pacific sites reported by Spencer-Cervato et al. (1993).

Lamprocyrtis nigrinae (Pl. 7, Fig. 9) only occurs in the three southern Leg 145 sites. The estimated age of this species' FO ranges from 0.52 to 1.24 Ma. This range encompasses age estimates for this event computed from data presented in other studies of sediment records from the eastern (Kling, 1973; Weaver et al., 1981; Wolfart, 1981), western (Foreman, 1975; Reynolds, 1980; Sakai, 1980) and entire (Spencer-Cervato et al., 1993) North Pacific. The upper limit of our range is similar to that reported for this event in the low-latitude Indian (1.11 Ma; Caulet et al., 1993), and central Pacific (1.23 Ma; Johnson et al., 1989) oceans, as well as at latitudes <40°N in the western North Pacific (1.06 Ma, this study) Ocean. Our age estimate is, however, somewhat younger than the age (1.33–1.35 Ma) calculated for this species' FO in the eastern equatorial Pacific (Moore et al., 1993; Moore, 1995).

The LO of *Lamprocyrtis neoheteroporos* (Pl. 7, Fig. 7) is only recorded in the three southern sites (881, 885, and 886), with an estimated age of 0.85 Ma. This age estimate is younger than that given by Moore et al. (1993) and Moore (1995) for this event (1.07 Ma) in eastern equatorial Pacific Leg 138 sites, by Caulet et al. (1993) for the low-latitude Indian Ocean (1.18 Ma), and by Reynolds (1980) in western North Pacific Leg 57 sites (LO of *L. neoheteroporos* coincides with LO of *Eucyrtidium matuyamai*, ~1.0 Ma). However, it is similar to the estimated age of this event of 0.93 Ma calculated from our studies of closely spaced samples from northwest Pacific Site 579, as well as that reported by Kling (1973) and Wolfart (1981) for the LO of *L. neoheteroporos* in records from the eastern North Pacific (LO of *L. neoheteroporos* occurs in the lower part of the *Stylatractus universus* Zone). The timing of this event in sediments from our Leg 145 sites is older than the age given for it in the western North Pacific by Foreman (1975; LO of *L. neoheteroporos* near the middle of *S. universus* Zone, ~0.7 Ma) and Sakai (1980; LO of *L. neoheteroporos* near top of *S. universus* Zone, ~0.45 Ma), in California sections by Weaver et al. (1981, ~0.58 Ma), and across the entire North Pacific (0.55 Ma) as averaged by Spencer-Cervato et al. (1993).

The LO of *Sphaeropyle robusta* (Pl. 1, Figs. 6, 7) occurs just above the termination of the Olduvai Subchron in all five Leg 145 sites. In four of the five sites, all except for Site 885, the age appears to range from ~1.5 to 1.7 Ma. Morley (1985) also reported the LO of this species between the Jaramillo and Olduvai Subchrons in the northwest Pacific Leg 86 sites. The timing of this event (in the lower part of the *Eucyrtidium matuyamai* Zone) is similar to that previously reported from western North Pacific DSDP sites (Foreman, 1975; Reynolds, 1980; Sakai, 1980). Kling (1973), however, placed the LO of *S. robusta* in the uppermost *Lamprocyrtis heteroporos* Zone before the FO of *E. matuyamai*. Kling's older estimate for this event may reflect differences in defining characteristics of this species.

Lamprocyrtis heteroporos (Pl. 7, Figs. 5, 8) occurs in only two samples from Gulf of Alaska Site 887 and in only four levels in our other northern site (884). Even at these low abundances, it appears as if this species' LO was recorded in all of the sites we examined with the exception of Site 887. In three of the four sites that record this event, the youngest sample containing *L. heteroporos* is positioned directly above the termination of the Olduvai Subchron (1.76 Ma). At

Site 881, the youngest sample in which this species is present falls below the onset of the Olduvai Subchron (1.98 Ma). The estimated age of this event ranges from ~1.3 to 2.0 Ma based on the combined presence/absence data in the range charts for this species (Tables 2–5). This age range in high-latitude North Pacific sediments encompasses most other estimates for this event in other regions of the world's oceans. In the eastern North Pacific, Kling's (1973) and Wolfart's (1981) data place this event near the middle of the *Eucyrtidium matuyamai* Zone (~1.5 Ma). Weaver et al. (1981) published an age of 1.65 Ma for this event in sediments from Californian sections. A wide range of values has been published for the LO of *L. heteroporos* in western North Pacific sediments. Sakai (1980) shows this event near the base of the *Stylatractus universus* Zone (~0.9 Ma) in studies of sediments from DSDP Leg 56 material off Japan. Other western North Pacific studies, however, indicate a much older age for this event, with Foreman (1975) reporting the LO of *L. heteroporos* as occurring near the middle of the *E. matuyamai* Zone (~1.4 Ma). Reynolds (1980), in his examination of western Pacific records from DSDP Leg 57, placed this event just below the LO of *E. matuyamai* (~2.0 Ma). We calculated an age of 1.37 Ma for this event in western North Pacific Site 579 positioned just south (39°N) of our Leg 145 sites. In eastern equatorial Leg 138 sites, Moore et al. (1993) and Moore (1995) give an age of 1.79 Ma for this event.

If data from Site 886 is included even though *Eucyrtidium matuyamai* (Pl. 5, Fig. 3) is present in only a single sample, then all five Leg 145 sites record the FO of this species near the base of the Olduvai Subchron (1.98 Ma). By combining the presence/absence information for this event from these five sites, we estimate an age for this species' FO at between 1.9 and 2.1 Ma. This age is similar to that published by others who have examined sediments from various regions of the North Pacific and from California (Kling, 1973; Foreman, 1975; Reynolds, 1980; Sakai, 1980; Wolfart, 1981; Weaver et al., 1981; Spencer-Cervato et al., 1993).

Lamprocyrtis neoheteroporos (Pl. 7, Fig. 7) is present only in the three southern sites drilled during Leg 145. The oldest sample containing this species at all three sites is positioned near the Matuyama/Gauss boundary. If we combine the presence/absence data for *L. neoheteroporos* from the range charts for these three sites (Tables 2, 4, 5), we estimate that the age of the FO of this species ranges from ~2.45 to 3.0 Ma. Our estimate for this event in Leg 145 sites is older than that reported in most other studies. In the eastern North Pacific, Kling (1973) and Wolfart (1981) reported this event as occurring in the middle of the *Eucyrtidium matuyamai* Zone (~1.35 Ma). In the western North Pacific, Foreman (1975) documented the gradual evolutionary development of this species from the upper part of the *Lamprocyrtis heteroporos* Zone into the middle of the *E. matuyamai* Zone. Sakai (1980) positioned the FO of *L. neoheteroporos* at the base of the *E. matuyamai* Zone (~2.0 Ma) in his range chart.

We have examined material from northwest Pacific Site 579 (Leg 86) situated just south (39°N) of Leg 145's southernmost sites and computed an estimated age of 2.25 Ma for this event. Caulet et al. (1993) reported a similar age of 2.34 Ma for this species' FO in sediments from the low-latitude Indian Ocean. The only published older age for the FO of *L. neoheteroporos* comes from the Leg 138 studies (Moore et al., 1993; Moore, 1995), where an estimated age of 3.25 Ma was determined for this event.

The FO of *Cycladophora davisiana davisiana* (Pl. 4, Figs. 3, 4) is distinctly recorded in North Pacific sediments. In the three Leg 145 sites (881, 884, and 887) that record the Kaena Subchron, the oldest sample in which this species is present falls just above the Kaena termination (3.05 Ma). From examination of our sample interval and the presence/absence data for this event in the range charts (Tables 2–6), we estimate that *C. davisiana davisiana* first occurred in the North Pacific between ~2.75 and 3.0 Ma.

Our estimated age range for this event is similar to that in DSDP Leg 86 sediments from Hole 579A, directly south of our sites, where we have computed an age of 2.82 Ma for the FO of *C. davisiana davi-*

siana. In North Pacific sediments at DSDP Legs 56 and 57 off Japan, Sakai (1980) and Reynolds (1980) placed this event in the lower half of the *Lamprocyrtis heteroporos* Zone, slightly older than the FO of *Lamprocyrtis neoheteroporos*. The FO of *C. davisiana davisiana* occurs at the base of the *L. heteroporos* Zone in eastern North Pacific Leg 18 sites (Kling, 1973). In their revision of radiolarian events, Spencer-Cervato et al. (1993) published an age of 2.8 Ma averaged using data from seven North Pacific DSDP sites. Moore et al. (1993) and Moore (1995) report an age of 2.71 Ma for this species' FO in eastern equatorial Pacific sediments. A younger age of 2.55 Ma has been given by Caulet et al. (1993) for this event in low-latitude sediments from the Indian Ocean.

Present only in the southern three North Pacific sites, *Dictyophimus bullatus* (Pl. 4, Figs. 5, 9, 10) has a short range (~4.2–5.6 Ma) centered about the Miocene/Pliocene boundary. From examination of our sample interval and the presence/absence data in our range charts for these sites (Tables 2, 4, 5), we calculated an estimated age of ~4.2 Ma for the LO of *D. bullatus*.

Stichocorys peregrina (Pl. 6, Figs. 2, 3) is not as abundant in high-latitude sites as it is in the mid- and low-latitude sites. In Leg 145 sites the LO of *S. peregrina* is diachronous. In the three southern Sites 881, 885, and 886, our best estimate of the age of this event is between 4.9 and 5.1 Ma. In the Gulf of Alaska site (887), the youngest sample in which this species is present has an estimated age of 6.4 Ma; whereas, in the western high-latitude North Pacific at Site 884, the youngest sample containing *S. peregrina* is of latest Miocene age (~5.6 Ma). Thus, it appears that *S. peregrina* disappeared from the Gulf of Alaska first, then from the western high-latitude North Pacific, before becoming extinct in the earliest Pliocene at the three southern sites drilled during Leg 145.

Our age estimates for the LO of *S. peregrina* are older than those reported for this event in other areas of the North Pacific and the Indian Ocean. The nearest age to our estimate for this event comes from the work of Weaver et al. (1981) who estimated an age of 4.6 Ma for this event in California sequences. In marine sediments off California, both Kling (1973) and Wolfart (1981) show the LO of *S. peregrina* taking place during the Pliocene. Kling lists this event just above the LO of *Cycladophora davisiana davisiana*. In the western North Pacific east of Japan, studies of sediments from four DSDP legs (Foreman, 1975; Reynolds, 1980; Sakai, 1980; Morley, 1985) all give an age of ~2.9 Ma for the LO of *S. peregrina*, with the placement of LO of *S. peregrina* in the late Pliocene defining the base of the *Lamprocyrtis heteroporos* Zone. From data provided by Alexandrovich (1992), we have calculated an age of ~3.75 Ma for the LO of *S. peregrina* in Japan Sea sediments. Calculated ages for this event in the eastern equatorial Pacific (ODP Leg 138; Moore et al., 1993; Moore, 1995), in the central Pacific (DSDP Leg 85; Johnson et al., 1989), and in the low-latitude Indian Ocean (Caulet et al., 1993) range from 2.69 to 2.78 Ma. Spencer-Cervato et al. (1993) give an average age of 2.9 Ma for the LO of *S. peregrina* in their recalibration of radiolarian events in a series of mid- and low-latitude North Pacific DSDP sites.

As with *Stichocorys peregrina*, *Stichocorys delmontensis* (Pl. 6, Fig. 5) is not as abundant in high-latitude sediments as it is in mid- and low-latitude sequences. The LO of *S. delmontensis* appears to be diachronous across the North Pacific. Combining the presence/absence data for this species for the three southern Leg 145 sites (Tables 2, 4, 5), the age of this event ranges between 4.9 and 5.1 Ma. In our northern Sites 884 and 887, however, we estimate the age of the LO of *S. delmontensis* to range from 6.4 to 7.0 Ma.

Other studies have also shown that the age of this event in Pacific sediments is quite variable. The youngest age estimates for the LO of *S. delmontensis* are apparently recorded in western North Pacific sediments where this datum level occurs in the early Pliocene within the upper half of the *Sphaeropyle langii* Zone (Foreman, 1975; Reynolds, 1980; Sakai, 1980). Both Kling (1973) and Wolfart (1981) re-

port an older age for this event, placing it in the late Miocene slightly below the Miocene/Pliocene boundary within the *Stichocorys peregrina* Zone. Weaver et al. (1981) also have the LO of *S. delmontensis* occurring in Californian sequences within the *S. peregrina* Zone at 6.2 Ma. From data published by Alexandrovich (1992) for this event, we estimate the LO of *S. delmontensis* in Japan Sea sediments at ~6.8 Ma.

As stated previously, *Dictyophimus bullatus* (Pl. 4, Figs. 5, 9, 10) is not present in our northern two sites (884 and 887). In our three southern sites (881, 885, and 886), the oldest sample in which this species is present appears to be positioned directly above the termination of magnetic event C3An.1n (Gilbert/Epoch 5 boundary, 5.71 Ma). Combining the presence/absence data for this species in our three southern sites (Tables 2, 4, 5) enables us to narrow the range of the estimated age for the first appearance of this species in the North Pacific to between 5.60 and 5.61 Ma.

Although present consistently in the younger portion of the record at all five Leg 145 sites, *Sphaeropyle langii* (Pl. 2, Figs. 2, 5, 7) is found very sporadically around the time of its FO in high-latitude North Pacific sediments. Foreman (1975) used this event in defining the base of her *Sphaeropyle langii* Zone, a North Pacific radiolarian zone covering much of the early Pliocene.

Data from Leg 145 indicate that not only is the FO of this species not distinctly recorded in high-latitude North Pacific sediments, but that this event is most likely diachronous and, therefore, its use as a zonal marker is questionable. In the southern three Leg 145 sites, our combined presence/absence data from our range charts (Tables 2, 4, 5) indicate that this event occurred between 5.8 and 6.0 Ma. The age of this species' FO in northern Sites 884 and 887 appears to take place one million years later, with combined presence/absence data from the range charts for these sites (Tables 2, 6) centering on an age ~4.8 Ma.

Our two age estimates for the FO of *S. langii* bracket those reported in studies of marine sediments from the western North Pacific south of our sites (Foreman, 1975; Reynolds, 1980; Sakai, 1980), which place this event at or just below the Miocene/Pliocene boundary. It appears that this event occurred earlier in Japan Sea sediments (Alexandrovich, 1992), where we have calculated an age of 3.2 Ma for this datum level. Spencer-Cervato et al. (1993), in their study of mid- and low-latitude North Pacific DSDP sites, arrived at an age of 4.95 Ma for the FO of *S. langii*.

