

## 32. EOCENE TO MIocene PALynoLOGY OF THE NORWEGIAN SEA (ODP LEG 104)<sup>1</sup>

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### ABSTRACT

Dinoflagellate cysts, pollen, and spores were studied from 78 samples of the Eocene to Miocene section of ODP Site 643 at the outer Voring Plateau. Dinoflagellate cysts ranging from less than 1,000 to rarely over 30,000 per gram of sediment in the Paleogene, and generally between 50,000 and 100,000 in the Miocene were present. The shift to conspicuously higher cyst frequencies takes place in the lowermost Miocene section and appears to reflect increased cyst recruitment rather than a change in sedimentation rate. Of the 179 dinoflagellate cyst forms whose ranges were recorded, 129 are known species. Fifteen assemblage zones have been recognized, although the upper Eocene is missing and no substantial lower Eocene was recorded at Site 643. Norwegian Sea and Rockall Plateau zonations were compared with this study. Detailed correlation with existing onshore section zonations was difficult because key zonal species are inadequately represented; however, the middle to upper Miocene zonation established for Denmark is applicable.

Pollen and spores occur with relatively low frequencies, and palynodebris is generally absent, in contrast to the observations from DSDP Leg 38.

Thirty-nine samples from Eocene to Miocene sediments at Site 642 were studied and correlated with Site 643. A lower Eocene cyst assemblage present in Hole 642D is older than the questionably lower Eocene assemblage from Site 643. Site 642 has a lower Eocene to lower Miocene hiatus.

### INTRODUCTION

Over the last few years there have been a number of contributions to the palynology of the Tertiary sediments from the Norwegian Sea. These include Manum (1976), Haaland (1981), Johnsen (1983), and Elde (1985) on the dinoflagellate cysts of DSDP Leg 38. Manum (1976) also presented a correlation of major changes in dinocyst/pollen ratios, (palynoevents; loc cit p. 905) for the Leg 38 sites. Koreneva et al. (1976) described the pollen and spore stratigraphy from Leg 38, and Boulter (1986) compared the pollen from Site 338 with that from marine Tertiary sections in the North Sea. Terrigenous and pelagic sources of palynodebris were analyzed from the Forties field in the North Sea by Boulter and Riddick (1986).

The spot coring practised on Leg 38 limited the usefulness of that material for biostratigraphic purposes. The continuous coring during Leg 104 increased considerably the palynological potential of these latter samples, and we have been able to make a much more detailed inventory of the palynomorphs than was possible with the material from Leg 38.

This article reports our results and conclusions on Eocene to Miocene material from Site 642, Holes B, C, and D, and Site 643 (Fig. 1). The palynology of post-Miocene cores is dealt with by Mudie (this volume) who, as the shipboard palynologist, did the preliminary palynological study of the Leg 104 sites (Eldholm, Thiede, Taylor, et al., 1987). Detailed dinocyst work was carried out by H. Gunnarsdottir (Eocene), by K. Rangnes (Oligocene), and by A. Scholze (Miocene) who also prepared the zonation section for the Miocene. M. C. Boulter studied the pollen and spores from the entire sequence; K. Rangnes and H. Gunnarsdottir did the quantitative work; S. B. Manum directed the project.

The major objectives of this article are: to establish the palynostratigraphy and provide a correlation for the Eocene to Mi-

cene parts of Sites 643 and 642, to compare the palynological data with other DSDP/ODP sites in the northern Atlantic and with onshore sections, and to identify palynoevents which might help with the interpretation of the Norwegian Sea geological history.

### MATERIAL AND METHODS

#### Sampling

Our studies have been concentrated on Site 643, as this was drilled with the principal objectives of establishing biostratigraphic and paleoenvironmental understanding. About 50 samples from Holes 642B to 642D were also examined to compare the two sections. More than 200 samples from 107 cores were processed, representing at least one sample per core from Holes 642B to 642D and two to three samples per core from Hole 643. Details of sampling positions for the various cores are given in Table 1. Results from separate studies of the deepest part of Site 642, the intrabasaltic volcaniclastics from Hole 642E, are reported in Boulter and Manum (this volume).

#### Sample Processing

Chemical processing was done as follows: (a) 10% cold HCl treatment for 1 hr, wash until neutral; (b) 40%–45% HF treatment at 70°C until all minerals are dissolved, directly followed by (c) 10% HCl at 60°–70°C until all fluorides are dissolved, centrifugation while still hot; (d) washing until neutral; (e) sieving through a 20-μm metal sieve having circular holes (one slide was made at this stage); (f) oxidation of half the residue in fuming nitric acid for 0.5 to 1 min, washing until neutral; (g) sieving through the 20-μm sieve and preparing at least four permanent slides.

#### Preparation for Quantitative Analysis

Studies on DSDP Leg 38 samples from the Norwegian Sea (Manum 1976) revealed changes through time in the marine to terrestrial palynomorph ratios and relative quantities of palynodebris at several sites, and these variations appeared to be corre-

<sup>1</sup> Eldholm, O., Thiede, J., Taylor, E., et al., 1989. *Proc. ODP, Sci. Results*, 104: College Station, TX (Ocean Drilling Program).

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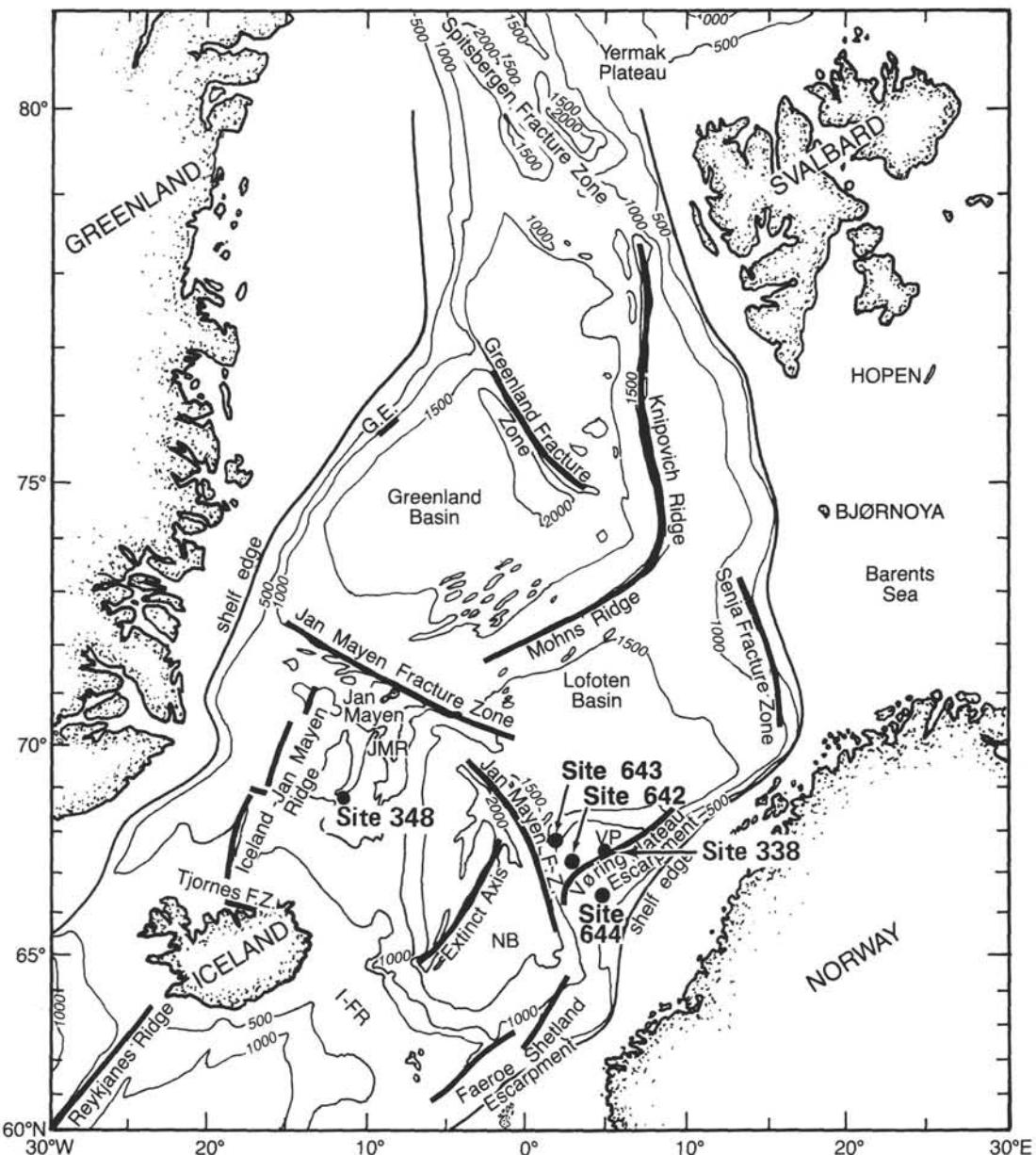


Figure 1. The Norwegian-Greenland Sea showing positions of ODP Leg 104 Sites 642, 643, and 644 and the DSDP Leg 38 Sites 338 and 348 used for correlation (Fig. 5).

latable events. However, Leg 38 material generated relative data only, as the task of processing samples within the short time available for initial reporting did not allow the use of absolute quantitative methods. So that palynomorph data may be related to other quantitative sediment parameters, we obtained absolute quantitative control of the palynomorph content in the sediments.

The method of adding a known number of *Lycopodium* spores to Quaternary samples to determine the absolute amount of pollen present was described by Stockmarr (1971). This method is widely used in Quaternary pollen analysis, but has rarely been attempted on pre-Quaternary material. Guidelines for application to the present material, particularly with respect to the amount of *Lycopodium* spores to be added, were gained from Haaland (1981) and Johnsen (1983) on Leg 38 material.

Samples consisting of 2 to 3 cm<sup>3</sup> of core were weighed after air drying for 24 hr in a drying cabinet. Then *Lycopodium* spores were added in the form of pills, each containing 12,077 ± 3.1% spores (supplier: Laboratory of Quaternary Biology, University of Lund, Sweden). Two pills added per gram of sediment yielded adequate results for most of the samples. Following the processing described in the section above, slides were produced by taking one drop of the thoroughly homogenized residue with a disposable pipette, mixing it with glycerol jelly on a slide, and sealing the preparation with wax after the cover slip was added.

Three slides from each sample were prepared in this way to provide an adequate number for counting. Counting was normally stopped at 300 palynomorphs (plus whatever number of *Lycopodium* spores were observed during the counting). Stock-

**Table 1. List of samples.**

Core section	(cm)	Depth (mbsf)
642 B		
9-7	50-52	75.90
11-5	50-52	91.90
12-4	59-61	99.99
13-5	68-70	110.88
13-6	68-70	112.38
15-1	84-86	124.34
16-6	74-76	136.34
17-6	76-78	146.26
18-3	77-79	151.57
19-6	77-79	165.97
20-6	83-85	175.73
21-6	83-85	185.43
22-1	67-70	187.57
23-3	64-66	199.23
24-1	63-66	206.23
25-1	63-66	213.73
642 C		
10-1	87-89	64.37
12-1	78-80	83.28
14-1	79-81	102.29
15-1	79-81	111.79
17-1	69-72	130.69
18-1	81-84	140.31
19-3	61-64	152.61
20-7	67-70	167.60
21-6	81-84	176.31
22-5	67-70	183.67
23-2	81-84	186.61
24-3	81-84	196.21
642 D		
2-6	80-82	198.20
3-2	80-82	201.90
5-6	80-82	227.20
6-5	80-82	235.30
7-6	80-82	246.50
8-6	80-82	256.10
9-7	27-30	266.77
10-5	63-66	273.73
10-6	63-66	275.23
11-1	59-62	277.39
11-2	59-62	278.89
12-1	81-84	287.31
12-2	81-84	288.81
12-3	81-84	290.31
12-4	84-87	291.01
12-5	81-84	293.31
12-6	81-84	294.81
13-1	81-84	297.09
13-2	81-84	298.51
13-3	81-84	300.01
13-4	81-84	301.51
14-1	85-87	306.65
14-2	85-87	308.15
643 A		
8-6	48-50	70.28
9-5	30-32	78.10
10-5	31-33	87.61
11-5	30-32	97.10
12-1	31-33	100.61
12-4	31-33	105.11
12-5	31-33	106.61
13-6	31-33	117.61
14-5	32-34	125.62
15-6	28-30	136.58
16-1	30-32	138.80
18-1	31-33	157.81
19-6	30-32	174.60
20-6	30-32	184.20
22-5	30-32	201.60
23-5	30-32	211.40
24-5	30-32	221.20
25-2	30-32	226.50

**Table 1 (continued).**

Core section	(cm)	Depth (mbsf)
642 A (Cont)		
25-6	30-32	232.50
26-5	30-32	240.80
27-5	31-33	250.61
28-7	30-32	263.40
29-6	30-32	271.70
31-2	30-32	285.30
32-1	30-32	293.60
33-1	53-54	303.63
34-2	30-32	314.70
36-5	30-32	338.80
37-3	20-22	345.50
38-2	29-31	353.89
39-1	30-32	362.10
41-1	18-20	381.28
42-1	19-21	390.89
42-2	19-21	392.39
42-3	19-21	393.89
42-4	19-21	395.39
44-1	30-32	410.50
44-2	30-32	411.80
44-3	30-32	413.30
44-4	30-32	414.80
44-6	30-32	417.80
45-2	29-31	421.49
45-4	29-32	424.39
45-5	29-31	425.99
46-1	82-84	430.22
46-2	82-84	431.72
46-5	82-84	436.22
47-1	90-92	440.00
47-3	90-92	443.00
47-4	90-92	444.50
47-5	90-92	446.00
48-1	90-92	449.60
48-3	90-92	452.60
48-4	90-92	454.10
48-5	90-92	455.60
48-6	90-92	457.10
49-1	30-32	458.70
49-2	30-32	460.20
49-3	30-32	461.70
49-4	30-32	463.20
50-1	30-32	468.40
51-1	30-32	478.00
51-2	30-32	479.50
51-3	30-32	481.00
51-4	30-32	482.50
52-3	28-30	490.58
52-4	28-30	492.08
53-3	30-33	500.30
54-1	30-32	507.00
54-5	30-32	513.00
55-2	30-32	518.20
55-5	30-32	522.70
55-6	30-32	524.20
56-2	30-32	527.80
56-4	30-32	530.80
57-4	30-32	540.40
57-5	30-32	541.90
60-2	31-33	556.71

marr (1971) showed that the reliability of calculated absolute palynomorph contents is not significantly improved by counting higher numbers. The number of indigenous palynomorphs per gram of samples (P) is calculated by using the formula:

$$P = \frac{\text{Lycopod. spores added to sample} \times \text{indig. palynomorphs counted}}{\text{weight of sample (grams)} \times \text{Lycopod. spores counted}}$$

Our quantitative method has not been subject to extensive tests to verify its reliability. However, an indicator of the success of our method is comparison of the results of counting from Holes 642B and 642C (Fig. 2). These holes were drilled a few

tens of meters apart through identical sequences. The counts produced consistently similar diagrams for palynomorph frequencies in 1 g of sediment, indicating that the errors inherent in the method are negligible. In Figure 2, comparison is also made with total organic carbon (TOC) analysis data (Henrich et al., this volume). There is fairly good agreement between our absolute counts and TOC values (TOC values and palynomorph counts are not from identical samples, and TOC sampling is much denser).

The processing residues are always rich in amorphous matter which can be removed by oxidation. Previous experience (Johnson, 1983) shows that the oxidation process selectively removes or destroys the *Lycopodium* spores and thus invalidates the quantitative control. However, oxidation for less than 1 min has proved to be satisfactory.

### TAXONOMIC APPROACH

Approximately 250 dinocyst species were recorded, approximately half of which can be referred to described taxa. The new taxa we use are not described here but are dealt with informally. Brief, preliminary descriptions of new taxa are available from either the authors or from the Ocean Drilling Program on floppy disk (MS-DOS, Wordstar) or printout. Our nomenclature for most of the known taxa follows Lentin and Williams' (1985) index of dinocyst genera and species. We have therefore omitted taxonomic authorships in the text and instead refer to that index for this taxonomic and bibliographic information. Our alphabetic species index (Table 2) gives information on the few taxa used here that are not indexed in Lentin and Williams (1985).

For reasons outlined in the Appendix to Boulter and Manum (this volume), a simple and informal nomenclature system has been adopted for pollen and spores, based on two words which convey something of their morphological character. Formal taxonomic treatment must wait until a full comparative study can be made.

### DINOFLAGELLATE CYST ZONATION: SITE 643

The zonation presented here is based on the semiquantitative records of dinocyst distribution for Site 643 as presented in Figures 3A and 3B. A summary of the ranges of the stratigraphically most significant taxa on which the zonation is based is presented in Figures 4A and 4B. An alphabetic index to assist in locating the individual taxa in range charts and plates is presented in Table 2. The stratigraphic resolution varies with our sampling density, which in the Eocene is 2 to 4 samples per core; in the Oligocene, 3 to 5 samples per core; and in the Miocene, 1 to 2 samples per core (Table 1).

Existing zonation schemes are difficult to use because their key species are inadequately represented. However, we have been able to apply Piasecki's (1980) zonation for the middle and upper Miocene. The Leg 104 shipboard zonation (Eldholm, Thiede, Taylor, et al., 1987) is also difficult to use, partly because it is based on Site 642 material, which is less complete than the Site 643 material we have used, and partly because of taxonomic differences. The tentative scheme proposed by Manum (1976) for DSDP Site 338 in the Voring Plateau was based on 57 cyst taxa, many of which were informally named. Some of the taxa which appeared to be important for Manum's (1976) zonation are insufficiently represented in our new material. Also, there appear to be considerable differences between Sites 338 and 643 in the portions of the stratigraphic column that are preserved or missing.

The cysts from Site 643 have been recorded in greater detail than was possible for the Leg 38 material. Of the more than 250 cyst taxa recorded from 78 samples, our range charts (Figs. 3A

and 3B) include only 179 taxa; taxa with rare occurrence in a single sample are not included.

### Eocene Section

The Eocene is recognized from Sections 104-643A-60-2 to -643A-51-1. The scarcity of species of the *Wetzelialesaceae* prevents the application of the Paleogene zonation established by Costa and Downie (1976; revised version in Williams and Bujak 1985: 883).

The scarcity of stratigraphically diagnostic representatives of this cyst family was also evident in Leg 38 material (Manum 1976), as well as in the correlative sequences from Leg 48 (Rockall Plateau; Costa and Downie, 1979).

Only a few taxa from the Eocene section are sufficiently restricted to be useful in dating. The lowermost sample studied (Section 104-643A-60-2), has species whose ranges include the lower Eocene and younger (i.e., *Achilleodinium biformoides*, *Diphyes colligerum*, *Eatonicysta ursulae*, *Palaeocystodinium golzowense*, *Samlandia chlamydophora*, *Thalassiphora pelagica*, and *Wetzelella articulata*). None of the recorded species from the lowermost sample indicate a conclusively lower Eocene dating. *Rottnestia borussica* occurs only in this sample, as does *Eatonicysta ursulae*, whose range is shown by Williams and Bujak (1985) to be restricted to the upper part of the middle Eocene, corresponding to the range documented in southern England (Bujak et al., 1980: Barton Beds). However, there are also records of this species from the lower Eocene (e.g., Morgenroth, 1966; Costa and Downie, 1979).

*Adnatosphaeridium vittatum* and *Areosphaeridium diktyoplokus* both first appear in Section 104-643A-57-5. Williams and Bujak (1985) show *A. vittatum* to be restricted to the lower Eocene, and *A. diktyoplokus* to appear first at the very top of the lower Eocene. In the Bracklesham Beds, however, these species are associated in what appears to be the middle Eocene (Zones B2-B4 of Bujak et al., 1980). Costa and Downie (1979) reported *A. vittatum* from lower Eocene sediments only from the Rockall Plateau, and its range did not overlap that of *A. diktyoplokus*. Thus, we find no conclusive support for an early Eocene age for Section 104-643A-57-5 either, and favor assigning a middle Eocene age to this sample. This is supported by the occurrence in a slightly higher sample, in Section 104-643A-57-4, of *Corrudinium incompositum*, which appeared in the middle Eocene in the North Sea (Ioakim, 1979). Williams and Bujak (1985) indicate a mid-middle Eocene first appearance for this species.

Species diagnostic of upper Eocene sediments were not found. One species, *Heteraulacocysta porosa*, recorded from Section 104-643A-51-1, has a known range restricted to mid-middle Eocene (NP16 equivalent, according to Williams and Bujak, 1985), and would therefore appear to exclude any upper Eocene sediments up to this level. Other species having their first appearances from Sections 104-643A-57-5 to -643-51-1 all have known ranges from at least as early as middle Eocene.

On this basis, we conclude that the entire section Sections 104-643-60-2 to -643-51-1 is middle Eocene, with the reservation that for Section 104-643-60-2 an early Eocene age seems possible. The upper Eocene appears to be missing at Site 643.

#### *Rottnestia borussica* Zone (Section 104-643A-60-2 only), lower?/middle Eocene

Interval from our lowest sample Section 104-643A-60-2 to lowest appearance of *Adnatosphaeridium vittatum*.

Other species: Highest appearance of *Rottnestia borussica* and *Eatonicysta ursulae* is within the zone; *Wetzelella articulata* is abundant.

Comparison: *R. borussica*, *E. ursulae*, and *W. articulata* are associated in the Rockall Zone IV (Costa and Downie, 1979); *R.*

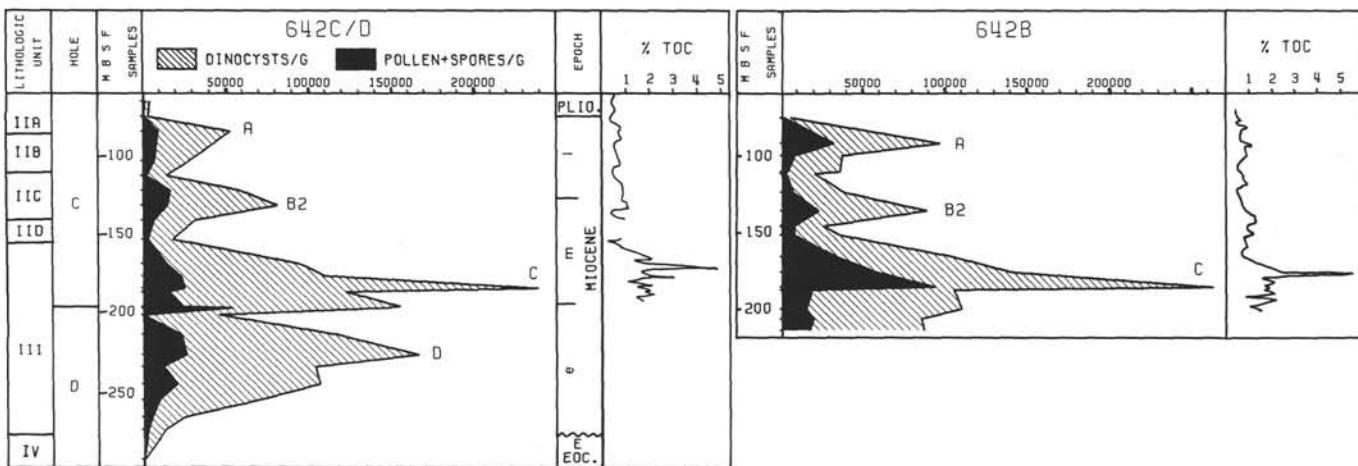


Figure 2. Graphical presentation of absolute frequency counts of marine (dinocysts) and terrestrial (pollen and spores) palynomorphs for Holes 642C/D and 642B, and total organic carbon (TOC) values (from Henrich et al., this volume). The palynological maxima B—D correlate with results from Site 643, shown in Figure 7.

*borussica* and *W. articulata* were both reported from Zone VI (but not in association) in material from Leg 38 (Manum 1976).

(Interval Sections 104-643A-60-2 to -643A-57-7: one sample from 59-1 barren; no sediment recovery from Core 104-643A-58.)

#### *Adnatosphaeridium vittatum* Zone (Sections 104-643A-57-5 to -643A-54-1), middle Eocene

Interval from lowest appearance of *Adnatosphaeridium vittatum* to lowest appearance of *Deflandrea* sp. B.

Other species: *Areosphaeridium diktyoplakus* and *Corrudinium incompositum* have their lowest appearance within the zone (the former from the base of the zone). *Cerebrocysta bartonensis* and *Phthanoperidinium geminatum* are restricted to the zone.

Comparison: *C. incompositum* and *P. geminatum* are both associated in the Barton Beds (Bujak et al., 1980). At least the upper part of this zone would seem to compare with the Barton Bed Zones 1-5 (NP16-NP17 equivalent, Williams and Bujak, 1985).

#### *Deflandrea* sp. B Zone (Sections 104-643A-53-3 to -643-52-3), middle Eocene

Interval from lowest appearance of *Deflandrea* sp. B to lowest appearance of *Areosphaeridium arcuatum*.

Other species: *Araneosphaera araneosa* has its lowest appearance at the base of zone; *Glyptocysta* sp. 1 is common-to-abundant in the upper part.

#### *Areosphaeridium arcuatum* Zone (Sections 104-643-51-4 to -643A-51-1), middle Eocene

Interval from lowest appearance of *Areosphaeridium arcuatum* to lowest appearance of *Chiropteridium lobospinosum*.

Other species: *Areosphaeridium pectiniforme*, *Nematosphaeropsis* sp. 2, and *Distatodinium ellipticum* are restricted to this zone. *Distatodinium craterum* has its lowest appearance within this zone.

(This zone marks the top of the Eocene sequence at Site 643, and our results consequently indicate that the entire upper Eocene is missing.)

#### Eocene/Oligocene Boundary

This boundary is placed between the samples from Sections 104-643A-51-1 and -643A-49-4, between the highest occurrence

of *Areosphaeridium pectiniforme* and *Distatodinium ellipticum* in Section 104-643A-51-1 and the lowest occurrence of *Chiropteridium lobospinosum* and *Heteraulacocysta campanula* in Section 104-643A-49-4. Between these two samples there is an undiagnostic sample from Section 104-643A-50-1, which lacks critical species of either Eocene or Oligocene sediments; the only species of stratigraphic significance recovered from it is *Svalbardella cooksoniae*, whose known range is upper Eocene to lower Oligocene. In the absence of other evidence for the upper Eocene, this sample is included in the Oligocene section. Unfortunately, Core 104-643A-50, which appears to be critical for the definition of the Eocene/Oligocene boundary, has poor sediment recovery. This boundary can therefore not be checked more closely.

#### Oligocene

##### *Chiropteridium lobospinosum* Zone (Sections 104-643A-50-1 to -643A-48-6), lower Oligocene

Interval from lowest appearance of *Chiropteridium lobospinosum* to highest appearance of *Areosphaeridium arcuatum*. (The undiagnostic sample from Section 104-643A-50-1 is included in this zone by implication; see Eocene/Oligocene boundary discussion.)

Other species: The distinctive *Spiniferites* forms designated "sp. 1" and "sp. 2" are restricted to this zone and are common-to-abundant through parts of the interval. *Gelatia* sp. 1 and *Dinocyst 3* (*Evittosphaerula?* sp. 1), are two other distinctive forms which are common at the top of the zone, the latter ranging into the lower part of the zone above. *Svalbardella cooksoniae* is common in the otherwise undiagnostic sample from Section 104-643A-50-1 and has not been recovered from other samples at Site 643.

Comparison: The presence of *Areosphaeridium arcuatum* indicates an early Oligocene age for this zone (Williams and Bujak, 1985).

##### *Areosphaeridium? actinocoronatum* Zone (Sections 104-643A-48-5 to -643A-47-1), lower/upper Oligocene

Interval from highest appearance of *Areosphaeridium arcuatum* to lowest appearance of *Impagidinium* sp. 1. (Samples from Sections 104-643A-48-5 to -643A-47-5 yield few and undiagnostic cysts and are included in this zone tentatively.)

Table 2. Alphabetical listing of dinocyst taxa referring to the numerical indexes in Figures 3-5 and to Plates 1-20.

	643		642C	642D	643A			PLATE/FIG.
	LO	HI	FIG. 6	TABLE 3	LO	ZONES	HI	
	FIG. 3A	FIG. 3B			FIG. 4A	FIG. 4B		
<i>Achilleodinium biformoides</i>	1	134			1	47		2/3
<i>Achromosphaera andalousiensis</i>	170	1	11	59	68	1		2/4
<i>Achromosphaera ramulifera</i>			12					3/8
<i>Achromosphaera</i> sp. 1	176	2						2/1-2
<i>Achromosphaera</i> spp.	2	97		7				
<i>Adnatosphaeridium robustum</i>	27	174						2/11-12
<i>Adnatosphaeridium vittatum</i>	15	155			6	59		2/7-8
<i>Aireiana</i> sp. 1	58	146						1/4
<i>Amiculosphaera umbracula</i>			1					1/6-7
<i>Amiculosphaera</i> cf. <i>umbracula</i>	177	3	26					1/5
<i>Apectodinium homomorphum</i>				100				
<i>Apectodinium quinquelatum</i>				101				
<i>Apectodinium</i> spp.				80				
<i>Apteodinium australiense</i>	32	99		8	11	32		3/1
<i>Apteodinium tectatum</i>	103	53	71					2/5-6
<i>Araneosphaera</i> cf. <i>araneosa</i>	45	148			12	56		3/4
<i>Areoligera</i> sp. 1	63	132			25	46		1/3
<i>Areosphaeridium?</i> <i>actinocoronatum</i>	71	38	13	39	29	7		3/2
<i>Areosphaeridium arcuatum</i>	49	141			15	51		1/1
<i>Areosphaeridium diktyoplokus</i>	16	156			7	60		3/3
<i>Areosphaeridium fenestratum</i>				81				
<i>Areosphaeridium pectiniforme</i>	50	149			16	57		1/2
<i>Ascostomocystis granosa</i> Matsuoka 1983	88	63	64	62	40	20		3/5
<i>Batiacasphaera baculata</i>	94	108		9				1/8-9
<i>Batiacasphaera hirsuta</i>	95	27	27	10				3/6
<i>Batiacasphaera micropapillata</i>	68	113		11				4/1-4
<i>Batiacasphaera</i> cf. <i>scrobiculata</i>	3	160						
<i>Batiacasphaera sphaerica</i>	100	39	14	12	46	8		1/10
<i>Batiacasphaera</i> sp. 1	99	100	76	52				1/11
<i>Batiacasphaera</i> sp. 2	171	64	77	40				1/12-14
<i>Bitectatodinium tepikiense</i>			2					2/9
<i>Bitectatodinium?</i> sp. 1	111	103		13	50	34		4/11-12
<i>Caligodinium amicum</i>	87	123		74				4/7
<i>Cannospaeropsis utinensis</i>	124	72	55					4/5-6
<i>Cannospaeropsis</i> sp. A of Costa & Downie 1979	104	65	72	66				4/13-14
<i>Cannospaeropsis</i> sp. 1	20	175						4/8
<i>Cannospaeropsis</i> sp. 2	35	171						4/9-10
<i>Cerebrocysta bartonensis</i>	28	161		82	9	63		2/10
<i>Chiropteridium lobospinosum</i>	59	131			21	45		5/1
<i>Chiropteridium mepilatum</i>	86	125			39	42		5/2-3
<i>Chiropteridium partispinatum</i>	72	126			30	43		
<i>Cleistosphaeridium</i> sp. 1	157	40	15					3/10-11
<i>Cordosphaeridium cantharellum</i>	48	104		41	14	35		6/1

Table 2 (continued).

