

21. RADIOLARIAN BIOSTRATIGRAPHY OF ODP LEG 111, SITE 677, EASTERN EQUATORIAL PACIFIC, LATE MIOCENE THROUGH PLEISTOCENE¹

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ABSTRACT

Well-preserved late Miocene through Pleistocene age radiolarian assemblages were recovered during ODP Leg 111 at Site 677, on the southern flank of the Costa Rica Rift in the eastern equatorial Pacific. Radiolarian "event" biostratigraphy (first and last morphotypic appearances) was established for Holes 677A and 677B using 21 species yielding 24 reliable datum levels. The cold upwelling waters above this site have prevented many typical tropical Pacific stratigraphic radiolarians from being useful age indicators. Biostratigraphic datum levels were assigned absolute ages based on previous work and were used to date the cores. Sedimentation rates varied from 3.7 cm/1000 yr in the late Pleistocene to 6.0 cm/1000 yr in the late Miocene. The age of the oldest sediments at this site is estimated as 5.89–6.37 Ma, which indicates that Site 677 is between magnetic anomalies 3A and 4. A total of 67 taxa were assessed for stratigraphic relevance at this site and are listed in the Appendix. One previously unknown Pliocene radiolarian stratigraphic indicator, *Botryostrobus euporus* (Ehrenberg), is identified.

INTRODUCTION

During the five days of Ocean Drilling Program (ODP) Leg 111 that were dedicated to coring sediment, two sites were visited. At Site 677, a double-cored record of Pleistocene pelagic sedimentation was obtained for high-resolution paleoclimatic studies. The single hole record (Hole 677A) of the entire sedimentary section (upper Miocene to Holocene) duplicated with better recovery previous coring at Deep Sea Drilling Project (DSDP) Site 504, which is 2.7 km to the northeast. The sophisticated coring techniques developed by ODP that were used at Site 677 facilitated the recovery of nearly complete, relatively undisturbed, continuous sections of sediments. The top 139.2 m of Hole 677A was recovered using the advanced piston corer (APC), with excellent recovery (102.4%). (Recovery greater than 100% results from expansion of the sediments as they are cored and brought aboard ship.) Below 144.2 m below seafloor (mbsf) in Hole 677A, recovery lessened to an average of 76.5% because of the greater induration of the sediments and the different coring apparatus (extended core barrel, XCB) used to recover this portion of the sedimentary section. A total of 308.5 m of sediment was cored in Hole 677A before basement was encountered. In Hole 677B, 93.1 m of sediment was cored, with an average recovery of 99.8%, which supplemented and improved the stratigraphic coverage of the upper part of Hole 677A. The second sedimentological site occupied during Leg 111, Site 678, was discontinuously cored mainly for pore-water studies and is not discussed further.

Slides prepared from core-catcher samples were examined to determine which radiolarians were stratigraphically useful within the recovered sediments. A list of 65 species (table 4 of Shipboard Scientific Party, 1988a) was compiled with two purposes in mind. First, since no interpretable paleomagnetic reversal data are available for age dating of the cores from Site 677, it is desirable to develop a biostratigraphy utilizing as many well-studied and dated events as possible. Second, any additional datum levels that can be determined within this core can be used to

tie the stratigraphic record of this site to that of other deep-sea sites. Of the 65 taxa on the initial radiolarian survey list, only 39 were present in sufficient abundance to be examined for this study. Several of the 26 species not studied from the original radiolarian survey list have proved useful at other tropical Pacific sites; however, due to the location of ODP Site 677 within a region of vigorous upwelling, many of these tropical indicators are rare or absent in the sediments. Cold upwelling water above Site 677 may also be responsible for the high abundance and reliability of cosmopolitan indicators such as *Stylatractus univertus*, *Theocalyptra davisiana*, and *Stichocorys peregrina*.

Radiolarian biostratigraphy, presented here as ranges and datum levels in Figure 1 and Table 1, respectively, is derived from semiquantitative data collected by observation of radiolarian slides. Twenty-nine events are reported. Of these, 24 are considered reliable and were determined to within 50 cm in the Pliocene and Pleistocene sections and to within 150 cm in the Miocene section. The high species diversity of the assemblages found at this site causes low relative abundance of individual radiolarian species (usually less than 1%). Given the low abundances, the apparent range of each stratigraphic indicator is evaluated separately in order to determine how consistent the presence or absence of each taxon is within the stratigraphic column (Table 2). Based on this information, a relative level of reliability has been assigned to each datum.

SAMPLE PREPARATION

Preliminary analysis of the radiolarian record of Hole 677A showed that radiolarians are abundant and well preserved at this site. Therefore, in order to prepare slides with an adequate number of radiolarians for biostratigraphic analysis—but not an overabundance, which can make quantitative counting difficult because of superimposed specimens—radiolarian slides were prepared with samples of approximately 1 g dry sediment weight. This yielded on the order of 10^4 to 10^5 radiolarians per slide.

Samples 5 cm³ in size were placed in porcelain crucibles and dried in an oven at 60°C overnight. Samples were then weighed, and approximately 1–2 g was used to prepare radiolarian slides. Hydrogen peroxide was added to remove organic matter and disaggregate the samples. Next, hydrochloric acid was added to remove carbonates. Calgon (sodium metaphosphate) solution was added to deflocculate clays. The solutions were subjected to brief ultrasonic treatment and then sieved through a 63- μ m mesh at least three times. During the final rinse the residues, composed mainly of radiolarians, were rinsed thoroughly with deionized water.

¹ Becker, K., Sakai, H., et al., 1989. *Proc. ODP, Sci. Results*, 111: College Station, TX (Ocean Drilling Program).

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The technique used to mount radiolarians randomly on microscopic slides was adapted from Moore (1973b). The radiolarian residues from sieving were carefully added to beakers prepared with gelatin solution, labeled slides, and 450 mL of deionized water and were stirred gently with a plunger. The radiolarians were allowed to settle completely. The deionized water in the settling beaker was siphoned down to a level above the slide, and the remaining water was evaporated using heat lamps. The slides coated with radiolarians were carefully removed from the beaker and placed on a hot plate to evaporate any excess moisture. Once dry, several drops of Canada Balsam were placed on top of the slide and a 24 × 50 mm cover slip was mounted to the slide.

TROPICAL PACIFIC INDICATOR SPECIES

Radiolarians used to represent the biostratigraphic makeup of the sediments recovered during Leg 111 have been used as zonal and stratigraphic indicators in equatorial Pacific sediments of late Miocene to Holocene age by previous workers (Nigrini, 1971; Riedel and Sanfilippo, 1978; Goll, 1980; Riedel and Westberg, 1982). Five additional species (*Pterocorys minythorax*, *Pterocorys zancleus*, *Lamprocyrtis hannai*, *Theocalyptra davisiana*, and *Phormostichoartus marylandicus*) were included because they have interesting evolutionary, stratigraphic, and paleoceanographic histories (Nigrini, 1977; Morley and Hays, 1979; Molina-Cruz, 1977). One newly recognized stratigraphic indicator, *Botryostrobus euporus*, was found useful in eastern equatorial Pacific deep-sea sites and is discussed in the Appendix. Core-catcher samples were examined for the Leg 111 *Initial Report* (Shipboard Scientific Party, 1988b) in order to note all important radiolarian taxa in the assemblages. This information was used to simplify the list of radiolarians used in this study from 65 to 39 species (Table 2).

The 26 radiolarian species on the original stratigraphic survey list that were not investigated for this report can be grouped into several categories. One category includes those species that range through the entire upper Miocene through Holocene section and, therefore, are not stratigraphically useful. This group consists of *P. zancleus*, *L. hannai*, *Phormostichoartus corbula*, and *Didymocyrtis tetrathalamus*. Another category includes those species of radiolarians that are absent in all of the samples examined or are extremely rare. Absent species are *Dendrospyrus bursa*, *Calocycletta caepa*, and the *Calocycletta robusta* group. Those species rarely encountered include *Amphispyris rogentheni*, *Neosemantis hofferti*, *Sphaerozoum punctatum*, *Sphaerozoum crassus*, *Lamprocyrtis heteroporos*, *Phormostichoartus fistula*, *Diartus hughesi*, *Spongaster berminghamsi*, and *P. marylandicus*. The evolutionary transition of *P. marylandicus* to *Phormostichoartus doliolum* occurred within the upper Miocene (Nigrini, 1977), near the base of the recovered section at this site. Some evolutionary intermediates were observed, but no classic morphotypes of *P. marylandicus* were located, so it was removed from the species list. *Acrosphaera lappacea*, *Botryostrobus aquilonaris*, and *Botryostrobus bramlettei* were removed from the list because they have sporadic ranges (they were not present in any series of consecutive samples), and the ranges determined using the method of Shaw (1964) did not appear to agree with previously published ranges (Goll, 1980; Nigrini, 1977). The last group of radiolarians excluded from the stratigraphic survey includes some taxa presented in the study of Goll (1980), which this author had difficulty in distinguishing because of (1) absence or rarity at this site (*Acrosphaera cyrtodon*, *Tholospyrus devexa devexa*, and *Tholospyrus devexa finalis*), (2) similarity to related taxa (*Siphonosphaera tenera*'s resemblance to *Siphonosphaera polysiphonia*; *Acrosphaera trepanata*'s resemblance to *Acrosphaera murrayana*), or (3) uncertain identification of the species (*Collospira huxleyi*, *A. cyrtodon*, *T. devexa devexa*, *T. devexa finalis*, and *Pseudocubus warreni*). There is conflicting taxonomic information in the literature on *C. huxleyi* which detracts from its usefulness as a stratigraphic

indicator at this site. Anderson et al. (1983) identified this species as an extant form, and Goll (1980) indicated this is an extinct form with a Pleistocene range. Individuals that fit Goll's (1980) description of *C. huxleyi* were found in the Pliocene of Hole 677A (Pl. 1, Fig. 5), as well as the Pleistocene of Holes 677A and 677B, but are very rare and not found in every sample.