Dictyophimus splendens (Pl. 7, Figs. 3, 4) was first described by Campbell and Clark (1944) in California Miocene sequences. More recently, Caulet (1986b) has reported this species' LO in lower Pliocene sediments from the subantarctic, whereas C. Nigrini (unpubl. data, 1994) gives an age between 4.6 and 4.9 Ma for this event in the Central Indian Basin.

Although diachronous, *D. splendens* occurs in all five Leg 145 sites. At Site 885, the youngest sample in which this species is present falls within magnetic event C3An.2n (6.08–6.38 Ma). When we combine the presence/absence information on the range charts for our three southern North Pacific sites (Tables 2, 4, 5), we arrive at an estimated age of 5.95 Ma for this event, disregarding data from Site 886 because of a 4.5 m gap in the sediment record from Core 5 of Hole 886C. In our two northern sites (884 and 887), the youngest sample containing *D. splendens* occurs within magnetic event C3n.4n (4.81–5.05 Ma). The estimated age of ~4.8 Ma for the timing of this event at high-latitude North Pacific Sites 884 and 887 is comparable to that reported by Caulet (1986b) and Nigrini (unpubl. data) in subantarctic and low-latitude Indian Ocean sediments, respectively.

The LO of *Theocorys redondoensis* (Pl. 7, Figs. 1, 2, 6) is diachronous in Leg 145 sites. In the two high-latitude northern sites (884 and 887), the youngest sample in which *T. redondoensis* is present occurs within (Site 884) or directly below (Site 887) magnetic event C3n.4n (4.81–5.05 Ma). If we combine the presence/absence data for this event from the range charts (Tables 2, 6) for these two sites, we

arrive at an age of ~4.9 Ma in our two northernmost sites. In our three sites to the south, the estimated age of this event ranges from 5.71 to 7.01 Ma. However, this is artificially too old because of the nonrecovery of about 4.5 m of sediment in the bottom of Core 145-886C-5H. If we discard the information from Site 886, the ages for this event at the remaining two sites (881 and 885) still do not coincide, with a younger date (~5.8 Ma) recorded in the western (Site 881) North Pacific compared to the computed date (6.6–6.9 Ma) for this event in the central North Pacific (Site 885).

Age estimates for this event published previously all support the diachronous nature of the LO of *T. redondoensis* in Pacific sediments. Kling (1973) and Wolfart (1981) both placed this datum just below the Miocene/Pliocene boundary (~5.3–5.4 Ma) in eastern North Pacific sediments from DSDP Legs 19 and 63, respectively. Further to the east, Weaver et al. (1981) reported an age of ~7.0 Ma for this event in sediment sequences from California. In western North Pacific sediments from DSDP Leg 57, Reynolds (1980) showed this event occurring in the early Pliocene (lower part of the *Sphaeropyle langii* Zone).

The LO of *Lychnocanoma nipponica nipponica* (Pl. 5, Figs. 4, 5) is accurately recorded in all Leg 145 sites except for Site 886. Although an apparent level for this event can be determined in sediments from Site 886, it is of questionable use because only the upper half (~4.5 m) of the core barrel of Core 145-886C-5H retained cored sediment, creating a gap of approximately 4.5 m in the sediment record from this site. The youngest sample containing this species at Site 885 falls within magnetic event C3An.2n (6.08–6.38 Ma). If we combine the presence/absence data for this event contained in the range charts for southern Sites 881 and 885 (Tables 2, 4), we arrive at an age estimate of ~6.25 Ma. The LO of *L. nipponica nipponica* in our two northern Leg 145 sites (884 and 887) is much older, with a range between 9.26 and 10.01 Ma. We can narrow the range of this event in our northern two sites by selecting the age of the oldest sample where *L. nipponica nipponica* is absent (9.44 Ma) and the age of the youngest sample containing this species (9.74 Ma), arriving at an estimated age for this event of ~9.6 Ma.

Previous studies support the data presented above, indicating that the LO of *L. nipponica nipponica* is diachronous, with this species evidently existing longer at lower latitudes. In analyses of DSDP Leg 56 sediments from the western North Pacific off Japan, Sakai (1980) listed the disappearance of this species in his radiolarian events table just before the FO of *Stylocystium acqulonium*. Alexandrovich (1992) reported the LO of *L. nipponica nipponica* in Japan Sea sediments just above the LO of *Stichocorys delmontensis* in the upper part of the late Miocene. Although Sakai placed these two events within the early Pliocene portion of the *Sphaeropyle langii* Zone, our study when combined with the results of Alexandrovich (1992) strongly suggests that these events occurred somewhat older in the late Miocene. Reynolds (1980) lists a late Pliocene age for this event in western Pacific Leg 57 sediments, with the LO of *Lychnocanum grande* (which we consider to be *L. nipponica nipponica*) occurring in his table of radiolarian datums between the LO of *Stichocorys peregrina* and the FO of *Cycladophora davisiana davisiana*.

The presence of *Lamprocyrtis heteroporos* (Pl. 7, Figs. 5, 8) in many of the samples immediately above the supposedly first recorded presence is so sporadic in Sites 884 and 887 that information from these Leg 145 northern sites is inadequate for definitive placement of its FO. This event is evident in the three southern sites that have higher abundances of *L. heteroporos*. At Site 885, the oldest sample containing this species is positioned between the termination of magnetic event C4n.1n (7.25 Ma) and the onset of magnetic event C3An.2n (6.38 Ma). Information regarding this event in Site 886 is somewhat misleading because Core 145-886C-5H did not recover sediment below the upper 4.5 m of the core barrel. If we use only the data pertaining to the FO of *L. heteroporos* from Sites 881 and 885, we arrive at an estimated age of 6.6 Ma for this event.

In most cases, our estimated age for the FO of *L. heteroporos* is significantly older than previously reported in North Pacific sedi-

ments. In the western North Pacific, Foreman (1975) and Reynolds (1980) place this event slightly above the Miocene/Pliocene boundary within the *Sphaeropyle langii* Zone. Sakai (1980), in his study of DSDP Leg 56 sediments off Japan, also had the FO of *L. heteroporos* occurring within the *S. langii* Zone, but with a somewhat younger age. Examination of the range chart for DSDP Leg 86 Site 578 (Morley, 1985) indicates that at least at this northwestern Pacific site, *L. heteroporos* extended into the upper Miocene. In the eastern North Pacific, Kling (1973) places this event within the latest Miocene just below the Miocene/Pliocene boundary, whereas Wolfart (1981) shows it coinciding with the Miocene/Pliocene boundary. In Californian sections, Weaver et al. (1981) also positioned the FO of *L. heteroporos* close to the Miocene/Pliocene boundary. Spencer-Cervato et al. (1993) give an age of 4.6 Ma for this event in their revision of radiolarian datum levels in DSDP sites situated across the mid- and low-latitude North Pacific. The youngest age for the FO of *L. heteroporos* is that reported for eastern equatorial Pacific sediments, where Moore et al. (1993) and Moore (1995) calculated an age for the FO of *L. heteroporos* of 3.29 Ma.

The radiolarian assemblage in four of the five Leg 145 sites shows a sharp definitive change in dominance from *Stichocorys delmontensis* to *Stichocorys peregrina*. The intermittent occurrences of *S. peregrina* in sediments from Site 884 make it difficult to locate precisely this change in dominance. This shift in dominance most likely occurs within magnetic event C4n.2n (7.46–7.89 Ma). If we combine the presence/absence data for this event shown in our range charts for these four sites (Tables 2, 4–6), we can narrow the estimated age range to between 7.55 and 7.63 Ma.

Our estimated age of this dominance shift in Leg 145 sediments is slightly older than the ages of 6.69 Ma (Moore et al., 1993) and 6.73 Ma (Moore, 1995) calculated from eastern equatorial Pacific Leg 138 sites, 6.58 Ma computed from data in central Pacific sites (Johnson et al., 1989), and 6.8 Ma (Weaver et al., 1981) reported from studies of Californian Miocene sections. In DSDP Leg 63 sediments from the eastern North Pacific, Wolfart (1981) reported this switch in dominance as occurring in the middle of the late Miocene. In western North Pacific sediments, Foreman (1975), Reynolds (1980), and Sakai (1980) place this shift in major abundance in the late Miocene near the base of the *Stichocorys peregrina* Zone. Spencer-Cervato et al. (1993) give a range of between 6.5 and 8.4 Ma in their recalibration of North Pacific radiolarian events.

Chen (1975b) first described *Prunopyle hayesi* (Pl. 2, Figs. 1, 4) in Antarctic sediments from DSDP Leg 28 sites. The range of this species in the Southern Ocean extends from the early Miocene into the late Miocene (Chen, 1975a, 1975b). Although it is not found in every sample, *P. hayesi* is present in samples from all five Leg 145 sites. In the four sites with good magnetic reversal stratigraphy throughout this interval, the youngest sample containing *P. hayesi* occurs just above (Sites 885 and 886) or below (Sites 884 and 887) the onset of magnetic event C4n.2n (7.89 Ma). We have calculated an estimated age of 7.6 Ma for this event by combining the presence/absence data from the range charts for all five Leg 145 sites (Tables 2–6). Our estimated late Miocene age for this event is comparable to that reported by Chen (1975a).

The FO of *Stylocystium acqulonium* (Pl. 3, Figs. 1, 2, 4) occurs in all five Leg 145 sites, with the oldest sample in which this species is present falling within magnetic event C4n.2n (7.46–7.89 Ma). From examination of our sample interval and the presence/absence charts from all five sites (Tables 2–6), we estimate the age of the FO of *S. acqulonium* between 7.65 and 7.81 Ma in the high-latitude North Pacific. This event, along with the dominance change between *S. delmontensis* and *S. peregrina*, forms a definitive marker for the middle late Miocene in North Pacific sediments.

Kling (1973) in the eastern North Pacific and Reynolds (1980) in the western North Pacific both placed this event within the upper portion of the *Stichocorys peregrina* Zone in the latest Miocene. Sakai (1980), however, reported a younger age for the FO of *S. acqulonium* in DSDP Leg 56 sediments off Japan, placing it within the early

Pliocene of the *Sphaeropyle langii* Zone. Spencer-Cervato et al. (1993), in their revised calibration of North Pacific events, show the FO of *S. acquilonium* occurring in the early Pliocene with an age of ~4.95 Ma.

Ling (1973) reported finding *Amphymenium* sp. in DSDP Leg 19 Miocene sediments from the North Pacific and the Bering Sea. *Amphymenium amphistylum* (Pl. 1, Figs. 8, 9) was present sporadically throughout the Miocene sequences recovered at all Leg 145 sites except Site 881. In all four sites where *A. amphistylum* was found except the Gulf of Alaska site (887), the youngest sample containing this species falls just above or below the onset of magnetic event C4n.2n (7.89 Ma). By combining the presence/absence data on the range charts for Sites 884, 885, and 886 (Tables 3–5) we can derive an age estimate of ~7.65 Ma for this event. At Site 887, this event has a range between 8.38 and 8.85 Ma. Our results show that apparently *A. amphistylum* disappeared from the eastern North Pacific (Site 887) about one million years before its LO in the western North Pacific.

The LO of *Lychnocanoma nipponica magnacornuta* (Pl. 5, Figs. 1, 2) forms a distinct stratigraphic datum in Leg 145 sediments. In the two northern sites (884 and 887) whose sediments clearly record the onset of magnetic event C4An (8.86 Ma), the youngest sample in which *L. nipponica magnacornuta* is present occurs either just above or just below this magnetic reversal. In southern Sites 885 and 886, radiolarian-bearing sequences and sediments that clearly record magnetic reversals do not extend below the upper 45 and 55 m, respectively. At these southern sites the youngest sample containing this species is below the oldest recorded magnetic event (C4n termination; 8.53 Ma).

Excluding the southern two sites because they have no magnetic control to bracket this event, we have computed an estimated age of 8.8 Ma for the LO of *L. nipponica magnacornuta*, based on the presence/absence data from the range charts for Sites 884 and 887 (Tables 3, 6). In DSDP Leg 57 sediments off Japan, Sakai (1980) listed the LO of *L. nipponica magnacornuta* in his radiolarian events table as coinciding with the top of the *Didymocyrtis antepenultima* Zone (~7.8 Ma). This may indicate that this species disappeared from the high-latitude North Pacific 1 m.y. before it vanished from the western Pacific off Japan.

The LO of *Cyrtocapsella japonica* (Pl. 3, Fig. 7) has an estimated age of ~10.0 Ma, based on the combined presence/absence data in the range charts from both Sites 884 and 887 (Tables 3, 6). At both of these Leg 145 sites, the youngest sample containing this species occurs within magnetic event C5n.2n (9.78–10.83 Ma). Our estimated age for the LO of *C. japonica* is similar to most other dates computed for this event around the Pacific: 10.1 Ma from Leg 138 sites in the eastern equatorial Pacific (Moore et al., 1993; Moore, 1995), 9.7 Ma from Leg 85 sites in the central Pacific (Johnson et al., 1989), and 11.5 Ma from the Miocene sections of California (Weaver et al., 1981). In the western North Pacific off Japan, both Reynolds (1980) and (Sakai, 1980) report the LO of *C. japonica* as occurring near the middle Miocene/late Miocene boundary within the *Diartus petterssoni* Zone. In eastern North Pacific DSDP sites this event appears to occur somewhat later, with Kling (1973) and Wolfart (1981) placing the LO of *C. japonica* within the *Didymocyrtis antepenultima* Zone. The oldest published age for this event in North Pacific sediments is 11.15 Ma given by Spencer-Cervato et al. (1993) from their reevaluation of radiolarian datum levels in mid- and low-latitude DSDP sites.

The LO of *Cyrtocapsella tetrapera* (Pl. 3, Fig. 6) appears to be dichronous. At Site 887, the youngest sample to contain this species falls between the onset of magnetic event C5n.2n (10.83 Ma) and the termination of magnetic event C5r.2n (11.38 Ma). However, at Site 884, the youngest occurrence of *C. tetrapera* is followed by several samples where this species was not found. Therefore, we had to decide which of these two levels (one between 9.26 and 9.74 Ma, and another between 11.57 and 12.24 Ma) marked the LO of *C. tetrapera*.

For purposes of this discussion, we have selected the youngest of these two choices, which places this event in sediments from Site 884 within magnetic event C5n.1n (9.59–9.74 Ma).

