

32. CALCAREOUS NANNOFOSSILS ACROSS THE K/T BOUNDARY, ODP HOLE 690C, MAUD RISE, WEDDELL SEA¹

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ABSTRACT

A biostratigraphically continuous, but intensely bioturbated, Cretaceous/Tertiary boundary sequence was cored during Ocean Drilling Program (ODP) Leg 113 on Maud Rise (65°S) in the Weddell Sea off East Antarctica. This interval is the first recovered by ODP/DSDP in the South Atlantic sector of the Southern Ocean and offers a unique opportunity to study the nannofossil sequences leading up to and beyond the terminal Cretaceous event at a high southern latitude.

The K/T boundary lies just within Chron 29R and is placed at ODP Sample 113-690C-15X-4, 41.5 cm. An iridium anomaly was independently noted at about this level as well. Upper Maestrichtian-lower Paleocene sediments consist mostly of light-colored nannofossil chalks. Dark brown sediments at the base of the Danian (Zone CP1a) are characterized by an increased clay content attributed to a drop in calcareous microplankton productivity following the terminal Cretaceous event.

Although delineation of the boundary is hampered by intense bioturbation, the sharp color contrast between overlying clay-rich, dark brown chalks of the Tertiary and light cream colored chalks of the Cretaceous aids in the selection of the K/T horizon. Several dark colored burrows sampled at intervals as far as 1.3 m below the boundary and within the light colored Cretaceous chalk were found to contain up to 17% Tertiary nannofossils.

Calcareous nannofossils from the boundary interval were divided into three groups for quantitative study. The three groups, "Cretaceous," "Tertiary," and "Survivor," exhibit a sequential change across the boundary with the Cretaceous forms giving way to a Survivor-dominated assemblage beginning at the boundary followed shortly thereafter by the appearance of the Tertiary taxa, *Cruciplacolithus* and *Hornibrookina*. The species, *H. edwardsii*, comprises nearly 50% of the assemblage just above the Zone CP1a/CP1b boundary, an abundance not reported elsewhere at this level. Calculation of individual species abundances reveals several additional differences between this K/T boundary interval and those studied from middle and low latitude sections. The percentage of *Thoracosphaera* is much lower at the boundary in this section and a small form, *Prediscosphaera stoveri*, is extremely abundant in Cretaceous sediments just below the boundary.

INTRODUCTION

Drilling during ODP Leg 113 at Site 690 on the Maud Rise in the Weddell Sea off East Antarctica (Fig. 1) produced a thick and fairly continuous Paleocene nannofossil ooze sequence including a biostratigraphically complete Maestrichtian/Danian boundary (i.e., all nannofossil zones are present). Hole 690C was drilled in 2925.4 m of water at latitude 65°09.621'S and longitude 1°12.285'E. The boundary is approximated biostratigraphically by the first appearance of *Biantholithus sparsus* in a heavily bioturbated interval from 247.815 mbsf (Sample 113-690C-15X-4, 41.5 cm) to 247.890 mbsf (Sample 113-690C-15X-4, 49–50 cm) (Fig. 2). The interval falls within but near the top of Chron 29R (Fig. 3) as determined by magnetostratigraphy (Hamilton, this volume) and corresponds to a distinct negative shift in ¹³C-isotope values (Stott and Kennett, this volume, chapter 47). In addition, an iridium anomaly is present in the sediments of the boundary interval (Michel et al., this volume).

The heavily bioturbated upper Maestrichtian-Danian section consists of white to pinkish-white nannofossil chalk and ooze; in contrast, the basal Danian material stands out conspicuously by its pale brown color (Fig. 2). The color is attributed to the presence of clay minerals that comprise up to 50% of the sediment and which were originally presumed to be derived from the alteration of volcanic ash (Shipboard Scientific Party, 1988). This interpretation has yet to be confirmed by shore based stud-

ies, however, and is seriously questioned by Michel et al. (this volume) from their study of Ir/Fe ratios. As will be documented below, Danian material was carried as much as 130 cm into the Cretaceous sediments by processes of bioturbation. The burrows are easily distinguished by their dark color and by presence of Danian nannofossils.

A second Cretaceous/Tertiary boundary sequence was recovered at Site 689 at a higher elevation on Maud Rise (water depth = 2080 m) but is apparently not complete as the basal Danian Subzone CP1a is either missing or completely obscured by bioturbation. In addition, no iridium anomaly was found there (Michel et al., this volume). Sediments at this boundary are more indurated, and the color of the clay-rich interval is greenish rather than brown.

A quantitative study on closely spaced samples across the boundary of Hole 690C was undertaken in order to more precisely determine the location of the boundary and to understand, in detail, the steps in nannoplankton extinction and subsequent repopulation of the Paleocene ocean (Fig. 4). The Upper Cretaceous-lower Paleocene interval on Maud Rise in the Weddell Sea is the southernmost section of this kind recovered by deep-sea drilling, thereby offering a unique opportunity to observe the changes in the Southern Ocean brought about by the terminal Cretaceous event.

Previous Work

Initial work on calcareous nannofossils in Cretaceous/Tertiary boundary sections was conducted by Bramlette and Martini (1964). Important stratigraphic studies were later done by Edwards (1966) in New Zealand, Hay and Mohler (1967) in France, Perch-Nielsen (1969) in Denmark, Worsley (1974) in Al-

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abama, Romein (1977) in Spain, and Perch-Nielsen (1981) in Tunisia. A formerly high latitude sequence from DSDP drilling in the Southern Hemisphere was described by Edwards (1973b). Thierstein (1981), Perch-Nielsen et al. (1982), and Smit and Romein (1985) published comprehensive reviews, where they have compiled information on calcareous nannofossils and planktonic foraminifers from a geographically wide range of K/T boundary sites.

METHODS

Smear slides of raw sediment were analyzed under the light microscope at 1560 \times and at least 500 specimens per sample were counted. The count of 500 is designed to ensure that infrequent taxa are included. Most samples were examined beyond this count, however, to uncover any additional species present and to assure that no stratigraphic information was lost. Such is the case with *Biantholithus sparsus*, which was not observed during the counting of Sample 113-690C-15X-4, 43–44 cm, but was observed at least three times during a routine examination of the same slide. Specimens not observed while counting were

not considered statistically but are indicated in the range chart (Table 1) by an X.

Samples were taken aboard ship at successively shorter intervals leading up to the boundary and at 1 cm intervals across the boundary (Fig. 5). In addition, burrows were sampled below and above the boundary. Analysis was made on 37 samples throughout this interval including several burrows.

Individually counted specimens were placed in one of three categories: Tertiary, Cretaceous, or Survivor. The procedure is similar to that used by Thierstein and Okada (1979) on DSDP Site 384 K/T samples, except that instead of just Tertiary vs. Cretaceous groups, we are comparing here three groups in the same manner as did Percival and Fischer (1977). Maintaining the "Survivors" as a separate category not only provides additional detail, but allows us to better define the interval just above the boundary where the number of survivor species sharply increases.

BIOSTRATIGRAPHY AND BOUNDARY CRITERIA

The calcareous nannofossil biozonation schemes generally used for the Maestrichtian are those of Sissingh (1977) or Roth (1978) and for the Danian, Okada and Bukry (1980) or Martini (1971). For the Danian, zonation schemes of finer detail have been proposed for various regions such as those by Romein (1979) for the Caravaca, Spain, section and by Perch-Nielsen (1977, 1979a, 1981) for Denmark and El Kef, Tunisia. More recently, van Heck and Prins (1987) have published a detailed zonation scheme for the Danian of the North Sea.

In low latitude sections, a biostratigraphically complete boundary section should include the uppermost Maestrichtian, *Micula prinsii* Zone (Perch-Nielsen, 1979a) overlain by an interval of the basal Danian dominated by Survivor forms (see below) deposited before the first appearance of the coccolith *Cruciplacolithus tenuis*. This interval corresponds to the *C. primus* Subzone (CP1a) of Okada and Bukry (1980) or the *Markalius inversus* Zone (NP1) of Martini (1971). In sections where preservation is poor, the *M. murus* Zone of Roth (1978) is used to mark the uppermost Maestrichtian. In the high latitudes where diversity is relatively low, and *M. murus* and *M. prinsii* are absent, the provincial *Nephrolithus frequens* Zone of Sissingh (1977) is used. According to Perch-Nielsen et al. (1982) and Smit and Romein (1985), certain lithologic criteria are also necessary for a marine boundary section to be complete. This includes a zone of iridium enrichment near the base of the Tertiary and an interval of highly reduced CaCO_3 referred to as the "boundary clay."

Biostratigraphic criteria for defining the K/T boundary varies somewhat with each zonal scheme and can be latitudinally

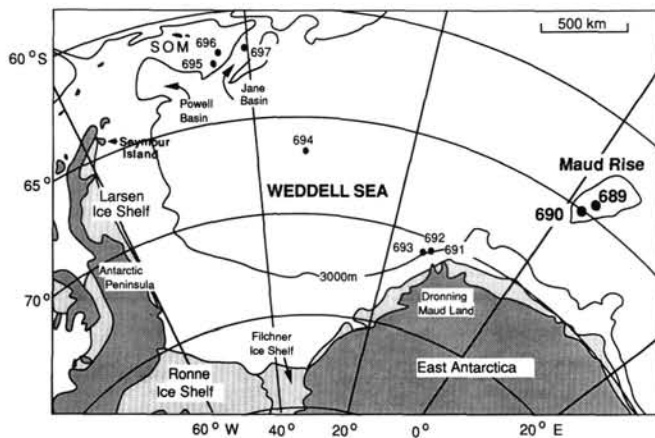


Figure 1. A. Location map of Sites 689, 690, and other ODP Leg 113 Sites, Weddell Sea off East Antarctica. SOM = South Orkney microcontinent. B. Bathymetric profile of Maud Rise projected to the west along a schematic northwest-southeast transect across the Weddell Sea, showing the relative positions and depth distributions of the Leg 113 sites. mbsl = meters below sea level.