SAMPLE STRATEGY AND BIOSTRATIGRAPHIC METHODS

The sampling strategy and sample set were designed with two purposes in mind. The first and primary purpose was to identify the ranges or partial ranges of all radiolarian stratigraphic indicators present in the assemblages, so that a chronology could be assigned to sample depths. The second purpose was to provide material for radiolarian faunal analysis experiments. A total of 626 slides from Site 677 samples were prepared. Four hundred fifty-five radiolarian slides were made from Hole 677A samples at a sample interval of 50 cm in the Pliocene and Pleistocene sections and 1.5 m in the Miocene section (Cores 111-677A-27X through 111-677A-33X). One hundred seventy-one radiolarian slides were prepared from Hole 677B samples at a 50-cm spacing to establish the stratigraphy of that hole. These sample spacings allow a time resolution of approximately 10,000 to 15,000 yr in the Pliocene and Pleistocene intervals and 30,000 to 45,000 yr in the Miocene interval.

Radiolarian datums were determined using strict definitions of morphological first and last occurrences rather than evolutionary limits (Riedel and Sanfilippo, 1971). Species were identified at 100× magnification with a compound microscope. Although some taxa show observable morphologic evolution over their ranges, the sampling interval is large enough so that continuous morphological change appears to occur in steps, enabling the establishment of criteria that can be consistently observed at the corresponding stratigraphic level in several cores. Generally, the bottom of a taxon's consistent range was used to determine the FAD (first-appearance datum) in cases of evolutionary transitions, because this limit tends to be more stratigraphically reliable for high-resolution hole to hole correlations. For the LAD (last-appearance datum) of a moderately abundant taxon, fragments or one to two specimens of the species were not considered as representative of the taxon's true range because upward reworking is likely to lengthen the apparent range. For rare taxa, however, one to two specimens were used to define LADs because upward reworking should not significantly modify their ranges. Data from core-catcher samples were ignored if they conflicted with information from other samples because the core catchers tend to be disturbed and contaminated. Some morphologic limits are not as well defined as others and some taxa are not as abundant or well preserved as others; therefore, each biostratigraphic level was assessed separately and assigned a level of reliability based on observations made by the author. Typical representatives of 49 of the taxa discussed in this paper are presented in the plates. All biostratigraphically useful species are represented.

The previously reported coarse radiolarian stratigraphy based on core-catcher samples (Shipboard Scientific Party, 1988b) served as the biostratigraphic framework of the sample analysis presented here (Tables 1 and 2). Each biostratigraphic level was determined to the closest sample interval used (0.5 to 1.5 m). Slides were scanned completely, and the presence or absence of each taxon was noted. The species richness (diversity) of these assemblages made estimation of relative abundances difficult. In cases of uncertainty the number of occurrences per slide of a particular species was tallied (Table 2) in order to clarify the selection of a particular datum level. A total of 111 slides (144 including core-catcher

Table 1. Radiolarian biodatums determined for Holes 677A and 677B. Level of datum reliability is discussed in the text.

Event ^a	Depth interval ^b (mbsf)		Age (m.y.B.P.) ^c	Reference ^d	Level of datum reliability
	Hole 677A	Hole 677B			
Pleistocene					
T <i>Stylatractus universus</i>	14.97–15.44	15.94–16.44	0.41	2	1
T <i>Androspyris anthropiscus</i>	*24.94		0.5	4	5
T <i>Lithopera bacca</i>	*35.82		0.7	4	5
T <i>Lamprocyrtis neoheteroporos</i>	39.44–39.94	35.92–36.44	0.95–1.0	1	2
T <i>Anthocyrtidium angulare</i>	43.94–44.20	41.44–41.94	1.1–1.2 (s)	5	2
T <i>Theocorythium vetulum</i>	46.94–47.34	45.44–45.94	1.1–1.2 (a)	5	3
B <i>Lamprocyrtis nigrinae</i>	54.94–55.44	50.94–51.94	1.4–1.5 (a)	5	3
B <i>Theocorythium trachelium</i>	58.44–58.86	58.94–59.44	1.5–1.6 (d)	5	3
B <i>Pterocorys minythorax</i>	61.86–62.44	62.44–62.94	NR		3
T <i>Didymocyrtis avita</i>	*63.44		NR		5
B <i>Anthocyrtidium angulare</i>	64.06–64.44	64.94–65.44	1.4–1.5 (s)	5	2
T <i>Pterocanium prismatium</i>	66.44–67.06	66.94–67.44	1.5–1.6 (s)	5	4
B <i>Androspyris anthropiscus</i>	**82.20–91.70		1.8	4	5
Pliocene					
B <i>Theocalyptra davisiana</i>	110.44–110.70		2.63	6	1
T <i>Stichocorys peregrina</i>	115.44–116.06		2.77	6	1
B <i>Lamprocyrtis neoheteroporos</i>	136.56–136.94		3.19	6	2
B <i>Botryostrobus euporus</i>	137.44–138.06		3.28	6	2
T <i>Phormostichoartus doliolum</i>	158.54–159.15		3.5–3.6 (s)	5	2
T <i>Pterocanium audax</i>	159.15–159.54		3.4–3.5 (s)	5	4
B <i>Amphirhopalum ypsilon</i>	163.50–163.74		3.6–3.7 (s)	5	4
T <i>Spongaster pentas</i>	163.50–163.74		3.0–3.1 (a)	5	3
B <i>Spongaster tetras</i>	167.74–168.24		3.67	6	3
T <i>Spongodiscus ambus</i>	172.24–173.20		NR		4
T <i>Didymocyrtis penultima</i>	173.20–173.44		3.71	6	3
B <i>Pterocanium prismatium</i>	*207.44		4.2–4.3 (d)	5	4
T <i>Solenosphaera omnitubus</i>	219.44–220.04		4.7–4.8 (s)	5	2
Miocene					
T <i>Siphostichartus corona</i>	247.64–249.15		4.9–5.0 (s)	4	4
T <i>Didymocyrtis antepenultima</i>	**250.40–260.00		5.5	3	5
T <i>Stichocorys johnsoni</i>	279.30–280.10		5.9–6.0 (s)	5	2

^a B = bottom of species range; T = top of species range.

^b Indicated interval represents the thickness of the unsampled section within which the event occurs. * = maximum range of the species found; ** = data not changed from that reported in Shipboard Scientific Party, 1988b.

^c The (s), and (d), and (a) refer to Johnson and Nigrini's (1985) recognition of datums that are synchronous, diachronous, or in need of additional work, respectively. NR means that ages for that datum have not been reported for the eastern equatorial Pacific.

^d 1 = Johnson and Knoll, 1975; 2 = Hays and Shackleton, 1976; 3 = Theyer et al., 1978; 4 = Goll, 1980; 5 = Johnson and Nigrini, 1985; 6 = J. M. Alexandrovich (unpubl. data)

samples) from Hole 677A and 32 slides from Hole 677B were examined. These samples and their radiolarian inventory are listed in Table 2. Datum level locations are listed in Table 1.

RADIOLARIAN BIOSTRATIGRAPHY OF SITE 677

The radiolarian zonal scheme of Riedel and Sanfilippo (1978) was used to define the stratigraphy of Site 677 sediments (Fig. 1). Four radiolarian zones subdivide the 6 m.y. spanned by these sediments. Due to the location of Site 677 in a zone of vigorous upwelling, two important zonal indicators, *Pterocanium prismatium* and *Spongaster pentas*, were not found in significant abundance probably due to their low tolerance for cold waters. Other indicators (see level of datum reliability, Table 1) are much more reliable and were dated quite accurately, facilitating high-resolution correlations by age.

Of the 39 species scrutinized in this paleontological analysis, 21 of them account for 24 biodatums that are consistent and reliable indicators of age (Table 1 and Fig. 1). Nine radiolarian datums were determined for the Pleistocene section of Holes 677A and 677B, and 16 additional datums were documented in Pliocene and Miocene samples from Hole 677A. One new datum, the FAD of *Botryostrobus euporus*, is reported here. The reasoning used to determine each datum listed in Table 1 is dis-

cussed in the following according to its level of reliability. Six levels of reliability were determined. The first level is the most reliable, and the sixth level is the least reliable. The divisions between levels were chosen to simplify the discussion that follows.

Level of Reliability 1

The three most reliable radiolarian indicators from Site 677 sediments are the LAD of *Stylatractus universus*, the FAD of *Theocalyptra davisiana*, and the LAD of *Stichocorys peregrina*, because they are consistent and common throughout their range of occurrence. In both Holes 677A and 677B, the slide with the last occurrence of *S. universus* had only one recorded specimen of this species. A more conservative estimate might lower the datum level by 50 cm, where *S. universus* is present in moderate abundance, but the fact that both holes showed identical trends suggests that the shallower datum level is reliable. The *T. davisiana* immigration event (J. D. Hays and M. Gross, pers. comm., 1987) is recorded between a sample with its definite presence (more than three specimens on that slide) and a sample that was the last in the series in which no *T. davisiana* were found. *S. peregrina*, usually present in great abundance, declined somewhat near the end of its range. The LAD of *S. peregrina* was chosen as the last sample with several specimens in the sample.