Our results appear to confirm findings of previous studies which show that the LO of *C. tetrapera* does not occur at the same time throughout the North Pacific. Weaver et al. (1981) give an age of 11.8 Ma for this event in Miocene California sections. Both Johnson et al. (1989) and Spencer-Cervato et al. (1993) report an age of ~12.0 Ma for the LO of *C. tetrapera* in sediments from central Pacific DSDP sites and from several DSDP sites located across the mid- and low-latitude North Pacific, respectively. In eastern North Pacific sediments, Kling (1973) and Wolfart (1981) both show this event occurring within the late Miocene *Didymocyrtis antepenultima* Zone, somewhat younger than our estimated ages. Data from DSDP sites off Japan indicate that the LO of *C. tetrapera* took place in the middle Miocene, with Reynolds (1980) positioning this event within the *Diartus petterssoni* Zone and Sakai (1980) locating it somewhat older in the *Dorcadospyrus alata* Zone.

The LO of *Eucyrtidium inflatum* (Pl. 4, Fig. 11) falls within magnetic event C5An.2n (12.11–12.33 Ma) at our high-latitude western Site 884. In Gulf of Alaska Site 887, this event apparently occurs one million years later, with the youngest sample containing this species positioned between the onset of magnetic event C5n.2n (10.83 Ma) and the termination of magnetic event C5r.2n (11.38 Ma).

In North Pacific sediments off California, *E. inflatum* apparently survives for several million years after disappearing from the high-latitude North Pacific, with both Kling (1973) and Wolfart (1981) finding the LO of this species centered about the boundary between the *Diartus petterssoni* and *Didymocyrtis antepenultima* Zones. Weaver et al. (1981), however, reported an age for this event of 11.8 Ma in California Miocene sections. In western North Pacific sediments off Japan, Reynolds (1980), and Sakai (1980) both placed this event within the upper half of the *Dorcadospyrus alata* Zone just below the LO of *Lithopera renzae*. Funayama (1988) showed the LO of *E. inflatum* occurring in Japanese Miocene sediments within the diatom *Denticulopsis praedimorpha* Zone (coincides with the lower portion of the radiolarian *D. petterssoni* Zone) at the same time as the LO of *L. renzae*. In revising the ages of published North Pacific radiolarian events, Spencer-Cervato et al. (1993) gave an age of 12.55 Ma for the disappearance of *E. inflatum*.

The LO of *Cyrtocapsella cornuta* (Pl. 3, Fig. 8) is recorded in both northern Leg 145 sites. The youngest sample from eastern Site 887 containing this species falls within magnetic event C5n.1n (11.85–12.0 Ma). At Site 884, the youngest sample in which *C. cornuta* is present occurs within the C5An.2n magnetic event (12.11–12.33 Ma). From examination of our sample interval and the presence/absence data in our range charts (Tables 3, 6), we estimate the age of this event at ~11.7 Ma.

This age is similar to that reported for the eastern equatorial Pacific (11.89 Ma; Moore, 1995) and the central Pacific (12.0 Ma; Johnson et al., 1989). Our age estimate, however, is younger than that computed for the LO of *C. cornuta* in sediments from Miocene sequences of California (~13.0 Ma; Weaver et al., 1981) and in DSDP Leg 56 sediments off Japan (upper half of the *Dorcadospyrus alata* Zone; Sakai, 1980). Reynolds (1980), in his study of western North Pacific sediments, lists a younger age for this event, placing it in the middle Miocene within the lower half of the *Diartus petterssoni* Zone. In their recent reexamination of radiolarian events in North Pacific DSDP records, Spencer-Cervato et al. (1993) published an estimated age of 12.4 Ma for the LO of *C. cornuta*. Our estimated age for this event is older than that given for eastern North Pacific sediments, where both Kling (1973) and Wolfart (1981) show the LO of *C. cornuta* occurring in the late Miocene (within the *Didymocyrtis antepenultima* Zone).

Although Sanfilippo et al. (1985) originally stated that *Lithopera renzae* (Pl. 3, Fig. 5) was confined to latitudes lower than 40°, Leg

145 samples from >50°N contain this species. At Site 887, the youngest sample with *L. renzae* occurs just below the termination of magnetic event C5An.1n (11.85 Ma). The youngest sample containing this species at Site 884 is positioned within magnetic event C5An.2n (12.11–12.33 Ma). By combining the data from both Sites 884 and 887 in their respective range charts (Tables 3, 6), we can narrow the range of the estimated age of this event to between 11.52 and 11.89 Ma.

Our estimated age is very similar to that calculated for the LO of *L. renzae* in Leg 138 sediments from the eastern equatorial Pacific (11.83 Ma; Moore, 1995) and Leg 85 sediments from the central Pacific (12.0 Ma; Johnson et al., 1989). Wolfart (1981), in his analyses of eastern North Pacific sediments off California, positioned this event slightly above the early Miocene/middle Miocene boundary. Also in the eastern North Pacific, Kling (1973) reported the LO of *L. renzae* as occurring near the middle of the radiolarian *Diartus petterssoni* Zone. In the western Pacific, Reynolds (1980) placed this event in the lower half of the *D. petterssoni* Zone. Also in the western Pacific, Sakai (1980) found that the LO of *L. renzae* was positioned between the FO of *Lychnocanoma nipponica magnacornuta* and the LO of *Cryptocapsella cornuta*, similar to where it occurs in our radiolarian events chart (Table 7). In siliceous Miocene sequences from Japan, Funayama (1988) placed this event in the middle of the diatom *Denticulopsis praedimorpha* Zone, coinciding with the lower part of the *D. petterssoni* Zone. Spencer-Cervato et al. (1993), in their revision of North Pacific datum levels, arrived at a slightly older age of 12.55 Ma for this event.

The FO of *Lychnocanoma nipponica magnacornuta* (Pl. 5, Figs. 1, 2) is clearly recorded in sediments from Sites 884 and 887. The oldest sample at Site 884 containing this species falls within magnetic event C5An.2n (12.11–12.33 Ma). At Site 887, the oldest sediments containing *L. nipponica magnacornuta* occur within magnetic event C5An.1n (11.85–12.0 Ma). If we combine presence/absence data for this event from our range charts (Tables 3, 6), we can narrow the estimated age of this event to between 12.24 and 12.73 Ma. Our estimated age for this event (~12.5 Ma) brackets other published times for the FO of *L. nipponica magnacornuta*. In sediments from DSDP Leg 56 Sites off eastern Japan, Sakai (1980) placed this event directly below the LO of *Lithopera renzae* in the upper half of the *Dorcadospyrus alata* Zone which is older than our estimate. Funayama (1988) reported this event in Japanese Miocene sections from Noto Peninsula as occurring in the uppermost diatom *Denticulopsis praedimorpha* Zone, coinciding with the radiolarian *Diartus petterssoni* Zone.

Stichocorys delmontensis (Pl. 6, Fig. 5) is not consistently present in samples from Sites 884 and 887. This species is much less abundant in the high-latitude North Pacific compared with the low- and mid-latitude Pacific. In western North Pacific Site 884, the oldest sample in which this species is present occurs within the lower half of Chron C5A between the onset of magnetic event C5Ar.2n (12.76 Ma) and the termination of magnetic event C5AAn (12.94 Ma). In eastern North Pacific Site 887, the oldest sample to contain *S. delmontensis* is positioned between the terminations of magnetic events C5ADn (14.16 Ma) and C5Bn.1n (14.80 Ma). These ages are similar to that proposed by Kling (1973) who listed this event as occurring in the early middle Miocene (*Dorcadospyrus alata* Zone) in eastern North Pacific sediments. However, they are much younger than those reported for this event by Reynolds (1980) in the western North Pacific and by Sanfilippo et al. (1985) in the low-latitude Pacific. Both of these latter studies place the FO of *S. delmontensis* in the lower part of the early Miocene.

Eucyrtidium asanoi (Pl. 4, Figs. 6, 7) has a relatively short range with distinct upper and lower limits in Leg 145 sediments. Based on the combined presence/absence data of this species in the range charts for our North Pacific sites (Tables 3, 6), the range of *E. asanoi* extends from approximately 14 to 15.8 Ma. At Site 887, the youngest

sample to contain this species occurs between the onset of magnetic event C5Bn.2n (15.16 Ma) and the termination of magnetic event C5Cn (16.04 Ma). At Site 884, the LO of *E. asanoi* is recorded in a sample that falls within magnetic event C5ACn (13.67–14.06 Ma). Based on the estimated ages of our sample intervals and the presence/absence data for this species listed in our range charts (Tables 3, 6), it appears that *E. asanoi* disappeared from the high-latitude eastern North Pacific ~1 m.y. before its LO in the high-latitude western North Pacific (14.9 vs. 13.7 Ma).

Our age estimate for the LO of *E. asanoi* throughout the high-latitude North Pacific is older than that reported from Japanese Miocene sediments by Funayama (1988) who placed this event in the uppermost diatom *Crucidenticula nicobarica* Zone, coinciding with the uppermost part of the radiolarian *Dorcadospyrus alata* Zone. Sakai (1980), on the other hand, presented data which positions the LO of *E. asanoi* somewhat older in DSDP Leg 56 (western North Pacific) sediments, where he shows this event coinciding with the LO of *Eucyrtidium inflatum* within the *D. alata* Zone. Weaver et al. (1981) also gives an older age than that of Funayama (1988) for this event, with the top of their *Eucyrtidium cienkowskii* group (which, from their illustrations, we think is *E. asanoi*) occurring in Miocene sediments from California at approximately 13.3 Ma.

The FO of *Lychnocanoma nipponica nipponica* (Pl. 5, Figs. 4, 5) appears to be diachronous, based on our Leg 145 results. In the western North Pacific at Site 884, the oldest sample in which this species is present occurs within magnetic event C5An.2n (12.11–12.33 Ma). In sediments from Gulf of Alaska Site 887, however, this species first occurs much older in the record, with the oldest sample in which *L. nipponica nipponica* is present bracketed by the onset of magnetic event C5Bn.2n (15.16 Ma) and the termination of magnetic event C5Cn (16.04 Ma). The timing of this event in western North Pacific Leg 56 sediments is approximately midway between our estimated ages for the FO of *L. nipponica nipponica*, occurring near the middle of the *Dorcadospyrus alata* Zone (Sakai, 1980). In studies of Leg 57 sediments from this same region, however, Reynolds (1980) reported the FO of *Lychnocanium grande* (which we consider to be *L. nipponica nipponica*) as occurring somewhat older, near the early Miocene/middle Miocene boundary.

The FO of *Dictyophimus splendens* (Pl. 7, Figs. 3, 4) is apparently isochronous in high-latitude North Pacific sediments. At Site 884 in the western North Pacific, the oldest sample with this species falls between the onset of magnetic event C5ACn (14.06 Ma) and the termination of magnetic event C5Cn (16.04 Ma). In Gulf of Alaska Site 887, the oldest *D. splendens* is recorded in a sample positioned between the onset of magnetic event C5Bn.2n (15.16 Ma) and the termination of magnetic event C5Cn (16.04 Ma). Our estimates from both North Pacific sites place the FO of *D. splendens* in the early middle Miocene at ~15.3 Ma.

The estimated age of the FO of *Eucyrtidium inflatum* (Pl. 4, Fig. 11) ranges from 14.44 to 16.27 Ma in Leg 145 sediments. The sample with the FO of *E. inflatum* in western North Pacific Site 884 falls between the onset of magnetic event C5ACn (14.06 Ma) and the termination of magnetic event C5Cn (16.04 Ma). At Site 887 in the Gulf of Alaska, the oldest sample containing this species occurs between the onset of magnetic event C5Bn.2n (15.16 Ma) and the termination of magnetic event C5Cn (16.04 Ma).

We can narrow the estimated age of this event by noting the age of the oldest sample where *E. inflatum* is present (15.26 Ma) and the age of the youngest sample where this species is absent (15.35 Ma). Most previous studies of this species in North Pacific sediments (Kling, 1973; Reynolds, 1980; Sakai, 1980; Wolfart, 1981; Spencer-Cervato et al., 1993) as well as in Miocene sequences from Japan (Funayama, 1988) have reported the FO of *E. inflatum* as occurring somewhere within the *Dorcadospyrus alata* Zone. Both Sakai (1980), in his study of DSDP Leg sediments from the western North Pacific, and Funayama (1988), in his analysis of the Miocene from Japan's

Noto Peninsula, place this event slightly above the FO of *E. asanoi*. However, Funayama (1988) has this event taking place in the diatom *Denticulopsis hyalina* Zone (coinciding with upper part of radiolarian *D. alata* Zone), whereas Sakai (1980) positions this species' first appearance in the middle of the *D. alata* Zone. In the eastern North Pacific, Wolfart (1981) also shows the FO of *E. inflatum* occurring near the middle of the *D. alata* Zone. Our estimated age for this event in the high-latitude North Pacific (~15.3 Ma) compares more favorably with that of Reynolds (1980) in analyses of western Pacific DSDP Leg 57 sediments, where he shows the FO of *E. inflatum* occurring at the base of the *D. alata* Zone near the early Miocene/middle Miocene boundary. The youngest age for this event (~13.25 Ma) is that published by Spencer-Cervato et al. (1993) in their summary paper on North Pacific radiolarian events.

Ling (1973) identified specimens in DSDP Leg 19 sediments that he referred to as "*Acanthodesmid*" sp. Similar forms were also present in our Leg 145 Miocene material. We tentatively have assigned the name of *Corythospyris*? sp. (Pl. 2, Fig. 8) to this species, which has a short, but distinct range (~15–17 Ma) bracketing the late early Miocene to early middle Miocene period. At Site 884, the youngest sample containing this species falls between the onset of magnetic event C5ACn (14.06 Ma) and the termination of magnetic event C5Cn (16.04 Ma). At Site 887 in the high-latitude eastern North Pacific, the only sample in which *Corythospyris*? sp. is present occurs between the termination of magnetic events C5Cn (16.04 Ma) and C5Dn (17.31 Ma). Based on the presence/absence data at Sites 884 and 887, the estimated age of the LO of this species can be narrowed to between 15.26 and 15.35 Ma.

Sediments from Sites 884 and 887 clearly record the FO of *Eucyrtidium asanoi* (Pl. 4, Figs. 6, 7). In the western North Pacific at Site 884, the first sample in which *E. asanoi* is present is located between the onset of magnetic event C5ACn (14.06 Ma) and the termination of magnetic event C5Cn (16.04 Ma). In Gulf of Alaska Site 887, the oldest sample identified with this species occurs between the onset of magnetic event C5Bn.2n (15.16 Ma) and the termination of magnetic event C5Cn (16.04 Ma).

