Barker, P. F., Kennett, J. P., et al., 1990
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 113

36. EOCENE AND OLIGOCENE SPOROMORPHS AND DINOFLAGELLATE CYSTS FROM LEG 113 DRILL SITES, WEDDELL SEA, ANTARCTICA[1]

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ABSTRACT

Palynological studies were carried out on Paleogene sections from Sites 693 and 696 of Ocean Drilling Project Leg 113 in the Weddell Sea region. Dinoflagellate cysts and sporomorphs were recovered at Site 696 (61°S, 42°W) indicating a middle Eocene to late Eocene/earliest Oligocene age for a glauconitic silt/sandstone. At Site 693 (70°S, 14°W) early Oligocene siliciclastic mud contains a low diversity palynoflora. In an upper Oligocene section (Site 693) only rare, reworked Mesozoic palynomorphs were encountered.

Palynological data from Kerogen analyses, dinocysts, and sporomorphs are used to reconstruct the climatic change on the South Orkney microcontinent from the middle Eocene to the late Eocene/earliest Oligocene at Site 696 and the late early Oligocene/early late Oligocene time interval at Site 693 near the continental margin. The middle Eocene was a warm period in the Orkney region with good growing conditions for a warm temperate *Nothofagus*/conifer forest with an admixture of Proteaceae. Temperate surface water masses, which allowed the growth of a reasonably diverse dinocyst assemblage (ca. 15–20 species), persisted until the end of the Eocene at Site 696. Late early Oligocene sediments of Site 693 (Antarctic continental margin) contain only a low diversity dinocyst flora (two species).

The major Cenozoic cooling event in the Weddell Sea region probably occurred at the Eocene/Oligocene boundary. A second dramatic climatic deterioration seems to have taken place during the late early/early late Oligocene, when dinocysts disappeared at the Dronning Maud Land margin area.

INTRODUCTION

One of the major goals of Leg 113 was to study the development of the present circum-Antarctic water masses, especially the onset of the cold Antarctic Bottom Water, associated with the increase of continental glaciation during the Cenozoic Era (Leg 113 Shipboard Scientific Party, 1987; Pudsey et al.,1988). Dating of the build-up of large ice-sheets on the Antarctic continent, with their strong feedback effects on the climatic development of the total globe, is still controversial (Hsü et al., 1984; Kennett, 1980; Webb et al., 1984; Robin, 1988).

One approach to answering these questions is the interpretation of paleobotanical and palynological data collected from the Paleogene time interval, from which the first signals of ice rafting were reported (Barker, Kennett, et al., 1988a and b).

Most previous palynological investigations on Antarctic Paleogene material (Cranwell et al., 1960; Cranwell, 1964; McIntyre and Wilson, 1966; Wilson, 1967, 1968; Kemp, 1972; Wrenn and Beckman, 1982; Truswell, 1983, 1986) are from reworked Quaternary and Neogene sediments. Former studies on *in situ* material in high southern latitudes are relatively rare and were undertaken on cores from the DSDP Sites 270 (Leg 28) by Kemp and Barrett (1975), Sites 264, 266, 268, 270, 274 (Leg 28) by Kemp (1975), Sites 511 to 514 (Leg 71) by Goodman and Ford (1983) and Bratzeva (1983). The palynologic results of the CIROS-1 drillsite in the McMurdo Sound area, which penetrates at least to the early Oligocene was described by Mildenhall, 1987, and Wilson, 1987. *In situ* palynomorphs from outcrops in the Antarctic Peninsula region are known from King George Island (Stuchlik, 1981) and Seymour Island (Cranwell, 1959; Hall, 1977; Palamarczuk, 1982; Palamarczuk et al., 1984; Baldoni and Barreda, 1986; Zamaloa et al. 1987; Askin, 1988; Wrenn and Hart, 1988).

MATERIALS AND METHODS

During Leg 113, Paleogene sections on Maud Rise (Sites 689 and 690), on the Dronning Maud Land margins (Site 693), and on the South Orkney microcontinent (Site 696) were sampled (see Fig. 1). The Paleogene white calcareous oozes of Sites 689 and 690 are virtually barren of organic matter (Barker, Kennett, et al., 1988b) and also proved to be barren of palynomorphs after processing of the core catcher samples on shore. The studies are therefore focused on samples from Sites 693 and 696.

The samples were processed using standard centrifuge preparation techniques (Van Erve, 1977) in addition to sieving with a 15 μm sieve. For purposes of taxonomic determination and photographic documentation single grain slides were made. Additional smear slides mounted with glycerine jelly were made to examine the kerogen and palynomorph content. ODP localities and slide numbers of the figured specimens are given in the plate captions. If the sporomorphs were found in smear slides, coordinates are mentioned that refer to the Nikkon Microscope "Microphot FX," No. 1020–1219. The slides are deposited at the Geological Institute of the ETH in Zürich.

RESULTS

Site 693

At Site 693 (Dronning Maud Land margin, approximately 70°S, 14°W; Fig. 1), two holes (693A and 693B) were drilled.

At Hole 693A the sediments recovered (Barker, Kennett, et al., 1988b) extend from Quaternary (Cores 113-693A-1R through -3R) and Neogene (Cores 113-693A-4R through -33R?) to the Oligocene (Cores 113-693A-34R? through -43R) and the Lower Cretaceous (Cores 113-693A-44R through -51R). Samples of Pliocene and Miocene age (Sections 113-693A-13R-3 through -32R, CC) proved to be completely barren of palynomorphs except for rare reworked Mesozoic palynomorphs (Table 1). Samples of Paleogene age are analyzed and described in greater detail in this paper. The Cretaceous material is partly discussed in other papers (Mohr, this volume; Mohr, in press), and is partly still under investigation (Mohr and Gee, in prep.).

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[1] Barker, P. F., Kennett, J. P., et al., 1990. *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program).

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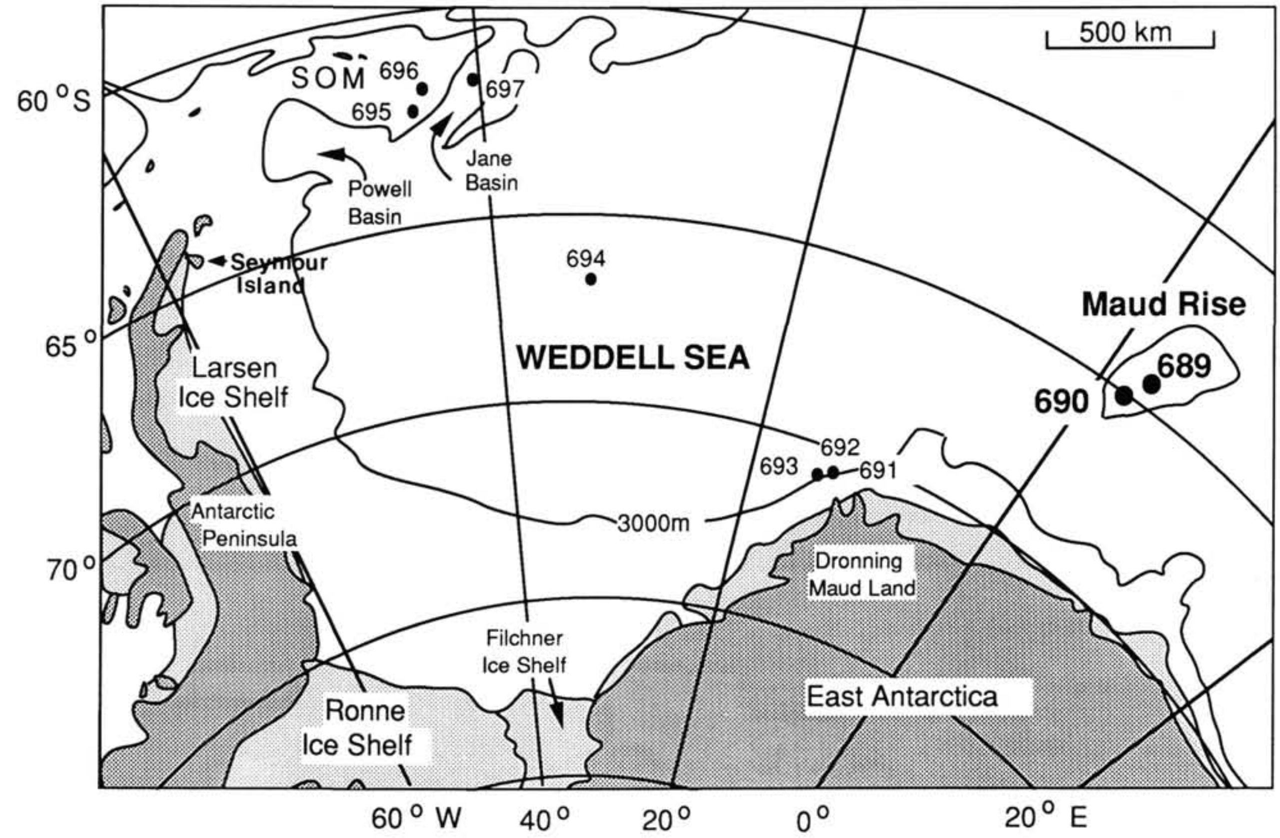


Figure 1. Location of Leg 113 Sites (689 through 697) in the Weddell Sea. All sites lie in the present-day Antarctic water mass, south of the Polar Front. SOM = South Orkney microcontinent.

The Paleogene sediments are mainly composed of two biogenic lithologies: a muddy nannofossil ooze and a diatom ooze with silty to clayey mud (Barker, Kennett, et al., 1988a). Age determinations of the Paleogene cores were carried out using nannofossils and diatoms (Pospichal and Wise, this volume, chapter 37; Burckle and Gersonde, this volume). According to these data, Cores 113-693B-38R through -42R are probably of early Oligocene age (see Fig. 2).

The organic detritus of these Oligocene samples is mainly composed of fine (less than 15 μm), light-colored structureless particles. In some of the late Oligocene samples, such as 113-693A-35R-1, 67–71 cm, and 113-693A-35R-1, 50–54 cm, light-colored organic matter greater than 15 μm is virtually absent. Only dark brown to black kerogen has been noted (see Table 1). It is partly angular, partly consisting of agglomerations of extremely fine particles, and micrhystrid acritarchs (ca. 10–15 μm) and may be recycled. Samples from Core 113-693A-40R, however, contain a very high percentage of large particles of light yellow to brown color.