	643		642C	642D	643A			PLATE/FIG.
	LO	HI			FIG. 3A	FIG. 3B	FIG. 6	
<i>Cordosphaeridium inodes</i>	4	165						6/2
<i>Cordosphaeridium</i> sp. I of Manum 1976	152	73	57				65	22
<i>Corrudinium incompositum</i>	21	157					8	61
<i>Corrudinium</i> sp. 1	149	70						15/8-9
<i>Cribroperidinium giuseppei</i>	5	162			83			5/5
<i>Cribroperidinium giuseppei</i> major	148	87			63			5/6-7
<i>Cribroperidinium tenuitabulatum</i>	105	92			42		48	29
<i>Danea manicata</i>	36	166						6/4
<i>Dapsilidinium pastielsii</i>	106	4	39	14				9/1
<i>Dapsilidinium pseudocolligerum</i>	91	88	65					9/2
<i>Dapsilidinium</i> sp. 1	158	93			15			9/3
<i>Deflandrea oebisfeldensis</i>				84				
<i>Deflandrea phosphoritica</i>	22	139		85				9/4-6
<i>Deflandrea</i> sp. B of Powell 1986	46	137					13	48
<i>Dinocyst</i> 1	23	176						8/1-2
<i>Dinocyst</i> 2	37	167						6/5-6
<i>Dinocyst</i> 3 ( <i>Evittosphaerula?</i> sp. 1)	64	140					26	50
<i>Dinocyst</i> 4	138	109						8/5-7
<i>Dinocyst</i> 5	139	105		43				8/14-15
<i>Dinocyst</i> 6	140	80	58				61	26
<i>Dinocyst</i> 7	153	74	73					8/10-11
<i>Dinocyst</i> 8				86				
<i>Dinocyst</i> II of Manum 1976	96	107	40	16				8/12
<i>Dinocyst</i> IV of Manum 1976	125	114		17				8/13
<i>Dinopterygium cladoides</i> sensu Morgenroth 1966	43	110		53				9/10
<i>Diphyes colligerum</i>				102				
<i>Diphyes</i> cf. <i>colligerum</i>	6	172				2	65	9/8
<i>Diphyes</i> sp. 1	38	168						9/9
<i>Distatodinium craterum</i>	52	111		75	18	37		7/2
<i>Distatodinium ellipticum</i>	54	150				19	58	7/1
<i>Distatodinium paradoxum</i>	74	81	16	44	32	27		7/3
<i>Eatonicysta ursulae</i>	7	177		87	3	67		6/3
<i>Emslandia spiridoidea</i>	81	94		18	37	30		3/12-13
<i>Evittosphaerula paratabulata</i>	113	112		54	52	38		6/7
<i>Evittosphaerula?</i> sp. 2			33					7/8-10
<i>Filisphaera filifera</i>	167	41	3					9/11-12
<i>Gelatia</i> sp. 1	65	142				27	52	6/8-9, 7/6-7
Gen. et sp. indet. of Piasecki 1980	164	54	41					10/1-3
<i>Glaphyrocysta intricata</i>	24	133						7/4
<i>Glaphyrocysta ordinata</i>				88				
<i>Glaphyrocysta</i> cf. <i>vicina</i>	47	144						7/5
<i>Glaphyrocysta</i> spp.	25	135						
<i>Hafniاسphaera</i> spp.				105				
<i>Heteraulacocysta campanula</i>	60	55		19	22	16		6/11-13
<i>Heteraulacocysta porosa</i>	56	151						6/14

Table 2 (continued).

	643		642C	642D	643A		PLATE/FIG.
	LO FIG. 3A	HI FIG. 3B			FIG. 6	TABLE 3	
<i>Homotryblium floripes</i>	75	95	59			33	31 10/6-7
<i>Homotryblium vallum</i>	150	56	34	60			10/8
<i>Hystrichokolpoma cinctum</i>	82	117					13/3
<i>Hystrichokolpoma rigaudiae</i>	76	5	28	55	34	2	13/4
<i>Hystrichokolpoma</i> sp. 1	8	178					
<i>Hystrichokolpoma?</i> sp. 2	112	115			51	39	13/1-2
<i>Hystrichokolpoma</i> sp. 3				89			
<i>Hystricosphaeridium latirictum</i>	77	42	74	70	35	9	10/9-10
<i>Hystricosphaeridium tubiferum</i>				90			
<i>Hystricosphaeridium</i> sp. 1	130	98		20			10/13-14
<i>Hystrichosphaeropsis</i> cf. <i>complanata</i>	131	43					11/4-5
<i>Hystrichosphaeropsis obscura</i>	107	6	17		49	3	11/1-2
<i>Hystrichosphaeropsis</i> sp. 1	33	169					11/3
<i>Hystrichostrogylon</i> cf. <i>membraniphorum</i>	168	66	60				10/11
<i>Hystrichostrogylon</i> sp. of Edwards 1984	151	68	42				10/12
<i>Hystrichostrogylon</i> sp. 1	161	67					13/11-13
<i>Impagidinium aculeatum</i>	73	44	2		31	10	17/9
<i>Impagidinium aquaeductum</i>	166	71	66		67	21	11/6-7
<i>Impagidinium japonicum</i>	154	28		64			12/1
<i>Impagidinium maculatum</i>	163	82	29	71			11/10-11
<i>Impagidinium pallidum</i>	92	29	18	72			17/10
<i>Impagidinium paradoxum</i>	117	45	43	21	54	11	11/9
<i>Impagidinium patulum</i>	141	46	19	45	62	12	17/3-4
<i>Impagidinium velorum</i>	39	33	67	23			11/8
<i>Impagidinium</i> sp. 1	78	116		73	36	40	17/7-8
<i>Impagidinium</i> sp. 2	101	30	4	65			11/12-14
<i>Impagidinium</i> sp. 3	114	31	44				12/2-4
<i>Impagidinium</i> sp. 4	146	83					12/5-6
<i>Impagidinium</i> spp.	17	32	35	22			
<i>Impletosphaeridium</i> spp.	66	34	6	46			
<i>Invertocysta lacrymosa</i>	172	7	20				10/15
<i>Invertocysta tabulata</i>	89	84	68	76	41	28	10/16
<i>Invertocysta?</i> sp. 1	126	118					3/9
<i>Kisselovia coleothrypta</i>				91			
<i>Labyrinthodinium truncatum</i>	165	47	46		66	13	12/7-8
<i>Labyrinthodinium</i> cf. <i>truncatum</i>	142	8	45		63	4	12/9-10
<i>Laternosphaeridium lanosum</i>				106			
<i>Lejeuneacysta fallax</i>	108	48		56			10/5
<i>Lejeuneacysta</i> cf. <i>hyalina</i>	132	76					10/4
<i>Lejeuneacysta</i> spp.				78			
<i>Lentinia serrata</i>				92			
<i>Lentinia wetzelii</i>				93			
<i>Leptodinium?</i> sp. III of Manum 1976	118	120		67			12/14-15
<i>Lingulodinium machaerophorum</i>	34	9	6	24			15/1-2

Table 2 (continued).

	643 LO HI		642C	642D	643A LO ZONES HI			PLATE/FIG.
	FIG. 3A	FIG. 3B	FIG. 6	TABLE 3	FIG. 4A	FIG. 4B		
<i>Lingulodinium</i> sp. 1	159	85	47	47				14/1-2
<i>Litosphaeridium</i> sp. 1			48					12/12-13
<i>Lophocysta sulcolimbata</i>	127	57			57	17	15/3	
<i>Melitasphaeridium choanophorum</i>	119	10	21	25				12/11
<i>Nematosphaeropsis downii</i>	136	101		48				14/4
<i>Nematosphaeropsis labyrinthica</i>	29	11	22	26				15/12-14
<i>Nematosphaeropsis lemniscata</i>	160	12	23	49				14/3
<i>Nematosphaeropsis</i> sp. 1	51	158			17	62	15/10-11	
<i>Nematosphaeropsis</i> sp. 2	173	13						14/9-11
<i>Operculodinium centrocarpum</i>	83	14	7	27				13/9
<i>Operculodinium crassum</i>	147	15	24	57				14/5-7
<i>Operculodinium cf. giganteum</i>			49					14/12-13
<i>Operculodinium israelianum</i>			25					16/1-2
<i>Operculodinium longispinigerum</i>	109	16	8					14/8
<i>Operculodinium placitum</i>	137	77	61	28	60	24	14/14-15	
<i>Operculodinium</i> sp. of Piasecki 1980	102	18	36	79	47	5	16/5	
<i>Operculodinium</i> sp. 1	90	102	75	29	42	33	16/3-4	
<i>Operculodinium</i> sp. 2	155	17						13/10
<i>Operculodinium</i> sp. 3	174	35	50					13/5-6
<i>Operculodinium</i> spp.	9	58						
<i>Palaeocystodinium golzowense</i>	10	69	56	1				19/8
<i>Palaeocystodinium</i> sp. A of Costa & Downie 1979	97	78	69	61	44	25	13/15	
<i>Palaeocystodinium</i> sp. 1	80	122		69				13/7-8
<i>Palaeocystodinium</i> sp. 2	93	124			43	41	19/7	
<i>Palaeocystodinium</i> sp. 3	128	106		58	58	36	13/14	
<i>Pentadinium laticinctum granulatum</i>	79	127						15/4
<i>Pentadinium laticinctum imaginatum</i>	115	49	70	50	53	14	15/6	
<i>Pentadinium laticinctum laticinctum</i>	40	129						15/5
<i>Phelodinium</i> spp.			94					
<i>Phthanoperidinium echinatum</i>				103				
<i>Phthanoperidinium</i> cf. <i>eocenicum</i>	55	152						16/13
<i>Phthanoperidinium geminatum</i>	30	163			10	64	16/15-17	
<i>Phthanoperidinium stockmansii</i>	44	164						16/8-9
<i>Platycystidia</i> sp. II of Manum 1976	133	36	78	51				16/6-7
<i>Polysphaeridium</i> cf. <i>subtile</i>	156	59		2				16/12
Problematicum IV of Manum 1976	120	119						16/10-11
<i>Pterodinium cingulatum cingulatum</i>	116	60						19/3-4
<i>Pterodinium</i> cf. <i>premnos</i>	31	170						19/2
<i>Pyxidiella?</i> <i>simplex</i>				30				16/18
<i>Pyxidiella</i> sp. 1	143	89						16/14
<i>Pyxidinopsis</i> sp. 1	69	91	62	31				3/7
<i>Rottnestia borussica</i>	11	179			4	68	15/16-17	

Table 2 (continued).

	643 LO HI		642C	642D	643 LO ZONES HI			PLATE/FIG.
	FIG. 3A	FIG. 3B	FIG. 6	TABLE 3	FIG. 4A	FIG. 4B		
<i>Samlandia chlamydophora</i>	12	159		95				15/7
<i>Samlandia</i> sp. 1	70	138			28	49	15/15	
<i>Selenopemphix nephroides</i>	144	79		77				19/5
<i>Spiniferites bentorii</i>	178	19	51					19/11
<i>Spiniferites elongatus</i>	179	20						19/1
<i>Spiniferites hyperacanthus</i>	67	90						19/10
<i>Spiniferites cf. mirabilis</i>	110	50	52	32				19/9
<i>Spiniferites pseudofurcatus</i>	18	21	53	33				17/1
<i>Spiniferites ramosus</i> -group	41	22	9	34				18/1-4, 8
<i>Spiniferites ramosus brevifurcatus</i>	134	86	63	3				
<i>Spiniferites</i> sp. 1	61	145			23	54	17/5	
<i>Spiniferites</i> sp. 2	62	143			24	53	17/2	
<i>Spiniferites</i> sp. 3	85	128						19/12-13
<i>Spiniferites</i> sp. 4	175	23						18/5-7
<i>Spiniferites</i> spp.	19	24	10	4				
<i>Sumatrardinium?</i> sp. C of Powell 1986	121	61	30	35	55	18	20/12, 15	
<i>Sumatrardinium?</i> sp. D of Powell 1986	122	62			56	19	20/14	
<i>Svalbardella cooksoniae</i>	57	147			20	55	19/6	
<i>Systematophora placacantha</i>	26	37	31	5				18/9-10
<i>Systematophora</i> sp. 1	84	130			38	44	18/11-13	
<i>Tanyosphaeridium</i> sp. I of Manum 1976	123	121						20/10
<i>Tectatodinium psilatum</i>	129	25		36	59	6	20/1, 5	
<i>Tectatodinium</i> sp. I of Manum 1976				104				
<i>Tectatodinium</i> sp. 1	42	153						20/2
<i>Tectatodinium</i> sp. 2	135	26	38	37				20/3-4
<i>Tectatodinium</i> sp. 3	162	96	54	68				20/8-9
<i>Tectatodinium</i> sp. 4	169	51		6				20/6-7
<i>Thalassiphora delicata</i>				96				
<i>Thalassiphora fenestrata</i>	53	154						17/6
<i>Thalassiphora pelagica</i>	13	136		97				
<i>Tuberculodinium vancampoae</i>	98	52	32	38	45	15	20/11	
<i>Trinovantedinium</i> cf. <i>capitatum</i>	145	75			64	23	6/10	
<i>Wetzelella articulata</i>	14	173		98	5	66	20/13	

Other species: *Areosphaeridium? actinocoronatum* has its lowest appearance within this zone (above a low productivity interval). *Areoligera* sp. 1 is common near the top. *Samlandia* sp. 1 is restricted to the zone.

Comparison: The lowest appearance of *Areosphaeridium? actinocoronatum* marked the base of Manum's (1976) Zone III at Site 338 and Costa and Downie's (1979) Zone VI at the Rockall Plateau (DSDP Leg 48). Costa and Downie (1979) compared their Zone VI and Manum's (1976) Zone III with upper Rupeilian-Chattian assemblages of North Germany (NP23/24 equivalent). The upper part of the present zone (above a sequence of low productivity) may be correlated with Zone III of Manum

(1976) and with Zone VI of Costa and Downie (1979), and represents upper lower to lower upper Oligocene.

#### *Impagidinium* sp. 1 Zone (Sections 104-643A-46-5 to -643A-46-1), upper Oligocene

Interval from lowest appearance of *Impagidinium* sp. 1 to lowest appearance of *Systematophora* sp. 1.

Other species: *Distatodinium paradoxum*, *Homotryblium floripes*, and *Hystrichokolpoma rigaudiae* appear simultaneously in similar numbers at the base of this zone. All three have a much earlier first appearance (Eocene) in other regions and so their late first appearance at this site is anomalous. (*H. ri-*

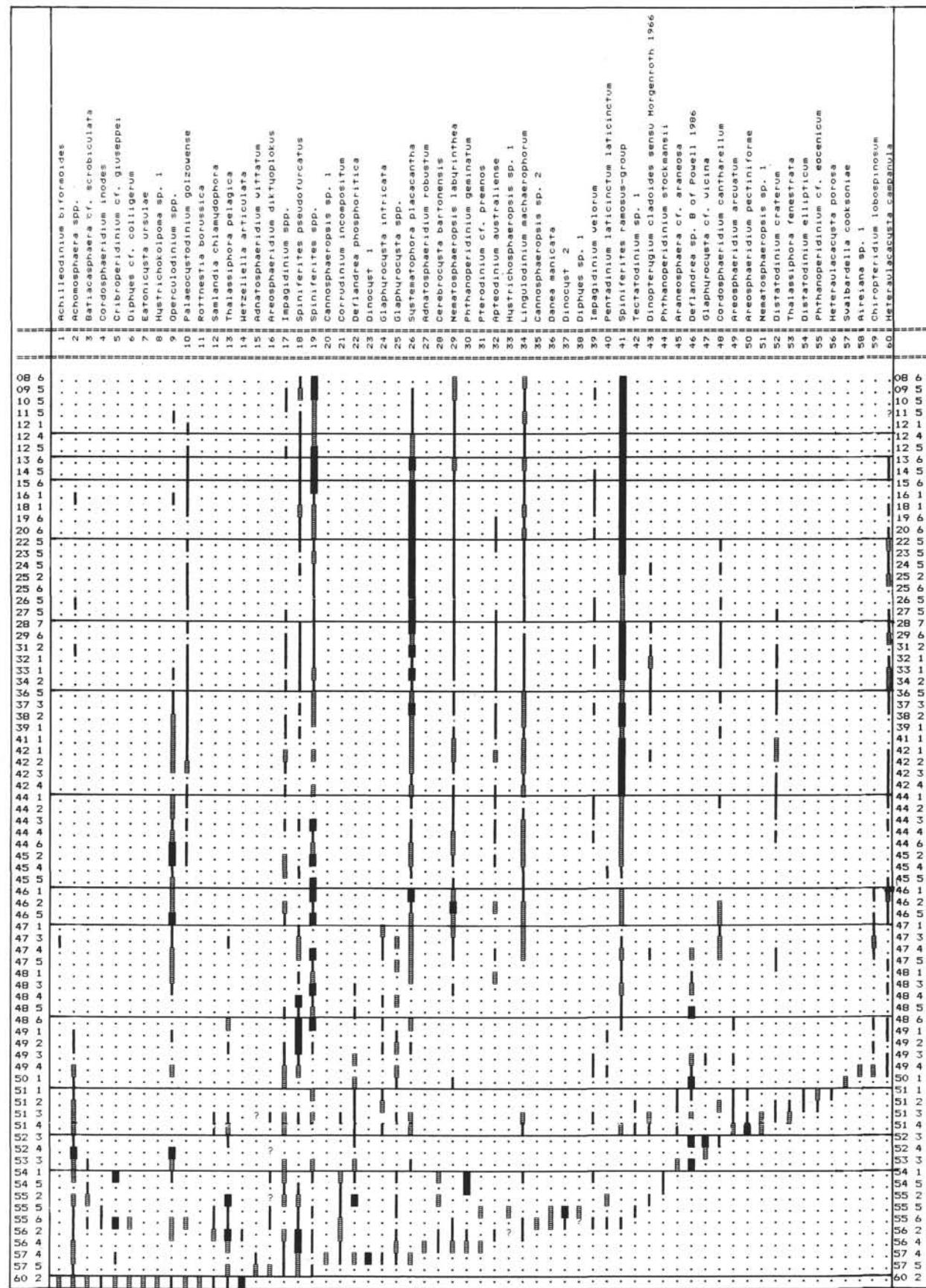


Figure 3. Range charts of dinocyst taxa at Site 643 arranged in the sequence of first (A) and last (B) appearances. Rare: <2%; Common: 2%-25%; Abundant: >25%.

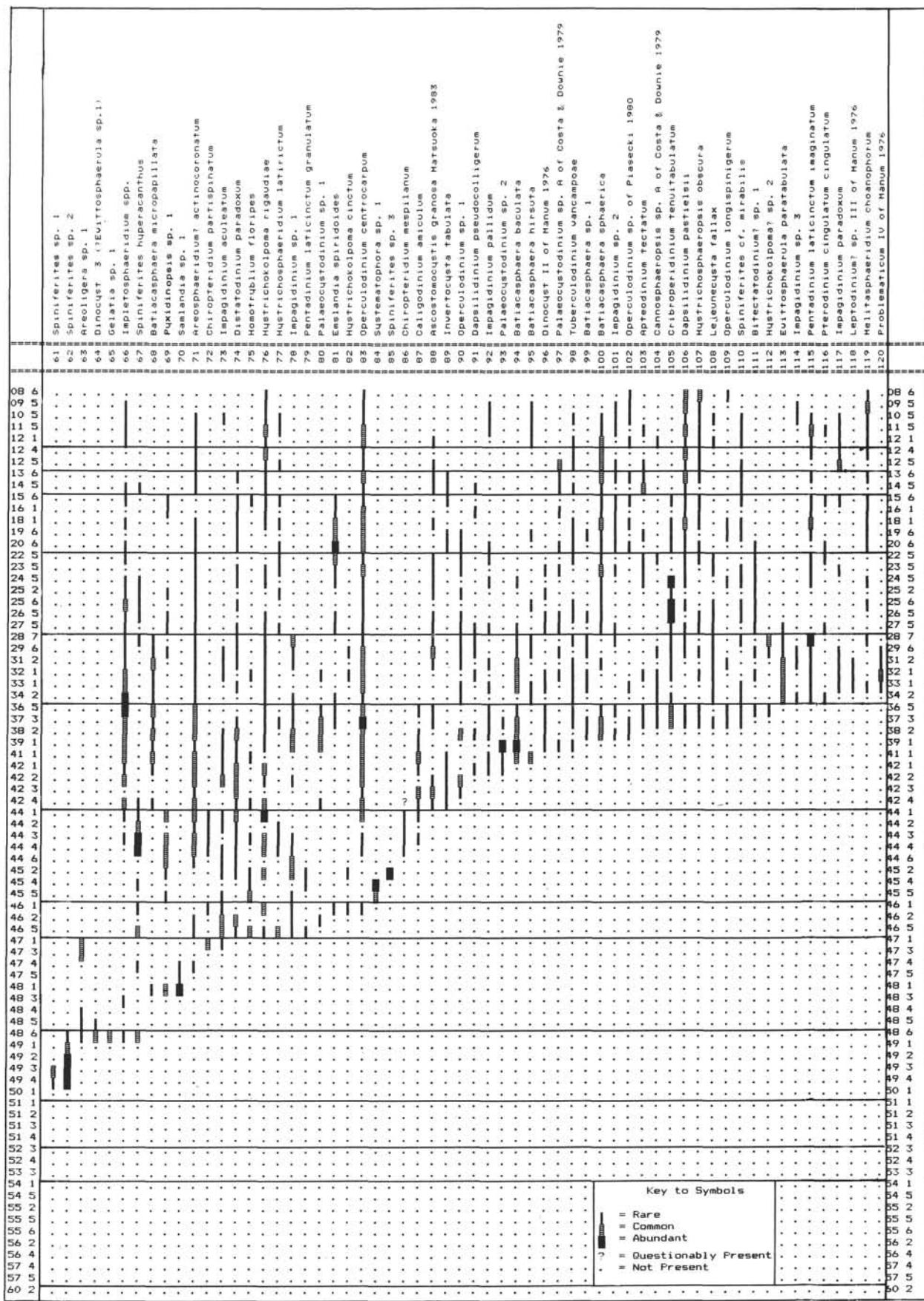
**A**

Figure 3 (continued).

A

08 6	1.21 <i>Sumatradinum?</i> sp. C. of Powell 1986
09 5	1.22 <i>Sumatradinum?</i> sp. D. of Powell 1986
10 5	1.23 <i>Tenuosphaeridium</i> sp. I. of Hanum 1976
11 5	1.24 <i>Cannosphaeropsis uteriensis</i>
12 1	1.25 <i>Dinocyst</i> II of Hanum 1976
12 4	1.26 <i>Invertocysta</i> sp. 1
12 5	1.27 <i>Lophocysta sulcolumba</i>
13 6	1.28 <i>Paleocystodinium</i> sp. 3
14 5	1.29 <i>Rectrodinium patulum</i> sp. 1
15 6	1.30 <i>Hastrichosphaeridium</i> sp. 1
16 1	1.31 <i>Hastrichosphaeropsis</i> cf. <i>complanata</i>
18 1	1.32 <i>Leiuncocysta</i> cf. <i>hawaii</i>
19 6	1.33 <i>Platyctetidium</i> sp. II of Hanum 1976
20 6	1.34 <i>Spiniferites raeosus brevifurcatus</i>
22 5	1.35 <i>Rectrodinium</i> sp. 2
23 5	1.36 <i>Nematosphaeropsis downii</i>
24 5	1.37 <i>Operculodinium placitum</i>
25 2	1.38 <i>Dinocyst</i> 4
25 6	1.39 <i>Dinocyst</i> 5
26 5	1.40 <i>Dinocyst</i> 6
27 5	1.41 <i>Impagidinium patulum</i>
28 7	1.42 <i>Labirinthodinium</i> cf. <i>truncatum</i>
29 6	1.43 <i>Polydialla</i> sp. 1
31 2	1.44 <i>Selenopeltix nephrodes</i>
32 1	1.45 <i>Trinovantidinium</i> cf. <i>capitatum</i>
33 1	1.46 <i>Impagidinium</i> sp. 4
34 2	1.47 <i>Operculodinium crassum</i>
35 6	1.48 <i>Cribroperidinium giuseppei major</i>
37 3	1.49 <i>Corridinium</i> sp. 1
38 2	1.50 <i>Homotubulum usum</i>
39 1	1.51 <i>Hastrichostrogodon</i> sp. of Edwards 1984
41 1	1.52 <i>Cordosphaeridium</i> sp. I. of Hanum 1976
42 1	1.53 <i>Dinocyst</i> 7
42 2	1.54 <i>Impagidinium japonicum</i>
42 3	1.55 <i>Operculodinium</i> sp. 2
42 4	1.56 <i>Polysphaeridium</i> cf. <i>subtile</i>
44 1	1.57 <i>Cleistosphaeridium</i> sp. 1
44 2	1.58 <i>Dapsilidinium</i> sp. 1
44 3	1.59 <i>Lingulodinium</i> sp. 1
44 4	1.60 <i>Nematosphaeropsis lemniscata</i>
44 6	1.61 <i>Hastrichostrogodon</i> sp. 1
45 2	1.62 <i>Rectrodinium</i> sp. 3
45 4	1.63 <i>Impagidinium maculatum</i> Piaseck 1980
45 5	1.64 Gen. et sp. indet. of Piaseck 1980
46 1	1.65 <i>Labirinthodinium truncatum</i>
46 2	1.66 <i>Impagidinium aquaeductum</i>
46 5	1.67 <i>Filisphaera filifera</i>
47 1	1.68 <i>Hastrichostrogodon</i> cf. <i>membraniphorum</i>
47 3	1.69 <i>Rectrodinium</i> sp. 4
47 4	1.70 <i>Ochmosphaera andalousiensis</i>
47 5	1.71 <i>Bartacaspheira</i> sp. 2
48 1	1.72 <i>Invertocysta lacrimosa</i>
48 3	1.73 <i>Hematosphaeropsis</i> sp. 2
48 4	1.74 <i>Operculodinium</i> sp. 3
48 5	1.75 <i>Spiniferites</i> sp. 4
48 6	1.76 <i>Ochmosphaera</i> sp. 1
49 1	1.77 <i>Helicospaera</i> cf. <i>umbraula</i>
49 2	1.78 <i>Spiniferites bentonii</i>
49 3	1.79 <i>Spiniferites elongatus</i>
49 4	
50 1	
51 1	
51 2	
51 3	
51 4	
52 3	
52 4	
53 3	
54 1	
54 5	
55 2	
55 5	
55 6	
56 2	
56 4	
57 4	
57 5	
58 2	
OB 6	
09 5	
10 5	
11 5	
12 1	
12 4	
12 5	
13 6	
14 5	
15 6	
16 1	
18 1	
19 6	
20 6	
22 5	
23 5	
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25 2	
25 6	
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27 5	
28 7	
29 6	
31 2	
32 1	
33 1	
34 2	
36 5	
37 3	
38 2	
39 1	
41 1	
42 1	
42 2	
42 3	
42 4	
44 1	
44 2	
44 3	
44 4	
44 6	
45 2	
45 4	
45 5	
46 1	
46 2	
46 5	
47 1	
47 3	
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48 1	
48 3	
48 4	
48 5	
48 6	
49 1	
49 2	
49 3	
49 4	
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51 1	
51 2	
51 3	
51 4	
52 3	
52 4	
53 3	
54 1	
54 5	
55 2	
55 5	
55 6	
56 2	
56 4	
57 4	
57 5	
58 2	
A.andalousiensis	
I.aquaeuctum	
L.truncatum	
E.spiridoides	
I.patulum	
E.paratabulata	
A.granosa	
Systematophora sp.1	
Impagidinium sp.1	
A.actinocoronatum	
C.lobospinosum	
A.arcuatum	
Dellandrea sp.B	
A.vittatum	
R.borussica	

Figure 3 (continued).

**B**

1	Achomosphaera andalousiensis	
2	Achomosphaera sp. 1	
3	Anculosphaera cf. umbrelula	
4	Dapsilidinium passieae	
5	Hustrichosphaeropsis ligulidae	
6	Invertrocusta lacrimosa	
7	Lingulodinium machaeophorum	
8	Labirinthodinium cf. truncatum	
9	Leptocystidium chaonophorum	
10	Leittasphaeridium labarinthea	
11	Nematosphaeropsis lemniscata	
12	Nematosphaeropsis sp. 2	
13	Nematosphaeropsis centrocarpum	
14	Operculodinium crassum	
15	Operculodinium longipinigerum	
16	Operculodinium ramosus-group	
17	Operculodinium sp. 2	
18	Spiniferites bentorii	
19	Spiniferites elongatus	
20	Spiniferites pseudoruficatus	
21	Spiniferites ramosus-group	
22	Spiniferites sp. 4	
23	Tectarodinium psiliatum	
24	Tectarodinium sp. 2	
25	Baffacaspheara hirsuta	
26	Impagidinium japonicum	
27	Impagidinium pallidum	
28	Impagidinium sp. 2	
29	Impagidinium sp. 3	
30	Impagidinium spp.	
31	Impagidinium velorum	
32	Impagidinium spp.	
33	Impagidinium spp.	
34	Impagidinium spp.	
35	Operculodinium sp. 3	
36	Platycystidium sp. II of Manum 1976	
37	Systematophora placacantha	
38	Arenosphaeridium? actinocoronatum	
39	Baffacaspheara sphaerica	
40	Cleistrosphaeridium sp. 1	
41	Filisphaera filifera	
42	Hustrichosphaeridium latirictum	
43	Hustrichosphaeridium cf. complanata	
44	Impagidinium aculeatum	
45	Impagidinium paradoxum	
46	Impagidinium patulum	
47	Labirinthodinium truncatum	
48	Leitunecusta failk	
49	Pentadinium laticinctum imaginatum	
50	Spiniferites cf. mirabilis	
51	Tectarodinium sp. 4	
52	Tuberculodinium vancaespae	
53	Sphaeridium tectatum	
54	Gen. et sp. indet. of Piasecki 1980	
55	Heterulocusta campanula	
56	Heterofibulum valium	
57	Lophocusta sulcolimbata	
58	Operculodinium spp.	
59	Foliosphaeridium cf. subtile	
60	Pterodinium cingulatum cingulatum	

Figure 3 (continued).

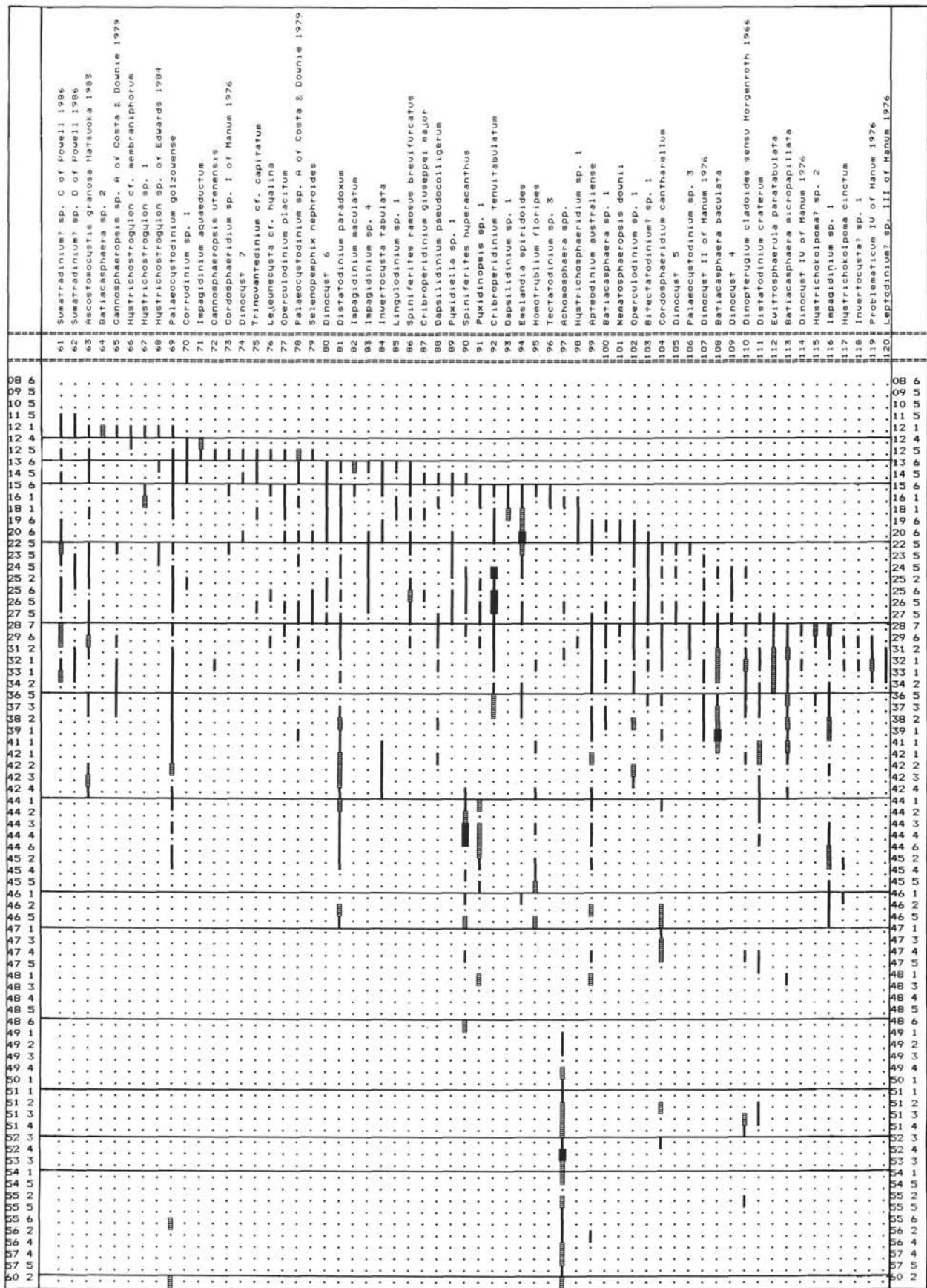
**B**

Figure 3 (continued).