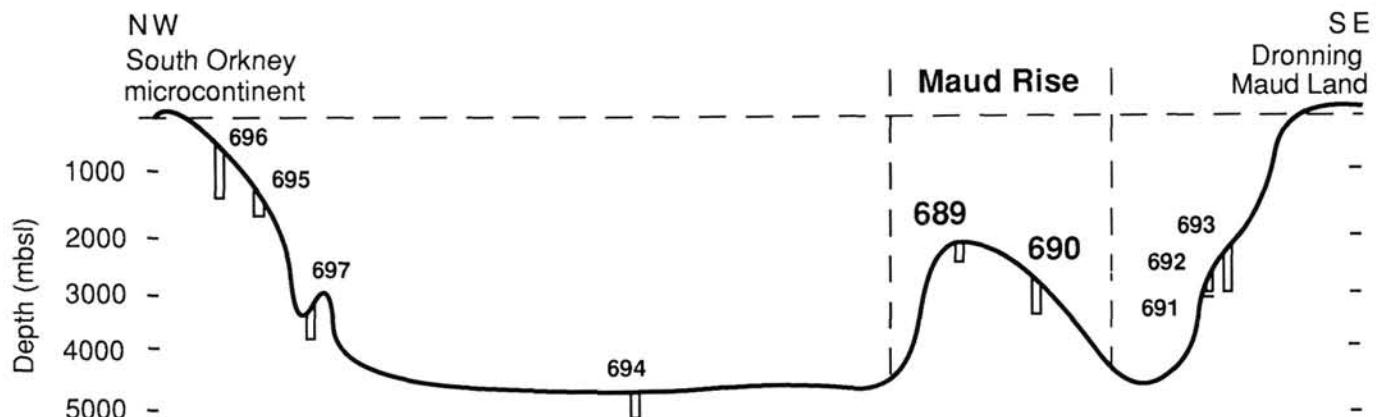


Figure 1 (continued).

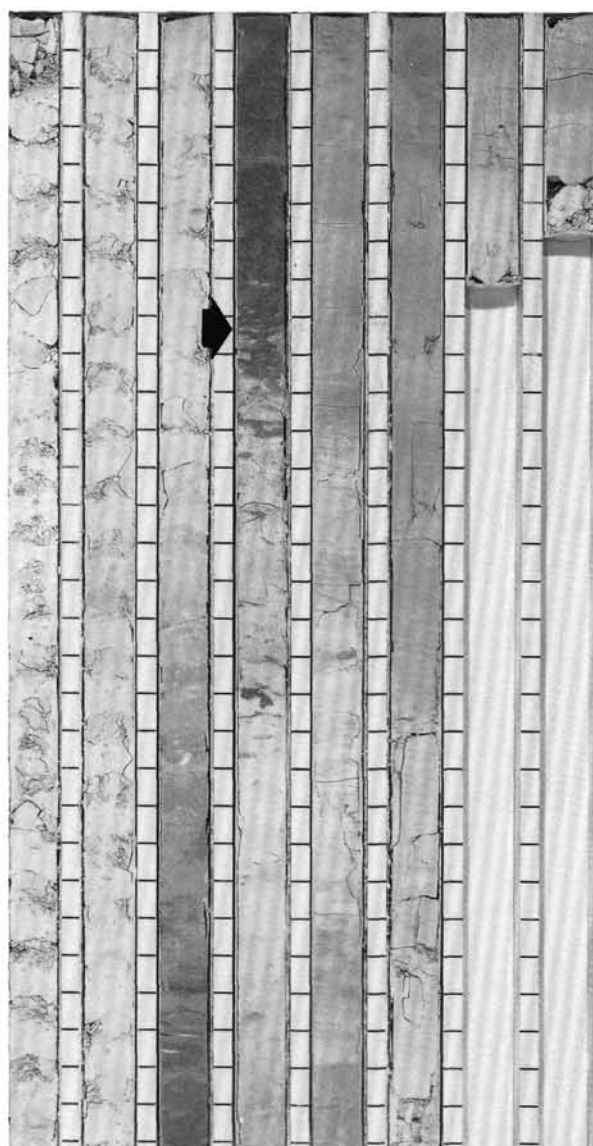


Figure 2. ODP Core 113-690C-15X. The K/T boundary is located in Section 4, between 41.5 and 41.8 cm as indicated by an arrow.

dependent. The low latitude schemes of Okada and Bukry (1980) and Martini (1971) utilize the last occurrence of Cretaceous species to define the boundary, a criterion also used by Sissingh (1977) and Roth (1978). Perch-Nielsen (1979a) uses the first occurrence of *B. sparsus* to denote the boundary in high latitude sections of the North Sea. She also indicates that the first appearance of the calcareous dinoflagellate, *Thoracosphaera*, may be used to mark the boundary in high latitudes and that in low latitudes its sharp increase in abundance can also be used.

From their North Sea work, van Heck and Prins (1987) draw the boundary at the sudden change of assemblages. They also point out that although *B. sparsus* is considered a Tertiary form by many, it has been observed on rare occasions in Maestrichtian assemblages.

Smit and Romein (1985), in an effort to define a type K/T section, compared biological events to lithologies from a number of well documented K/T boundary sites. They find that in general the mass extinctions coincide exactly with an iridium anomaly immediately below the "boundary clay." Because of

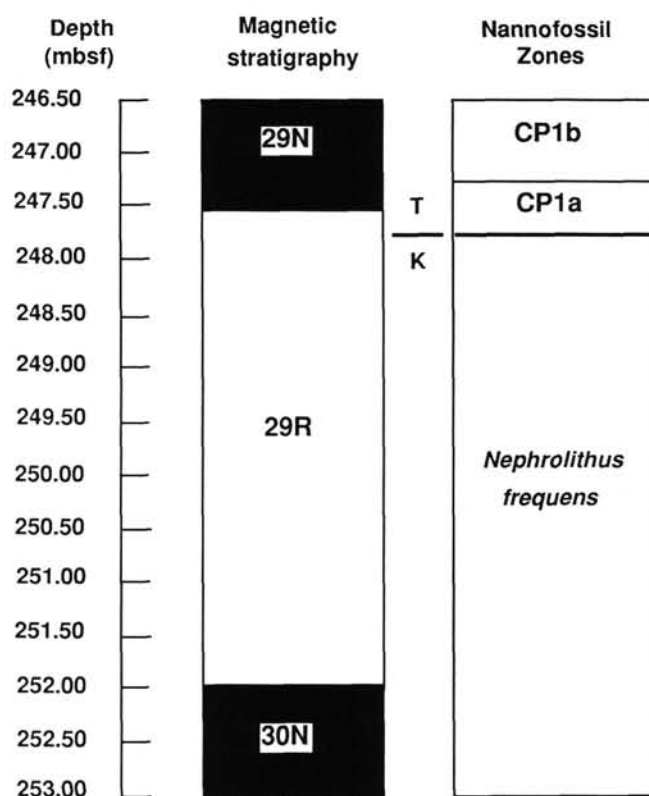


Figure 3. Correlation of magneto- and biostratigraphy across the K/T boundary at Site 690. Tertiary nannofossil zonation scheme is after Okada and Bukry (1980). Cretaceous zonation is from Pospichal and Wise (this volume, chapter 30).

the apparent global synchronicity of these events, they think that the base of the iridium layer would be the ideal level to draw the K/T boundary.

Biostratigraphy and Boundary Selection Criteria at Hole 690C

The biozonation for the Maestrichtian used in this report is that of Wise (1983) as modified by Pospichal and Wise (this volume, chapter 30). The uppermost Maestrichtian *Nephrolithus frequens* Zone of this high latitude scheme developed from South Atlantic drill core sequences can be correlated with Sissingh's combined Zones CC25-CC26. For the Danian interval, the low latitude zonation scheme of Okada and Bukry (1980) is used here with one slight modification at the Maestrichtian/Danian boundary. We prefer to use the first occurrence of *Biantholithus sparsus* instead of the last occurrence of Cretaceous species to define the boundary. The use of the last Cretaceous species presents many problems when dealing with sections such as the present one where bioturbation has been intense and reworking of microfossils up- and downsection is pervasive. By using this definition we would be required to place our boundary at least a meter upsection and even then a subjective decision would have to be made as to just where the last Cretaceous species occurred since reworked forms are present in varying amounts throughout the Paleocene section at this site.

Van Heck and Prins's (1987) use of a sudden assemblage turnover could encounter similar problems to those mentioned above as reworking and bioturbation may obscure the "suddenness" of the turnover. By their criteria, including the suggestion that *B. sparsus* has been observed as a component of uppermost

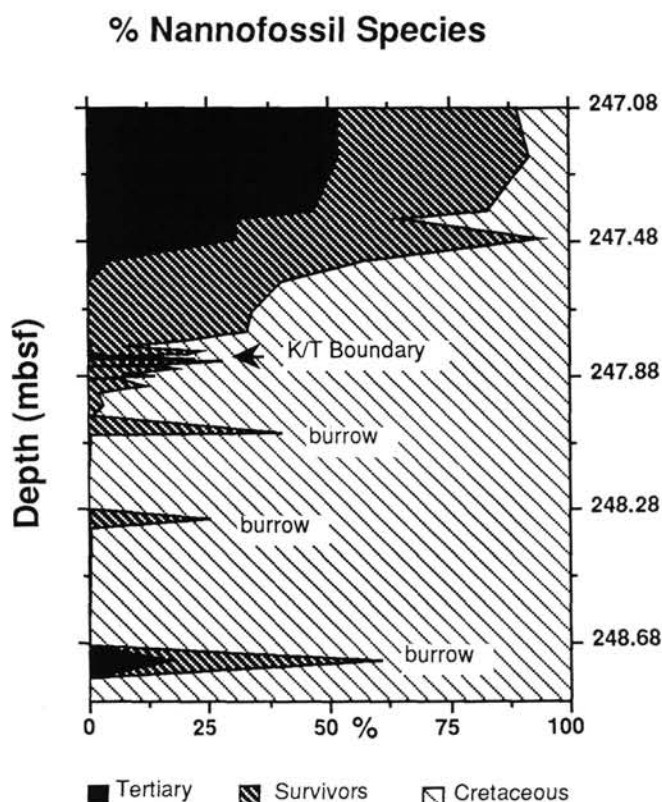


Figure 4. Percent abundance of Cretaceous vs. Tertiary vs. Survivor nannofossil species across the K/T boundary, ODP Section 113-690C-15X-4.

Maestrichtian assemblages, we would again be inclined to place the boundary higher in the section, though not much higher.

Biantholithus sparsus could be considered the first species to appear in Tertiary seas and its first occurrence may be the best criterion to mark the Cretaceous/Tertiary boundary. However, this criterion is not without drawbacks. As easily as bioturbation can obscure last occurrences and assemblage turnover, it can also bring sediments containing younger nannofossils well down into the zone below. In sections where no color change occurs across the boundary this could create some obvious problems (see section "Bioturbation and Burrows"). To further illustrate the problems encountered when attempting to define the K/T boundary biostratigraphically, the use of *B. sparsus* is also hampered by the fact that it is, as Perch-Nielsen et al. (1982) suggest, quite rare and in some cases absent, although it is clearly not latitudinally restricted.

The use of *B. sparsus* appears to work reasonably well at Site 690 if the bioturbation is taken into account. Its first occurrence coincides with the beginning of the rapid increase in abundance of survivor species and the beginning of the Cretaceous-Tertiary assemblage turnover. Although this turnover is not exactly sudden, the criteria of van Heck and Prins (1987) are probably met here. Criteria of Perch-Nielsen (1979a) are also met as an increase in *Thoracosphaera* is noted in the same interval.