Combining the presence/absence data of this species in our two North Pacific sites enables us to narrow the range of the estimated age for the FO of this species to between 15.35 and 16.24 Ma. In his study of DSDP Leg 56 sediments, Sakai (1980) reported the FO of *E. asanoi* as occurring in the lower part of the *Dorcadospyrus alata* Zone (~15.0 Ma). Funayama (1988) gives a slightly older (~15.3 Ma) age for this event from his study of the Miocene section from Japan's Noto Peninsula, placing it within the upper portion of the diatom *Denticulopsis lauta* Zone (lowermost radiolarian *Dorcadospyrus alata* Zone). These data indicate that *E. asanoi* first occurred throughout the western and high-latitude North Pacific at about the same time.

The FO of *Theocorys redondoensis* (Pl. 7, Figs. 1, 2, 6) in the eastern North Pacific (Gulf of Alaska Site 887) falls between the onset of magnetic event C5Bn.2n (15.16 Ma) and the termination of magnetic event C5Cn (16.04 Ma). The oldest sample in which this species is present in Site 884 sediments is positioned between the terminations of magnetic events C5Cn (16.04 Ma) and C5Dn (17.31 Ma). We have narrowed the estimated age of this event by selecting the age of the oldest sample where *T. redondoensis* is present (16.24 Ma) and the age of the youngest sample where this species is absent (16.27 Ma), arriving at an estimated age of ~16.25 Ma.

Reynolds (1980) placed the FO of *T. redondoensis* much earlier in Miocene western North Pacific sediments (above the FO of *Didymocyrtis violina* which Sanfilippo et al. [1985] list as occurring at the base of the *Stichocorys delmontensis* Zone [~21 Ma]) than our age estimated for this event in the high-latitude North Pacific. In the eastern North Pacific, Kling (1973) and Wolfart (1981) reported the FO of this species as taking place within the *Dorcadospyrus alata* Zone (~13–15.5 Ma). Weaver et al. (1981) give an age of ~13.5 Ma for this event in Californian Miocene sequences.

Our data indicates that the FO of *Lithopera renzae* (Pl. 3, Fig. 5) is diachronous in the high-latitude North Pacific. In sediments from western North Pacific Site 884, the oldest sample containing this species falls between the onset of magnetic event C5ACn (14.06 Ma) and the termination of magnetic event C5Cn (16.04 Ma). However, in Gulf of Alaska Site 887, the oldest sample in which *L. renzae* is present is positioned between the termination of magnetic events C5Cn (16.04 Ma) and C5Dn (17.31 Ma).

Reynolds (1980), Wolfart (1981), and Sanfilippo et al. (1985) all place the FO of this species near the early Miocene/middle Miocene boundary (~16.0 Ma). Kling (1973) placed this event just below the FO of *T. redondoensis* in his list of radiolarian events in sediments from eastern North Pacific DSDP Site 173. Funayama (1988) reported this event in Miocene sediments from the Noto Peninsula of Japan as occurring in the uppermost *Calocyclletta costata* Zone. Our estimate for this event in the high latitude eastern North Pacific brackets those given by these other studies.

The FO of *Corythospyris*? sp. (Pl. 2, Fig. 8) appears to be isochronous in the high-latitude North Pacific. The oldest sample in Sites 884 and 887 to contain this species occurs between the terminations of magnetic events C5Cn (16.04 Ma) and C5Dn (17.31 Ma). Based on the estimated ages of samples from our Leg 145 sites located on either side of this event, we estimate its age to range between 16.27 and 16.96 Ma.

The apparent timing of the LO of *Cenosphaera* sp. (Pl. 1, Fig. 2) is identical in eastern and western high-latitude North Pacific sediments. Because of the high degree of dissolution that coincides with this event, we are not convinced that the effects of dissolution created what appears to be the LO of this robust-shelled species. The youngest sample from Site 884 containing *Cenosphaera* sp. is positioned between the terminations of magnetic events C5Cn (16.04 Ma) and C5Dn (17.31 Ma). In sediments from Gulf of Alaska Site 887, the youngest sample in which this species is present occurs within of magnetic event C5Dn (17.31–17.65 Ma). From examination of our sample interval and the presence/absence data in our range charts (Tables 3, 6), our best estimate of the timing of the LO of *Cenosphaera* sp. is approximately 16.7 Ma.

The FO of *Cycladophora cosma cosma* (Pl. 4, Fig. 2) also appears to be isochronous in the high-latitude North Pacific. At both Sites 884 and 887, the oldest sample to contain *C. cosma cosma* occurs between the terminations of magnetic events C5Cn (16.04 Ma) and C5Dn (17.31 Ma). By combining the data on this event in our range charts (Tables 3, 6), we can narrow the estimated age of this event to between 16.96 and 17.51 Ma.

SUMMARY

This study is the first comprehensive study of the Miocene to Pleistocene radiolarian assemblage in the high-latitude North Pacific. The abundance and distribution of 39 taxa were determined in five Leg 145 sites. Except for central Pacific Sites 885 and 886 where radiolarian preservation was generally good throughout the late Pliocene and Pleistocene, radiolarians were only well preserved in sediments <2 Ma in age. Radiolarian concentrations (number of radiolarians/gram) in the two far northern sites, from the Detroit Seamount in the west (884), and from the Gulf of Alaska in the east (887), are highest throughout the middle Miocene (Fig. 2). All five sites show a concentration maximum of various degrees between 0.75 and 1.5 Ma (mid-Pleistocene). The three southern sites (881, 885, and 886) record another radiolarian maximum between 2.0 and 2.5 Ma that is equal in magnitude to the mid-Pleistocene concentration peak.

The five Leg 145 sites contained a nearly continuous Miocene through Pleistocene record of siliceous sedimentation in addition to a nearly complete magnetic reversal stratigraphy. Thus, not only were

we able to examine various radiolarian events across a wide latitudinal and longitudinal band, but we also were able to derive an accurate estimate of the age of each event (Tables 7, 8). Many of these events have been recorded in marine sediments from other areas; therefore, our data should provide an excellent compilation of radiolarian events for revision and updating of radiolarian stratigraphy.

SYSTEMATICS

The systematics of the radiolarians recorded in Leg 145 sediments is presented in two parts:

1. Taxonomic notes: descriptions of new species and revision or emendations to previously published descriptions.
2. Species list: bibliographic references for well-known taxa that are not discussed in the taxonomic notes.

The only literature references given are to the original description and to our present concept of the species, if different from the original one. Type specimens are deposited in the United States National Museum, Washington, D.C.

Taxonomic Notes

Amphymenium amphistylum Haeckel emend. Morley and Nigrini
(Pl. 1, Figs. 8, 9)

Amphymenium amphistylum Haeckel, 1887, p. 520, pl. 44, fig. 9
Amphymenium sp., Ling, 1973, p. 780, pl. 1, figs. 11, 12

Description. Shell with two opposite pored chambered arms arising from a central structure composed of a single spherical medullary shell and an irregular cortical shell. Arms increase in diameter distally, as few as 7, but generally 9 to 13; chambers bearing randomly placed subcircular pores on each arm; surface rough with occasional thornlike projections. Shell may become spongy at the distal end of the arms. Termination blunt, but in some specimens there are strong pyramidal terminal spines at the end of each arm. The central structure and the proximal chambers on each arm are surrounded and partly obscured by a spongy cylindrical patagium. There may also be an outer pored, spindle-shaped patagium surrounding all but the last 1 to 3 chambers and constricted distally so as to join the main part of the shell. Surface of secondary patagium smooth.

Haeckel (1887) described this form as having only 7 chambers on each arm and he did not describe the outer patagium.

Dimensions (based on 20 specimens). Maximum length of shell = 190–290 μm ; maximum width of arms = 34–60 μm ; minimum breadth of arms, excluding patagium = 20–30 μm ; breadth of arms, including patagium = 50–52 μm .

Table 8. Radiolarian events in North Pacific Leg 145 sediments.

Event	Species	Age (Ma)			
Age of isochronous North Pacific events:					
LO	<i>Lychnocanoma nipponica sakaii</i>	0.05			
LO	<i>Stylocanarium acqulonium</i>	0.4			
LO	<i>Stylatractus univertus</i>	0.55			
LO	<i>Anthocyrta(?) callopisma</i>	0.62			
LO	<i>Lamprocyrtis neoheteroporos</i>	0.85			
LO	<i>Eucyrtidium matuyamai</i>	1.0			
LO	<i>Sphaeropyle robusta</i>	1.5–1.7			
FO	<i>Eucyrtidium matuyamai</i>	2.0			
FO	<i>Cycladophora davisiana davisiana</i>	2.9			
LO	<i>Dictyophimus bullatus</i>	4.2			
FO	<i>Dictyophimus bullatus</i>	5.6			
FO	<i>Lamprocyrtis heteroporos</i>	6.6			
	<i>S. delmontensis</i> → <i>S. peregrina</i>	7.55			
LO	<i>Prunopyle hayesi</i>	7.6			
FO	<i>Stylocanarium acqulonium</i>	7.7			
LO	<i>Lychnocanoma nipponica magnacornuta</i>	8.8			
LO	<i>Cyrtocapsella japonica</i>	10.0			
LO	<i>Cyrtocapsella cornuta</i>	11.7			
LO	<i>Lithopera renzae</i>	11.7			
FO	<i>Lychnocanoma nipponica magnacornuta</i>	12.5			
FO	<i>Dictyophimus splendens</i>	15.3			
FO	<i>Eucyrtidium inflatum</i>	15.3			
LO	<i>Corythospyris? sp.</i>	15.3			
FO	<i>Eucyrtidium asanoi</i>	15.8			
FO	<i>Theocorys redondoensis</i>	16.25			
FO	<i>Corythospyris? sp.</i>	16.7			
LO	<i>Cenosphaera sp.</i>	16.7			
FO	<i>Cycladophora cosma cosma</i>	17.25			
Age (Ma)					
		Southern sites	Northern sites		
Event	Species	West (881)	Central (885/886)	West (884)	East (887)
Age of diachronous North Pacific events:					
LO	<i>Stichocorys peregrina</i>	5.0		5.6–6.4	
FO	<i>Sphaeropyle langii</i>	5.8–6.0		4.8	
LO	<i>Dictyophimus splendens</i>	5.95		4.8	
LO	<i>Theocorys redondoensis</i>	5.8–6.75		4.9	
LO	<i>L. nipponica nipponica</i>	6.25		9.6	
LO	<i>Stichocorys delmontensis</i>	5.0		6.7	
LO	<i>Amphymenium amphistylum</i>		7.55	7.9	8.6
LO	<i>Cyrtocapsella tetrapera</i>			9.5	10.9
LO	<i>Eucyrtidium inflatum</i>			11.9	10.9
FO	<i>L. nipponica nipponica</i>			12.6	15.7
FO	<i>Stichocorys delmontensis</i>			13.2	14.9
LO	<i>Eucyrtidium asanoi</i>			13.7	14.9
FO	<i>Lithopera renzae</i>			14.9	16.9

Notes: Time scale used is Cande and Kent (1992). LO = last occurrence, and FO = first occurrence.

Distinguishing characters. This species is distinctive in that it is relatively long compared to its width. The arms, unlike those of *A. splendarmatum*, are chambered.

Remarks. The relationship between this species and *Amphymenium splendarmatum* Clark and Campbell (1942, p. 46, pl. 1, figs. 12, 14) is not clear. The principal difference noted by Clark and Campbell is that *A. splendarmatum* lacks distinct chambering on the arms. *A. splendarmatum* has been reported primarily in Paleogene sediments, although Nishimura (1987) records a similar form from the middle Miocene that also apparently lacks chambers on the arms. Until the relationship between these forms is understood, we prefer to retain the specific name *amphistylum* for the North Pacific Miocene form. Petrushevskaya and Kozlova (1972) placed the genus *Amphymenium* in synonymy with *Ommatocampe* Ehrenberg, but subsequent authors have not followed this suggestion.

Cenosphaera sp.
(Pl. 1, Fig. 2)

Description and dimensions. Simple thick-walled spherical shell with a rough surface and closely spaced circular pores, 7–9 on a half equator; shell diameter = 145–185 μ m.

Remarks. This species is abundant in the lowermost samples of Sites 884 and 887. Its abundance in these samples may be a local result of dissolution of more delicate forms. However, because its LO in both sites is at approximately the same level, we have retained it as a potentially useful stratigraphic biomarker.

Corythospyris? sp.
(Pl. 2, Fig. 8)

Acanthodesmid sp. Ling, 1973, p. 780, pl. 2, fig. 1

Description. Robust bilocular cephalis with a slight sagittal constriction dividing the two halves. Pores irregular in size, shape, and arrangement, separated by thick, sometimes ridged, lattice bars. Some pores may have small, inwardly directed thorns. Prominent tubercles at junctions of lattice bars and junction of lattice bars and basal ring. Number of lattice bars joining the sagittal and basal rings is variable. Secondary laterals absent; no apical horn, but a thornlike vertical spine may be seen on some specimens. Six stout, cylindrical basal spines project downward from the basal ring; four are aligned with the sternal, frontal, and primary lateral spines; and two originate between the frontal and primary lateral spines. These spines are joined distally by horizontal bars so as to form six large pores. Additional skeletal growth is irregular and produces a characteristic "cagelike" meshwork up to 73 μ m in length. Termination always ragged.

Dimensions (based on 20 specimens). Maximum breadth of cephalis = 80–108 μ m, maximum height of cephalis = 50–70 μ m, maximum length of "thorax" = 50–73 μ m.

Remarks. This form is clearly the same as that illustrated by Ling (1973), although he states that there are only five basal spines. Based on the above description, this species does not fit all the specifics of any genus as currently defined. It comes closest to matching the characteristics set forth for the genus *Corythospyris*, however, it might also be placed within the genus *Phormospyris*.

Cycladophora pliocenica (Hays)
(Pl. 4, Fig. 1)

Clathrocyclus bicornis Hays, 1965, p. 179, pl. 3, fig. 3

Cycladophora pliocenica (Hays) n. comb., Lombardi and Lazarus, 1988, p. 104

Cycladophora bicornis Hays, Sakai, 1980, p. 709, pl. 6, figs. 9a–11b

Clathrocyclus spp., Kling, 1973, pl. 3, figs. 19, 20, 22 (only)

Remarks. The apparent North Pacific equivalent of this species is similar to that described by Hays (1965) in the Antarctic, but it is smaller and the lower part of the thorax is not so straight-sided as in Hays's illustration. The dimensions given by Hays (1965) are as follows: length of apical horn = 15–40 μ m, length of cephalis = 15–30 μ m, length of thorax = 80–150 μ m, width of cephalis = 20–37 μ m, width of thorax = 115–140 μ m. In our North Pacific material, the dimensions are as follows: length of apical horn = 8–55 μ m (usually 8–32 μ m), length of cephalis = 10–18 μ m, length of thorax = 60–105 μ m, maximum width of cephalis = 18–28 μ m, maximum width of thorax = 78–100 μ m.