B

08	6		121	Tanysphaeridium sp. 1 or Hanum 1926		
09	5		122	Palaeocystodinium sp. 1		
10	5		123	Caligodinium aciculum		
11	5		124	Palaeocystodinium lobospinosum	sp. 2	
12	1		125	Chiropteridium respilatum		
12	4		126	Chiropteridium partispinatum		
13	6		127	Pentadinium laticinctum granulatum		
14	5		128	Spiniferites sp. 3		
15	6		129	Pentadinium laticinctum laticinctum		
16	1		130	Systematophora sp. 1		
18	1		131	Chiropteridium lobospinosum		
19	6		132	Reoliogera sp. 1		
20	6		133	Glaophryocysta intricata		
22	5		134	Rhilleodinium biformosides		
24	5		135	Glaophryocysta spp.		
25	2		136	Thalassiphora pelagica		
26	5		137	Deflandrea sp. B or Powell 1986		
27	5		138	Saxlandia sp. 1		
28	7		139	Deflandrea phosphoritica		
29	6		140	Dinocyst 3 (Eu)toposphaerulus sp. 1)		
31	2		141	Reiosphaeridium arcuatum		
33	1		142	Gelata sp. 1		
34	2		143	Spiniferites sp. 2		
35	6		144	Glaophryocysta cf. vicina		
37	3		145	Spiniferites sp. 1		
38	2		146	Rizolana sp. 1		
39	1		147	Sabardella cookeanae		
41	1		148	Ranosephaera cf. araneosa		
42	1		149	Reiosphaeridium pectiniforme		
42	2		150	Distrotidinium ellipticum		
42	3		151	Heteraulacacysta porosa		
42	4		152	Phthanoperidinium cf. eocenicum		
44	1		153	Tectotidinium sp. 1		
44	2		154	Thalassiphora fenestrata		
44	3		155	Adinatosphaeridium vittatum		
44	4		156	Reiosphaeridium dictyoplakus		
44	6		157	Cerudinium inconspicuum		
45	2		158	Nesatosphaeropsis sp. 1		
45	4		159	Saxlandia chlamydophora		
45	5		160	Barticasphaera cf. scrobiculata		
47	1		161	Cerebrocytus bartonis		
47	3		162	Chiroperidinium cf. giessae		
47	4		163	Phthanoperidinium gennatum		
47	5		164	Phthanoperidinium stockmansi		
48	1		165	Cordosphaeridium inodes		
48	3		166	Dinaea manicata		
48	4		167	Dinocyst 2		
48	5		168	Diphies sp. 1		
48	6		169	Histriophphaeropsis sp. 1		
49	1		170	Peridinium cf. prenos		
49	2		171	Cannosphaeropsis sp. 2		
49	3		172	Diphies cf. colligerum		
49	4		173	Heitzellella articulata		
50	1		174	Ranostrophasarcidium robustum		
51	2		175	Dannosphaeropsis sp. 1		
51	3		176	Dinocyst 1		
52	3		177	Eutrichocystis unisulae		
52	4		178	Histriochokolpoma sp. 1		
53	3		179	Rottnestia borussica		
54	1					08 6
54	5					10 5
55	2					11 5
55	5					12 1
56	2					12 4
56	4					12 5
57	4					13 6
57	5					14 5
60	2					15 6
						16 1
						18 1
						19 6
						20 6
						22 5
						23 5
						24 5
						25 6
						26 5
						27 5
						28 7
						29 6
						31 2
						32 1
						33 1
						34 2
						35 6
						37 3
						38 2
						39 1
						41 1
						42 2
						42 3
						42 4
						44 1
						44 2
						44 3
						44 4
						44 6
						45 2
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						56 4
						57 4
						57 5
						57 5
						60 2

Figure 3 (continued).

A

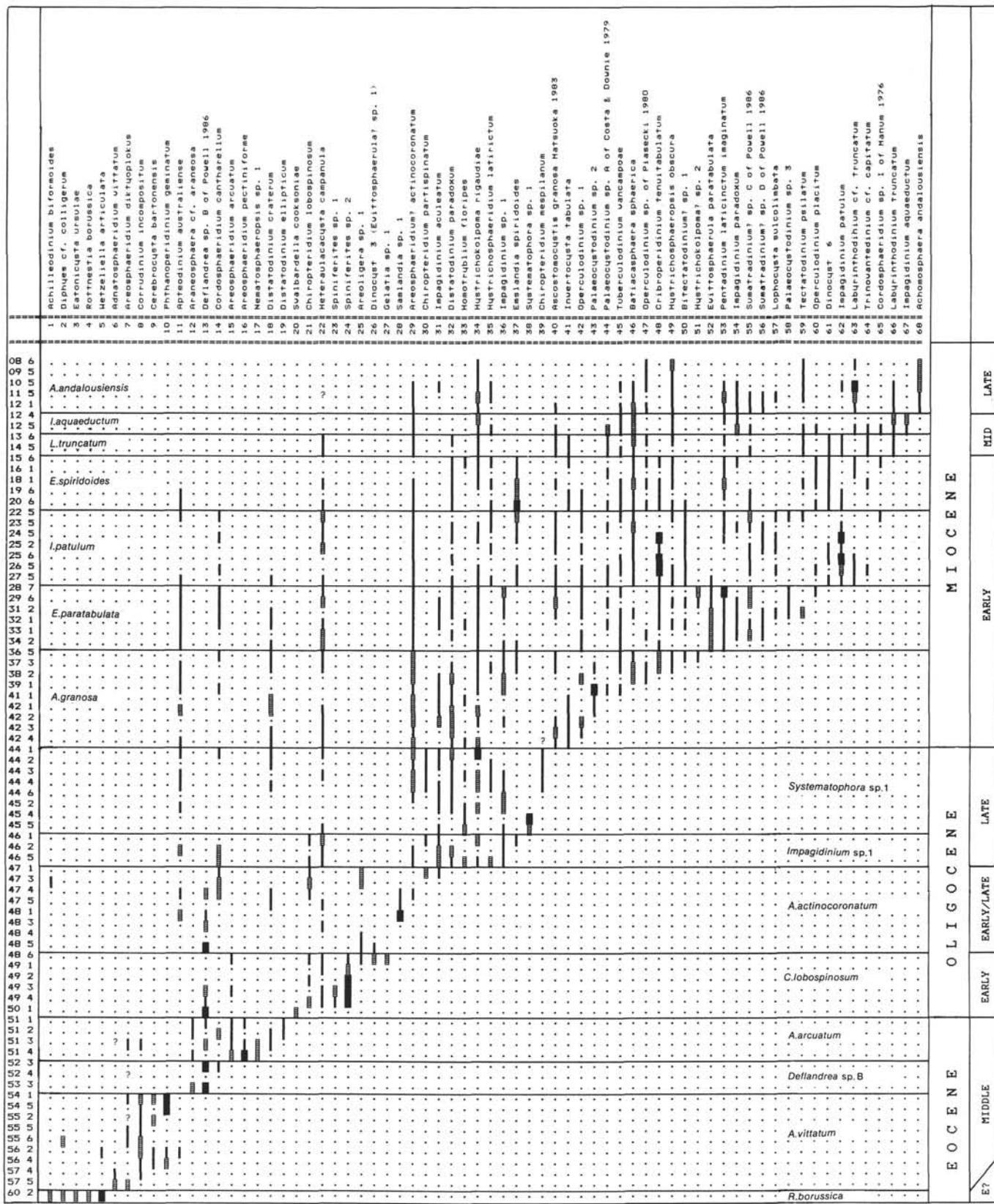


Figure 4. Range charts of the stratigraphically most significant taxa used for zonation at Site 643 arranged in the sequence of first (A) and last (B) appearances (key to symbols is in Fig. 3A).

B

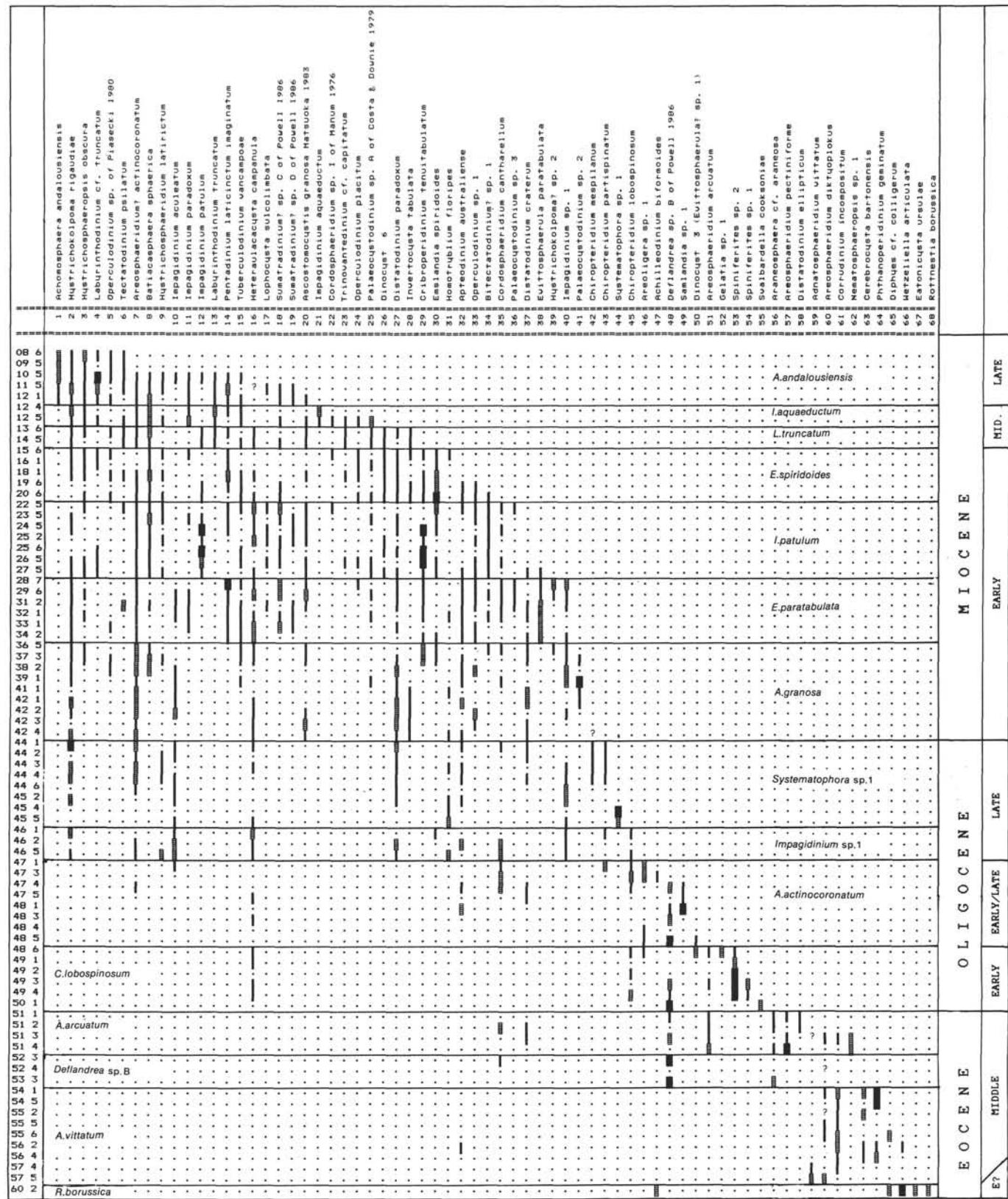


Figure 4 (continued).

*gaudiae* has been recorded from around the Paleocene/Eocene boundary at Site 642E; Boulter and Manum, this volume).

#### **Systematophora sp. 1 Zone (Sections 104-643A-45-5 to -643A-44-1), upper Oligocene**

Interval from lowest appearance of *Systematophora* sp. 1 to lowest appearance of *Ascostomocystis granosa*.

Other species: *Hystrichokolpoma rigaudiae* is common to abundant more or less throughout, *Spiniferites hyperacanthus* is abundant in the middle of the zone; *Batiacasphaera* sp. 1 is common in the upper part of the zone. *Chiropertidium partispinatum* has its highest appearance in this zone; *C. mespilanum* has its lowest appearance within this zone and ranges into the lowermost part of the zone above.

#### **Oligocene/Miocene Boundary**

The Oligocene/Miocene boundary is placed between the samples from Sections 104-643A-44-1 and -643A-42-4, marked by the highest appearance of *Chiropertidium partispinatum* (Section 104-643A-44-1) and the lowest appearance of *Ascostomocystis granosa* (Section 104-643A-42-4). (There was no sediment recovery from the intervening Core 104-643A-43). The pollen also shows a marked change at this point in the section, as discussed on page 22.

Williams and Bujak (1985) indicate the stratigraphically highest appearance for *C. partispinatum* at the Oligocene/Miocene boundary; at Site 643 its highest appearance is in Section 104-643-44-1. In general, the highest appearance of the genus *Chiropertidium* is considered to be a reliable marker for the top of the Oligocene (Williams, 1975, 1977; Williams and Brideaux, 1975; Bujak, 1984). However, *C. mespilanum* ranges into the lowermost Miocene (NN1 equivalent; Williams and Bujak, 1985), Stover (1977), Ioakim (1979), and Powell (1986a) report *Chiropertidium* spp. from the earliest Miocene.

*Ascostomocystis granosa* is considered to be another boundary marker at Site 643. Williams and Bujak (1985) indicate lowest appearance of this species (alias *A. sp. I*) in the latest Oligocene (late NP25 equivalent). At Site 643, *C. mespilanum* (identified on a few fragments only) and *Ascostomocystis granosa* occur together in the sample from Section 104-643A-42-4. Therefore, following our discussion above, this sample cannot be assigned conclusively to either the Oligocene or the Miocene. Section 104-643A-38-2 has the lowest appearance of *Batiacasphaera sphaerica*, which is believed to be a Miocene indicator (Stover, 1977).

For Site 643 we have defined the Oligocene/Miocene boundary by the highest appearance of *C. partispinatum*, and the lowest appearance of *A. granosa*, i.e., between Sections 104-643A-44-1 and -643A-42-4.

#### **Miocene**

##### ***Ascostomocystis granosa* Zone (Sections 104-643A-42-4 to -643A-36-5), lower Miocene**

Interval from lowest appearance of *Ascostomocystis granosa* to lowest appearance of *Evittosphaerula paratabulata*.

Other species: lowest appearance at the base of the zone: *Invertocysta tabulata*. Lowest appearance close to the base of the zone: *Operculodinium* sp. 1. Lowest appearance within the zone: *Batiacasphaera sphaerica*, *Criboperidinium tenuitabulatum*, *Hystrichosphaeropsis obscura*, *Operculodinium* sp., *Palaeocystodinium* sp. A, and *Tuberculodinium vancampoae*. Restricted to the zone: *Palaeocystodinium* sp. 2.

Comparison: *A. granosa* occurs from the base of Zone IIa of Manum (1976; alias *A. sp. I*), indicating a correspondence to

this zone; however, it is uncertain to what extent they overlap. Costa and Downie's (1979) Zone VIIa from the Rockall Plateau, and Powell's (1986b) Subzone LAN-1-A from the Piedmont Basin, both stated to be latest Oligocene, share a few first appearances with this zone, viz. *T. vancampoae* (Rockall and Piedmont), *Palaeocystodinium* sp. A, and *Invertocysta tabulata* (Rockall only; both in Piedmont from middle Miocene). However, *A. granosa* was not recorded in either of the two areas. Stover (1977) reported the lowest appearance of *B. sphaerica* and *T. vancampoae* in his lower Miocene *Tuberculodinium* interval from the eastern United States; his assemblage compares well with ours.

##### ***Evittosphaerula paratabulata* Zone (Sections 104-643A-34-2 to -643A-28-7), lower Miocene**

Interval from lowest appearance of *Evittosphaerula paratabulata* to lowest appearance of *Impagidinium patulum*.

Other species: lowest appearance at the base of the zone: *Pentadinium laticinctum imaginatum*. Lowest appearance within the zone: *Impagidinium paradoxum*, *Lophocysta sulcolimbata*, *Palaeocystodinium* sp. 3, *Sumatradinium?* sp. C and S.? sp. D, and *Tectatodinium psilatum*. Highest appearance at the top of the zone: *Impagidinium* sp. 1 and *Hystrichokolpoma?* sp. 2. Restricted to the zone: *Invertocysta?* sp. 1, *Leptodinium?* sp. III, *Problematicum* IV, *Tanyosphaeridium* sp. I.

Comparison: *E. paratabulata* is common to abundant in lower Miocene sediments from DSDP Sites 338, 342, 345, 346, and 348 (Manum, 1979); however, it also occurs in an upper Oligocene sample from Site 338 (Core 23) and in unconfirmed Oligocene from Site 348 (Core 30). *Pentadinium laticinctum imaginatum* (alias *P. cf. taeniagerum*) and *Problematicum* IV have their first appearances at the base of Manum's (1976) Zone IIa from the lower Miocene of Site 338, indicating that Zone IIa overlaps the lower part of the present zone; the lower part of Manum's Zone Ic appears to overlap the upper part of this zone.

In the Piedmont Basin, Powell (1986b) recorded the lowest appearance of his *Sumatradinium?* sp. C in Subzone LAN-1-B, and the highest appearance of *Distatodinium craterum* at the top of the same zone. These two lowest and highest appearances compare with the present zone (*D. craterum* ranges just into our next zone); however, LAN-1-B is stated to be upper Oligocene. In Rockall, the highest appearance of *D. craterum* is in the lower Miocene, within Zone VIIb of Costa and Downie (1979).

##### ***Impagidinium patulum* Zone (Sections 104-643A-27-5 to -643A-22-5), lower Miocene**

Interval from lowest appearance of *Impagidinium patulum* to highest appearance of *Cordosphaeridium cantharellum*.

Other species: lowest appearance at the base of the zone: *Dinocyst* 6 and *Labyrinthodinium* 6, cf. *truncatum*. Lowest appearance within the zone: *Impagidinium* sp. 4. Highest appearance within the zone: *Batiacasphaera baculata* and *Dinopterygium cladooides*. Restricted to the zone: *Dinocyst* 4 and 5.

Comparison: Assemblages containing *I. patulum* were recorded by Costa and Downie (1979) from the middle Miocene of the Rockall Plateau, but otherwise their assemblages show little similarity to ours. From the Bay of Biscay, Brown and Downie (1985) recorded lower Miocene assemblages (in NN2-NN4 strata) which can be compared to the present zone. Their lowest record of *I. patulum* was from NN2 strata, where it is associated with *Areosphaeridium?* *actinocoronatum* (alias *Impletosphaeridium* sp. I), *Cannosphaeropsis* sp. A, *Distatodinium paradoxum*, *Emslandia spiridooides* and *Hystrichosphaeropsis obscura*.

In the Piedmont Basin, Powell (1986b) recorded *I. patulum* from the middle Miocene (LAN-5-B), and *I. cf. patulum* from the lower Miocene (LAN-3-B). From the illustration of the latter we consider Powell's (l.c.) morphotype to be within the range of variability acceptable for *I. patulum*, whose stratigraphic range would thus begin in the lower Miocene in Piedmont.

Williams (1977) recognized a *Cordosphaeridium cantharellum* Zone from the lower Miocene in the Grand Banks which appears to compare with the present *A. granosa* to *I. patulum* zones. Both *C. cantharellum* and *D. cladoidea* disappear in the *C. cantharellum* Zone as well as in the *I. patulum* Zone.

#### *Emslandia spiridooides* Zone (Sections 104-643A-20-6 to -643A-15-6), lower Miocene

Interval from highest appearance of *C. cantharellum* to lowest appearance of *Labyrinthodinium truncatum*.

Other species: highest appearance at the top of the zone: *Emslandia spiridooides* and *Cribroperidinium tenuitabulatum*. Highest appearance within the zone: *Apteodinium australiense*, *Bitectatodinium?* sp. 1 and *Operculodinium* sp. 1. Restricted to the zone: *Hystrichostrogylon* sp. 1.

Comparison: We agree with Williams and Bujak (1985) that *Apteodinium* sp. B of Williams and Brideaux (1975) is synonymous with *E. spiridooides*. As defined by Williams and Bujak (1985) for offshore eastern Canada, the *A. sp. B* Zone spans the interval from the highest appearance of *Chiropteridium mesplanum* to the highest appearance of *A. sp. B* (= *E. spiridooides*), thus starting much earlier than the present *E. spiridooides* Zone. The tops of the Canadian and the present zone are defined by the disappearance of the same species, yet there is a difference which makes the correlation of tops uncertain: highest appearance of *C. cantharellum* is at the base of the present zone, whereas in sediments offshore Canada it coincides with the top of *E. spiridooides*. Williams and Bujak (1985) indicate highest appearance of *A. spiridooides* at the top of the lower Miocene. However, based on the biostratigraphic synthesis of all data from Leg 104 (Goll, this volume), our *A. spiridooides* Zone may range into the middle Miocene. The upper part of Manum's (1976) Zone Ic compares well to this and the preceding zones, particularly with regard to the highest appearances of *C. cantharellum*, *D. cladoidea*, and *E. spiridooides*.

#### *Labyrinthodinium truncatum* Zone (Sections 104-643A-14-5 to -643A-13-6), middle Miocene

Interval from lowest appearance of *Labyrinthodinium truncatum* to lowest appearance of *Impagidinium aquaeductum*.

Other species: lowest appearance at the base of the zone: *Corrudinium* sp. 1 and "Gen. et sp. indet." Highest appearance at the top of the zone: *Distatodinium paradoxum*.

Comparison: The present zone is recognized on the basis of the same species as those used by Piasecki (1980) for the *L. truncatum* Zone he erected for the Danish Miocene. In the Danish material as well as the present, first appearances and ranges of "Gen. et sp. indet." and *L. truncatum* coincide. Similarly, there is also a disappearance of *D. paradoxum* at the top of this zone. The lowest appearances of *Apteodinium tectatum* and *Spiniferites mirabilis* were noted within this zone in Denmark, but at Site 643 they appear earlier, in the *Ascostomocystis granosa* Zone; however, Piasecki (1980) had no lower Miocene material, which may explain this difference. In the Rockall Plateau, *L. truncatum* and "Gen. et sp. indet." are restricted to the middle Miocene (NN7/8 strata; Edwards, 1984). Although their lowest appearance seems to correspond to Site 643, we have ob-

served their disappearance in younger sediments than at Rockall. Manum (1976) reported *L. truncatum* (alias *Cordosphaeridium* sp. II) from Zone Ia in the middle Miocene. In addition, Edwards (1986) reported *L. truncatum* from middle Miocene sediments in South Carolina.

The middle Miocene age for the species characteristic of this zone appears to be well documented (Manum, 1976; Edwards, 1984: nannofossils; Piasecki, 1980: molluscs). The lower/middle Miocene boundary is therefore defined at the base of this zone. However, data from other biostratigraphers of Leg 104 (Goll, this volume) indicate that this zone boundary may be placed somewhat up into the middle Miocene.

#### *Impagidinium aquaeductum* Zone (Sections 104-643A-12-5 to -643A-12-4), middle Miocene

Interval from lowest appearance of *Impagidinium aquaeductum* to lowest appearance of *Achomosphaera andalousiensis*.

Other species: highest appearance within the zone: *Cordosphaeridium* sp. I, *Trinovantedinium* cf. *capitatum*, *Operculodinium placitum*, and *Palaeocystodinium* sp. A.

Comparison: The present zone is recognized on the same basis as the *I. aquaeductum* Zone of Piasecki (1980) defined for the Danish Hodde Formation (middle Miocene). *Systematophora placacantha* and *Spiniferites pseudofurcatus* have their highest appearance at the top of this zone in the Hodde Fm., whereas at Site 643 they range into the zone above.

Manum (1976) recorded *I. aquaeductum* (as *Leptodinium* sp. V) from his Zone Ia (middle Miocene), which compares well with our *L. truncatum* and *I. aquaeductum* zones. Edwards (1984) and Brown and Downie (1985) reported the lowest appearance of *I. aquaeductum* in the middle Miocene of Rockall and the Bay of Biscay respectively; Brown and Downie (1985) reported *I. aquaeductum* also from the upper Miocene. In the Piedmont Basin, Powell (1986b) recognized an *I. aquaeductum* Zone (LAN-6) from the Serravallian (middle Miocene), but with a quite different cyst association.

#### *Achomosphaera andalousiensis* Zone (Sections from 104-643A-12-1), upper Miocene

Interval from lowest appearance of *Achomosphaera andalousiensis*; the top of this zone cannot be defined (highest sample, Section 104-643A-8-6; compare Mudie (this volume) for higher samples and overlap with ours).

Other species: highest appearance within the zone: *Areosphaeridium?* *actinocoronatum*, *Ascostomocystis granosa*, *Batiacospaera sphaerica*, *Hystrichosphaeridium latirictum*, *Labyrinthodinium truncatum*, *Palaeocystodinium golzowense*, *Pentadinium laticinctum imaginatum*, *Sumatrardinum?* sp. C and S.? sp. D. Restricted to the zone: *Achomosphaera* sp. 1, *Nematospaeropsis* sp. 2.

Comparison: The *A. andalousiensis* Zone Piasecki (1980) defined for the Danish Gram Formation (upper Miocene, stratigraphic control: molluscs; planktonic foraminifer Zone N15-N16) is recognized on the basis of the lowest appearance of *A. andalousiensis*, as well as corresponding highest appearances of *P. laticinctum*, *P. golzowense*, and "Gen. et sp. indet." Data from Site 643 agrees closely with Piasecki (1980). In the Bay of Biscay area, *A. andalousiensis* has its lowest appearance in the upper Miocene (Harland, 1979; Brown and Downie, 1985: NN11 strata. However, the latter authors have a hiatus from NN7 to NN10). In the Piedmont Basin, Powell (1986b) identified the *A. andalousiensis* Zone (LAN-8) with an association that may be compared to the present showing the following highest appearances within the zone: *P. golzowense*, *H. latirictum* (alias? *Cor-*

*dosphaeridium? minimum*) and *Dapsilidinium pastielsii*. Powell (l.c.) indicated a late middle Miocene age for this zone in the Piedmont Basin (planktonic foraminifer Zone N12). However, upper Miocene highest appearances were reported in Piedmont for *P. laticinctum* and *Sumatradinium?* sp. C, both with highest appearances in the *A. andalousiensis* zone at Site 643. Benedek (1980) reported *A. andalousiensis* from presumed middle Miocene strata of the Netherlands. Harland (1978) placed the lowest appearance of *A. andalousiensis* at the middle/upper Miocene boundary. Offshore eastern Canada, Williams (1977) and Williams and Bujak (1977) defined a *P. laticinctum* Zone that may be compared to the *L. truncatum* Zone and the lower part of the *A. andalousiensis* Zone herein; species characteristic of the *P. laticinctum* Zone (*P. laticinctum*, *H. obscura*, and *P. golzowense*) range into the *A. andalousiensis* Zone at Site 643.

The base of this zone is used here to define the boundary between the middle and upper Miocene in our material. For this, we rely mainly on the stratigraphic control by Piasecki (1980) for his Danish material. Data from other relevant areas also support this age determination (Harland, 1978 and 1979; Brown and Downie, 1985). However, *A. andalousiensis* has also been reported from middle Miocene sediments in the Piedmont Basin (Powell, 1986b) and from the Netherlands (Benedek, 1980). These occurrences may well represent range differences which are environmentally controlled, particularly the Mediterranean one for which there also appears to be good stratigraphic control.

## CORRELATION OF DINOCYSTS BETWEEN SITES 642 AND 643

### Hole 642D (Figs. 5A and 5B, Table 3)

Sections 104-642D-14-2 to -642D-13-3 contain an early Eocene assemblage based on the presence of *Deflandrea oebisfeldensis* and *Apectodinium quinquelatum*, which is older than the lowest zone at Site 643 (*Rottnestia borussica* Zone). *A. quinquelatum*, *Cerebrocysta bartonensis*, *Eatonicysta ursulae*, and *Diphyes colligerum* were also reported from lower Eocene sediments at the Goban Spur (Brown and Downie, 1985).

Sections 104-642D-13-1 to -642D-8-6 contain completely different assemblages which are of distinctly Miocene composition.\* Smalley et al. (this volume) have reported isotope ages for carbonate (microfossils) and phosphate (fish teeth) from core 104-642D-12, Sections 4 and 5, which yielded dates of  $38.0 \pm 1.5$  Ma and  $37.0 \pm 1.0$  Ma, respectively, equating a late Eocene age. They argue that the consistency of their isotope ages makes reworking unlikely, and that the palynomorphs, therefore, must be contaminants from higher levels in the borehole. Against this we argue that the stratigraphic distribution of the dinocyst taxa shown in Table 3 presents a coherent and convincing story, strongly indicating *in-situ* conditions. We therefore think that the radiometrically dated fossils are reworked. Some support for this conclusion is also to be found in the core descriptions for Core 104-642D-12 (Eldholm, Thiede, Taylor, et al., 1987, page 354), where reworked sand is stated to be among the major lithologies. In Section 104-642D-13-2 there is a change in lithology just below our undiagnostic sample from Section 104-642D-13-2. Our sample below this lithologic change, from Section

104-642D-13-3, is the highest sample with an Eocene assemblage. There is a distinct assemblage change between Sections 104-642D-13-3 and 642D-13-1, marking the boundary between the Eocene and the Miocene. Our samples from Sections 104-642D-13-2, -642D-12-6, and -642D-11-2 have few diagnostic cysts, but the others have good assemblages diagnostic of the Miocene. Eocene forms are missing. The assemblage from Section 104-642D-13-1 belongs to the *E. paratabulata* zone, those from the interval 104-642D-12-6 to -642D-5-6 belongs to the *I. patulum* Zone. The assemblage from Section 104-642D-3-2 belongs to the *E. spiridoides* Zone. The sample from Section 104-642D-2-6 contains a poor and undiagnostic assemblage, which could not positively be correlated to either the *E. spiridoides* or the *L. truncatum* Zone. Between the Sections 104-642D-3-2 and -642D-2-6 there is another assemblage change, suggesting a hiatus (Fig. 6; we have not studied any material from Core 104-642D-1).