Michel et al. (this volume) document an iridium spike coincident with the level at which we place the boundary, thereby meeting part of the criteria of Smit and Romein (1985). Any distinct clay layer though, might have been smeared out completely by bioturbation at Site 690. In addition, an iridium anomaly was not noted at Site 689, further suggesting the presence of a hiatus there.

An alternative criterion used for selecting the boundary here, in conjunction with paleontological evidence, is the sharp color contrast between the pinkish-white Cretaceous sediment and the darker pale brown Tertiary material (Fig. 2; see discussion below).

QUANTITATIVE STUDY

Several specimens of *Biantholithus sparsus* were observed under the light microscope in Sample 113-690C-15X-4, 43–44 cm (247.83 mbsf), and one specimen was noted in Sample 113-690C-15X-4, 49–50 cm (247.89 mbsf), using the scanning electron microscope (SEM). The species was also observed in burrow Samples 113-690C-15X-4, 90–91 cm, and -15X-4, 133.1 cm.

Considering the amount of bioturbation, we would ideally place the boundary between the samples at 41.5 cm and 41.8 cm (Fig. 5). The light colored blocky sediment in this interval is considered to be Cretaceous material still in place, while the darker sediment is interpreted to be burrowed downward. Examination of the nannofossil content of different colored samples at 41.5 cm and 41.8 cm demonstrates this point. The lighter material contains 100% Cretaceous forms while the darker material contains 18% Survivors and about 80% Cretaceous, although the two samples are nearly from the same level and appear to differ only in color (Fig. 5 and Table 1). The light blocky material is in place although it has been "trimmed" on all sides by burrowers. If these light blocks were actual burrows, they would be rounded with occasional concentric internal structures such as are seen in the burrows that carried Cretaceous material above this level (e.g., Fig. 5, samples at 36 and 39.3 cm).

Thoracosphaera were noted in Cretaceous sediments but their occurrence there is inconsistent. Rare specimens were recorded at the boundary, but their abundance ranges around only 1% to about 50 cm above the boundary, in Zone CP1b, where a peak of about 4% is reached (Fig. 6). Though very rare at first, their occurrence, starting at the boundary, is consistent enough to be considered as a biostratigraphic marker at this locality.

The nannofossil assemblage turnover encompasses the interval from Samples 113-690C-15X-4, 14–15 cm (247.54 mbsf), to -15X-4, 49–50 cm (247.89 mbsf). In this interval the percentage of Cretaceous species drops from 94% to 43% as survivor forms increase from 6% to 53% (Fig. 4, Table 1). The sequence of nannofossil assemblage change across the boundary is discussed below in terms of three groups: Cretaceous, Tertiary, and Survivors. Cretaceous forms are those considered to become extinct at the boundary. Tertiary forms are those which do not appear until at or above the boundary, and Survivors are those which appeared in the Cretaceous and cross the boundary. It should be noted that the percent abundance of Survivor forms above the boundary remains low due to the abundance of the Cretaceous species, *Prediscosphaera stoveri*. For example, this species comprises 50% of all forms counted in Sample 113-690C-15X-4, 37.7 cm, just above the boundary (Fig. 6 and discussion below).

Cretaceous

Sediments of the uppermost Maestrichtian *Nephrolithus frequens* Zone extend down 23.6 m below the boundary. Except where many forms disappear near the base of this zone (see Pospichal and Wise, this volume, chapter 30), the high latitude nannofossil assemblage changes very little through the interval with species diversity ranging around 20 to 25. About 15 of these are consistently present (Table 1) in the samples from below the boundary. The basic assemblage includes abundant *Acuturris scotus*, *Arkhangelskiella cymbiformis/specillata*, *Cribrosphaerella daniae*, *Kamptnerius magnificus*, *Prediscosphaera cretacea*, and *Nephrolithus frequens*.

The most dominant form is a small (3–6 μ m) species of the genus *Prediscosphaera*. This tiny, elliptical species is up to 60% of the total assemblage below the boundary (Fig. 6, Table 1).

Identification of this form on the specific level is difficult due to poor preservation. For the most part, the structures within the central area have been dissolved, leaving just the rim. Preservation does improve downsection and several specimens have been observed with the central cross structure intact. The forms can best be identified as *P. stoveri*. Jiang and Gartner (1986) observed an acme of *P. quadripunctata*, a similar (synonymous?) form, at nearly the same level in K/T boundary sediments of the Brazos River section in east Texas and at El Kef, Tunisia. At these localities, its peak abundance is about 15% (up from 3%), which is not nearly as high as it is here. However, because their method of preparation may have biased the sample toward larger forms, the true abundance of this species may be higher in those sections (see "Systematic Paleontology" section).

As shown in Figure 4, the overall percentage of Cretaceous species drops very little from 248.85 mbsf to the boundary nearly 1 m above at 247.815 mbsf, where it remains a high 79.5%. The drop is rapid from there as the survivor forms (see below) begin their dominance. Just 40 cm above the boundary at 247.47 mbsf, the Cretaceous species reach a low at 6%.

The gradual reduction in the number of Cretaceous species through the lower Danian has been reported by several authors from various sites, and it has been traditional to consider all the Cretaceous forms above the boundary to be reworked. This idea, however, was challenged by Perch-Nielsen et al. (1982). From isotopic measurements of basal Danian sediments, in which the bulk of the measured material consisted of Cretaceous forms, they noted strongly differing values between the uppermost Maestrichtian and lowermost Danian. They, in turn, concluded that the Cretaceous forms present in the basal Danian material did live in Tertiary seas. Smit and Romein (1985) suggest similarly that the final Cretaceous nannoplankton extinctions did not occur until 1000–10,000 yr into the Tertiary. The hypothesis of Perch-Nielsen et al. (1982), however, has been challenged by Officer and Drake (1983).

Tertiary

The basal Danian *Cruciplacolithus primus* Subzone (CP1a), extends some 45 cm above the Cretaceous/Tertiary boundary. The zone is characterized by a reduced number of nannofossils, which in this case, consist of poorly preserved and mostly broken specimens in samples immediately at or above the boundary. Here, the percentage of survivor forms sharply increases along with the gradual decline in the number of Cretaceous species.

Other than *Biantholithus sparsus*, the first true Tertiary species noted in the sediments of Maud Rise is a small elliptical form, *Hornibrookina edwardsii* (Pl. 2, Fig. 1). This species is possibly an evolutionary link between this genus and *Biscutum*, which managed to survive the terminal Cretaceous crisis. This link was first hypothesized by Perch-Nielsen (1977) in her original description. For further discussion of this species see "Systematic Paleontology" below.

The first occurrence of *Hornibrookina edwardsii* is interpreted to be about 15 cm above the boundary in Sample 113-690C-15X-4, 35–36 cm (247.75 mbsf). Its appearance is also noted lower in the section in samples considered to be burrows. As shown in Figure 5, the abundance of this form increases sharply starting at Sample 113-690C-15X-4, 7–8 cm, (247.47 mbsf) and reaches a peak at 46% of the entire assemblage in Sample 113-690C-15X-3, 150–151 cm (247.39 mbsf). At this level the first *Cruciplacolithus tenuis* is noted marking the CP1a/1b boundary. This species, combined with its precursor form, *C. primus*, make up 45% of the assemblage in Sample 113-690C-15X-3, 118–120 cm (247.08 mbsf) (Fig. 6). At this level, Tertiary species comprise 52% of the assemblage, Survivors 37%, and Cretaceous forms 11% (Fig. 4). Diversity, if all

the Cretaceous forms are considered reworked at this point, stands at about ten or eleven species.

Most authors report the first appearance of *C. primus* as preceding that of *C. tenuis*. Here, they both first occur at nearly the same horizon. This could be attributed to intense bioturbation; alternatively, a hiatus at this level is entirely possible (see discussion section).

The recent work of van Heck and Prins (1987) has shown that the first occurrence of *C. primus* (*Cruciplacolithus* forms smaller than 7 μ m) is followed by the appearance of an intermediate form, *C. intermedius*. This form is described as being slightly smaller than *C. tenuis* but greater than 7 μ m and lacking the triangular blocks ("feet") on the base of central cross bars at the attachment point to the inner wall. Specimens with well defined "feet" were rarely observed here because of less than ideal preservation. Thus, it was necessary to define the CP1a/1b boundary on the first occurrence of forms greater than 7 μ m or forms which may be *C. intermedius* and not *C. tenuis*.

Survivors

Perch-Nielsen et al. (1982) defined "Survivors" as those species which appear in the Cretaceous as only minor components of the assemblage but which either do not become extinct at the end of the Cretaceous or have known descendants surviving into the Danian. She also points out that these forms are most prevalent in the basal Danian of high- and mid-latitude sites and less common in low latitude sections. Some of these forms are considered to be "opportunistic." These taxa, sometimes referred to as disaster species, show a sharp increase in abundance and appear to "bloom" in the absence of other forms.

The following "Survivor" species are present in the sediments of Maud Rise: *Zygodiscus sigmoides*, *Markalius inversus*, *Biscutum castrorum*, *Neorepidolithus* spp., *Thoracosphaera*, *Cyclagelosphaera reinhardtii*, and *Lapideacassis* sp. Their percentage in the assemblage ranges from 0.4% to 6% just below the boundary, and their peak abundance at 63% of the assemblage is reached some 40 cm above the K/T boundary (Fig. 4). This peak in abundance is coincident with the lowest abundance of Cretaceous forms and the beginning of the rise in abundance of true Tertiary forms.

The dominant Survivor form is *Zygodiscus sigmoides*, which occurs sporadically throughout the Maestrichtian. The species bloomed shortly after the boundary event, and peaked at 40% of the assemblage in Sample 113-690C-15X-4, 7–8 cm (247.47 mbsf) (Fig. 6). The next most abundant Survivor form is *Biscutum castrorum* (= *B. constans* of some authors), which peaks at 18% of the assemblage in the same sample (Fig. 6). *Markalius inversus* and *Neorepidolithus* spp. do not reach the same abundances, with *M. inversus* peaking in Sample 113-690C-15X-4, 14–15 cm (247.54 mbsf) at 7% and *Neorepidolithus* spp. in Sample 113-690C-15X-4, 29–30 cm (247.67 mbsf), at 5% (Fig. 6). *Thoracosphaera*, *Cyclagelosphaera reinhardtii*, and *Lapideacassis* sp. generally make up less than 1% of the assemblage in sediments directly above the boundary except where *Thoracosphaera*, as mentioned above, exhibits a slight increase in abundance above the CP1a/1b zonal boundary.

