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20. LATE CRETACEOUS DINOFLAGELLATE CYSTS (?SANTONIAN-MAESTRICHTIAN) FROM THE SOUTHERN INDIAN OCEAN (HOLE 748C)[1]

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ABSTRACT

At Ocean Drilling Program Hole 748C in the Southern Indian Ocean, a total of 171 Late Cretaceous dinoflagellate taxa were encountered in 38 productive samples from Cores 120-748C-27R through 120-748C-62R (407–740 mbsf). Four provisional dinoflagellate assemblage zones and five subzones were recognized based on the character of the dinoflagellate flora and the first/last occurrences of some key species. *Isabelidinium korojonense* and *Nelsoniella aceras* occur in Zone A together with *Oligosphaeridium pulcherrimum* and *Trithyrodinium suspectum*. Zone B was delineated by the total range of *Odontochitina cribropoda*. Zone C was separated from Zone B by the presence of *Satyrodinium haumuriense*, and Zone D is dominated by new taxa. The dinocyst assemblages bear a strong affinity to Australian assemblages. Paleoenvironmental interpretations based mainly on dinocysts suggest that during the ?Santonian-Campanian to the Maestrichtian this portion of the Kerguelen Plateau was a shallow submerged plateau, similar to nearshore to offshore to upper slope environments with water depths of tens to hundreds of meters, but isolated from the major continents of the Southern Hemisphere. Starting perhaps in the late Cenomanian (Mohr and Gee, this volume), the Late Cretaceous transgression over the plateau reached its maximum during the late Campanian. The plateau may have been exposed above sea level and subjected to weathering during the latest Maestrichtian. The studied dinocyst assemblages characterized by species of *Amphidiadema, Nelsoniella, Satyrodinium*, and *Xenikoon* together with abundant *Chatangiella* (the large-size species) and *Isabelidinium* suggest that a South Indian Province (tentatively named the Helby suite) may have existed during the Campanian-Maestrichtian in comparison with the other four provinces of Lentin and Williams. One new genus, three new species, and two new subspecies of dinocysts are described.

INTRODUCTION

Ocean Drilling Program (ODP) Site 748 is located on the Southern Kerguelen Plateau (58°26.45′S, 78°58.89′E) (Fig. 1) in a water depth of 1290 m. The objective at Site 748 was to recover an expanded section of Cretaceous and Paleogene sediments to decipher the tectonic and geologic history of this part of the plateau. To achieve this goal, it is necessary to date the seismic stratigraphic section precisely by paleontologic methods. Equally important is reconstruction of the environments under which the sediments formed. Dinoflagellates have proven useful in biostratigraphy and paleoenvironmental reconstruction because of their planktonic habit and their preservable organic-walled (some with calcareous or siliceous walls) cysts.

Late Cretaceous dinoflagellates from the Southern Hemisphere, especially from Australia, have been studied for almost half a century, in particular by the late Isabel Cookson, often in association with coworkers (Cookson, 1956; Cookson and Eisenack, 1958, 1960a, 1960b, 1961, 1962, 1971, 1974, 1982; Manum and Cookson, 1964). These previous studies, however, were chiefly concerned with systematic descriptions, and the various zonation schemes proposed by several authors (Edgell, 1964; Evans, 1966; Morgan, 1977; among others) are based mainly on data from wells in different basins. Not until the mid-1980s was a more complete zonation scheme given by Wilson (1984) for New Zealand and by Helby et al. (1987) for Australia. These zonation schemes have provided palynologists with important criteria for stratigraphic correlation. Site 748 provides a unique, nearly continuous section of Cenomanian-Maestrichtian sediments that contains nannofossils and foraminifers as well as palynomorphs. The dating of the section is, therefore, more precise, as it is based on well-documented multidisciplinary calcareous microfossil chronostratigraphy. As a result, this study will add more information to what is already known about dating and correlating dinoflagellate zones in this region and should enhance the value of the zonation schemes proposed by Wilson (1984) and Helby et al. (1987).

The sediments from Hole 748C were divided into four units (Schlich, Wise, et al., 1989). A detailed description of the upper two lithologic units ranging from Pleistocene through Paleocene (Cores 120-748C-1R through 120-748C-26R), the basal unit, and the basal two subunits of Unit III ranging from Cenomanian to Santonian (Core 120-748C-78R through Section 120-748C-62R-CC) is found in Schlich, Wise, et al., 1989). Samples for the present study are from the upper two Subunits IIIB and IIIA of ?Santonian through Maestrichtian age (from 407 to 740 m below seafloor (mbsf); Core 120-748C-27R through Section 120-748C-62R-4). They consist of glauconitic rudstones, packstones, and grainstones, intermittently silicified, with intervals of abundant bryozoans, inoceramid prisms, and crinoid columnals and rare red algal debris (Fig. 2).

MATERIALS AND METHODS

The samples studied from Core 120-748C-27R through Section 120-748C-62R-4 are mainly glauconitic sandstones, siltstones, and claystones. One or two samples were processed from each core, and about the same volume of rock was used for each processed sample. Samples were processed using standard maceration and centrifuge preparation tech-

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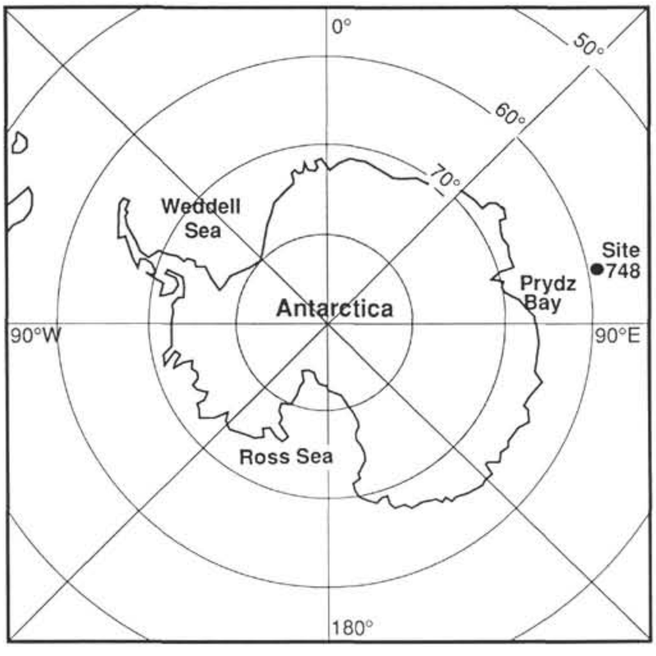

Figure 1. Location of Site 748 study area (simplified from Wei, this volume).

niques for palynomorphs, in addition to screening with a 15-μm mesh sieve. The microscopic observation and counting of each sample were carried out on two slides (each with one 20 × 40 mm cover slide). For taxonomic determinations and photographic documentation, additional single-specimen mounts were made. ODP localities and slide numbers of the holotype specimens are given in the plate captions.

The U.S. National Museum, Washington, D.C., is the curator of all slides with type specimens.

RESULTS

Dinoflagellate Stratigraphy and Age

General Aspects

One hundred and seventy-one taxa of dinoflagellate cysts were recovered from the studied section (Table 1), of which most have been recorded previously from the Southern Hemisphere. The general preservation of the dinocysts is moderate, but it varies from good to poor in different intervals. In addition to the abundant and diverse dinoflagellates, a small number of acritarchs (such as *Palambags morulosa, Pterospermella australiensis,* and *Veryhachium* sp.) and rare pollen and spores were recovered (such as *Nothofagidites* sp. and *Proteacidites* sp.) (Plate 5, Figs. 11 and 14–16; Plate 6, Fig. 9).

Zonation and Age

The geological ranges of dinocyst species, like those of some other fossils, vary geographically; they are controlled apparently by a variety of factors, such as facies, sedimentation rates, local discontinuities, etc., and are not as well known as those of nannofossils. Certain species, however, do have consistent ranges that can be used for stratigraphic correlation and age determination. The dinocyst taxonomy used here generally follows the index of Lentin and Williams (1989). The index contains the full citations to the original papers used in the present paper. These citations, therefore, will not be repeated in the references. A complete list of all taxa encountered in our material is given in Appendix A. The geological ranges of selected dinocyst species compiled from data by Harker and Sarjeant (1975), Williams and Bujak (1985), and Helby et al. (1987) as well as some individual papers are given in Appendix B.

The four provisional dinoflagellate assemblage zones here proposed and defined in ascending stratigraphic order are based on the content of dinoflagellate flora and the first/last occurrence (FO/LO) of certain species recorded in Hole 748C (Table 1 and Fig. 3).

Dinocyst Zone A (Sections 120-748C-62R-4 through 120-748C-62R-1, approximately 740–732 mbsf)

Zone A is characterized by the co-occurrence of *Chatangiella tripartita, Chlamydophorella discreta, Isabelidinium korojonense, I. microarmum, Nelsoniella aceras, Palaeohystrichophora infusorioides,* and *Trithyrodinium suspectum* as well as the acme species *Oligosphaeridium pulcherrimum.* The species diversity in the zone is as low as 27 taxa.

Isabelidinium microarmum was described from the Campanian-Maestrichtian of arctic Canada (McIntyre, 1975). *Chatangiella tripartita* (Cookson and Eisenack, 1960a), *C. victoriensis* (Manum and Cookson, 1964), and *Isabelidinium belfastense* (Cookson and Eisenack, 1961) were described from the undifferentiated Senonian of Australia, as were *Callaiosphaeridium asymmetricum* (Deflandre and Courteville, 1939), *Chatangiella spectabilis,* and *Isabelidinium cooksoniae* (upper Senonian; Alberti, 1959) from Europe. In North America, *Chatangiella tripartita* together with *Circulodinium distinctum* and *Odontochitina* spp. was found in Campanian sediments (Roberts, 1980, unpubl. data). These species have longer ranges on a global scale than at the localities where they were described (Fig. 4). The known ranges of the 13 species in Zone A shown in Figure 4 suggest a more reasonable age assignment of Campanian to early Maestrichtian for the zone. However, it is more likely that Zone A is early Campanian or possibly Santonian to early Campanian in age in comparison to the nannofossil data (Watkins, this volume; Fig. 5) and the age of the underlying interval (Mohr and Gee, this volume). Comparison with other dinoflagellate zonations for the Late Cretaceous does not provide a more definite answer. The top of Zone A was delineated tentatively at Section 120-748C-62R-1 because of a sampling gap between Section 120-748C-62R-1 and Core 120-748C-56R.

Dinocyst Zone B (Sections 120-748C-56R-1 through 120-748C-38R-1, approximately 692–512 mbsf)

Zone B is delineated by the total range of *Odontochitina cribropoda* with the FO of *Spinidinium*? *clavus* at its base in Hole 748C (Fig. 3). This zone contains the most abundant and diversified assemblage among the four zones and includes 146 taxa (Tables 1 and 2).

Circulodinium distinctum, C. distinctum subsp. *longispinatum, Odontochitina cribropoda,* and *Nelsoniella aceras* (in the upper part of the zone) are the most abundant taxa, dominating some assemblages and occurring continuously throughout Zone B. *Areoligera* sp. cf. *A. senonensis, Heterosphaeridium*? *heteracanthum, H. conjunctum, Nelsoniella tuberculata,* and *Odontochitina porifera* have their FOs within the zone. Together with *Trithyrodinium suspectum* these species are common in Zone B. Species of *Chatangiella* are most diverse in this zone in comparison with the other three zones. In addition to *C. tripartita* and *C. victoriensis, C.*? *biapertura, C. ditissima, C. granulifera, C. serratula, C. spectabilis,* and *C. verrucosa* occur within Zone B. *Xenikoon australis* has its FO near the top of the zone.

Zone B can be divided into three abundance acme subzones:

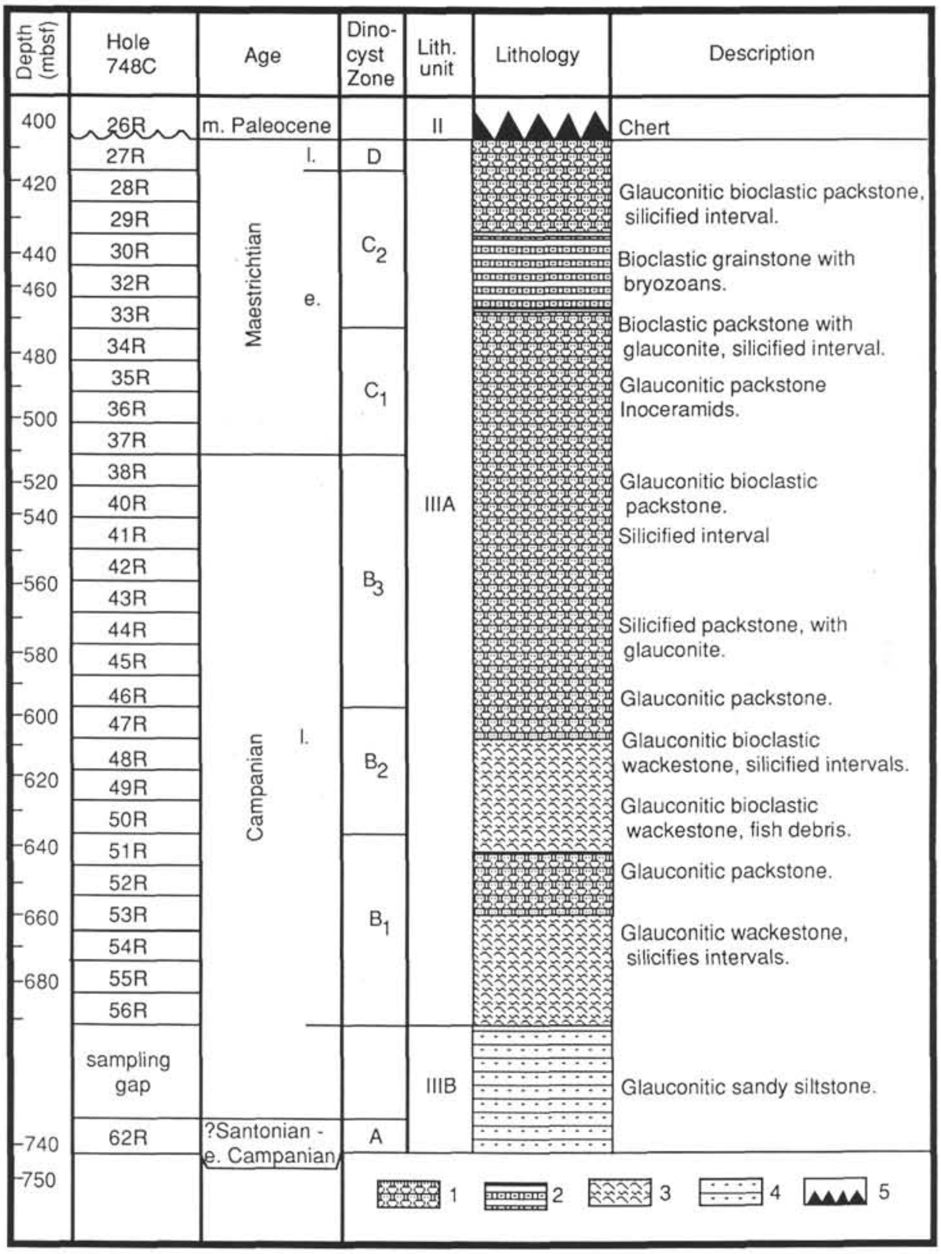

Figure 2. Lithology of the study section. Lithologic patterns: 1 = packstone, 2 = grainstone, 3 = wackestone, 4 = sandy siltstone, and 5 = chert (simplified from Schlich, Wise, et al., 1989).

Subzone B-1 (Cores 120-748C-56R through 120-748C-50R, approximately 692–626 mbsf) is characterized by the acme of *Chatangiella tripartita*. *C. ditissima*, *C. granulifera*, and *C. spectabilis* are limited to this subzone.

Subzone B-2 (Cores 120-748C-49R through 120-748C-47R, approximately 626–587 mbsf) is defined at its base by the FO of *Isabelidinium cretaceum oviforme* n. subsp. and characterized by the acme of the same subspecies.

Subzone B-3 (Cores 120-748C-46R through 120-748C-38R, approximately 587–512 mbsf) is characterized by the acme of *Nelsoniella aceras*. *Nelsoniella tuberculata* is abundant in the upper part of the subzone. *Isabelidinium* sp. A and *Xenikoon australis* have their FOs within the subzone.

Figure 6 shows the ranges of 17 species that have their FOs within Zone B. A Campanian age for Zone B is suggested based on the co-occurrence of these species, and a late Campanian assignment for Zone B is in better agreement with the age from nannofossils (Watkins, this volume; Fig. 5).

Dinocyst Zone C (Cores 120-748C-37R through 120-748C-28R, approximately 512–418 mbsf)

Zone C is defined by the total range of *Satyrodinium haumuriense* with the LO of *Xenikoon australis* at its top and the FO of *Elytrocysta druggii* at the bottom (Fig. 3). *Alterbidinium acutulum* and *Cerodinium diebelii* also occur Zone C. Other diagnostic species are *Fromea chytra*, *Isabelidinium pellucidum*, and *I.* sp. A. *Odontochitina porifera*, *Satyrodinium bengalense*, *Trithyrodinium fragile*, and *Xenascus ceratioides* are also present in the zone. Dinocyst specimen abundance decreases dramatically and species diversity also decreases to 104 taxa in Zone C (Table 1).

Table 1. Dinoflagellate range chart.

Lithologic unit/subunit	Dinocyst zones and subzones	Age	Core, section, interval (cm)	*Abratopdinium cardioforme* n. gen. & sp.	*Abratopdinium kerguelense* n. gen. & sp.	*Achomosphaera ramulifera*	*Achomosphaera* sp.	*Alterbidinium acutulum*	*Alterbidinium minus*	*Alterbidinium* sp.	*Amphidiadema denticulata*	*Amphidiadema* sp.	*Amphorosphaeridium fenestratum*	*Ampharasphaeridium* sp.	*Apteodinium maculatum*	*Areoligera coronata*	*Areoligera senonensis*	*Areoligera* sp.	*Areoligera* sp. cf. *A. senonensis*	*Batiacasphaera* sp.	*Bulbodinium seitzii*	*Callaiosphaeridium asymmetricum*	*Canningia kukebaiensis*	*Canningia reticulata*	*Canningia senonica*	*Canningia* sp.	*Canningia* sp. cf. *C. scabrosa*	*Canninginopsis colliveri*	*Cannosphaeropsis utinensis*	*Cassiculosphaeridia reticulata*	*Cerodinium diebelii*
IIIA	D	l. Maestrichtian	27R-2, 11-14	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	C, C_2	e. Maestrichtian	28R-1, 48-51	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			29R-1, 1-2	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.
			29R-1, 30-31	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	F	.	.	.	.	.	.
			30R-1,110-111	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			32R-1, 30-31	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	P	.	P	R
			33R-1, 37-40	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	C_1		34R-1, 62-65	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	P	P	.	.	.	.	.	.	.	.	.	.	.
			34R-1,113-115	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
			35R-1, 93-95	P	R	P	.	.	R	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	R	P	.	.
			36R-1, 68-70	F	F	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	P	P	.	.
			37R-1, 74-78	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	P	P	.	.	.	.	.	P	.	P	.	.	.
	B, B_3	l. Campanian	38R-1,125-128	R	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			40R-1, 20-23	C	C	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			40R-1, 67-69	P	R	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	R	.	.	.	.
			41R-1, 20-23	.	.	.	.	.	.	.	.	.	.	.	.	.	R	C	.	.	.	.	.	R	.	.	F	.	.	.	.
			42R-1, 20-22	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.
			43R-1, 60-63	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	P	.	.	.
			44R-1, 67-69	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.
			44R-1,126-128	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.
	B_2		45R-1,112-115	.	.	.	.	.	.	.	.	.	.	.	.	.	V	R	.	.	.	.	.	P	F	P	.	.	.	.	.
			46R-1, 86-89	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.
			47R-1, 92-95	.	P	.	.	.	.	.	P	.	.	.	P	.	.	.	R	.	P	.	.	.	P	.	.	.	.	.	.
			47R-CC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.
	B_1		48R-1, 80-85	.	.	.	.	.	.	.	A	R	.	.	.	.	.	.	A	P	.	.	.	.	.	.	.	.	.	.	.
			49R-1, 80-82	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.
			50R-1, 50-52	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	R	.	.	.	.	F	.	.	.	P	.	.	.
			51R-1,105-108	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	P	.	P	.	.	R	.	.	.
			52R-1, 45-47	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	F	.	.	.	.	.	.	.
			53R-1, 55-58	.	.	R	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.	.
			54R-1,146-148	.	.	.	.	.	.	.	.	.	.	.	F	R	.	.	V	.	.	.	.	.	.	.	.	.	.	.	.
			54R-CC	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			55R-1, 42-45	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			55R-2,125-129	.	.	.	R	.	P	.	.	.	.	.	.	.	P	R	P	.	P	.	.	P	.	.	.	.	.	.	.
			56R-1, 77-79	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	P	.	.	.	.	.
IIIB	A	?Santonian-e. Campan.	62R-1, 52-55	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	F	.	.	.	P	.	.	.
			62R-4, 98-101	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	P	.	.	.	.	.	.	.

Zone C can be divided into two subzones on the basis of the acmes of certain species:

Subzone C-1 (Cores 120-748C-37R through 120-748C-34R, approximately 512–475 mbsf) is characterized by the abundance acme of *Xenikoon australis*. In addition, *Elytrocysta druggii* is common to abundant, and *Palaeohystrichophora infusorioides* has its LO within the subzone.