### Hole 642C (Figs. 5A and 6)

Our highest sample from Hole 642D (from Section 104-642D-2-6) and the lowest from Hole 642C (from Section 104-642C-24-3) lack the zone diagnostic species *E. spiridoides* and *L. truncatum*. It is therefore difficult to correlate between them and with Site 643. However, the presence of *Batiacasphaera* sp. 1 and *Operculodinium* sp. 1 in Section 104-642C-24-3, which have their highest appearance in the *E. spiridoides* Zone at Site 643, suggests a correlation for Section 104-642C-24-3 to that zone. This sample contains Dinocyst II and *Palaeocystodinium golzowense* in abundance, which is not observed from Site 643; furthermore, there is an increase in species diversity from Section 104-642C-24-3 to -642C-23-2. These differences between Sites 642 and 643 suggest the presence of a sequence at Site 642 that is missing at Site 643, occupying a position between the *E. spiridoides* and *L. truncatum* Zones. The interval 104-642C-23-2 to -642C-21-6 correlates with the *L. truncatum* Zone, and the interval from Section 104-642C-20-7 to -642C-17-1 correlates with the *I. aquaeductum* zone. *I. aquaeductum* is of rare to common occurrence throughout the zone at Site 643. At Site 642C, however, *I. aquaeductum* is recorded only at the base of the zone.

The interval from Sections 104-642C-19-3 to -642C-17-1 contains species not observed at Site 643 (*Litosphaeridium* sp. 1 and *Operculodinium* cf. *giganteum*), suggesting that this interval at Site 642 represents a sequence that is missing from Site 643 between the *I. aquaeductum* and *A. andalousiensis* Zones (Fig. 5A).

The interval 104-642C-15-1 to -642C-12-1 contains *A. andalousiensis*, associated also are species which were not recorded from Site 643, viz. *Achromosphaera ramulifera*, *Bitectatodinium tepikiense*, and *Evittosphaerula?* sp. 2. The association of *B. tepikiense* with *A. andalousiensis* in the upper part of the latter's range has been observed also in the Bay of Biscay (Brown and Downie, 1985) and the central North Atlantic (Mudie, 1986). Since this association was not observed at Site 643, we conclude that Sections 104-642C-15-1 and higher are younger than our highest sample from Site 643 (Fig. 6). Section 104-642C-10-1 is considered to be of Pliocene age. *Hystrichosphaeropsis obscura*, the highest appearance of which is believed to be a good Miocene-Pliocene marker (Drugg and Stover, 1975; Williams and Bujak, 1985) has its highest appearance in our sample from Section 104-642C-12-1. The presence of *Filisphaera filifera* in Section 104-642C-10-1 suggests a Pliocene age for this interval (Bujak, 1984). We do not propose any zonation for the Pliocene (see Mudie, this volume).

\* In his biostratigraphic synthesis of Leg 104 Goll (this volume) argues that drilling disturbances from younger strata have produced mixing of younger fossils in 104-642D-13-1 through 642D-11. Consequently he concludes that this section is of Eocene age. We now favor this conclusion.

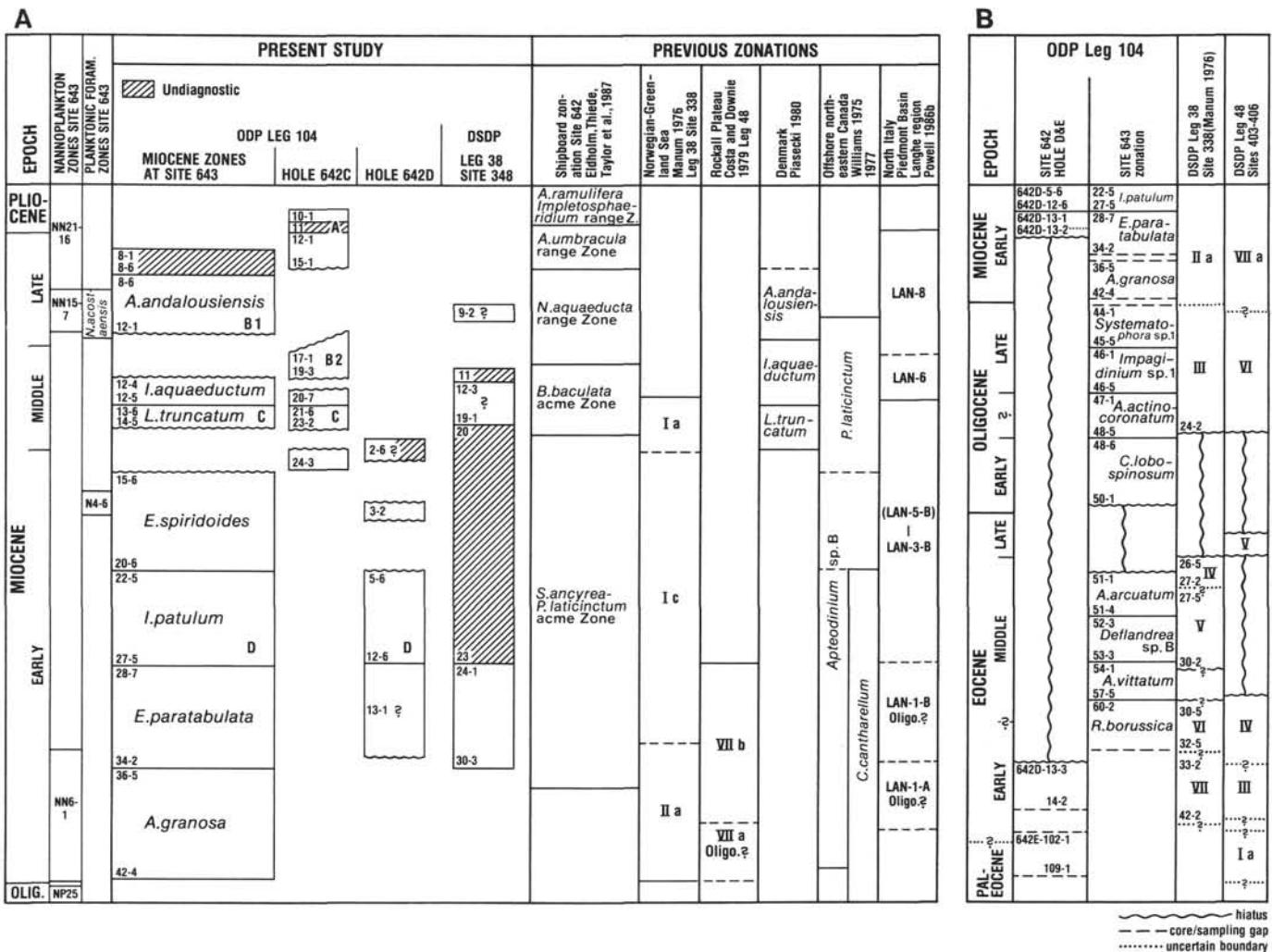


Figure 5. A. Proposed correlation of the Miocene dinocyst zonation for Leg 104, Sites 643, 642C/D, with Legs 38 and 48, Denmark, offshore Northeast Canada, and the northern Italy Piedmont Basin. The palynomorph maxima A–D shown in Figures 2 and 7 are indicated in the respective zones for Sites 642 and 643. B. Proposed dinocyst correlation of Paleogene sections, Leg 104, with those of DSDP Legs 38 and 48.

The absolute palynomorph frequency maximum B (Fig. 7) appears in the lower upper Miocene at Site 643 (indicated by B1), but appears in the upper middle Miocene at Site 642, Holes B and C (indicated by B2 in Fig. 2). This differentiation of the maximum B is based on our zonal correlation between Sites 643 and 642 as discussed above and shown in Figure 5A.

#### INTERPRETATION OF THE POLLEN AND SPORE DATA

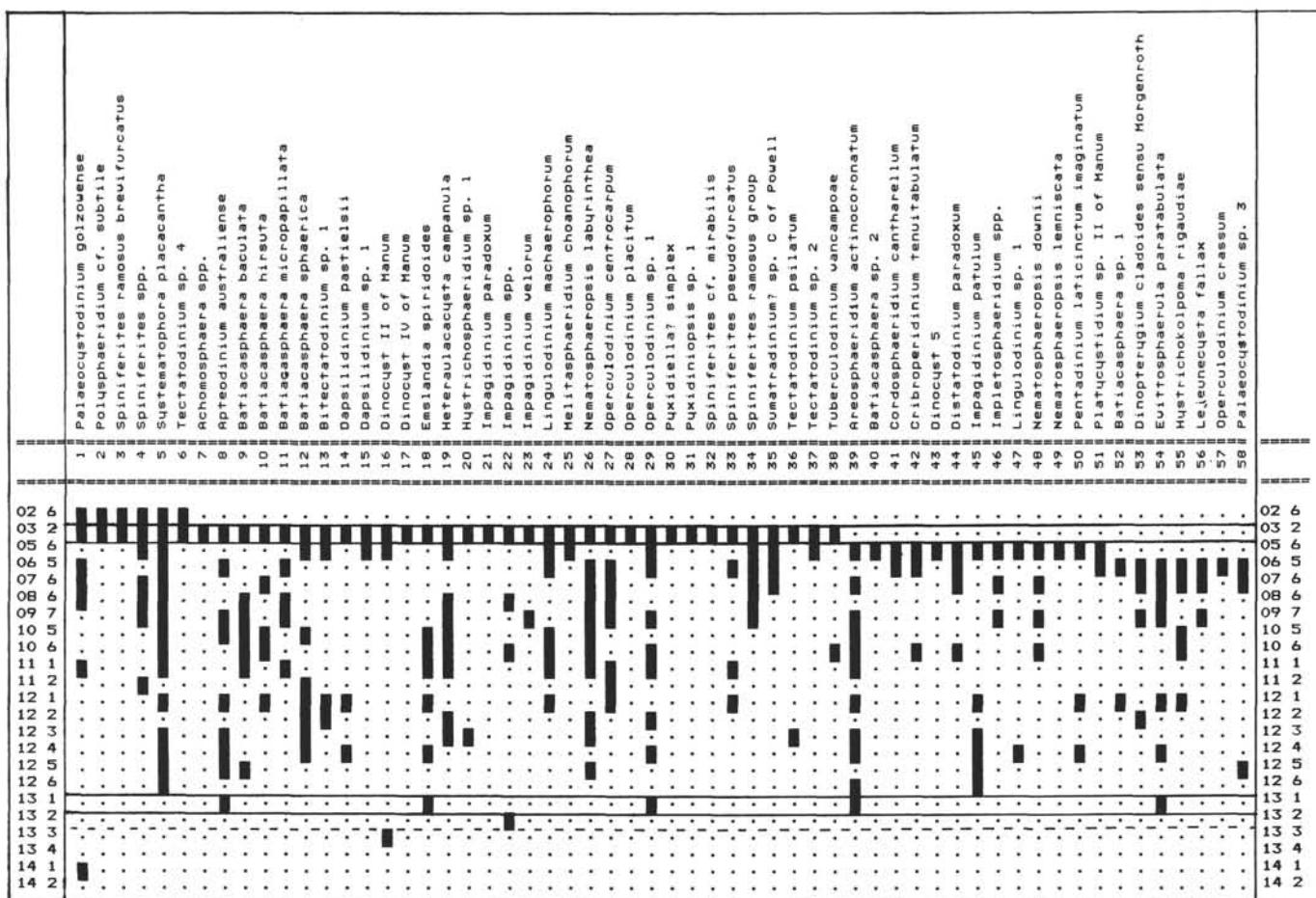
Besides being relatively uncommon in most of the samples we have studied, the pollen and spores are far less useful for zonation and correlation. In most of the samples pollen and spores are absent, or else are represented by a few specimens of bisaccate pollen which have been transported long distances by wind and water. The results of our semiquantitative analysis are presented in Figures 8 and 9. The lowest sample we have examined from Site 643 is Section 104-643A-60-2, 32 cm. It contains abundant remains of *Azolla* massulae with glochidia (Plate 21), suggesting that warm freshwater conditions were close to the area of deposition. Identical fossils have been recorded from DSDP Leg 38 Site 338, at 300 m (Boulter, 1986) and from Site 343 at 148 m (middle Eocene). We do not suggest that a correlation between the two holes can be based on just one sample from each.

One very clear trend within these data is the difference between the Paleogene and Neogene assemblages. The Paleogene samples from Site 643 are dominated by conifer pollen, many of which are of types absent in the Neogene. A particularly noticeable form is what we call BIGFRILLED MONOSACCATES (Plate 21), in which the frill is up to 20 µm wide. Paleogene forms of triporate pollen are also present only in these samples.

Pollen is more or less absent in samples close to the Eocene/Oligocene boundary, but that from adjacent samples can contribute to the debate on the position of this boundary. Figure 8 shows that BIGFRILLED MONOSACCATES have their highest appearance at Section 104-643A-42-4, 20 cm, in the same sample that contains common VERRUCATE MONOCOLPATES. This is just below a part of the section which is more or less lacking terrestrially derived fossils. Paleogene bisaccates have their highest appearance in the sample below, Section 104-643A-44-3, 30 cm. Our dinocyst data cause us to place the Oligocene/Miocene boundary between our Sections 104-643A-42-4 and -643A-44-1. Although there is no useful pollen assemblage in this latter sample, it is clear that another feature of the boundary is the highest appearance of BIGFRILLED MONOSACCATES.

The considerable changes in the pollen and spore assemblages at this part of Site 643 (Fig. 8) have not been detected so

Table 3. Dinocyst ranges in Sections 104-642D-8-6 through -14-2. Carbonate and phosphate fossils radiometrically dated from the upper Eocene were sampled from Sections 104-642D-12-4 and -5 (Smalley et al., this volume).



clearly before in sections of this age. The palynomorphs are from a similar marine facies and there are enough productive samples to make a reliable comparison between Paleogene and Neogene pollen and spore assemblages. The results show clearly that the Neogene assemblage is consistent and different from the Paleogene one (which is also consistent taxonomically). There are at least three explanations for this difference: (a) The change is due to major alterations in ocean currents causing palynomorphs from a different source to be deposited at Site 643. The consistency of both the Neogene and Paleogene assemblages means that largely the same taxa were present in each region for more than 10 m.y. before and after the change. (b) The change is due to an event that stimulated a surge in the rate of evolution of some of the land plants. (c) The change is due to plant migration caused by alterations in the environment.

The Miocene samples from Sites 643 and 642 show very little variation in their pollen assemblages. We can expect a well-mixed and allochthonous range of terrigenous fossils in marine sediments such as these, but the continuity of the pollen suggests that there was very little change in the source vegetation throughout the Miocene. This observation is in line with DSDP Leg 38 work by Koreneva et al. (1976), who identified one palynoflora (NK3) during the Miocene, and with Leg 104 shipboard observations (Eldholm, Thiede, Taylor, et al., 1987). The lack of change may be due to the selective influences of marine deposition or else may partly represent a truly static vegetation

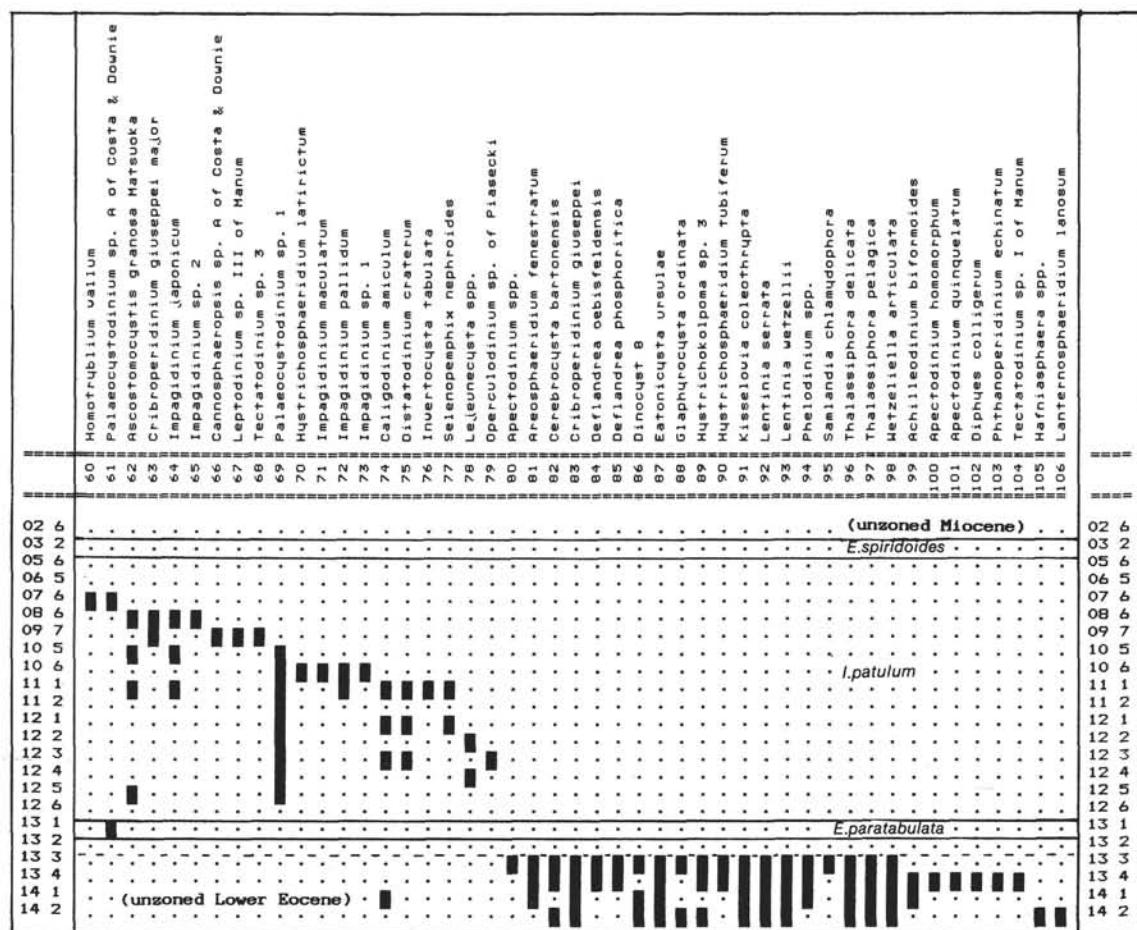
at the source of these sediments for the greater part of the Miocene.

### INTERPRETATION OF THE ABSOLUTE PALYNOLOGICAL COUNTS

Significant qualitative and quantitative changes in the Eocene-to-Miocene palynomorph assemblages of the Norwegian Sea were observed by Manum (1976). These changes undoubtedly reflect much of the changing depositional environments such as land-sea relationships and oceanic circulation patterns which developed during the post-Paleocene tectonic evolution of the North Atlantic. However, the evolution and distribution of organisms were also affected. Manum (1976) presented only relative palynomorph data to illustrate some of the major changes. For the present study, absolute quantitative control of the palynomorph concentrations in the sediments have been obtained, with the objective of gaining improved insight into the events reflected by these newly recognised changes.

Three variables: fossil pollen and spores, dinoflagellates, and the *Lycopodium* spores added in controlled quantities, were counted in at least one sample from each pre-Pliocene core, and the total quantity of palynomorphs present in one gram of sediment were calculated. Absolute palynomorph frequencies for Site 643 (Fig. 7) show some striking variations, and it is possible to correlate maxima and minima between Sites 643 and 642

Table 3 (continued).



(Figs. 2, 5A and 7). The most prominent change occurs between 380 and 350 mbsf (Cores 104-643-41 to -643-37). During this interval, the average amounts increase from a level of the order of 10,000–20,000 palynomorphs to the order of 100,000–150,000 in 1 g of sediment. The cyst stratigraphy and shipboard nannoplankton studies (Eldholm, Thiede, Taylor, et al., 1987) indicate that the age of this event is earliest Miocene.

Another noteworthy feature is the frequent large fluctuations between maxima and minima, more or less throughout the entire sequence, and a drop to about half the average palynomorph contents at about 200 mbsf in the upper lower Miocene. The increase in palynomorph contents noted at 380–350 mbsf is mainly due to higher frequencies of dinocysts. Dinocyst frequencies in the Paleogene range from less than 1,000 to rarely exceeding 30,000, while from the lowermost Miocene frequencies are generally between 50,000 and 100,000 in 1 g of sediment, with a conspicuous maximum just below 350 m (Fig. 7). We believe that this shift to higher cyst frequencies is related to increased cyst recruitment rather than to changes in sediment input. There is no corresponding lithological shift at this level (Eldholm, Thiede, Taylor, et al., 1987). In fact, the lithology shift from Unit V to Unit IV appears earlier and is not expressed in our data (Fig. 7).

Our view that the lowermost Miocene event reflects a change in cyst recruitment rather than in the sediment dilution factor is also supported by preliminary estimates of sedimentation rates. A conservative figure for the thickness of the middle Eocene

section is 90 m. As indicated by our distinct cyst zones, there are breaks in this section, as well as truncations below and above. If about half the middle Eocene is thought to be missing, the average sedimentation rate is 15 mm per m.y. An estimate for the 250 m of lower Miocene section above the event (interval from 380 mbsf to 130 mbsf) leads to an average sedimentation rate of 36 mm per 1 m.y. This rate is based on the assumption, for which there is biostratigraphical support, that there is no major break in this section except in the upper part (see Figure 5A). Sedimentation rates therefore appear to be considerably higher after, than before, this event. The dilution effect on marine palynomorphs is thus higher after the event, but is more than compensated by higher cyst recruitment.

The Paleogene section shows low pollen frequencies and there is hardly any terrestrially derived palynodebris, quite unlike the situation in lower to middle Eocene sections at DSDP Leg 38 Sites 338 and 343 (Manum, 1976; Talwani, Udintsev, et al., 1976; Boulter and Riddick, 1986). The Paleogene section at Site 643 has several large gaps which make further interpretation of our data difficult. The terrestrial vs. marine palynomorph ratios (Fig. 10) show large variations, particularly in the middle Eocene, which suggest changing conditions. The early lower Miocene event takes place over a little less than 1 m.y., estimated from the Miocene sedimentation rates proposed above. This appears to be too early to be related to the submergence of the Iceland-Faeroe Ridge, which substantially changed the oceanic circulation in the Norwegian Sea. The fluctuations observed in the

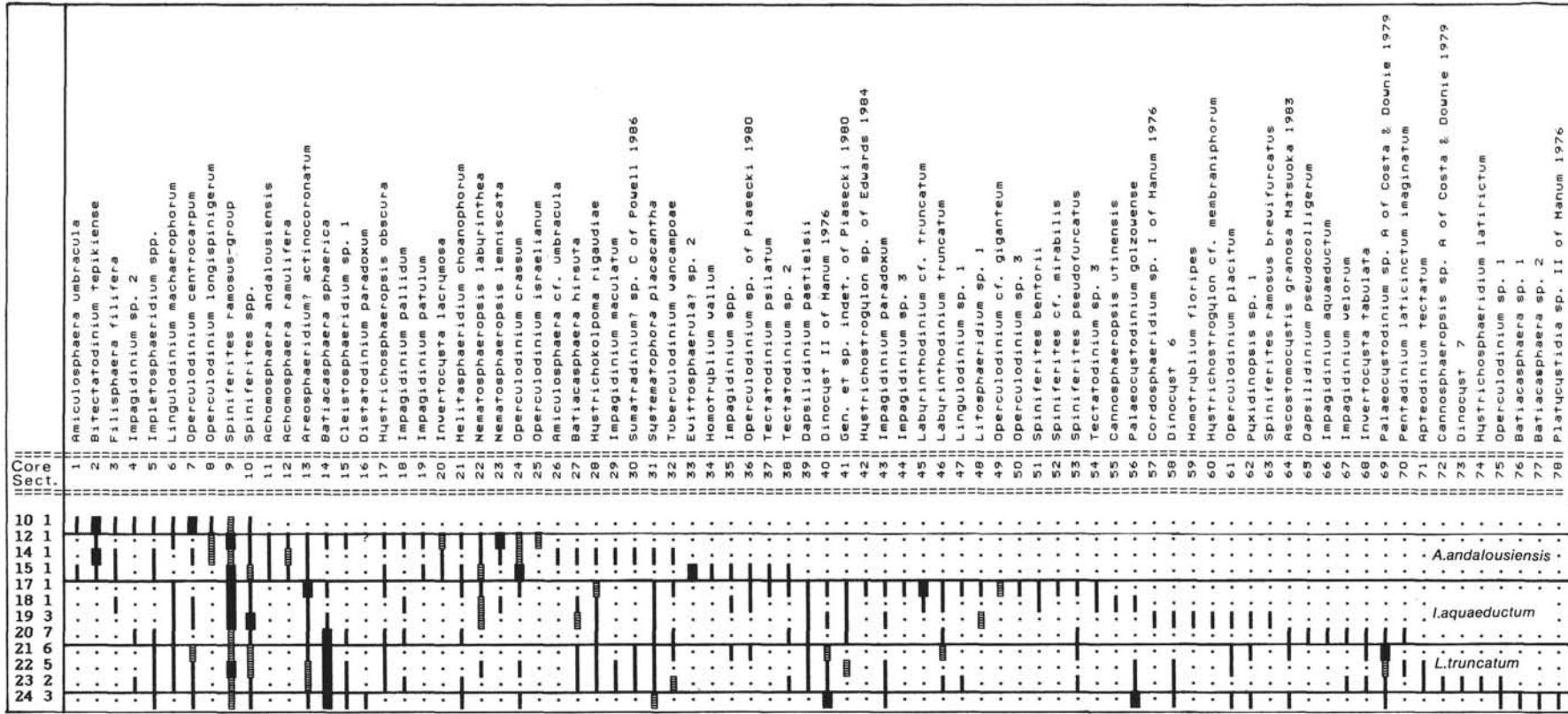


Figure 6. Range chart of dinocyst taxa arranged in the sequence of first appearance at Hole 642C (key to symbols is in Fig. 3A).

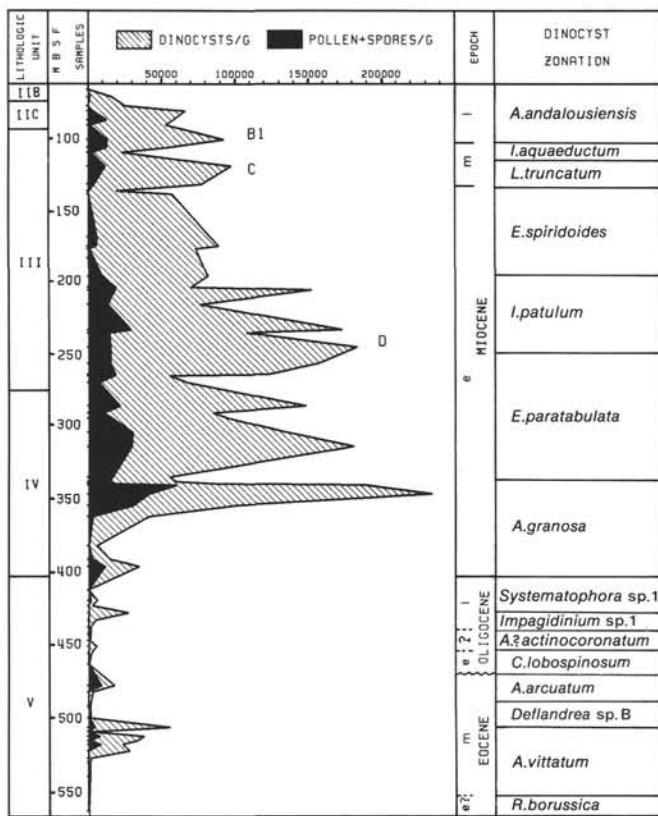


Figure 7. Graphical presentation of absolute frequency counts of marine and terrestrial palynomorphs for Site 643. The palynological maxima B-D correlate with results from Site 642 in Figure 2.

Miocene section may have been controlled by ecological factors which have affected cyst input. Opal data (Henrich et al., this volume) suggests changes in planktonic productivity which appear to support this interpretation.

### COMPARISONS TO DSDP LEG 38

Correlation with Norwegian Sea sites from DSDP Leg 38 are difficult because of differences between the dinocyst assemblages from the various sites. These differences may in part be explained by environmental variations. However, results from Leg 104 have confirmed the impression from Leg 38 that nowhere is there a continuous Tertiary sequence that offers a complete micropaleontological record. Major hiatuses evidently occur at different stratigraphical positions at different sites (Fig. 6), and this is obviously creating correlation problems. Dinocyst correlations which can be made with Leg 38, and Site 338 in particular, are discussed above under the individual zones. Correlations to Site 348 and to Manum's (1976) zonation for Site 338 are presented in Figure 5A.

The Oligocene and Miocene palyno-events shown for Site 338 in the Voring Plateau and other Leg 38 sites (Manum, 1976), also appear at Site 643. In Figure 10, absolute palynomorph counts for Site 643 are presented as relative frequencies to compare with those for Site 338. Compared to the Site 338 data, there appears, possibly, to be less consistency and more "noise" in the data from Site 643; also, Site 643 shows less dramatic change in relative frequencies in the Eocene than Site 338. However, the lower Eocene section showing low relative cyst frequencies at Site 338 is missing at Site 643, and the middle Eocene was represented by only two samples on the steep upward-trending part of the curve for Site 338. Both Site 338 and Site 643 curves

show a downward trend in the late Oligocene, an upward trend in the early Miocene, and again a downward dinocyst frequency trend in the middle Miocene. The latest Paleogene and early Neogene records for Site 643 therefore show similarity to those from Site 338.

### CONCLUSION

Palynomorphs are present in useful amounts in nearly all cores of the Eocene to Miocene sections studied from ODP Sites 642 and 643. While pollen and spores are of limited biostratigraphic value, dinoflagellate cysts can be used throughout for zonation and correlation; however, key species for existing zonations are generally scarce or lacking. A local zonation scheme was established based on the sequence from Site 643. Still, sufficient age diagnostic species are present that allow identification of epochs. The dinocysts thus become particularly important in the Paleogene sections where other biostratigraphic indicators are missing (Eldholm, Thiede, Taylor, et al., 1987: 144, 483).

The number of previously undescribed taxa recorded is high, even for the taxonomically better-known Paleogene. The environments prevailing in the Norwegian Sea were clearly different from areas of previous taxonomic studies, as indicated by the different species composition and ranges. Detailed paleoenvironmental interpretations and their effect on dinocyst distribution, however, were not possible within the scope of this paper. Of the 15 local dinocyst assemblage zones distinguished at Site 643, the top three zones, representing middle and upper Miocene, were recognized previously in Denmark; the remainder were defined from the Leg 104 material alone, but are to varying degrees correlatable with previous DSDP zonations from the northern Atlantic (Legs 38, 48, and 81) and from the Piedmont Basin in northern Italy (Miocene).

At Site 643, dinocysts indicate a middle Eocene age from Cores 104-643A-51 to -643A-57. The lower Eocene has not been confidently identified, although one sample from Section 104-643A-60-2 is possibly of the lower Eocene. Otherwise, Cores 104-643A-58 to -643A-62 (bottom of the hole) are either barren or with undiagnostic assemblages. No upper Eocene section has been identified, indicating a middle Eocene to lower Oligocene hiatus somewhere in the section between our samples from Sections 104-642A-50-1 and -642A-51-1. The Oligocene section contains upper Oligocene assemblages from Sections 104-643A-46-5 to -643A-44-1 and lower Oligocene assemblages from Sections 104-643A-50-1 to -643A-48-6. The intervening cores represent a dinocyst zone that is not diagnostic of either lower or upper Oligocene.

The Oligocene/Miocene boundary is placed between Sections 104-643A-42-4 and -643A-44-1, which has few dinocysts but abundant pollen which show a major change at this part of the section.

Miocene dinocyst ages at Site 643 conform to those based on other microfossil groups, lower Miocene assemblages being identified in Sections 104-643A-15-6 to -643A-42-4, middle Miocene in Sections 104-643A-12-4 to -643A-14-5, and upper Miocene from Sections 104-643A-8-6 to -643A-12-1; our sample from -643A-8-1 yielded an undiagnostic Miocene-Pliocene assemblage.

At Site 642, the Paleogene section above the basalts is represented only by the lower Eocene (Sections 104-642D-13-3 to -642D-14-2). The lower Miocene is identified from Core 642D-10, thus indicating a lower Eocene-lower Miocene hiatus at Site 642.

Dinocyst assemblage changes in the middle Miocene in Hole 642D suggest hiatuses between Sections 104-642D-2-6 and -642D-3-2, and between -642D-3-2 and -642D-5-6. An upper middle Miocene sequence appears to be represented in Hole 642C but is missing at Site 643 (Fig. 5A).