DISCUSSION

Boundary Comparisons

The lowermost Tertiary assemblage, including the Survivor taxa in Maud Rise sediments, appears to be most similar to the assemblage reported by Perch-Nielsen et al. (1982) from mid-latitude DSDP Sites 524 and 356 in the South Atlantic and the high-latitude assemblages from Denmark and the North Atlantic. One difference is the abundance of *Thoracosphaera* within Subzone CP1a just above the boundary on Maud Rise, which is

Table 1. Abundance counts of calcareous nannofossils across the K/T boundary, ODP Section 113-690C-15X-4. X = present, but not noted within count of 500 specimens.

Age	Zone or subzone		Core, section, interval (cm)	Depth (mbsf)	Tertiary			"Survivors"							
					<i>Biantholithus sparsus</i>	<i>Cruciplacolithus primus/tenuis</i>	<i>Hornbrookina edwardsii</i>	<i>Biscutum castrorum</i>	<i>Cyclagelosphaera reinhardtii</i>	<i>Lapideacassis</i> sp.	<i>Markalius inversus</i>	<i>Neorepidolithus</i> spp.	<i>Thoracosphaera</i> spp.	<i>Zygodiscus sigmoides</i>	
early Paleocene	<i>Zygodiscus sigmoides</i>	<i>Cruciplacolithus tenuis</i> (CP1b)	15X-3, 118–120	247.08		226	34	31		1	8	12	14	121	
			15X-3, 133–134	247.23		220	51	71			14	12	5	104	
			15X-3, 151–152	247.39		3	235	70			38	2	22	50	
		<i>C. primus</i> (CP1a)	15X-4, 1–2	247.41	X		155	57	1		22	1	8	86	
			15X-4, 7–8	247.47		1	154	95			16	1	6	203	
			15X-4, 14–15	247.54			20	55			38	10	9	177	
			15X-4, 20–21	247.60			X	56	1	1	16	8	3	116	
			15X-4, 29–30	247.69			X	44	2		20	26	1	77	
			15X-4, 35–36	247.75			1	48	2		18	24	2	71	
			15X-4, 37.7	247.777				13	1		7	5	2	65	
			15X-4, 39.3	247.793				3			9	4		20	
			15X-4, 40.9	247.809							21	12	9	4	74
			15X-4, 41.5	247.815				12			21	10	4	7	54
			late Maestrichtian	<i>Nephrolithus frequens</i>	<i>Cribrosphaerella daniae</i>	15X-4, 41.8	247.818	X			26			8	4
15X-4, 42.7	247.827	19									7	5	1	35	
15X-4, 43.0	247.830	15				1					8	5	1	26	
15X-4, 43–44	247.83	1												2	
15X-4, 43.1	247.831	27									4	13	1	99	
15X-4, 43.8	247.837	20									8	4		69	
15X-4, 44.7	247.846													1	
15X-4, 45.3	247.852						2								
15X-4, 45.3(a)	247.852(a)	14									6	7	1	47	
15X-4, 46–47	247.86	18									11	3	2	60	
15X-4, 47.0	247.869	12						4	4		19				
15X-4, 48–49	247.88	12						9	7	1	44				
15X-4, 48.6	247.885										1				
15X-4, 49–50	247.89	8					1	1	2		19				
15X-4, 50.8	247.907	12				1	2	5	4	1	35				
15X-4, 53–54	247.93	4						1	2		5				
15X-4, 57–58	247.97	1									13				
15X-4, 65.7	248.05	48				2	1	15	11	3	130				
15X-4, 66–67	248.06										1	1			
15X-4, 78–79	248.18							1							
15X-4, 90–91	248.31	2			35	1	1	11	15	1	66				
15X-4, 94–95	248.34									1	1				
15X-4, 133.1	248.73		6	84	52	1	16	4	2	154					
15X-4, 145–146	248.85														

a maximum of 5% of the assemblage as compared to 50% at Site 524.

Another difference is the first occurrence and dominance by *Hornibrookina edwardsii* above the boundary at Maud Rise. This form was not reported from Site 524 and, except for Jiang and Gartner's (1986) observations that rare *H. teuriensis* were present down to the boundary in the Brazos River section of Texas, *Hornibrookina* has always been reported to first occur at the base of, or within, Zone CP2 (NP3) (Edwards, 1973a; Perch-Nielsen, 1977; Angelozzi, 1988; Varol, 1989).

In comparison with the low-latitude boundaries of El Kef, Tunisia, and Caravaca, Spain, *Thoracosphaera* are much less abundant in Maud Rise sediments. In addition, common to abundant *Braarudosphaera* have been reported from the basal Danian at El Kef, Site 356 (Perch-Nielsen et al. 1982), and other localities such as Pont Labau, France (Hay and Mohler, 1967), and Brazos River, Texas (Jiang and Gartner, 1986), but, as expected, this normally shallow water species is not present in the deep-sea section at Site 690.

Other forms present in lower Danian sediments at these low-latitude sites and not present at Maud Rise are *Toweius petalo-*

sus, *Biscutum? romeinii* (Perch-Nielsen, 1981), and *B.? parvulum* (Romein, 1979). These forms were also not found at Site 524 (Perch-Nielsen et al., 1982). One poorly preserved specimen (not illustrated here) possibly related to *B.? romeinii* was noted in the SEM in a sample from just above the boundary at Site 690. However, it should be noted that with the light microscope, reworked specimens of *Prediscosphaera stoveri* in which the central area is dissolved may be confused with other tiny elliptical forms such as *B.? romeinii*.

In summary, it appears that Cretaceous/Tertiary transitional nannofossil assemblages around the world are controlled by a variety of paleoceanographic, paleoenvironmental, and paleolatitudinal factors. The environmental generalist Survivor forms such as *Markalius inversus*, *Zygodiscus sigmoides*, *Biscutum castrorum*, and *Neocrepidolithus* are more prevalent in high latitudes. With the addition of the Maud Rise data these forms show a bipolar distribution in their peak abundances. Perch-Nielsen et al. (1982) reported that of all the forms that bloomed in the vicinity of the boundary, only blooms of *Thoracosphaera* appear to have a global distribution. The lack of dominance of this form on Maud Rise, however, is an exception to this gener-

Table 1 (continued).

Cretaceous																							
<i>Acuturris scotus</i>	<i>Ahmullerella octoradiata</i>	<i>Arkhangelskiella</i> spp.	<i>Chastozogus</i> sp.	<i>Cretarhabdus conicus</i>	<i>Cribrosphaerella daniae</i>	<i>Cribrosphaerella ehrenbergii</i>	<i>Eiffellithus turrisseiffelii</i>	<i>Gartnerago</i> spp.	<i>Kampitnerius magnificus</i>	<i>Micula decussata</i>	<i>Nephrolithus frequens</i>	<i>Prediscosphaera cretacea</i>	<i>Prediscosphaera spinosa</i>	<i>Prediscosphaera stoveri</i>	Tertiary	Survivor	Cretaceous	Total	% Tertiary	% Survivor	% Cretaceous	Depth (mbsf)	
2	1	5	1	3	3	1		7		7	5	22		260	187	57	504	52	37	11	247.08		
5		5			2	1	1	11		5		12		271	206	42	519	52	40	8	247.23		
9	1	14		2	7	1	1	14		15	14	11		238	182	89	509	47	36	17	247.39		
4		10		6	10	3	3	16	2	16	19	89		155	175	178	508	31	34	35	247.41		
7		3		1	1			6	2	2	6	5		155	321	33	509	31	63	6	247.47		
13		26	2	5	14	1	3	49	7	22	21	65		20	289	229	538	4	53	43	247.54		
13	5	23	1	4	17	3	2	29		44	39	117			201	300	501		40	60	247.60		
8	4	26	2	9	19	3	2	34		45	45	3	137		170	338	508		33	67	247.69		
12	2	39	4	7	25	1	3	32	4	45	38	1	123	1	165	336	502	0.2	32.8	67	247.75		
7		13	5	7	16	4	7	15		45	35	2	252		93	409	502		19	81	247.777		
36		32	2	13	17	6	9	2	21	63	53	1	213	3	33	470	506	0.6	6.4	93	247.793		
16	2	33	2	20	27	9	5	3	24	57	37	5	158		120	398	518		23	77	247.809		
10	3	16	5	15	22	4	2	8	22	57	35	5	215	12	96	419	527	2	18	80	247.815		
11	3	30	6	8	21	7	6	5	29	53	42	283				504	504			100	247.818		
12	3	18	1	7	13	6	2	3	10	57	33	2	224		106	392	498		21	79	247.827		
13		26	2	13	20	7	4	8	21	59	50	3	224		67	450	517		13	87	247.830		
11	5	48	1	14	27	1	2	2	52	56	46	190			56	457	513		11	89	247.83		
7	1	28	9	16	20	9	2	1	20	76	39	1	298		3	527	530		0.6	99.4	247.831		
7	4	12	2	8	18	4	4	6	6	37	25	1	238		144	373	517		28	72	247.837		
7	2	15	1	9	16	9	1	3	19	63	42	5	234		101	426	527		19	81	247.846		
11	3	35	5	13	32	7	3	6	48	76	32	1	230		3	502	505		0.6	99.4	247.852		
9	1	23	1	8	24	5	4	3	17	73	43	1	218	1	75	430	506	0.2	14.8	85	247.852(a)		
9	7	44	2	10	27	5	3	4	28	77	39		176		94	431	525		18	82	247.86		
5	3	11		6	25	5	2	2	17	63	17	1	304		39	461	500		8	92	247.869		
16	1	34	2	11	23	8	4	6	35	73	40	1	198		73	453	526		14	86	247.88		
13	6	16	2	11	18	3	3	5	5	97	21	1	290		1	505	506		0.2	99.8	247.885		
9	9	44	2	13	21	6	2	3	24	78	46	2	228		31	491	492		6	94	247.89		
12	3	13	2	12	18	6	2	5	19	64	38	2	252		60	448	510		12	88	247.907		
15	7	30	2	23	22	4	3	10	25	106	37	4	207		12	496	508		2	98	247.93		
12	6	41	4	12	27	8	9	8	32	91	45	3	212		14	510	524		3	97	247.97		
14	1	16	2	4	10	3	4	2	23	45	26		158		210	309	519		40	60	248.05		
17	11	38	6	21	25	4	10	8	44	96	57	1	182		2	520	522		0.4	99.6	248.06		
19	6	44	1	19	29	6	9	4	25	85	61	2	191		1	502	503		0.2	99.8	248.18		
16	3	31	1	13	17	7	7	3	32	56	36		169		2	130	391	523	0.4	24.8	74.8	248.31	
20	9	28	3	19	23	10	18	10	30	94	44	3	214		2	525	527		0.4	99.6	248.34		
12		15		7	11	4	3	1	14	26	31	2	75		90	229	201	520	17	44	39	248.73	
28	2	44		23	23	7	6	38	1	73	69		194			508	508			100		248.85	

alization. The distribution of the Survivor *Braarudosphaera* is less complex, and is probably dependent on water depth or water chemistry.