The interval between Cores 113-693A-34R and -39R proved to be barren of palynomorphs, except for recycled Mesozoic material. Sample 113-693A-40R-1, 68–72 cm, and Section 113-693A-40R, CC, contain the dinoflagellate cyst species, *Selenopemphix nephroides* Benedek 1972 and "Forma T" sensu Goodman and Ford (1983), (see Table 1).

In the upper cores of Hole 693B, Neogene sediment was recovered (Cores 113-693B-2X through -9X?). Cores 113-693B-10X? through -19X were determined using nannofossils and diatoms (Pospichal and Wise, this volume, chapter 37; Gersonde and Burckle, this volume) to be of Paleogene age (Fig. 2). The late Oligocene is represented by Cores 113-693B-10X? through -13X. Cores 113-693B-14X through -19X are of early to latest early Oligocene age.

Like those of Site 693A, the sediments are composed of clayey and silty mud with nannofossils and diatoms (Barker, Kennett, et al., 1988a and b). In Cores 113-693B-17X through -19X, 80%–90% of the kerogen is (light) yellow in color. Three-fourths of this kerogen is composed of structureless particles of a size between 5 and 70 μm, probably of algal origin. One-fourth, or sometimes even less, consists of fragmentary plant tissue.

About 10% of the total kerogen of these samples is composed of dark brown (at the edges) to opaque (at the center) angular particles of medium to large size (mainly between 30 and 100 μm) and dark brown agglomerations of extremely small particles. These dark-colored fragments may be reworked from older strata.

As in sediments of Hole 693A (Core 113-693A-40R), only the dinoflagellate cyst species *Selenopemphix nephroides* and "Forma T" sensu Goodman and Ford (1983) were found (Core 113-693B-17X through -19X), in addition to some Mesozoic spores and bisaccate pollen grains (Table 2).

Site 696

This site, located on the South Orkney microcontinent, approximately 60°S, 42°W (Fig. 1), yielded Neogene (Cores 113-696B-1R through -50R) and Paleogene sediment (Cores 113-696B-51R through -62R)(Fig. 2).

The Paleogene core section is composed of a glauconitic silty to sandy mudstone and is rich in organic matter, including dino-

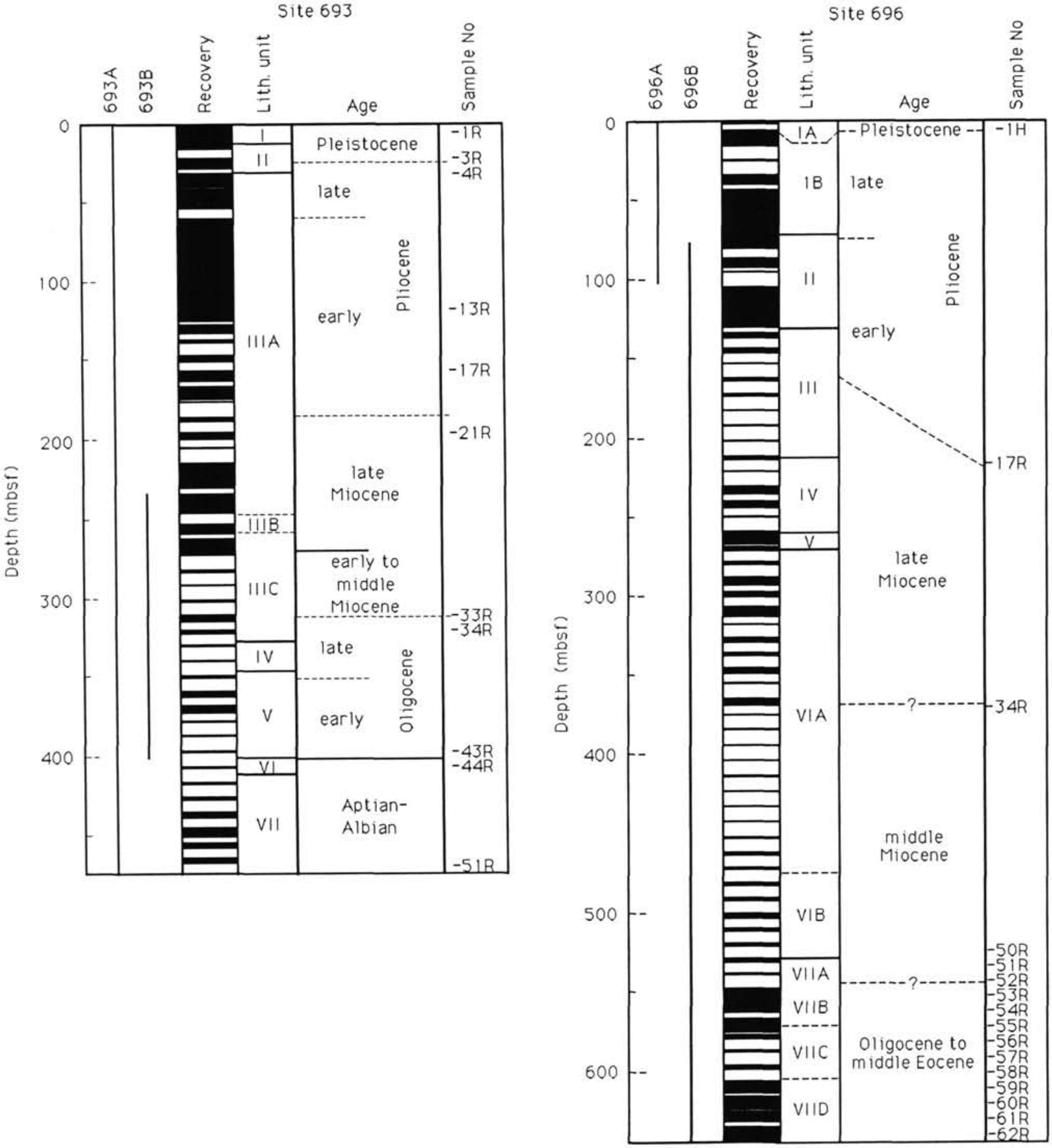


Figure 2. Summary columns of Sites 693 and 696. Cored interval for each hole, core recovery (white = no recovery), lithostratigraphic units, age, and selected core numbers for some of the samples which are mentioned in the text. mbsf = meters below seafloor.

flagellate cysts (Table 3) and sporomorphs. Benthic foraminifers (Thomas, this volume) and calcareous nannofossils (Pospichal and Wise, this volume, chapter 37) indicate, in addition to the dinocysts (see discussion below), a middle Eocene age (Cores 113-696B-59R through -62R) at the base of the section. The dating of the Cores 113-696B-53R through -58R with palynomorphs is possible, but difficult for the upper cores of the Paleogene section (Cores 113-696B-51R to -53R).

The kerogen is composed mainly of fine to large (5–150 μm) land-derived particles. Some of this organic tissue shows well preserved cellular structures of vascular plants, such as cuticles with stomata or tracheans of conifers. Small cubes and agglomerations of pyrite are incorporated in most of the organic particles as well as in the palynomorphs (Pl. 6, Fig. 3).

PALYNOMORPHS OF SITES 696 AND 693

Taxonomy of the Paleogene sporomorphs listed below are primarily based on Truswell (1983), Askin (1988), and Dettmann and Jarzen (1988). A more detailed taxonomic description of these species is in preparation by the author (Mohr, in press). Dinoflagellate cyst taxon-

Table 1. Kerogen and palynomorph content of selected Hole 693A samples. mbsf = meters below seafloor.

Depth (mbsf)	Sample	Organic matter	Palynomorphs	Recycled organic matter	Recycled palynomorphs
112.28	693A-13R- 3, 68-72 cm	light brown, marine	barren	dark brown, land derived	Callialasporites
118.88	693A-14R- 1, 68-72 cm	rare	barren	rare	
137.50	693A-15R-CC	light brown, marine	barren	rare	
156.90	693A-17R-CC	rare	barren	rare	
157.57	693A-18R- 1, 67-71 cm	light brown, marine	barren	dark brown	Mesozoic spores and dinocysts
160.57	693A-18R- 3, 67-71 cm	rare	barren	dark brown, land derived	
166.60	693A-18R-CC	rare	barren	dark brown, marine	
173.28	693A-19R- 5, 68-72 cm	light brown, marine	barren	rare	
176.30	693A-19R-CC	rare	barren	dark brown, land derived	
186.58	693A-21R- 1, 68-72 cm	light brown, marine	barren	dark brown, land derived	
195.60	693A-21R-CC	rare	barren	dark brown, land derived	
199.28	693A-22R- 3, 68-72 cm	light brown, marine	barren	dark brown, land derived	
205.30	693A-22R-CC	rare	barren	rare	
228.28	693A-25R- 1, 68-70 cm	light brown, marine	barren	rare	
234.30	693A-25R-CC	rare	barren	dark brown, land derived	
234.98	693A-26R- 1, 68-70 cm	light brown, marine	barren	rare	
243.90	693A-26R-CC	rare	barren	dark brown, marine & land derived	
254.28	693A-28R- 1, 68-72 cm	light brown, marine	barren	rare	
257.26	693A-28R- 3, 66-70 cm	light brown, marine	barren	rare	
263.56	693A-29R- 1, 66-70 cm	light brown, marine	barren	dark brown, land derived	
266.56	693A-29R- 3, 66-70 cm	light brown, marine	barren	dark brown, land derived	
269.56	693A-29R- 5, 66-70 cm	light brown, marine	barren	rare	
272.50	693A-29R-CC	rare	barren	rare	
282.89	693A-31R- 1, 69-73 cm	rare	barren	rare	
291.90	693A-31R-CC	rare	barren	rare	
302.18	693A-33R- 1, 68-73 cm	rare	barren	rare	
311.20	693A-33R-CC	rare	barren	rare	
312.03	693A-34R- 1, 83-88 cm	rare	barren	dark brown, land derived	
318.53	693A-34R- 2, 83-88 cm	rare	barren	rare	
321.57	693A-35R- 1, 67-71 cm	rare	barren	dark brown, marine	
331.18	693A-36R- 1, 68-72 cm	rare	barren	dark brown, marine	
340.20	693A-36R-CC	rare	barren	dark brown, marine & land derived	Callialasporites, bisaccates
340.70	693A-37R- 1, 50-54 cm	rare	barren	rare	spore fragments
350.56	693A-38R- 1, 66-70 cm	rare	barren	rare	
360.28	693A-39R- 1, 68-72 cm	rare	barren	dark brown, marine	
368.90	693A-39R-CC	rare	barren	rare	
369.56	693A-40R- 1, 68-72 cm	rare	S. nephroides, "Forma T"	dark brown, marine	
372.58	693A-40R- 3, 68-72 cm	rare	barren	dark brown, marine	
378.60	693A-40R-CC	rare	"Forma T"	rare	

Table 2. Kerogen and palynomorph content of selected Hole 693B samples. mbsf = meters below seafloor.