Subzone C-2 (Cores 120-748C-33R through 120-748C-28R, approximately 475–418 mbsf) is characterized by the abundance acme of *Satyrodinium haumuriense* and the presence of *Isabelidinium pellucidum*. Species diversity in Subzone C-2 is lower than in Subzone C-1.

Satyrodinium haumuriense was described from the Maestrichtian of New Zealand (Wilson, 1984), and *S. bengalense* was reported from the Campanian at Deep Sea Drilling Project (DSDP) Site 217 in the Indian Ocean (Lentin and Manum, 1986). *Elytrocysta druggii* has a range of Campanian to Danian (Drugg, 1967; McIntyre, 1975; Ioannides, 1986). *Isabelidinium pellucidum* has a previously recorded range from Campanian to Maestrichtian (see Appendix B), *Cerodinium diebelii* ranges from Coniacian to Maestrichtian (Appendix B), and *Fromea chytra* was described from the Santonin to basal Danian (Drugg, 1967). *Xenikoon australis* was reported only from the lower Campanian in Australia (Helby et al., 1987), whereas in North America it has

Table 1 (continued).

Chatangiella ditissima	*Chatangiella granulifera*	*Chatangiella serratula*	*Chatangiella* sp.	*Chatangiella spectabilis*	*Chatangiella tripartita*	*Chatangiella verrucosa*	*Chatangiella victoriensis*	*Chatangiella? biapertura*	*Chlamydophorella discreta*	*Chlamydophorella nyei*	*Circulodinium distinctum*	*Circulodinium distinctum longispinatum*	*Cleistosphaeridium armatum*	*Cleistosphaeridium huguoniotii*	*Cleistosphaeridium* sp.	*Cleistosphaeridium? aciculae*	*Cleistosphaeridium? flexuosum*	*Cleistosphaeridium? multifurcatum*	*Cordosphaeridium* sp.	*Coronifera* sp. cf. *C. striolata*	*Cyclonephelium brevispinatum*	*Cyclonephelium compactum*	*Cyclonephelium crassimarginatum*	*Cyclonephelium hughesii*	*Cyclonephelium paucimarginatum*	*Cyclopsiella* sp.	*Deflandrea* sp.	*Diconodinium arcticum*	*Diconodinium psilatum*	*Diconodinium* sp.	*Diconodinium* sp. cf. *D. arcticum*	*Doconodinium? rhombiforme*	*Dinogymnium albertii*	*Dinogymnium curvatum*	*Dinogymnium digitus*	*Dinogymnium* sp.
.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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.	.	R	.	.	V	R	F	.	C	.	A	A	.	.	.	.	.	A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R
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R	.	.	C	.	F	.	.	.	.	.	F	P	.	.	R	.	.	.	.	.	P	.	P	.	.	.	P	P	.	R	.	.	.	.	.	P
R	C	.	A	P	C	P	.	P	.	P	F	F	.	.	.	.	.	.	.	.	.	.	A	P	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	P	.	A	.	.	.	.	.	.	.	.	.	C	F	C	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	R	.	P	.	P	.	R	.	P	.	.	.	F	.	.	.	.	.	P	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	A	.	.	C	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.

been found from the lower to upper Maestrichtian (Benson, 1976; Firth, 1987). Because Zone B is late Campanian, it is suggested that Zone C is early Maestrichtian, which would agree with the nannofossil data (Watkins, this volume; Fig. 5).

Dinocyst Zone D (recognized only in Sample 120-748C-27R-2, 11–14 cm, approximately 418–407 mbsf)

Zone D is distinguished from the underlying three zones by its low species diversity and poor preservation. The zone contains only 12 taxa, dominated by *Eurydinium ellipticum* n. sp. and *Isabelidinium cretaceum gravidum* n. subsp. The latter subspecies is similar to *Isabelidinium cretaceum* from the Maestrichtian of arctic Canada (Ioannides, 1986, pl. 15, figs. 5–7) and to *Isabelidinium greenense* from the Campanian of southeastern Australia (Marshall, 1990, fig. 21, D and E only). *Odontochitina spinosa* was described from the Maestrichtian of New Zealand (Wilson, 1984). It is reasonable to date Zone D as Maestrichtian in age, and a late Maestrichtian age for Zone D is in agreement with the nannofossil stratigraphy (Watkins, this volume). The absence of the late Maestrichtian–basal Danian *Manumiella druggii* Zone of Helby et al. may suggest that Zone D probably represents the early late Maestrichtian, and the uppermost Maestrichtian may be missing.

Although Campanian to Maestrichtian dinocyst assemblages have been widely studied in the Arctic, Europe, North America, Australia, and New Zealand, precise correlation of the present zones with other proposed zonations remains difficult. The Australian zonation given by Helby et al. (1987) provides the best correlation (Fig. 7). The five zones of their *Isabelidinium* Superzone, which in ascending order are the *Odontochitina porifera* Zone, *Isabelidinium cretaceum* Zone, *Nelsoniella aceras* Zone, *Xenikoon australis* Zone, and *Isabelidinium korojonense* Zone, were dated as early Santonian to early Maestrichtian. In this paper, the Subzones B-1, B-2,

Table 1 (continued).

Lithologic unit/subunit	Dinocyst zones and subzones	Age	Core, section, interval (cm)	*Dinogymnium undulosum*	*Dinogymnium westralium*	*Elytrocysta druggii*	*Endoceratium* sp.	*Eschariasphaeridia* sp.	*Eucladinium gambangense*	*Eucladinium madurense*	*Eucladinium spinosissimum*	*Eurydinium ellipticum* n. sp.	*Eurydinium eyrense*	*Eurydinium ingramii*	*Eurydinium tempestivum*	*Exochosphaeridium arnace*	*Exochosphaeridium phragmites*	*Exochosphaeridium* sp.	*Florentinia* sp. cf. *F. mantellii*	*Fromea chytra*	*Fromea* sp.	*Gillinia hymenophora*	*Gonyaulacysta* sp.	*Heterosphaeridium conjunctum*	*Heterosphaeridium cordiforme*	*Heterosphaeridium* sp.	*Heterosphaeridium? heteracanthum*	*Hystrichodinium pulchrum*	*Hystrichodinium* sp.	*Hystrichokolpoma* sp.	*Hystrichosphaeridium tubiferum*	*Impagidinium cristatum*	*Impagidinium* sp.	*Isabelidinium acuminatum*	*Isabelidinium bakeri*	*Isabelidinium belfastense*	*Isabelidinium cooksoniae*	*Isabelidinium cretaceum cretaceum*	*Isabelidinium cretaceum gravidusum* n. subsp.	*Isabelidinium cretaceum oviforme* n. subsp.	*Isabelidinium korojonense*
IIIA	D	Maestrichtian, l.	27R-2, 11–14	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	P	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.
IIIA	C, C_2	Maestrichtian, e.	28R-1, 48–51	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	P	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.
			29R-1, 1–2	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			29R-1, 30–31	.	.	P	.	.	.	.	.	P	.	.	P	.	.	P	.	P	.	.	.	P	.	.	P	.	.	.	.	P	.	.	.	.	.	.	.	.	.
			30R-1, 110–111	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	P	.	.	.	P	.	.	.	.	.	P	.	.	.	.	.	.	P	.	P
			32R-1, 30–31	.	.	R	.	.	P	.	.	A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	P	P	.	.	.	.
			33R-1, 37–40	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.
	C, C_1		34R-1, 62–65	.	P	.	.	P	.	.	.	.	.	.	.	.	.	R	.	.	.	P	.	.	.	R	.	R	.	.	.	.	.	P	P	.	.	.	.	.	.
			34R-1, 113–115	.	.	P	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	P	.	.	P	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.
			35R-1, 93–95	.	.	F	.	P	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			36R-1, 68–70	.	.	F	.	.	.	.	.	.	.	P	.	.	.	.	.	P	.	P	.	.	P	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			37R-1, 74–78	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	P	.	P	.	.	.
	B, B_3	l. Campanian	38R-1, 125–128	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			40R-1, 20–23	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.
			40R-1, 67–69	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	P	R	.	A	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			41R-1, 20–23	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	A	.	A	A	.	R	.	.	.	.	.	.	.	.	P	.	P	P
			42R-1, 20–22	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	V	.	.	V	.	.	.	R	.	.	R	.	.	.	.	.	F	.
			43R-1, 60–63	.	.	.	.	.	A	A	C	.	.	P	.	.	.	.	.	.	.	.	.	V	.	.	A	.	.	.	.	.	.	R	.	A	.	.	.	.	.
			44R-1, 67–69	P	P	.	.	.	.	.	R	.	.	.	.	.	.	R	.	.	R	.	.	.	.	A	.	.	.	.	.	P	.	P	.	.	.	.	.	.	.
			44R-1, 126–128	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	A	.	R	.	.	.	.	P	P	.	.	.	.	.	.	.	.	.
	B, B_2		45R-1, 112–115	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	R	.	C	.	A	F	.	.	.	F	.	.	.	.	.	.	.	.	.	.
			46R-1, 86–89	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	.	F	R	R	F	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			47R-1, 92–95	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	A	.
			47R-CC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	A	.
	B, B_1		48R-1, 80–85	.	.	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	A	.	F	.	.	.	.	.	.	.	.	.	C	.	C	.
			49R-1, 80–82	.	.	.	.	.	.	.	.	.	.	.	.	.	P	R	.	.	.	R	.	R	.	R	.	P	.	.	.	.	.	.	.	.	.	.	.	C	.
			50R-1, 50–52	.	.	.	.	.	.	.	.	.	.	P	.	.	.	R	.	.	.	.	.	.	.	.	F	C	.	.	.	.	.	P	.	.	.	.	.	.	.
			51R-1, 105–108	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	P	.	R	P	.	.	.	.
			52R-1, 45–47	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	P	.	F	.	A	P	R	.	.	P	.	.	.	.	.	.	.	.	.	.
			53R-1, 55–58	.	.	.	.	V	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	V	.	.	.	.	.	.	.	.	.	F	.	A	.	.	.	.	.
			54R-1, 146–148	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	V	.	.	.	A	.	.	.	.	.	.	.	.	.	.
			54R-CC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			55R-1, 42–45	.	.	.	.	V	.	.	P	.	R	.	P	.	.	.	.	.	P	.	.	A	.	.	P	F	.	.	.	.	.	P	.	.	.	.	.	.	.
IIIB	A		55R-2, 125–129	.	P	.	.	R	.	.	.	.	P	.	.	.	.	.	P	.	.	.	.	.	.	C	.	.	.	P	F	.	.	R	.	P	.	.	.	.	.
			56R-1, 77–79	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	F	F	.	.	.	.	.	.	.	.	.	.	.	.	.
		?Santonian-e. Campan.	62R-1, 52–55	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	C	.	.	.	R	.	.	.	.	F	P	.	.	.	P
			62R-4, 98–100	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.

B-3, C-1, and C-2 correlate approximately to their five zones, respectively, but the ranges of some important species in the subzones of this paper are different from those in the zones of Helby et al. (Fig. 7). The age assignment for our five subzones, therefore, is from late Campanian to early Maestrichtian based on the worldwide known ranges of those species. This assignment is in better agreement with the dates from nannofossils as well (Watkins, this volume). The reasons that result in such discrepancy as one stage in age between the two zonation schemes are unknown now. Further studies in this region may find the correct answer. Anyway, a multidisciplinary approach should be to date sediments in areas under new investigation if possible.

PALEOENVIRONMENTAL INTERPRETATION AND DINOFLAGELLATE PROVINCIALISM

Wall et al. (1977) studied dinocyst distributions in modern marine sediments and considered that these clearly showed both latitudinal-climatic and onshore-offshore trends, as evidenced by the data from four marine environments. These environments are estuarine, neritic, transitional neritic-ocean, and oceanic (pelagic), which correspond to the following four physiographic units: estuaries, continental shelves, continental slope-rise, and abyssal zones, respectively. Dinocyst assemblages from the different environments show distinct changes in three aspects: assemblage composition, species

Table 1 (continued).

Isabelidinium magnum	*Isabelidinium microarmum*	*Isabelidinium pellucidum*	*Isabelidinium* sp.	*Isabelidinium* sp. A	*Isabelidinium thomasii*	*Kallosphaeridium* sp.	*Kallosphaeridium? granulatum*	*Kallosphaeridium? helbyi*	*Kallosphaeridium? ringnesiorum*	*Kiokansium polypes*	*Kiokansium* sp. cf. *K. polypes*	*Laciniadinium firmum*	*Laciniadinium williamsii*	*Lanternosphaeridium* sp.	*Leberidocysta chlamydata*	*Lejeunecysta* sp.	*Leptodinium* sp.	*Maduradinium pentagonum*	*Manumiella* sp.	*Manumiella* sp. cf. *M.* sp. 2 of Askin	*Microdinium ornatum*	*Microdinium* sp.	*Nelsoniella aceras*	*Nelsoniella semireticulata*	*Nelsoniella* sp.	*Nelsoniella tuberculata*	*Nematosphaeropsis* sp.	*Odontochitina cribropoda*	*Odontochitina operculata*	*Odontochitina porifera*	*Odontochitina* sp.	*Odontochitina spinosa*	*Oligosphaeridium complex*	*Oligosphaeridium pulcherrimum*	*Oligosphaeridium* sp.	*Palaeocystodinium* sp. cf. *P. scabrata*
.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	R	P	.	.	.	.	.	P	.	.	.	P
.	.	P	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.
.	.	.	P	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	P	.	.	.	.	.
.	.	R	F	.	.	.	.	P	.	.	.	.	.	P	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	P	.	.	.
.	.	R	F	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.
.	.	.	A	.	P	.	.	P	F	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	R	.	.	.	.	.	.	.	.	.	.	.
.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.
.	.	.	A	A	.	.	.	P	P	.	.	.	.	.	P	.	P	.	.	P	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.
.	.	.	R	R	.	.	R	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	P	.	.	.	.	.	.	P	.	.	.	.	.	.
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P	R	.	F	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.	.	P	.	.	.
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.	F	.	A	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	V	.	.	.	.	.	F	.	.
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diversity, and specimen abundance. For example, assemblages from cool temperate, brackish stratified estuary environments are dominated by *Operculodinium centrocarpum* with a smaller proportion of *Spiniferites bulloides, Peridinium* (now *Protoperidinium*) (including grouped *Peridinium* species), *P. conicum,* and *P. pentagonum* and minor numbers of *Nematosphaeropsis balcombiana* and *Tectatodinium pellitum.* Assemblages dominated by either *Operculodinium centrocarpum* or by grouped *Peridinium* (now *Protoperidinium*) species and with *P. conicum* with minor numbers of *Spiniferites bulloides* and *S. mirabilis* indicate a temperate, low to medium salinity, seasonally stratified neritic environment, whereas assemblages from the tropical-subtropical open-sea environment are characterized by the dominance of *Leptodinium* (now *Impagidinium*: *I. aculeatum, I. strialatum, I. paradoxum, I. sphaericum,* and *I. patulum*) with *Operculodinium centrocarpum* and *Spiniferites ramosus* common in samples. Species diversity in different environments as indicated by the Hurlbert Index value varies from 1.4–10.5 (estuarine), to 3.6–8.0 (continental shelf), to 3.7–9.2 (continental slope-rise), and to 7.7–12.1 (intercontinental sea). The highest values for the index were generally encountered in warm-water environments. The specimen abundance (or specimen density) measured as the number of cysts per gram of sediment was clearly higher in sediments of the slope-rise zone than in all others. Harland (1983) illustrated some of Wall et al.'s conclusions with his distribution maps of several common species. A number of other studies of dinocysts from both modern and Quaternary sediments indicated that climate variations, water salinity, and ocean currents cause fluctuations in the dinocyst assemblages or communities (Rossignol, 1961, 1962; Wall, 1967; Wall and Dale, 1968; Harland, 1983).

It is difficult to interpret paleoenvironments for the pre-Quaternary as precisely as for the modern and Quaternary based on dinocysts alone. However, studies based on modern and Quaternary dinocysts can give important clues to pre-

Table 1 (continued).

Lithologic unit/subunit	Dinocyst zones and subzones	Age	Core, section, interval (cm)	*Palaeocystodinium* sp.	*Palaeohystrichophora infusorioides*	*Palaeohystrichophora* sp.	*Palaeoperidinium parvum*	*Paralecaniella* sp.	*Pierceites schizocystis*	*Platycystidia diptera*	*Pterodinium cingulatum*	*Satyrodinium bengalense*	*Satyrodinium haumuriense*	*Senegalinium* sp. cf. *S. microgranulatum*	*Spinidinium lanterna*	*Spinidinium* sp.	*Spinidinium uncinatum*	*Spinidinium? clavus*	*Spiniferites ramosus*	*Spiniferites* sp.	*Subtilisphaera pirnaensis*	*Subtilisphaera* sp.	*Talimudinium scissurum*	*Tanyosphaeridium variecalamus*	*Tanyosphaeridium xanthiopyxides*	*Trichodinium castanea*	*Trichodinium* sp.	*Trithyrodinium fragile*	*Trithyrodinium* sp.	*Trithyrodinium suspectum*	*Xenascus ceratioides*	*Xenascus* sp.	*Xenikoon australis*	*Xenikoon* sp.
IIIA	D	Maestrichtian l.	27R-2, 11–14	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	C, C_2	Maestrichtian e.	28R-1, 48–51	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	P	.
			29R-1, 1–2	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.
			29R-1, 30–31	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	R	.	.	.	.	P	P	.	.	.	.	.	.	P	.
			30R-1, 110–111	P	.	.	.	.	.	.	.	P	R	.	.	.	.	.	.	.	.	.	.	.	P	P	.	.	.	.	.	.	.	.
			32R-1, 30–31	.	.	.	.	.	.	.	.	.	A	.	.	.	R	.	.	P	.	P	.	.	.	P	.	C	F	.	F	.	.	.
			33R-1, 37–40	.	.	.	.	.	.	.	.	F	F	.	.	.	.	.	.	F	.	.	.	.	.	.	.	P	.	.	P	R	R	.
	C_1		34R-1, 62–65	.	.	.	.	.	.	.	.	P	.	P	.	.	.	.	R	.	.	.	.	.	.	P	.	R	.	F	F	.	P	.
			34R-1, 113–115	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	F	.
			35R-1, 93–95	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	P	.	.	.	.	R	.	.	P	.	.	.	.	A	.
			36R-1, 68–70	.	P	.	.	.	.	.	.	F	P	.	.	.	.	.	.	.	.	.	.	P	.	R	.	F	.	.	.	.	A	P
			37R-1, 74–78	.	.	.	.	.	.	.	P	.	.	.	.	P	.	.	.	P	.	.	.	.	.	.	.	.	.	.	.	.	R	.
	B, B_3	l. Campanian	38R-1, 125–128	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			40R-1, 20–23	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	P	.	.	.	.	.	A	.	.	.	.	.	.	P
			40R-1, 67–69	.	R	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.
			41R-1, 20–23	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	R	.
			42R-1, 20–22	.	A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			43R-1, 60–63	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	R	.	P	.	.	.	.
			44R-1, 67–69	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	P	P	.	.	.	.	.	.	.	.	.	R	P	.	.	.
			44R-1, 126–128	.	F	R	.	.	R	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	P	.	.	R	A	F	.	.	.	.
	B_2		45R-1, 112–115	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	F	F	.	.	.	R	.	.	.	.	F	.	.	.	.	.
			46R-1, 86–89	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	P	.	.	F	A	A	.	.	.	.
			47R-1, 92–95	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.
			47R-CC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	P	.	.	.	.	.	.	.	.
	B_1		48R-1, 80–85	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	A	A	.	.	.	.
			49R-1, 80–85	.	.	.	.	.	.	.	P	.	.	.	.	.	.	P	P	.	.	.	.	.	.	P	.	.	.	R	.	.	.	.
			50R-1, 50–52	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	P	.	.	.	F	.	A	.	.	.	.
			51R-1, 105–108	.	.	.	.	.	.	.	.	.	.	.	.	R	.	F	.	.	.	.	.	.	.	.	.	R	.	P	.	.	.	.
			52R-1, 45–47	.	P	.	P	.	.	.	.	.	.	.	R	A	C	A	P	P	.	.	R	.	.	.	.	.	.	P	.	.	.	.
			53R-1, 55–58	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.
			54R-1, 146–148	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
			54R-CC	.	.	.	.	.	.	.	.	.	.	.	.	F	.	.	.	.	.	.	.	.	.	.	.	.	.	.	C	.	.	.
			55R-1, 42–45	.	F	.	.	.	.	.	.	.	.	.	.	.	.	R	F	P	.	.	.	P	.	P	.	P	.	P	A	.	.	.
			55R-2, 125–129	.	.	.	.	.	P	.	.	.	.	.	F	F	.	C	F	.	.	.	.	P	.	.	.	P	.	F	F	.	.	.
			56R-1, 77–79	.	.	.	.	.	.	.	.	.	.	.	.	F	.	F	P	P	.	.	.	.	.	P	.	.	.	R	.	.	.	.
		?Santonian-e. Campan.	62R-1, 52–55	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	.	P	P	.	.	.
IIIB	A		62R-4, 98–101	.	P	.	.	.	.	.	.	.	.	.	.	.	.	.	.	P	.	.	.	.	.	.	.	.	.	F	P	.	.	.