Dictyophimus bullatus Morley and Nigrini n. sp.
(Pl. 4, Figs. 5, 9, 10)

Description. Three-segmented shell with three prominent wings. Cephalis hemispherical with small circular pores or infilled pits. Apical and vertical spines project as two short, pointed horns. Collar stricture indistinct. Thorax inflated conical to onion shaped with subcircular to subangular pores increasing in size distally, 7 to 12 on a half equator at its maximum width. Thoracic surface sometimes thorny. Indistinct thoracic ribs become external just above the termination of the thorax to form divergent, cylindrical wings, up to 95 μ m in length (usually up to 50 μ m). Distally, thorax somewhat constricted with a smooth peristome or, in some specimens, there is an irregular cylindrical or tapering distally abdomen. Abdominal pores irregular in size, shape and arrangement. The degree of silicification that affects pore size and wall thickness is highly variable in our North Pacific samples.

Etymology. Named for inflated nature of its thorax, *bullatus*, Latin, meaning inflated.

Holotype. Pl. 4, Fig. 9, Sample 145-885A-3H-CC, Q10/2, USNM 483757

Paratype. Pl. 4, Fig. 5, Sample 145-885A-3H-CC, R9/0, USNM 483758

Dimensions (based on 20 specimens). Length of cephalis = 15–22 μ m, length of thorax = 75–130 μ m, length of abdomen = up to 50 μ m, maximum breadth of cephalis = 24–32 μ m, maximum breadth of thorax = 100–135 μ m.

Distinguishing characters. This species is distinguished from other members of the genus by its inflated rather than conical thorax.

Dictyophimus splendens (Campbell and Clark) emend. Morley and Nigrini
(Pl. 7, Figs. 3, 4)

Pterocorys (*Pterocyrtidium*) *splendens* Campbell and Clark, 1944, p. 46, pl. 6, figs. 19, 20

Dictyophimus splendens (Campbell and Clark) n. comb., Caulet, 1986a, p. 852

Description. Cephalis hemispherical, poreless, hyaline. Inside the cephalis both the apical and vertical spines are free of the shell wall. Externally the apical spine is prolonged into an unusually long cylindrical horn tapering to a point distally. In our North Pacific material, the horn is up to four times as long as the cephalothorax, but in tropical material it may be even longer. Campbell and Clark's (1944) original description described the horn as "sinuous," but it may also be straight or curved. Collar stricture indistinct. Thorax conical, thickwalled, sometimes thorny, with subcircular pores increasing in size distally, 4 to 6 on a half equator at the base of the thorax. Indistinct thoracic ribs become external just above the termination of the thorax and are prolonged into three weakly bladed or cylindrical wings tapering to a point distally. Wings diverge freely, forming an extension of the conical line of the thorax. Thoracic termination smooth or may have irregularly placed, inwardly curving teeth or projections or other indications of the beginnings of an abdomen. Abdomen irregular, varying in state of development and having pores similar to those on the thorax. Termination ragged.

Dimensions (based on 20 specimens). Length of cephalis = 15–22 μ m, length of thorax = 55–100 μ m, length of abdomen = up to 45 μ m, maximum breadth of cephalis = 18–30 μ m, maximum breadth of thorax = 65–100 μ m, length of wings = up to 65 μ m, length of apical horn = up to 275 μ m. Campbell and Clark (1944) report a length of 370 μ m for the apical horn.

Distinguishing characters. The extraordinary length of the apical horn of this species distinguishes it from all others.

Remarks. It is likely that the form described by Riedel (1952, p. 7, pl. 1, fig. 2) as *Pterocorys splendens* Campbell and Clark *albatrossensis* Riedel from the western tropical Pacific is a synonym of *Dictyophimus splendens*, but it would be necessary to examine topotypic material to verify this synonymy.

Eucyrtidium asanoi Sakai
(Pl. 4, Figs. 6, 7)

Eucyrtidium asanoi Sakai, 1980, p. 709, pl. 7, figs. 12a–b, 13a–c, 14a–b

Eucyrtidium sp. Ling, 1973, pl. 2, fig. 9

Eucyrtidium cienkowskii group, Weaver et al., 1981, pl. 1, figs. 6–8

Eucyrtidium asanoi Sakai, Funayama, 1988, pl. 3, figs. 5a–b, 7, 8, 13

Remarks. Both the truncate conical form of Sakai (1980) and Funayama (1988) and the nearly cylindrical form of Funayama (1988, pl. 3, fig. 7) occur in our material.

Eucyrtidium inflatum Kling
(Pl. 4, Fig. 11)*Eucyrtidium inflatum* Kling, 1973, p. 636, pl. 11, figs. 7–8; pl. 15, figs. 7–10**Remarks.** The maximum breadth of specimens encountered in our material is generally greater (85–110 µm) than that reported by Kling (80–94 µm).*Haliometta miocenica* (Campbell and Clark)
(Pl. 1, Fig. 3)*Heliosphaera miocenica*, Campbell and Clark, 1944, p. 16, pl. 2, figs. 10–14
Haliometta miocenica (Campbell and Clark) group, Petrushevskaya and Kozlova, 1972, p. 517, pl. 9, figs. 8, 9; Chen, 1975b, p. 453, pl. 20, figs. 14, 15**Dimensions.** Additional dimensions for this species are as follows: diameter of medullary shell = 35–50 µm, diameter of cortical shell = 110–130 µm, diameter of pores = 7–10 µm, length of spines = 10–80 µm, number of spines = up to 11, and number of pores on a half equator = 11–18.**Remarks.** Although first described in Miocene sediments from California, Petrushevskaya and Kozlova (1972) and Chen (1975b) reported this species in Antarctic sediments of Pleistocene age. Caulet (1991) shows it ranging from the late Miocene to the NR2 Zone, just below the last appearance datum of *Stylatractus universus*, in Site 745 on the Kerguelen Pl. au. In our material from the North Pacific, *H. miocenica* occurs only in Pliocene to Holocene sediments.**The *Lychnocanium grande* Problem**

The use and misuse of this species has had a long and tortuous history that may best be explained by examining its literature chronologically.

1944. Campbell and Clark described *Lychnocanium grande* from the California Miocene. It is a *Pterocorythidae* with pores on the cephalis and on the upper parts of the legs. The thorax is described as subconical. They also described a similar, but smaller subspecies called *Lychnocanium grande brevis*. Weaver et al. 1981 (pl. 2, figs. 4, 5) rephotographed Campbell and Clark's figured specimens.**1952.** Dogel and Reshetnyak described, but did not illustrate, a similar form with many cephalic pores as *Lychnocanium vitiazii*. As this form was not illustrated, it cannot be considered further herein.**1952.** Riedel described the subspecies *Lychnocanium grande rugosum* in presumably Holocene (top of SDSE Core 87B) material from the western tropical Pacific. It is similar to *L. grande* but has a rougher surface and smaller thoracic pores.**1960.** Kozlova, using material from northern Sakhalin, described the Miocene species *Lychnocanium laesum* as being similar to *L. grande* but with a rougher surface, no porous plate around the mouth, and a narrower thorax, although this last difference is not consistent with her recorded measurements. It seems likely that this species is synonymous with *Lychnocanium nipponicum* Nakaseko (see below).**1963.** Nakaseko described *Lychnocanium nipponicum* from the Japanese Miocene. The only difference noted between *nipponicum* and *grande* is that the former has no pores on the cephalis. He includes in this species *Lychnocanium* cf. *grande* in Nakaseko, 1955, p. 100, pl. VIII, figs. 6, 7; *Lychnocanium nipponicum* in Nakaseko, 1959 and 1960; *Lychnocanium* a, b, and c spp. in Nakaseko, 1954.**1972.** Petrushevskaya and Kozlova recorded the presence of *Lychnocanium grande* in Oligocene to Miocene sediments from the Antarctic, but they noted that there are no pores on the cephalis.**1973.** Foreman changed the generic name to *Lychnocanoma*.**1973.** Kling recorded *Lychnocanoma grande* (Campbell and Clark) in Miocene sediments from the northeastern Pacific. He noted a similar form in Holocene material but was unsure how to deal with it.**1976.** Kruglikova reported the occurrence of a form similar to *L. grande rugosum* in upper Pleistocene, but not Holocene, sediments from the North Pacific. She suggested that its LO might be a useful stratigraphic marker at about 35–40 k.y.**1980.** Sakai described the new subspecies *Lychnocanoma nipponica magnicornuta* from the Miocene of the North Pacific. In the taxonomy of this subspecies, he included *L. nipponicum* in Nakaseko and Sugano, 1973, pl. 3, fig. 1a–b, and *Lychnocanium* sp. in Ling, 1973, p. 781, pl. 2, figs. 10, 11. This subspecies is similar to *L. nipponica nipponica*, but has a markedly larger apical horn. Sakai also recorded the presence of *Lychnocanoma nipponica nipponicum* in Miocene sediments, and he described, but without dimensions, *Lychnocanoma* sp. in Pleistocene material.**1980.** Reynolds recorded *L. grande* in his North Pacific Miocene material and *L. cf. grande* in his Pleistocene material.**1985.** Morley reported the presence of *L. grande* in his North Pacific material, however, according to his range charts, this is the Pleistocene form.**1985.** Lazarus et al. placed Kling's (1973) Miocene *L. sp. cf. grande*, Reynolds' (1980) Pleistocene *L. sp. cf. L. grande*, and Sakai's (1980) Pleistocene *Lychnocanoma* sp. in synonymy with *Pterocanium korotnevi* (Dogel). We do not agree with these assignments. The cephalic structure of *P. korotnevi* is quite different and the shell much less robust.**1990.** Nishimura, in disagreement with Foreman (1973), reinstated the genus *Lychnocanium* and placed *L. nipponica magnicornuta* in synonymy with *L. nipponica nipponica*, which would become *Lychnocanium nipponicum* again.**1992.** Wang and Yang described *L. nipponicum* as ranging from the middle Miocene to the Quaternary, although they only record specimens in Miocene and Pliocene samples. Examination of their figured specimens from the Pliocene (pl. 5, figs. 7, 8) suggests to us that neither specimen is *L. nipponicum*.**This paper.** Our examination of material from the California Miocene has convinced us that the species described by Campbell and Clark as *L. grande* is not the same as the Miocene species we have observed in the North Pacific. Primarily, we find that the shape of the thorax is quite different and the shell wall is not as robust. We do not consider the presence or absence of pores on the cephalis to be a valid specific distinction. It is true that most of the North Pacific specimens have a poreless cephalis, although this is not always true, but we think that this reflects the degree of silicification rather than a specific difference. It is possible that there is a continuum between the North Pacific and the California forms, but we have not observed it and, therefore, have chosen not to use the specific name *grande* at this time. At the same time, however, we are less certain of the taxonomic position of the specimens figured by Akers et al. (1987, pl. 6, figs. 1, 2) from the upper Miocene to Pliocene Sweeny Road Section near Lompoc, California. Other references to species within this group are included in the synonymies listed below.We have observed some forms (Pl. 6, Fig. 3) transitional between *L. nipponica nipponica* and *L. nipponica magnicornuta* and agree with Nishimura (1990) that they are probably the same species. In addition, subspecies should, strictly speaking, be separated geographically. However, we have found that by recording the two forms, most of which clearly belong to one or the other subspecies, we can obtain some useful stratigraphic information. For that reason they remain separated herein. We reject, for the time being, Nishimura's reinstatement of the genus *Lychnocanium* until the sweeping changes proposed in her study can be evaluated as a whole.The Pleistocene form is clearly very similar to the Miocene form, but we have not observed intermediate specimens. For this reason, we propose herein to erect a new subspecies, *Lychnocanoma grande sakaii*. Normally, subspecies must be separated geographically, but we have chosen herein to use the category of subspecies for forms that are separated stratigraphically.*Lychnocanoma nipponica* (Nakaseko) *sakaii* Morley and Nigrini n. ssp.
(Pl. 6, Figs. 1, 4)? *Lychnocanium grande* Campbell and Clark *rugosum* Riedel, 1952, p. 6, pl. 1, fig. 1*Lychnocanoma grande* Campbell and Clark *rugosum* Riedel, Kruglikova, 1976, pl. 1, figs. 1, 2*Lychnocanium* sp. aff. *Lychnocanoma grande rugosum*, Kruglikova, 1976, pl. 1, figs. 4–6*Lychnocanoma* sp., Sakai, 1980, p. 711, pl. 9, fig. 1a–b*Lychnocanoma* sp. cf. *L. grande* (Campbell and Clark), Reynolds, 1980, p. 766, pl. 1, figs. 21, 22*Lychnocanoma grande* (Campbell and Clark), Morley, 1985, p. 412, pl. 6, fig. 4A–B**Description.** Cephalis hemispherical with a few small subcircular pores or infilled pits. Apical spine free within the cephalis and prolonged into a slender cylindrical apical horn tapering distally. Base of apical horn may be three-bladed. Collar stricture distinct. Thorax hemispherical, usually thick walled with a rough surface and bearing subcircular pores aligned longitudinally, 8–12 on a half equator. Thorax is constricted distally and terminates in a smooth, poreless peristome. From the base of the thorax arise three robust, three-bladed legs that may flare outward or curve inward; legs may have one or two proximal pores. In some specimens, there is a delicate skirt or abdomen of irregular meshwork attached to the peristome and, at least proximally, to the feet. Even when the third segment is missing, there may be small thorns on the inner margin of the feet indicating where the meshwork was attached.

Etymology. After Toyosaburo Sakai, who first described it in the DSDP Leg 56 report in 1980.

Holotype. Pl. 6, Fig. 4, Sample 145-881C-1H-CC, M19/3, USNM 483759

Paratype. Pl. 6, Fig. 1, Sample 145-887A-2H-1, 12–13 cm, P44/0, USNM 483760

Dimensions (based on 20 specimens). Length of apical horn = up to 55 μm , length of cephalis = 20–30 μm , length of thorax = 45–65 μm , length of legs = up to 220 μm ; maximum breadth of cephalis = 28–40 μm , maximum breadth of thorax = 90–115 μm .

Distinguishing characters. This subspecies is essentially the same as *L. nipponica nipponica*, but it is restricted to the latest Pliocene and Pleistocene.