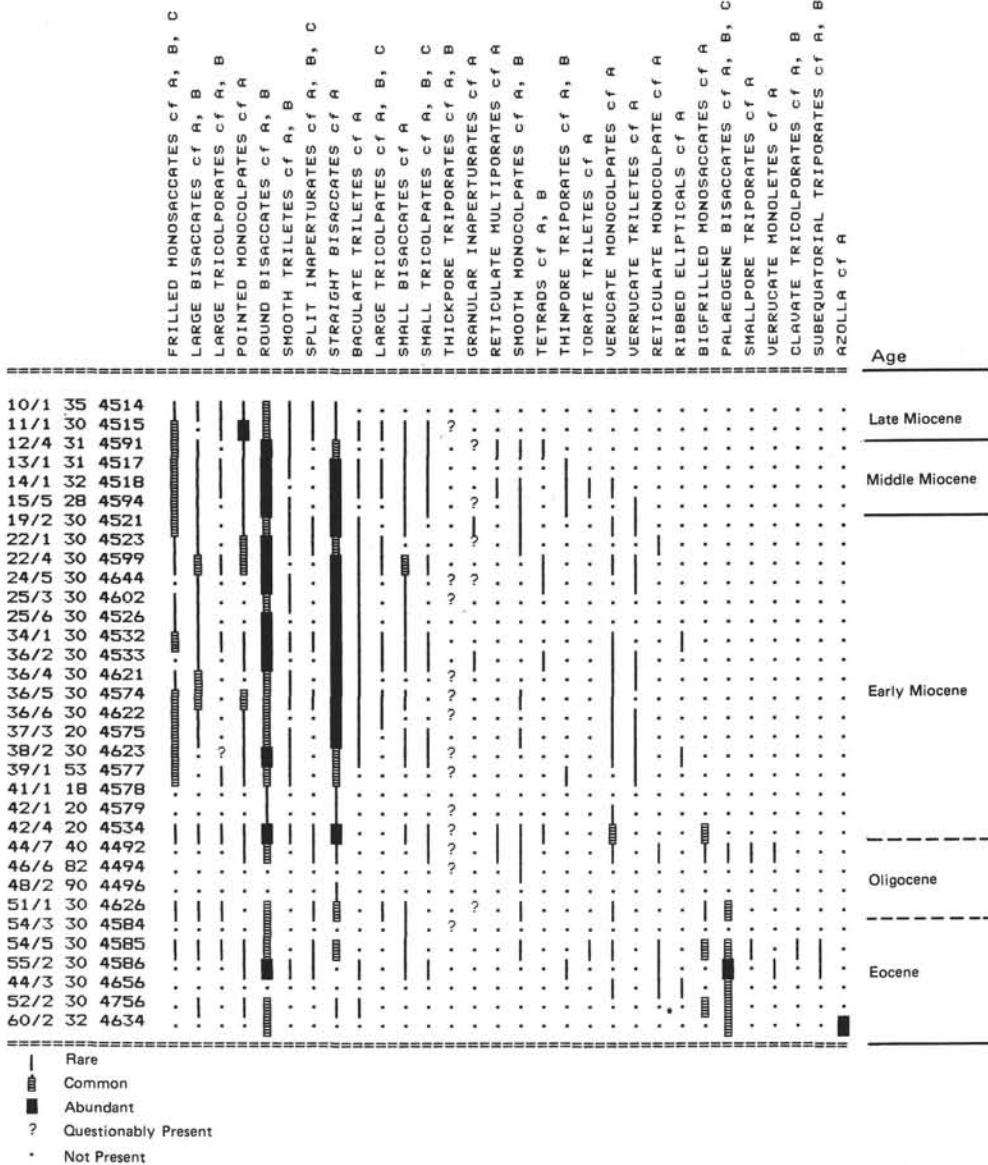


Figure 8. Range chart of pollen and spore types at Site 643 arranged in the sequence of last appearance.

In the lowermost Miocene sediments at Site 643, absolute dinocyst frequencies increase substantially over a relatively short interval and remain at a higher level than in the Paleogene. Because sedimentation rate considerations make it unlikely that the observed change is related to a change in the sediment dilution effect, the most likely explanation is an ecological event.

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#### REFERENCES

- Benedek, P. N., 1980. Vorläufige Ergebnisse der Phytoplankton-Untersuchungen aus dem nordwesteuropäischen Tertiärbecken. *IGCP Project 124, The northwest European Tertiary Basin, Rept.*, 6:87-92.

Boulter, M. C., 1986. Pollen and spore events from the marine Tertiary of north Europe. *J. Micropalaeontol.*, 5:75-84.

Boulter, M. C., and Riddick, A., 1986. Classification and analysis of palynodebris from the Palaeocene sediments of the Forties Field. *Sedimentology*, 33:871-886.

Brosius, M., 1963. Plankton aus dem nordhessischen Kasseler Meeresrand (Oberoligozän). *Z. deutsch. Geol. Ges.*, 114:32-56.

Brown, S., 1986. Nematosphaeropsis downii sp. nov.: a new dinoflagellate cyst from Miocene sediments in the Bay of Biscay. *J. Micropalaeontol.*, 5:7-10.

Brown, S., and Downie, C., 1985. Dinoflagellate cyst stratigraphy of Paleocene to Miocene sediments from the Goban Spur (Sites 548-550, Leg 80). In Graciansky, P. C. de, and Poag, C. W., et al., *Init. Repts. DSDP*, 80: Washington (U. S. Govt. Printing Office), 643-651.

- Bujak, J. P., 1984. Cenozoic dinoflagellate cysts and acritarchs from the Bering Sea and northern North Pacific, D.S.D.P. Leg 19. *Micropaleontology*, 30:180-212.
- Bujak, J. P., Downie, G., Eaton, G. L., and Williams, G. L., 1980. Dinoflagellate cysts and acritarchs from the Eocene of southern England. *Spec. Pap. Palaeontol.*, 24:1-100.
- Costa, L. I., and Downie, C., 1976. The distribution of the dinoflagellate Wetzeliella in the Palaeogene of north-western Europe. *Palaeontology*, 19:591-614.
- \_\_\_\_\_, 1979. Cenozoic dinocyst stratigraphy of sites 403 to 406 (Rockall Plateau), IPOD, Leg 48. In Montadert, L., and Roberts, D. G., *Init. Repts. DSDP*, 48: Washington (U. S. Govt. Printing Office), 513-529.
- Drugg, W. S., and Stover, L. E., 1975. Stratigraphic range charts—selected Cenozoic dinoflagellates. *Am. Assoc. Stratigr. Palynol., Contr. Ser.*, 4:73-77.
- Eaton, G. L., 1976. Dinoflagellate cysts from the Bracklesham Beds (Eocene) of the Isle of Wight, southern England. *Bull. Br. Mus. (Nat. Hist.), Geol.*, 26:227-332.
- Elde, T., 1985. The late Eocene dinoflagellate flora at DSDP Site 338 (Vørings Plateau) [unpublished thesis], University of Oslo, Norway.
- Eldholm, O., Thiede, J., Taylor, E., et al., 1987. *Proc. ODP, Init. Repts.*, 104: College Station, TX (Ocean Drilling Program).
- Edwards, L. E., 1984. Miocene dinocysts from Deep Sea Drilling Project Leg 81, Rockall Plateau, eastern North Atlantic Ocean. In Roberts, D. G., Schnitker, D., et al., *Init. Repts. DSDP*, 81: Washington (U.S. Govt. Printing Office), 581-594.
- \_\_\_\_\_, 1986. Late Cenozoic dinoflagellate cysts from South Carolina, U.S.A. *Am. Assoc. Stratigr. Palynol., Contr. Ser.*, 17:45-57.
- Haaland, T., 1981. A palynological study of Eocene-Oligocene sediments on the Jan Mayen Ridge (DSDP Site 346). [unpublished thesis], University of Oslo, Norway.
- Harland, R., 1978. Quaternary and Neogene dinoflagellate cysts. In Thusu, B., (Ed.), Distribution of biostratigraphically diagnostic dinoflagellate cysts and miospores from the northwest European continental shelf and adjacent areas. *Institut for kontinentsokkelundersøkelser (IKU), Publ.* 100:7-17.
- \_\_\_\_\_, 1979. Dinoflagellate biostratigraphy of Neogene and Quaternary sediments at holes 400/400A in the Bay of Biscay (Deep Sea Drilling Project Leg 48). In Montadert, L., Roberts, D. G., *Init. Repts. DSDP*, 48: Washington (U.S. Govt. Printing Office), 531-545.
- Ioakim, K., 1979. Étude comparative des dinoflagellés du Tertiaire inférieur de la Mer du Labrador et de la Mer du Nord [Thèse diplôme de docteur], troisième cycle à l'Université Pierre et Marie Curie (Paris IV): 1-204.
- Johnsen, K., 1983. Palynological study of Tertiary sediments on the Iceland-Faeroe Ridge (DSDP Site 336). [unpublished thesis], University of Oslo, Norway.
- Koreneva, E. V., Zaklinskaya, E. D., Bratseva, G. M., and Kartashova, G. G., 1976. Palynology studies of sites 336, 338, 345, 346, and 348, DSDP Leg 38. In Talwani, M., Udintsev, G., et al., *Init. Repts. DSDP*, 38: Washington (U.S. Govt. Printing Office), 1169-1194.
- Lentin, J. K., and Williams, G. L., 1985. Fossil dinoflagellates: index to genera and species. *Can. Tech. Rep. Hydrogr. Ocean. Sci.*, 60.
- Matsuoka, K., 1983. Late Cenozoic dinoflagellates and acritarchs in the Niigata District, Central Japan. *Palaeontographica B*, 187:89-154.
- Manum, S. B., 1976. Dinocysts in Tertiary Norwegian-Greenland Sea sediments (Deep Sea Drilling Project Leg 38) with observations on palynomorphs and palynodebris in relation to environment. In Talwani, M., Udintsev, G., et al., *Init. Repts. DSDP*, 38: Washington (U.S. Govt. Printing Office), 897-919.
- \_\_\_\_\_, 1979. Two new Tertiary dinocyst genera from the Norwegian Sea: Lophocysta and Evittosphaerula. *Rev. Palaeobot. Palynol.*, 28: 237-248, pl. 1-2.
- Morgenroth, P., 1966. Mikrofossilien und Konkretionen des Nordwest-europäischen Untereozäns. *Palaeontographica B*, 119:1-53.
- Mudie, P. J., 1986. Palynology and dinoflagellate biostratigraphy of Deep Sea Drilling Project Leg 94, Sites 607 and 611, North Atlantic Ocean. In Ruddiman, W. F., Thomas, E., et al., *Init. Repts. DSDP*, 94: Washington (U.S. Govt. Printing Office), 785-812.
- Piasecki, S., 1980. Dinoflagellate cyst stratigraphy of the Miocene Hodde and Gram Formations, Denmark. *Bull. Geol. Soc. Denmark*, 29: 53-76.
- Piasecki, S., 1980. Dinoflagellate cyst stratigraphy of the Miocene Hodde and Gram Formations, Denmark. *Bull. Geol. Soc. Denmark*, 29:53-76.
- \_\_\_\_\_, 1986b. A dinoflagellate cyst biozonation for the late Oligocene to middle Miocene succession of the Langhe region, northwest Italy. *Am. Assoc. Stratigr. Palynol. Contr. Ser.*, 17:105-127.
- Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores*, 13:615-621.
- Stover, L. E., 1977. Oligocene and early Miocene dinoflagellates from Atlantic corehole 5/5B, Blake Plateau. *Am. Assoc. Stratigr. Palynol., Contr. Ser.*, 5A:66-89.
- Talwani, M., Udintsev, G., et al., 1976. *Init. Repts. DSDP*, 38: Washington (U.S. Govt. Printing Office).
- Williams, G. L., 1975. Dinoflagellate and spore stratigraphy of the Mesozoic-Cenozoic, offshore eastern Canada. *Geol. Surv. Can., Paper* 74-30, 2:107-161.
- \_\_\_\_\_, 1977. Dinocysts: their paleontology, biostratigraphy, and paleoecology. In Ramsay, A. T. S., (Ed.), *Oceanic Micropalaeontology*: London (Academic Press), 1231-1325.
- Williams, G. L., and Brideaux, W. W., 1975. Palynologic analyses of upper Mesozoic and Cenozoic rocks of the Grand Banks, Atlantic continental margin. *Geol. Surv. Can. Bull.*, 236:1-162.
- Williams, G. L., and Bujak, J. P., 1977. Cenozoic palynostratigraphy of offshore Eastern Canada. *Am. Assoc. Stratigr. Palynol., Contr. Ser.*, 5A:14-47.
- \_\_\_\_\_, 1985. Mesozoic and Cenozoic dinoflagellates. In Bolli, H. M., Saunder, J. B., and Perch-Nielsen, K., (Eds.), *Planktonic stratigraphy*: Cambridge, U.K. (Cambridge Univ. Press), 847-964.

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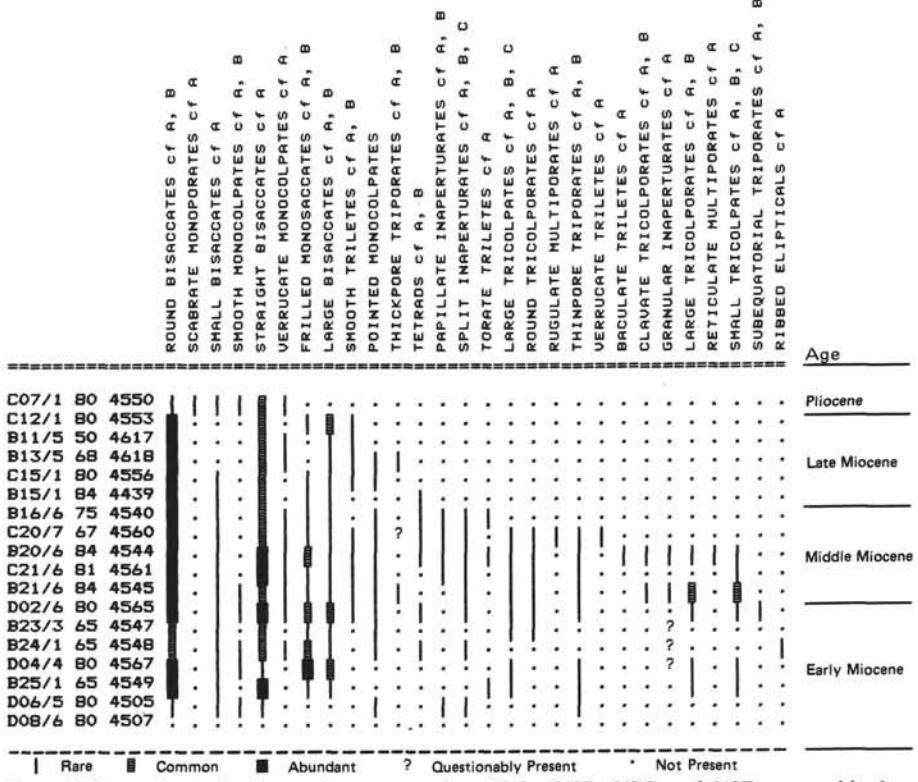


Figure 9. Range chart of pollen and spore types from Holes 642B, 642C, and 642D arranged in the sequence of last appearance.

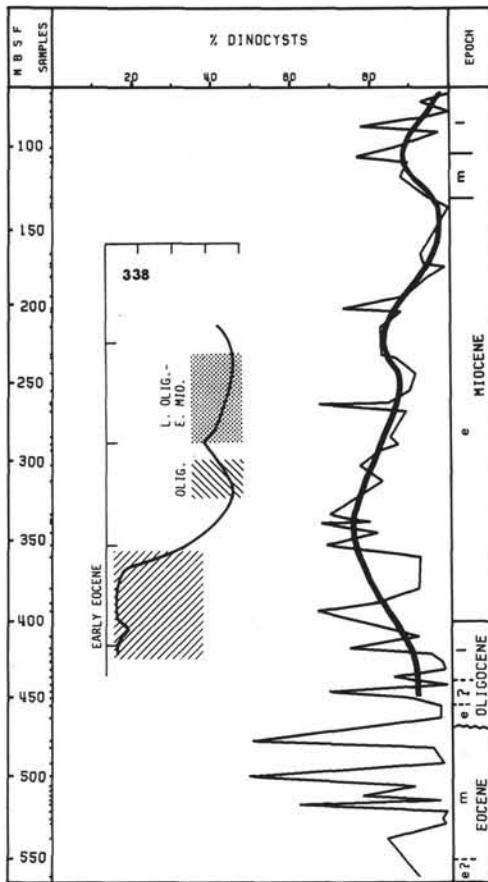


Figure 10. Absolute counts expressed as relative frequencies of marine and terrestrial palynomorphs, to compare with palyno-events recognized by Manum (1976, Fig. 3) at Site 338.

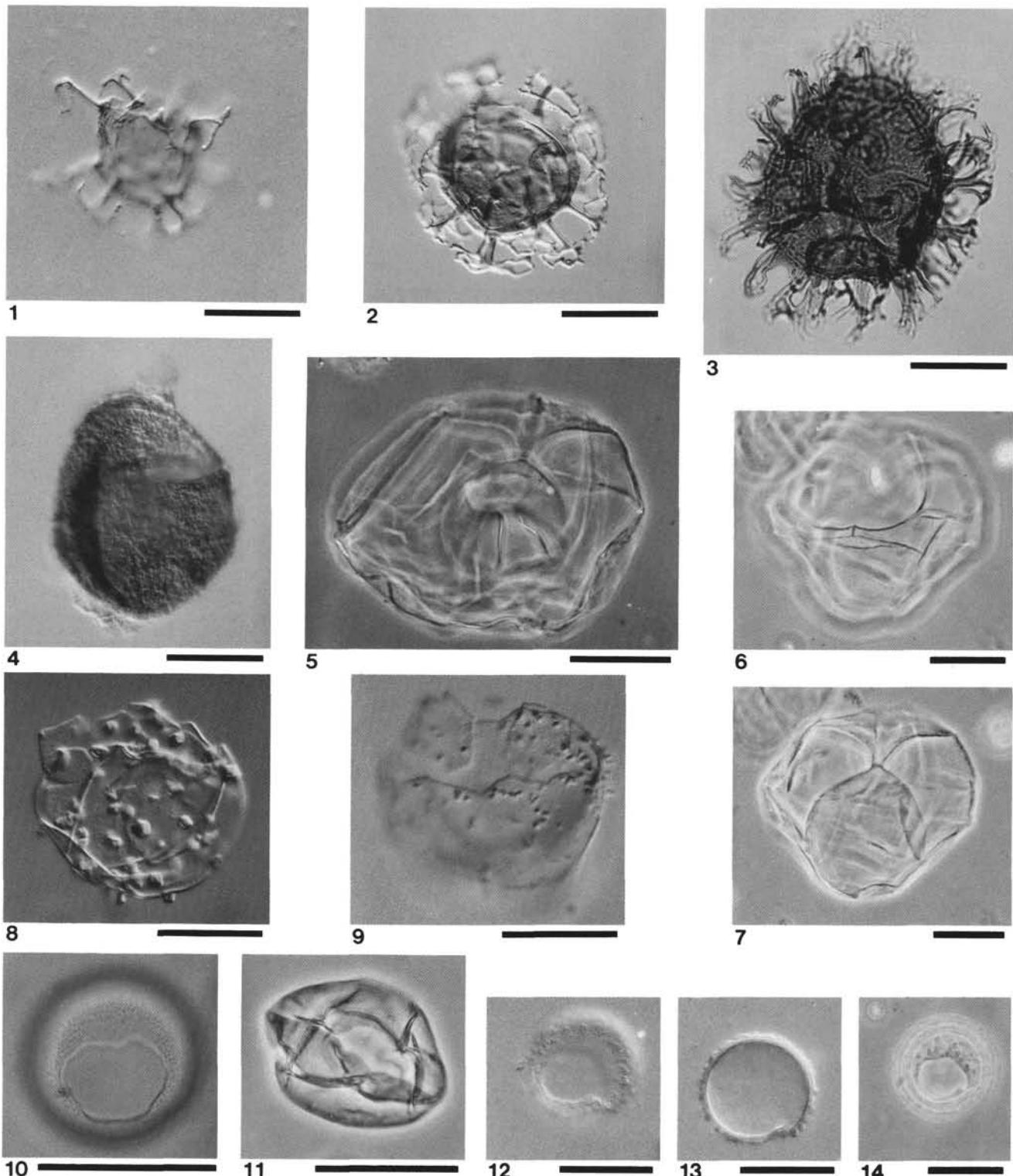


Plate 1. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1. *Areosphaeridium arcuatum*; 104-643A-48-6, 90-92 cm (I). 2. *A. pectiniforme*; 104-643A-51-4, 30-32 cm (I). 3. *Areoligera* sp. 1; 104-643A-47-1, 90-92 cm (B). 4. *Aireiana* sp. 1; 104-643A-49-4, 30-32 cm (I). 5. *Amiculiosphaera* cf. *umbracula* 104-643A-8-6, 48-50 cm (Ph). 6-7. *A. umbracula* 104-642C-15-1, 79-81 cm (Ph). 8. *Batiacasphaera baculata*; 104-643A-39-1, 30-32 cm (I). 9. *B. baculata*; 104-643A-29-6, 30-32 cm (I). 10. *B. sphaerica*; 104-643A-22-5, 31-32 cm (B). 11. *Batiacasphaera* sp. 1; 104-643A-20-6, 30-32 cm. Apical, hi. (Ph). 12-14. *Batiacasphaera* sp. 2; 104-643A-12-1, 31-33 cm (12-13:I, 14:Ph). 12 and 14: apical, hi. 13: equatorial.

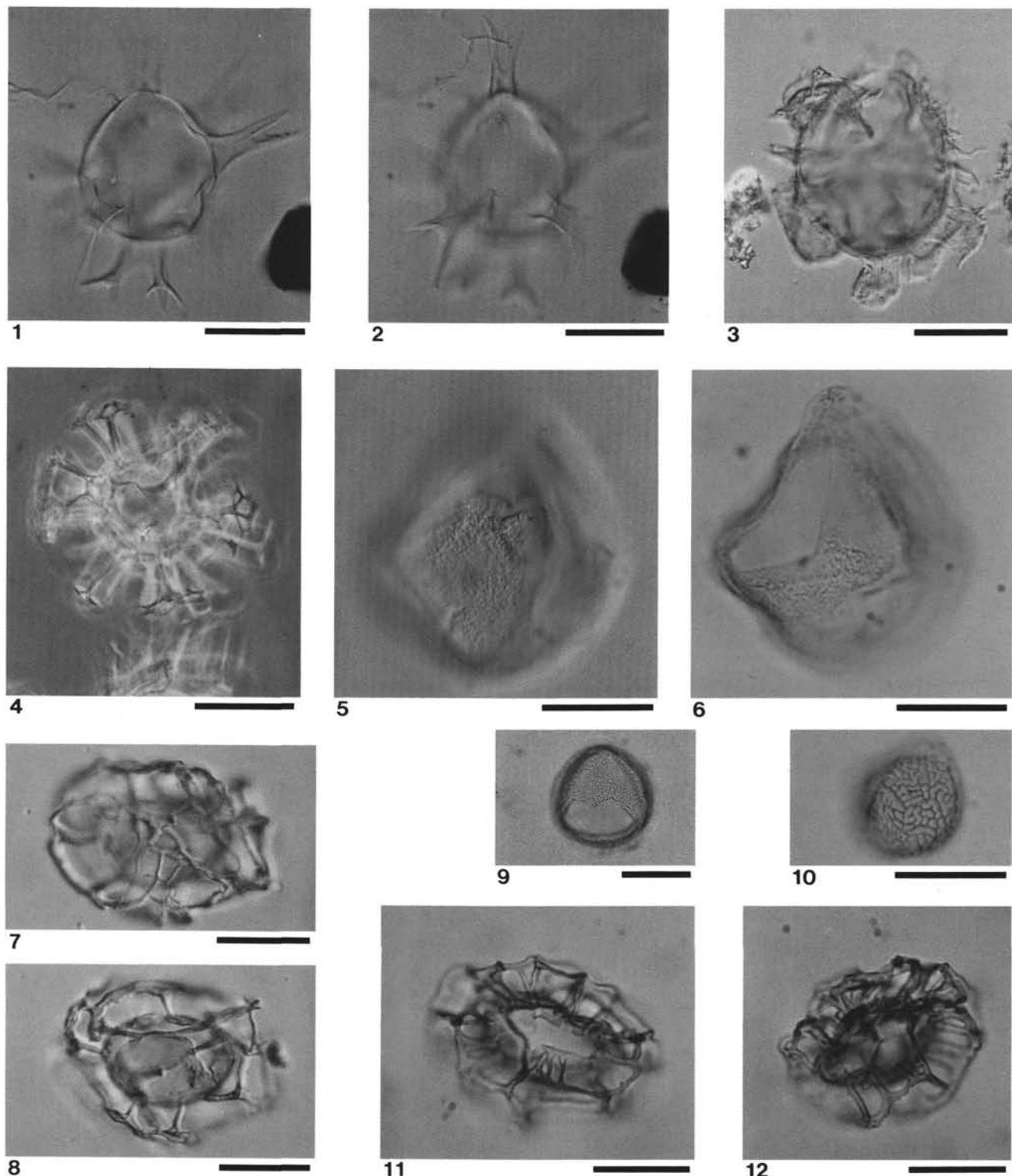


Plate 2. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1-2. *Achomosphaera* sp. 1; 104-643A-8-6, 48–50 cm (I). 1: equatorial. 2: ventral, lo. 3. *Achilleodinium biformoides*; 104-643A-60-2, 30–32 cm (I). 4. *Achomosphaera andalousiensis*; 104-643A-11-5, 30–32 cm (Ph). 5–6. *Apteodinium tectatum*; 104-643A-14-5, 32–34 cm (5:I, 6:B). 7–8. *Adnatosphaeridium vittatum*; 104-643A-57-5, 30–32 cm (I). 9. *Bitectatodinium tepikiense*; 104-642C-14-1, 79–81 cm (B). 10. *Cerebrocysta bartonensis*; 104-643A-54-1, 30–32 cm (B). 11–12. *Adnatosphaeridium robustum*; 104-643A-56-4, 30–32 cm (I).

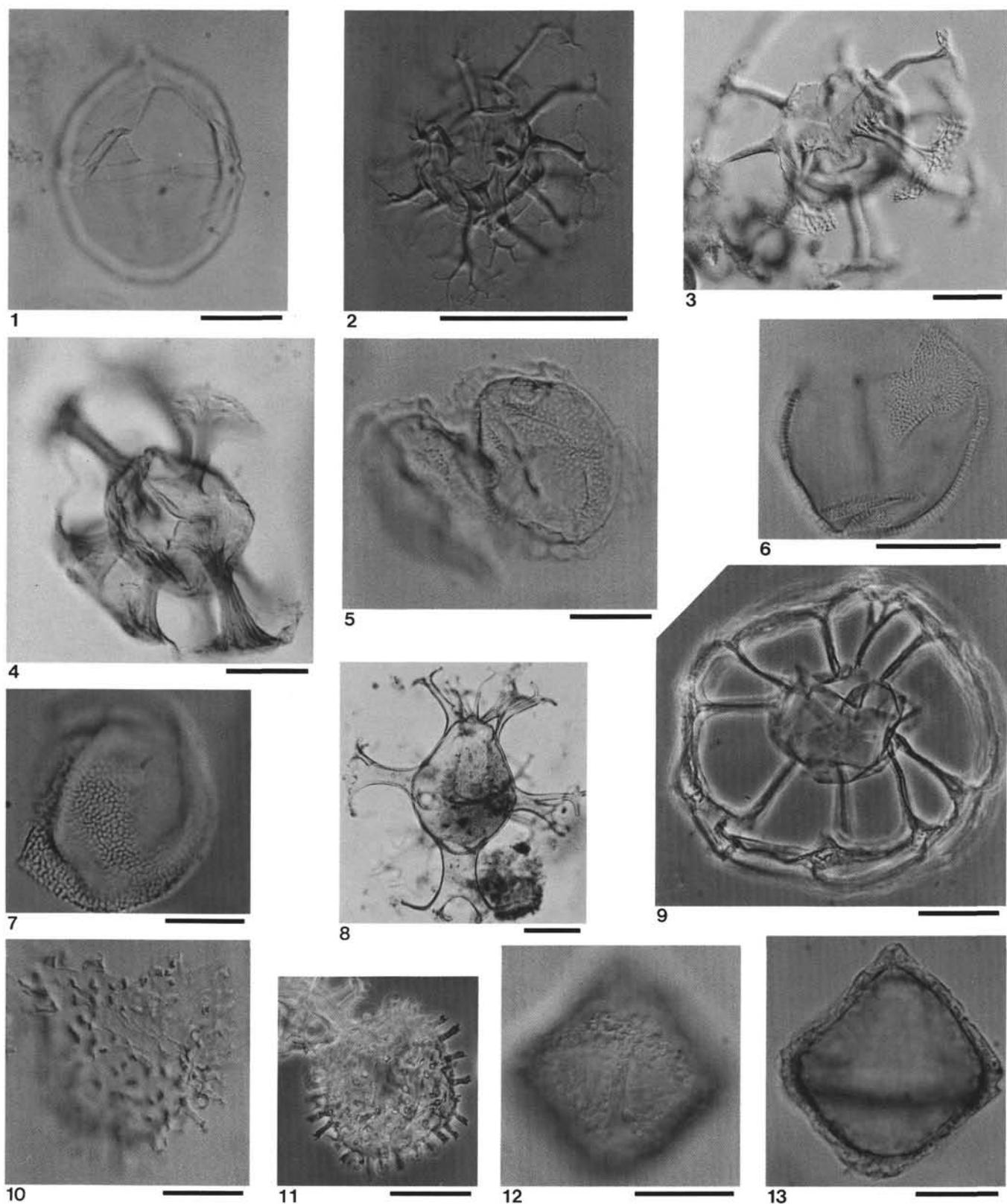


Plate 3. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1. *Apteodinium austriale*; 104-643A-33-1, 53–54 cm (B). 2. *?Areosphaeridium actinocoronatum*; 104-643A-42-3, 19–21 cm (I). 3. *A. diktyoplakus*; 104-643A-54-1, 30–32 cm (I). 4. *Araneosphaera araneosa*; 104-643A-53-3, 30–33 cm (B). 5. *Ascostomocystis granosa* matsuoka 1983; 104-643A-29-6, 30–32 cm (I). 6. *Batiacasphaera hirsuta*; 104-643A-9-5, 30–32 cm (I). 7. *Pyxidinopsis* sp. 1; 104-643A-44-1, 19–21 cm (I). 8. *Achmosphaera ramulifera*; 104-642C-14-1, 79–81 cm (B). 9. *?Invertocysta* sp. 1; 104-643A-29-6, 30–32 cm (Ph). Probably a new genus. Oblique dorsal, hi. 10–11. *Cleistosphaeridium* sp. 1; 104-643A-11-5, 30–32 cm. 10: hi. (I) 11: equatorial. (Ph) 12–13. *Emslandia spiridoides*; 104-643A-20-6, 30–32 cm (12:I, 13:B).