Pleistocene environmental interpretations. Many attempts have been made since the 1960s to provide paleoenvironmental interpretation on the basis of dinocyst assemblages or communities (Vozzhennikova, 1965, 1967, 1979; Scull et al., 1966; Gruas-Cavagnetto, 1967, 1968; Davey, 1970, 1971; Downie et al., 1971; Harland, 1973; Goodman, 1979; Chateauneuf, 1980; May, 1980; Mao and Norris, 1988; Williams and Bujak, 1977). In these previous studies, the following factors have been used to interpret the paleoenvironment: (1) specimen abundance, (2) cyst types and their relative abundances, (3) content of reworked cysts, and (4) state of preservation. In addition, the occurrences and abundances of other palynomorphs, microfossils, and nannofossils as well as lithologic characters should be considered, and provincial control may be seen in some areas. The present study is based mainly on information from dinoflagellates, but has been integrated with data from other fossils and petrologic analyses.

Planktonic foraminifers were found only in Sample 120-748C-27R-1, 90–92 cm. Below this sample the fauna is dominated by bryozoans and echinoid and crinoid debris, with benthic foraminifers of small size constituting only a minor part. Calcareous nannofossils occur from Cores 120-748C-27R through 120-748C-56R (407–711 mbsf) and make up only a small proportion of the sediments. The sequence from Core 120-748C-62R, where dinocysts were recovered, is barren of calcareous nannofossils. Diatoms and radiolarians were found in Cores 120-748C-46R through 120-748C-48R, and in Sections 120-748C-45R-CC through 120-748C-53R-CC, respectively. In addition, Sample 120-748C-27R-1, 89–91 cm, contains radiolarians (Schlich, Wise, et al., 1989; Fig. 8).

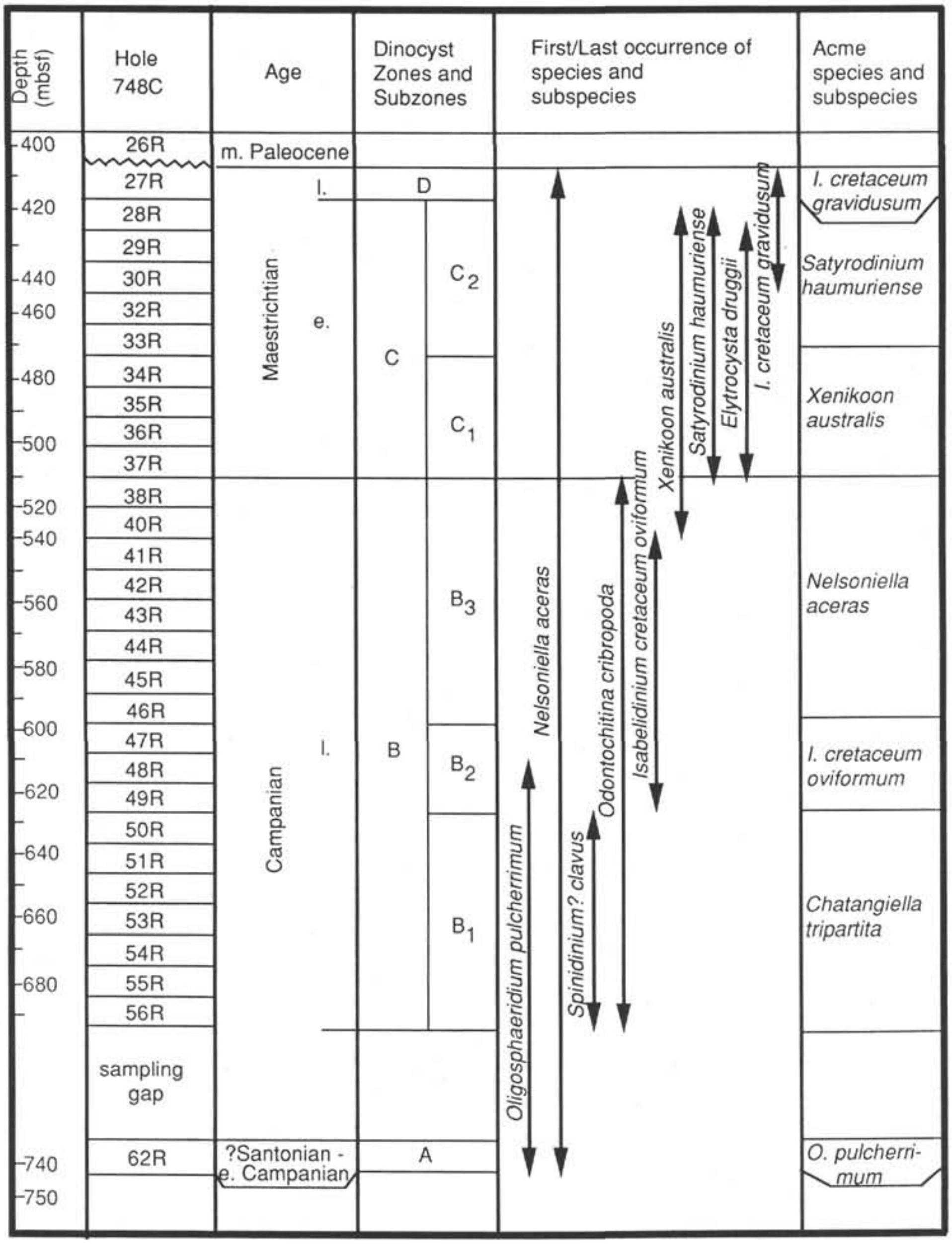

Figure 3. Dinoflagellate assemblage zones and subzones defined by the first and/or last occurrence and abundance acme of species, Hole 748C.

The lithology of Subunit IIIA (dinocyst Zones B–D) is composed of intermittently silica-cemented glauconitic rudstones, grainstones, and packstones, which contain 5%–65% glauconite grains and have bioclasts of bryozoans and inoceramids as the dominant components. The upper part of Subunit IIIB (dinocyst Zone A included) consists of glauconitic sandstones, and clayey sandstones (Schlich, Wise, et al., 1989).

All samples studied for this paper from Site 748 contain dinocysts, but are variable in specimen abundance throughout (Table 2 and Fig. 9). For example, dinocyst assemblages in Zone B contain the most abundant specimens, with an average count of about 287 specimens per slide, whereas above Core 120-748C-38R this figure decreases dramatically to about 55 specimens per slide. Although the counts are not absolute counts per gram of sample, they can be used as guides to indicate grossly the dinocyst productivity and applied for a rough paleoenvironmental interpretation. It is likely that the counts represent diminished absolute counts, if all of the slides were of a uniform density, because of the general tendency that the greater the volume of sample residue produced, the greater abundance of dinocyst specimens that residue will contain. Exceptions to this are rare. Reworked Early Cretaceous dinocysts are insignificant, and spores and pollen are very rare and occur only sporadically in the upper part of the interval studied (Maestrichtian).

The general aspects of dinocyst assemblages indicate that this portion of the Kerguelen Plateau was under shallow-water conditions similar to environments from the continental shelf to upper slope, with a water depth of tens to hundreds of meters, during ?Santonian-Campanian to Maestrichtian time, in comparison to the distribution patterns of

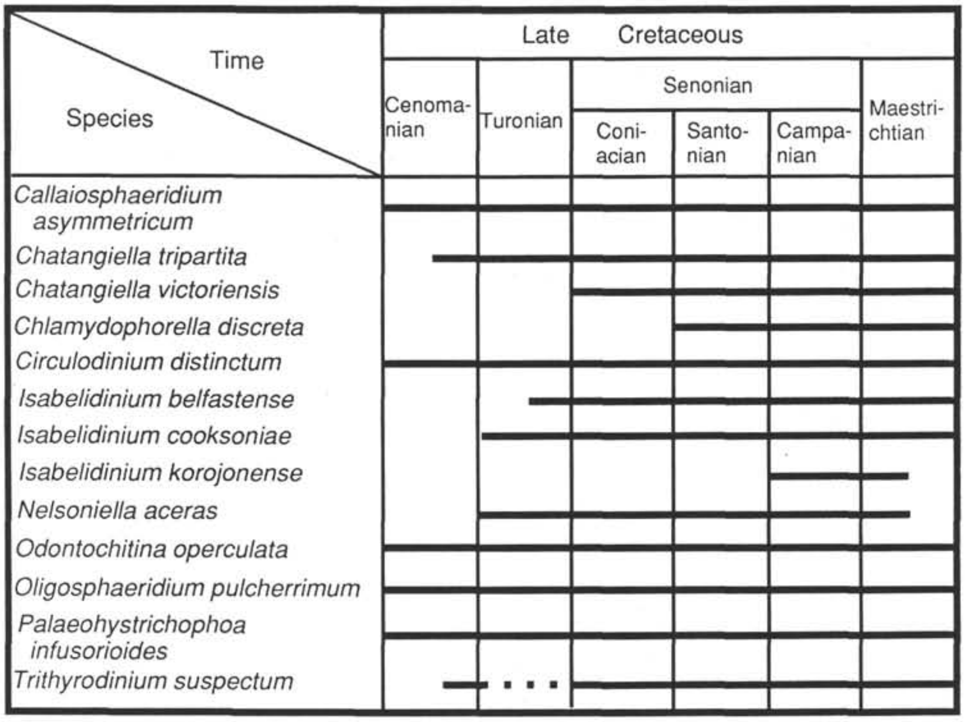

Figure 4. Range of selected species from Zone A.

palynomorphs, nannofossils, and foraminifers summarized by Stover and Williams (1982; Fig. 10). During the ?Santonian–early Campanian, the study area was as shallow as the nearshore (inner part of continental shelf) environment, but isolated from the main continents of the Southern Hemisphere, judging from the less abundant dinocyst specimens and lower species diversity and the very rare occurrence of spores in dinocyst Zone A. The lack of nannofossils, planktonic foraminifers, and siliceous microfossils as well as the coarser sandy sediments in the same interval also supports this conclusion. During the late Campanian the area deepened and was similar to the outer part of a continental shelf and the inner part of a continental slope environment, as evidenced by the abundant dinocyst specimens, the high species diversity, and higher percentage of gonyaulacoid, chorate cysts in Zone B and the occurrences of nannofossils, foraminifers, radiolarians, and diatoms. The Late Cretaceous regression from the plateau may have started in the early Maestrichtian, and small islands may have existed not far from the study area, as suggested by the decrease in dinocyst specimen abundance and species diversity, as well as by the higher percentage of peridinioid and cavate + proximate cysts in Zone C (Figs. 8–10). The increase in oxidized, poorly preserved dinocysts and the increase in pollen and spores toward the upper part of the section (dinocyst Zones C and D) also support this interpretation. During the course of the Late Cretaceous regression the possible occurrence of a short period of transgression is based on the presence of calcareous nannofossils, planktonic foraminifers, and radiolarians in samples from Core 120-748C-27R, but during most of the late Maestrichtian, the study area might have been above sea level and experienced weathering and erosion, as marked by a discontinuity above the top of Core 120-748C-27R (Schlich, Wise, et al., 1989).

Fossil dinoflagellate provincialism has not yet been well studied, and only one paper dealing with Late Cretaceous peridiniacean dinoflagellate provincialism is available (Lentin and Williams, 1980). In that monograph the authors presented a Late Cretaceous paleobiogeographic map integrated with both information on the Campanian dinocyst assemblages from all over the world and data from other sources. Three realms were delineated and three peridiniacean dinoflagellate suites (provinces) were proposed by Lentin and Williams (1980). Data from the Southern Hemisphere, particularly from the Indian Ocean, however, are scare. The present work will add information from the study area and will complement the Late Cretaceous dinoflagellate provincialism of Lentin and Williams's scheme.

The Campanian-Maestrichtian dinoflagellate assemblage from the study area bears a strong affinity to Australian assemblages (Table 3), which are characterized by having more peridinioid and cavate cysts than gonyaulacoid and chorate cysts (Fig. 9). *Isabelidinium, Chatangiella,* and *Nelsoniella* are abundant and occur continuously in the assemblage. *Chatangiella* illustrates a high species diversity and is large in size. *Spiniferites* is never abundant and is also low in species diversity in the assemblage. *Andalusiella* and *Senegalinium* are almost absent from the assemblage. *Amphidiadema, Nelsoniella, Satyrodinium,* and *Xenikoon* are probably endemic genera for this area. Taking this evidence into account, a different province from those of the North Pacific, North Atlantic, and Caribbean might have existed in the Southern Hemisphere during the Campanian to Maestrichtian. We tentatively name it the South Indian province (Helby suite), indicating a cool temperate climate in the Southern Hemisphere (Fig. 11).

CONCLUSIONS

Dinoflagellates have proven to be useful for stratigraphic investigations and paleoenvironmental reconstructions of upper Mesozoic strata drilled during Leg 120 on the Southern Kerguelen Plateau. The age of the interval from Core 120-748C-27R through Section 120-748C-62R-4 is ?Santonian–early Campanian to late Maestrichtian based primarily on

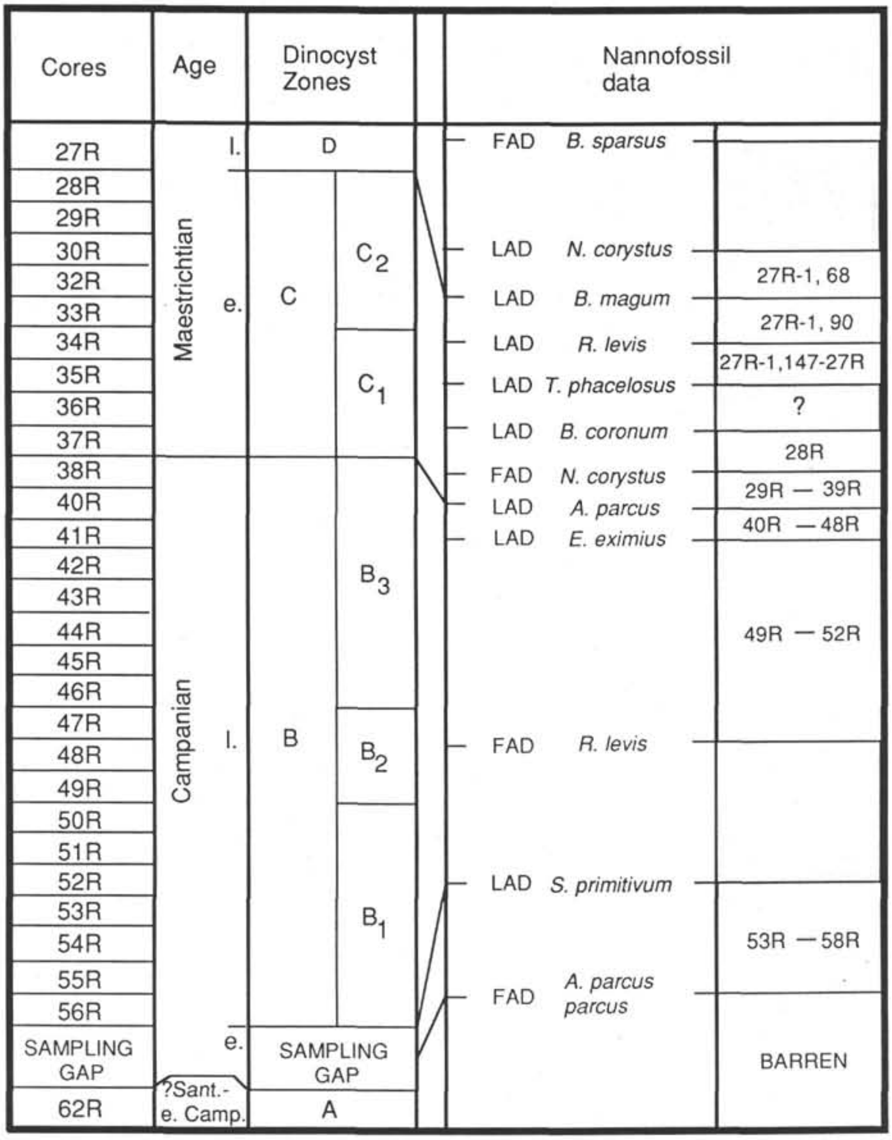

Figure 5. Correlation of dinocyst zonation and nannofossil data, Hole 748C.

dinoflagellate assemblages, which is in good agreement with the nannofossil data. As interpreted from dinoflagellates and integrated with information from other disciplines, Site 748 was located on a shallow submerged plateau, isolated from the main continents of the Southern Hemisphere during that time. The Late Cretaceous transgressions and regressions over the plateau during this period were also traced by means of dinoflagellates and other fossils. A South Indian cool temperate dinoflagellate province (tentatively named the Helby suite) is proposed based on brief comparisons of the Campanian to Maestrichtian dinoflagellate assemblages at Site 748 with those from other parts of the world.

SYSTEMATIC DESCRIPTIONS

A specimen designation such as 1-12.5/98.5 indicates the slide number of the sample (1) with coordinates (12.5/98.5) valid for Zeiss Photomicroscope III no. 0378 in the Nannofossil Laboratory of the Department of Geology, Florida State University.

Division PYRHOPHYTA Pascher, 1914
Class DINOPHYCEAE Fritsch, 1927
Order PERIDINIALES Haeckel, 1894
Suborder PERIDINIINEAE Fott, 1959, emend. Bujak and Davies, 1983
Family DEFLANDREACEAE Eisenack, 1954, emend. Bujak and Davies, 1983
Subfamily DEFLANDREOIDEAE Bujak and Davies, 1983

Genus *ABRATOPDINIUM* n. gen.

Derivation of name. From the Greek *abr,* meaning graceful, exquisite, and *atop,* meaning bizarre, in reference to the general appearance of the cyst, that is, its thin, transparent wall and shape.

Type species. *Abratopdinium kerguelense* n. gen., n. sp., upper Campanian to lower Maestrichtian of Hole 748C.

Description. Circumcavate cysts, ambital outline circular, subcircular, to heartlike. Both periphragm and endophragm thin and hyaline; periphragm smooth or with features of low relief; endophragm smooth. Paracingulum generally indicated by ridges only seen marginally, seldom by sparse verrucae seen on the surface. Parasulcus, where present, limited to the hypocyst. Archeopyle intercalary [2a],

Table 2. Count of encountered dinocyst specimens per slide and percentage of cysts in each sample.

Core number	Total counts of dinocyst specimens per slide	Relative abundance (%)			
		Proximate and cavate cysts	Chorate cyst	Peridinioid cysts	Gonyaulacoid cysts
27R	38	100	0	94.5	5.5
28R	9	65	35	38	62
29R	21	75	25	32	68
30R	22	82.5	17.5	59	41
32R	170	99	1	87.5	12.5
33R	30	78	22	54.5	46
34R	69	88	12	64	36
35R	76	85	15	62.5	37.5
36R	79	92.5	7.5	76	24
37R	31	86.5	13.5	61	39
38R	168	100	0	96	4
40R	228	70	30	57.5	42.5
41R	319	33	67	9	91
42R	424	33	67	7	93
43R	321	56	44	31	69
44R	188	73	27	61	39
45R	233	51	49	17	83
46R	351	92	8	24	76
47R	66	71	29	62.5	37.5
48R	468	58	42	20	80
49R	95	67	33	26	74
50R	435	94	6	66.5	33.5
51R	67	87.5	12.5	55.5	44.5
52R	191	63	37	55	45
53R	950	75	25	36	64
54R	276	14	86	14	86
55R	186	81.5	18.5	42	58
56R	127	49	51	7.5	92.5
62R	114	42	57	12.5	87.5

standard hexastyle, iso-thetaform or rounded at each corner, AI = 0.53–0.63; operculum free.

Remarks. *Abratopdinium* differs from any published genus in its thin and hyaline wall, small to medium size, archeopyle type, and rounded shape with no distinct horns. *Nelsoniella,* which may have a similar outline, has a thicker wall and is epicavate only.

Abratopdinium cardioforme n. sp.
(Plate 1, Figs. 3–4)

Derivation of name. From the Greek *cardi,* meaning heart, with reference to the shape of cyst.

Description. Cyst circumcavate, ambital outline heartlike, rounded rhombic to rounded pentagonal. Epicyst is rounded triangular; hypocyst is rounded or slightly concave at antapex, but without any indications of horns or projections. Wall two layered; both periphragm and endophragm are thin. The periphragm is smooth or with scattered apiculae of about 1 × 1 μm; the endophragm is smooth and hyaline, as a result, the endocyst is faintly visible. Paracingulum usually present, slightly levorotatory, 4–7 μm wide, indicated by low ridges, clearly seen along the cyst margin. Parasulcus, where present, is limited to the hypocyst. Archeopyle intercalary [2a], standard hexastyle, iso-thetaform; operculum usually free.

Comparison. *Abratopdinium cardioforme* differs from *A. kerguelense* in its heartlike shape and delicately apiculate periphragm.

Occurrence. Rare to common in Zones B to C of the upper Campanian to lower Maestrichtian.

Size. Length of cysts, 34.5–49 (holotype 45.8) μm; width of cysts, 33–53.2 (holotype 53.1) μm; 20 specimens measured.

Holotype. USNM No. 453932 (Plate 1, Fig. 4; 1-128/4.5).

Type locality. South Indian Ocean, Sample 120-748C-40R-1, 20–23 cm.

Abratopdinium kerguelense n. sp.
(Plate 1, Figs. 1–2 and 6)

Derivation of name. From the name Kerguelen, with reference to the Kerguelen Plateau, the operational area for Leg 120.