Lychnocanoma nipponica (Nakaseko) *magnacornuta* Sakai
(Pl. 5, Figs. 1, 2)

Lychnocanium nipponicum Nakaseko, 1963, p. 168, text-fig. 2, pl. 1, fig. 1a–b; Nakaseko and Sugano, 1973, pl. 3, fig. 1a–b

Lychnocanium sp. Ling, 1973, p. 781, pl. 2, figs. 10, 11

Lychnocanoma nipponica (Nakaseko) *magnacornuta* Sakai, 1980, p. 710, pl. 9, fig. 3a–b

Lychnocanoma nipponica nipponica (Nakaseko)
(Pl. 5, Figs. 4, 5)

Lychnocanium nipponicum Nakaseko, 1963, p. 168, text-fig. 2, pl. 1, fig. 1a–b

Lychnocanoma grande (Campbell and Clark), Kling, 1973, p. 637, pl. 10, figs. 10–14

Lychnocanoma nipponica nipponica Sakai, 1980, p. 710, pl. 9, fig. 2a–b

Sphaeropyle langii Dreyer emend. Foreman emend. Morley and Nigrini
(Pl. 2, Figs. 2, 5, 7)

Sphaeropyle langii Dreyer, 1889, p. 13, pl. 4, fig. 54; Kling, 1973, p. 634, pl. 1, figs. 5–10, pl. 13, figs. 6–8 (with synonymy); Foreman, 1975, p. 618, pl. 9, figs. 30, 31 (with synonymy)

Remarks. Foreman's updated definition of this species is emended herein to include only those forms having a maximum of 8–9 pores on the outermost medullary shell rather than 8–12 pores.

Sphaeropyle robusta Kling emend. Foreman emend. Morley and Nigrini
(Pl. 1, Figs. 6, 7)

Sphaeropyle robusta Kling, 1973, p. 634, pl. 1, figs. 11, 12; pl. 6, figs. 9–13; pl. 13, figs. 1–5

Sphaeropyle robusta Kling emend. Foreman, Foreman, 1975, p. 618, pl. 9, figs. 24–26

Remarks. Foreman's emended definition of this species is emended herein to include only those forms having ten or more pores on a half-equator of the outer medullary shell.

Stichocorys peregrina (Riedel)
(Pl. 6, Figs. 2, 3)

Eucyrtidium elongatum peregrinum Riedel, 1953, p. 812, pl. 85, fig. 2

Stichocorys peregrina (Riedel), Sanfilippo and Riedel, 1970, p. 451, pl. 1, fig. 10

Remarks. Specimens in our material conform to descriptions given for high latitude forms by Sanfilippo et al. (1985).

Dimensions (based on 20 specimens). Of third and fourth segments: maximum length of third segment = 28–50 μm , maximum length of fourth segment = 30–50 μm , maximum breadth of third segment = 60–100 μm , maximum breadth of fourth segment = 72–105 μm .

Theocorys redondoensis (Campbell and Clark) emend. Morley and Nigrini
(Pl. 7, Figs. 1, 2, 6)

Theocorys redondoensis Campbell and Clark, 1944, p. 49, pl. 7, fig. 4

Theocorys redondoensis (Campbell and Clark), Kling, 1973, p. 638, pl. 11, figs. 26–28

Remarks. The species definition is emended herein to include forms with up to six randomly placed cylindrical spines, up to 65 μm in length, projecting from the thorax. Additional dimensions for this species are as follows: length of apical horn = up to 60 μm , length of cephalis = 40–55 μm , length of thorax

= 60–110 μm , length of abdomen = up to 65 μm , maximum breadth of cephalis = 35–50 μm , maximum breadth of thorax = 90–120 μm , number of pores on a half equator of thorax at the widest point = 7–10. These measurements are in good agreement with those originally given by Campbell and Clark (1944).

Gen. et sp. indet.
(Pl. 1, Fig. 1)

Remarks. We have found the form described by Reynolds (1980, p. 761, pl. 1, figs. 5–9) as *Collosphaera pyloma*. However, we do not think that this form is a collosphaerid, nor have we been able to find a satisfactory generic assignment for the taxon. It appears, nevertheless, to be a useful stratigraphic marker with its LO near the top of Riedel and Sanfilippo's *Diartus petterssoni* Zone. For this reason we have documented its occurrence in our North Pacific material. We have restricted our counts to those forms in which the pylome is clearly visible.

Species List

Actinomma popofskii (Petrushevskaya)
(Pl. 1, Figs. 4, 5)

Echinomma popofskii Petrushevskaya, 1967, p. 23, fig. 12, I–III

Actinomma popofskii (Petrushevskaya) n. comb., Caulet, 1986a, p. 851

Anthocyrtella (?) *callopisma* Caulet
(Pl. 3, Fig. 3)

?*Anthocyrtella* sp. A, Petrushevskaya, 1975, p. 587, pl. 15, fig. 2, pl. 16, fig. 5
Anthocyrtella (?) *callopisma* Caulet, 1986b, p. 227, pl. 1, figs. 1, 2

Botryostrobos aquilonaris (Bailey)
(Pl. 6, Fig. 7)

Eucyrtidium aquilonaris Bailey, 1856, p. 4, pl. 1, fig. 9

Botryostrobos aquilonaris (Bailey), Nigrini, 1977, p. 246, pl. 1, fig. 1 (with synonymy)

Cycladophora cosma cosma Lombardi and Lazarus
(Pl. 4, Fig. 2)

Cycladophora davisiana (Ehrenberg) var. *cornuoides* Petrushevskaya, 1967, p. 126, fig. 70, I–III

Cycladophora cosma cosma Lombardi and Lazarus, 1988, p. 104, pl. 1, figs. 1–6 (with synonymy)

Cycladophora davisiana davisiana (Ehrenberg)
(Pl. 4, Figs. 3, 4)

Cycladophora (?) *davisiana* Ehrenberg, 1861, p. 297; 1873, pl. 2, fig. 11
Theocalyptra davisiana (Ehrenberg), Riedel, 1958, p. 239, pl. 4, figs. 2, 3, text-fig. 10 (with synonymy)

Cycladophora davisiana Ehrenberg, Petrushevskaya, 1967, p. 122, fig. 69, I–VII

Cyrtocapsella cornuta (Haeckel)
(Pl. 3, Fig. 8)

Cyrtocapsa (*Cyrtocapsella*) *cornuta* Haeckel, 1887, p. 1513, pl. 78, fig. 9

Cyrtocapsella cornuta (Haeckel), Sanfilippo and Riedel, 1970, p. 453, pl. 1, figs. 19, 20 (with synonymy)

Cyrtocapsella japonica (Nakaseko)
(Pl. 3, Fig. 7)

Eusyringium japonicum Nakaseko, 1963, p. 193, text-figs. 20, 21, pl. 4, figs. 1–3

Cyrtocapsella japonica (Nakaseko), Sanfilippo and Riedel, 1970, p. 452, pl. 1, figs. 13–15 (with synonymy)

Cyrtocapsella tetrapera (Haeckel)
(Pl. 3, Fig. 6)

Cyrtocapsa (*Cyrtocapsella*) *tetrapera* Haeckel, 1887, p. 1512, pl. 78, fig. 5
Cyrtocapsella tetrapera (Haeckel), Sanfilippo and Riedel, 1970, p. 453, pl. 1, figs. 16–18 (with synonymy)

Didymocyrtis tetrathalamus (Haeckel)
 (Pl. 2, Fig. 6)

Panartus tetrathalamus Haeckel, 1887, p. 378, pl. 40, fig. 3
Didymocyrtis tetrathalamus (Haeckel), Sanfilippo and Riedel, 1980, p. 1010

Eucyrtidium calvertense Martin
 (Pl. 4, Fig. 8)

Eucyrtidium calvertense Martin, 1904, p. 450, pl. 130, fig. 5; Hays, 1965, p. 181, pl. III, fig. 6

Eucyrtidium matuyamai Hays
 (Pl. 5, Fig. 3)

Eucyrtidium matuyamai Hays, 1970, p. 213, pl. 1, figs. 7–9

Lamprocyrtis heteroporos (Hays)
 (Pl. 7, Figs. 5, 8)

Lamprocyrtis 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
 (Pl. 7, Fig. 7)

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

Lamprocyrtis nigrinae (Caulet)
 (Pl. 7, Fig. 9)

Conarachnium? sp. Nigrini, 1968, p. 56, pl. 1, fig. 5a–b
Conarachnium nigrinae 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 nigrinae (Caulet), Kling, 1977, p. 217, pl. 1, fig. 17

Lithopera (*Lithopera*) *renzae* Sanfilippo and Riedel
 (Pl. 3, Fig. 5)

Lithopera (*Lithopera*) *renzae* Sanfilippo and Riedel, 1970, p. 454, pl. 1, figs. 21–23, 27

Phormostichoartus crustula (Caulet)
 (Pl. 6, Fig. 8)

Lithamphora crustula Caulet, 1979, p. 131, pl. 2, fig. 1
Phormostichoartus crustula (Caulet), Nigrini and Caulet, 1992, p. 161, pl. 6, figs. 10–14

Phormostichoartus fistula Nigrini
 (Pl. 6, Fig. 6)

Phormostichoartus fistula Nigrini, 1977, p. 253, pl. 1, figs. 11–13

Phormostichoartus pitomorphus Caulet
 (Pl. 6, Fig. 9)

Phormostichoartus pitomorphus Caulet, 1986a, p. 850, pl. 3, figs. 3, 4, 9, 10, and 12

Prunopyle hayesi Chen
 (Pl. 2, Figs. 1, 4)

Prunopyle hayesi Chen, 1975b, p. 454, pl. 9, figs. 3–5; Chen, 1975a, p. 482, pl. 1, figs. 7, 8, pl. 2, figs. 1, 2
 non *Prunopyle hayesi* Chen, Weaver, 1976, p. 578, pl. 7, figs. 1–3

Stichocorys delmontensis (Campbell and Clark)
 (Pl. 6, Fig. 5)

Eucyrtidium delmontense Campbell and Clark, 1944, p. 56, pl. 7, figs. 19, 20
Stichocorys delmontensis (Campbell and Clark), Sanfilippo and Riedel, 1970, p. 451, pl. 1, fig. 9 (with synonymy)

Stylocantarium acquilonium (Hays)
 (Pl. 3, Figs. 1, 2, 4)

Drupptractus acquilonius Hays, 1970, p. 214, pl. 1, figs. 4, 5
Stylocantarium acquilonium (Hays), Kling, 1973, p. 634, pl. 1, figs. 17–20, pl. 14, figs. 1–4

Stylatractus universus Hays [= *Axoprimum angelinum* (Campbell and Clark)]
 (Pl. 2, Fig. 3)

Stylatractus sp. Hays, 1965, p. 167, pl. 1, fig. 6
Stylatractus universus Hays, 1970, p. 215, pl. 1, figs. 1, 2

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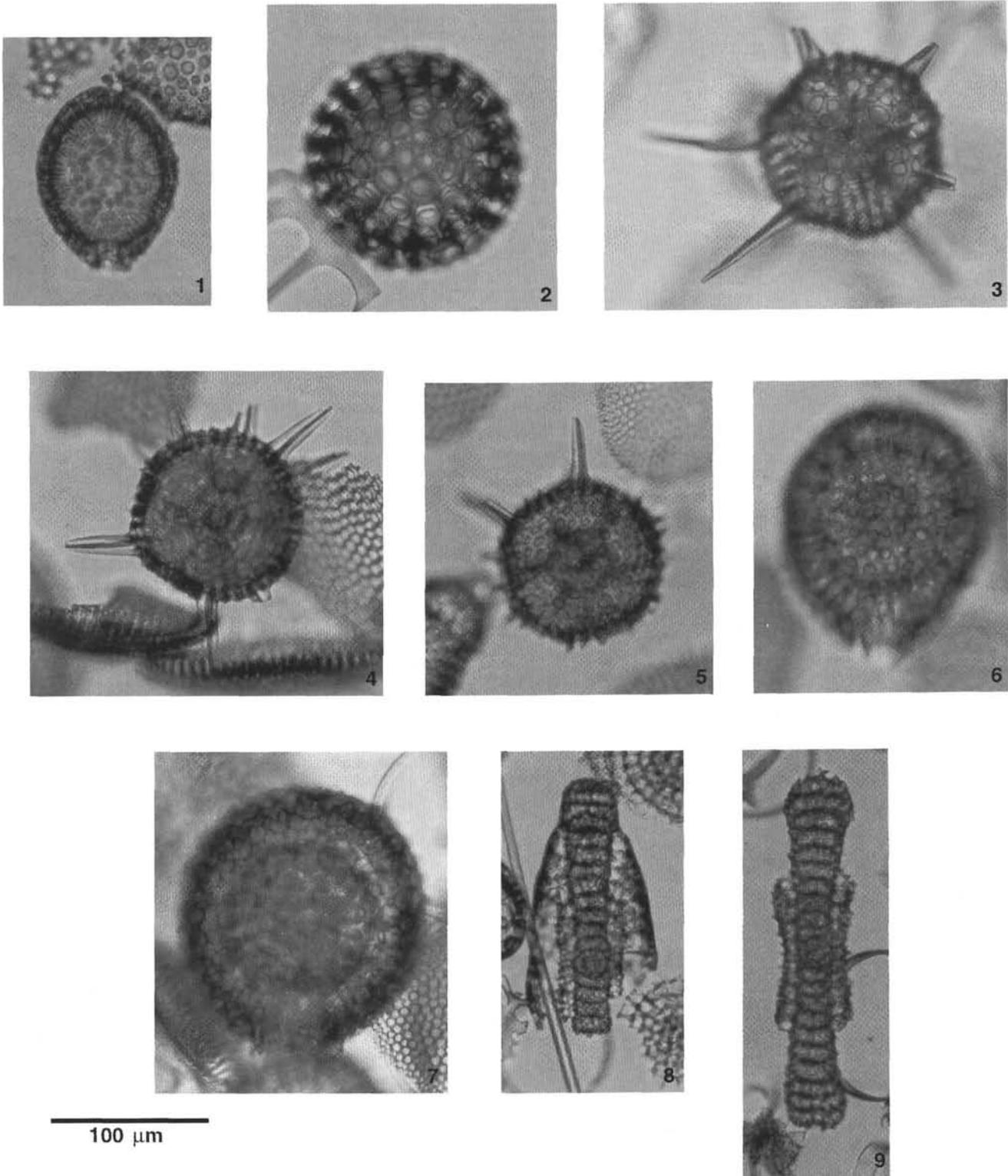


Plate 1. **1.** Gen. et sp. indet., Sample 145-887A-28H-3, 54–55 cm, Q35/1. **2.** *Cenosphaera* sp., Sample 145-884B-65X-5, 135–136 cm, V43/3. **3.** *Haliometta miocenica*, Sample 145-881C-1H-CC, M38/1. **4–5.** *Actinomma popofskii*; (4) Sample 145-886C-6H-5, 114–115 cm, Q37/2; (5) Sample 145-886C-6H-5, 114–115 cm, U35/4. **6–7.** *Sphaeropyle robusta*; (6) Sample 145-886C-4H-CC, N9/2; (7) Sample 145-886C-6H-4, 114–115 cm, V20/1. **8–9.** *Amphymenium amphistylium*; (8) with partial patagium, Sample 145-887A-29H-3, 54–55 cm, Y49/0; (9) Sample 145-884B-62X-5, 135–136 cm, M14/3.