The distribution of newly-evolving Tertiary forms is more complex. *Biantholithus sparsus*, possibly the first Tertiary form, is rare in most sections and absent in some. However, its presence in the high-latitude, deep-sea section at Site 690 (65°S), as well as in the marginal, *Braarudosphaera*-bearing El Kef section denotes its broad latitudinal distribution. Just what controls its presence or absence is not well understood.

The distribution of the low-latitude Tertiary forms *Biscutum? romeinii*, *B.? parvulum*, and *Toweius petalosus*, appears to be latitudinally dependent, although not all of these forms or their blooms are found in every Tethyan section. According to Perch-Nielsen et al. (1982), *B.? romeinii*, though present at El Kef, was not found at Caravaca. *Biscutum? parvulum* and *T. petalosus* are present at both sites. Of the three, *T. petalosus* appears to be more widely distributed. Perch-Nielsen et al. (1982) report the form as very rare in mid-latitude sections at DSDP Site 356 and in Denmark. The presence of these forms, and the occurrence of their blooms within the low latitudes, may have been modu-

lated by local paleoceanographic conditions. Such may be the case with *Hornibrookina edwardsii* whose bloom above the boundary has only been noted at Site 690. Their blooms may have been short term events which could be missed in a particular section if minor hiatuses are present or if the sampling interval is too great. For example, the bloom of *H. edwardsii* at Site 690 might have been missed if sample spacing had been greater than 20 cm.

Latitudinal differences also appear to be expressed even among the latest Cretaceous forms on Maud Rise where *Prediscosphaera stoveri* is strongly dominant. Elsewhere, Perch-Nielsen et al. (1982, p. 358) found that "The Maestrichtian calcareous nannofossil assemblages are usually very diverse and no particular species dominates the assemblage."

Figure 7 shows a comparison of the thickness of Subzone CP1a of several deep sea and marginal boundary sites. The thickness of the basal Danian Subzone CP1a is about 45 cm at Site 690. This is thin compared to the approximately 3 m at DSDP Site 524 and the 7 m at Stevns Klint in Denmark (Perch-Nielsen, 1979b). The interval is also much thicker at EL Kef, Zumaya, and Caravaca. Data on the K/T interval from ODP

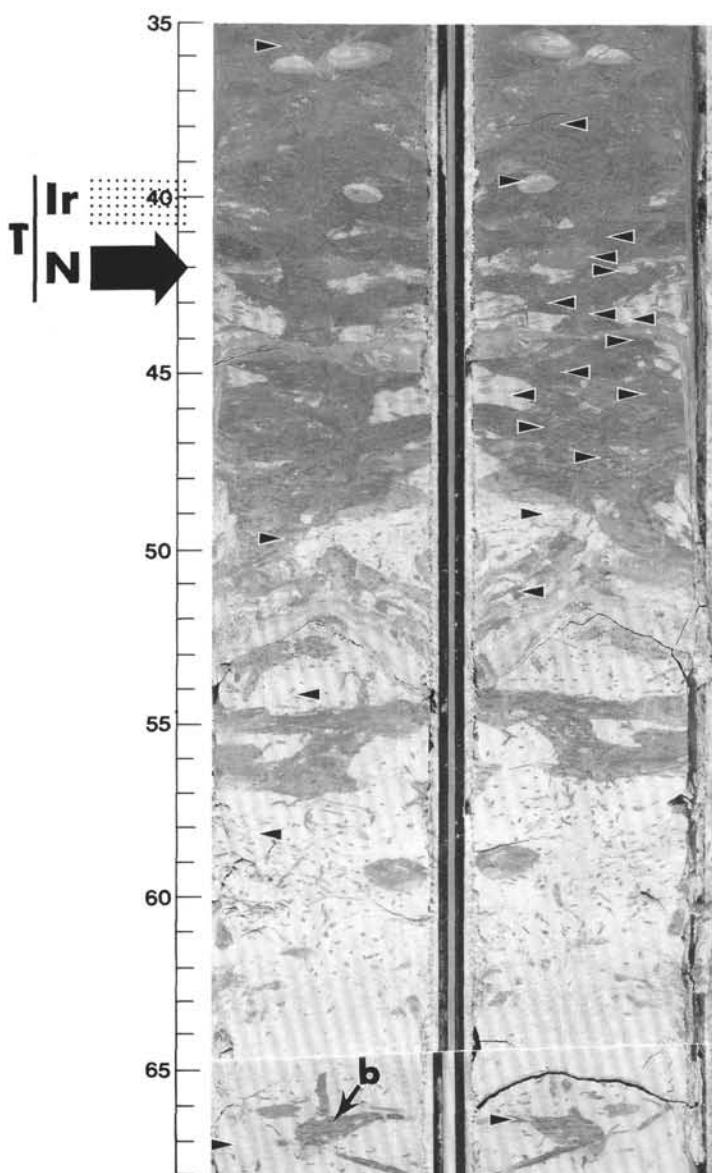


Figure 5. Enlargement of K/T boundary interval. Nannofossil boundary horizon is indicated by arrow "N"; maximum iridium abundance (see Michel et al., this volume) is indicated by stippled pattern "Ir". Fine millimeter-scale burrows between 48 and 62 cm are *Chondrites*. Arrow "b" indicates burrow at 65.7 cm. Small arrows show locations of samples from the "working" half of the core (left) and the "archive" half (right). "Toothpick" samples were taken from the "archive" half.

Leg 121, Site 752, though not yet complete, suggest a thickness of about 5 m for the Subzone CP1a (ODP Leg 121 Shipboard Scientific Party, 1989).

Bioturbation and Burrows

Intense bioturbation created some problems in accurately determining the precise K/T boundary level. However, this was alleviated somewhat by the strong contrast in color between Tertiary and Cretaceous sediments (Figs. 2 and 5). This relationship was proven when dark blebs sampled from the pinkish-white sediment below the boundary were found to contain Tertiary

nannofossils. These blebs, or burrows, are present at various levels up to 85 cm below the boundary. The lowest burrow sampled at 248.73 mbsf (Sample 113-690C-15X-4, 133.1 cm) was dark brown, contrasting strongly with the light Cretaceous chalk (Fig. 8). Oval-shaped, it measured nearly 2 cm long. It contained only 39% Cretaceous species, whereas the surrounding matrix contained 100% Cretaceous forms. The same sample had 17% Tertiary species, including *Hornibrookina* and *Cruciplacolithus*, which would have had to have been brought down from Subzone CP1b sediments, over a distance of at least 1.3 m. This indicates a very great burrowing depth by a large-bodied bioturbator.

This example at Site 690 illustrates the obvious problems one would encounter in trying to determine the position of the K/T boundary in heavily bioturbated sections where there is no abrupt color change. Where bioturbation may go unnoticed, the K/T boundary might be placed either too high or too low in the section on the basis of reworked microfossils. It should be noted that considerable amounts of Cretaceous material can be reworked upward in burrows above the boundary (e.g., sample at 39.3 cm, Fig. 5) as well as Tertiary material being reworked downward. The overall effect on the section in Hole 690C has been to lower the apparent K/T contact by about 6 cm from the original surface, only small vestiges of which remain in the form of small (millimeter-scale) blocky pods of Cretaceous ooze (Fig. 5).

In addition to moving Tertiary nannofossils well below the K/T contact, the activity by large-bodied bioturbators has also smeared out and displaced the enriched iridium layer, leaving general anomalous peaks in iridium abundance below the boundary (Michel et al., this volume). These are false peaks that could be misinterpreted as indicators of a succession of extraterrestrial impact events rather than just one as originally proposed by Alvarez et al. (1980).

The K/T section at Site 690 also displays the great depth range achieved by some burrowing organisms. Generally, in the deep sea, the effects of bioturbation are thought not to exceed 40 cm and to average in the range of 10–20 cm (Wright et al., 1982; Smit and Romein, 1985). It is apparent here that this range needs to be expanded, almost tripled in this case. In near-shore environments, certain shrimp are known to burrow to depths of over a meter (Scoffin, 1987). Perhaps such organisms colonized this site following the K/T event and contributed to the extensive bioturbation we have described. We suggest that bioturbation should be taken into account when analyzing any K/T boundary section.

CP1a/CP1b Hiatus?

Several lines of evidence suggest the presence of a hiatus separating Zones CP1a and CP1b. The first appearance of *Cruciplacolithus primus* should precede that of *C. tenuis*, but this is not the case here as they both appear at about the same time. The increase in abundance of *Cruciplacolithus* between 247.39 mbsf and 247.23 mbsf is quite sharp, from <1% to 44%. At the same time the abundance of *Hornibrookina* drops considerably (Fig. 6). It may not be difficult to interpret such a turnover as natural in a span of 16 cm considering the low rate of sediment accumulation during this time. However, it is reasoned here that a hiatus is a distinct possibility.

Carbon-13 isotope measurements of Stott and Kennett (this volume, chapter 47) show a sudden positive shift coincident with the rapid rise in abundance of *Cruciplacolithus*. They conclude from this that normal productivity resumed much sooner in the Weddell Sea area than in the middle and low latitudes. A hiatus may better explain this sudden change in stable isotope values as well as the nannofossil assemblages. Thus it is not clear if the "Strangelove" ocean event was any shorter in the