Description. Cyst circumcavate, spherical to subspherical. Both apex and antapex rounded without any horns or projections. Wall two layered; both periphragm and endophragm are thin and hyaline. Periphragm smooth, some with folds usually parallel to the outline or ornamented with verrucae 1.5–2.5 μm across and 2–3.5 μm apart. The verrucae, where present, delineate the paracingulum. The width of lateral pericoel varies, depending on the relative size of the endocyst, usually about one-third to one-tenth of the total width of the cyst. Endocyst spherical to subspherical. Paracingulum usually present, 5–7 μm wide, slightly lavorotatory, indicated by two rows of low ridges, some of which are visible only around the cyst margins or rarely indicated by the aligned verrucae. Parasulcus, where present, is limited to the hypocyst, and widened toward the posterior. Archeopyle intercalary [2a], standard hexastyle, iso-thetaform, or rounded at each corner; operculum usually free.

Size. Length of cysts, 36.5–51 (holotype 47.6) μm; width of cysts, 39.5–53 (holotype 44) μm; 20 specimens measured.

Occurrence. Few to abundant in Zones B to C of the upper Campanian to lower Maestrichtian.

Holotype. USNM no. 453931 (Plate 1, Fig. 1; 4-126/6.5).

Type locality. South Indian Ocean, Sample 120-748C-36R-1, 68–70 cm.

Genus *EURYDINIUM* Stover and Evitt, 1978

Eurydinium ellipticum n. sp.
(Plate 2, Figs. 1–2 and 8–9; Plate 10, Fig. 1)

Derivation of name. From the Latin *ellipticus,* elliptical, with reference to the general shape of the cyst.

Description. Cyst circumcavate. Apex rounded, truncate, or slightly concave in the middle anterior without any horns or projections; antapex almost rounded or slightly asymmetrical with one corner less rounded than the other. Endocyst subcircular to elliptical in outline. Wall two layered; both periphragm and endophragm are thin and smooth. Ambital pericoel, where developed, is as narrow as less than one-tenth of the total width of the cyst. Archeopyle intercalary [2a], standard hexastyle, iso-thetaform, some rounded at each corner; AI = 0.48–0.61; operculum usually free. No indications of paracingulum or parasulcus are present.

Discussion. This species is distinguished by its elliptical shape with no apical or antapical horns, for which reason it is better allocated to genus *Eurydinium* than to *Isabelidinium* or *Manumiella* (Stover and Evitt, 1978; Stover and Williams, 1987). The large size and the elliptical shape of the species distinguish it from any previously described species of *Eurydinium.*

Occurrence. Few to abundant in Subzone C-2 and Zone D of the Maestrichtian.

Size. Length of cysts, 78.5–100.5 (holotype 100) μm; width of cysts, 47.5–86.5 (holotype 71) μm; 20 specimens measured.

Holotype. USNM No. 453933 (Plate 2, Fig. 9; 2-127.5/6).

Type locality. South Indian Ocean, Sample 120-748C-32R-1, 30–31 cm.

Isabelidinium cretaceum (Cookson) Lentin and Williams

Deflandrea cretacea Cookson, 1956, pp. 184–185, pl. 1, figs. 1–4 and 7, non figs. 5–6.

Isabelia cretacea (Cookson) Lentin and Williams, 1976, p. 57.

Isabelidinium cretaceum (Cookson) Lentin and Williams, 1977, p. 167.

Remarks. Cookson (1956, pp. 184–185) described *Deflandrea cretacea* from the Upper Cretaceous of Nelson Bore, Victoria, Australia, as a circumcavate-bicavate cyst with a concave, rounded, or broadly tapered antapex. The illustration of the holotype shows a slightly concave posterior with two shallow antapical lobes and very narrow lateral pericoels. Since then the species has been transferred to the genera *Isabelia,elidinium,* and then questionably *Manumiella* (Bujak and Davies, 1983). *I. cretaceum* has been identified by a number of palynologists. We consider that the species should remain in the genus *Isabelidinium* on the basis that its main features are closer to *Isabelidinium* than to *Manumiella.*

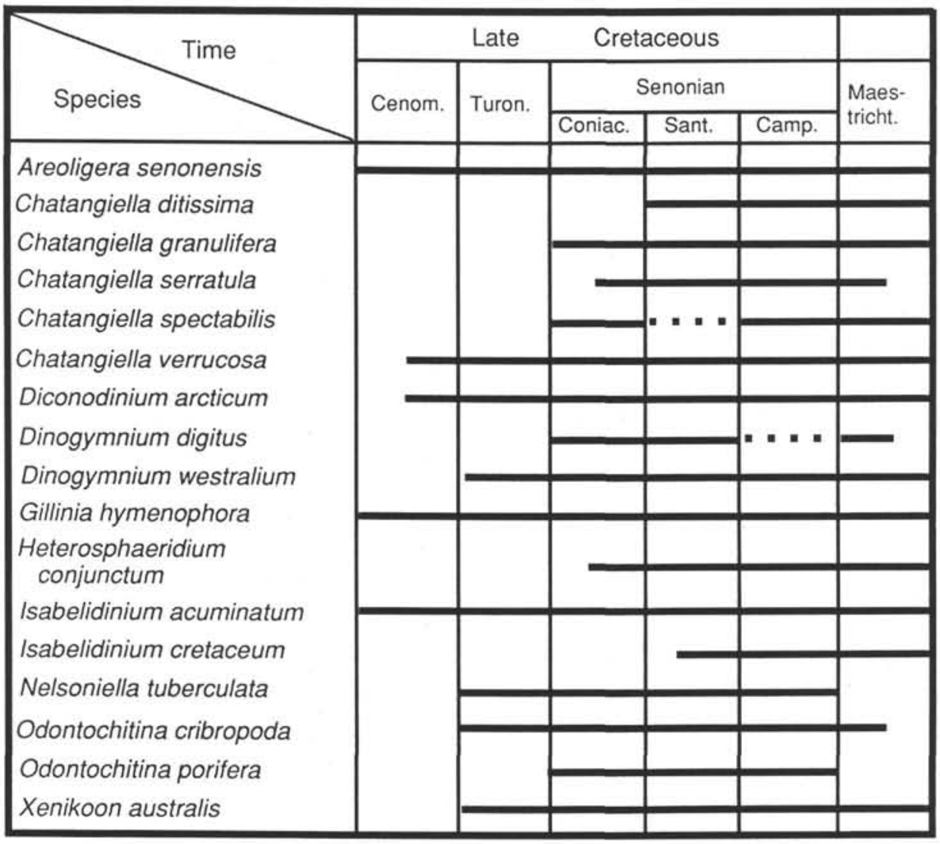

Figure 6. Range of selected species from Zone B.

Isabelidinium cretaceum cretaceum
(Plate 1, Fig. 10; Plate 10, Fig. 3; Plate 11, Fig. 6)

Deflandrea cretacea Cookson, 1956, pp. 184–185, pl. 1, figs. 1–3, non figs. 4–7.

Isabelidinium cretaceum (Cookson) Lentin and Williams, 1977, p. 167.

Remarks. The original description of *Deflandrea cretacea* (Cookson, 1956, pp. 184–185) included a variety of forms. The diagnosis for the present subspecies is featured as the illustration of the holotype (Cookson, 1956, pl. 1, fig. 1) and is bicavate or circumcavate with a very narrow lateral pericoel and has a concave antapex.

Holotype. Cookson (1956, pl. 1, fig. 1).

Type locality. Nelson Bore, Victoria, at 6233, 6065, and 5304 ft.

Isabelidinium cretaceum gravidum n. subsp.
(Plate 1, Figs. 11–12)

Deflandrea cretacea Cookson, 1956, pp. 184–185, pl. 1, fig. 4, but not figs. 1–3, 5–7.

Isabelidinium cretaceum (Cookson) Lentin and Williams, Ioannides, 1986, pl. 15, figs. 5–7.

Isabelidinium cretaceum (Cookson) Lentin and Williams, Askin, 1988, figs. 8-2 and 8-3.

Isabelidinium greenense Marshall, Marshall, 1990, figs. 21-D and 21-E, but not figs. 21-A–21-C, 21-F–21-R, and 22-A–22-D.

Derivation of name. From the Latin *gravidus*, meaning plump or pregnant, with reference to the expanded endocyst.

Description. Cyst bicavate. Both apex and antapex rounded without horns. Endocyst spherical to transversely elliptical, forming the widest part and occupying the major portion of the cyst. Cyst asymmetrical to both long and short axes or only to long axis with the apical pericoel larger than the antapical pericoel. Wall thin and two layered; both periphragm and endophragm smooth. Archeopyle intercalary [2a], standard hexastyle, iso-thetaform or rounded at each corner; AI = 0.52–0.65; operculum free.

Discussion. The range of *Isabelidinium cretaceum* has been extended from the Santonian (Helby et al., 1987) to the Maestrichtian (Ioannides, 1986) and to the Maestrichtian-Danian (Drugg, 1967). Comparison of the species identified by different authors, however, makes it necessary to subdivide the species into three subspecies to aid in its stratigraphic usage. The present subspecies is characterized by its bicavate cyst and transversely expanded endocyst. The present new subspecies is similar to some specimens of *Isabelidinium greenense* Marshall, 1990 (figs. 21-D and 21-E only). According to the description (Marshall, 1990, p. 24), "ventro-dorsal outline of endocyst subcircular to ovoidal and longitudinally elongate." Figures 21-D and 21-E, however, show the endocyst to be transversely elliptical rather than longitudinally elongate in outline, which is similar to the present new subspecies. We, therefore, consider them to be conspecies and consubspecies with the present subspecies. The subspecies differs from *I. cretaceum cretaceum* by having a rounded antapex, whereas the latter subspecies has a concave antapex and includes forms of both bicavate cysts and circumcavate cysts with very narrow lateral pericoel.

Occurrence. Few to abundant in Subzone C-2 and Zone D of the lower to upper Maestrichtian.

Size. Length of cysts, 73.5–99.5 (holotype 90) μm; width of cysts, 58.5–80.5 (holotype 80) μm; length of cysts/width of cysts = 1.1–1.6; 20 specimens measured.

Holotype. USNM No. 453934 (Plate 1, Fig. 11; 6-129/2.5).

Type locality. South Indian Ocean, Sample 120-748C-27R-2, 11–14 cm.

Isabelidinium cretaceum oviforme n. subsp.
(Plate 1, Figs. 7 and 9; Plate 10, Fig. 2; Plate 11, Fig. 5)

Deflandrea cretacea (Cookson, 1956), pp. 184–185, pl. 1, fig. 7, but not figs. 1–6.

Deflandrea cretacea (Cookson), Cookson and Eisenack, 1961, p. 7, pl. XI, figs. 1 and 2.

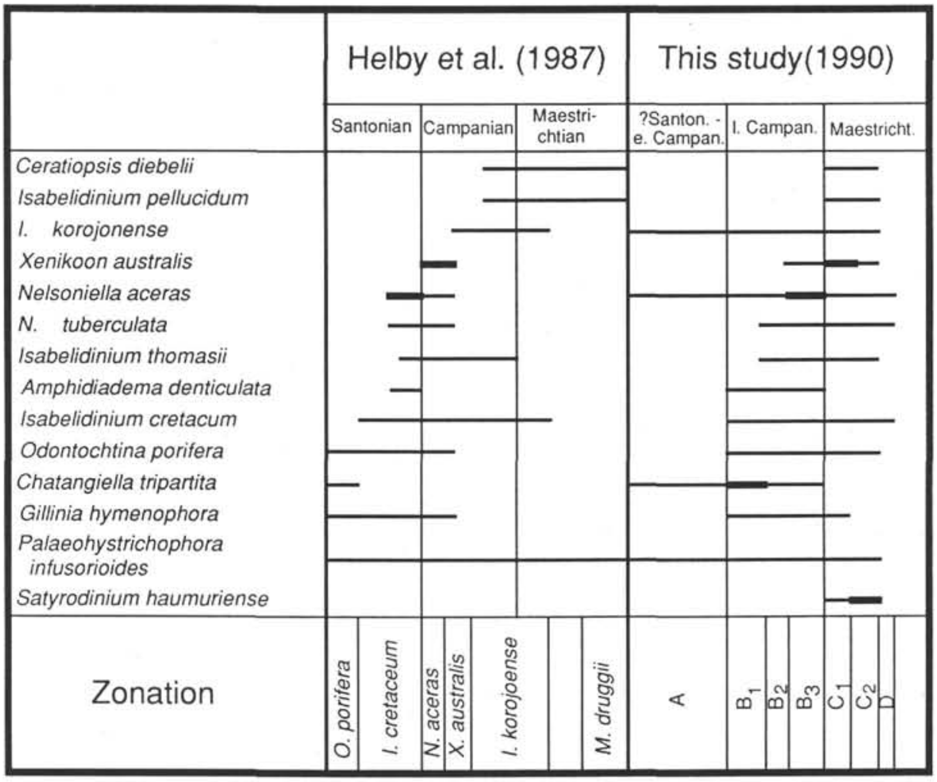

Figure 7. Comparison of dinocyst zones proposed by Helby et al. (1987) and those defined by this study.

Derivation of name. From the Latin *oviformis,* ovoidal, with reference to the shape of the cyst.

Description. Cyst circumcavate, ovoid. Apex rounded or slightly projecting; antapex broadly tapered, some slightly concave. The apex is always wider and more round than the antapex. Endocyst subspherical, dorsal side more convex than ventral side. The width of the lateral pericoel is commonly narrower than one-tenth of the total width of the cyst. Wall two layered; periphragm smooth or with verrucae on both apical and antapical areas, and endophragm smooth. Parasulcus, where present, is limited to the hypocyst. Archeopyle intercalary, standard hexastyle, iso-deltaform or rounded at each corner; operculum usually free, rarely attached.

Discussion. The subspecies differs from *I. cretaceum gravidum* because it has a circumcavate cyst and ovoid shape with the apex always wider and more rounded than the antapex. *I. cretaceum cretaceum,* according to the holotype (Cookson, 1956, pl. 1, fig. 1), is typically bicavate with a slightly concave antapex.

Occurrence. Common to abundant in Subzone B-2 and few in Subzone B-3 of the upper Campanian.

Size. Length of cysts, 90.5 to 112 (holotype 97.2) μm; width of cysts, 80 to 100.5 (holotype 80.2) μm; 20 specimens measured.

Holotype. USNM No. 453935 (Plate 1, Fig. 7; 1-97.2/4).

Type locality. South Indian Ocean, Sample 120-748C-47R-CC.

Isabelidinium sp. A
(Plate 4, Figs. 11–12)

Description. Cyst circumcavate and elongate with one apical and two antapical horns. The lateral sides parallel each other around equatorial area in ambital outline. The apical horn is bluntly pointed or truncated, formed by thickened and folded periphragm; two antapical horns are always pointed and unequal in size with the right one shorter and less pointed than the left one. The endocyst is circular to subcircular in dorso-ventral view, its lateral view is asymmetrical with the dorsal side more prominent than the ventral side. The width of the lateral pericoel is as narrow as one-tenth of the total width of the cyst. Archeopyle intercalary [2a], standard hexastyle, iso-deltaform to iso-thetaform, or rounded at each corner; AI = 0.40–0.46; operculum usually free. No indication of paracingulum and parasulcus is present.

Occurrence. Common to abundant in Zone C of the lower Maestrichtian.

Comparison. The illustrated specimens resemble *Isabelidinium glabrum,* which was recorded from the Albian to the Cenomanian of Australia (Cookson and Eisenack, 1969), but differ from it by having a more elongated shape and two pointed antapical horns.

Size. Length of cysts, 128–155.5 μm; width of cysts, 58.5–82.5 μm; length of left antapical horns, 29–38 μm; length of right antapical horns, 7–11 μm; width of endocysts, 55–58.5 μm; 20 specimens measured.

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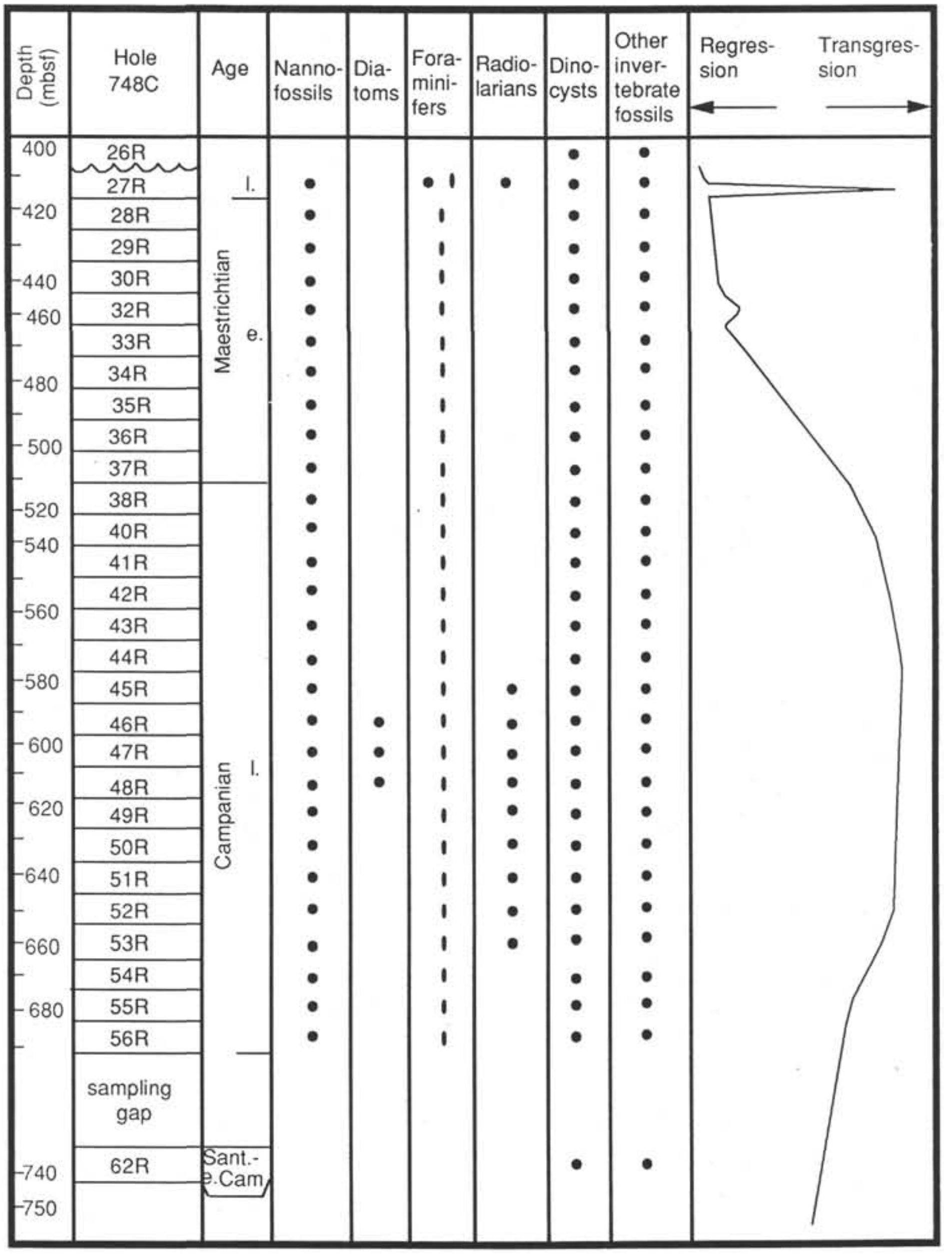

Figure 8. Vertical distribution of various fossil groups through the studied interval and the assumed course of transgression/regression during the ?Santonian-Campanian to Maestrichtian, based mainly on the fossils. For the foraminifers the round symbol represents planktonic, the oval benthic.