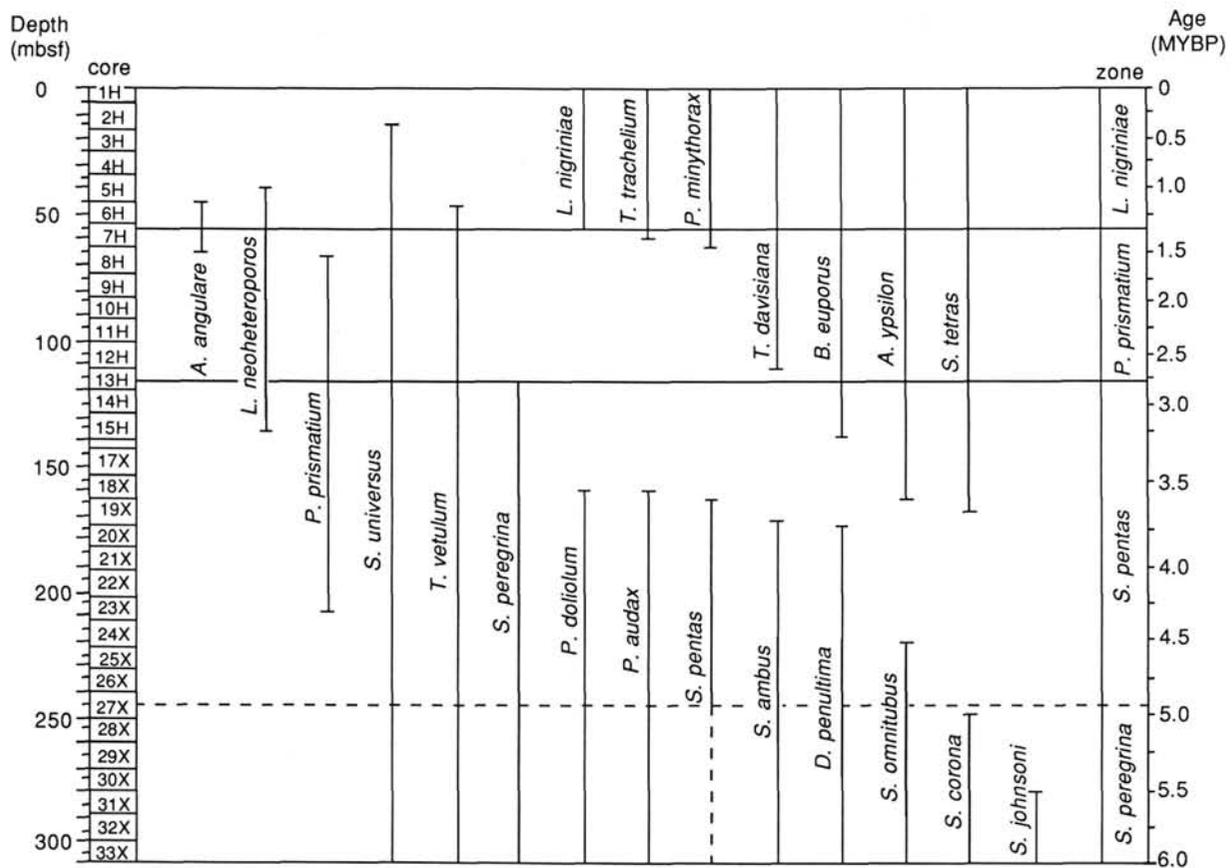


Figure 1. Ranges of radiolarian stratigraphic indicators in Hole 677A. Zones are after Riedel and Sanfilippo (1978). The boundary between the *Stichocorys peregrina* and *Spongaster pentas* Zones is not well constrained. Age scale is based on the following events: LAD *Stylatractus universus* = 0.41 Ma, LAD *Theocorythium vetulum* = 1.20 Ma, LAD *Pterocanium prismatium* = 1.55 Ma, FAD *Theocalyptra davisiana* = 2.63 Ma, FAD *Botryostrobus euporus* = 3.28 Ma, LAD *Didymocyrtis penultima* = 3.71 Ma, FAD *Pterocanium prismatium* = 4.3 Ma, and LAD *Siphostichartus corona* = 5.0 Ma. The base of the sedimentary section is assigned an age of 6.0 Ma.

Level of Reliability 2

The second most reliable group of radiolarian stratigraphic datums includes the FAD and LAD of *Lamprocyrtis neoheteroporos*, the FAD and LAD of *Anthocorythidium angulare*, the FAD of *B. euporus*, the LAD of *Phormostichoartus doliolum*, the LAD of *Solenosphaera omnitubus*, and the LAD of *Stichocorys johnsoni*. The main reason these indicators are considered slightly less reliable than level of reliability 1 is that this group of radiolarians was found in relatively lower abundances. When radiolarians occur in low abundance, it is possible that a species actually present during the time of sediment deposition might not be included in a sample and is therefore recorded as absent during biostratigraphic analysis. *A. angulare*, *P. doliolum*, and *S. johnsoni* exhibited mostly consistent ranges, and their datum levels are simply located. Two core-catcher samples were ignored in identifying the LAD of *S. omnitubus*. Because the FADs of *L. neoheteroporos* and *B. euporus* are complicated by their evolutionary histories, their datum levels were selected at their first consistent appearances.

Level of Reliability 3

This group of indicators is present in the samples in approximately equal abundances as those of reliability level 2. They are considered less reliable because of complexities created by morphological evolution which are evident in the samples. Datums included in this group are the LAD of *Theocorythium vetulum*, the FAD of *Lamprocyrtis nigrinae*, *Theocorythium trachelium*,

and *Pterocorys minythorax*, the LAD of *S. pentas*, the FAD of *Spongaster tetras*, and the LAD of *Didymocyrtis penultima*. Representative forms of these species are presented in Plates 2, 4, and 5. With the exceptions of *S. tetras* and *S. pentas*, intermediate forms were seen for all species in this group; therefore, strict morphological definitions were applied so that datum levels could be identified. Near the transition of *S. pentas* to *S. tetras*, in Samples 111-677A-19X-3, 123-124 cm, to 111-677A-19X-1, 23-24 cm (164.74-163.74 mbsf), both species occur with only one or two specimens per slide. Below this interval *S. pentas* appears sporadically, and above this interval *S. tetras* is always present in moderate abundance. Because the FAD of *S. pentas* is hard to define due to extremely low abundance, the boundary between the *S. peregrina* and *S. pentas* Zones (Fig. 1) is not well constrained. *L. nigrinae* presents more of a problem because several examples of this morphotype (Pl. 2, Fig. 4) were found well below its published range (Johnson and Nigrini, 1985; Goll, 1980). It is found as deep as 166.74 mbsf in Hole 677A, or at an approximate age of 3.6 m.y.B.P. This indicates that the evolution of *L. nigrinae* is not a simple transition from *L. neoheteroporos* (Kling, 1973). The LAD of *D. penultima* was selected by distinguishing it from *Didymocyrtis tetrathalamus* by its well-developed columns (Pl. 4, Figs. 2 and 3).

Level of Reliability 4

Six radiolarian datums presented in Table 1—the FAD and LAD of *Pterocanium prismatium*, the LAD of *Pterocanium audax*, the FAD of *Amphirhopalum ypsilon*, the LAD of *Spongo-*

discus ambus, and the LAD of *Siphostichartus corona*—are less reliable than any of the datums previously presented because of the rarity of the species at this site. The range of *P. audax* was extended substantially over the original biostratigraphic analysis of core-catcher samples (from Cores 111-677A-29X to 111-677A-18X), but it is not consistently present in samples within this interval. In this case the range-through method of Shaw (1964) was applied. The FAD of *P. prismatium* reported in Table 1 is the deepest sample in which *P. prismatium* was found. Whether this depth is representative of *P. prismatium*'s true first appearance at this site is not known, but it does appear in proper relative order (see ages referenced in Table 1).

Level of Reliability 5

The least reliable radiolarian datums presented in Table 1 are the LAD and FAD of *Androspyrus anthropiscus*, the LAD of *Lithopera bacca* and the LADs of *Didymocyrtis avita* and *Didymocyrtis antepenultima*. Species from the subfamily Artiscinae (Sanfilippo and Riedel, 1980), *D. avita* and *D. antepenultima*, are problematical, because the last occurrences of these taxa are actually pseudoextinctions or arbitrary cut-off limits within a lineage. The LADs of *D. avita* and *D. antepenultima* reported here (Table 1) are maximum ranges. The reliability of these datum levels is low because the best way to pinpoint these datum levels is by the statistical evaluation of morphological measurements (e.g., Westberg and Riedel, 1978). *A. anthropiscus* and *L. bacca* appear sporadically and in low abundances, with *L. bacca* commonly in fragments, within the Site 677 samples. Analysis of additional samples is necessary to increase the reliability of these datum levels.

Level of Reliability 6

Fourteen radiolarians searched for during this survey are not presented as stratigraphic indicators in Table 1. These are *Collosphaera invaginata*, *Collosphaera orthoconus*, *Collosphaera tuberosa*, *Nephrospyrus renilla renilla*, *Androspyrus fenestrata*, *Androspyrus huxleyi*, *Pterocorys hertwigii*, *Stichocorys delmontensis*, *Botryostrobos miralestensis*, *Spirocorytis gyrosalaris*, *Spirocorytis scalaris*, *Acrobotrys tritubus*, *Centrobotrys thermophila*, and *Dictyocoryne ontongensis*. All but *S. delmontensis* and *C. thermophila* are presented in the plates accompanying this report. In general, these radiolarians are not stratigraphically reliable at this site because they (1) occur in extremely low abundances (lower than those in the previously discussed reliability levels) causing discontinuous apparent ranges (see Table 2) and/or (2) exhibit evolution within the interval which makes identification of datum levels difficult. The *C. orthoconus*, *C. tuberosa*, and *C. invaginata* (or intermediate *Collosphaera irregularis*; Knoll and Johnson, 1973) datums were not located because of time constraints and because the LAD of *S. univertus* displayed excellent correlation control for the top 15 m of sediment. *C. thermophila* was never encountered in Site 677 samples. A related radiolarian (Pl. 3, Fig. 15) belonging to the *Botryopyle* genus (p. 1602, Riedel and Sanfilippo, 1971) was found, but never in any abundance. In the oldest sediments examined, classic *S. delmontensis* morphotypes were not found in sufficient numbers to identify the evolutionary transition of *S. peregrina* from *S. delmontensis* (the LAD of *S. delmontensis*), but this does indicate that the oldest sediments recovered at this site are as old as magnetic Epoch 6 (Saito et al., 1975). Further analysis of Site 677 samples may determine that several datums from this last group of 14 radiolarians will indeed be reliable stratigraphic indicators.