Depth (mbsf)	Sample	Organic matter	Palynomorphs	Recycled organic matter	Recycled palynomorphs
312.80	693B-10X-CC	light brown, marine	barren	rare	
318.40	693B-11X-CC	light brown, marine	barren	dark brown aggl., marine ?	
335.50	693B-12X-CC	light brown, marine	barren	dark brown aggl., marine	Mesozoic dinocysts
345.10	693B-13X-CC	light brown, marine	barren	dark brown aggl., marine	
354.70	693B-14X-CC	light brown, marine	dinocyst fragments	dark brown, land derived	dinocyst fragments
364.40	693B-15X-CC	light brown, marine	barren	dark brown, land derived	
374.74	693B-17X- 1, 74-78 cm	light brown, marine	"Forma T"	dark brown, land derived	
376.60	693B-17X-CC	light brown, marine	barren	dark brown, land derived	
386.81	693B-18X- 3, 11-18 cm	rare	barren	dark brown, rare	spores, bisaccates
388.81	693B-18X- 4, 61-66 cm	light brown, marine	barren	dark brown, rare	
393.30	693B-18X- CC	rare	"Forma T"	dark brown, rare	spores
395.39	693B-19X- 2, 49-54 cm	light brown, marine	S. nephroides	dark brown, rare	
395.82	693B-19X- 2, 92-97 cm	light brown, marine	"Forma T"	very rare	
398.17	693B-19X- 4, 27-32 cm	light brown, marine	"Forma T", S. nephroides	very rare	
403.10	693B-19X-CC	rare	barren	very rare	

Table 3. Occurrence of dinoflagellate cyst species in Hole 696B samples. mbsf = meters below seafloor.

Depth (mbsf)	Sample	A. diktyoplokus	B. compta	D. antarctica	D. ssp.	"Forma T"	I. victorianum	K. cf. capulatum	L. hyalina	O. askiniae	O. bergmannii	S. asymmetricum	S. nephroides	S. luciae	T. filosa	V. apertura
503.87	696B-48R-2, 117-121 cm															
520.62	696B-50R-1, 42-43 cm															
539.79	696B-52R-CC															
550.90	696B-53R-2, 50-54 cm															
553.90	696B-53R-4, 50-54 cm												x			
556.90	696B-53R-6, 50-54 cm	x				x	x		x	x		x	x			
560.50	696B-54R-2, 50-54 cm	x			x								x			
563.50	696B-54R-4, 50-54 cm			x	x	x					x	x	x			x
570.19	696B-55R-2, 49-51 cm		x				x			x			x			
573.26	696B-55R-4, 56-60 cm	x		x		x				x			x			
576.04	696B-55R-6, 34-36 cm			x				x	x				x			
578.54	696B-56R-1, 64-66 cm												x			
579.62	696B-56R-2, 22-24 cm			x			x		x	x						
579.92	696B-56R-2, 52-54 cm			x									x			
588.25	696B-57R-1, 65-67 cm			x						x			x			x
597.83	696B-58R-1, 124-126 cm								x				x	x		
607.41	696B-59R-1, 51-56 cm															
608.17	696B-59R-1, 127-131 cm								x					x		x
609.12	696B-59R-2, 12-14 cm															
610.41	696B-59R-3, 51-56 cm	x		x	x		x	x	x	x	x	x		x		x
613.41	696B-59R-5, 51-56 cm			x					x	x				x		x
614.16	696B-59R-CC								x					x		
618.85	696B-60R-2, 75-79 cm			x			x	x	x	x			x		x	
620.35	696B-60R-3, 75-79 cm								x	x						
621.85	696B-60R-4, 75-79 cm				x			x								x
623.35	696B-60R-5, 75-79 cm								x	x			x			x
624.83	696B-60R-CC															x
626.20	696B-61R-1, 61-65 cm													x		
628.31	696B-61R-2, 61-65 cm															
629.82	696B-61R-3, 62-66 cm								x				x			
631.33	696B-61R-4, 63-67 cm															
632.44	696B-61R-CC			x	x		x	x	x	x		x	x	x	x	x
637.03	696B-62R-2, 72-75 cm															
640.03	696B-62R-4, 72-75 cm															
644.53	696B-62R-7, 72-75 cm								x	x	x			x	x	
645.60	696B-62R-CC								x	x	x		x			

omy and cited references are given in Lentin and Williams (1989), and Wrenn and Hart (1988).

Site 696

Spores

Baculatisporites sp. (Pl. 1, Fig. 2)
Gleicheniidites sp. (possibly reworked)
Ischyosporites gremius Stover, 1973, in Stover and Evans, 1973 (Pl. 1, Fig. 1)
Laevigatosporites sp.
Polypodiisporites sp.
Retitriletes sp. (Pl. 1, Fig. 3)

Pollen grains

Conifers

Dacrydiumites florinii Cookson and Pike, 1953b, (Pl. 1, Figs. 9 and 10)
Microcachryidites antarcticus Cookson, 1947 ex Couper 1953 (Pl. 1, Fig. 11)
Phyllocladidites, sp. 1
Phyllocladidites mawsonii Cookson ex Couper 1953 (Pl. 1, Figs. 6, 7, and 8)
Podocarpidites sp. (Pl. 1, Fig. 5)
?*Podocarpidites* sp. (Pl. 1, Fig. 4)

Angiosperms

Beaupreaidites verrucosus Cookson, 1950 (Pl. 2, Fig. 5)
Ericipites scabratus Harris, 1965 (Pl. 3, Fig. 6)
Haloragacidites harrisii (Couper) Harris, 1971 (Pl. 2, Fig. 12)
Indet. (Pl.3, Fig. 11)
Nothofagidites asperus (Cookson) Stover and Evans, 1973
N. flemingii (Couper) Potonié, 1960 (Pl. 4, Fig. 5)
N. lachlanae (Couper) Truswell, 1983 (Pl. 4, Figs. 6 and 7)
N. sp. (Pl. 4, Fig. 10)
Peninsulapollis gillii (Cookson) Dettmann and Jarzen, 1988 (Pl. 4, Fig. 8)
Peninsulapollis cf. *truswelliae* Dettmann and Jarzen, 1988 (Pl. 2., Fig. 11),
?*Peninsulapollis* sp. (Pl. 2, Fig. 13)
Periporopollenites pallidus Truswell and Owen, 1988
Propylipollis concretus (Harris) Martin and Harris, 1974
Propylipollis sp. (Pl. 2, Figs. 6 and 7)
Proteacidites pseudomoides Stover, 1982, in Stover and Partridge, 1982 (Pl. 3, Figs. 8A and B)
P. rynthius Stover and Partridge, 1982 (Pl. 2, Figs. 1 and 4)
P. cf. *parvus* Cookson, 1950 (Pl. 2, Fig. 9)
P. sp. 2 sensu Truswell 1983
Rhamnaceae sp. 2 sensu Stuchlik, 1981
Rhoipites cf. *aralioides* Pocknall and Mildenhall, 1984 (Pl. 3, Figs. 2A and B)
Rhoipites sphaerica (Cookson) Pocknall and Crosbie, 1982 (Pl. 2, Figs. 10A and B)
Sparganiaceaepollenites irregularis Kemp, 1977, in Kemp and Harris, 1977 (Pl. 3, Fig. 1)
Tricolpites sp. 1
Triporopollenites sp. 1, sensu Kemp, 1975 (Pl. 2, Figs. 2 and 3)
T. sp. 1, sensu Truswell, 1983 (Pl. 2, Fig. 8)
Tricolporopollenites sp. 1 (Pl. 3, Fig. 4)
Tricolporopollenites sp. 2 (Pl. 3, Figs. 9A and B)
Tubulifloridites cf. *antipodica* Cookson, 1947, in Kemp and Harris, 1977 (Pl. 4, Figs. 9A and B)

Dinoflagellate cysts

Areosphaeridium diktyoplokus (Klumpp) Eaton, 1971 (Pl. 5, Figs. 2 and 8)
Batiacasphaera compta Drugg, 1970 (Pl. 3, Fig. 3)
Brigantedinium sp. (Pl. 5, Figs. 4 and 5)
Deflandrea antarctica Wilson, 1967 (Pl. 6, Figs. 6 and 9)
D. webbii Wrenn and Hart, 1988
Deflandrea sp. (Pl. 6, Fig. 8)
"Forma T" sensu Goodman and Ford, 1983
Hystrichosphaeridium cf. *H. astartes* Sannemann, in Wrenn and Hart, 1988 (Pl. 3, Fig. 7)
Impagidinium victorianum (Cookson and Eisenack) Stover and Evitt, 1978 (Pl. 6, Fig. 4)
Impletosphaeridium sp. (Pl. 5, Fig. 3)
Indet. (Pl. 5, Fig. 4 and 5)
Kallosphaeridium cf. *capulatum* Stover, 1977
Lejeunecysta hyalina (Gerlach) Artzner and Dörhöfer, 1978 (Pl. 6, Fig. 2)
Octodinium askiniae Wrenn and Hart, 1988 (Pl. 6, Fig. 5)
Operculodinium bergmannii (Archangelsky) Stover and Evitt, 1978 (Pl. 6, Figs. 7A and B)
Selenopemphix nephroides Benedek emend. Bujak, 1980
Senegalinium asymmetricum (Wilson) Stover and Evitt, 1978 (Pl. 5, Fig. 7)
Spinidinium essoi Cookson and Eisenack, 1967 (Pl. 6, Fig. 1)
S. luciae Wrenn and Hart, 1988 (Pl. 5, Figs. 1 and 6)
S. macmurdoense (Wilson) Lentin and William, 1976
Spiniferites ramosus (Ehrenberg) Loeblich and Loeblich, 1966
Turbiosphaera filosa (Wilson) Archangelsky, 1968 (Pl. 6, Fig. 3)
Vozzhennikovia apertura (Wilson) Lentin and Williams, 1976 (Pl. 6, Fig. 10)

Reworked palynomorphs

Cribroperidinium edwardsii (Cookson and Eisenack) Davey, 1969
Heterosphaeridium heteracanthum (Deflandre and Cookson) Eisenack and Kjellström, 1971 (Pl. 4, Fig. 3)
Odontochitina operculata (Wetzel) Deflandre and Cookson, 1955
O. porifera Cookson, 1956 (Pl. 4, Fig. 2)
Oligosphaeridium pulcherrimum (Deflandre and Cookson) Davey and Williams, 1966
Satyrodinium sp. (Pl. 4, Fig. 4)