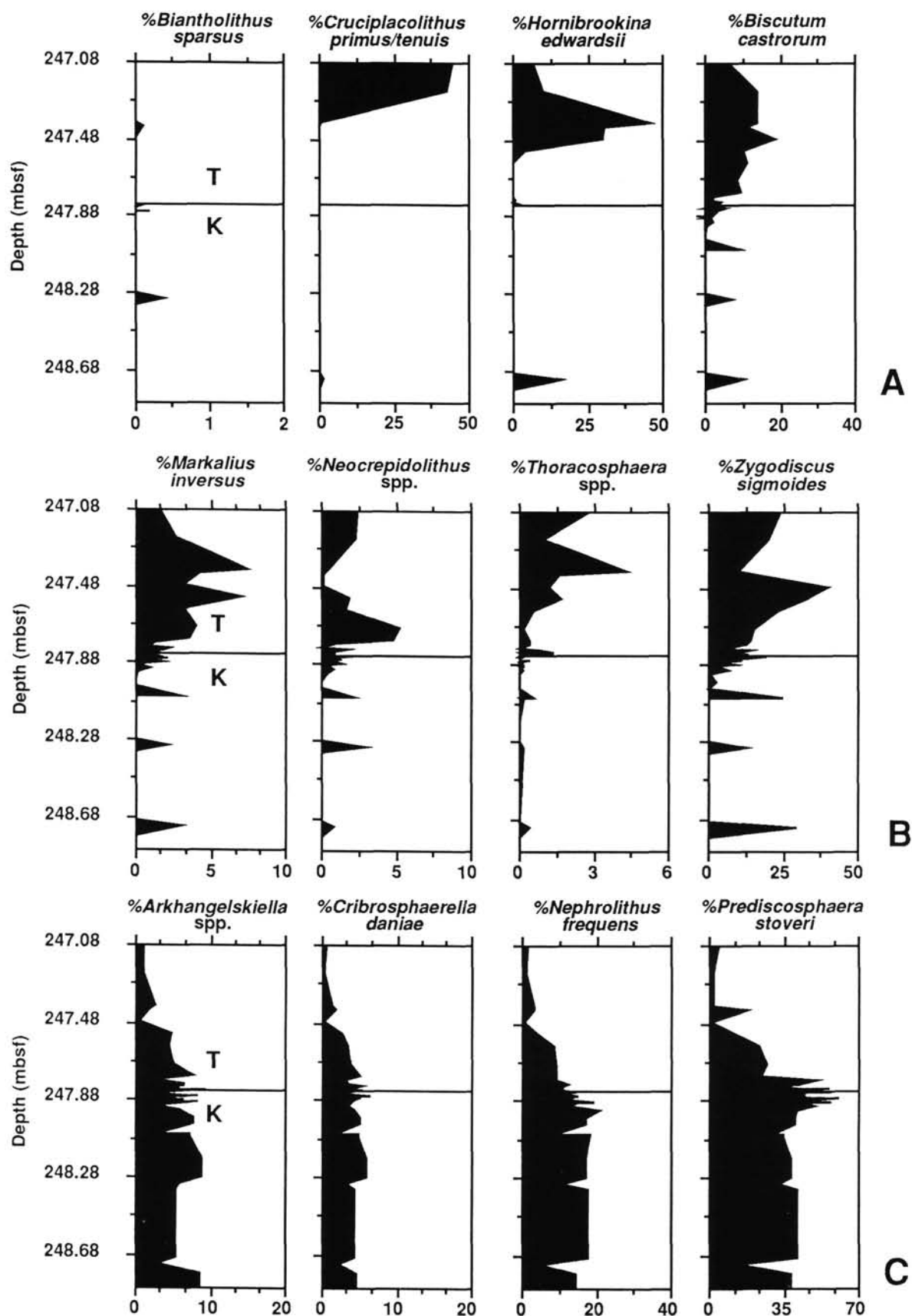


Figure 6. Percent abundance of selected individual nannofossil species across the K/T boundary, Section 113-690C-15X-4. Tertiary taxa are in row A except for *B. castrorum*, which belongs to the Survivor subassemblage in row B. Cretaceous taxa are in row C.

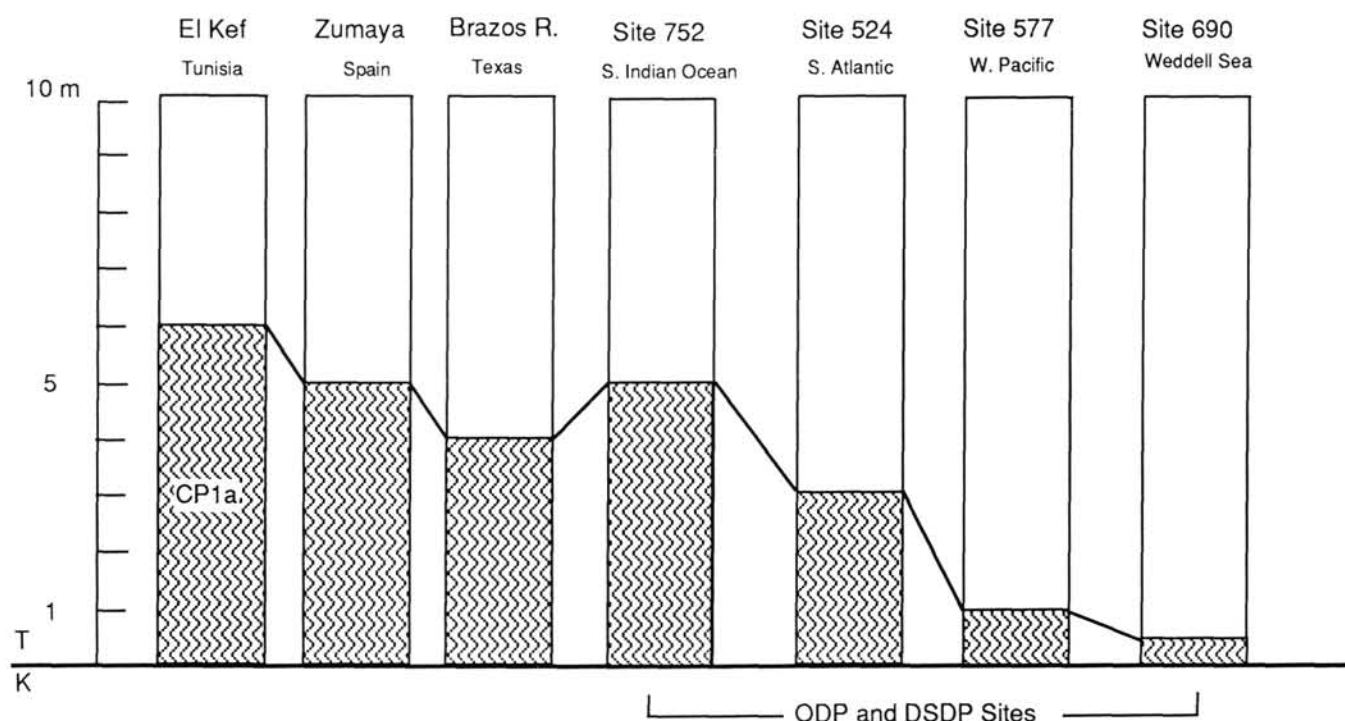


Figure 7. Comparison of the thickness of Subzone CP1a (NP1) from various land-based and DSDP and ODP K/T boundary sections. Note: thicknesses are implied for sections in which the standard zonation schemes were not applied (El Kef).

high-latitude Southern Oceans than in other localities around the globe.

SUMMARY AND CONCLUSIONS

The Cretaceous/Tertiary boundary section captured at Site 690 on Maud Rise is a biostratigraphically complete sequence. Although not as expanded as some land K/T sections, the section contains a fairly thick (23.6 m) upper Maestrichtian *Nephrolithus frequens* Zone, which is overlain by a 45 cm thick unit of the basal Danian CP1a (*Cruciplacolithus primus*) Subzone. Upper Maestrichtian-lower Paleocene calcareous nannofossil assemblages are comparable to the northern high-latitude assemblages of the North Sea, North Atlantic, and Denmark. Differences are in the presence and dominance of *Hornibrookina* in sediments above the boundary at Maud Rise and in the abundance of *Thoracosphaera*, which does not become a major constituent of the assemblage until higher in the sequence. In addition, although acmes of the small *Prediscosphaera* forms have been reported from El Kef and Brazos River, Texas, the extremely high abundance of *Prediscosphaera stoveri* immediately below the boundary here may be unique to these high latitudes.

The use of *Biantholithus sparsus* as a marker for the K/T boundary appears to work well for this high-latitude section despite the complications introduced by bioturbation. Though it is rare in basal Danian sediments, it was found to be most abundant right at the boundary. Its occurrence coincides well with the beginning of the rise in number of the survivor taxa and the decline of Cretaceous species. As shown in Figures 4 and 6 and Table 1, the sequence of events, in ascending order, across the K/T boundary on Maud Rise is as follows:

1. Near the end of the Maestrichtian, nannoplankton assemblages were dominated by *Nephrolithus frequens*, *Cribo-*

sphaerella, *Prediscosphaera*, *Arkhangelskiella*, and *Kamptnerius magnificus*. *Prediscosphaera stoveri* is the most abundant form and appears to bloom at the very end of the Maestrichtian (Samples 113-690C-15X-4, 57-58 cm, to 49-50 cm). Diversity stands at about 20 species and appears to vary little except at the base of the *N. frequens* Zone where several species disappear (see Pospichal and Wise, this volume, chapter 30).

2. *Biantholithus sparsus* first appears coincident with a rise in abundance of the Survivor forms, *Zygodiscus sigmoides*, *Markalius inversus*, and *Biscutum castrorum*. *Thoracosphaera* and *Neorepidolithus* spp. are present also (Sample 113-690C-15X-4, 49-50 cm).

3. Survivor forms further increase in abundance along with the decline in abundance of Cretaceous forms. *Zygodiscus sigmoides* dominates the Survivor species assemblage but *P. stoveri* (presumably reworked) remains the most abundant form overall (Samples 113-690C-15X-4, 48-49 cm, to 20-21 cm). *Hornibrookina* first appears at about this point (Sample 113-690C-15X-4, 35-36 cm).

4. The number of Cretaceous species drops abruptly and *Z. sigmoides*, *Biscutum castrorum*, and *Hornibrookina* make up nearly 90% of the assemblage (Sample 113-690C-15X-4, 7-8 cm).

5. Few *Cruciplacolithus* appear while *Hornibrookina* is now the dominant form at over 45% of the assemblage, which consists of five or six survivor forms in addition to the two Tertiary taxa. About 10 Cretaceous species still remain although these are undoubtedly reworked at this point (Sample 113-690C-15X-3, 151-152 cm).

6. *Cruciplacolithus* rapidly increases in abundance and becomes the dominant form while the abundance of *Hornibrookina* decreases quite rapidly (Sample 113-690C-15X-3, 133-134 cm). Survivor forms become a minor component of the assemblage as rapid Tertiary speciation occurs. Cretaceous species dwindle.