CHRONOSTRATIGRAPHY

Because the paleomagnetic record of the sediments from Site 677 can not be used to establish a chronology for Leg 111 sedi-

ments (Shipboard Scientific Party, 1988b), biostratigraphy is used as the primary time control. The datums have been assigned ages (Table 1 and Fig. 1) that serve as proxies for paleomagnetic data, as the ages of radiolarian datum levels were previously determined by interpolation between magnetic reversal levels or other microfossil events that have been tied to the paleomagnetic reversal chronology in other cores. Figure 2 shows the age vs. depth plot of dated radiolarian datums levels from Hole 677A. The indicated sedimentation rates were used to devise the age scale in Figure 1. Although interpretation is subject to change, on average, the sedimentation rate at Site 677 decreased from 6.0 cm/1000 yr in the late Miocene to 3.7 cm/1000 yr in the Pleistocene. The age of the oldest sediments recovered at this site can be estimated by examining the transition of *Stichocorys delmontensis* to *Stichocorys peregrina*. According to Saito et al. (1975), this transition occurs in the upper reversed portion of paleomagnetic Epoch 6 in Core RC 12-66 (between 5.89 and 6.37 m.y.B.P., according to the time scale of Berggren et al., 1985). In Hole 677A, this transition is observed in the bottom 60 m of section (in and below Sample 111-677A-28X-1, 83–84 cm; Table 2). This age estimate for the oldest sediments recovered in Hole 677A is confirmed by the presence of the diatom *Thalassiosira praeconvexa* and the absence of the diatom *Thalassiosira usatschevii* in Sample 111-677A-33X-3, 75–76 cm (L. H. Burckle, pers. comm., 1988). Therefore, Site 677 (and DSDP Site 504) was drilled on crust between anomalies 3A and 4 (Berggren et al., 1985). It is possible that the age of the oldest sediments at this site is greater than 6.37 Ma, but this can not be deduced using siliceous microfossils because no opaline material is preserved in the 5 m of sediments recovered below the chert layer at 303.60 mbsf.

The biostratigraphic data presented in Table 1 can be used to study the relative synchronicity or diachroneity of events on a more global scale by examining the positions of events relative to other stratigraphic records such as calcium carbonate or oxygen isotopes. It is already apparent that some evolutionary events, such as the FAD of *Lamprocyrtis nigrinae* and *Spongaster pentas*, display quite different histories here than at other sites; however, the majority of the datums reported here are found in the same relative sequence as in other localities. No significant diachroneities were found between Holes 677A and 677B.

SUMMARY

A late Miocene through Holocene record of continuous pelagic deposition was recovered in cores obtained with the APC and XCB systems during ODP Leg 111. The sediments of Site 677 have a remarkable record of well-preserved radiolarian assemblages with high taxonomic diversity (estimated to be well over 100 species). In this report, the stratigraphic usefulness of the radiolarian assemblages from these sites is assessed, and 24 reliable datum levels are presented in Table 1. Each datum is assigned to a relative level of reliability. The accuracy of this radiolarian biostratigraphy is determined by the sample spacing, species abundances, and a semiquantitative method used to locate datum levels. Bioturbation is judged to be minimal throughout these cores because the radiolarian skeletons are well preserved and abundant and the upward redistribution of LADs (Hays, 1971) does not appear to affect the data presented here. For example, upward reworking of *Stichocorys peregrina*, such as that documented at Site 503 by Riedel and Westberg (1982), is not found in the sediments of Site 677.

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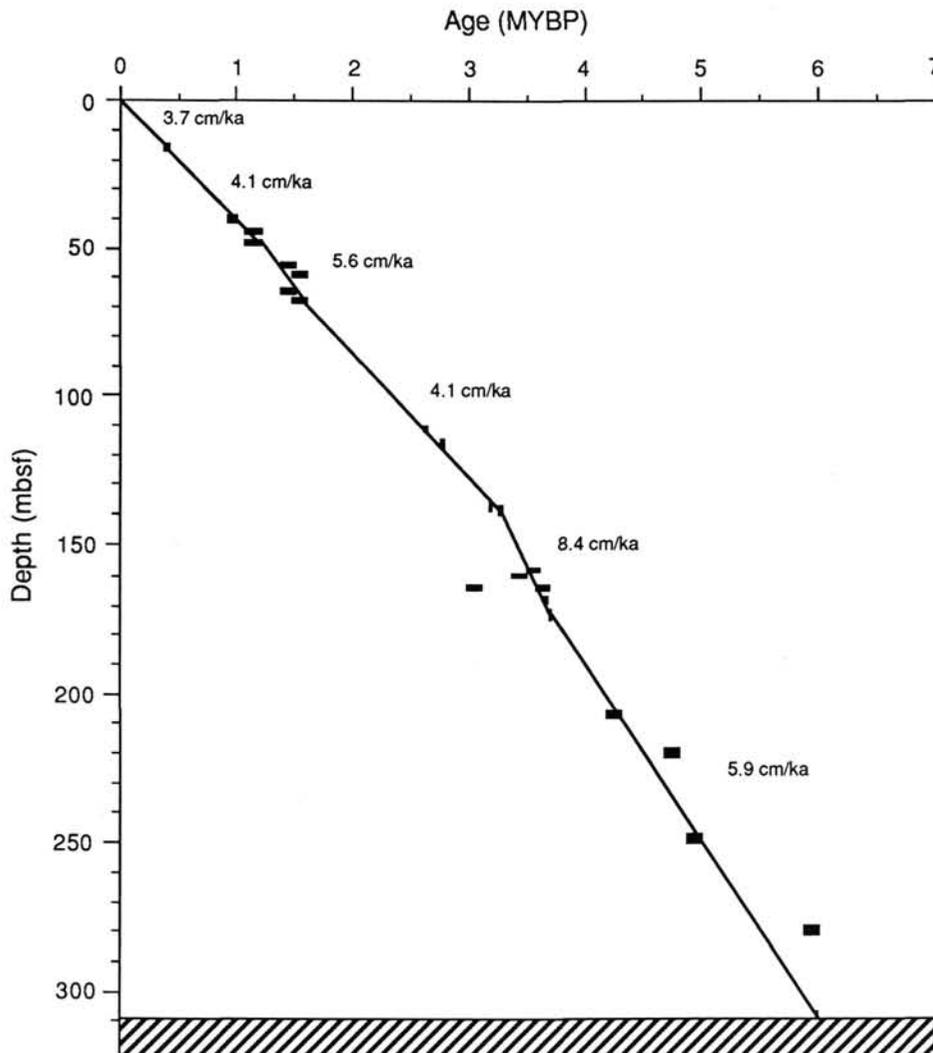


Figure 2. Age vs. depth plot of radiolarian datum levels from Table 1. Sedimentation rates are indicated. Hatchured lines designate the depth of basement.

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APPENDIX Species List

Many of the radiolarians discussed in this report were identified using published descriptions, drawings, and photographs. All of the radiolarians discussed are listed in alphabetical order according to generic name and by specific name where applicable. Detailed synonymies are supplied for important stratigraphic indicators. Corrections, amendments, and/or supplements are added where considered appropriate. One new combination species name is given with an emended description.

Acrobotrys tritubus Riedel, 1957
(Pl. 3, Fig. 11)

Acrosphaera cyrtodon (Haeckel, 1887) Goll, 1980

Acrosphaera lappacea (Haeckel, 1887) Strelkov and Reshetnyak, 1971

Acrosphaera murrayana (Haeckel, 1887) Strelkov and Reshetnyak, 1971

Acrosphaera trepanata (Haeckel, 1887) Goll, 1980

Amphirhopalum ypsilon Haeckel, 1887
(Pl. 4, Fig. 1)

Amphirhopalum ypsilon Haeckel, 1887, p. 522; Nigrini, 1967, p. 35, pl. 3, figs. 3a-3d; Nigrini, 1970, p. 168, pl. 2, fig. 2; Molina-Cruz, 1977, p. 334, pl. 1, fig. 6; Nigrini and Moore, 1979, p. S75, pl. 10, figs. 1a-1e.

Amphicraspedum wyvilleanum Haeckel, 1887, p. 523, pl. 45, fig. 12; Benson, 1966, p. 221, pl. 11, figs. 5, 6.

Amphispyris roggentheni Goll, 1980

Androsphyris anthropiscus Haeckel, 1887
(Pl. 2, Fig. 11)

Androsphyris fenestrata (Haeckel, 1887) Goll, 1980
(Pl. 1, Fig. 10)

Androsphyris huxleyi (Haeckel, 1887) Goll, 1980
(Pl. 2, Fig. 10)

Anthocyrtdium angulare Nigrini, 1971
(Pl. 1, Fig. 6)

Anthocyrtdium angulare Nigrini, 1971, p. 445, pl. 34.1, figs. 3a, 3b; Goll, 1980, p. 436, pl. 3, fig. 9.

Botryostrobus aquilonaris (Bailey, 1856) Nigrini, 1977
(Pl. 3, Fig. 4)

Botryostrobus bramlettei (Campbell and Clark, 1944) Nigrini, 1977
(Pl. 3, Fig. 5)

Botryostrobus euporus (Ehrenberg, 1873a), new comb.
(Pl. 3, Fig. 3)

Eucyrtidium euporum Ehrenberg, 1873a, p. 291; Ehrenberg, 1873b, pl. IV, fig. 20.

Lithocampe(?) euporum Ehrenberg, Haeckel, 1887, p. 1502.

Lithocampe(?) eupora (Ehrenberg) Petrushevskaya, 1968, p. 139, fig. 80, I-IV.

Lithostrobos(?) botryocyrtis (Haeckel) (N18), Molina-Cruz, 1977, p. 336, pl. VII, fig. 18.

Remarks. This species is a newly recognized stratigraphic indicator within the sediments of Hole 677A, as well as at DSDP Holes 503A, 503B, and 504. Its first morphological appearance has been dated to occur at approximately 3.3 m.y.B.P. by interpolation between (1) the top of the Kaena Reversed Subchron (2.92 Ma) of the Gauss Normal Chron and the top of the Cochiti Normal Subchron (3.88 Ma) of the Gilbert Reversed Chron in Hole 503A and (2) the bottom of the Mammoth Reversed Subchron (3.18 Ma) of the Gauss Normal Chron and the top of the Gilbert Reversed Chron (3.40 Ma) in Hole 503B. The paleomagnetic time scale is from Berggren et al. (1985). Generic assignment is after Nigrini (1977). Species assignment is after Petrushevskaya (1968) and Molina-Cruz (1977). The descriptions and illustrations presented in Petrushevskaya (1968) are consistent with the species identified here, except possibly for Petrushevskaya's description of a "distinct" apical horn and a "marked" vertical tube. The photograph presented in Molina-Cruz (pl. VIII, fig. 18; 1977) is identical to the *B. euporus* species identified in this study. The original designations of *B. euporus* as *E. euporum* of Ehrenberg (1873a, 1873b) and *L. eupora* of Haeckel, as listed in the synonymy of Petrushevskaya (1968), have not been confirmed. In general, *B. euporus* is closely related to *B. aquilonaris* and *B. bramlettei*, but can be distinguished by its constrictions, which are marked by distinct poreless bands. The test walls of *B. euporus* are thinner than those of *B. aquilonaris*, and the vertical tube of *B. euporus* is less developed than those of *B. aquilonaris* and *B. bramlettei*.