Site 693

Dinoflagellate cysts

"Forma T" sensu Goodman and Ford, 1983 (Pl. 6, Figs. 11 and 12)
Selenopemphix nephroides Benedek emend. Bujak, 1980 (Pl. 3, Fig. 5)

Reworked palynomorphs

Bisaccates
Callialasporites sp.
Deltoidospora sp.
Gleicheniidites sp.
Ischyosporites sp.
Odontochitina operculata (Wetzel) Deflandre and Cookson, 1955

DISCUSSION

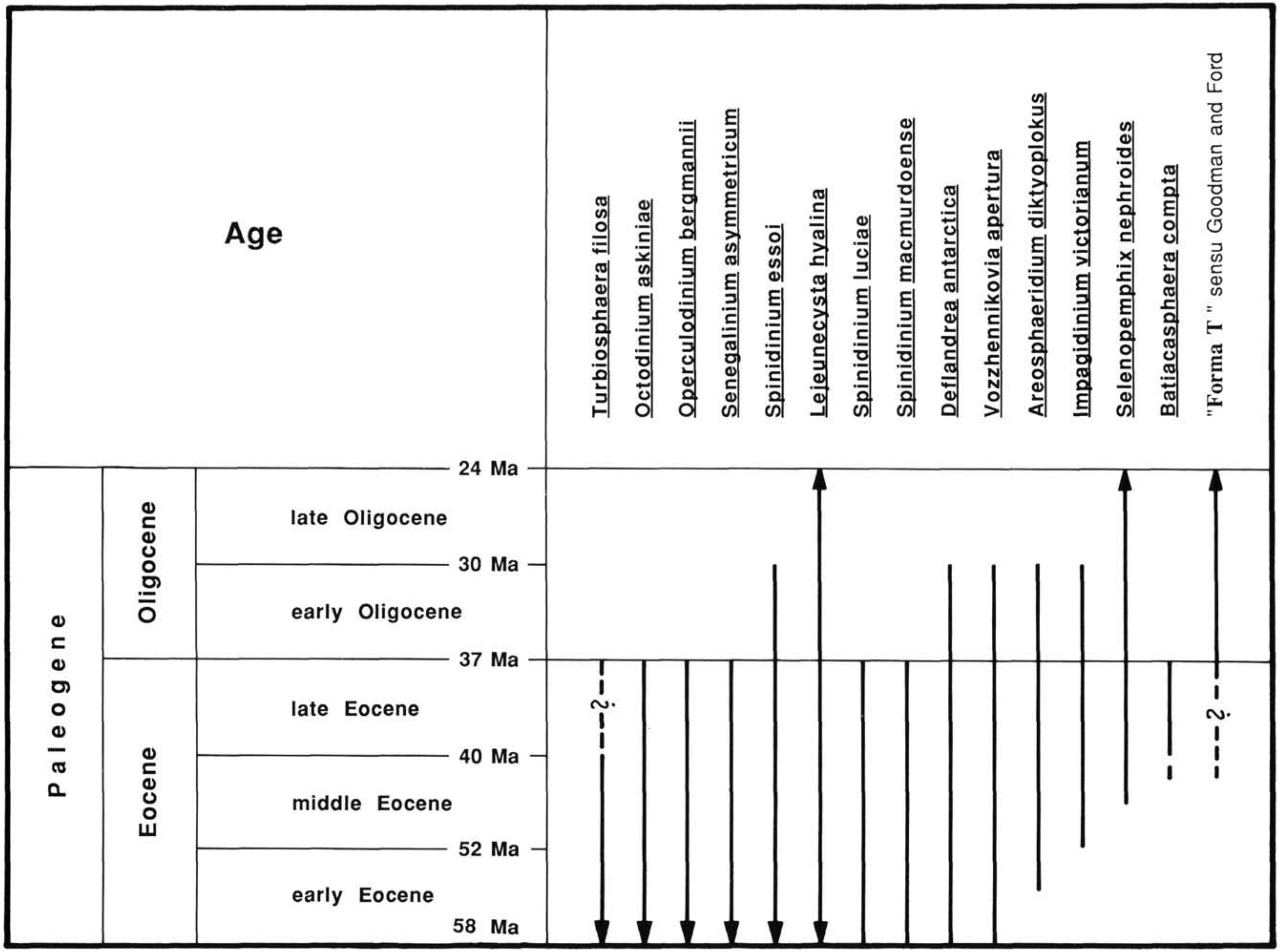
Stratigraphy

Many stratigraphically useful dinocyst taxa and one useful pollen species (*Tubulifloridites* cf. *antipodica*) were seen at Site 696. The Oligocene sediments of Site 693 yielded only two dinocyst species. All taxa occur within restricted depth intervals within Sites 693 and 696 and in the order expected from their published chronostratigraphic time ranges (Table 4). Therefore the pollen and dinocyst assemblages of Sites 693 and 696 are believed to represent *in situ* deposition rather than reworking.

The known stratigraphic ranges (data from Wrenn and Hart, 1988) of the dinocyst taxa from Sites 693 and 696 are listed in Table 4. The dinoflagellate cyst species from these two sites range from Late Cretaceous to Neogene in age. Most of the taxa occur exclusively in the Paleogene, and are most abundant in the Eocene.

Turbiosphaera filosa (Wilson) Archangelsky, 1968 (Cores 113-696B-60R through -62R) is a common Maestrichtian to middle Eocene indicator (Wrenn and Hart, 1988). Although it is occasionally seen in upper Eocene strata (Kemp, 1975), these occurrences are probably reworked. *Impagidinium victorianum*

Table 4. Reported stratigraphic ranges of the dinoflagellate cyst species encountered in Hole 696B samples. Time scale according to Berggren et al. (1985).



is observed only from the middle Eocene until the early Oligocene (Wrenn and Hart, 1988). *Selenopemphix nephroides* ranges from the middle part of the middle Eocene until the Holocene. Cores 113-696B-60R through -62R are therefore of middle Eocene age, probably of mid- to late middle Eocene age, which is also in accordance with benthic foraminiferal data (Thomas, this volume).

Only one species was encountered (Section 113-696B-55R-2) with a range found exclusively in the late Eocene (*Batiacasphaera compta*, Table 4). The occurrence of this species, in combination with other dinocysts ranging until the late Eocene (Wrenn and Hart, 1988) such as *Spinidinium luciae* (Sections 113-696B-58R-1 through -62R-7), *Operculodinium bergmannii* (Sections 113-696B-54R-4 through -62R, CC) and *Senegalinium asymmetricum* (Sections 113-696B-53R-6 through -61R, CC), imply a late Eocene age for Sections 113-696B-53R-6 through -59R, CC. In samples of Cores 53R and 54R (Sections 113-696B-53R-6 and -54R-2), however, most of the encountered species, such as *Areosphaeridium diktyoplokus* (Sections 113-696B-53R-6 through -59R-5), *Deflandrea antarctica* (Sections 113-696B-54R-4 through -61R, CC), *Impagidinium victorianum* (Sections 113-696B-53R-6 through -61R, CC), *Lejeunecysta hyalina* (Sections 113-696B-53R-6 through -62R, CC) and *Selenopemphix nephroides* (Sections 113-696B-53R-6 through -62R, CC) have been observed formerly also in younger strata (see Table 4). "Forma T" sensu Goodman and Ford (Sections 113-696B-53R-6 through -55R-4), was found earlier, with certainty, only in early Oligocene strata (Goodman and Ford, 1983).

The middle part of Core 53R (Section 113-696B-53R-4) contains only a few badly preserved dinocysts (*Selenopemphix nephroides*), dinocyst fragments and pollen grains. Cores 113-696B-50R through the upper part of -53R are barren of palynomorphs. Age control is therefore difficult for the sequence between Core 113-696B-50R through Section 113-696B-53R-4.

The time ranges of the pollen species found in the Weddell Sea area are not listed, because the taxonomic and stratigraphic knowledge available for these taxa are extremely poor. But even the reported ages of well defined taxa from different geographic regions differ widely. The ranges for *Beaupreaidites verrucosus* for example, are listed by Pocknall and Crosbie (1988) as early Eocene to early Oligocene in the Gippsland Basin, the Eocene of the eastern Murray Basin, the middle to late Eocene of Western Australia, and the late Eocene to early Miocene in New Zealand. Thus, sporomorph range charts given for certain areas (Stover and Partridge, 1973) or more generally for Australia (Martin, 1978) are only of doubtful use in the Weddell Sea area.

Many of the species encountered on the South Orkney Plateau (Site 696), such as *Ischyosporites gremius, Parvisaccites catastus,* and *Proteacidites pseudomoides* seem to have their ranges between late Paleocene/early Eocene and early Oligocene (Stover and Partridge, 1973). *Periporopollenites pallidus* (Sample 113-696B-54R-4, 50–54 cm) was only once observed by Truswell and Owen (1988) from a sequence in New South Wales, in an interval assigned to the lower *Nothofagidites asperus* Zone (middle Eocene). *Sparganiaceaepollenites irregularis,* found at Site 696 (Samples 113-696B-60R-2, 75–79 cm, and -54R-4, 50–54 cm), was first described from late Eocene/early Oligocene sediments from the Ninetyeast Ridge (Kemp and Harris, 1977).

The occurrence of *Tubulifloridites* cf. *antipodica*, a composite pollen in Samples 113-696B-54R-2, 50–54 cm, and -54R-4, 50–54 cm (latest Eocene to earliest Oligocene), is of special interest, because of the stratigraphic aspect. In general, pollen grains of Asteraceae are considered to occur not earlier than the Oligocene (Muller, 1981). Kemp and Harris (1977) found *T.* cf. *antipodica* in strata at the Ninetyeast Ridge below sediments dated as Oligocene, of probable late Eocene/early Oligocene age. An Oligocene occurrence of Tubuliflorae pollen, mentioned by Mildenhall (1987) from the McMurdo Sound (Antarctica) was regarded by her as contamination. But after the findings of Compositae pollen in the Weddell Sea area, these pollen can be considered to be *in situ*.

If the data on dinocysts and sporomorphs are combined, the sediments in Cores 113-696B-60R through -62R are of middle to late middle Eocene age, which correlates to a time interval between 45 and 40 Ma, according to the time scale of Berggren et al. (1985). Sections 113-696B-55R-2 through -59R, CC have most likely a late Eocene age (time interval between 40 and 37 Ma). The sedimentation of the glauconitic siltstones found in Sections 113-696B-53R-6 through -54R-4 seem to have taken place in the Eocene/Oligocene boundary time interval (at ca. 37 ± 1 Ma).