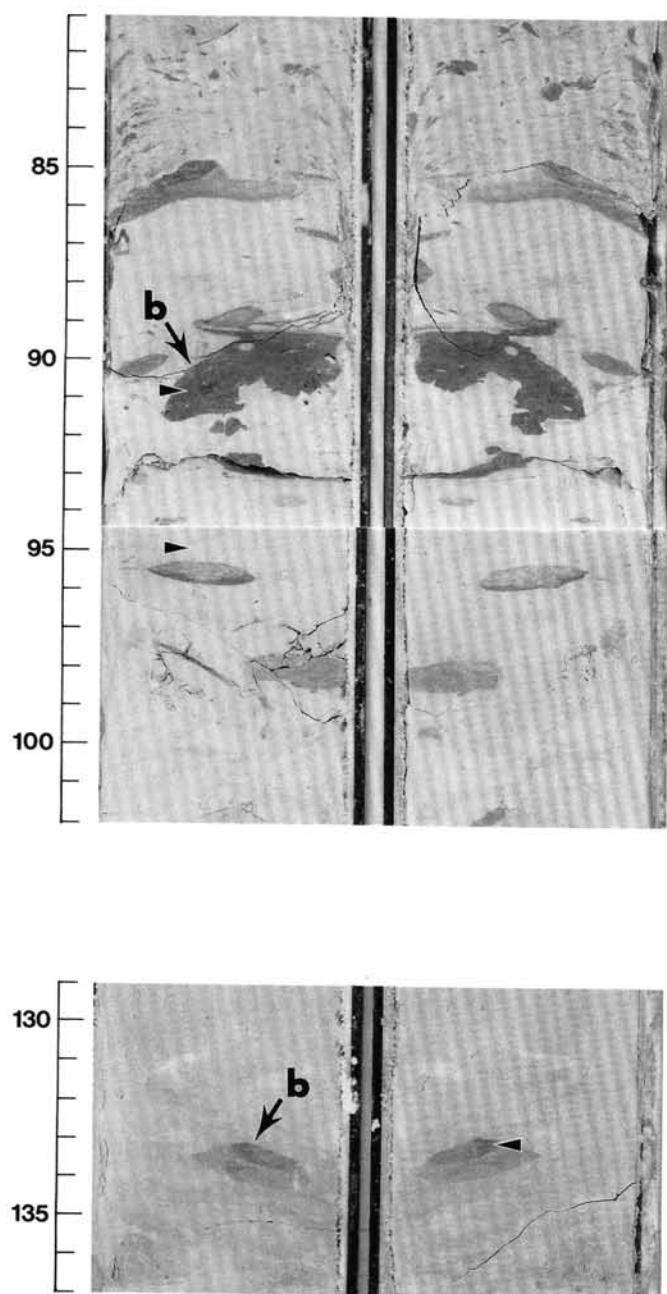


Figure 8. Top. Burrow (arrow "b") 47 cm below the K/T boundary in Core 113-690C-15X, Section 4 at 90-91 cm (248.31 mbsf) contains 24.6% Survivor and 0.4% Tertiary nannofossils. Bottom. Burrow (arrow "b") 92 cm below the boundary at 133 cm (247.73 mbsf) contains 17% Tertiary nannofossils (see Fig. 4). The Tertiary nannofossils in this sample were transported a minimum of 1.3 m. Small arrows show precise location of samples. Working half = left, archive half = right.

SYSTEMATIC PALEONTOLOGY

Genus *HORNIBROOKINA* Edwards (1973a)
Hornibrookina edwardsii Perch-Nielsen (1977)
 (Pl. 2, Fig. 1)

Description. Elliptical placoliths with an outer rim consisting of clockwise imbricated laths similar to *Biscutum*. The inner cycle of nearly vertical elongate rectangular elements form a wall around the central area. A distinct row of elements resembling teeth surround the central area and separate the inner cycle or wall and the outer rim. The "teeth" are

vertical to slightly imbricated in the clockwise direction. The central area consists of non-overlapping, radial elements which support a narrow central structure.

In phase contrast and cross-polarized light, the outer rim, the inner cycle of elements, and the central area are in optical continuity. In cross-polarized light, the outer rim displays a very low order of birefringence as does the central area. In addition, the central area are bisected by a dark extinction line parallel to the long axis. The "teeth," which outline the central area, are distinctly bright in phase contrast and cross-polarized light. The outer rim, inner cycle, and central area are dark in phase contrast light.

Remarks. Specimens of this species are quite overgrown in all samples examined. The elements of the central area, as shown in the holotype (Perch-Nielsen, 1977; pl. 46, fig. 6), are completely obscured. The knobs or "teeth" are probably also accentuated by overgrowth.

In the SEM, and especially with the light microscope, *H. edwardsii* and *H. teuriensis* can appear quite similar and are difficult to distinguish. Overall size and size of the central area are used here in an attempt to differentiate the two forms. However, since no attempt was made to biometrically analyze differences in gross morphology of the two species, a minimum of confidence is placed on just where, in the samples analyzed, *H. edwardsii* becomes extinct and *H. teuriensis* first occurs. There is more than likely a gradual transition between the two with a slight overlap in ranges.

In addition, the overall appearance of smaller forms of *H. edwardsii* tends to support the suggestion of Perch-Nielsen (1977) that this genus originally evolved from *Biscutum*. This is best illustrated in Plate 2, Figures 1h and 1i.

The relationship between the first occurrences of *H. teuriensis* and *H. edwardsii* varies at different localities. As stated above, we note the first occurrence of *H. edwardsii* below that of *H. teuriensis* as does Perch-Nielsen (1977). However, she observes its first occurrence in Zone CP2 whereas we note the event in the upper part of Subzone CP1a. Angelozzi (1988), on the other hand, reports the occurrence of *H. teuriensis* in Zone NP3 from a mid-latitude, land-based section from Argentina and suggested that it preceded *H. edwardsii* in the section. From the Brazos River section in Texas, Jiang and Gartner (1986) did not observe *H. edwardsii* and report very rare *H. teuriensis* at the K/T boundary, but no pictures of this taxon were provided. Thus, at present, the ultrastructure of the species we illustrate cannot be compared with those specimens reported by Jiang and Gartner or Angelozzi. Although our data support the sequence of *H. edwardsii* preceding *H. teuriensis*, the observations of these other authors might suggest that the opposite is the case. It is clear that detailed morphologic study is necessary to resolve this problem along with additional stratigraphic data from other sections.

Hornibrookina edwardsii was reported as occurring only rarely in the South Atlantic sites of DSDP Leg 39. On Maud Rise, the species apparently enjoyed considerable success, especially when it first occurred. The anomalous abundance of this species just above the K/T boundary here is interpreted at this stage as being a highly provincial phenomena. Recent high-latitude drilling in the Southern Indian Ocean may extend this provincial event beyond the limits of the Weddell Sea.

Genus *PREDISCOSPHAERA* Vekshina, 1959

Prediscosphaera stoveri

(Pl. 5, Fig. 9)

Deflandrius stoveri Perch-Nielsen, 1968, p. 66, pl. 16, figs. 11-13.

Prediscosphaera stoveri Shafik and Stradner, 1971, p. 126, pl. 22, fig. 1.

Remarks. The identification of this species in samples taken from just below the K/T boundary was difficult due to poor preservation. However, preservation was improved further down in the section and complete specimens were observed with the SEM. The ultrastructure of these forms is comparable to electron micrographs of Perch-Nielsen (1968, pl. 16, figs. 11-13). Questions have arisen as to the precedence of *P. quadripunctata* over *P. stoveri* and whether or not they are synonymous. According to Gartner (pers. comm., 1989), *P. quadripunctata* does take precedence if the two are the same form. However, after observing the samples first hand, Gartner expressed to us the possibility that the *P. stoveri* in the Maud Rise sediments might be an ecophenotypic variation.

Regardless of the systematics, the presence of acmes of small *Prediscosphaera* at the top of the Maestrichtian in the Brazos River, Texas, and

El Kef, Tunisia, and on Maud Rise in the Weddell Sea has been shown to be stratigraphically useful (Jiang and Gartner, 1986; Pospichal and Wise, this volume, chapter 30). In addition, the paleoceanographic signal represented by these apparently widespread blooms of *Prediscosphaera* is no less important. Apparently, the forms prefer cooler water as demonstrated by their extremely high abundance in the Maud Rise section. Stott and Kennett (this volume, chapter 47) report a positive shift in $\delta^{18}\text{O}$ values in the uppermost Maestrichtian of Maud Rise indicating a latest Maestrichtian cooling event. Additional quantitative study down-section in Hole 690C may show some correlation between the increase in abundance of the small forms of *Prediscosphaera* with the stable isotope record. If such a relationship can be positively proven, then the distribution of the acmes of these forms may prove to be a useful paleoceanographic tool.

ACKNOWLEDGMENTS

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APPENDIX

Calcareous Nannofossils Considered in this Report
(In alphabetical order of generic epithets)

Cenozoic

Biantholithus sparsus Bramlette and Martini, 1964
Biscutum castrorum Black, 1959
Biscutum sp.
C. danicus (Brotzen) Hay and Mohler, 1967
Coccolithus cavus (Hay and Mohler) Perch-Nielsen, 1969
Cruciplacolithus asymmetricus van Heck and Prins, 1987
C. edwardsii Romein, 1979
C. intermedius van Heck and Prins, 1987
C. primus Perch-Nielsen, 1977
C. tenuis (Stradner) Hay and Mohler, 1967
Cyclagelosphaera reinhardtii (Perch-Nielsen) Romein, 1977
Hornibrookina edwardsii Perch-Nielsen, 1977
H. teuriensis Edwards, 1973a
Lapideacassis sp.
Markalius inversus (Deflandre) Bramlette and Martini, 1964
Neocrepidolithus cruciatus (Perch-Nielsen) Perch-Nielsen, 1981a
Neocrepidolithus sp.
Prinsius dimorphosus (Perch-Nielsen) Perch-Nielsen, 1977
P. martinii (Perch-Nielsen) Haq, 1971
P. sp. cf. P. tenuiculum (Okada and Thierstein) Perch-Nielsen, 1984
Thoracosphaera crassa Van Heck and Prins, 1987
T. operculata Bramlette and Martini, 1964
Thoracosphaera sp.
Zygodiscus sigmoides Bramlette and Sullivan, 1961

Mesozoic

Acuturris scotus (Risatti) Wind and Wise, 1977
Ahmuellerella octoradiata (Gorka) Reinhardt, 1970
Arkhangelskiella cymbiformis Vekshina, 1959
A. specillata Vekshina, 1959
B. castrorum Black in Black and Barnes, 1959
B. constans (Gorka) Black, 1959
Chiastozygus sp.
Cretarhabdus conicus Bramlette and Martini, 1964
Cribrosphaerella ehrenbergi (Arkhangelsky) Deflandre, 1952
C. daniae Perch-Nielsen, 1973
Eiffellithus turriseiffeli (Deflandre and Fert) Reinhardt, 1965
Gartnerago sp.
Kamptnerius magnificus Deflandre, 1959
Lapideacassis sp.
Markalius inversus (Deflandre) Bramlette and Martini, 1964
Micula decussata Vekshina, 1959
Nephrolithus frequens frequens Gorka, 1957
N. frequens (Gorka) *miniporus* (Reinhardt and Gorka) emend. Pospi-
 chal and Wise, this volume, chapter 30
Prediscosphaera cretacea (Arkhangelsky) Gartner, 1968
P. spinosa (Bramlette and Martini) Gartner, 1968
P. stoveri (Perch-Nielsen) Shafik and Stradner, 1971
Thoracosphaera sp.
Zygodiscus sigmoides Bramlette and Sullivan, 1961
Z. spiralis Bramlette and Martini, 1964