Botryostrobus miralestensis (Campbell and Clark, 1944)
Petrushevskaya and Kozlova, 1972
(Pl. 3, Fig. 8)

Calocycletta caepa Moore, 1972

Calocycletta robusta Moore, 1971, group sensu Riedel and Sanfilippo, 1978

Centrobotrys thermophila Petrushevskaya, 1965

Collosphaera huxleyi Müller, 1858
(Pl. 1, Fig. 5)

Collosphaera invaginata (Haeckel, 1887) Bjorklund and Goll, 1979
(Pl. 1, Fig. 3)

Collosphaera orthoconus (Haeckel, 1887) Goll, 1980
(Pl. 1, Fig. 8)

Collosphaera tuberosa Haeckel, 1887
(Pl. 1, Fig. 4)

Dendrosphyris bursa Sanfilippo and Riedel, 1973

Diartus hughesi (Campbell and Clark, 1944) Sanfilippo and Riedel, 1980

Dictyocoryne ontongensis Riedel and Sanfilippo, 1971
(Pl. 5, Fig. 4)

Didymocyrtis antepenultima (Riedel and Sanfilippo, 1970) Sanfilippo and Riedel, 1980

Didymocyrtis avita (Riedel, 1953) Sanfilippo and Riedel, 1980
(Pl. 4, Fig. 5)

Didymocyrtis penultima (Riedel, 1957) Sanfilippo and Riedel, 1980
(Pl. 4, Fig. 3)

Panarium penultimum Riedel, 1957, p. 76, pl. 1, fig. 1; Riedel and Funnell, 1964, p. 311.

Ommatartus penultimus (Riedel) Riedel and Sanfilippo, 1970, p. 521; Riedel and Sanfilippo, 1971, p. 1588, pl. 1C, figs. 8-10.

Didymocyrtis penultima (Riedel) Sanfilippo and Riedel, 1980, p. 1010; Nigrini and Lombardi, 1984, p. S57, pl. 7, figs. 3a-3c.

Didymocyrtis tetrathalamus (Haeckel, 1887) Sanfilippo and Riedel, 1980
(Pl. 4, Fig. 2)

- Lamprocyrtis hannai* (Campbell and Clark, 1944) Nigrini and Moore, 1979
(Pl. 2, Fig. 3)
- Lamprocyrtis heteroporos* (Hays, 1965) Kling, 1973
- Lamprocyrtis neoheteroporos* Kling, 1973
(Pl. 2, Fig. 4)
- Lamprocyrtis neoheteroporos* Kling, 1973, p. 639, pl. 5, figs. 17, 18, pl. 15, figs. 4, 5; Goll, 1980, p. 436, pl. 3, fig. 11.
- Lamprocyrtis nigrinia* (Caulet, 1971) Kling, 1973
(Pl. 2, Fig. 8)
- Conarachnium?* sp. Nigrini, 1968, p. 56, pl. 1, figs. 5a, 5b; Moore, 1973a, p. 103.
- Conarachnium nigrinia* Caulet, 1971, p. 3, pl. 3, figs. 1-4, pl. 4, figs. 1-4; Goll, 1980, p. 436, pl. 3, fig. 10.
- Lamprocyrtis haysi* Kling, 1973, p. 639, pl. 5, figs. 15, 16, pl. 15, figs. 1-3; (N5), Molina-Cruz, 1977, p. 337, pl. VI, fig. 9.
- Lamprocyrtis nigrinia* Nigrini and Moore, 1979, p. N81, pl. 25, fig. 7.
- Lithopera bacca* Ehrenberg, 1873b
(Pl. 3, Fig. 12)
- Neosemantis hofferti* Goll, 1980
(Pl. 1, Fig. 12)
- Nephrospyris renilla renilla* Haeckel, 1887
(Pl. 1, Fig. 11)
- Phormostichoartus corbula* (Harting, 1863) Nigrini, 1977
(Pl. 3, Fig. 2)
- Phormostichoartus doliolum* (Riedel and Sanfilippo, 1971) Nigrini, 1977
(Pl. 3, Fig. 1)
- Artostrobium doliolum* Riedel and Sanfilippo, 1971, p. 1599, pl. 1H, figs. 1-3, pl. 8, figs. 14, 15.
- Phormostichoartus doliolum* Nigrini, 1977 p. 252, pl. 1, fig. 14; Nigrini and Lombardi, 1984, p. N181, pl. 31, figs. 5a, 5b.
- Phormostichoartus fistula* Nigrini, 1977
(Pl. 3, Fig. 7)
- Phormostichoartus marylandicus* (Martin, 1904) Nigrini, 1977
- Pseudocubus warreni* Goll, 1980
- Pterocanium audax* (Riedel, 1953) Lazarus et al., 1985
(Pl. 4, Fig. 7)
- Lychnodictyum audax* Riedel, 1953, p. 810, pl. 85, fig. 9; Nigrini and Lombardi, 1984, p. N123, pl. 25, fig. 1.
- Pterocanium audax* (Riedel) Lazarus et al., 1985, p. 202, figs. 19.1-19.4, 20.1, 20.2.
- Pterocanium prismatium* Riedel, 1957
(Pl. 4, Fig. 4)
- Pterocanium prismatium* Riedel, 1957, p. 87, pl. 3, figs. 4, 5; Riedel and Sanfilippo, 1970, p. 529; Riedel and Sanfilippo, 1971, p. 1594, pl. 8, fig. 1; Goll, 1980, p. 437, pl. 3, fig. 4; Nigrini and Lombardi, 1984, p. N125, pl. 25, fig. 2.
- Pterocorys hertwigii* (Haeckel, 1887) Nigrini and Moore, 1979
(Pl. 2, Fig. 7)
- Pterocorys minythorax* (Nigrini, 1968) Nigrini and Moore, 1979
(Pl. 2, Fig. 2)
- Theoconus minythorax* (Nigrini) Nigrini, 1968, p. 57, pl. 1, fig. 8; (N7), Molina-Cruz, 1977, p. 338, pl. VII, fig. 1.
- Pterocorys minythorax* (Nigrini) Nigrini and Moore, 1979, p. N87, pl. 25, fig. 10.
- Pterocorys zancleus* (Müller, 1858) Petrushevskaya, 1971
(Pl. 2, Fig. 6)
- Siphonshaera polysiphonia* Haeckel, 1887
- Siphonosphaera tenera* Brandt, 1885
(Pl. 1, Fig. 1)
- Siphostichartus corona* (Haeckel, 1887) Riedel and Sanfilippo, 1971
(Pl. 3, Fig. 6)
- Cyrtophormis (Acanthocyrtis) corona* Haeckel, 1887, p. 1462, pl. 77, fig. 15.
- Lithostrobos* cf. *botryocyrtis* Haeckel, Nakaseko, 1963, p. 185, pl. 3, figs. 11a, 11b.
- Siphostichartus corona* (Haeckel), Riedel and Sanfilippo, 1971, p. 1600, pl. II, figs. 13-15, pl. 2J, figs. 1-5; Nigrini, 1977, p. 257, pl. 2, figs. 5-7; Nigrini and Lombardi, 1984, p. N193, pl. 32, figs. 4a-4d.
- Solenosphaera omnitubus* Riedel and Sanfilippo, 1971
(Pl. 1, Fig. 2)
- Solenosphaera omnitubus* Riedel and Sanfilippo, 1971, p. 1586, pl. 1A, figs. 23, 24, pl. 4, figs. 1, 2; *Solenosphaera omnitubus omnitubus*, Nigrini and Lombardi, 1984, p. S7, pl. 1, fig. 4.
- Sphaerozoum punctatum* Müller, 1858
- Sphaerozoum crassus* Goll, 1980
- Spirocyrtis gyrosularis* Nigrini, 1977
(Pl. 3, Fig. 13)
- Spirocyrtis scalaris* Haeckel, 1887
(Pl. 3, Fig. 14)
- Spongaster berminghamsi* (Campbell and Clark, 1944) Sanfilippo and Riedel, 1973
(Pl. 5, Fig. 2)
- Spongaster pentas* Riedel and Sanfilippo, 1970
(Pl. 5, Fig. 1)
- Spongaster pentas* Riedel and Sanfilippo, 1970, p. 523, pl. 15, fig. 3; Riedel and Sanfilippo, 1971, p. 1589, pl. 1D, figs. 5-7; Nigrini and Lombardi, 1984, p. S65, pl. 9, fig. 2.
- Spongaster tetras* Ehrenberg, 1861
(Pl. 4, Fig. 6)
- Spongaster tetras* Ehrenberg, 1861, p. 833; Ehrenberg, 1862, p. 301; Ehrenberg, 1873b, p. 299, pl. VI(iii), fig. 8; Benson, 1966, p. 238, pl. 15, fig. 2; Nigrini, 1970, p. 169, pl. 2, fig. 7; Riedel and Sanfilippo, 1971, p. 1589, pl. 1D, figs. 2-4; (S40), Molina-Cruz, 1977, p. 334, pl. V, fig. 17.
- Spongaster tetras tetras* Ehrenberg, Nigrini, 1967, p. 41, pl. 5, figs. 1a, 1b; *Spongaster tetras tetras* Ehrenberg, Nigrini and Moore, 1979, p. S93, pl. 13, fig. 1.
- Spongodiscus ambus* Sanfilippo and Riedel, 1974
(Pl. 5, Fig. 3)
- Spongodiscus ambus* Sanfilippo and Riedel, 1974, p. 1024, pl. 1, figs. 12-14; Nigrini and Lombardi, 1984, p. S67, pl. 9, figs. 3a-3c.
- Stichocorys delmontensis* (Campbell and Clark, 1944) Sanfilippo and Riedel, 1970
- Stichocorys johnsoni* (Johnson, 1974) Caulet, 1986
(Pl. 3, Fig. 9)
- Eucyrtidium* sp. cf. *E. diaphanes*, Johnson, 1974, pl. 8, fig. 18; Johnson and Nigrini, 1985, p. 506.
- Stichocorys johnsoni* (Johnson) Caulet, 1986, p. 851, pl. 6, figs. 5, 6.
- Stichocorys peregrina* (Riedel, 1953) Sanfilippo and Riedel, 1970
(Pl. 3, Fig. 10)