The restricted occurrences of the palynomorphs at Sites 696 and 693 are in accordance with their stratigraphic ranges. This is a strong indication for a normal sedimentation process rather than reworking. Other data gathered at Site 696 seem to support this assumption. The measured bulk densities, for example (Barker, Kennett, et al., 1988b, p. 624–625), in the Cores 113-696B-62R through -54R also are very constant and only decrease significantly above Core 113-696B-50R. Dropstones, with the exception of a questionable one in Core 113-696B-54R, occur in Cores 113-696B-51R through -53R and from Core 113-696B-51R on upward (Barker, Kennett, et al., 1988b, p. 658).

Some of the pollen recovered at the South Orkney Plateau (Site 696) may have been derived from long-distance wind dispersal, which is apparent in studies on recent Antarctic moss turfs (Scott and van Zinderen-Bakker, 1985; Kappen and Straka, 1988). Transport by marine currents from more temperate climatic zones and recycling from older strata can also not be completely excluded.

However, considering all the arguments discussed above, the pollen flora recovered from the Cores 113-696B-62R through -54R is interpreted as *in situ* and of middle to latest Eocene/earliest Oligocene age.

Environmental Interpretation Based on Kerogen Analyses and Dinocyst Assemblages

The deposition of the sediments of Site 696 (South Orkney plateau) was probably very nearshore, evidenced by the occurrence of large, nearly unaltered plant debris, the fresh-water algae *Botryococcus* and a mixture of marine dinocysts and land-derived pollen grains.

A relatively high number of dinocyst taxa (ca. 12–15 species, Table 3) in middle and upper Eocene strata from Site 696 suggests at least temperate surface water temperatures during this time interval in the Antarctic Peninsula area. The diversity of dinocysts decreases at the top of this sequence (Core 113-696B-53R) to seven species, which might be due to cooling of the water masses during the late Eocene.

Cold water temperatures are indicated by the extremely low dinoflagellate species diversity (only two species) during the late early Oligocene (Site 693, Holes 693A and 693B; Plates 1 and 2) on the Dronning Maud Land margin. In the late Oligocene all dinoflagellate species have disappeared. The low diversity of the late early Oligocene dinoflagellate assemblage seems to be similar to modern dinoflagellate floras around Antarctica in which only two thecate dinoflagellate genera (El-Sayed, 1985) are found. Supporting this idea is the fact that of these two living genera, *Protoperidinium* is by far the most abundant form in species and individuals. *Protoperidinium* produces cysts which can in part be assigned to the fossil genus *Selenopemphix* (Harland, 1982) which is common in the early Oligocene material of Holes 693A and 693B. The onset of cold Antarctic surface (and bottom) waters near the Antarctic continent therefore probably occurred during the early Oligocene. This assumption, based on dinoflagellate/pollen data, is supported by stable-isotope analyses. $\delta^{18}O$ data gathered from planktonic foraminifers from Leg 29 south of Australia and New Zealand (Shackleton and Kennett, 1975) and in the South Atlantic (Oberhänsli and Toumarkine, 1985), show a significant positive shift at or shortly after the Eocene/Oligocene boundary (at about 37 Ma), indicating a cooling of the surface waters.

The late early Oligocene to early Pliocene samples (Cores 113-693A-13R through -40R and 113-693B-10X through -19X) from the Dronning Maud Land margin contain light brown, structureless kerogen, which is probably derived exclusively from marine sources. The input of land-derived organic matter from higher plants had probably stopped completely by the late early Oligocene. Only recycled plant debris are observed (see Tables 1 and 2). Thus higher plant growth on the Antarctic continent must have stopped during the early Oligocene.

This climatic history of the Antarctic continental margin seems to contrast with data from the Antarctic Peninsula area, where megafloras are still found in late Oligocene strata (e.g., King George Island, in Zastawniak et al., 1985). One explanation for this discrepancy may be that, during the Oligocene, strong climatic differences (like present) existed between the northern Antarctic Peninsula and the Antarctic continent.

Environmental Interpretation of the Sporomorphs

Nothofagus pollen grains predominate (up to 70% of the spore/pollen content) in samples from Cores 113-696B-62R through -54R. Fairly common are also *Baculatisporites* (3%–5%), and *Phyllocladidites mawsonii* (5%–10%). Similar percentages were reported by Zamaloa et al. (1987) for a pollen flora from the late early to late Eocene La Meseta Formation on Seymour Island. In sediments of Site 696 angiosperm pollen other than *Nothofagus* is generally rare, but increases, in contrast to the Seymour Island flora, up to 10%–20%, such as in samples from Core 113-696B-54R.

This microfloral composition indicates that during the late Eocene in the South Orkney region, the vegetation was probably dominated by *Nothofagus*/Podocarp forests with an understory of ferns. The mostly epiphytic fern genus *Hymenophyllum* was probably represented by *Baculatisporites* (see Tryon and Tryon, 1982). This genus is found today in South America in warm to temperate climates in the Southern Hemisphere, and subgenera are adapted to southern South American conditions (e.g., *Hymenoglossum*, *Cycloglossum*).

Leaf impressions in the Antarctic Peninsula area (Seymour Island) suggest a cool temperate flora during the middle to late Eocene (Case, 1988; Case and Woodburne, 1988). There the dominant component of the flora is *Nothofagus*, but a variety of angiosperm pollen species is also present. The samples from the South Orkney microcontinent (Site 696), however, contain a larger diversity of angiosperm pollen. This higher diversity is also found in South American Paleogene sporomorph floras (Romero and Zamaloa, 1985; Romero and Castro, 1986), which suggests a vegetation on the South Orkney microcontinent in character between those of southern South America and those of the Antarctic Peninsula during the middle/late Eocene.

The pollen composition of the South Orkney microcontinent flora also shows some similarity with those described from the Ninetyeast Ridge (Kemp and Harris, 1977), located in the Pacific Ocean between Madagascar and Australia, and Western Australian sites (Milne, 1988).

Among the angiosperms, pollen of the family Proteaceae are very prominent in the South Orkney flora. The extant genus *Beauprea* produces pollen grains that are similar to those of the Paleogene genus *Beaupreaidites*. Modern *Beauprea* is endemic to New Caledonia (mean annual precipitation 1700 mm, mean temperature of the warmest month about 26°C, mean temperature of the coldest month about 20°C; Jaffré, 1980) and is found, with rare exceptions, only in the mountainous regions in diverse bush and open forests (Pocknall and Crosbie, 1988). High annual precipitation seems to fit data gathered from Paleogene megafloras at the Antarctic Peninsula (Thomson and Burn, 1977; Case, 1988) as well as pollen floras (Stuchlik, 1981; Zamaloa et al., 1987). The high temperatures, found in New Caledonia, however, are probably too high by far even for the warmest periods of the Eocene on the South Orkney microcontinent region. The above mentioned mixture of floral elements contain taxa of cool temperate to tropical origin, making a precise climatic interpretation of the Site 696 assemblage impossible at present, but at least (warm) temperate conditions were probable.

CONCLUSIONS

The palynoflora recovered from the South Orkney microcontinent (Site 696) is, according to the stratigraphic ranges of the dinocysts, of late middle Eocene to late Eocene/earliest Oligocene age. This flora and the low diversity dinocyst flora of the Dronning Maud Land margin (Site 693) of late early Oligocene age are both found *in situ*.

The Site 696 pollen flora, in contrast to coeval floras from the Antarctic Peninsula area, is more diverse in angiosperms. Warm temperate climatic conditions and fairly high precipitations (probably over 1500 mm) during the middle/late Eocene seem to be most likely for the South Orkney area. The floral aspect seems to be intermediate between the Antarctic Peninsula floras (Seymour Island) and South American/Australasian pollen floras. A thermal gradient during the late Eocene and late Oligocene from the Antarctic continent, northward through the Antarctic Peninsula, to the South Orkney area is hypothesized, with low temperatures on the continent and higher temperatures in the South Orkney region.

ACKNOWLEDGMENTS

Participation in the Leg 113 cruise was made possible through a grant from the Swiss National Foundation, which also supported the scientific work on Leg 113 cores. For reading the English version of the text, I thank C. Gee and D. Lazarus (Zürich). Processing of the samples was carried out by N. Harley Wyss and K. Yemane (Zürich). For helpful advice and sending unpublished manuscripts I especially thank my colleagues R. Askin (California), M. Dettmann (Brisbane), E. Truswell (Canberra), and J. Wrenn (Tulsa). For their enormous effort in reviewing this paper carefully, I am grateful to R. Askin, D. Mildenhall (Lower Hutt), E. Truswell, and G. Wilson (Lower Hutt), whose experience with Gondwana floras helped to improve this paper. J. Kennett (California) coordinated all this communication between the continents. The photographic work was carried out by U. Gerber, the artwork by K. Meyer (Zürich).

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Date of initial receipt: 11 January 1989
Date of acceptance: 5 June 1989
Ms 113B-140