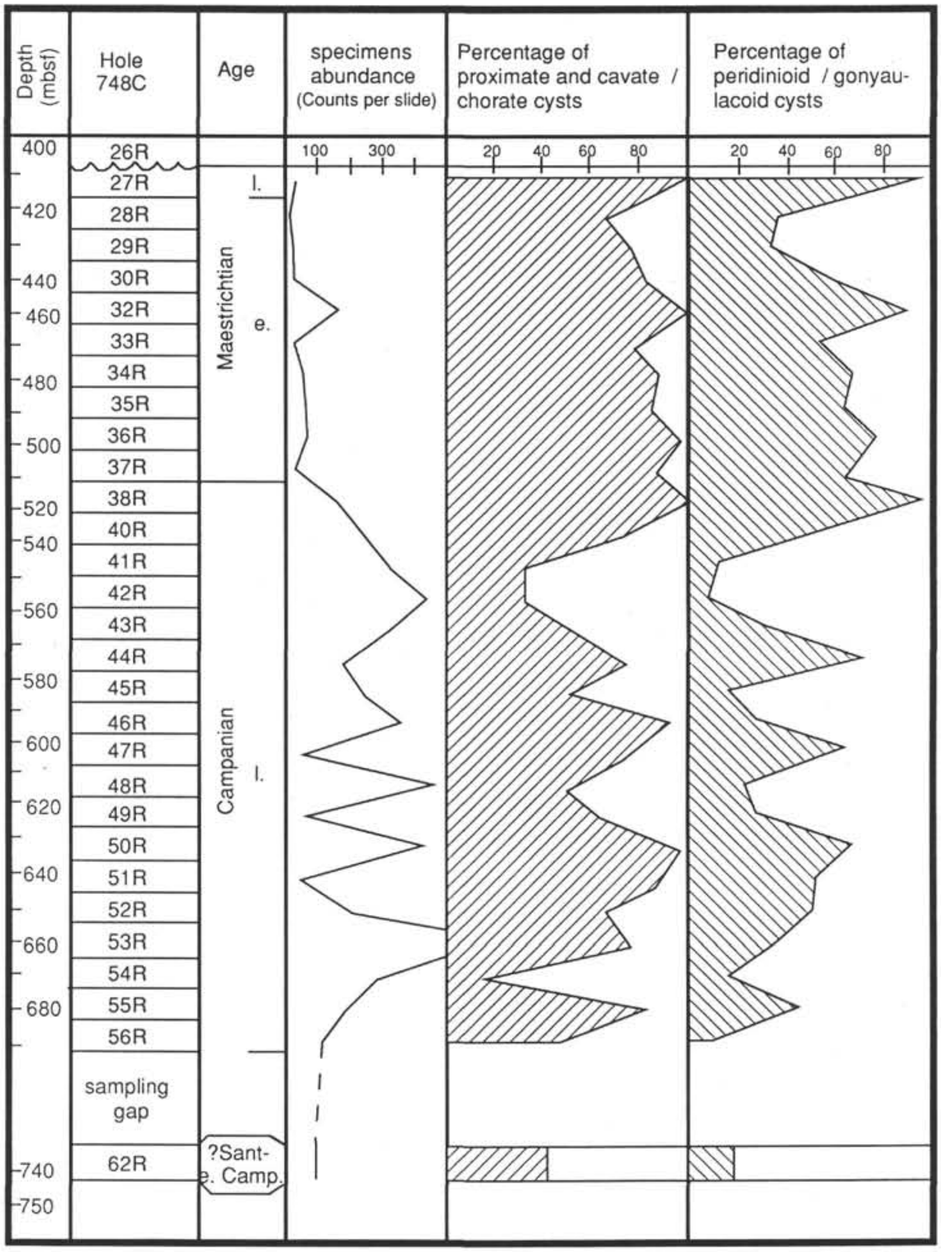

Figure 9. Variation in dinocyst specimen abundance and different types of dinocysts in the studied interval.

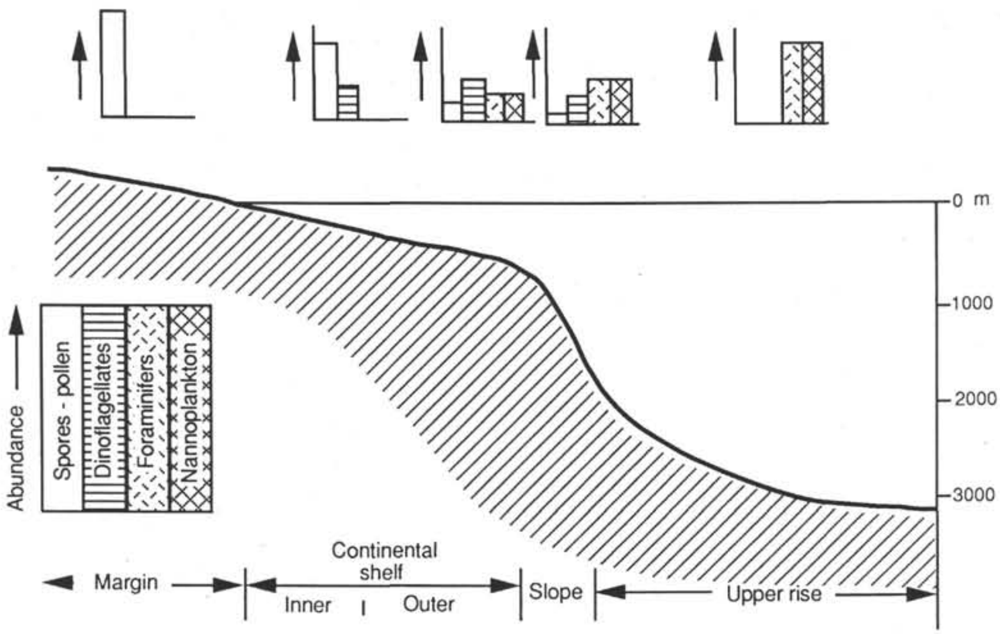

Figure 10. Relative distribution patterns of spores and pollen, dinoflagellates, foraminifers, and nannoplankton in various paleoenvironments (from Stover and Williams, 1982).

Table 3. The main features of Campanian to Maestrichtian dinocyst assemblages from different parts of the world.

Name of area or country	Age of dinocyst assembs.	Characters of dinocyst assemblages	Source of data	Province
Arctic Canada	Santonian-Maestrichtian	Dominated by peridinioid cysts, with abundant specimens and diverse species of *Chatangiella*, *Diconodinium*, *Spinidinium* and other cavate cysts present.	Ioannides, 1986	North Pacific cool - temperate McIntyre suite
New Jersey U.S.A.	Campanian to Maestrichtian	More peridinioid cysts than chorate cysts, but with diverse species of *Spiniferites*. Among peridinioid cysts, *Isabelidinium* are more common than *Chatangiella*.	Aurisano, 1989	North Atlantic warm - temperate Williams suite
Georgia, U.S.A.	Maestrichtian to Danian	*Spiniferites* and *Exochosphaeridium* abundant, diverse species of *Spiniferites* and other chorate cysts. *Isabelidinium*, *Xenikoon* and *Andalusiella* present.	Firth, 1987	? Probably transitional from temperate to subtropical
West-central Alabama and east Mississippi	Campanian	More diverse chorate genera, such as *Achomosphaera*, *Florentinia*, *Hystrichosphaeridium* and *Spiniferites*. High species diversity of *Spiniferites*, *Chatangiella* and *Isabelidinium* present.	Roberts, 1980	
Hemmoor, northwest Germany	Maestrichtian	Dominated by chorate and spiniferate cysts, mainly *Spiniferites ramosus*, with minor *Chatangiella*, *Isabelidinium*, *Cerodinium* and *Deflandrea* present.	Marheinecke, 1986	
Australia	Senonian	Dominated by peridinioid cysts, characterized by the presence of *Amphidiadema*, *Nelsoniella*, and *Xenikoon*. *Chatangiella* also present.	Cookson and Eisenack, 1960	South Indian cool - temperate Helby suite
south-western Victoria, Australia	Senonian	Dominated by peridinioid cysts, with abundant *Isabelidinium*, particular *I. cretaceum* and *I. belfastense*. *Amphidiadema denticulata* and *Odontochitina porifera* present.	Cookson and Eisenack, 1961.	
Australia	Upper Mesozoic (Senonian)	Dominated by species of *Isabelidinium*, *Chatangiella*, *Nelsoniella* and other peridinioid cysts.	Cookson and Eisenack, 1974, 1982.	
northern Antarctic Peninsula	late Campanian to Paleocene	Abundant cysts of *I. cretaceum*, *Deflandrea*, *Cerodinium*, *Spinidinium*, and *Manumiella*.	Askin, 1988	
Kerguelen Plateau, southern Indian Ocean	Campanian to Maestrichtian	Dominated by peridinioid cysts, with diverse species of *Chatangiella*, *Isabelidinium*, and *Nelsoniella*. *Amphidiadema*, *Cerodinium*, *Satyrodinium* and *Xenikoon* present. *Areoligera*, *Circulodinium distinctum* and *Heterosphaeridium* common.	This paper, 1991	

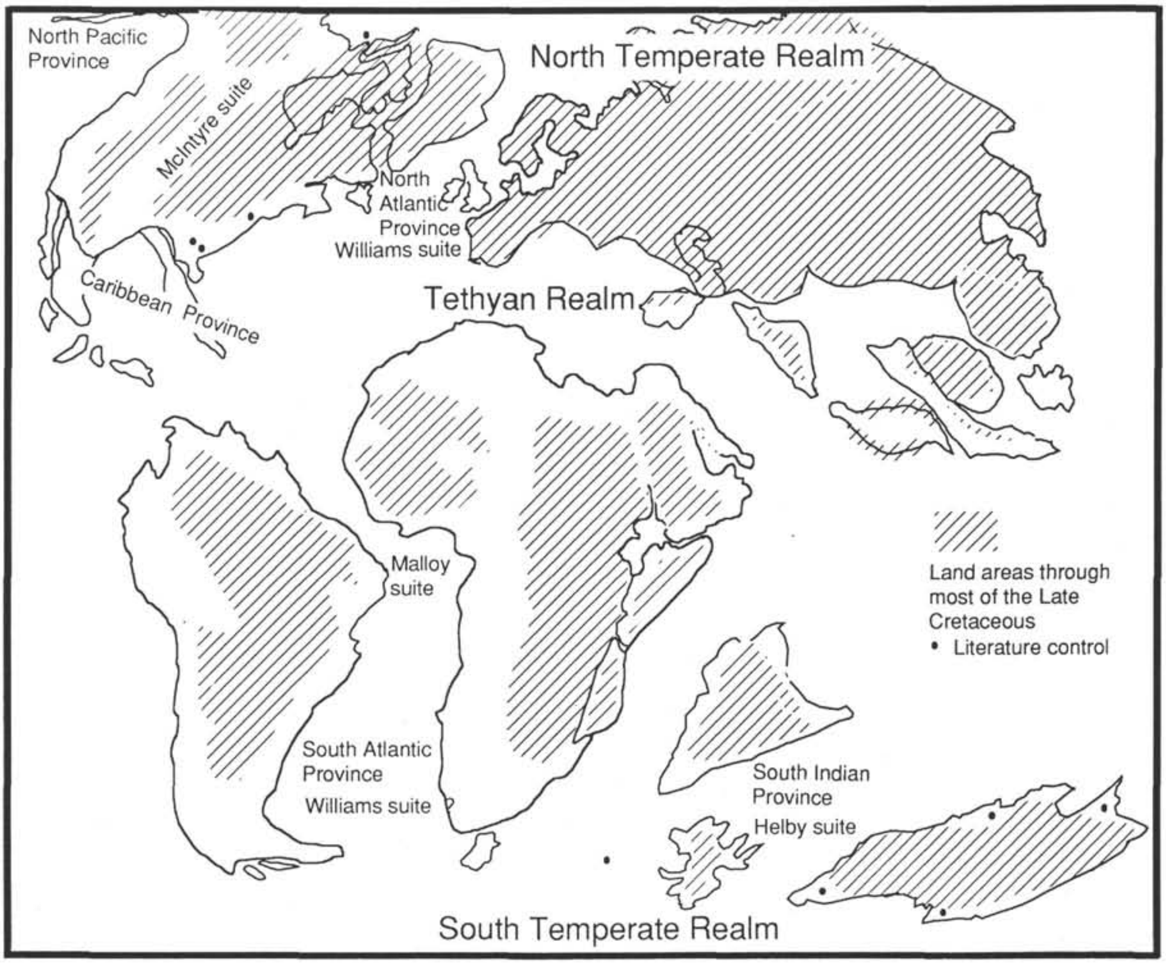

Figure 11. Campanian (to Maestrichtian) biogeographic map, based on Scotese et al. (1987), Lentin and Williams (1980), and information from this paper.

APPENDIX A

Dinoflagellate Cysts from Hole 748C

Abratopdinium cardioforme n. sp. (Plate 1, Figs. 3–4)
Abratopdinium kerguelense n. sp. (Plate 1, Figs. 1–2 and 6)
Achomosphaera ramulifera (Deflandre, 1937) Evitt, 1963
Achomosphaera sp.
Alterbidinium acutulum (Wilson, 1967) Lentin and Williams, 1985. (Plate 4, Fig. 4)
Alterbidinium minus (Alberti, 1959) Lentin and Williams, 1985. (Plate 9, Fig. 11)
Alterbidinium sp.
Amphidiadema denticulata Cookson and Eisenack, 1960a. (Plate 3, Figs. 6–7)
Amphidiadema sp. (Plate 3, Fig. 1)
Amphorosphaeridium fenestratum Davey, 1969
Amphorosphaeridium sp.
Apteodinium maculatum Eisenack and Cookson, 1960
Areoligera coronata (Wetzel, 1933) Lejeune-Carpenter, 1938
Areoligera senonensis Lejeune-Carpenter, 1938. (Plate 8, Fig. 1)
Areoligera sp.
Areoligera sp. cf. *A. senonensis* Lejeune-Carpenter, 1938. (Plate 8, Fig. 7)
Balteocysta perforata (Davey, 1978) Wilson and Clowes, 1980
Batiacasphaera sp.
Bulbodinium seitzii Wetzel, 1960
Callaiosphaeridium asymmetricum (Deflandre and Courteville, 1939) Davey and Williams, 1966
Canningia kukebaiensis Mao and Norris, 1988
Canningia reticulata Cookson and Eisenack, 1960. (Plate 7, Fig. 10)
Canningia senonica Clarke and Verdier, 1967
Canningia sp. (Plate 9, Fig. 2)
Canningia sp. cf. *C. reticulata* Cookson and Eisenack, 1960
Canningia sp. cf. *C. scabrosa* Cookson and Eisenack, 1970
Canninginopsis colliveri (Cookson and Eisenack, 1960) Backhouse, 1988
Cannosphaeropsis utinensis Wetzel, 1933
Cassiculosphaeridia reticulata Davey, 1969
Cerodinium diebelii (Alberti, 1959) Lentin and Williams, 1987. (Plate 3, Fig. 10)
Chatangiella? biapertura (McIntyre, 1975) Lentin and Williams, 1976
Chatangiella ditissima (McIntyre, 1975) Lentin and Williams, 1976. (Plate 3, Fig. 9)
Chatangiella granulifera (Manum, 1963) Lentin and Williams, 1976
Chatangiella serratula (Cookson and Eisenack, 1958) Lentin and Williams, 1976. (Plate 4, Fig. 6)
Chatangiella sp.
Chatangiella spectabilis (Alberti, 1959) Lentin and Williams, 1976. (Plate 3, Fig. 2)
Chatangiella tripartita (Cookson and Eisenack, 1960) Lentin and Williams, 1976. (Plate 3, Fig. 12; Plate 4, Fig. 7)
Chatangiella verrucosa (Manum, 1963) Lentin and Williams, 1976. (Plate 3, Fig. 13)
Chatangiella victoriensis (Cookson and Manum, 1964) Lentin and Williams, 1976. (Plate 4, Fig. 1)
Chlamydophorella discreta Clarke and Verdier, 1967. (Plate 6, Fig. 4)
Chlamydophorella nyei Cookson and Eisenack, 1958
Circulodinium distinctum (Deflandre and Cookson, 1955) Jansonius, 1986. (Plate 7, Fig. 5; Plate 9, Fig. 3)
Circulodinium distinctum subsp. *longispinatum* (Davey, 1978) Lentin and Williams, 1989. (Plate 7, Figs. 1 and 8)
Cleistosphaeridium? aciculare Davey, 1969
Cleistosphaeridium armatum (Deflandre, 1937) Davey, 1969
Cleistosphaeridium? flexuosum Davey et al., 1966
Cleistosphaeridium huguoniotii (Valensi, 1955) Davey, 1969
Cleistosphaeridium? multifurcatum (Deflandre, 1937) Davey et al., 1969
Cleistosphaeridium sp.
Cordosphaeridium sp.
Coronifera sp. cf. *C. striolata* (Deflandre, 1937) Stover and Evitt, 1978
Cyclonephelium brevispinatum (Millioud, 1969) Below, 1981
Cyclonephelium compactum Deflandre and Cookson, 1955. (Plate 7, Figs. 2 and 6)
Cyclonephelium crassimarginatum Cookson and Eisenack, 1974. (Plate 7, Fig. 9; Plate 9, Fig. 1)
Cyclonephelium hughesii Clarke and Verdier, 1967
Cyclonephelium paucimarginatum Cookson and Eisenack, 1962
Cyclopsiella sp.
Deflandrea sp.
Diconodinium arcticum Manum and Cookson, 1964
Diconodinium psilatum Morgan, 1977
Diconodinium? rhombiforme Vozzhennikova, 1967
Diconodinium sp. (Plate 3, Fig. 4)
Diconodinium sp. cf. *D. arcticum* Manum and Cookson, 1964. (Plate 4, Fig. 3)
Dinogymnium albertii Clarke and Verdier, 1967. (Plate 4, Fig. 14)
Dinogymnium curvatum (Vozzhennikova, 1967) Lentin and Williams, 1973
Dinogymnium digitus (Deflandre, 1935) Evitt et al., 1967. (Plate 1, Fig. 5)
Dinogymnium sp.
Dinogymnium undulosum Cookson and Eisenack, 1970. (Plate 11, Fig. 2)
Dinogymnium westralium (Cookson and Eisenack, 1958) Evitt et al., 1967
Elytrocysta druggii Stover and Evitt, 1978. (Plate 5, Figs. 12–13; Plate 9, Fig. 10)
Endoceratium sp.
Escharisphaeridia sp. (Plate 5, Fig. 9)
Eucladinium gambangense (Cookson and Eisenack, 1970) Stover and Evitt, 1978. (Plate 5, Fig. 1)
Eucladinium madurense (Cookson and Eisenack, 1970) Stover and Evitt, 1978. (Plate 5, Fig. 10)
Eucladinium spinosissimum (Cookson and Eisenack, 1970) Stover and Evitt, 1978
Eurydinium ellipticum n. sp. (Plate 2, Figs. 1–2 and 8–9; Plate 10, Fig. 1)
Eurydinium eyrense (Cookson and Eisenack, 1971) Stover and Evitt, 1978
Eurydinium ingramii (Cookson and Eisenack, 1970) Stover and Evitt, 1978. (Plate 3, Fig. 8)
Eurydinium tempestivum Mao and Norris, 1988
Exochosphaeridium arnace Davey and Verdier, 1973
Exochosphaeridium phragmites Davey et al., 1966
Exochosphaeridium sp.
Florentinia sp. cf. *F. mantellii* (Davey and Williams, 1966) Davey and Verdier, 1973
Fromea chytra (Drugg, 1967) Stover and Evitt, 1978. (Plate 6, Fig. 8)
Fromea sp.
Gillinia hymenophora Cookson and Eisenack, 1960. (Plate 5, Fig. 5)
Gonyaulacysta sp.
Heterosphaeridium conjunctum Cookson and Eisenack, 1968. (Plate 8, Figs. 4–5 and 8)
Heterosphaeridium cordiforme Yun, 1981
Heterosphaeridium? heteracanthum (Deflandre and Cookson, 1955) Eisenack and Kjellström, 1971. (Plate 8, Fig. 2)
Heterosphaeridium sp. (Plate 8, Fig. 6; Plate 11, Fig. 4)
Hystrichodinium isodiametricum (Cookson and Eisenack, 1958) Stover and Evitt, 1978
Hystrichodinium pulchrum Deflandre, 1935. (Plate 8, Fig. 3)
Hystrichodinium sp.
Hystrichokolpoma sp.
Hystrichosphaeridium tubiferum (Ehrenberg, 1838) Deflandre, 1937
Impagidinium cristatum (May, 1980) Lentin and Williams, 1981
Impagidinium sp.
Isabelidinium acuminatum (Cookson and Eisenack, 1958) Stover and Evitt, 1978. (Plate 3, Fig. 5)
Isabelidinium bakeri (Deflandre and Cookson, 1955) Lentin and Williams, 1977
Isabelidinium belfastense (Cookson and Eisenack, 1961) Lentin and Williams, 1977. (Plate 4, Fig. 5)
Isabelidinium cooksoniae (Alberti, 1959) Lentin and Williams, 1977. (Plate 3, Fig. 3)
Isabelidinium cretaceum cretaceum (Cookson, 1956) Lentin and Williams, 1977. (Plate 1, Fig. 10; Plate 10, Fig. 3; Plate 11, Fig. 6)
Isabelidinium cretaceum gravidum n. subsp. (Plate 1, Figs. 11–12)