- Eucyrtidium elongatum peregrinum* Riedel, 1953, p. 812, pl. 85, fig. 2; Riedel, 1957, p. 94.
- Stichocorys peregrina* (Riedel), Sanfilippo and Riedel, 1970, p. 451, pl. 1, fig. 10; Riedel and Sanfilippo, 1971, p. 1595, pl. 1F, figs. 5-7, pl. 8, fig. 5; Nigrini and Lombardi, 1984, p. N133, pl. 25, fig. 6.
- Stylatractus univertus* Hays, 1970
(Pl. 1, Fig. 7)
- Stylatractus* sp. Hays, 1965, p. 167, pl. 1, fig. 6.
- Stylatractus univertus* Hays, 1970, p. 215, pl. 1, figs. 1, 2; Goll, 1980, p. 437, pl. 3, fig. 7.
- "*Stylatractus univertus*" Hays, Nigrini and Lombardi, 1984, p. S29, pl. 4, fig. 3.
- Theocalyptra davisiana* (Ehrenberg, 1862) Riedel, 1958
(Pl. 1, Fig. 9)
- Cycladophora(?) davisiana* Ehrenberg, 1862, p. 297; Ehrenberg, 1873b, p. 289, pl. 2, fig. 11.
- Pterocodon davisianus* Ehrenberg, 1862, p. 300.
- Eucyrtidium davisianum* (Ehrenberg), Haeckel, 1862, p. 328.
- Pterocodon davisianus* Ehrenberg, 1873b, p. 299, pl. 2, fig. 10.
- Stichopilium davisianum* (Ehrenberg), Haeckel, 1887, p. 1437.
- Theocalyptra davisiana* (Ehrenberg), Riedel 1958, p. 239, pl. 4, figs. 2, 3, text fig. 10; Benson, 1966, p. 441, pl. 29, figs. 14, 15; Ling et al., 1971, p. 714, pl. 2, figs. 6, 7; Nigrini and Moore, 1979, p. N57, pl. 24, figs. 2a, 2b.
- Cycladophora davisiana* Ehrenberg, Petrushevskaya, 1968, p. 120, fig. 69, I-VII, fig. 70, I-VI; (N35), Molina-Cruz, 1977, p. 337, pl. VII, fig. 19.
- Theocalyptra davisiana davisiana* (Ehrenberg), Nigrini and Lombardi, 1984, p. N139, pl. 26, fig. 2.
- Theocorythium trachelium* (Ehrenberg, 1873) Nigrini, 1967
(Pl. 2, Fig. 1)
- Eucyrtidium Trachelius* Ehrenberg, 1873a, p. 312; Ehrenberg, 1873b, p. 293, pl. VII, fig. 8.
- Calocyclus amicae* Haeckel, 1887, p. 1405; Benson, 1966, p. 487, pl. 33, figs. 8, 9.
- Theocorys diana* Haeckel, 1887, p. 1416, pl. 69, fig. 11.
- Theocorythium trachelium trachelium* (Ehrenberg), Nigrini, 1967, p. 79, pl. 8, fig. 2, pl. 9, fig. 2; Nigrini and Moore, 1979, p. N93, pl. 26, fig. 2.
- Theocorythium trachelium* (Ehrenberg) *diana* (Haeckel) Nigrini, 1967, p. 77, pl. 8, figs. 1a, 1b, pl. 9, figs. 1a, 1b; Nigrini and Moore, 1979, p. N97, pl. 26, figs. 3a, 3b.
- Theocorythium trachelium* (Ehrenberg), (N42), Molina-Cruz, 1977, p. 338, pl. VIII, fig. 4.
- Remarks.** Both subspecies are recognized as *T. trachelium*.
- Theocorythium vetulum* Nigrini, 1971
(Pl. 2, Fig. 5)
- Theocorythium vetulum* Nigrini, 1971, p. 447, pl. 34.1, figs. 6a, 6b; Nigrini and Lombardi, 1984, p. N169, pl. 30, figs. 4a, 4b.
- Tholospyris devexa devexa* Goll, 1969
(Pl. 2, Fig. 9)
- Tholospyris devexa finalis* Goll, 1972

Photographs presented in the following plates were taken using a 35 mm camera mounted on a beam splitter on a Wild M20 microscope. All figures are at the same scale (2.5 cm = 100 μ m). All important Site 677 stratigraphic indicators are shown, as well as many of the less reliable stratigraphic indicators. The latter group is included for identification and to illustrate some of the diversity of this site. EF refers to the England Finder location (Riedel and Foreman, 1961) of the particular specimen on the sample slide.

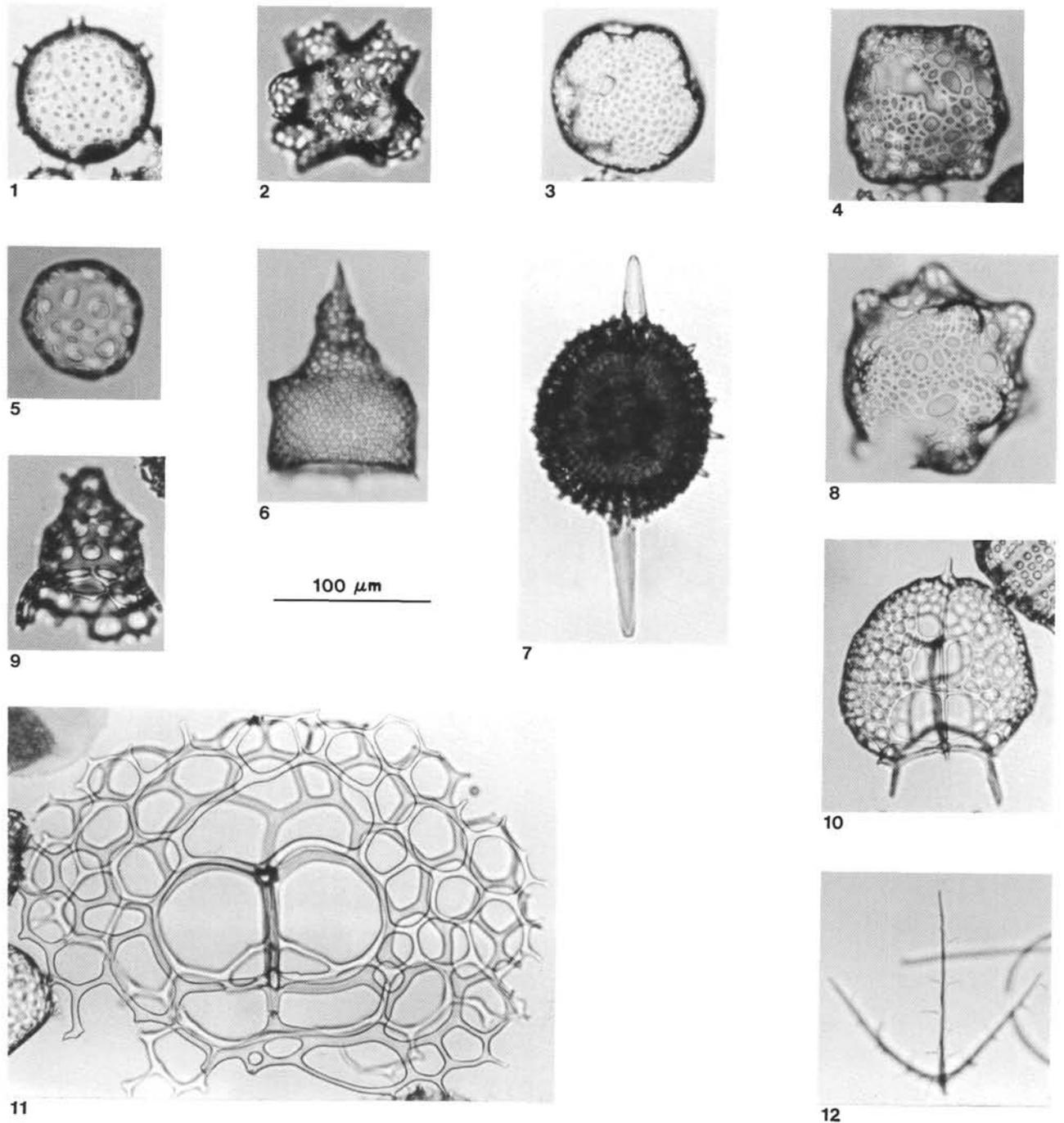


Plate 1. 1. *Siphonosphaera tenera*. Sample 111-677A-10H-CC. EF E47/1. 2. *Solenosphaera omnitubus*. Sample 111-677A-28X-1, 83-84 cm. EF J44. 3. *Collosphaera invaginata*. Sample 111-677A-3H-1, 23-24 cm. EF G15/1. 4. *Collosphaera tuberosa*. Sample 111-677A-2H-CC. EF U50. 5. *Collosphaera huxleyi*. Sample 111-677A-30X-4, 83-84 cm. EF S58/1. 6. *Anthocyrtidium angulare*. Sample 111-677A-6H-6, 123-124 cm. EF G42/3. 7. *Stylatractus universus*. Sample 111-677A-14H-CC. EF S24/2. 8. *Collosphaera orthoconus*. Sample 111-677A-3H-CC. EF D19/4. 9. *Theocalyptra davisiana*. Sample 111-677A-5H-CC. EF T28. 10. *Androsipyris fenestrata*. Sample 111-677A-15H-3, 123-124 cm. EF P19/1. 11. *Nephrosipyris renilla renilla*. Sample 111-677A-13H-CC. EF J31/3. 12. *Neosemantis hofferti*. Sample 111-677A-24X-CC. EF K46/2.