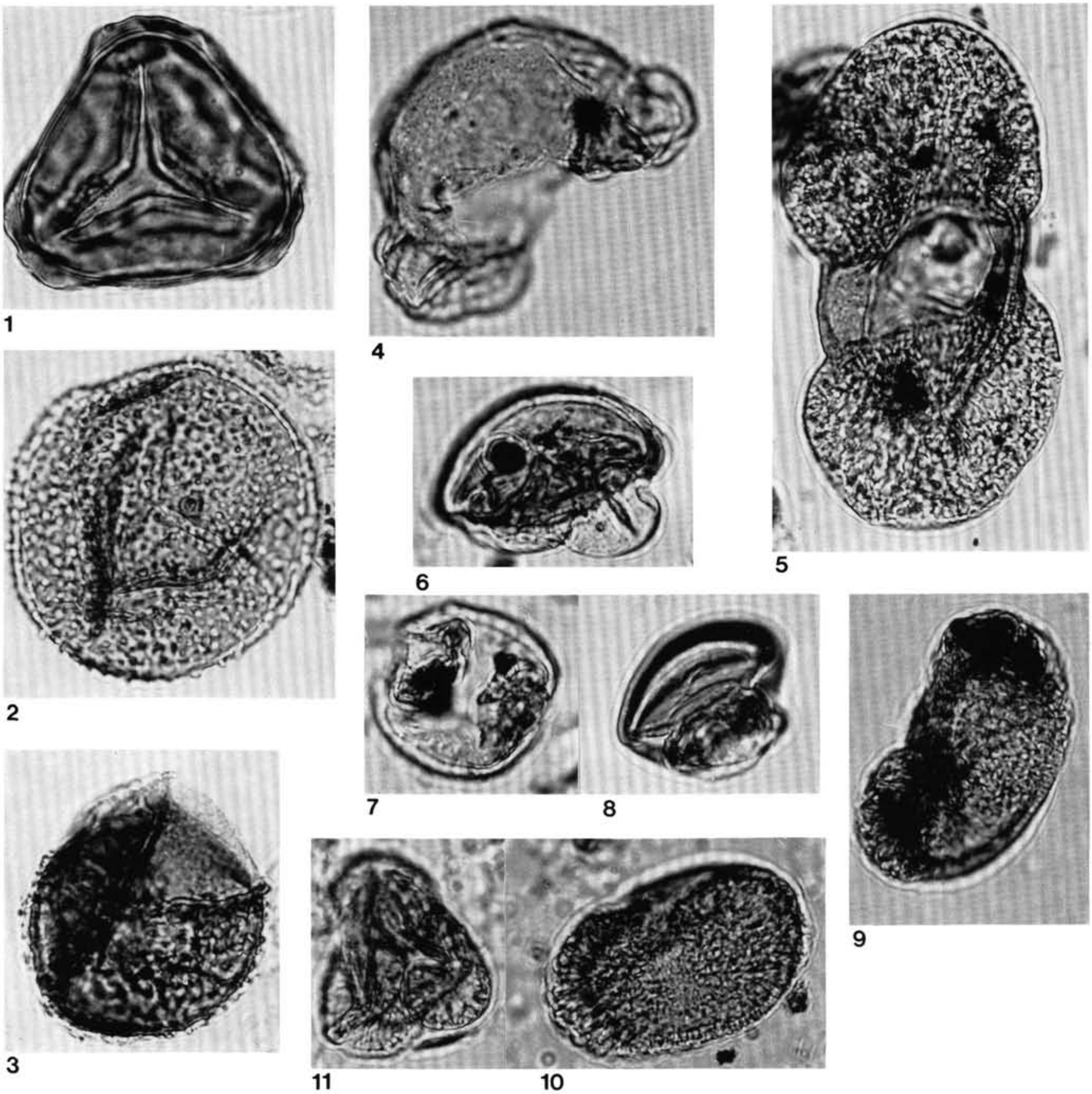

Plate 1. All magnifications × 1000. **1.** *Ischyosporites gremius* Stover, 1973. Sample 113-696B-60R-2, 75–79 cm; sl. 13. **2.** *Baculatisporites* sp. Sample 113-696B-54R-4, 50–54 cm; sl. 2. **3.** *Retitriletes* sp. Sample 113-696B-60R-2, 75–79 cm; sl. 27a. **4.** ?*Podocarpidites* sp. Sample 113-696B-60R-2, 75–79 cm; sl. 10a. **5.** *Podocarpites* sp. Sample 113-696B-59R-3, 51–56 cm; sl. 5. **6.** *Phyllocladidites mawsonii* Cookson, ex Couper, 1953. Sample 113-696B-54R-4, 50–54 cm; sl. C. **7.** *Phyllocladidites mawsonii* Cookson, ex Couper, 1953. Sample 113-696B-54R-4, 50–54 cm; sl. C. **8.** *Phyllocladidites mawsonii* Cookson, ex Couper, 1953. Sample 113-696B-54R-4, 50–54 cm; sl. 2a. **9.** *Dacrydiumites florinii* Cookson and Pike, 1953b. Sample 113-696B-59R-3, 51–56 cm; sl. 1. **10.** *Dacrydiumites florinii* Cookson and Pike, 1953b. Sample 113-696B-54R-4, 50–54 cm; sl. C. **11.** *Microcachryidites antarcticus* Cookson, 1947 ex Couper, 1953. Sample 113-696B-60R-2, 75–79 cm; sl. 6a.

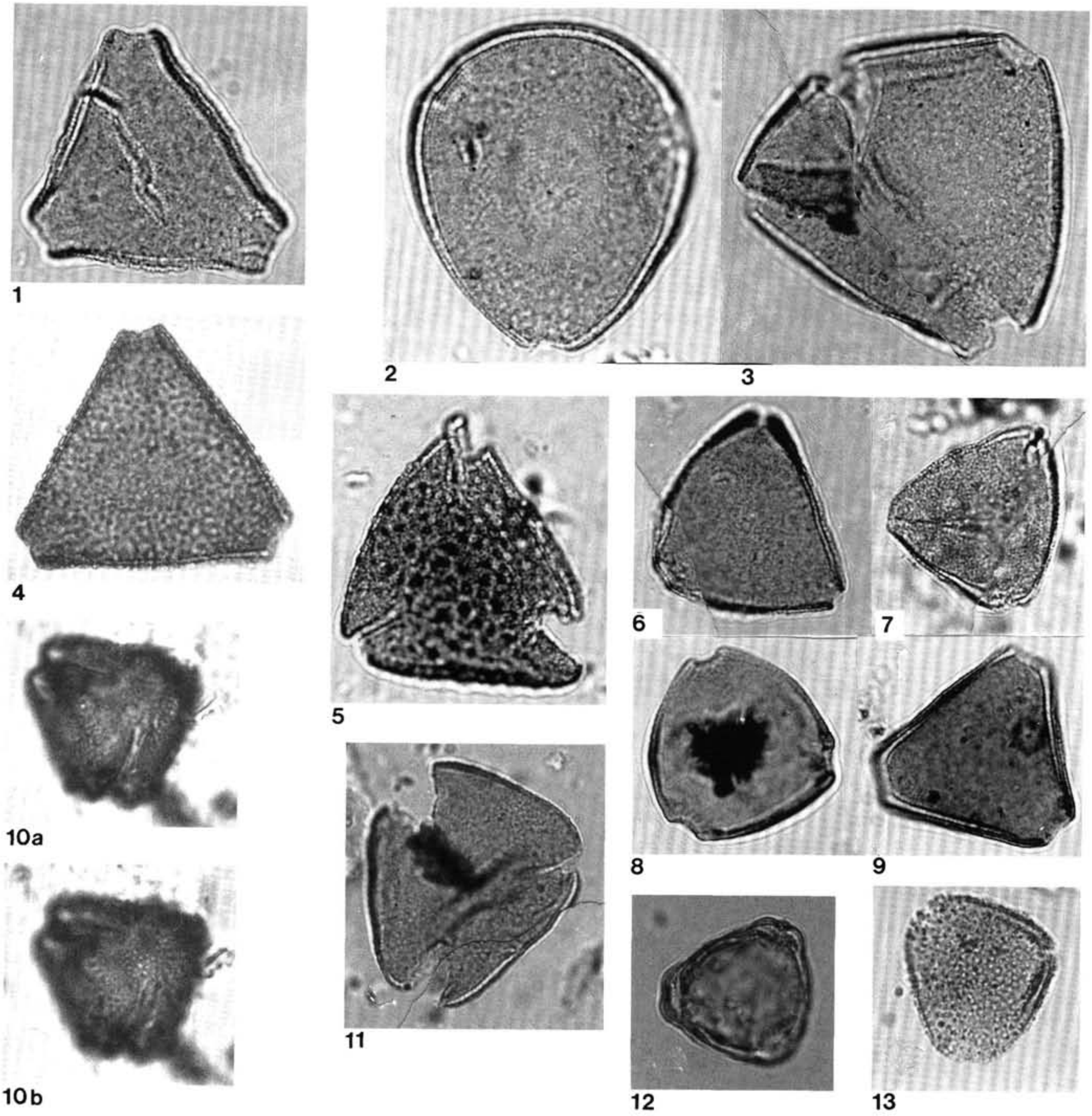

Plate 2. All magnifications × 1000. **1.** *Proteacidites rynthius* Stover and Partridge, 1982. Sample 113-696B-54R-4, 50–54 cm; sl. 8. **2.** *Triporopollenites* sp. 1, sensu Kemp, 1975. Sample 113-696B-59R-6, 127–131 cm; sl. 2. **3.** *Triporopollenites* sp. 1, sensu Kemp, 1975. Sample 113-696B-62R-7, 15–17 cm; sl. S1, 41.2/93.5. **4.** *Proteacidites rynthius* Stover and Partridge, 1982. Sample 113-696B-60R-2, 75–79 cm; sl. 24a. **5.** *Beaupreadites verrucosus* Cookson, 1950. Sample 113-696B-60R-2, 75–79 cm; s1. 7a. **6.** *Propylipollis* sp. Sample 113-696B-60R-2, 75–79 cm; sl. 17a. **7.** *Propylipollis* sp. Sample 113-696B-61R-1, 61–65 cm; sl. A. **8.** *Triporopollenites* sp.1, sensu Truswell 1983. Sample 113-696B-60R-2, 75–79 cm; sl. 26a. **9.** *Proteacidites* cf. *parvus* Cookson, 1950. Sample 113-696B-59R-3, 51–56 cm; sl. 4a. **10A.** and **B.** *Rhoipites sphaerica* (Cookson) Pocknall and Crosbie, 1982. Sample 113-696B-60R-4, 75–99 cm; sl. 18. **11.** *Peninsulapollis* cf. *truswelliae* Dettmann and Jarzen, 1988. Sample 113-696B-54R-4, 50–54 cm; sl. 3A, 40.2/90. **12.** *Haloragacidites harrisii* (Couper) Harris, 1971. Sample 113-696B-54R-4, 50–54 cm; sl. 5A, 37.0/91.5. **13.** ?*Peninsulapollis* sp. Sample 113-696B-54R-4, 50–54 cm; sl. 5A, 37.0/91.5.