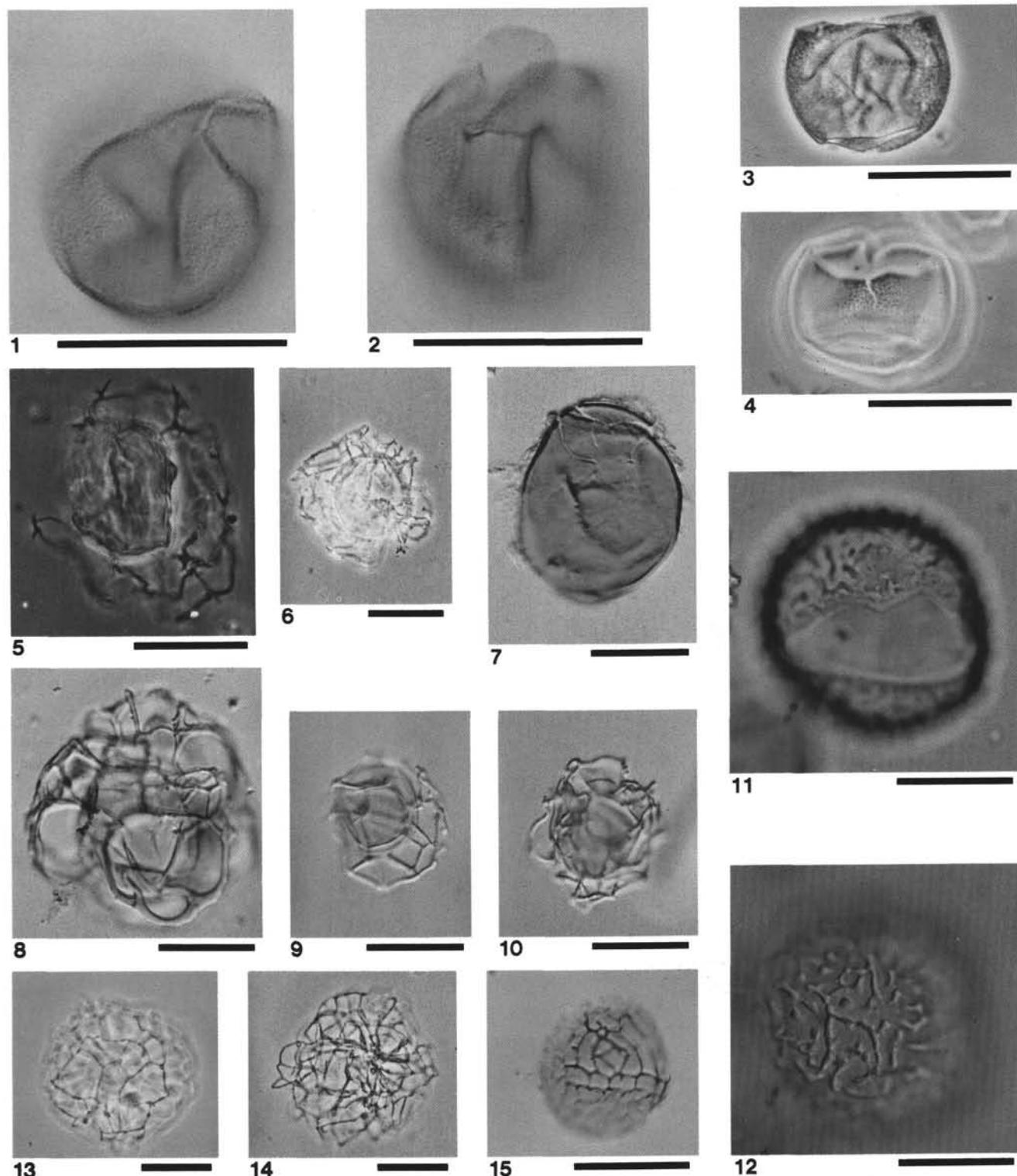


Plate 4. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1-2. *Batiacasphaera micropapillata*; 104-643A-41-1, 18-20 cm (I). 3-4. *B. micropapillata*; 104-643A-37-3, 20-22 cm (Ph). 5. *Cannospaeropsis utinensis*; 104-643A-32-1, 30-32 cm (Ph). 6. *C. utinensis*; 104-643A-12-5, 31-33 cm (Ph). 7. *Caligodinium amiculum*; 104-643A-42-1, 19-21 cm (B). 8. *Cannospaeropsis* sp. 1; 104-643A-57-4, 30-32 cm (I). 9-10. *Cannospaeropsis* sp. 2; 104-643A-55-6, 30-32 cm (I). 11-12. *?Bitectatodinium* sp. 1; 104-643A-32-1, 30-32 cm. 11: ventral lo. (B), 12: ventral, hi. (I). 13. *Cannospaeropsis* sp. A of Costa and Downie 1979; 104-642D-9-7, 27-30 cm (Ph). 14. *Cannospaeropsis* sp. A of Costa & Downie 1979; 104-643A-32-1, 30-32 cm (Ph). 15. *Corrudinium incompositum*; 104-643A-54-1, 30-32 cm (B).

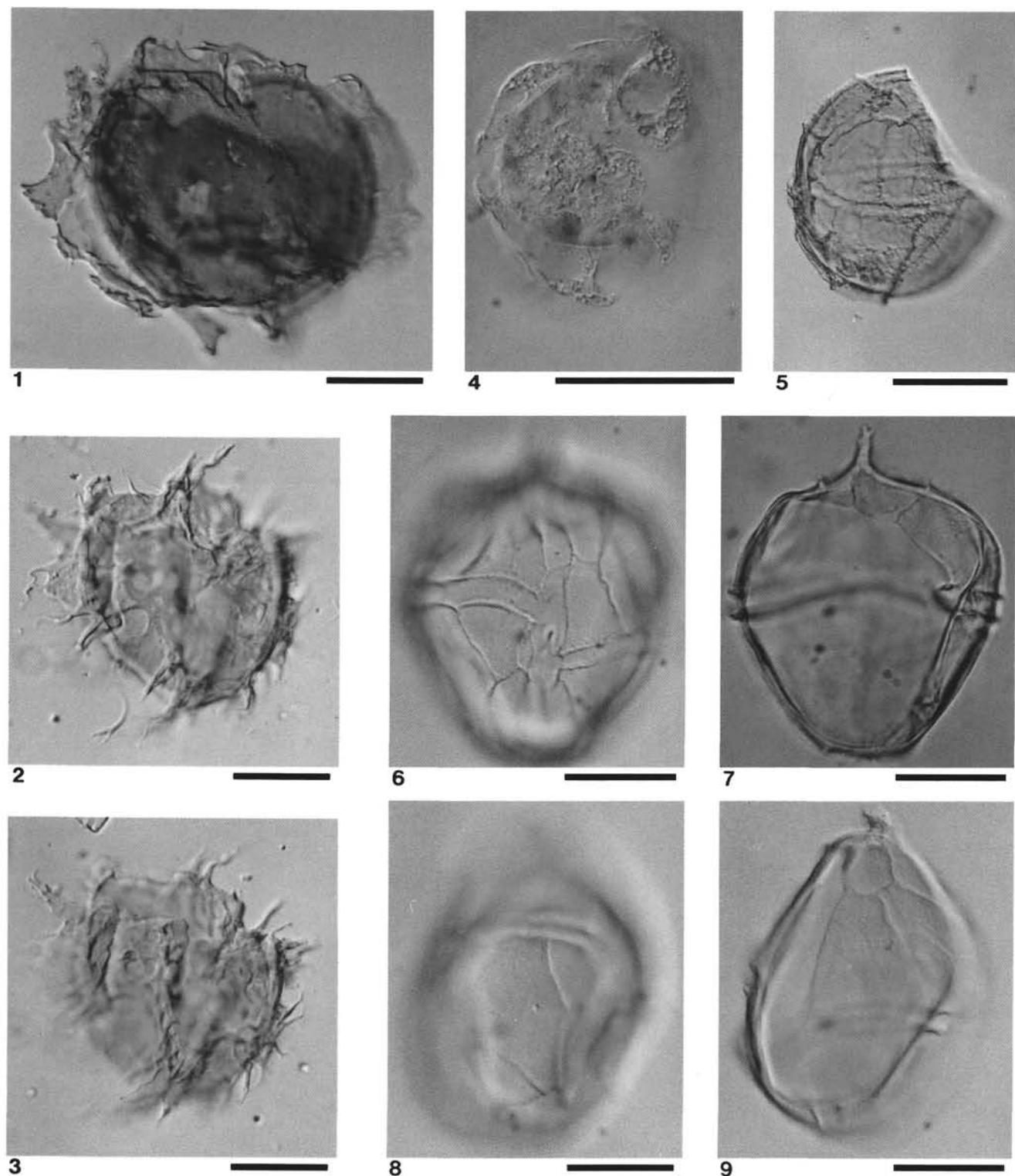


Plate 5. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1. *Chiropteridium lobospinosum*; 104-643A-47-4, 90-92 cm (I). 2-3. *C. mespilatum*; 104-643A-44-2, 30-32 cm (I). 4. *Cordosphaeridium* sp. I of Manum 1976; 104-643A-15-6, 28-30 cm (I). 5. *Criboperidinium giuseppei*; 104-643A-54-1, 30-32 cm (B). 6-7. *C. giuseppei* major; 104-643A-25-6, 30-32 cm (I). 8-9. *C. tenuitabulatum*; 104-643A-25-3, 30-32 cm (I).

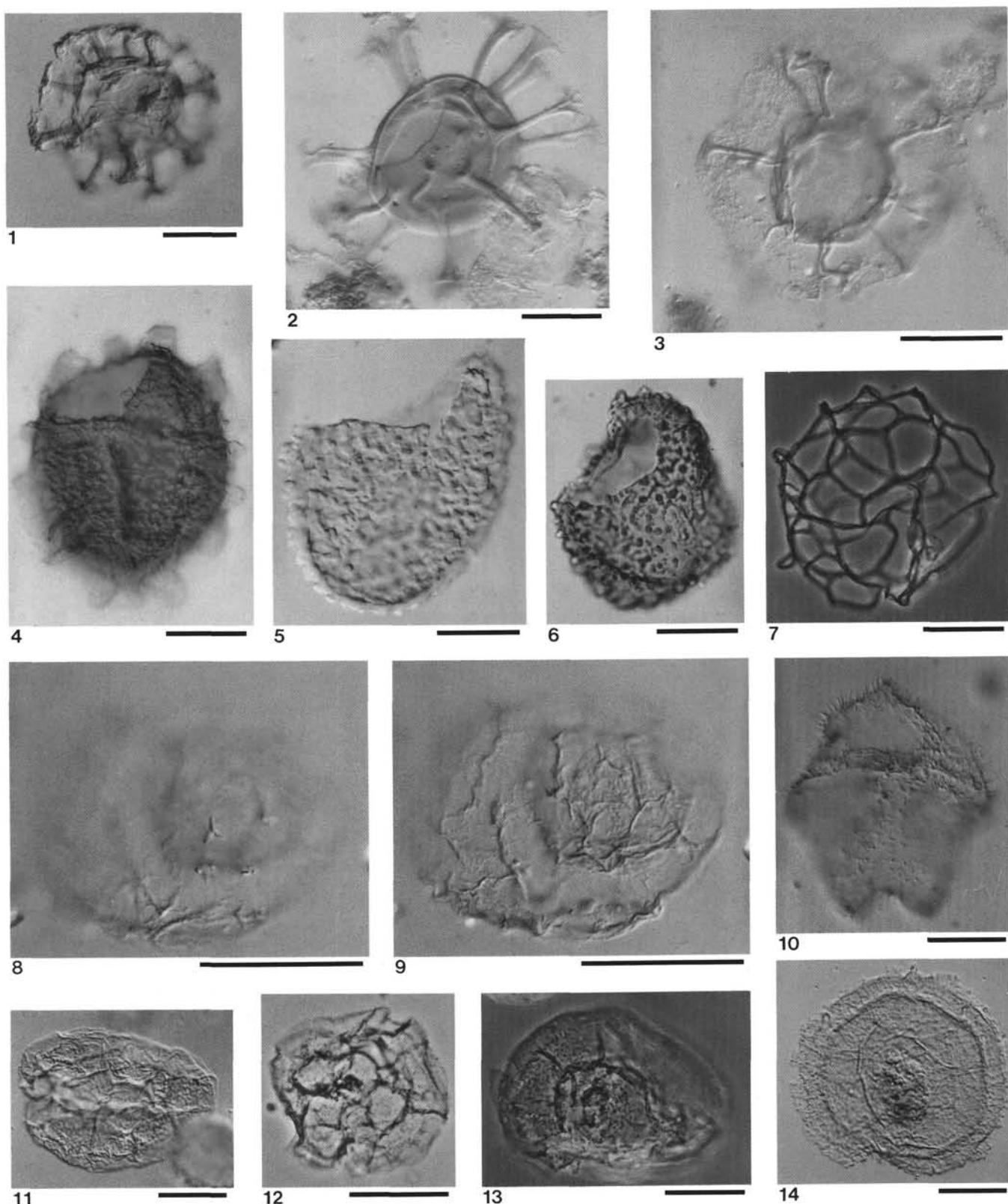


Plate 6. (Scale bars = 30  $\mu\text{m}$ , Ph = phase, I = interference, B = bright field). 1. *Cordosphaeridium cantharellum*; 104-643A-44-1, 30–32 cm (I). 2. *C. inodes*; 104-643A-60-2, 31–33 cm (B). 3. *Eatonicysta ursulae*; 104-643A-60-2, 31–33 cm (B). 4. *Danea manicata*; 104-643A-55-5, 30–32 cm (B). 5–6. Dinocyst 2; 104-643A-55-5, 30–32 cm (B). 7. *Evittosphaerula paratabulata*; 104-643A-29-6, 30–32 cm (Ph). 8–9. *Gelatia* sp. 1; 104-643A-48-6, 90–92 cm (I). Note trifurcate processes on presumed dorsal hypocyst. 10. *Trinovantedinium* cf. *capitatum*; 104-643A-12-5, 31–33 cm (I). 11. *Heteraulacysta campanula*; 104-643A-46-5, 82–84 cm (I). 12. *H. campanula*; 104-643A-36-5, 30–32 cm (I). 13. *H. campanula*; 104-643A-11-5, 30–32 cm (Ph). 14. *H. porosa*; 104-643A-51-1, 30–32 cm (I).

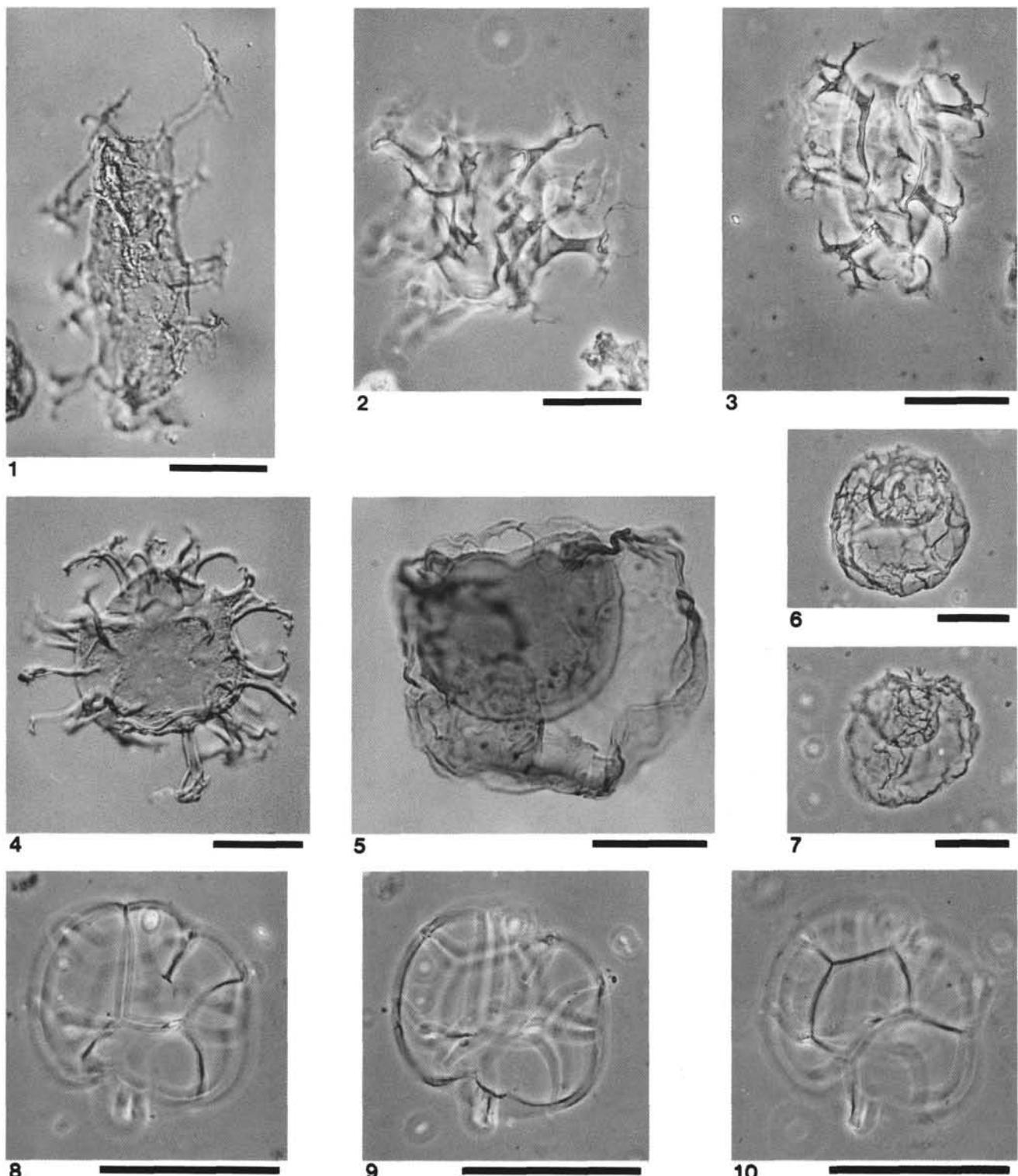


Plate 7. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1. *Distatodinium ellipticum*; 104-643A-51-1, 30-32 cm (I). 2. *D. craterum*; 104-643A-32-1, 30-32 cm (Ph). 3. *D. paradoxum* (Brosius) Eaton 1976; 104-643A-33-1, 53-54 cm (Ph). 4. *Glyphaeocystis intricata*; 104-643A-47-1, 90-92 cm (I). 5. *Glyphaeocystis* cf. *vicina*; 104-643A-52-4, 28-30 cm (B). 6-7. *Gelatia* sp. 1; 104-643A-48-6, 90-92 cm (Ph). dorsal side up. 8-10. *?Evittosphaerula* sp. 2; 104-642C-15-1, 79-81 cm (PH). 8: antapical, hi. 9: equatorial. 10: antapical, lo.

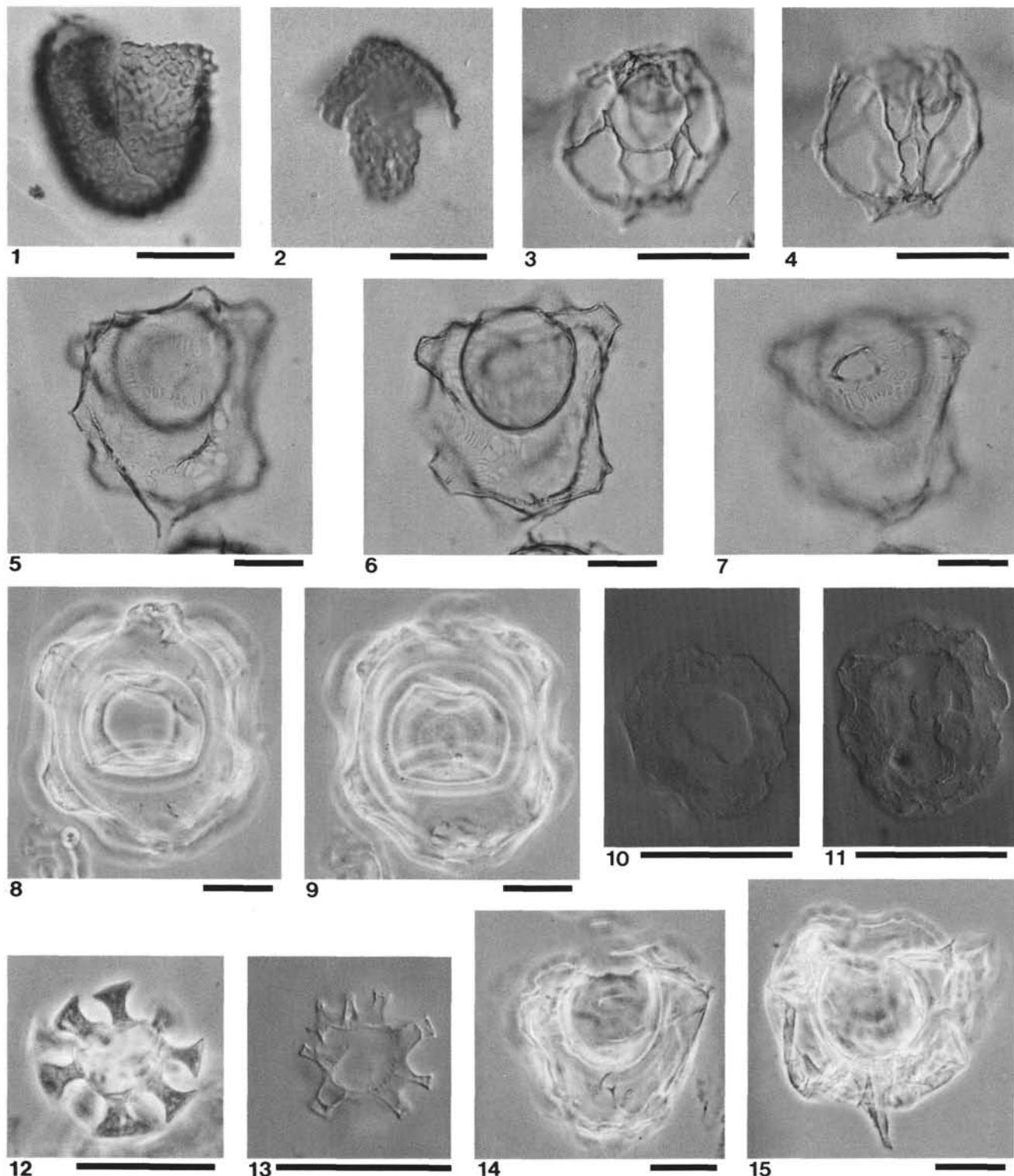


Plate 8. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1-2. Dinocyst 1; 104-643A-57-4, 30-32 cm (B). 2: shows the operculum. 3-4. Dinocyst 3 (*?Evittosphaerula* sp. 1); 104-643A-48-6, 90-92 cm (I). 5-7. Dinocyst 4; 104-643A-24-5, 30-32 cm (B). 5: left lateral, hi. 6: equatorial. 7: left lateral, lo. 8-9. Dinocyst 6; 104-643A-23-2, 81-84 cm (Ph). 10-11. Dinocyst 7; 104-643A-12-5, 31-33 cm (I). 10: antapical, lo. 11: hi. 12. Dinocyst II of Manum 1976; 104-642C-21-6, 30-32 cm (Ph). 13. Dinocyst IV of Manum 1976; 104-643A-32-1, 30-32 cm (I). 14. Dinocyst 5; 104-643A-24-5, 30-32 cm. Dorsal, hi. (Ph) 15. Dinocyst 5; 104-643A-27-5, 31-33 cm. Equatorial. (Ph).

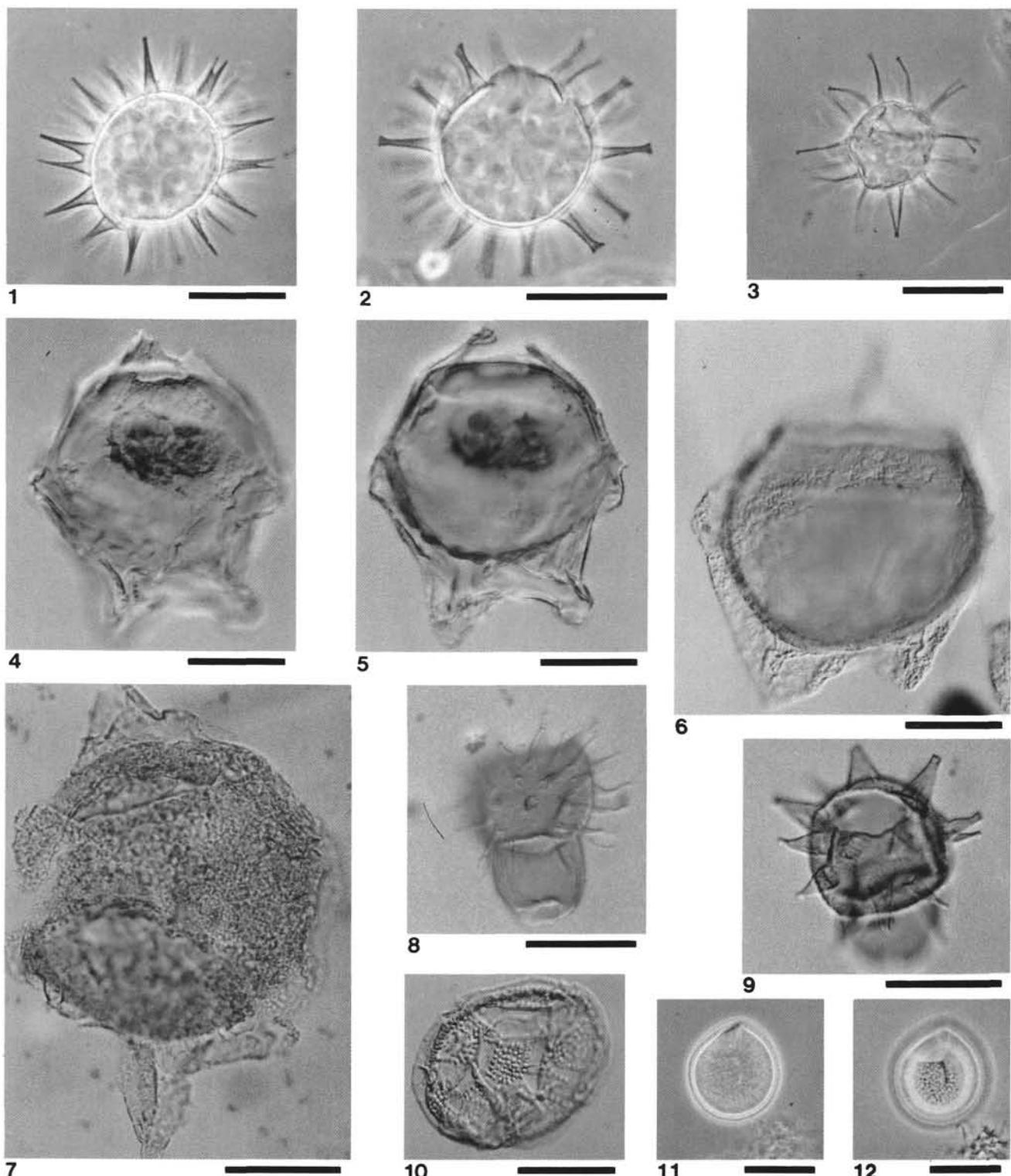


Plate 9. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1. *Dapsilidinium pastielsii*; 104-643A-8-6, 48-50 cm (Ph). 2. *D. pseudocolligerum*; 104-643A-32-1, 30-32 cm (Ph). 3. *Dapsilidinium* sp. 1; 104-643A-16-1, 30-32 cm (Ph). 4-5. *Deflandrea phosphoritica*; 104-643A-48-5, 90-92 cm (I). 6. *D. cf. phosphoritica*; 104-643A-53-3, 30-33 cm (I). 7. *Deflandrea* sp. B of Powell 1986a; 104-643A-50-1, 30-32 cm (B). All specimens in state of bad preservation; this one is among the best preserved. 8. *Diphyes* cf. *colligerum*; 104-643A-60-2, 31-33 cm (B). 9. *Diphyes* sp. 1; 55-5, 30-32 cm (B). 10. *Dinopterygium cladoides* sensu Morgenroth 1966; 104-643A-51-3, 30-32 cm (I). 11-12. *Filisphaera filifera*; 104-643A-12-4, 31-33 cm (Ph).

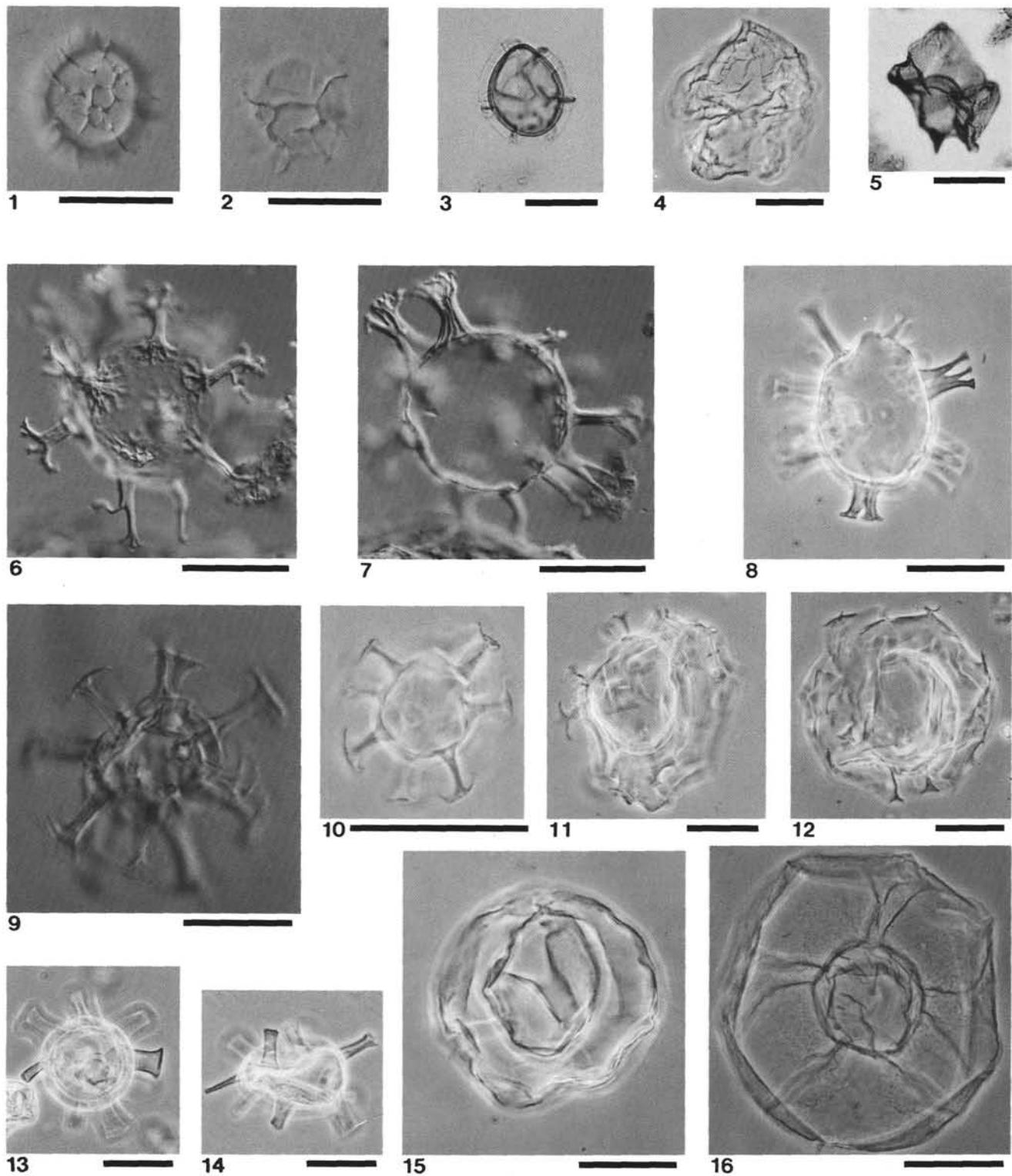


Plate 10. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1-2. Gen. et sp. indet. of Piasecki 1980; 104-643A-11-5, 30-32 cm (I). 1: dorsal, lo. 2: dorsal, hi. 3. Gen. et sp. indet. of Piasecki 1980; 104-642C-22-5, 67-70 cm (B). Probably a *Corrudinium* sp. Equatorial. 4. *Lejeuneocysta* cf. *hyalina*; 104-643A-15-6, 28-30 cm (Ph). 5. *L. fallax*; 104-643A-12-1, 31-33 cm (B). 6-7. *Homotryblium floripes*; 104-643A-46-5, 82-84 cm (I). 8. *H. vallum*; 104-643A-11-5, 30-32 cm (Ph). 9. *Hystrichosphaeridium latirictum*; 104-643A-46-5, 82-84 cm (I). 10. *H. latirictum*; 104-643A-25-2, 30-32 cm (Ph). 11. *Hystrichostroglylon* cf. *membraniphorum*; 104-643A-12-1, 31-33 cm (Ph). 12. *Hystrichostroglylon* sp. of Edwards 1984; 104-643A-12-1, 31-33 cm (Ph). 13. *Hystrichosphaeridium* sp. 1; 104-643A-18-1, 31-33 cm (Ph). Left lateral, hi. 14. *Hystrichosphaeridium* sp. 1; 104-643A-20-6, 30-32 cm (Ph). Equatorial. 15. *Invertocysta lacrymosa*; 104-643A-13-6, 31-33 cm (Ph). 16. *I. tabulata*; 104-643A-13-4, 31-33 cm (Ph).