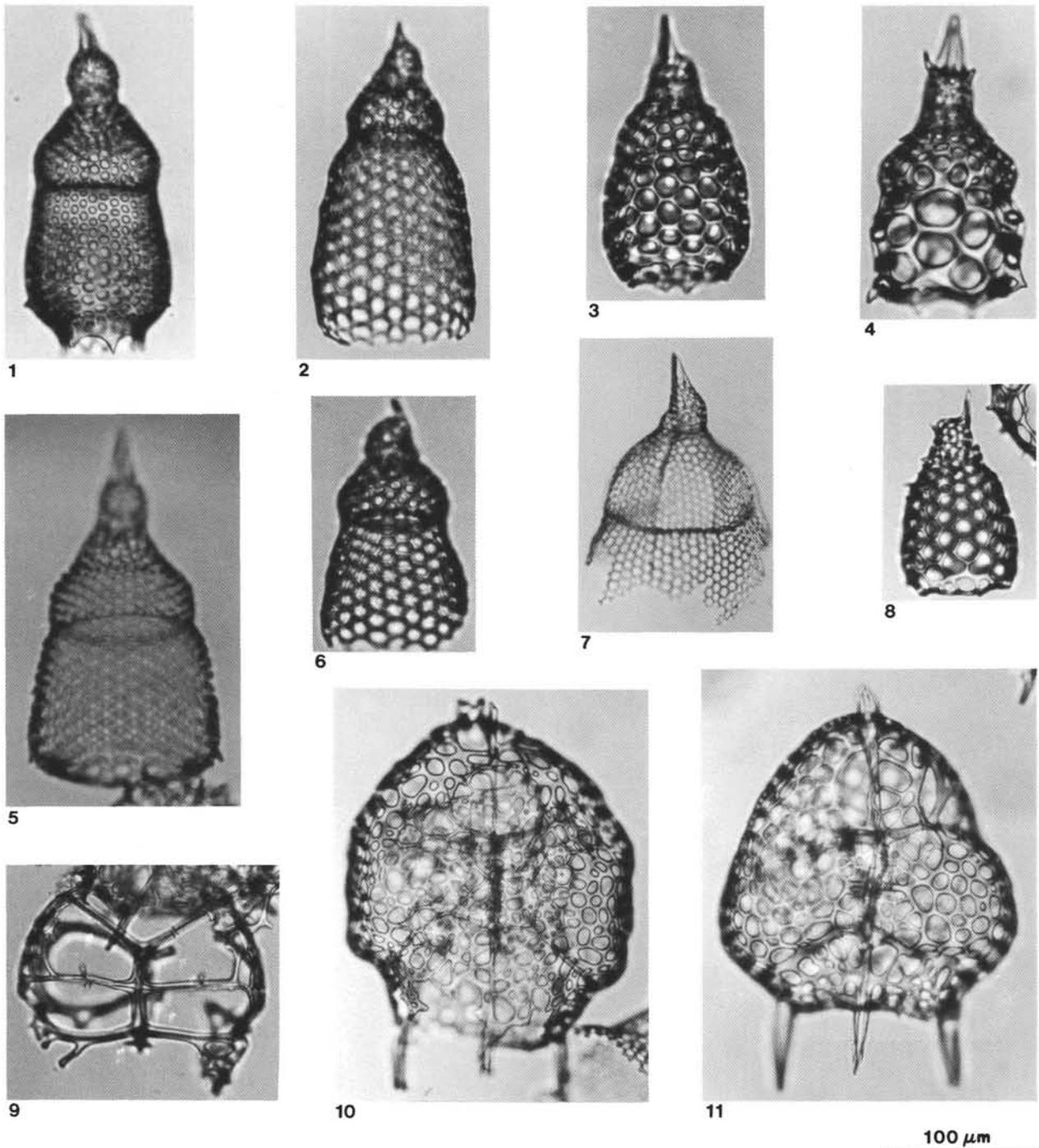


Plate 2. 1. *Theocorythium trachelium*. Sample 111-677A-7H-6, 23-24 cm. EF R27/1. 2. *Pterocorys minythorax*. Sample 111-677A-2H-CC. EF T18/3. 3. *Lamprocyrtis hannai*. Sample 111-677A-27X-6, 24-25 cm. EF W25/1. 4. *Lamprocyrtis neoheteroporos*. Sample 111-677A-10H-CC. EF V29/3. 5. *Theocorythium vetulum*. Sample 111-677A-14H-CC. EF P51. 6. *Pterocorys zancleus*. Sample 111-677A-3H-CC. EF T22/1. 7. *Pterocorys hertwigii*. Sample 111-677A-6H-3, 12-14 cm. EF Y17/3. 8. *Lamprocyrtis nigrinia*. Sample 111-677A-2H-CC. EF D23/1. 9. *Tholospyrus devexa devexa*(?). Sample 111-677A-5H-CC. EF L37/3. 10. *Androsipyris huxleyi*. Sample 111-677A-7H-1, 23-24 cm. EF E32. 11. *Androsipyris anthropiscus*. Sample 111-677A-7H-4, 23-24 cm. EF C49/1.

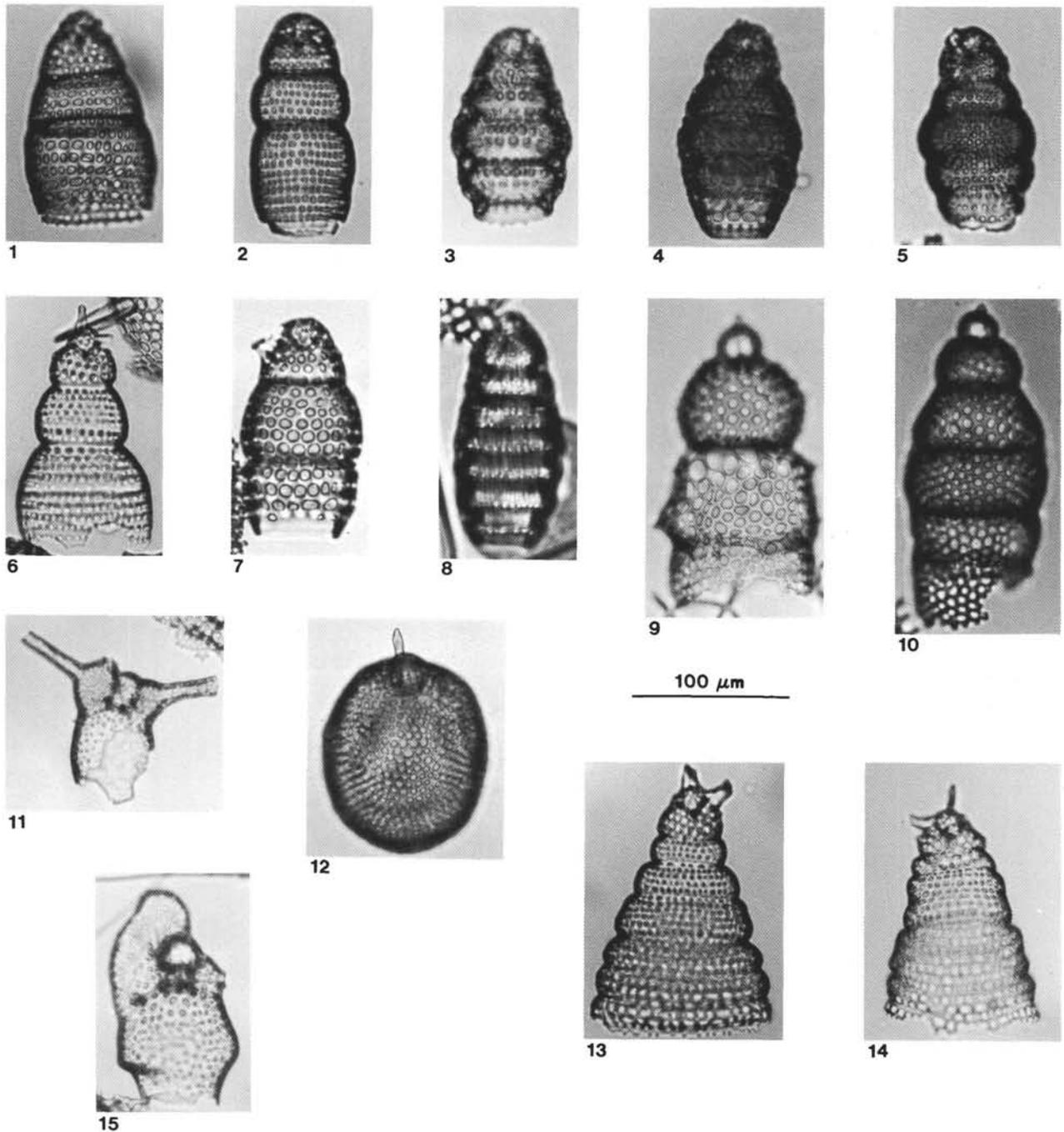


Plate 3. 1. *Phormostichoartus doliolum*. Sample 111-677A-21X-CC. EF C14/1. 2. *Phormostichoartus corbula*. Sample 111-677A-14H-CC. EF E45/1. 3. *Botryostrobos euporus*. Sample 111-677A-5H-4, 110-112 cm. EF K38/4. 4. *Botryostrobos aquilonaris*. Sample 111-677A-7H-6, 23-24 cm. EF G41/3. 5. *Botryostrobos bramlettei*. Sample 111-677A-26X-CC. EF Z34. 6. *Siphostichartus corona*. Sample 111-677A-27X-CC. EF D42/3. 7. *Phormostichoartus fistula*. Sample 111-677A-25X-CC. EF J14/2. 8. *Botryostrobos miralestensis*. Sample 111-677A-33X-3, 75-76 cm. EF D42/3. 9. *Stichocorys johnsoni*. Sample 111-677A-31X-1, 82-83 cm. EF M57/4. 10. *Stichocorys peregrina*. Sample 111-677A-13H-CC. EF S39/3. 11. *Acrobotrys tritubus*. Note broken central tube. Sample 111-677A-31X-CC. EF N45/2. 12. *Lithopera bacca*. Sample 111-677A-12H-7, 23-24 cm. EF O21/2. 13. *Spirocyrtis gyrosularis*. Sample 111-677A-27X-CC. EF D42/3. 14. *Spirocyrtis scalaris*. Sample 111-677A-13H-3, 123-124 cm. EF J16/3. 15. *Botryopyle* species. Sample 111-677A-32X-CC. EF L55/2.