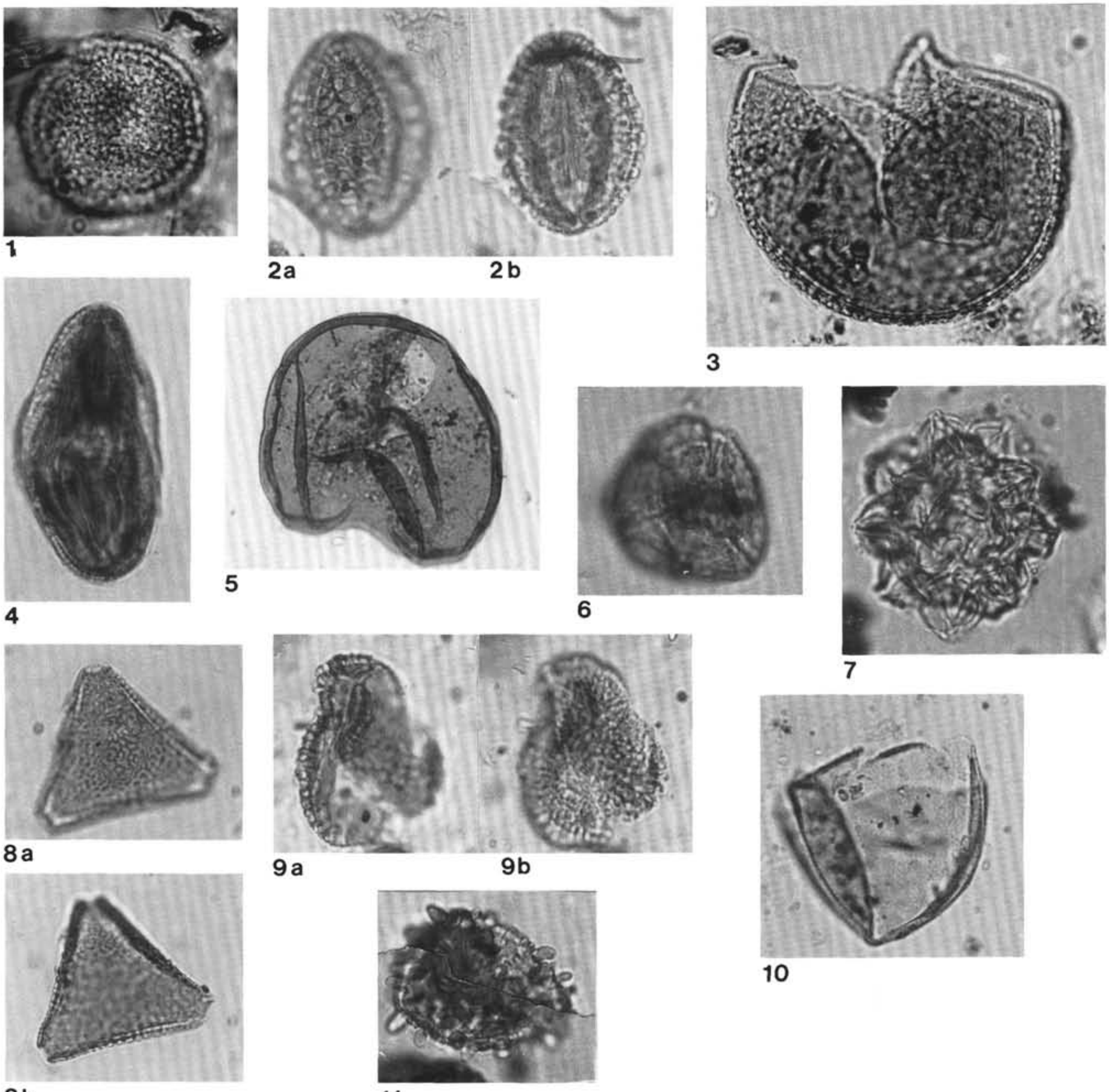

Plate 3. **1.** *Sparganiaceaepollenites irregularis* Kemp, 1977. Sample 113-696B-60R-2, 75–79 cm; sl. S1; × 1000. **2A.** and **B.** *Rhoipites* cf. *aralioides* Pocknall and Mildenhall, 1984. Sample 113-696B-54R-4, 50–54 cm; sl. A, 46.0/91.5; × 1000. **3.** *Batiacasphaera compta* Drugg, 1970. Sample 113-696B-55R-2, 49–51 cm; sl. 9; × 800. **4.** *Tricolporopollenites* sp. 1. Sample 113-696B-54R-4, 50–54 cm; sl. 1A, 39.3/92.5; × 1000. **5.** *Selenopemphix nephroides* Benedek emend. Bujak, 1980. Sample 113-693B-19X-4, 27–30 cm, sl. 7; × 500. **6.** *Ericipites scabratus* Harris, 1965. Sample 113-696B-54R-4, 50–54 cm; sl. 1A, 40.5/85.5; × 1000. **7.** *Hystrichosphaeridium astartes* Sannemann, in Wrenn and Hart, 1988. Sample 113-696B-54R-4, 50–54 cm; sl. 3A; × 1000. **8A.** and **B.** *Proteacidites pseudomoides* Stover, in Stover and Partridge 1973. Sample 113-696B-54R-4, 50–54 cm; sl. 5A, 39.0/91.5; × 1000. **9A.** and **B.** *Tricolporopollenites* sp. 2. Sample 113-696B-54R-4, 50–54 cm; sl. A, 36.5/ 97.2; × 1000. **10.** "Forma T" sensu Goodman and Ford, 1983. Sample 113-693B-19X-4, 50–54 cm; sl. JR; × 500. **11.** Indet. Sample 113-696B-54R-4, 50–54 cm; sl. C, 42.5/96.5; × 1000.

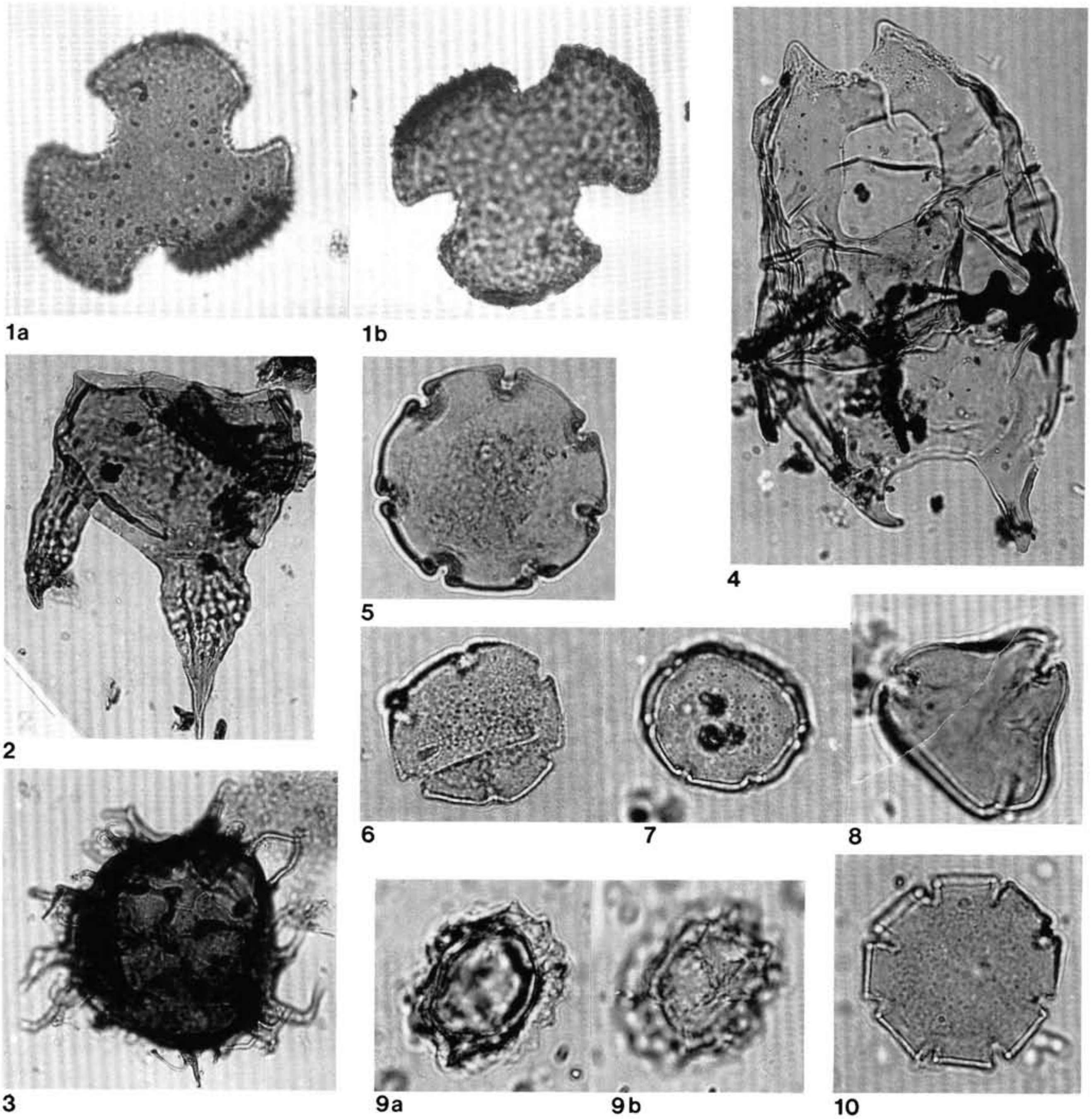

Plate 4. **1A.** and **B.** *Tricolporopollenites* sp. 1. Sample 113-696B-54R-5, 15–17 cm; sl. C, 44.5/90.7; × 1000. **2.** *Odontochitina porifera* Cookson, 1956. Sample 113-696B-55R-2, 49–51 cm; sl. 13, × 500. **3.** *Heterosphaeridium heteracanthum* (Deflandre and Cookson) Eisenack and Kjellström, 1971. Sample 113-696B-55R-2, 49–51 cm; sl. 11, × 500. **4.** *Satyrodinium* sp. Sample 113-696B-55R-2, 49–51 cm; sl. 2, × 500. **5.** *Nothofagidites flemingii* (Couper) Potonié, 1960. Sample 113-696B-59R-2, 12–14 cm; sl. A, 46.5/90.5; × 1000. **6.** *Nothofagidites lachlanae* (Couper) Truswell, 1983. Sample 113-696B-61R-1, 61–65 cm; sl. A; × 1000. **7.** *Nothofagidites lachlanae* (Couper) Truswell, 1983. Sample 113-696B-61R-1, 61–65 cm; sl. A, 35.7/89; × 1000. **8.** *Peninsulapollis gillii* (Cookson) Dettmann and Jarzen, 1988. Sample 113-696B-60R-4, 75–99 cm; sl. 18; × 1000. **9A.** and **B.** *Tubulifloridites* cf. *antipodica* Cookson, 1947. Sample 113-696B-54R-4, 50–54 cm; sl. C, 41.2/89.5; × 1000. **10.** *Nothofagidites* sp. Sample 113-696B-60R-2, 75–79 cm; sl. 1a; × 1000.