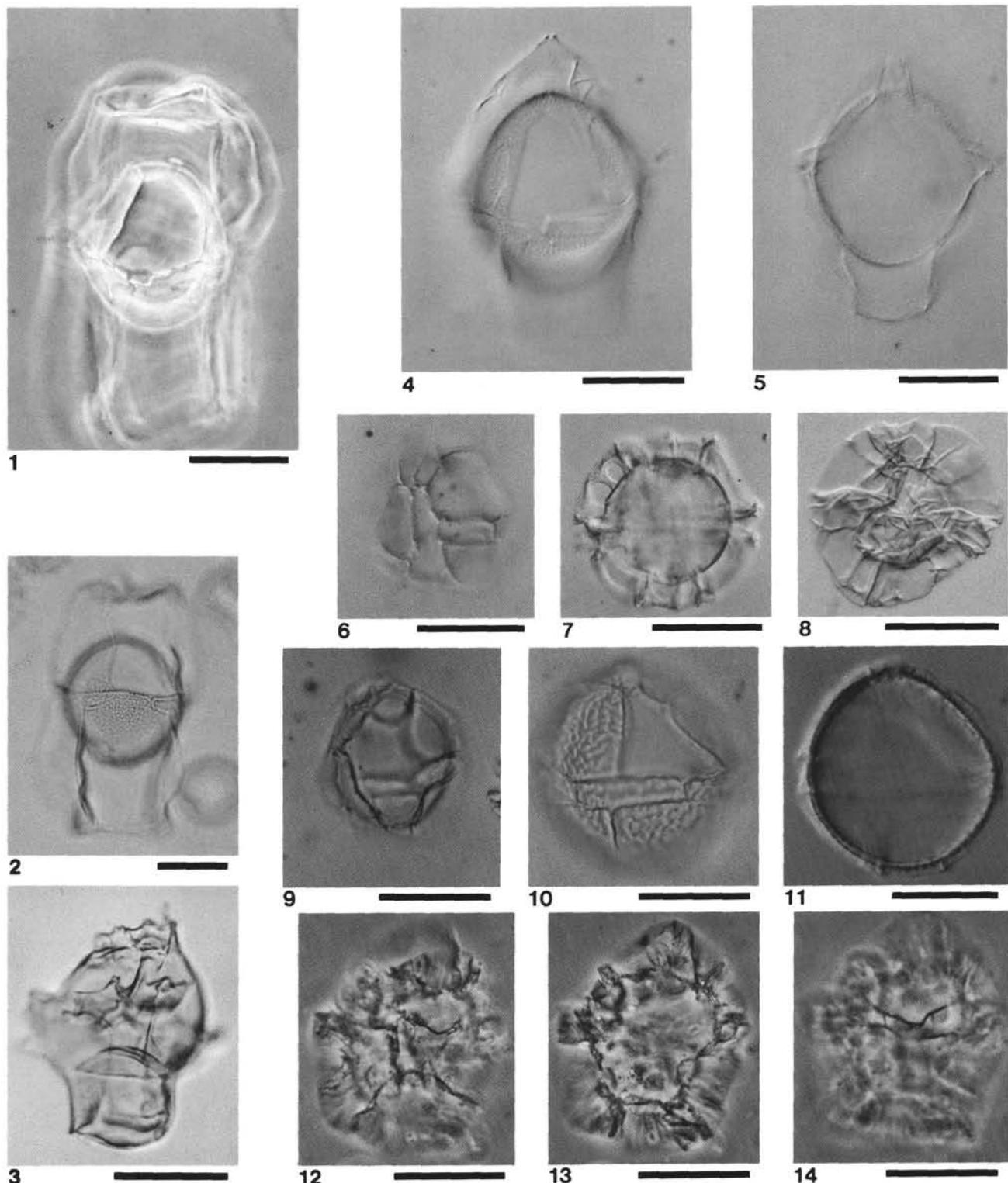


Plate 11. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1. *Hystrichosphaeropsis obscura*; 104-643A-15-6, 28–30 cm (Ph). With smooth endophragm. 2. *H. obscura*; 104-643A-12-4, 31–33 cm (I). With granular endophragm. 3. *Hystrichosphaeropsis* sp. 1; 104-643A-55-5, 30–32 cm (B). 4–5. *H. cf. complanata*; 104-643A-16-1, 30–32 cm (I). 6–7. *Impagidinium aqueductum*; 104-643A-12-5, 31–33 cm (I). 8. *I. velorum*; 104-643A-55-5, 30–32 cm (B). 9. *I. paradoxum*; 104-643A-12-5, 31–33 cm (I). 10–11. *I. maculatum*; 104-643A-13-6, 31–33 cm (I). 12–14. *Impagidinium* sp. 2; 104-643A-12-5, 31–33 cm (Ph). 12: ventral, hi. 13: equatorial. 14: ventral, lo.

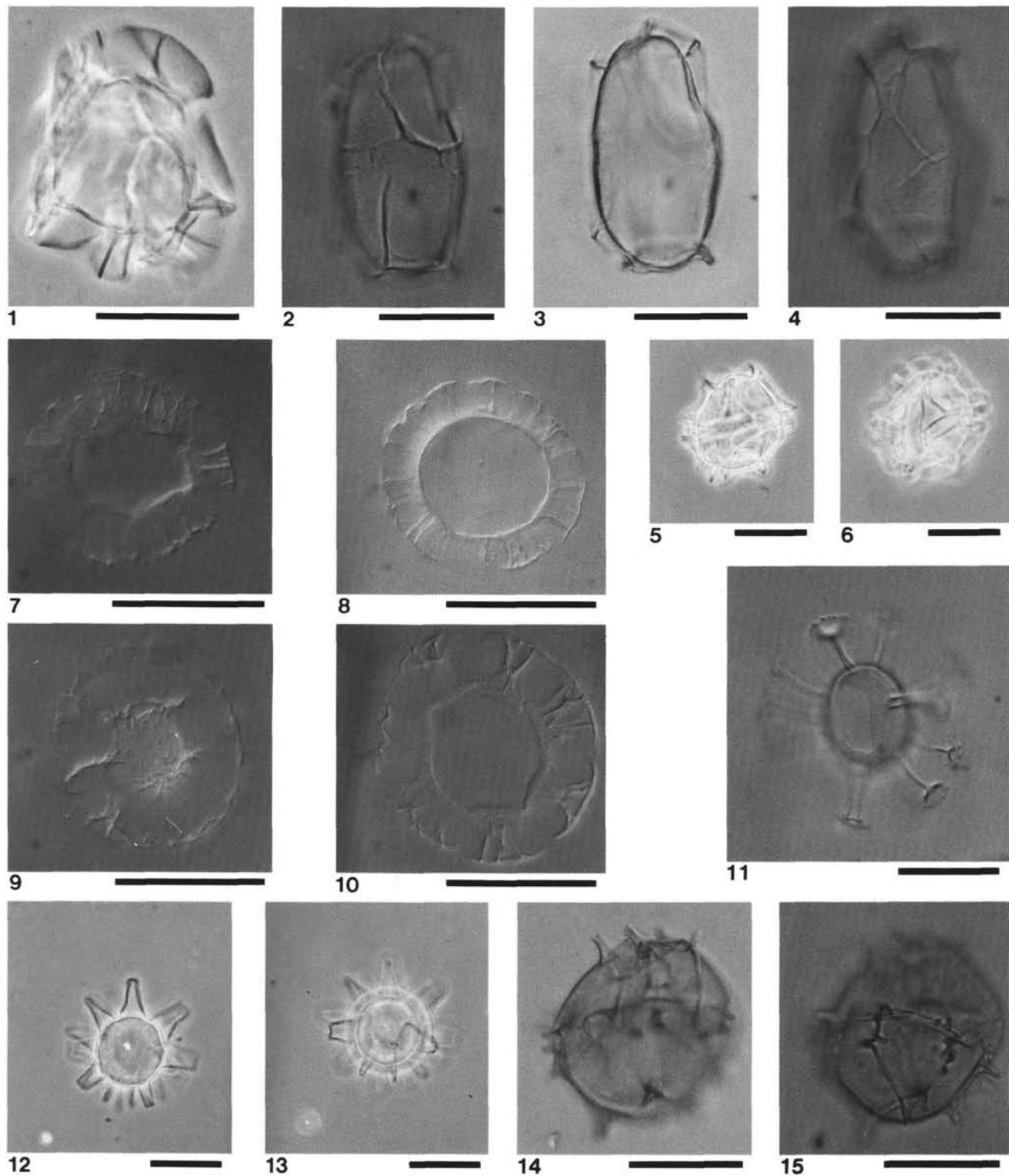


Plate 12. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1. *Impagidinium japonicum*; 104-643A-20-6, 30-32 cm (Ph). 2-4. *Impagidinium* sp. 3; 104-643A-10-5, 31-33 cm. 2: oblique dorsal, hi. (I). 3: equatorial. (B). 4: oblique dorsal, lo. (Ph). 5-6. *Impagidinium* sp. 4; 104-643A-24-5, 30-32 cm (Ph). 5: equatorial. 6: dorsal, lo. 7-8. *Labyrinthodinium truncatum*; 104-643A-11-5, 30-32 cm (I). 9-10. *L. cf. truncatum*; 104-643A-11-5, 30-32 cm (I). 9: apical, hi. 10: apical, lo. 11. *Melitasphaeridium choanophorum*; 104-643A-11-5, 30-32 cm (I). 12-13. *Liotosphaeridium* sp. 1; 104-642C-17-1, 69-72 cm (I). 12: equatorial. 13: antapical, lo. 14-15. ?*Leptodinium* sp. III of Manum 1976; 104-643A-32-1, 30-32 cm (I). Probably a *Impagidinium* sp.

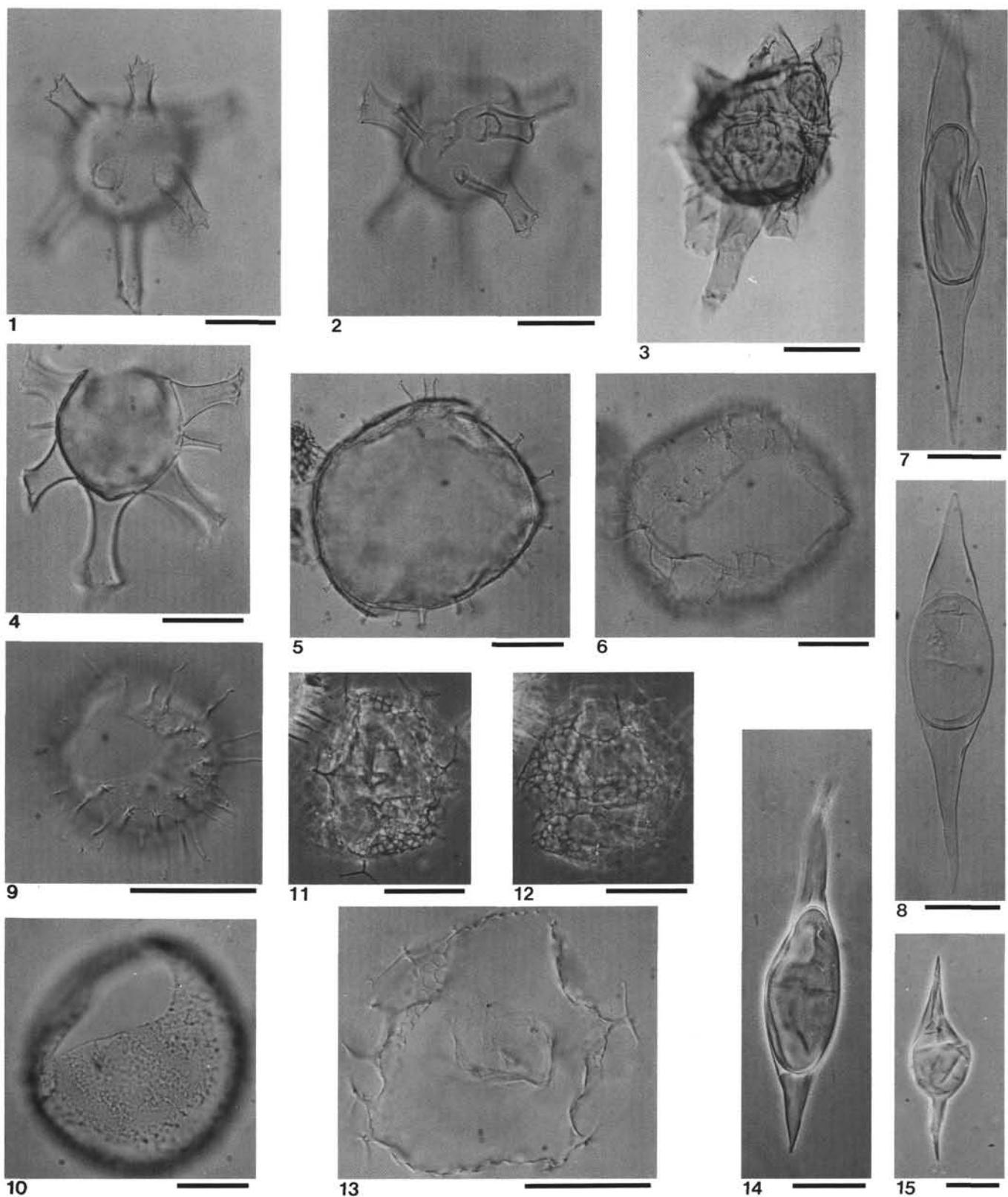


Plate 13. (Scale bars = 30 µm; Ph = phase, I = interference, B = bright field). 1–2. *?Hystrichokolpoma* sp. 2; 104-643A-28-7, 30–31 cm (I). The species lacks paracingular processes, but shows affinity to *H. rigaudiae*. 1: ventral, lo. 2: ventral, hi. 3. *Hystrichokolpoma cinctum*; 104-643A-45-2, 29–31 cm (B). 4. *H. rigaudiae*; 104-643A-11-5, 30–32 cm (I). 5–6. *Operculodinium* sp. 3; 104-643A-10-5, 31–33 cm (I). 5: equatorial. 6: dorsal, hi. 7–8. *Palaeocystodinium* sp. 1; 104-643A-37-3, 31–33 cm (I). 7: equatorial. 8: ventral, lo. 9. *Operculodinium centrocarpum*; 104-643A-16-1, 30–32 cm (I). 10. *Operculodinium* sp. 2; 104-643A-13-6, 31–33 cm (I). 11–13. *Hystrichostrogylom* sp. 1; 104-643A-16-1, 30–32 cm. 11: oblique dorsal, medium hi. (Ph) 12: oblique dorsal, hi. (Ph) 13: left lateral, medium hi. (I) 14. *Palaeocystodinium* sp. 3; 104-643A-29-6, 30–32 cm (Ph). Similar to *Svalbardella hampdenensis*. 15. *Palaeocystodinium* sp. A of Costa and Downie 1979; 104-643A-12-5, 31–32 cm (Ph).

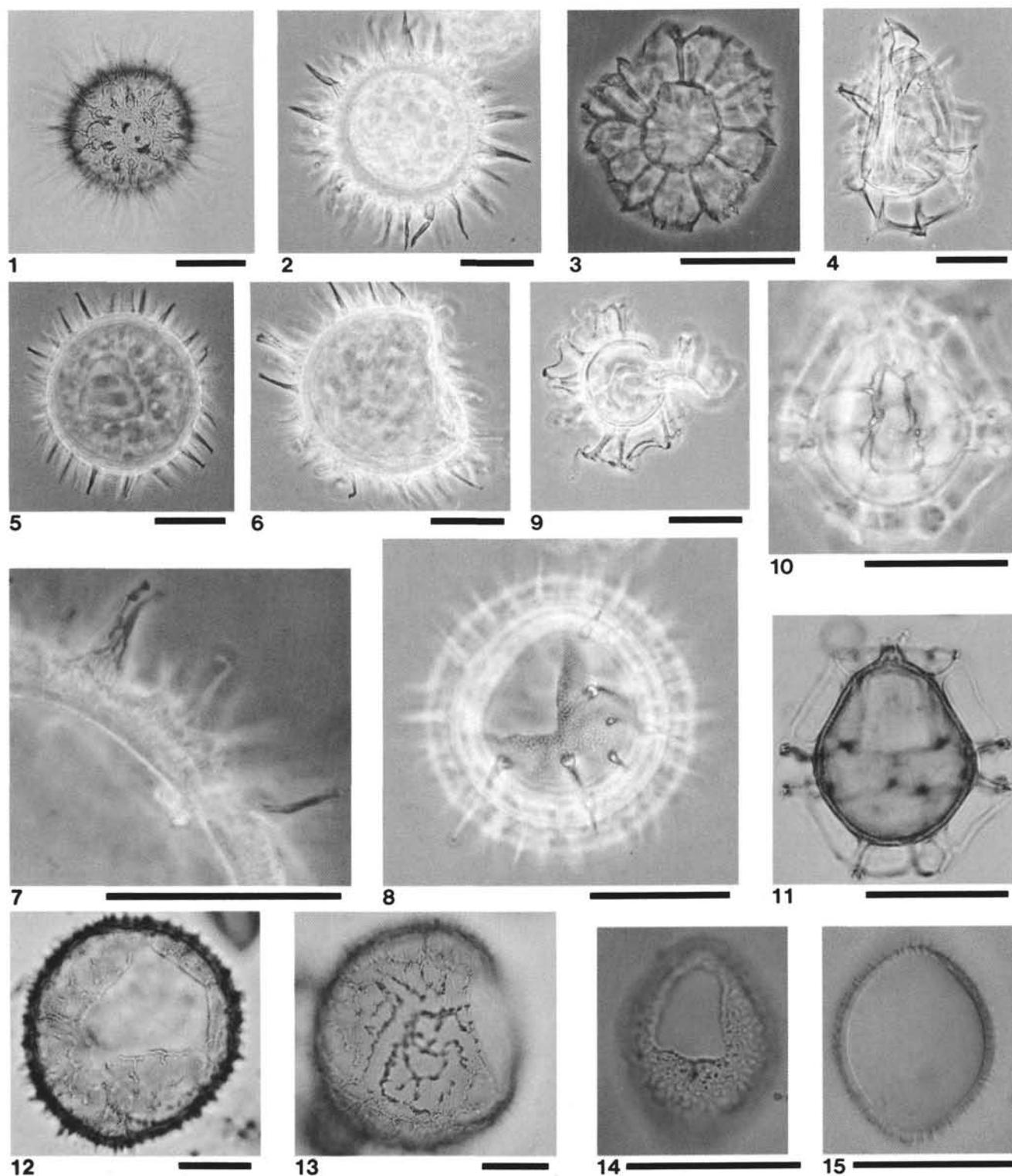


Plate 14. (Scale bars = 30  $\mu$ m; Ph = phase, I = interference, B = bright field). 1-2. *Lingulodinium* sp. 1; 104-643A-18-1, 31-33 cm (1:B, 2:Ph). Epicystral archeopyle. 3. *Nematosphaeropsis lemniscata*; 104-643A-16-1, 30-32 cm (Ph). 4. *N. downii*; 104-643A-20-6, 30-32 cm (Ph). 5. *Operculodinium crassum*; 104-643A-9-5, 30-32 cm (Ph). 6. *O. crassum*; 104-643A-26-5, 30-32 cm (Ph). 7. *O. crassum*; 104-643A-16-1, 30-32 cm (Ph). Detail showing processes. 8. *O. longispinigerum*; 104-642C-12-1, 79-80 cm (Ph). 9. *Nematosphaeropsis* sp. 2; 104-643A-8-6, 48-50 cm. Equatorial (Ph). Rare type with long processes. 10-11. *Nematosphaeropsis* sp. 2; 104-643A-12-1, 31-33 cm. 10: ventral, hi. (Ph). 11: equatorial. (B). 12-13. *Operculodinium* cf. *giganteum*; 104-642C-17-1, 69-72 cm (B). 12: ventral, lo. 13: left lateral. 14-15. *O. placitum*; 104-643A-16-1, 30-32 cm (I).

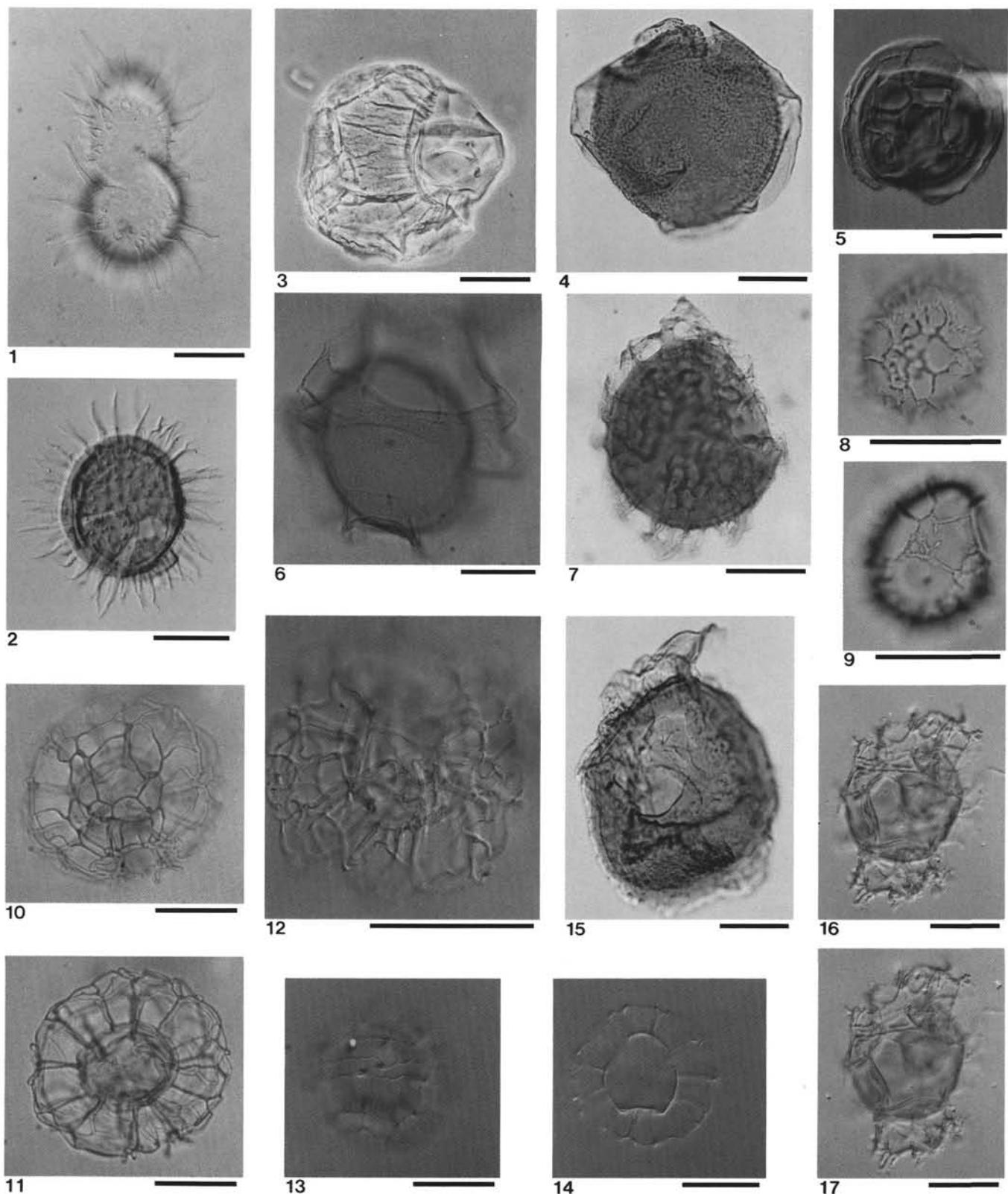


Plate 15. (Scale bars = 30 µm; Ph = phase, I = interference, B = bright field). 1. *Lingulodinium machaerophorum*; 104-643A-13-6, 31–33 cm (I). 2. *L. machaerophorum*; 104-643A-45-2, 29–31 cm (I). 3. *Lophocysta sulcolimbata*; 104-643A-26-5, 30–32 cm (Ph). 4. *Pentadinium laticinctum granulatum*; 104-643A-45-2, 29–31 cm (I). 5. *P. laticinctum laticinctum*; 104-643A-49-1, 30–32 cm (B). 6. *P. laticinctum imaginatum*; 104-643A-29-6, 30–32 cm (I). 7. *Samlandia chlamydophora*; 104-643A-51-4, 30–32 cm (B). 8–9. *Corrudinium* sp. 1; 104-643A-13-6, 31–33 cm (I). 8: left lateral/ventral, hi. 9: left lateral/ventral, lo. 10–11. *Nematosphaeropsis* sp. 1; 104-643A-51-4, 30–32 cm (B). 12. *Nematosphaeropsis labyrinthaea*; 104-643A-44-4, 30–32 cm (I). 13–14. *N. labyrinthaea*; 104-643A-15-6, 28–30 cm (I). 15. *Samlandia* sp. 1; 104-643A-48-1, 90–92 cm (I). Typical is the incomplete ectophragm. 16–17. *Rottnestia borussica*; 104-643A-60-2, 31–33 cm (I).

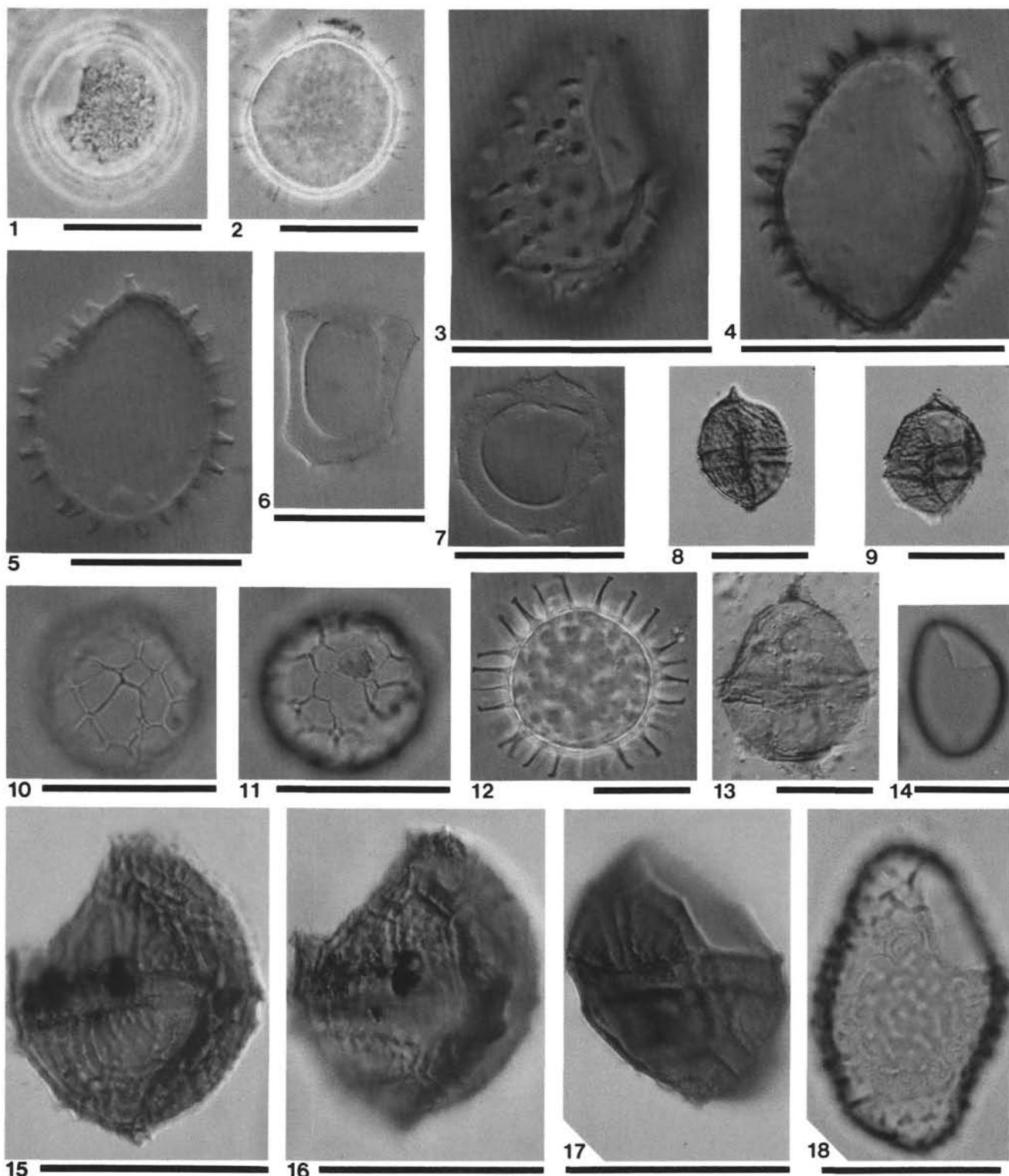


Plate 16. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1-2. *Operculodinium israelianum*; 104-642C-12-1, 78-80 cm (Ph). 3-4. *Operculodinium* sp. 1; 104-643A-42-3, 19-21 cm (I). 5. *Operculodinium* sp. of Piasecki 1980; 104-643A-20-6, 30-32 cm (I). 6. *Platycystidium* sp. II of Manum 1976; 104-643A-29-6, 30-32 cm (I). 7. *Platycystidium* sp. II of Manum 1976; 104-643A-11-6, 30-32 cm (I). 8-9. *Phthanoperidinium stockmansii*; 104-643A-54-1, 30-32 cm (I). 10-11. *Problematicum* IV of Manum 1976; 104-643A-32-1, 31-32 cm (I). 10: apical, hi. 11: apical, lo. 12. *Polysphaeridium* cf. *subtile*; 104-643A-14-5, 32-34 cm (Ph). 13. *Phthanoperidinium* cf. *eocenicum*; 104-643A-51-1, 30-32 cm (I). 14. *Pyxidiella* sp. 1; 104-643A-22-5, 30-32 cm (B). 15-16. *Phthanoperidinium* *geminatum*; 104-643A-54-1, 30-32 cm (I). 17. *P. geminatum*; 104-643A-56-4, 30-32 cm (I). Two plates are lost in the archeopyle, one intercalary and one precingular. 18. *?Pyxidiella simplex*; 104-642D-3-2, 80-82 cm (I).