Isabelidinium cretaceum oviforme n. subsp. (Plate 1, Figs. 7–9; Plate 10, Fig. 2; Plate 11, Fig. 5)
Isabelidinium korojonense (Cookson and Eisenack, 1958) Lentin and Williams, 1977
Isabelidinium magnum (Davey, 1970) Stover and Evitt, 1978
Isabelidinium microarmum (McIntyre, 1975) Lentin and Williams, 1977. (Plate 3, Fig. 11)
Isabelidinium pellucidum (Deflandre and Cookson, 1955) Lentin and Williams, 1977. (Plate 4, Figs. 8–9)
Isabelidinium sp.
Isabelidinium sp. A (Plate 4, Figs. 11–12)
Isabelidinium thomasii (Cookson and Eisenack, 1961) Lentin and Williams, 1977
Kallosphaeridium? *granulatum* (Norvick, *in* Norvick and Burger, 1976) Stover and Evitt, 1978
Kallosphaeridium? *helbyi* (Cookson and Hughes, 1964) Helby, 1987. (Plate 4, Fig. 13)
Kallosphaeridium? *ringnesiorum* (Manum and Cookson, 1964) Helby, 1987
Kallosphaeridium sp.
Kiokansium polypes (Cookson and Eisenack, 1962) Below, 1982
Kiokansium sp. cf. *K. polypes* (Cookson and Eisenack, 1962) Below, 1982
Laciniadinium firmum (Harland, 1973) Morgan, 1977. (Plate 4, Fig. 2)
Laciniadinium williamsii Ioannides, 1986
Lanternosphaeridium sp.
Leberidocysta chlamydata (Cookson and Eisenack, 1962) Stover and Evitt, 1978
Lejeunecysta sp.
Leptodinium sp.
Maduradinium pentagonum Cookson and Eisenack, 1970
Manumiella sp.
Manumiella sp. cf. *M.* sp. 2 of Askin (1988). (Plate 4, Fig. 10)
Microdinium ornatum Cookson and Eisenack, 1960
Microdinium sp.
Nelsoniella aceras Cookson and Eisenack, 1960. (Plate 5, Figs. 6–7; Plate 11, Fig. 1)
Nelsoniella semireticulata Cookson and Eisenack, 1960
Nelsoniella sp. (Plate 1, Fig. 13)
Nelsoniella tuberculata Cookson and Eisenack, 1960. (Plate 5, Figs. 2–3; Plate 9, Fig. 6)
Nematosphaeropsis sp.
Odontochitina cribropoda Deflandre and Cookson, 1955. (Plate 6, Fig. 2; Plate 10, Fig. 4)
Odontochitina operculata Wetzel, 1933. (Plate 6, Fig. 11)
Odontochitina porifera Cookson, 1956. (Plate 2, Fig. 3; Plate 6, Fig. 1)
Odontochitina sp.
Odontochitina spinosa Wilson, 1984
Oligosphaeridium complex (White, 1842) Davey and Williams, 1966
Oligosphaeridium pulcherrimum (Deflandre and Cookson, 1955) Davey and Williams, 1966. (Plate 7, Fig. 7)
Oligosphaeridium sp.
Palaeocystodinium sp.
Palaeocystodinium sp. cf. *P. scabratum* Jain et al., 1975. (Plate 2, Fig. 11)
Palaeohystrichophora infusorioides Deflandre, 1935. (Plate 7, Fig. 4)
Palaeohystrichophora sp.
Palaeoperidinium parvum (Harland, 1973) Lentin and Williams, 1976
Paralecaniella sp.
Pierceites schizocystis Habib and Drugg, 1987. (Plate 9, Fig. 7)
Platycystidia diptera Cookson and Eisenack, 1960
Pterodinium cingulatum (Wetzel, 1933) Below, 1981
Satyrodinium bengalense Lentin and Manum, 1986. (Plate 2, Figs. 7 and 10)
Satyrodinium haumuriense (Wilson, 1984) Lentin and Manum, 1986. (Plate 2, Figs. 4–6; Plate 9, Fig. 5)
Senegalinium sp. cf. *S.*? *microgranulatum* (Stanley, 1965) Stover and Evitt, 1978
Spinidinium? *clavus* Harland, 1973. (Plate 9, Fig. 4; Plate 11, Fig. 3)
Spinidinium lanternum Cookson and Eisenack, 1970. (Plate 7, Fig. 3; Plate 9, Fig. 9)
Spinidinium sp. (Plate 11, Fig. 7)
Spinidinium uncinatum May, 1980. (Plate 6, Fig. 3)
Spiniferites ramosus (Ehrenberg, 1838) Loeblich and Loeblich, 1966
Spiniferites sp.
Subtilisphaera pirnaensis (Alberti, 1959) Jain and Millepied, 1973
Subtilisphaera sp.
Talimudinium scissurum Mao and Norris, 1988
Tanyosphaeridium variecalamus Davey and Williams, 1966
Tanyosphaeridium xanthiopyxides (Wetzel, 1933) Stover and Evitt, 1978. (Plate 6, Fig. 7)
Trichodinium castanea (Deflandre, 1935) Clarke and Verdier, 1967
Trichodinium sp.
Trithyrodinium fragile Davey, 1969. (Plate 6, Fig. 5)
Trithyrodinium suspectum (Manum and Cookson, 1964) Davey, 1969. (Plate 6, Fig. 6; Plate 8, Fig. 9; Plate 9, Fig. 8)
Xenascus ceratioides (Deflandre, 1937) Lentin and Williams, 1973. (Plate 6, Figs. 10 and 12; Plate 10, Fig. 5)
Xenikoon australis Cookson and Eisenack, 1960. (Plate 5, Fig. 8)
Xenikoon sp.

APPENDIX B

Compiled Ranges of Selected Species

"General" data from Williams and Bujak (1984); specific sources are Harker and Sarjeant (1975) for unnumbered entries; 1 = Aurisano (1989); 2 = Benson (1976); 3 = Firth (1987); 4 = Helby et al. (1987); 5 = Ioannides (1986); 6 = Marheinecke (1986); 7 = May (1980); McIntyre (1975); 9 = Wilson (1974).

Species	Europe	North America	Australia	General
Alterbidinium acutulum	early Maestrichtian (9)	Campanian - Maestrichtian (1), early Maestrichtian (2), Maes - trichtian - Danian (3), Campa - nian - Maestrichtian (7)		
Areoligera senonensis		Maestrichtian, Santonian - Maestrichtian (1)		late Campan. - early Eocene
Callaiosphaeridium asymmetricum	Cenomanian - late Maestrichtian	Campanian, Turonian - early Campanian (1).		Hauterivian - early Campanian
Cerodinium diebelii	Coniacian - Maestrichtian, Maestrichtian (6).	late Maestrichtian, Maestrichtian (1), (5), (7)	late Campanian - basal Danian (4)	late Cam- panian, early Paleocene
Chatangiella ditissima		Santonian - Maestrichtian (8)		
Chatangiella granulifera	Santonian	late Campanian, late Santonian (1), Santonian - Maestrichtian (5)		Coniacian - Campanian
Chatangiella serratula			late Coniacian - early Maestrichtian	
Chatangiella spectabilis	Coniacian	late Campanian , Santonian - Maestrichtian (5)		
Chatangiella tripartita	Campanian - early Maestrichtian	late Cenomanian - early Maestrichtian, late Santonian - Campanian (1)	Cenomanian - Coniacian, early Santonian (4)	
Chatangiella verrucosa		late Cenomanian - early Maestrichtian, Santonian - Maestrichtian (5)	late Santonian - early Campanian	
Chatangiella victoriensis	Coniacian - Santonian	Santonian - Maestrichtian (1)	Santonian - early Campanian (4)	Coniacian - early Maestrichtian
Chlamydophorella discreta		Santonian - Maestrichtian (1)		
Circulodinium distinctum	Cenomanian - early Maestrichtian, Maestrichtian (9)	Cenomanian -Campanian, Cenomanian - Maestrichtian (1), late Maestrichtian (2),(3), Santonian - Maestrichtian (5)	Cenomanian - early Campanian	late Kimmeridgian - Maestrichtian
Diconodinium arcticum	Santonian	late Cenomanian - late Campanian, Santonian - Maestrichtian (5)		
Dinogymnium albertii	Santonian - late Maestrichtian	late Campanian, Santonian - Maestrichtian (1).		
Dinogymnium digitus	Santonian	early Maestrichtian	Coniacian	
Dinogymnium westralium	late Campanian - early Maestrichtian	Maestrichtian, Maestrichtian - Danian (3)	Turonian - early Maes- trichtian, Santonian - basal Danian (4)	
Exochosphaeridium phragmites	Cenomanian - late Campanian	Turonian - Campanian, Cenomanian - Maestrichtian (1)	Cenomanian - Coniacian	
Fromea chytra		Maestrichtian (5)	Santonian - basal Danian (4).	
Gillinia hymenophora		Campanian - Maestrichtian (1), Santonian - Maestrichtian (5)	Cenomanian - Cam- panian, Santonian - early Campanian (4)	

Heterosphaeridium conjunctum			late Coniacian - early Campanian	
Heterosphaeridium ?heteracanthum			late Coniacian - late Maestrichtian	
Isabelidinium acuminatum	Cenomanian - Santonian	Cenomanian - early Maestrichtian, late Turonian - Santonian (1), Santonian - Maestrichtian (5)	Cenomanian - Coniacian	Santonian - Maestrichtian
Isabelidinium belfastense	Campanian - Maestrichtian		Coniacian, late Santonian (4)	late Turonian - Maestrichtian
Isabelidinium cooksoniae	Coniacian - Maestrichtian, Maestrichtian (6)	Cenomanian - Maestrichtian, Santonian - early Maestrichtian (1), Maestrichtian (2), Campanian - Maestrichtian (7)		Turonian - Maestrichtian
Isabelidinium cretaceum	late Maestrichtian	late Maestrichtian, Maestrichtian (5)	middle Santonian - early Maestrichtian (4)	Maestrichtian
Isabelidinium korojonense		late Campanian	late Campanian - early Maestrichtian, middle Campanian - early Maestrichtiasn (4)	
Isabelidinium pellucidum			Campanian - Maestrichtian, late Campanian - Maestrichtian (4)	
Nelsoniella aceras			Turonian - early Maestrichtian, late Santonian - early Campanian (4)	
Nelsoniella tuberculata			Turonian - Campanian, late Santonia - early Campanian (4)	
Odontochitina cribropoda	Coniacian		Turonian - early Maestrichtian	
Odontochitina operculata	Cenomanian - Maestrichtian	Cenomanian - early Campanian, Turonian - Campanian (1), Santonian - Maestrichtian (5)	Cenomanian - early Maestrichtian	Barremian - early Maestrichtian
Odontochitina porifera			early Santonian -early Campaniannm (4)	Coniacian - early Santonian
Oligosphaeridium pulcherrimum	Cenomanian - Santonian	Cenomanian - Campanian, late Maestrichtian - Danian (3)	Cenomanian - early Campanian	Kimmeridgian - early Turonian
Palaeohystrichophora infusorioides	Cenomanian - Santonian	Cenomanian - early Maestrichtian, Santonian - Maestrichtian (5)	Cenomanian - Campanian, Cenomanian - basal Danian (4)	late Albian - Campanian
Trithyrodinium suspectum		Cenomanian, Santonian - early Maestrichtian (1), Santonian - Maestrichtian (5)		late Cenomanian
Xenascus ceratioides	Cenomanian - Turonian	Cenomanian - early Maestrichtian (1), Santonian - Maestrichtian (5)		late Albian -early Maestrichtian
Xenikoon australis		Maestrichtian (2), (3)	Turonian - late Campanian, early Campanian (4)	

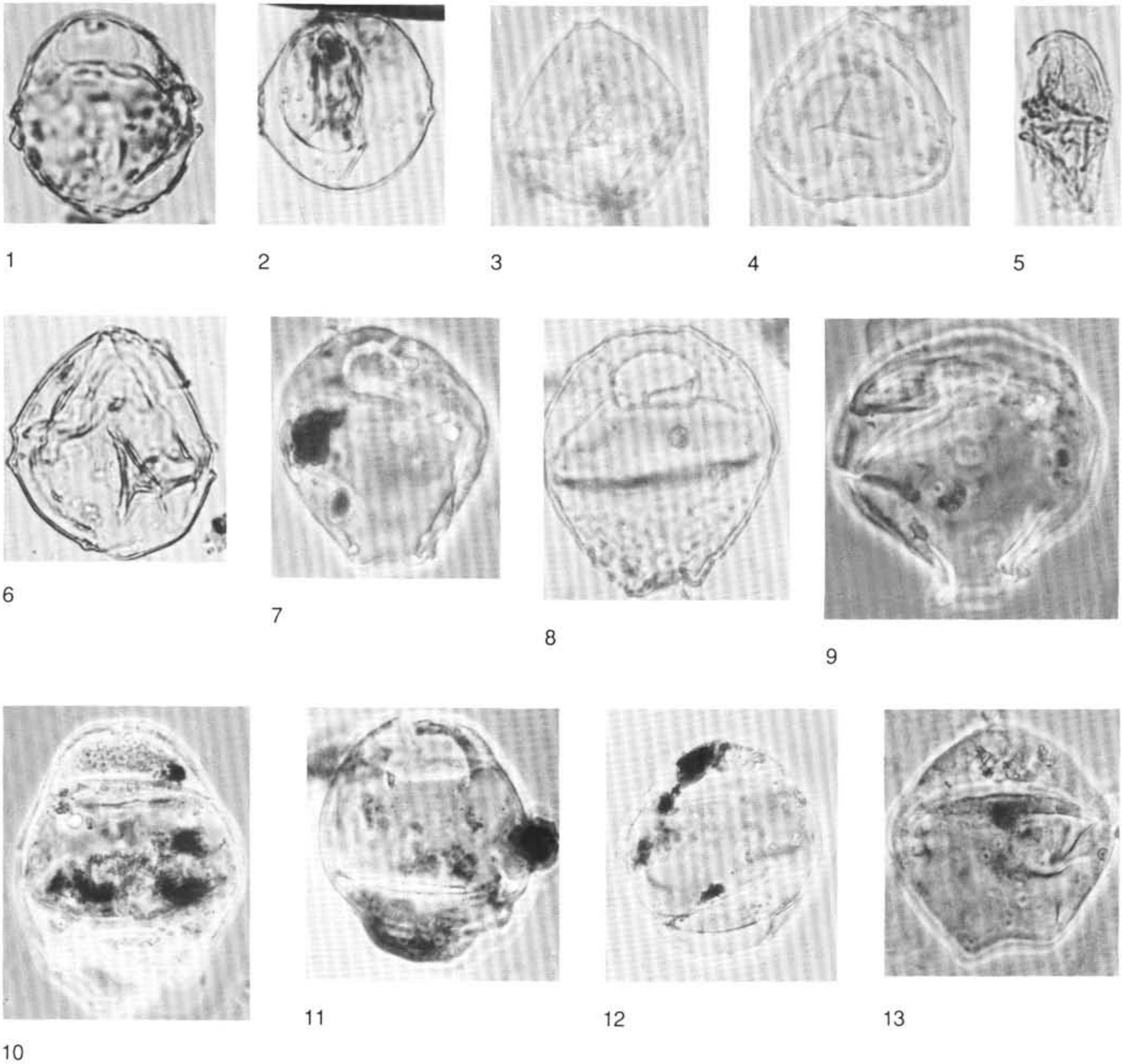

Plate 1. **1, 2, 6.** *Abratopdinium kerguelense* n. sp. (1) Holotype, Sample 120-748C-36R-1, 68–70 cm, USNM no. 453931, 47.6 × 44 μm; (2) Sample 120-748C-40R-1, 20–23 cm, ×730; (6) Sample 120-748C-40R-1, 67–69 cm, ×700. **3, 4.** *Abratopdinium cardioforme* n. sp., Sample 120-748C-40R-1, 20–23 cm. (3) ×630; (4) holotype, USNM no. 453932, 45.8 × 53.1 μm. **5.** *Dinogymnium digitus*, Sample 120-748C-48R-1, 80–85 cm, ×600. **7, 9.** *Isabelidinium cretaceum oviforme* n. subsp., Sample 120-748C-47R-CC. (7) Holotype, USNM no. 453935, 90.5 × 80.2 μm; (9) ×450. **8.** *Isabelidinium cretaceum oviforme* n. subsp., Sample 120-748C-48R-1, 80–85 cm, ×450. **10.** *Isabelidinium cretaceum cretaceum*, ×450, Sample 120-748C-48R-1, 80–86 cm. **11, 12.** *Isabelidinium cretaceum gravidum* n. subsp., Sample 120-748C-27R-2, 11–14 cm. (11) Holotype, USNM no. 453934, 84.2 × 69.5 μm; (12) ×450. **13.** *Nelsoniella* sp., Sample 120-748C-47R-CC, ×450.

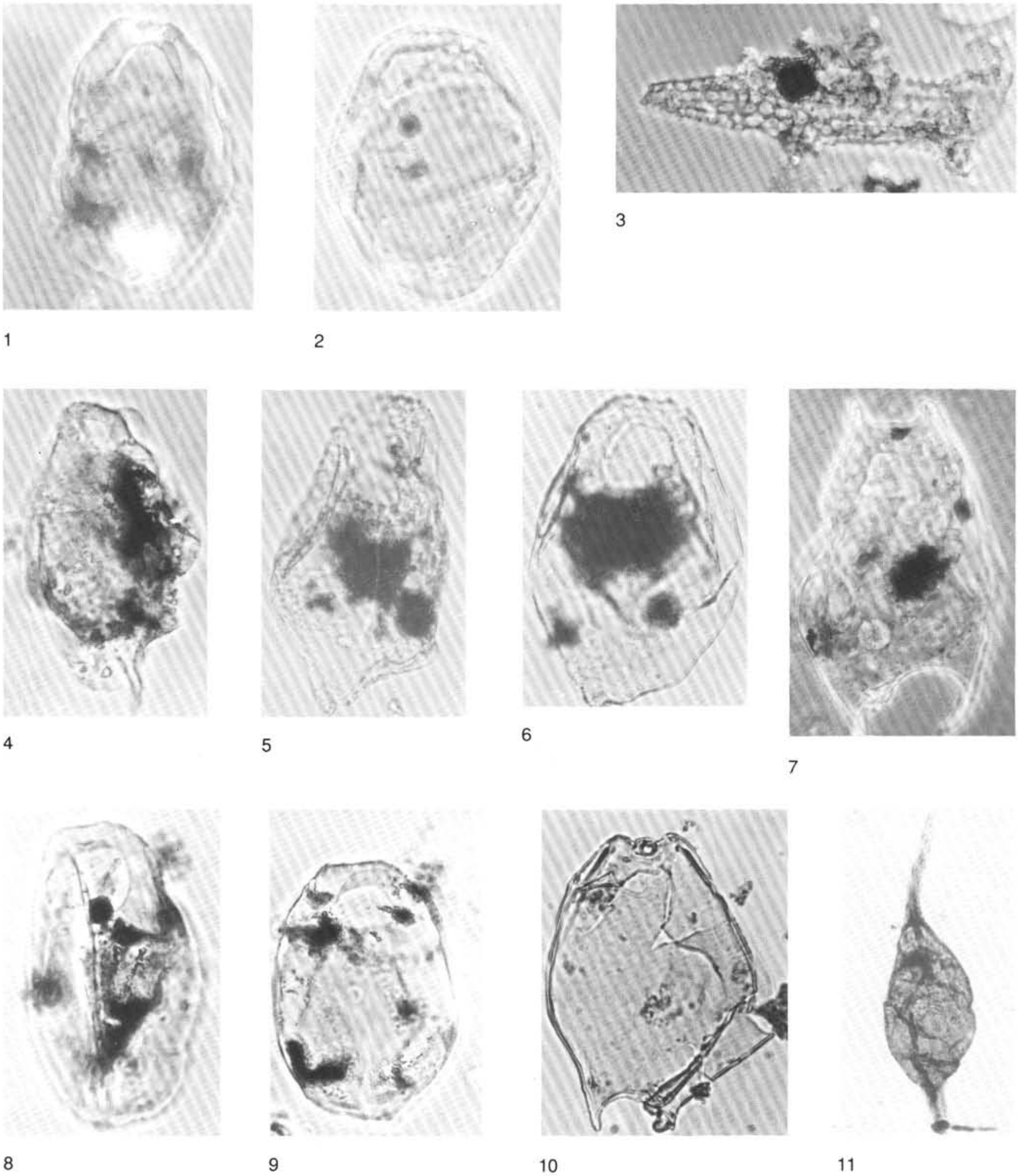

Plate 2. **1, 2, 8, 9.** *Eurydinium ellipticum* n. sp. (1) Sample 120-748C-32R-1, 30–31 cm, ×500; (2) Sample 120-748C-27R-2, 11–14 cm; (8) Sample 120-748C-32R-1, 30–31 cm, ×550; (9) holotype, Sample 120-748C-32R-1, 30–31 cm, USNM no. 453933, 100.5 × 71.4 μm. **3.** *Odontochitina porifera*, Sample 120-748C-34R-1, 62–65 cm, ×400. **4–6.** *Satyrodinium haumuriense*, Sample 120-748C-32R-1, 30–31 cm, ×550. **7, 10.** *Satyrodinium bengalense*. (7) Sample 120-748C-32R-1, 30–31 cm, ×550; (10) Sample 120-748C-36R-1, 93–95 cm, ×400. **11.** *Palaeocystodinium* sp. cf. *P. scabratum*, Sample 120-748C-27R-2, 11–14 cm, ×250.