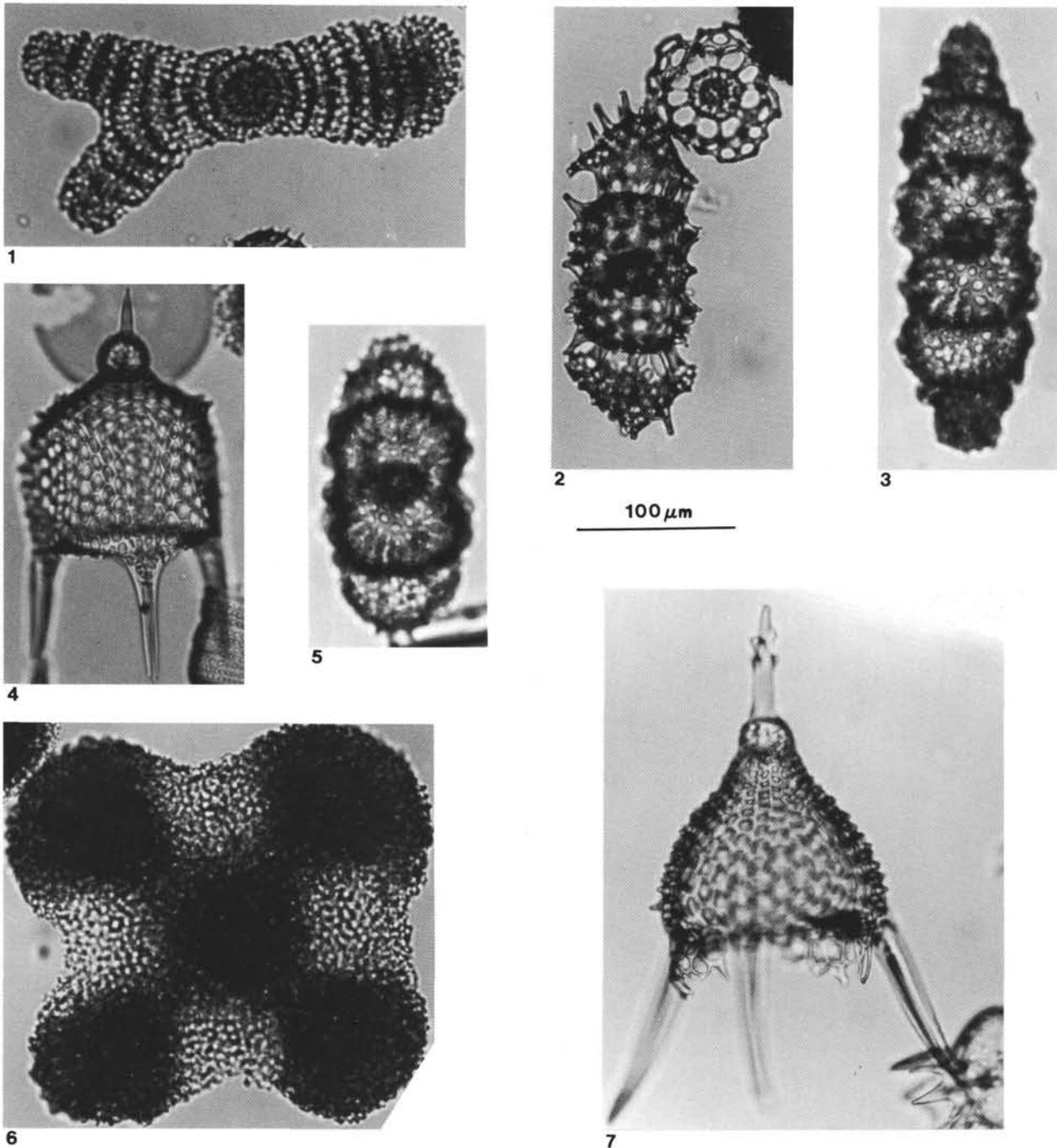
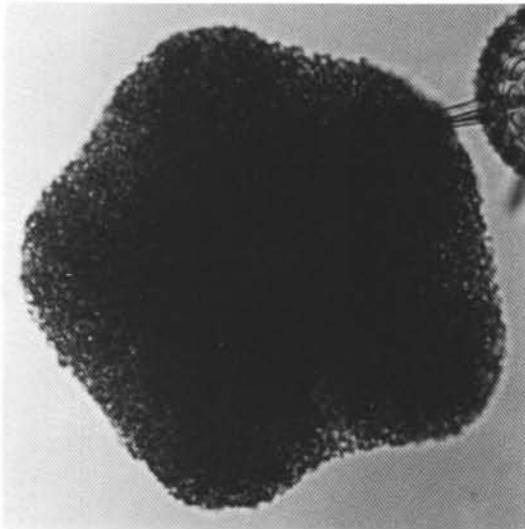
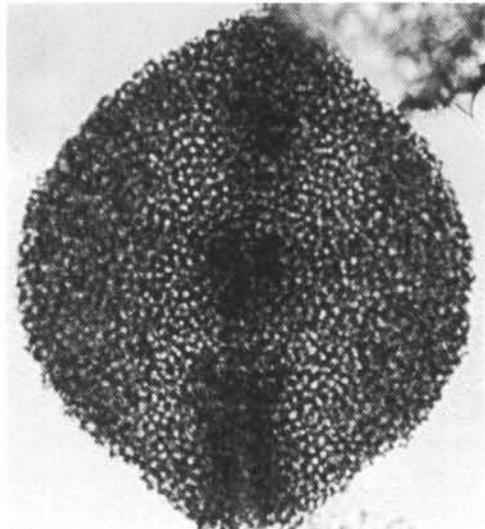


Plate 4. 1. *Amphirhopalum ypsilon*. Sample 111-677A-2H-CC. EF J22. 2. *Didymocyrtis tetralthamus* and a central rosette. Sample 111-677A-1H-CC. EF X33. 3. *Didymocyrtis penultima*. Sample 111-677A-28X-CC. EF K35/4. 4. *Pterocanium prismatium*. Sample 111-677A-13H-CC. EF E43/2. 5. *Didymocyrtis avita*. Sample 111-677A-27X-6, 24-25 cm. EF K35/4. 6. *Spongaster tetras*. Sample 111-677A-3H-CC. EF T22/1. 7. *Pterocanium audax*. Sample 111-677A-30X-4, 83-84 cm. EF K49/3.

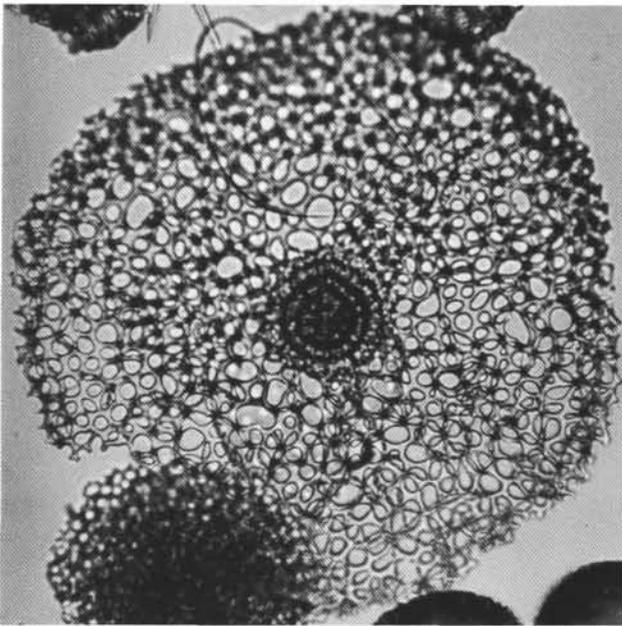


1

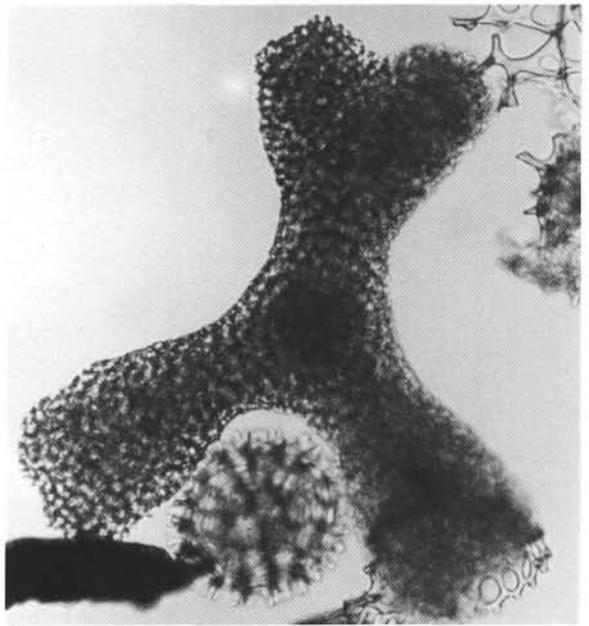


2

100 μ m



3



4

Plate 5. 1. *Spongaster pentas*. Sample 111-677A-19X-1, 83-84 cm. EF G31/3. 2. *Spongaster berminghami*. Sample 111-677A-30X-CC. EF K12. 3. *Spongodiscus ambus*. Sample 111-677A-21X-CC. EF E25/3. 4. *Dictyocoryne ontongensis*. Sample 111-677A-29X-CC. EF Z40.