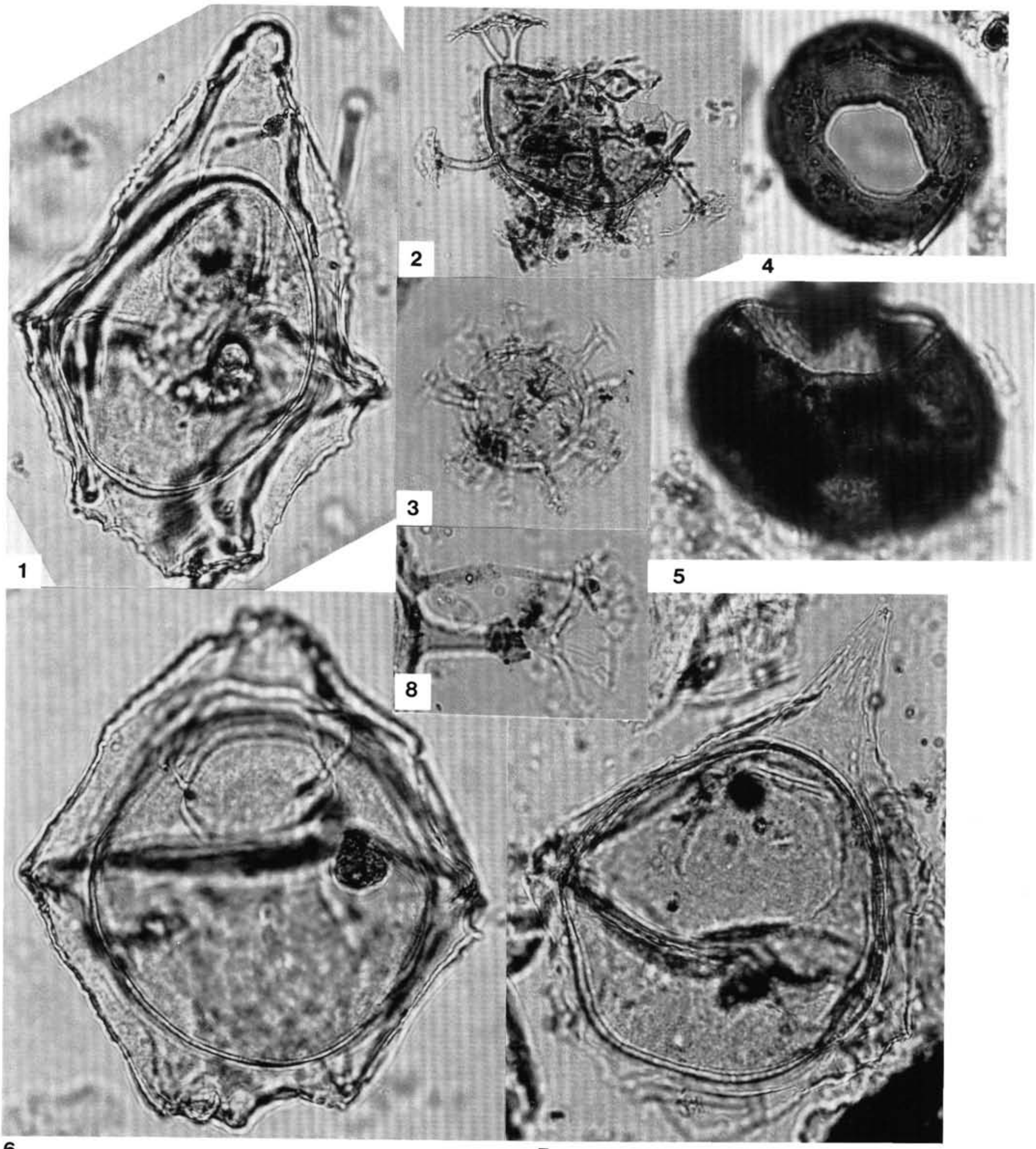

Plate 5. **1.** *Spinidinium luciae* Wrenn and Hart, 1988. Sample 113-696B-61R-1, 61–65 cm; sl. A, 42.5/98; × 850. **2.** *Areosphaeridium diktyoplokus* (Klumpp) Eaton, 1971. Sample 113-696B-53R-6, 50–54 cm; sl. B 45.3/96.1; × 500. **3.** *Impletosphaeridium* sp. Sample 113-696B-53R-6, 50–54 cm, sl. B, 45.3/96.1; × 850. **4.** *Brigantedinium* sp. Sample 113-696B-56R-1, 64–66 cm; smearslide; × 850. **5.** *Brigantedinium* sp. Sample 113-696B-56R-1, 64–66 cm; smear slide; × 850. **6.** *Spinidinium luciae* Wrenn and Hart, 1988. Sample 113-696B-60R-2, 75–79 cm; smear slide; × 850. **7.** *Senegalinium asymmetricum* (Wilson) Stover and Evitt, 1978. Sample 113-696B-59R-3, 51–56 cm; Sl. A, 36,2/89,9; × 850. **8.** *Areosphaeridium diktyoplokus* (Klumpp) Eaton, 1971. Sample 113-696B-54R-4, 50–54 cm; sl. C, 37.5/89; × 1000.

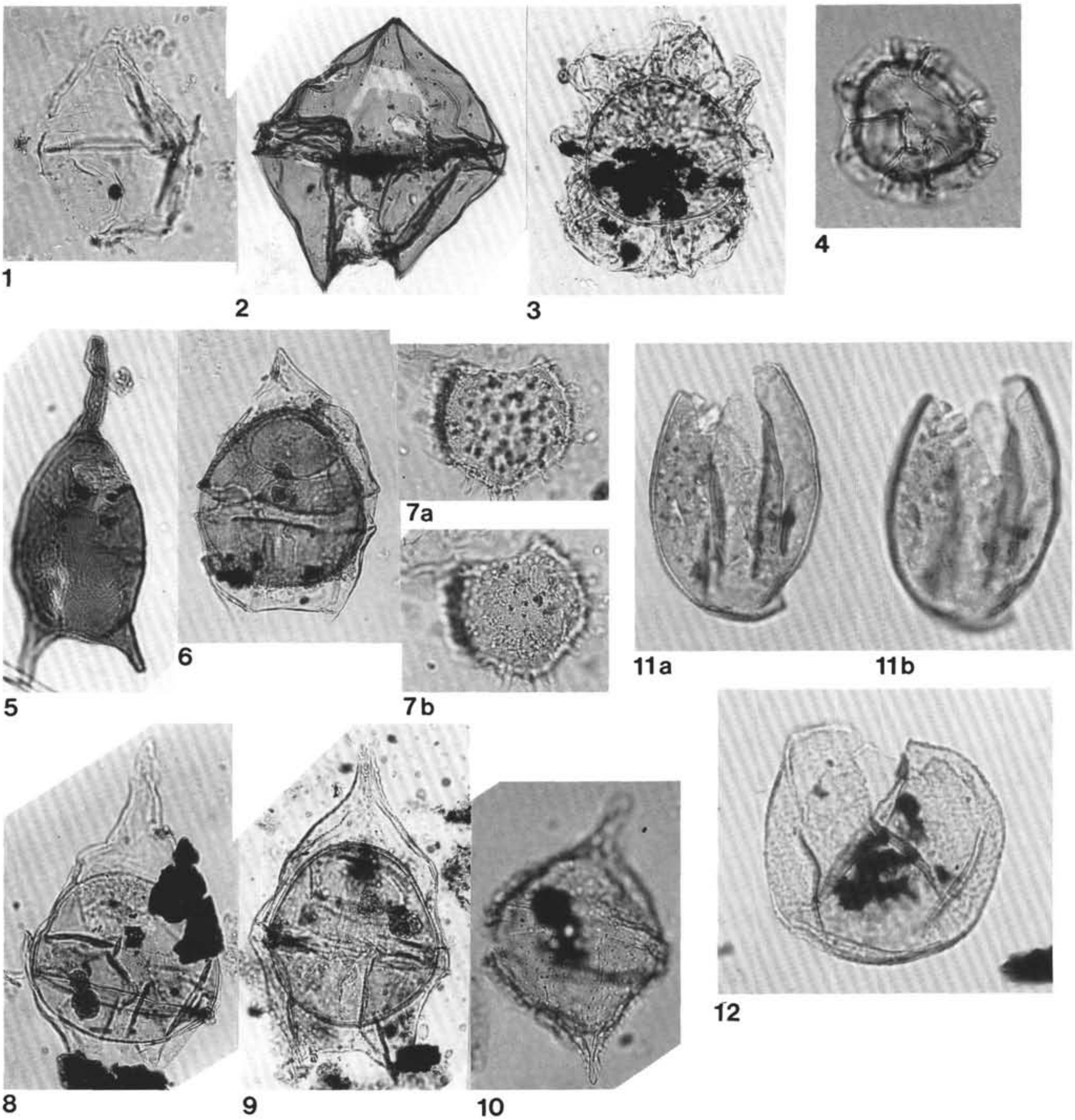

Plate 6. **1.** *Spinidinium essoi* Cookson and Eisenack, 1967. Sample 113-696B-59R-3, 51–56 cm; sl. A; × 550. **2.** *Lejeunecysta hyalina* (Gerlach) Artzner and Dörhöfer, 1978. Sample 113-696B-59R-3, 75–79 cm; sl. 5; × 450. **3.** *Turbiosphaera filosa* (Wilson) Archangelsky, 1968. Sample 113-696B-62R-7, 72–75 cm; sl. 2a; × 550. **4.** *Impagidinium victorianum* (Cookson and Eisenack) Stover and Evitt, 1978. Sample 113-696B-60R-2, 75–79 cm; sl. 37; × 550. **5.** *Octodinium askiniae* Wrenn and Hart, 1988. Sample 113-696B-60R-2, 75–79 cm; sl. 11; × 550. **6.** *Deflandrea antarctica* Wilson, 1967. Section 113-696B-60R, CC; sl. 6; × 450. **7A.** and **B.** *Operculodinium bergmannii* (Archangelsky) Stover and Evitt, 1978. Section 113-696B-60R, CC; sl. 8; × 550. **8.** *Deflandrea* sp. Sample 113-696B-54R-4, 50–54 cm; sl. 9. **9.** *Deflandrea antarctica* Wilson, 1967. Sample 113-696B-55R-6, 34–36 cm; sl. A, 40/93.7; × 450. **10.** *Vozzhennikovia apertura* (Wilson) Lentin and Williams, 1976. Sample 113-696B-59R-3, 51–56 cm; sl. 6; × 550. **11.** "Forma T" sensu Goodman and Ford, 1983. Sample 113-693B-19X-4, 27–32 cm; sl. 1; × 500. **12.** "Forma T", sensu Goodman and Ford, 1983. Sample 113-693B-19X-2, 92–97 cm; sl. S1, 37.5/93.2; × 550.