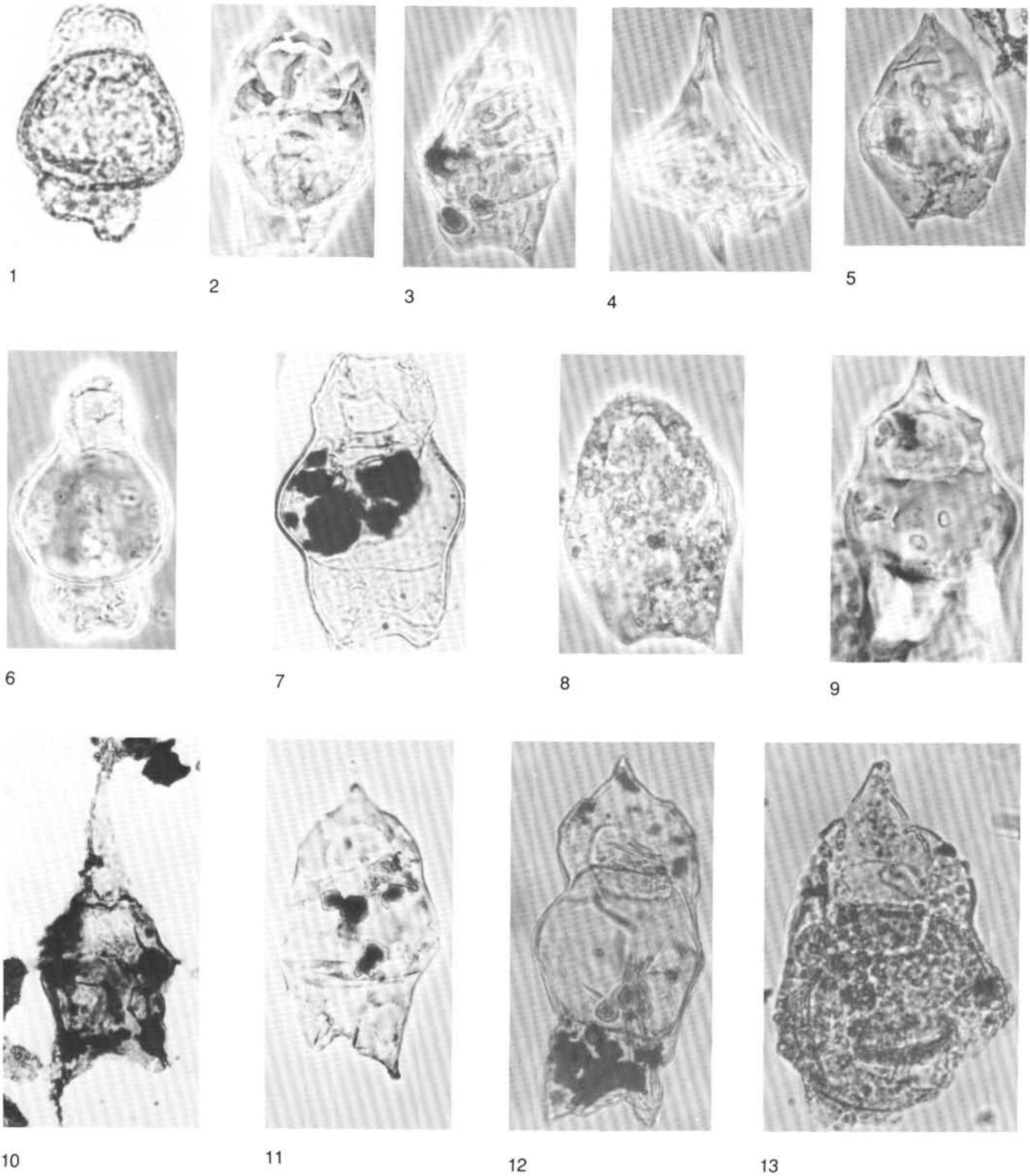

Plate 3. **1.** *Amphidiadema* sp., Sample 120-748C-48R-1, 80–85 cm, ×550. **2.** *Chatangiella spectabilis,* Sample 120-748C-55R-2, 125–129 cm, ×550. **3.** *Isabelidinium cooksoniae,* Sample 120-748C-34R-1, 62–65 cm, ×600. **4.** *Diconodinium* sp., Sample 120-748C-35R-1, 93–95 cm, ×600. **5.** *Isabelidinium acuminatum,* Sample 120-748C-50R-1, 50–52 cm, ×500. **6, 7.** *Amphidiadema denticulata,* ×500. (6) Sample 120-748C-48R-1, 80–85 cm; (7) Sample 120-748C-50R-1, 50–52 cm. **8.** *Eurydinium ingramii,* Sample 120-748C-50R-1, 50–52 cm, ×450. **9.** *Chatangiella ditissima,* Sample 120-748C-55R-2, 125–129 cm, ×550. **10.** *Cerodinium diebelii,* Sample 120-748C-32R-1, 30–31 cm, ×450. **11.** *Isabelidinium microarmum,*Sample 120-748C-51R-1, 105–108 cm, ×450. **12.** *Chatangiella tripartita,* Sample 120-748C-62R-1, 52–55 cm, ×550. **13.** *Chatangiella verrucosa,* Sample 120-748C-50R-1, 50–52 cm, ×500.

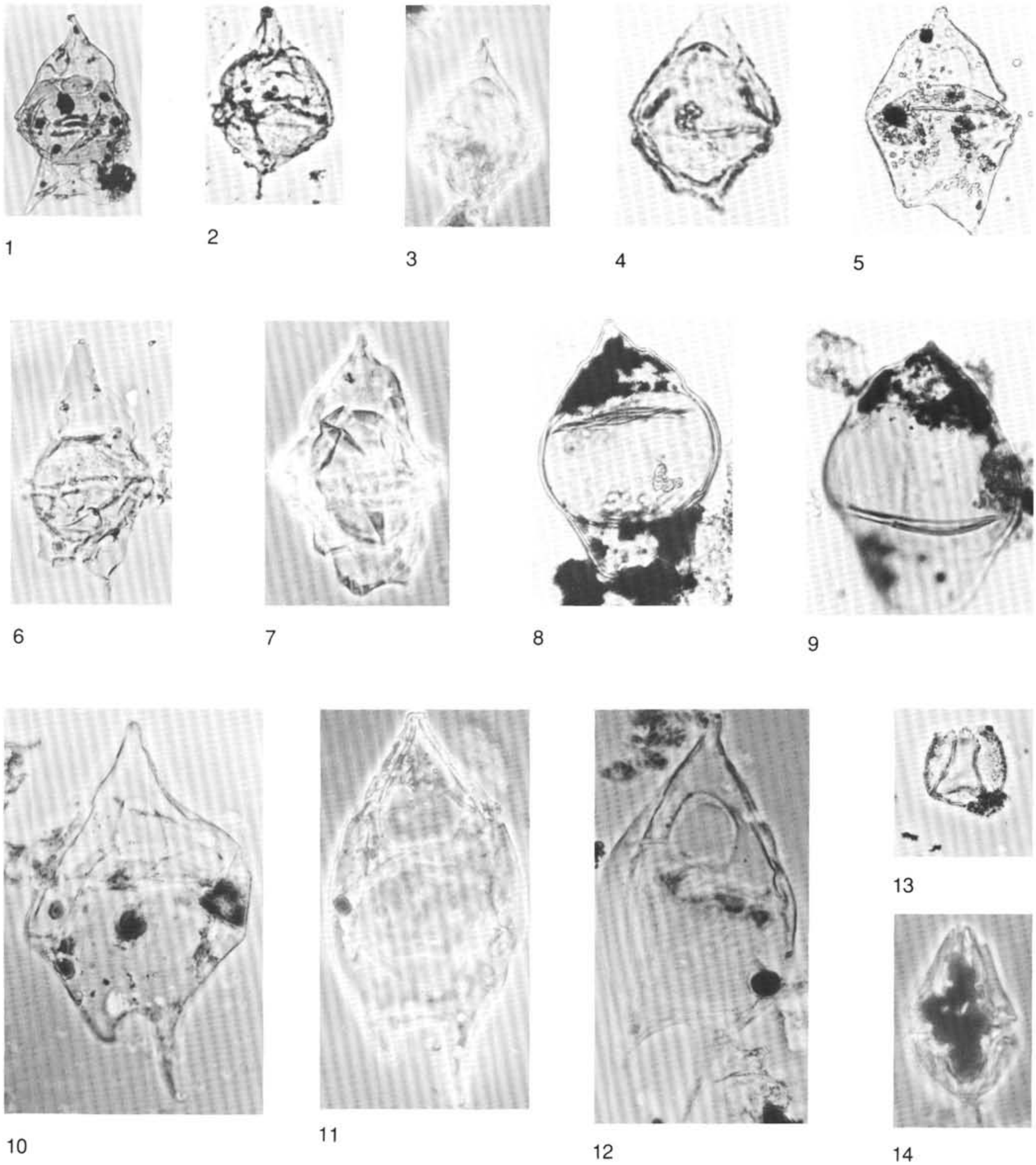

Plate 4. **1.** *Chatangiella victoriensis,* Sample 120-748C-50R-1, 50–52 cm, ×300. **2.** *Laciniadinium firmum,* Sample 120-748C-56R-1, 77–79 cm, ×600. **3.** *Diconodinium* sp. cf. *D. arcticum,* Sample 120-748C-34R-1, 62–65 cm, ×550. **4.** *Alterbidinium acutulum,* Sample 120-748C-29R-1, 30–31 cm, ×500. **5.** *Isabelidinium belfastense,* Sample 120-748C-28R-1, 48–51 cm, ×500. **6.** *Chatangiella serratula,* Sample 120-748C-32R-1, 30–31 cm, ×500. **7.** *Chatangiella tripartita,* Sample 120-748C-55R-1, 42–45 cm, ×450. **8, 9.** *Isabelidinium pellucidum,* ×450. (8) Sample 120-748C-29R-1, 30–31 cm; (9) Sample 120-748C-32R-1, 30–31 cm. **10.** *Manumiella* sp. cf. *M.* sp. 2 of Askin (1988, pp. 144–145, fig. 9-4), Sample 120-748C-34R-1, 62–65 cm, ×500. **11, 12.** *Isabelidinium* sp. A, Sample 120-748C-34R-1, 62–65 cm, ×500. **13.** *Kallosphaeridium*? *helbyi,* Sample 120-748C-32R-1, 30–31 cm, ×500. **14.** *Dinogymnium albertii,* Sample 120-748C-50R-1, 50–52 cm, ×500.

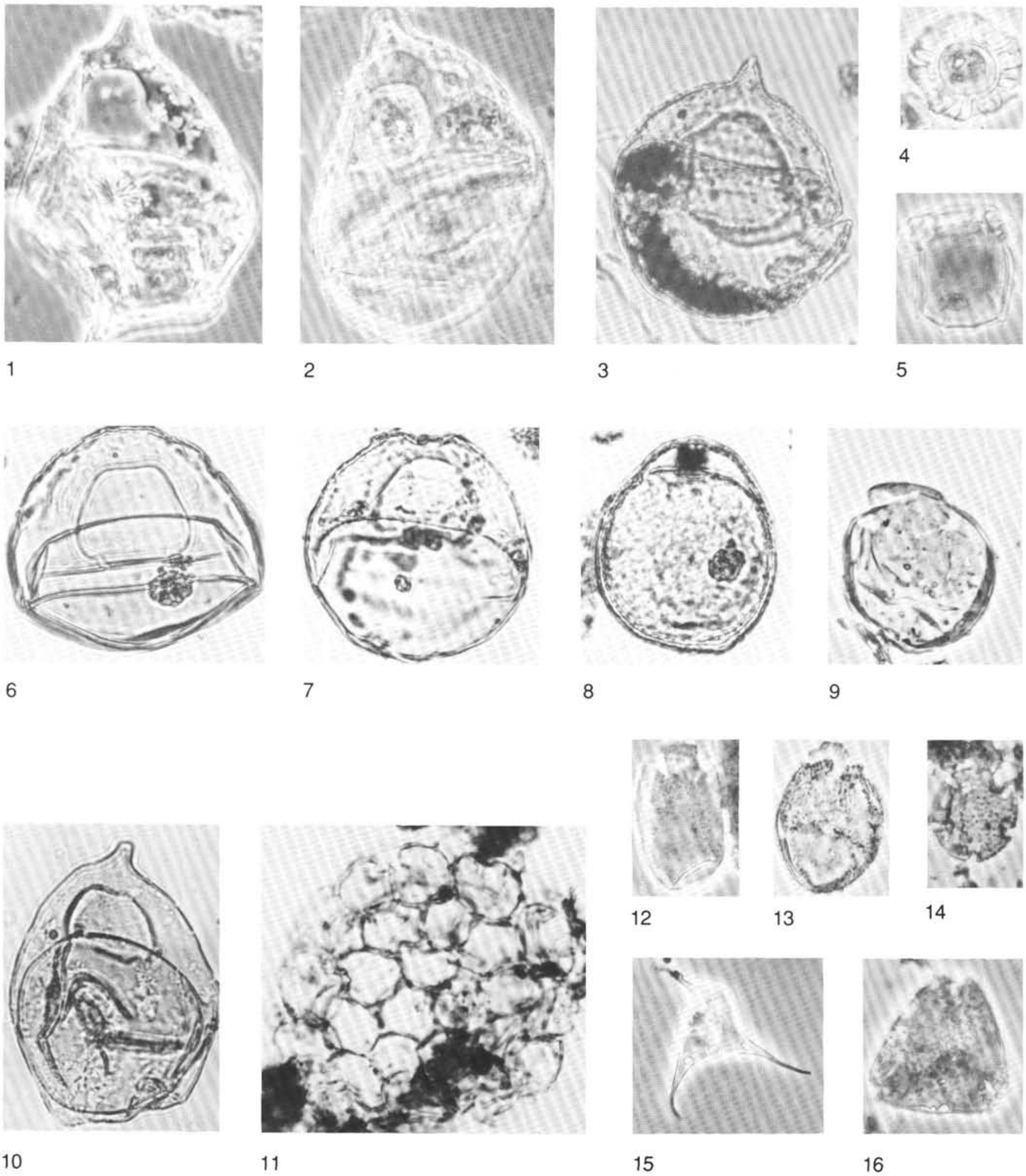

Plate 5. **1.** *Eucladinium gambangense,* Sample 120-748C-43R-1, 60–63 cm, ×600. **2, 3.** *Nelsoniella tuberculata,* ×450. (2) Sample 120-748C-41R-1, 20–23 cm; (3) Sample 120-748C-40R-1, 67–69 cm. **4.** *Pterospermella australiensis,* Sample 120-748C-45R-1, 112–115 cm, ×700. **5.** *Gillinia hymenophora,* Sample 120-748C-34R-1, 62–65 cm, ×700. **6, 7.** *Nelsoniella aceras,* Sample 120-748C-44R-1, 126–128 cm, ×500. **8.** *Xenikoon australis,* Sample 120-748C-35R-1, 93–95 cm, ×550. **9.** *Eschariasphaeridia* sp., Sample 120-748C-55R-1, 42–45 cm, ×450. **10.** *Eucladinium madurense,* Sample 120-748C-43R-1, 60–63 cm, ×600. **11.** *Palambages morulosa,* Sample 120-748C-35R-1, 93–95 cm, ×500. **12, 13.** *Elytrocysta druggii,* ×500. (12) Sample 120-748C-36R-1, 68–70 cm; (13) Sample 120-748C-35R-1, 93–95 cm. **14.** *Nothofagidites* sp., Sample 120-748C-36R-1, 68–70 cm, ×500. **15.** *Veryhachium* sp., Sample 120-748C-52R-1, 45–47 cm, ×500. **16.** *Proteacidites* sp., Sample 120-748C-44R-1, 67–69 cm, ×500.

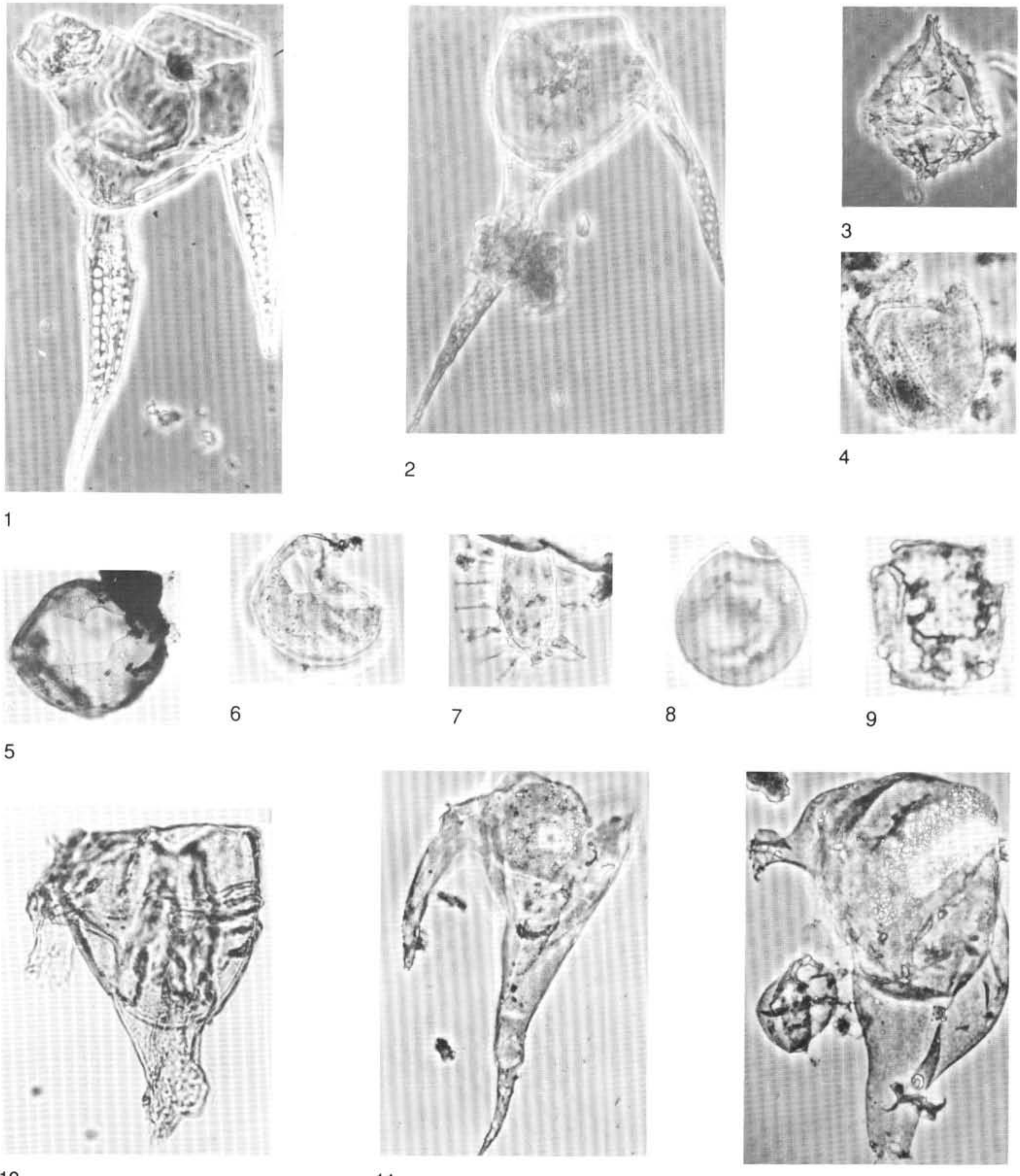

Plate 6. **1.** *Odontochitina porifera,* Sample 120-748C-43R-1, 60–63 cm, ×350. **2.** *Odontochitina cribropoda,* Sample 120-748C-48R-1, 80–85 cm, ×400. **3.** *Spinidinium uncinatum,* Sample 120-748C-52R-1, 45–47 cm, ×500. **4.** *Chlamydophorella discreta,* Sample-120-748C-56R-1, 77–79 cm, ×600. **5.** *Trithyrodinium fragile,* Sample 120-748C-34R-1, 62–65 cm, ×500. **6.** *Trithyrodinium suspectum,* Sample 120-748C-32R-1, 30–31 cm, ×500. **7.** *Tanyosphaeridium xanthiopyxides,* Sample 120-748C-36R-1, 68–70 cm, ×500. **8.** *Fromea chytra,* Sample 120-748C-36R-1, 68–70 cm, ×600. **9.** *Alnipollenites* sp., Sample 120-748C-32R-1, 30–31 cm, ×1000. **10, 12.** *Xenascus ceratioides,* ×500. (10) Sample 120-748C-55R-1, 42–45 cm; (12) Sample 120-748C-33R-1, 37–40 cm. **11.** *Odontochitina operculata,* Sample 120-748C-51R-1, 105–108 cm, ×400.