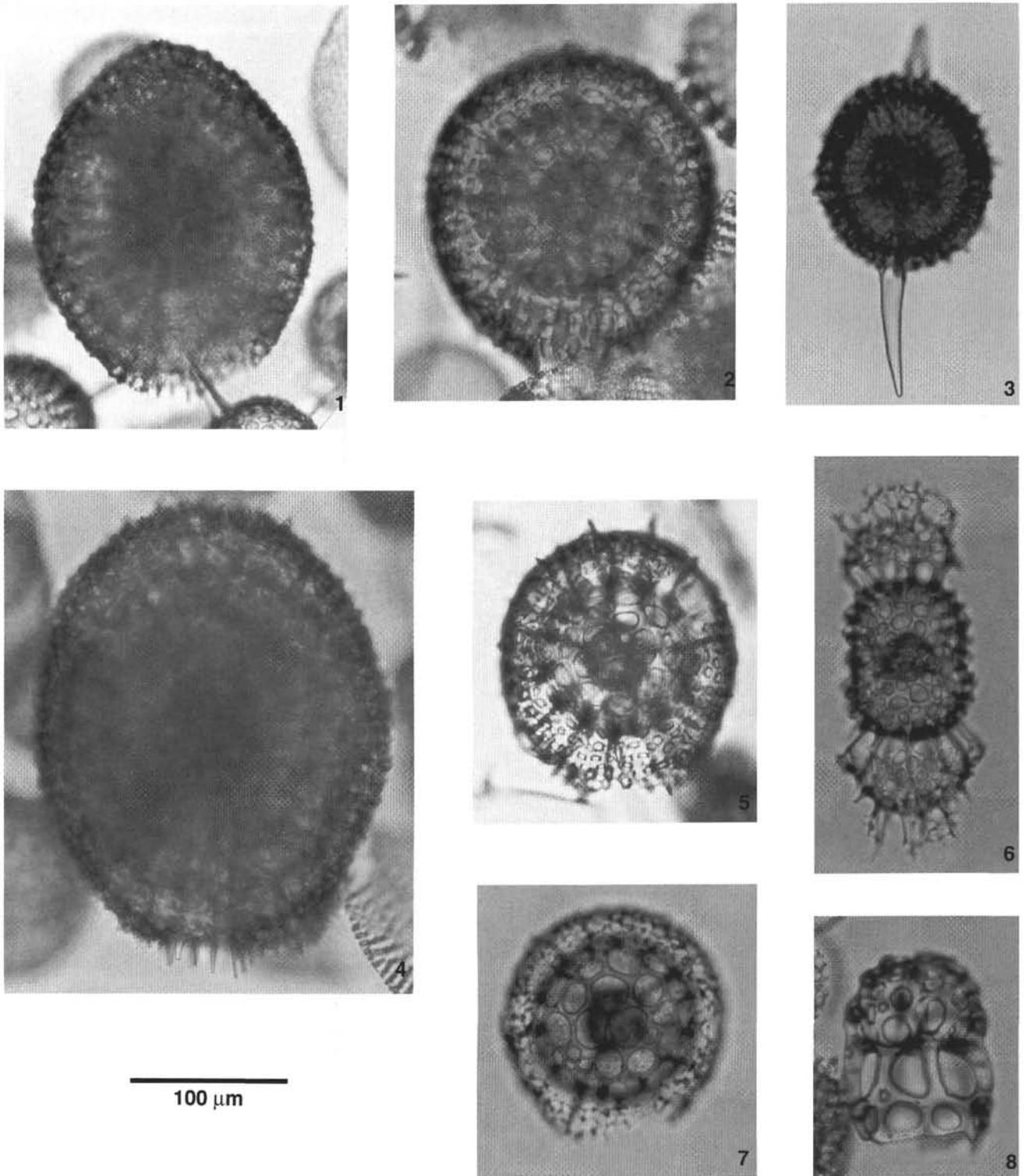


Plate 2. 1. *Prunopyle hayesi*, Sample 145-885A-5H-6, 115–116 cm, X41/0. 2. *Sphaeropyle langii*, Sample 145-886C-3H-4, 114–115 cm, R51/0. 3. *Stylatractus universus*, Sample 145-881C-13H-CC, P29/3. 4. *Prunopyle hayesi*, Sample 145-881C-36X-1, 29–30 cm, J57/3. 5. *Sphaeropyle langii*, Sample 145-887A-2H-1, 12–13 cm, M41/0. 6. *Didymocyrtis tetrathalamus*, Sample 145-881C-6H-CC, P52/1. 7. *Sphaeropyle langii*, Sample 145-881C-3H-3, 20–21 cm, O52/3. 8. *Corythospyris?* sp., Sample 145-887A-29H-3, 54–55 cm, Q5/0.

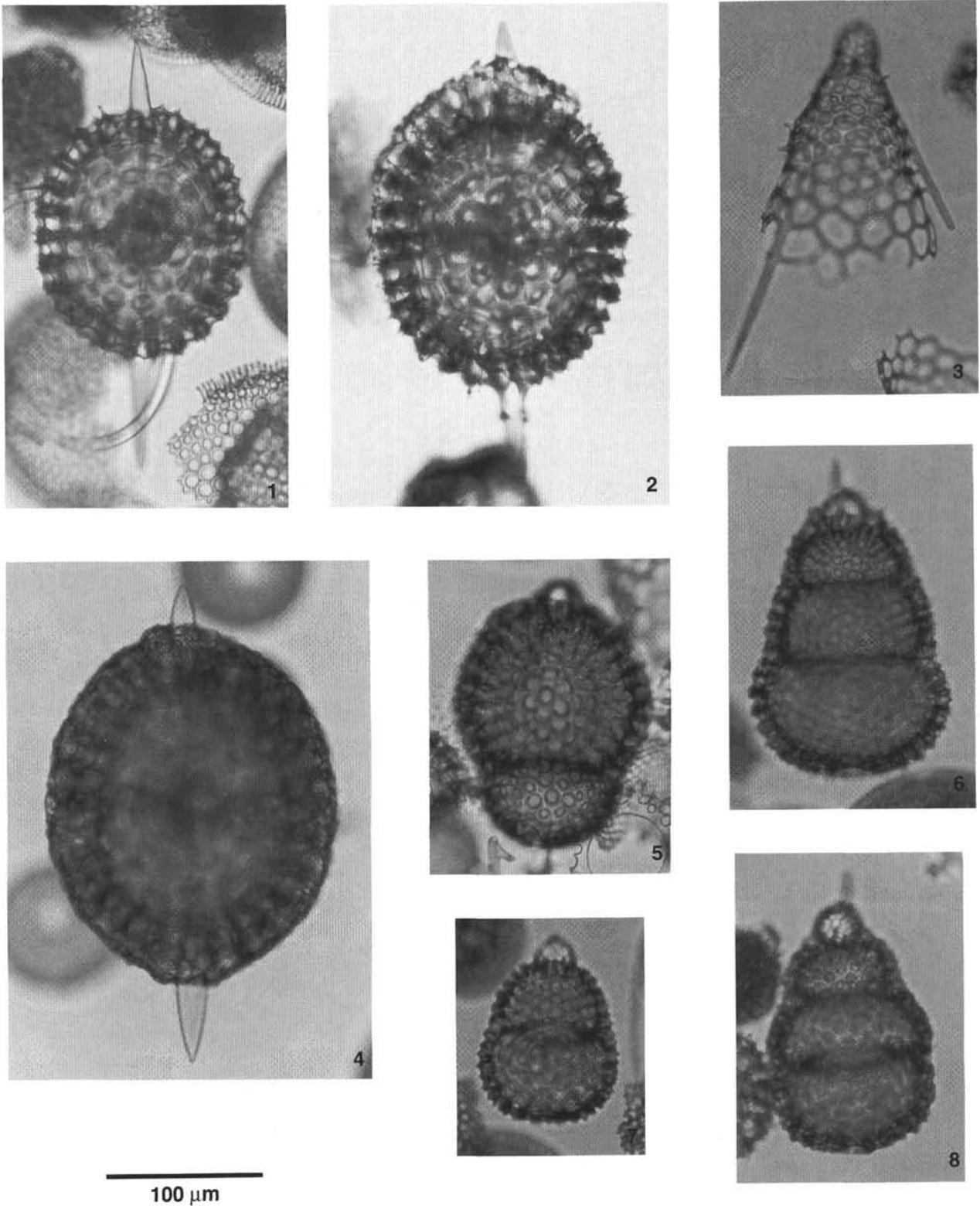


Plate 3. 1–2. *Stylocontarium acqilonium*; (1) Sample 145-885A-5H-5, 115–116 cm, R14/2; (2) with start of thickening of cortical shell, Sample 145-881C-6H-4, 143–144 cm, Q30/0. 3. *Anthocyrtella* (?) *callopsima*, Sample 145-885A-2H-1, 115–116 cm, S12/0. 4. *Stylocontarium acqilonium*, with complete thickening of cortical shell, Sample 145-884B-8H-5, 135–136 cm, O6/2. 5. *Lithopera renzae*, Sample 145-887C-27H-3, 55–56 cm, O52/2. 6. *Cyrtocapsella tetrapera*, Sample 145-884B-63X-5, 135–136 cm, S30/3. 7. *Cyrtocapsella japonica*, Sample 145-887A-25H-3, 54–55 cm, S9/1. 8. *Cyrtocapsella cornuta*, Sample 145-887A-28H-3, 54–55 cm, N40/0.

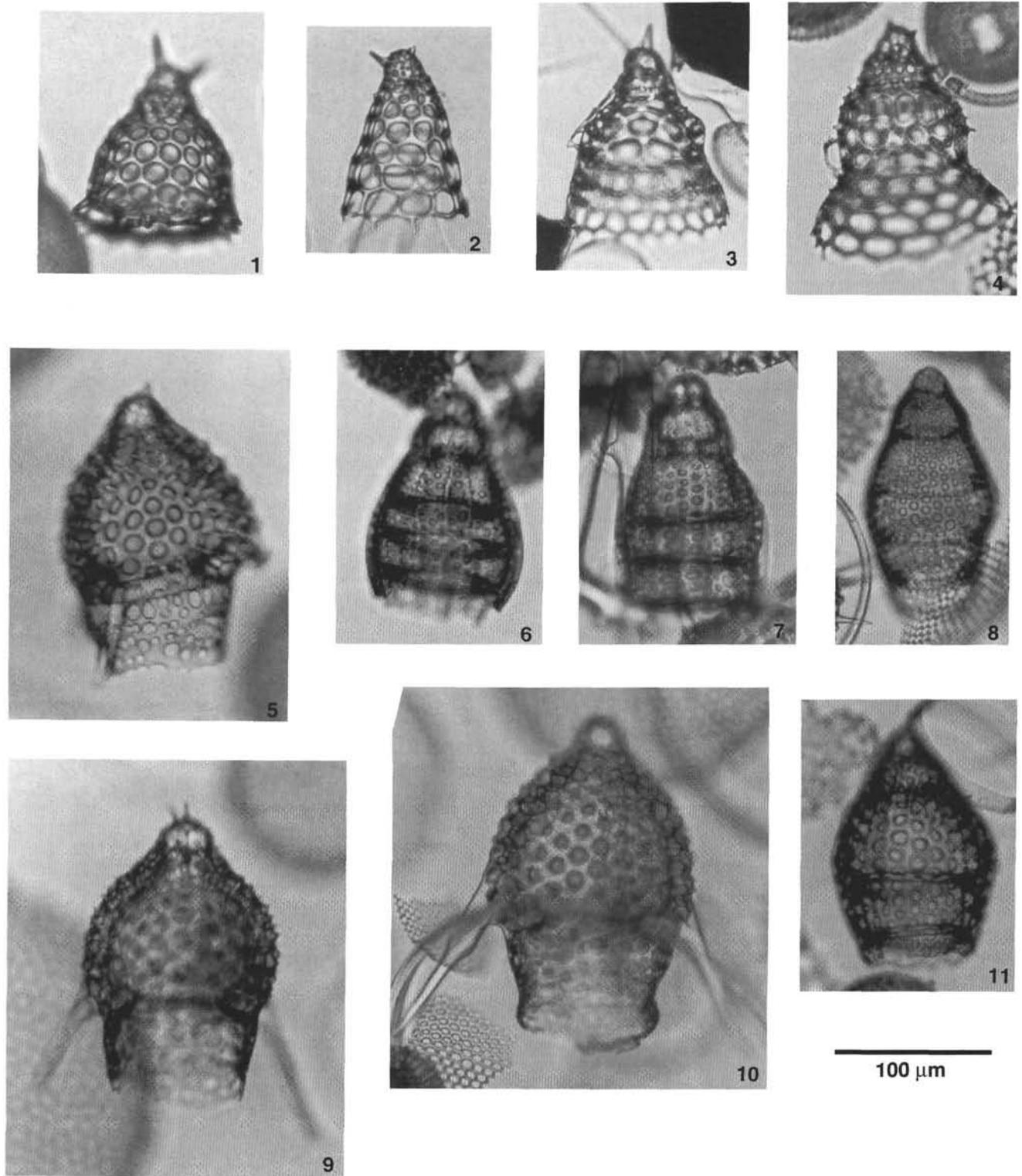


Plate 4. **1.** *Cycladophora pliocenica*, Sample 145-887A-2H-3, 133–134 cm, M35/4. **2.** *Cycladophora cosma cosma*, Sample 145-881B-6H-5, 111–112 cm, D57/2. **3–4.** *Cycladophora davisiana davisiana*; (3) Sample 145-887A-7H-3, 54–56 cm, R41/3; (4) with beginnings of spongy mantle over upper portion of abdomen, Sample 145-887A-10H-6, 54–55 cm, O17/2. **5.** *Dictyophimus bullatus*, Sample 145-885A-3H-CC, R9/0. **6–7.** *Eucyrtidium asanoi*; (6) truncate conical form, Sample 145-884B-60X-CC, G46/0; (7) roughly cylindrical form, Sample 145-887A-28H-6, 55–56 cm, S10/0. **8.** *Eucyrtidium calvertense*, Sample 145-885A-3H-CC, Y34/3. **9–10.** *Dictyophimus bullatus*; (9) holotype, Sample 145-885A-3H-CC, Q10/2; (10) Sample 145-886C-4H-CC, M34/3. **11.** *Eucyrtidium inflatum*, Sample 145-884B-58X-5, 135–136 cm, E22/0.