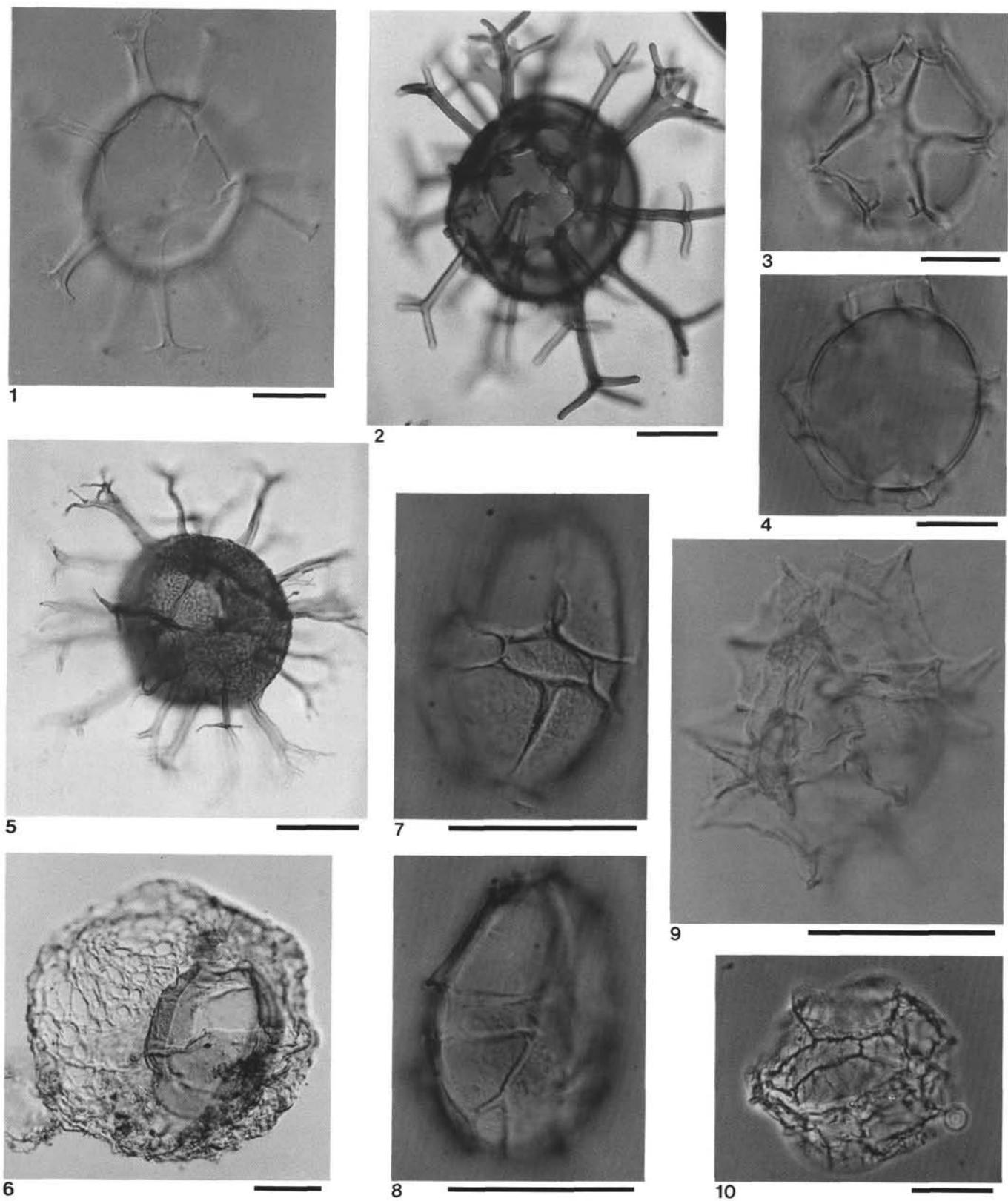


Plate 17. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1. *Spiniferites pseudofurcatus*; 104-643A-9-5, 30–32 cm (I). 2. *Spiniferites* sp. 2; 104-643A-49-1, 30–32 cm (B). 3–4. *Impagidinium patulum*; 104-643A-25-6, 30–32 cm (I). 5. *Spiniferites* sp. 1; 104-643A-49-4, 30–32 cm (B). 6. *Thalassiphorafenestrata*; 104-643A-51-3, 30–32 cm (I). 7–8. *Impagidinium* sp. 1; 104-643A-44-6, 30–32 cm (I). 9. *Impagidinium aculeatum*; 104-643A-44-6, 30–32 cm (I). 10. *I. pallidum*; 104-643A-27-5, 31–33 cm (Ph).

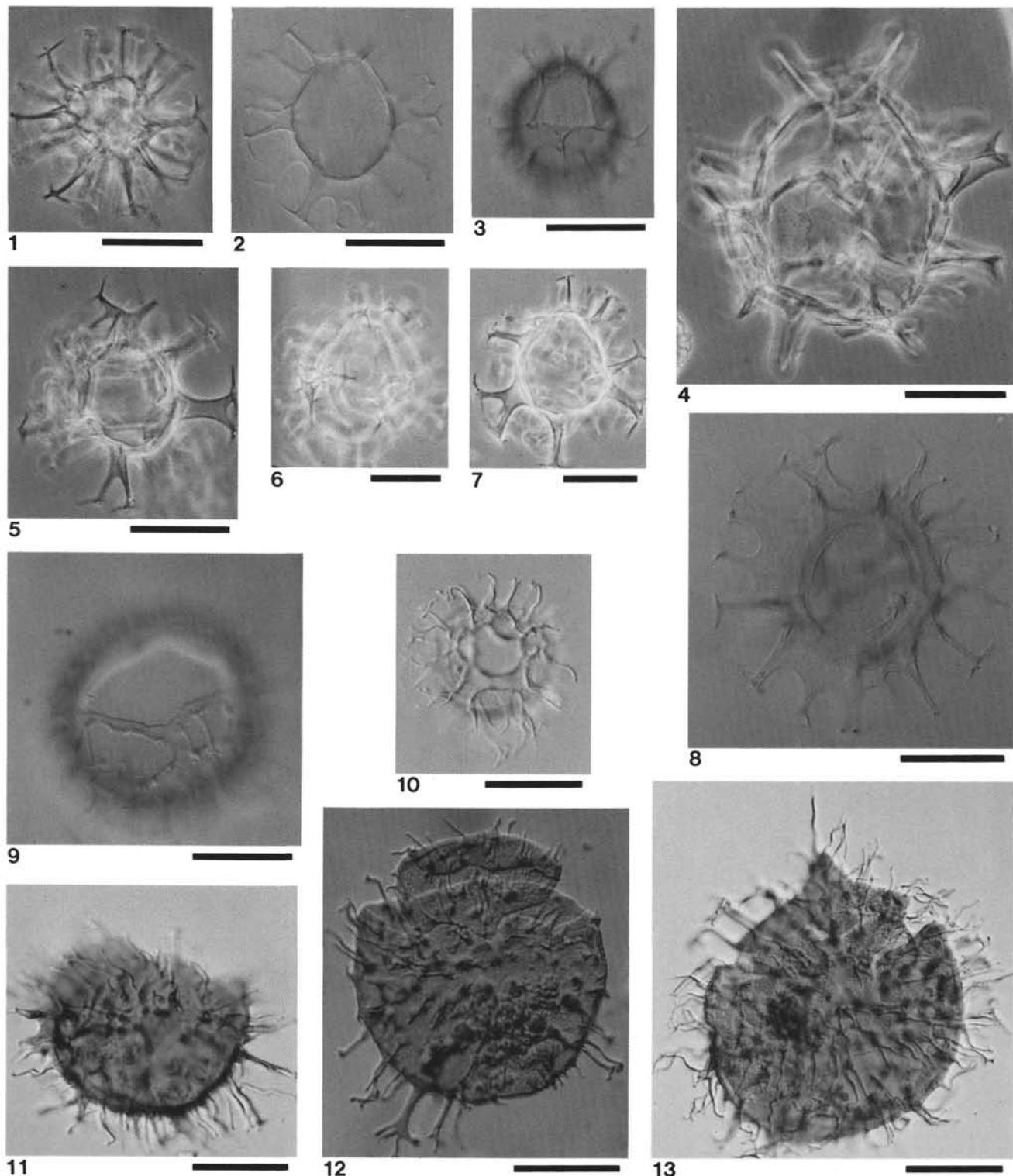


Plate 18. (Scale bars = 30  $\mu$ m, Ph = phase, I = interference, B = bright field). 1. *Spiniferites ramosus*-group; 104-643A-11-5, 30-32 cm (Ph). 2. *S. ramosus*-group; 104-643A-11-5, 30-32 cm (I). 3. *S. ramosus*-group; 104-643A-20-6, 30-32 cm (I). 4. *S. ramosus*-group; 104-643A-18-1, 31-33 cm (Ph). 5-7. *Spiniferites* sp. 4; 104-643A-11-5, 30-32 cm (Ph). 5: equatorial. 6: left lateral, hi. 7: equatorial. 8. *Spiniferites ramosus*-group; 104-643A-8-6, 48-50 cm (I). 9. *Systematophora placacantha*; 104-643A-15-6, 28-30 cm (I). 10. *S. placacantha*; 104-643A-41-1, 18-20 cm (I). 11-13. *Systematophora* sp. 1; 104-643A-45-4, 29-31 cm (I). Note the great variability, ring-structures at the process-bases more or less distinct.

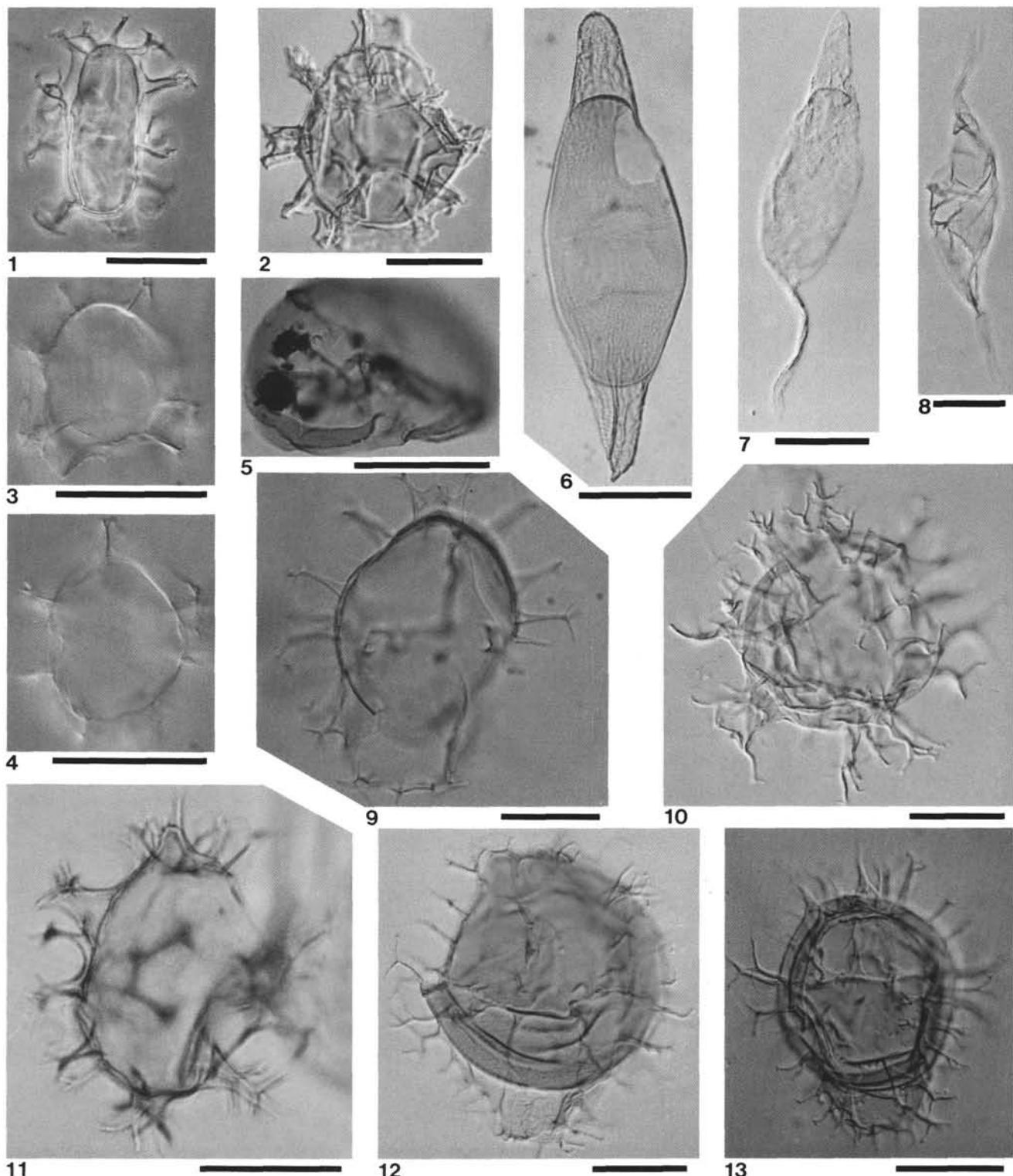


Plate 19. (Scale bars = 30  $\mu\text{m}$ , Ph = phase, I = interference, B = bright field). 1. *Spiniferites elongatus*; 104-643A-8-6, 48–50 cm (Ph). 2. *Pterodinium cf. premnos*; 104-643A-55-5, 30–32 cm (I). 3–4. *P. cingulatum cingulatum*; 104-643A-11-5, 30–32 cm (I). 5. *Selenopemphix nephroides*; 104-643A-12-5, 30–32 cm (I). 6. *Svalbardella cooksoniae*; 104-643A-50-1, 30–32 cm (B). 7. *Palaeocystodinium* sp. 2; 104-643A-39-1, 30–32 cm (Ph). All specimens badly preserved. 8. *Palaeocystodinium golzowense*; 104-643A-25-2, 30–32 cm (Ph). 9. *Spiniferites* cf. *mirabilis*; 104-643A-11-5, 30–32 cm (I). Note the apical "crown". 10. *S. hyperacanthus*; 104-643A-44-4, 30–32 cm (I). 11. *S. bentorii*; 104-643A-8-6, 48–50 cm (B). 12–13. *Spiniferites* sp. 3; 104-643A-45-2, 29–31 cm (I) resembles *S. mirabilis*, but have more processes participating in the antapical fringe.

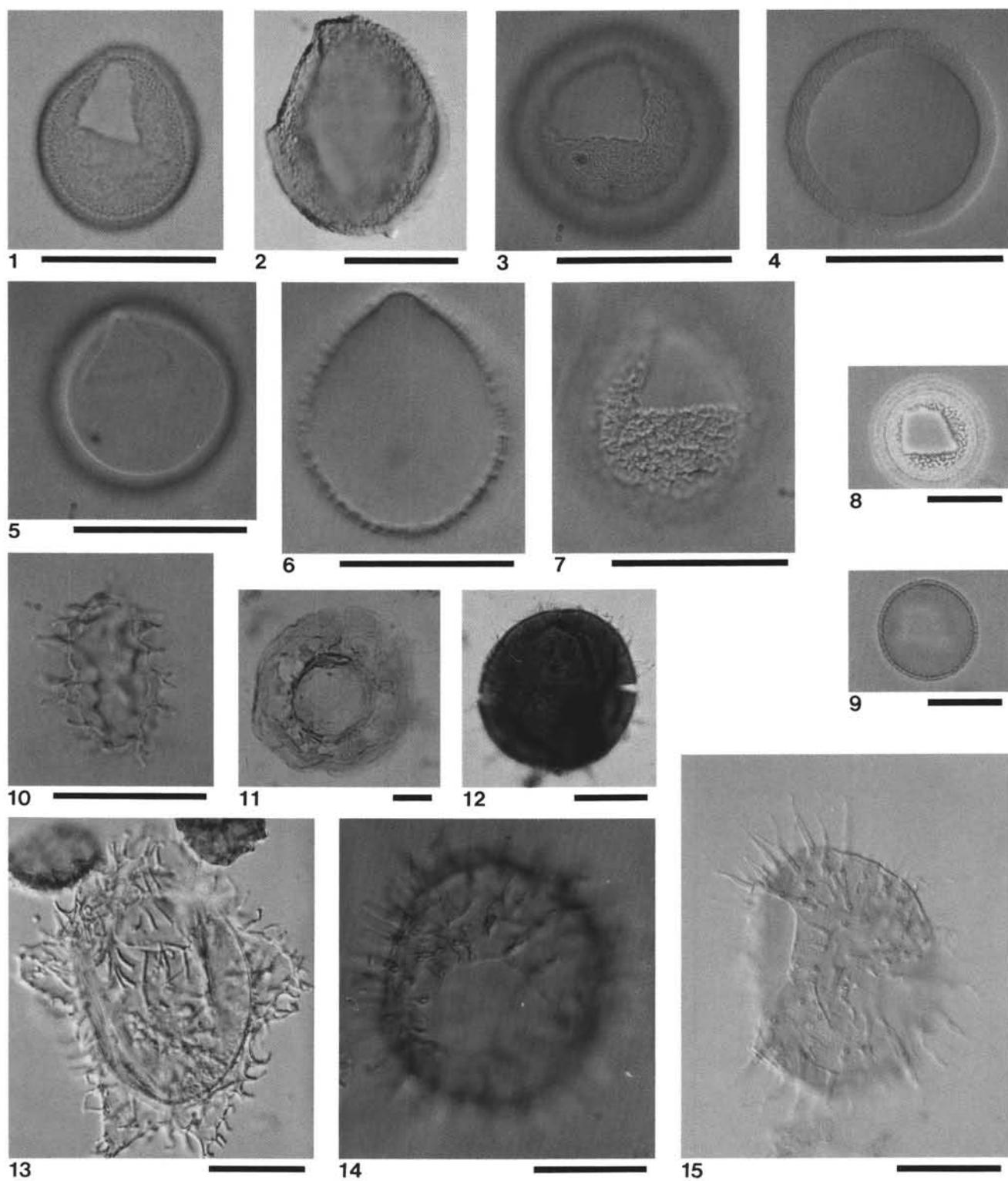


Plate 20. (Scale bars = 30  $\mu\text{m}$ ; Ph = phase, I = interference, B = bright field). 1. *Tectatodinium psilatum*; 104-643A-11-5, 30–32 cm (I). Sca-brate type. 2. *Tectatodinium* sp. 1; 104-643A-55-5, 30–32 cm (B). 3–4. *Tectatodinium* sp. 2; 104-643A-8-6, 48–50 cm (I). 3: dorsal, hi. 4: equato-rial. 5. *Tectatodinium psilatum*; 104-643A-22-5, 30–32 cm (I). Psilate type. 6–7. *Tectatodinium* sp. 4; 104-643A-11-5, 30–32 cm (I). 6: equato-rial. 7: dorsal, hi. 8–9. *Tectatodinium* sp. 3; 104-643A-15-6, 28–30 cm. 8: dorsal, hi. (Ph) 9: equatorial (I). 10. *Tanyosphaeridium* sp. I of Manum 1976; 104-643A-33-1, 53–54 cm (I). 11. *Tuberculodinium vancampoae*; 104-643A-29-1, 30–32 cm (I). 12. ?*Sumatrardinium* sp. C of Powell 1986a; 104-642D-6-5, 80–82 cm (B). Specimen from unoxidized sample. 13. *Wetzelella articulata*; 104-643A-60-2, 31–33 cm (B). 14. ?*Sumatrardinium* sp. D of Powell 1986a; 104-643A-11-5, 30–32 cm (I). 15. ?*Sumatrardinium* sp. C of Powell 1986a; 104-643A-28-7, 30–31 cm (I). Specimen from oxidized sample.

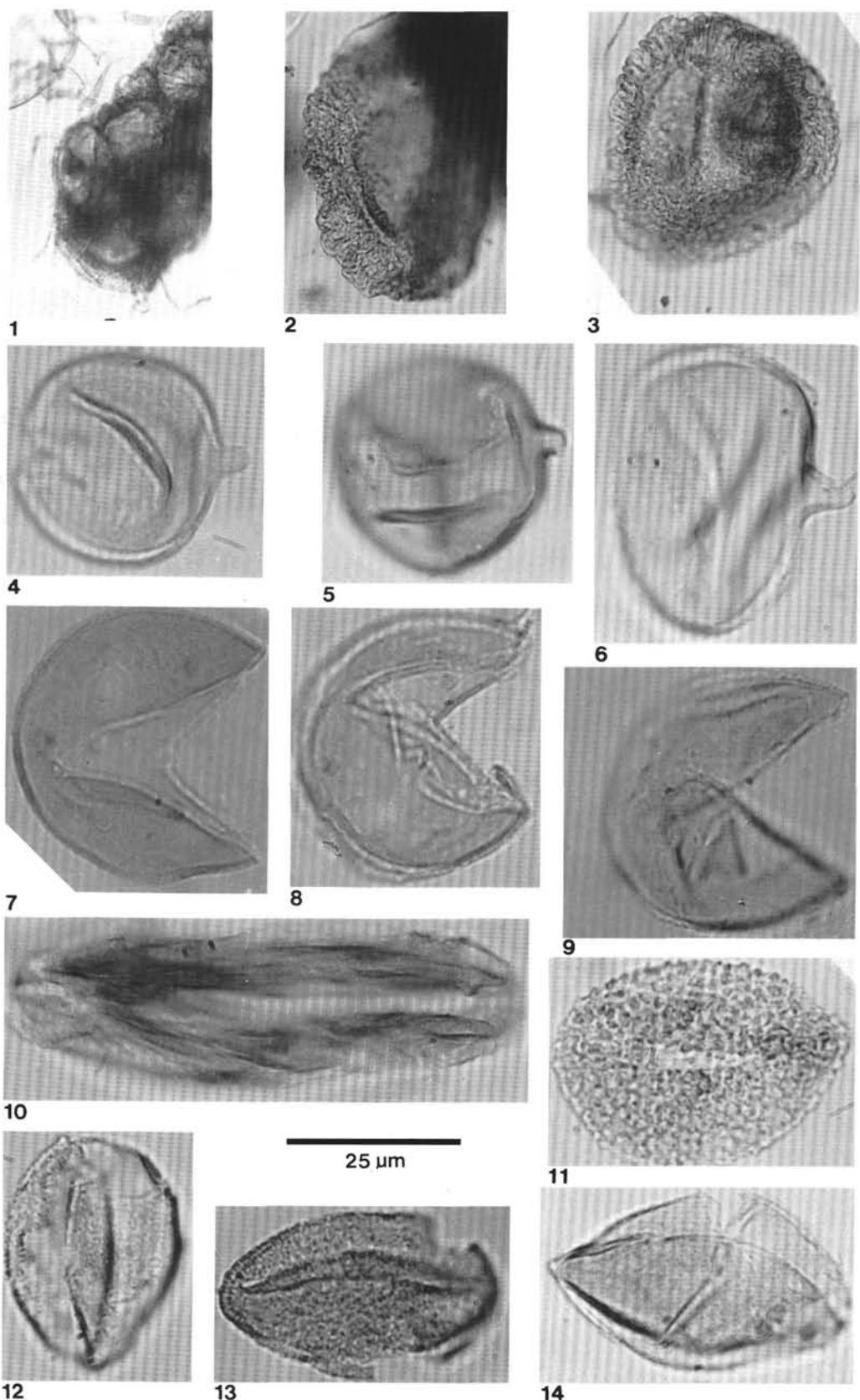


Plate 21. (Scale bars = 25 µm) 1. *Azolla MASSULA* with GLOCHIDIA; 104-643A-60-2, 32 cm. 2-3. BIGFRILLED MONOSACCATES; 104-643A-42-4, 20 cm. 4-6. PAPILLATE INAPERTURATES; 104-642B-20-7, 67 cm. 7-9. SPLIT INAPERTURATES; 104-642B-20-7, 67 cm. 10. RIBBED ELLIPTICAL; 104-643A-38-2, 30 cm. 11. VERRUCATE MONOCOLPATE; 104-643A-34-1, 30 cm. 12-13. RETICULATE MONOCOLPATES; 104-643A-22-1, 30 cm. 14. POINTED MONOCOLPATE; 104-643A-11-1, 30 cm.

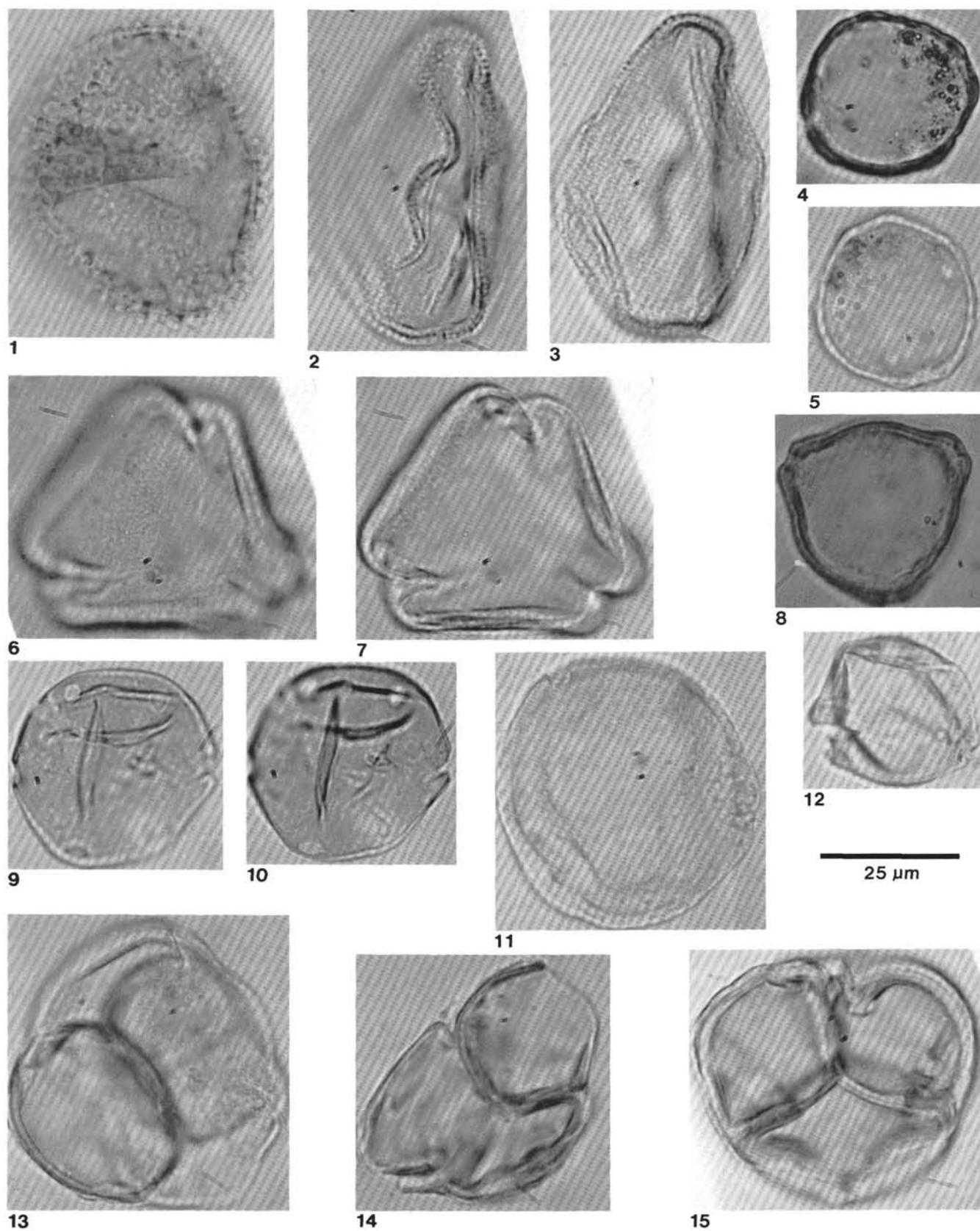


Plate 22. (Scale bars = 25  $\mu\text{m}$ ) 1. BACULATE TRILETE; 104-643A-25-3, 30 cm. 2-3. RETICULATE MONOCOLPATE; 104-643A-22-1, 30 cm. 4-5. RUGULATE MULTIPORATES; 104-642C-20-7, 67 cm. 6-7. LARGE TRICOLPATE; 104-642C-21-6, 84 cm. 8. THICKPORE TRIPORE; 104-642B-13-5, 68 cm. 9-10. RUGULATE MULTIPORATE; 104-642C-20-7, 67 cm. 11. THINPORE TRIPORATE; 104-643A-15-5, 28 cm. 12. SMALLPORE TRIPORATE; 104-643A-44-7, 40 cm. 13-15. TETRADS; 104-643A-24-5, 30 cm.

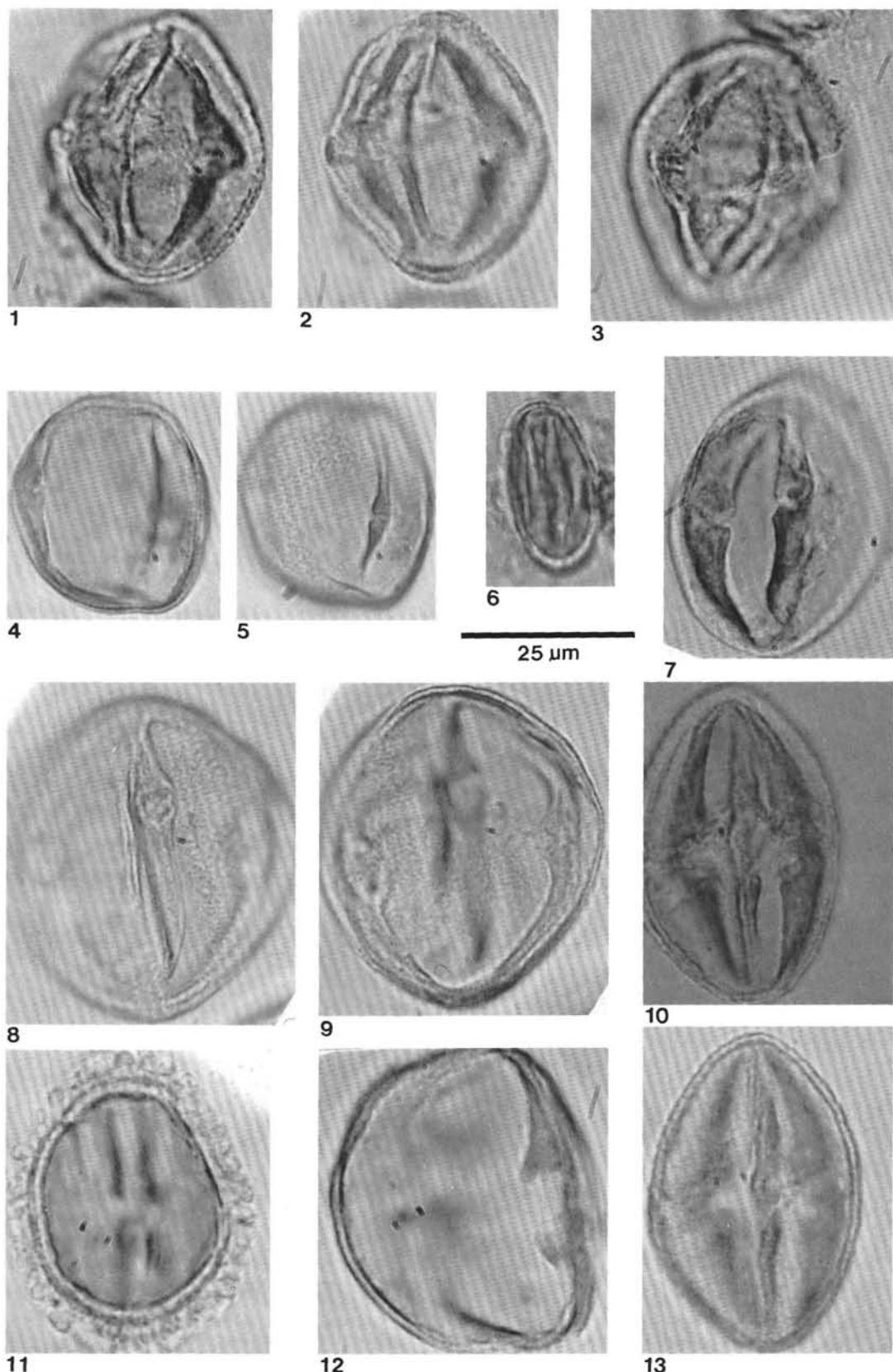


Plate 23. (Scale bars = 25  $\mu\text{m}$ ) 1-3. LARGE TRICOLPORATES; 104-643A-10-1, 35 cm. 4-5. ROUND TRICOLPORATE; 104-642C-20-7, 67 cm. 6. SMALL TRICOLPATE; 104-642B-21-6, 84 cm. 7-10. LARGE TRICOLPORATES; 104-642B-21-6, 84 cm. 11. CLAVATE TRICOLPORATE; 104-642B-20-6, 84 cm. 12-13. LARGE TRICOLPORATES; 104-642B-21-6, 84 cm.