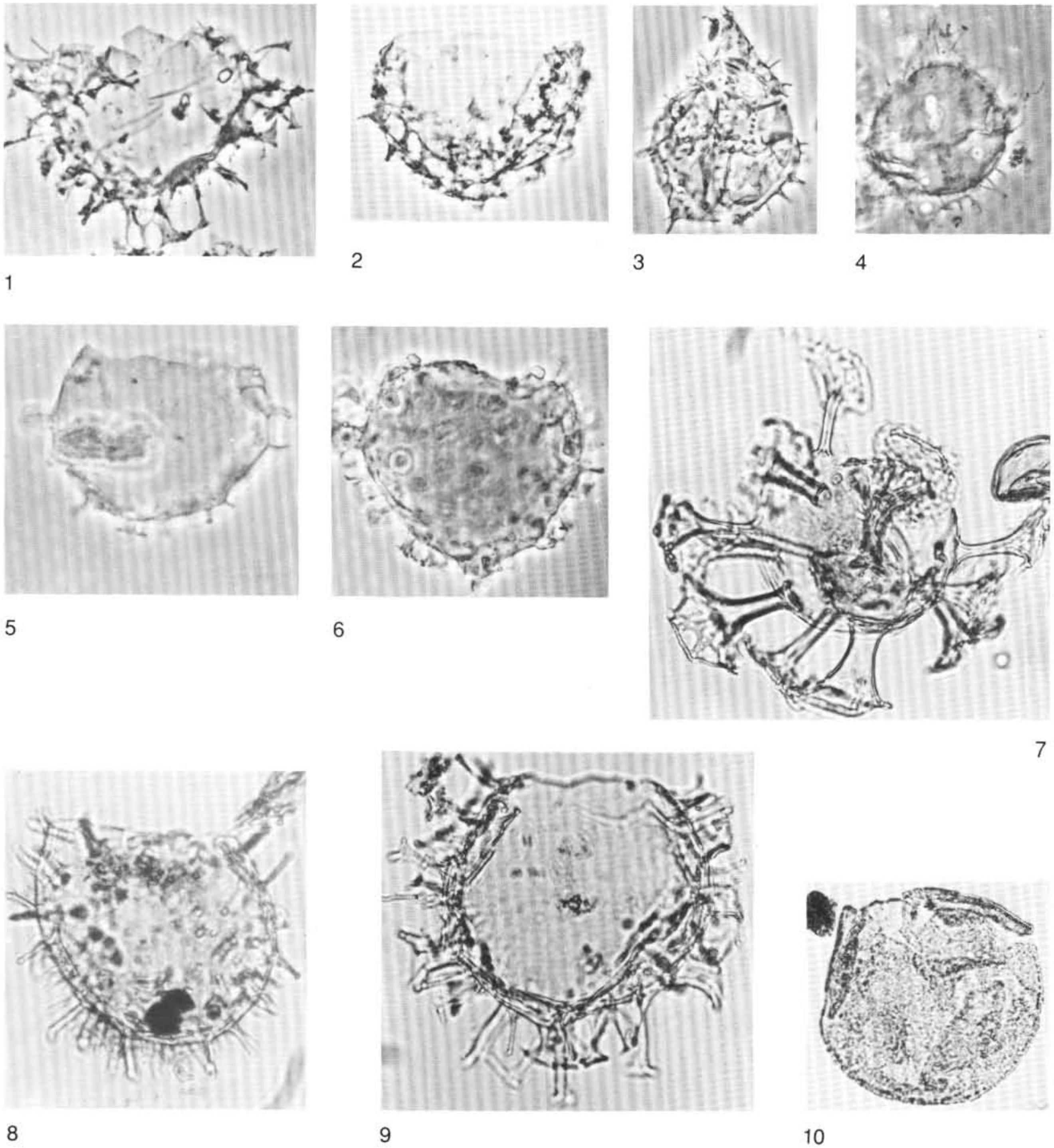

Plate 7. **1, 8.** *Circulodinium distinctum* subsp. *longispinatum,* ×500. (1) Sample 120-748C-52R-1, 45–47 cm; (8) Sample 120-748C-50R-1, 50–52 cm. **2, 6.** *Cyclonephelium compactum,* ×500. (2) Sample 120-748C-51R-1, 105–108 cm; (6) Sample 120-748C-56R-1, 77–79 cm. **3.** *Spinidinium lanternum,* Sample 120-748C-52R-1, 45–47 cm, ×600. **4.** *Palaeohystrichophora infusorioides,* Sample 120-748C-44R-1, 67–68 cm, ×500. **5.** *Circulodinium distinctum* subsp. *distinctum,* Sample 120-748C-56R-1, 77–79 cm, ×500. **7.** *Oligosphaeridium pulcherrimum,* Sample 120-748C-55R-2, 125–129 cm, ×500. **9.** *Cyclonephelium crassimarginatum,* Sample 120-748C-52R-1, 45–47 cm, ×500. **10.** *Canningia reticulata,* Sample 120-748C-52R-1, 45–47 cm, ×500.

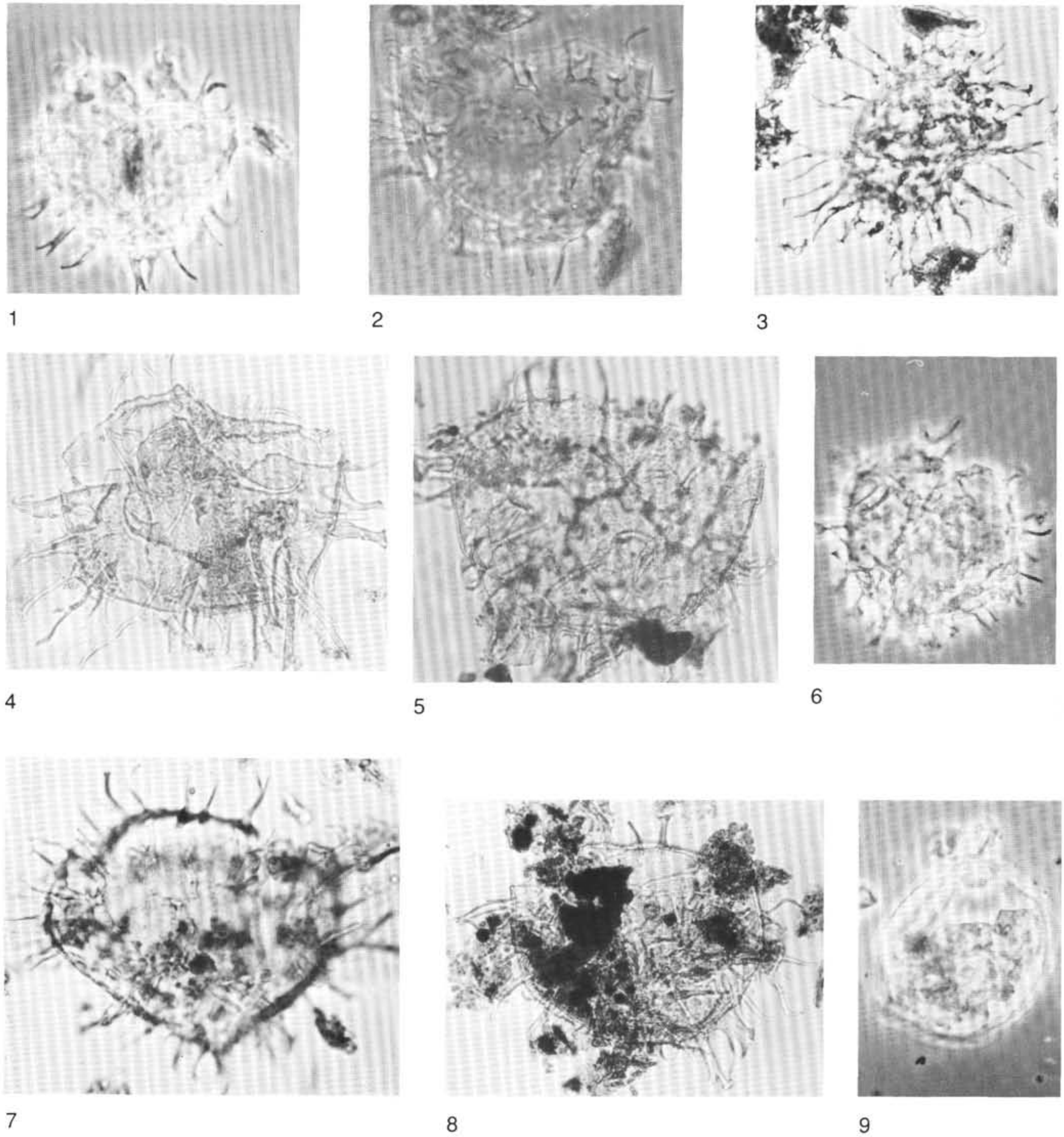

Plate 8. **1.** *Areoligera senonensis,* Sample 120-748C-55R-2, 125–129 cm, ×450. **2.** *Heterosphaeridium*? *heteracanthum,* Sample 120-748C-41R-1, 20–23 cm, ×500. **3.** *Hystrichodinium pulchrum,* Sample 120-748C-52R-1, 45–47 cm, ×500. **4, 5, 8.** *Heterosphaeridium conjunctum,* ×500. (4) Sample 120-748C-41R-1, 20–23 cm; (5), (8) Sample 120-748C-35R-1, 93–95 cm. **6.** *Heterosphaeridium* sp., Sample 120-748C-43R-1, 60–63 cm, ×500. **7.** *Areoligera* sp. cf. *A. senonensis,* Sample 120-748C-48R-1, 80–85 cm, ×500. **9.** *Trithyrodinium suspectum,* Sample 120-748C-48R-1, 80–85 cm, ×500.

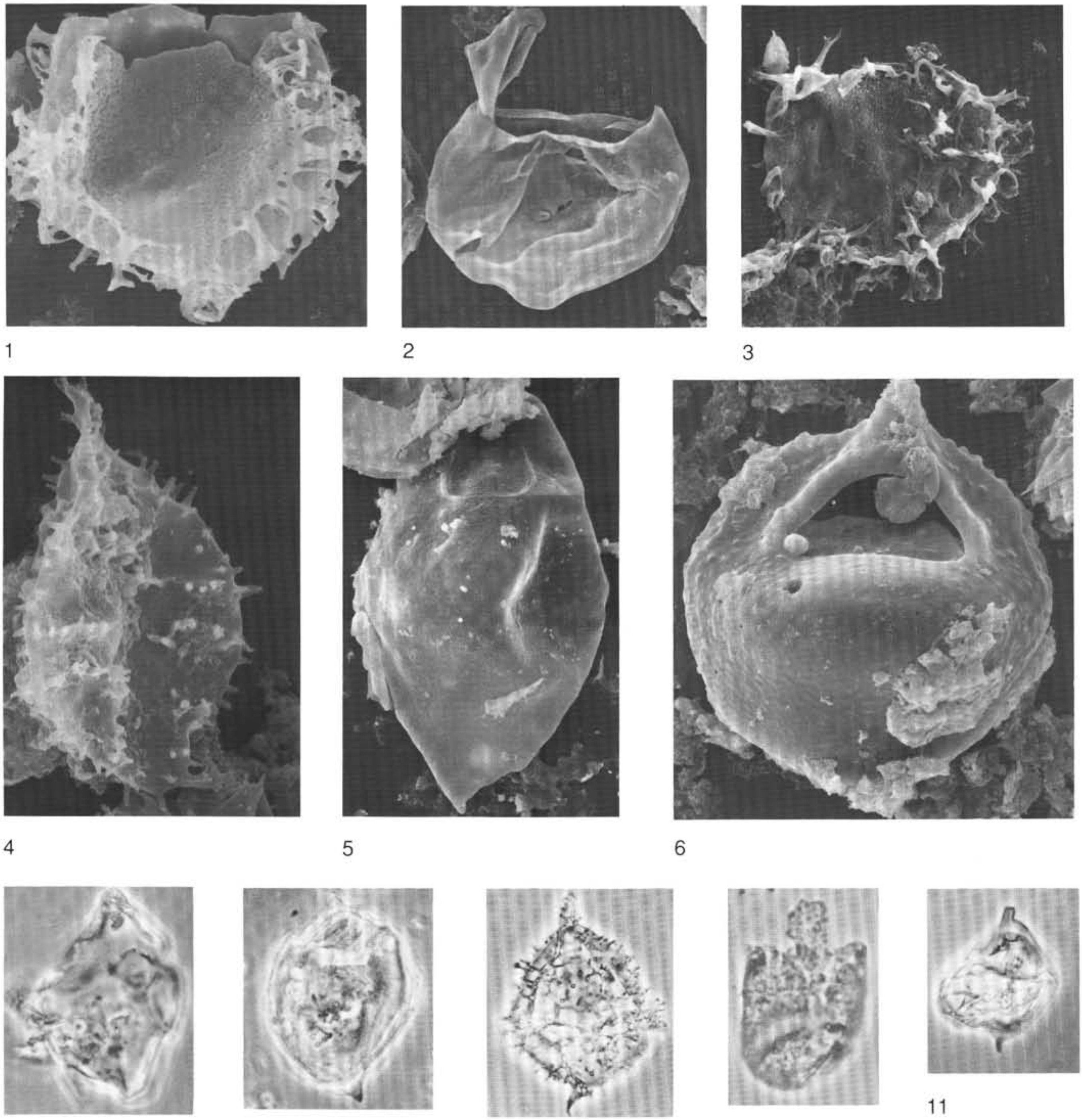

Plate 9. 1–6 SEM photographs. **1.** *Cyclonephelium crassimarginatum,* Sample 120-748C-55R-2, 125–129 cm, ×900. **2.** *Canningia* sp., Sample 120-748C-56R-1, 77–79 cm, ×900. **3.** *Circulodinium distinctum* subsp. *distinctum,* Sample 120-748C-50R-1, 50–52 cm, ×900. **4.** *Spinidinium*? *clavus,* Sample 120-748C-52R-1, 45–47 cm, ×1700. **5.** *Satyrodinium haumuriense,* Sample 120-748C-32R-1, 30–31 cm, ×700. **6.** *Nelsoniella tuberculata,* Sample 120-748C-48R-1, 80–85 cm, ×700. **7.** *Pierceites schizocystis,* Sample 120-748C-44R-1, 67–69 cm, ×500. **8.** *Trithyrodinium suspectum,* Sample 120-748C-48R-1, 80–85 cm, ×500. **9.** *Spinidinium lanternum,* Sample 120-748C-52R-1, 45–47 cm, ×600. **10.** *Elytrocysta druggii,* Sample 120-748C-37R-1, 74–78 cm, ×500. **11.** *Alterbidinium minus,* Sample 120-748C-55R-2, 125–129 cm, × 500.

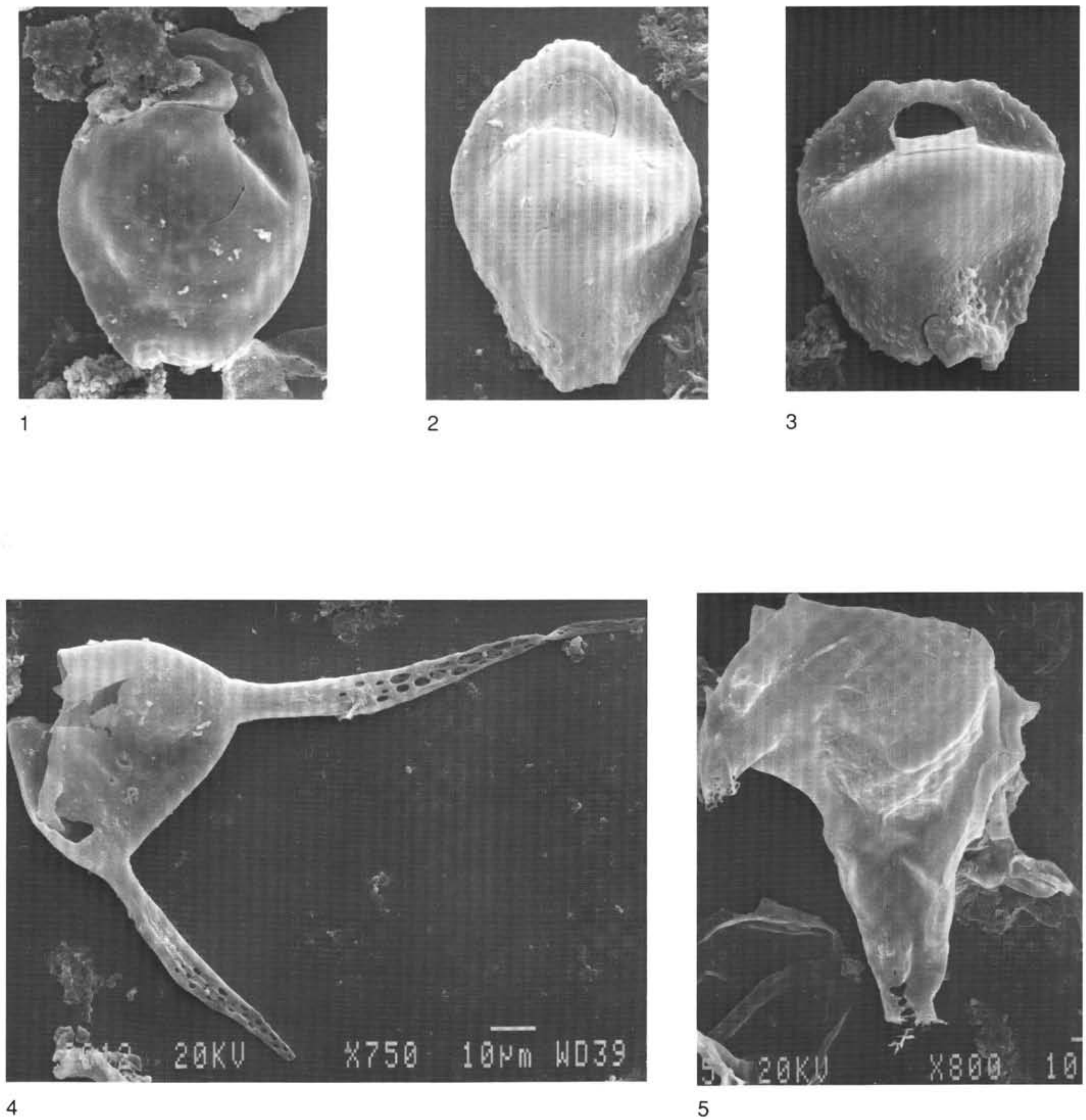

Plate 10. SEM photographs. **1.** *Eurydinium ellipticum* n. sp., Sample 120-748C-32R-1, 30–31 cm, ×900. **2.** *Isabelidinium cretaceum oviforme* n. subsp., Sample 120-748C-47R-1, 92–95 cm, ×900. **3.** *Isabelidinium cretaceum cretaceum,* Sample 120-748C-40R-1, 20–23 cm, ×700. **4.** *Odontochitina cribropoda,* Sample 120-748C-48R-1, 80–85 cm, ×750. **5.** *Xenascus ceratioides,* Sample 120-748C-55R-1, 42–45 cm, ×800.

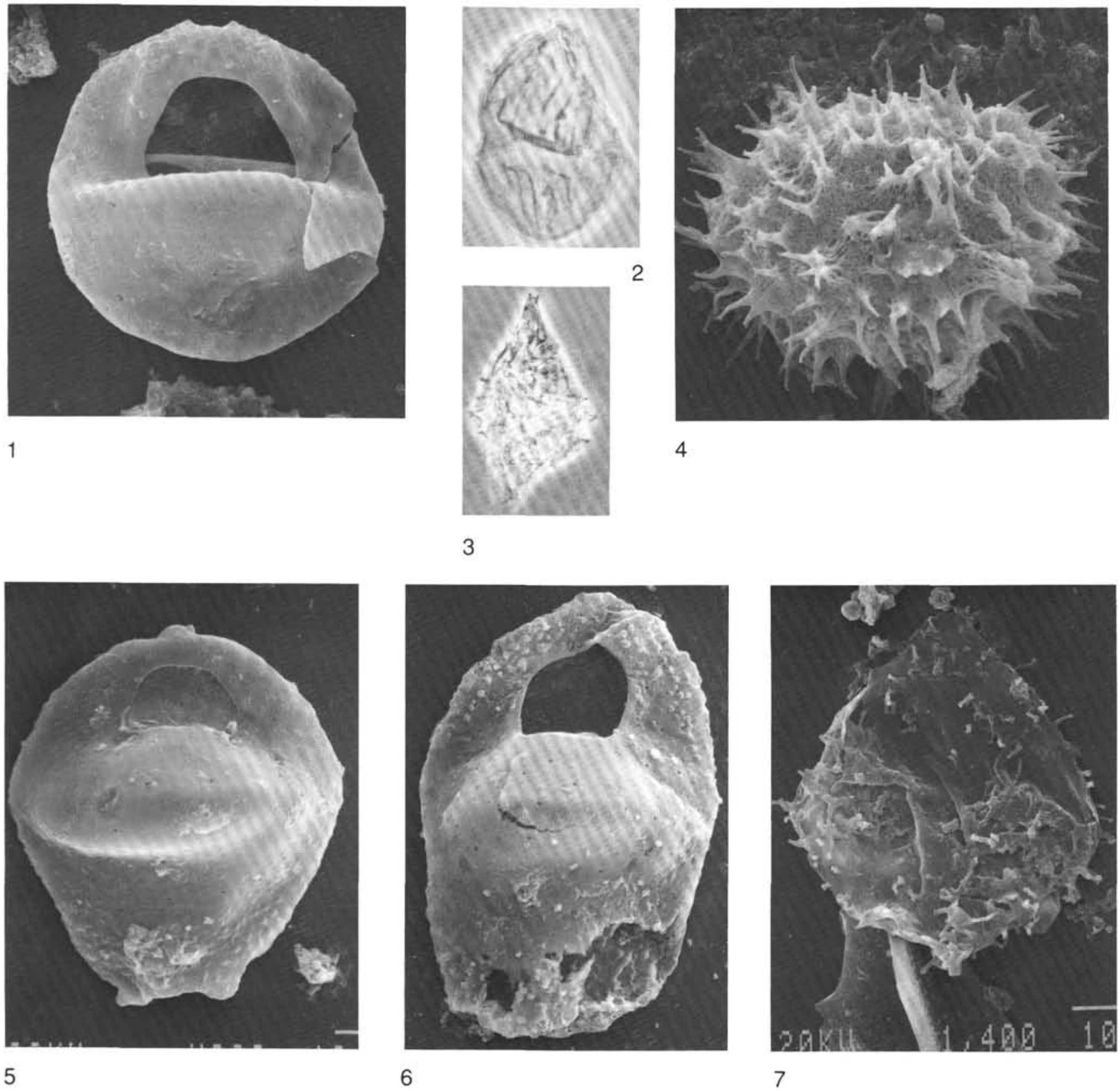

Plate 11. SEM photographs, except for Figures 2 and 3. **1.** *Nelsoniella aceras,* Sample 120-748C-44R-1, 126–128 cm, ×800. **2.** *Dinogymnium undulosum,* Sample 120-748C-44R-1, 67–69 cm, ×550. **3.** *Spinidinium*? *clavus,* Sample 120-748C-55R-1, 42–45 cm, ×500. **4.** *Heterosphaeridium* sp., Sample 120-748C-48R-1, 80–85 cm, ×900. **5.** *Isabelidinium cretaceum oviforme* n. subsp., Sample 120-748C-48R-1, 80–85 cm, ×900. **6.** *Isabelidinium cretaceum cretaceum,* Sample 120-748C-40R-1, 20–23 cm, ×700. **7.** *Spinidinium* sp., Sample 120-748C-52R-1, 45–47 cm, ×1400.