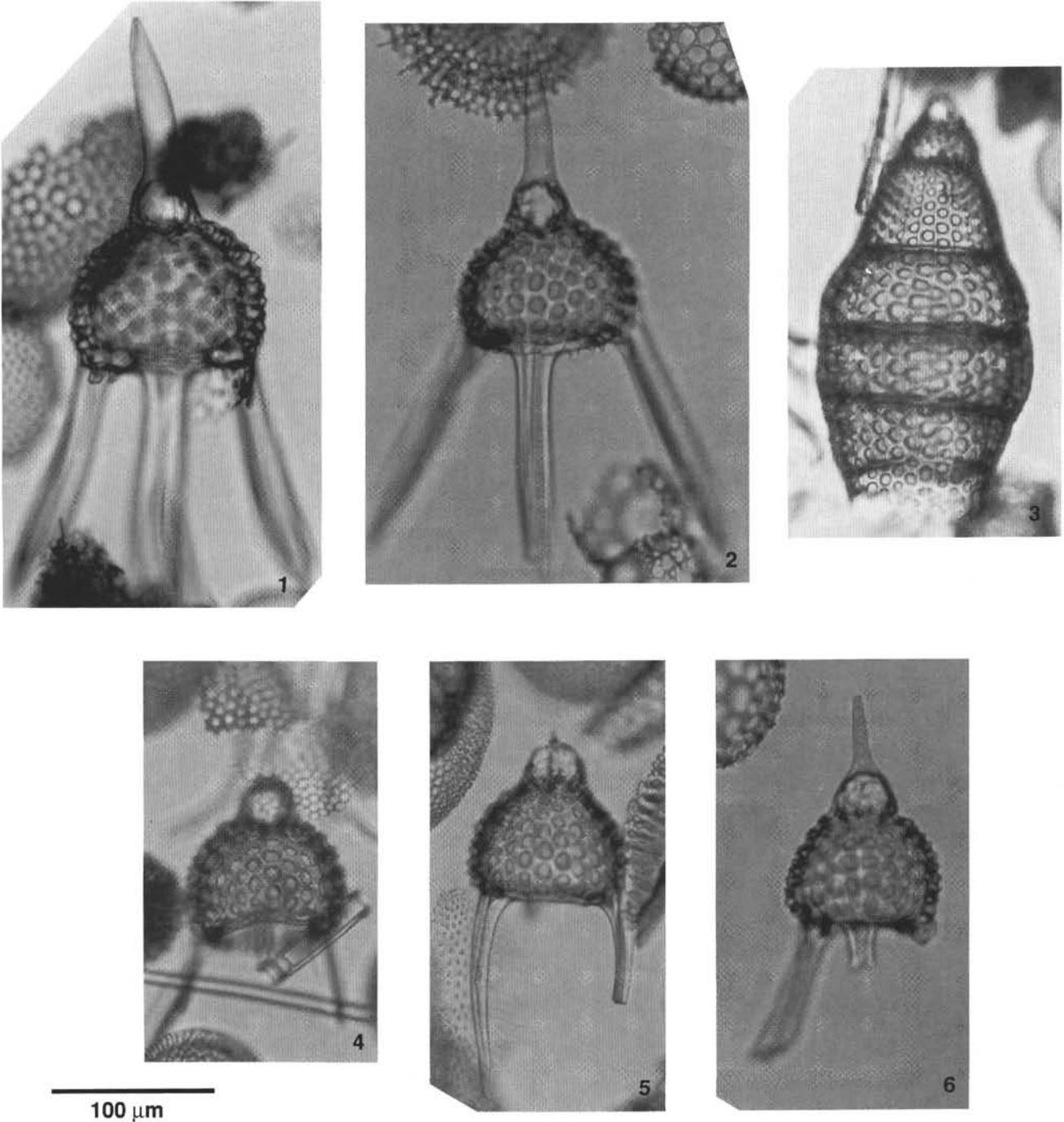


Plate 5. 1–2. *Lychnocanoma nipponica magnacornuta*; (1) Sample 145-883B-53X-CC, N39/0; (2) Sample 145-886C-6H-CC, K39/1. 3. *Eucyrtidium matuyamai*, Sample 145-887A-7H-6, 54–56 cm, P28/1. 4–5. *Lychnocanoma nipponica nipponica*; (4) Sample 145-884B-54X-5, 135–136 cm, T50/1; (5) Sample 145-886C-6H-5, 114–115 cm, C8/0. 6. Intermediate form between *L. nipponica nipponica* and *L. nipponica magnacornuta*, Sample 145-886C-6H-CC, N39/0.

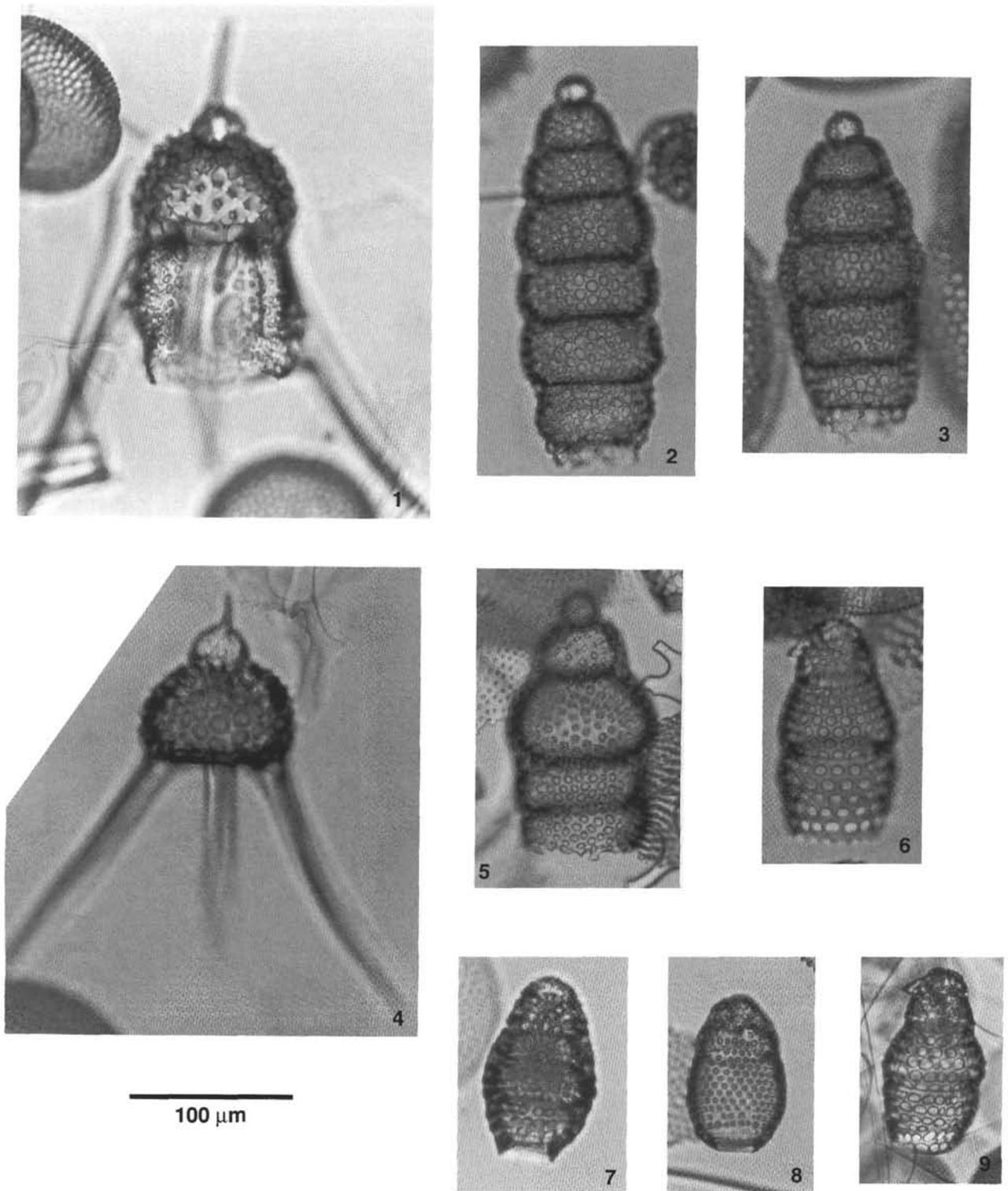


Plate 6. **1.** *Lychnocanoma nipponica sakaii*, Sample 145-887A-2H-1, 12–13 cm, P44/0. **2–3.** *Stichocorys peregrina*; (2) Sample 145-886C-5H-3, 98–99 cm, D30/4; (3) Sample 145-885A-5H-4, 115–116 cm, K13/2. **4.** *Lychnocanoma nipponica sakaii*, holotype, Sample 145-881C-1H-CC, M19/3. **5.** *Stichocorys delmontensis*, Sample 145-886C-6H-5, 114–115 cm, K30/0. **6.** *Phormostichoartus fistula*, Sample 145-886C-6H-3, 112–113 cm, Q52/0. **7.** *Botryostrobus aquilonaris*, Sample 145-887A-1H-1, 12–13 cm, L37/0. **8.** *Phormostichoartus crustula*, Sample 145-885A-3H-CC, K11/3. **9.** *Phormostichoartus pitomorphus*, Sample 145-887A-6H-6, 54–55 cm, H11/4.

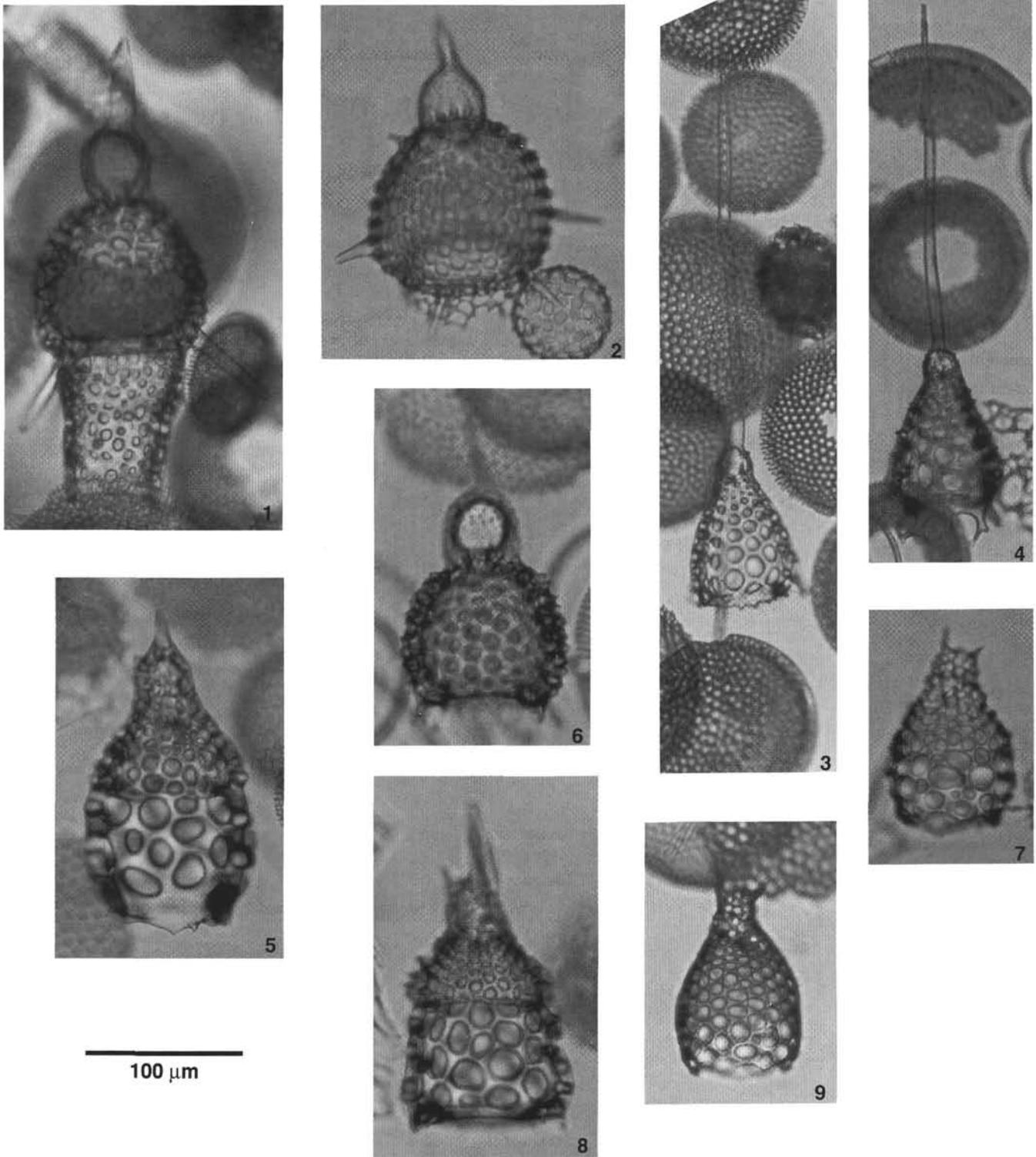


Plate 7. 1–2. *Theocorys redondoensis*; (1) Sample 145-884B-48X-5, 135–136 cm, L9/0; (2) Sample 145-886C-6H-CC, Y32/2. 3–4. *Dictyophimus splendens*; (3) Sample 145-884B-52X-5, 135–136 cm, L40/1; (4) Sample 145-884B-54X-5, 135–136 cm, S28/1. 5. *Lamprocyrtis heteroporos*, Sample 145-886C-3H-3, 114–115 cm, J9/1. 6. *Theocorys redondoensis*, Sample 145-886C-6H-2, 114–115 cm, U24/4. 7. *Lamprocyrtis neoheteroporos*, Sample 145-885A-2H-1, 115–116 cm, H41/4. 8. *Lamprocyrtis heteroporos*, Sample 145-881C-18X-3, 50–51 cm, S49/2. 9. *Lamprocyrtis nigrinia*, Sample 145-886C-1H-3, 114–115 cm, P51/0.