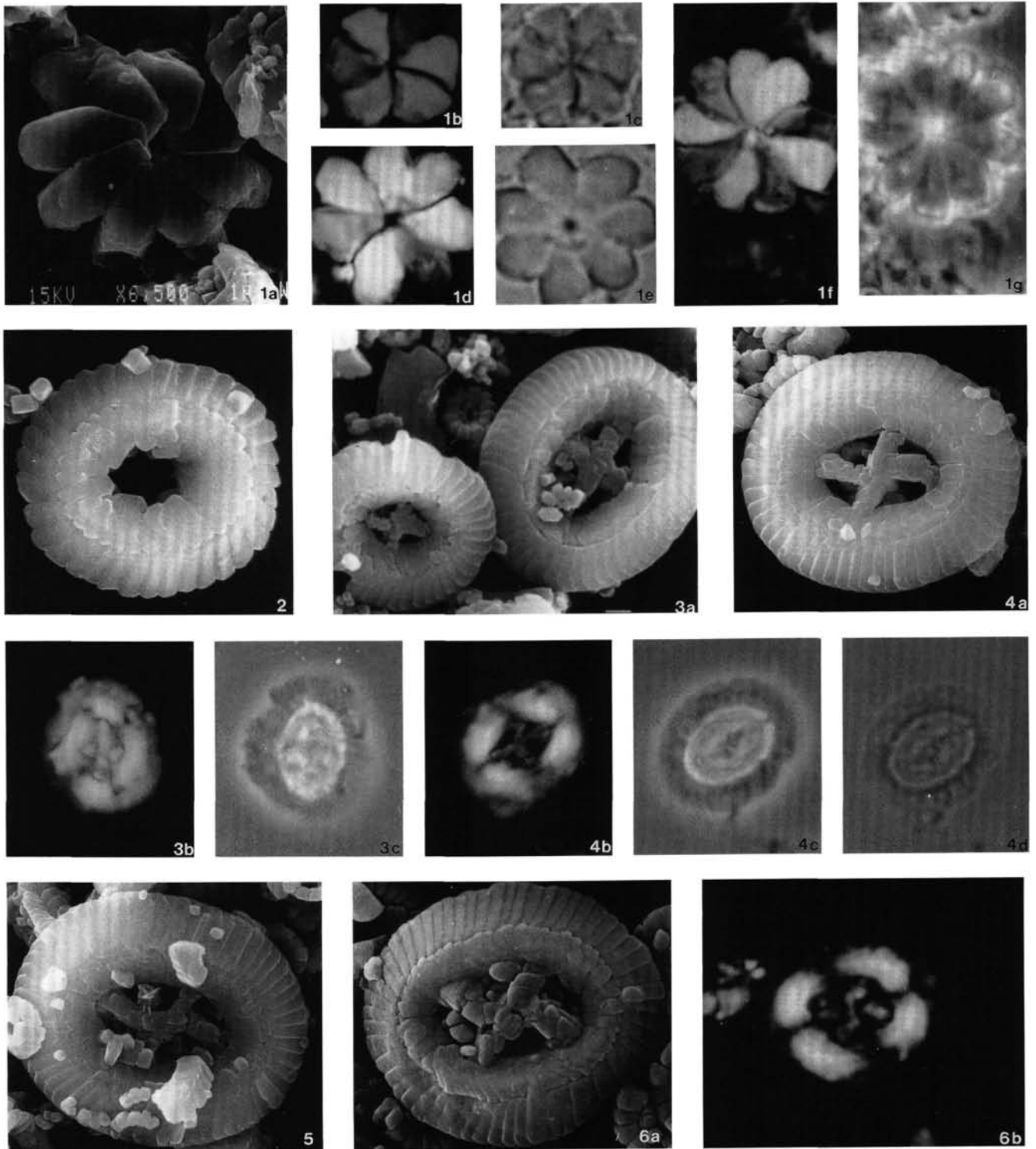


Plate 1. Note on the plates: All micrographs of coccoliths are of the distal view except where noted otherwise. Pol, Ph, Tr, and SEM denote polarized, phase contrast, transmitted, and scanning electron micrographs, respectively. Where more than one illustration is provided of a specimen, the sample and magnification designation are not repeated in the caption. (Tertiary assemblage) 1. *Biantholithus sparsus* (a) SEM, $\times 4100$, Sample 113-690C-15X-4, 49–50 cm; (b) Pol, $\times 2800$, Sample 113-690C-15X-4, 1–2 cm; (c) Tr; (d) Pol, $\times 2800$, Sample 113-690C-15X-4, 43–44 cm; (e) Tr; (f) Pol, $\times 2800$, Sample 113-690C-15X-4, 43–44 cm; (g) Ph. 2. *Coccolithus cavus* SEM, $\times 7800$, Sample 113-689B-25X-2, 6–7 cm. 3. *Cruciplacolithus tenuis* (a) SEM, $\times 4400$, Sample 113-690C-15X-2, 8–9 cm; (b) Pol, $\times 2600$, Sample 113-690C-15X-3, 7–8 cm; (c) Ph. 4. *Cruciplacolithus* sp. cf. *C. asymmetricus* (a) SEM, $\times 4700$, Sample 113-690C-15X-3, 7–8 cm; (b) Pol, $\times 2600$, Sample 113-690C-15X-3, 7–8 cm; (c) Ph; (d) Tr. 5. *Cruciplacolithus edwardsii* SEM, $\times 4400$, Sample 113-689B-25X-2, 6–7 cm. 6. *Chiasmolithus danicus* (a) SEM, $\times 5500$, Sample 113-690C-14X-3, 28–30 cm; (b) Pol, $\times 3100$, Sample 113-690C-13X-5, 129–131 cm.

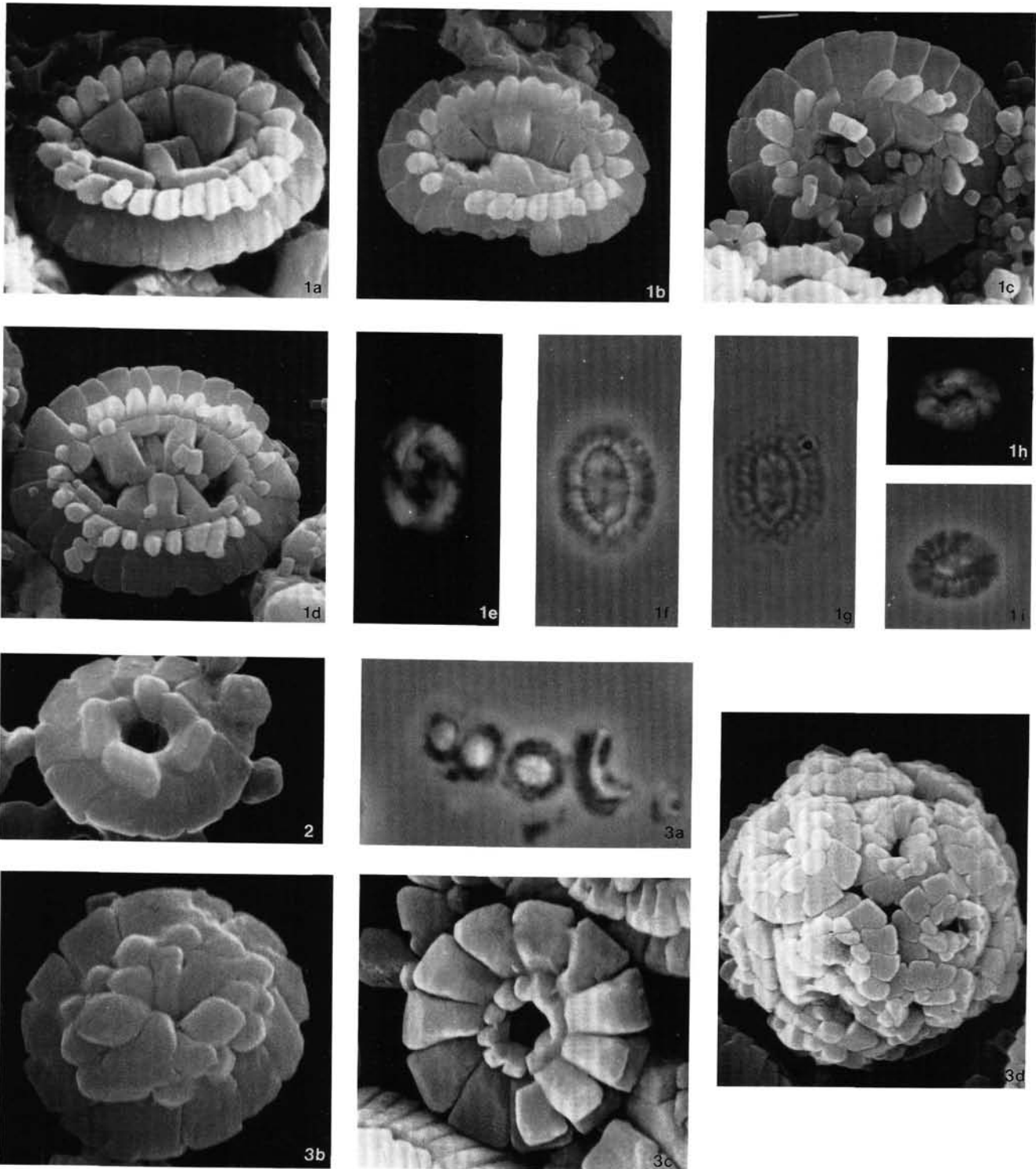


Plate 2. (Tertiary assemblage) 1. *Hornibrookina edwardsii* (a) SEM, $\times 6800$, Sample 113-690C-15X-4, 1–2 cm; (b) SEM, $\times 5800$, Sample 113-690C-15X-3, 151–152 cm; (c) SEM, $\times 6500$, Sample 113-690C-15X-1, 2–3 cm; (d) SEM, $\times 5900$, Sample 113-690C-15X-2, 8–9 cm; (e) Pol, $\times 2600$, Sample 113-690C-15X-3, 151–152 cm; (f) Ph; (g) Tr; (h) Pol, $\times 2200$, Sample 113-690C-15X-3, 151–152 cm; (i) Ph. 2. *Prinsius* sp. cf. *P. tenuiculum* SEM, $\times 14,600$, Sample 113-689B-25X-2, 6–7 cm. 3. *Prinsius dimorphosus* (a) Ph, $\times 3100$, Sample 113-690C-13X-5, 129–131 cm; (b) SEM, $\times 16,000$, Sample 113-690C-13X-5, 129–131 cm; (c) SEM, $\times 13,100$, proximal view, Sample 113-690C-14X-3, 28–30 cm; (d) SEM, $\times 7300$, coccosphere, Sample 113-690C-13X-1, 28–30 cm.

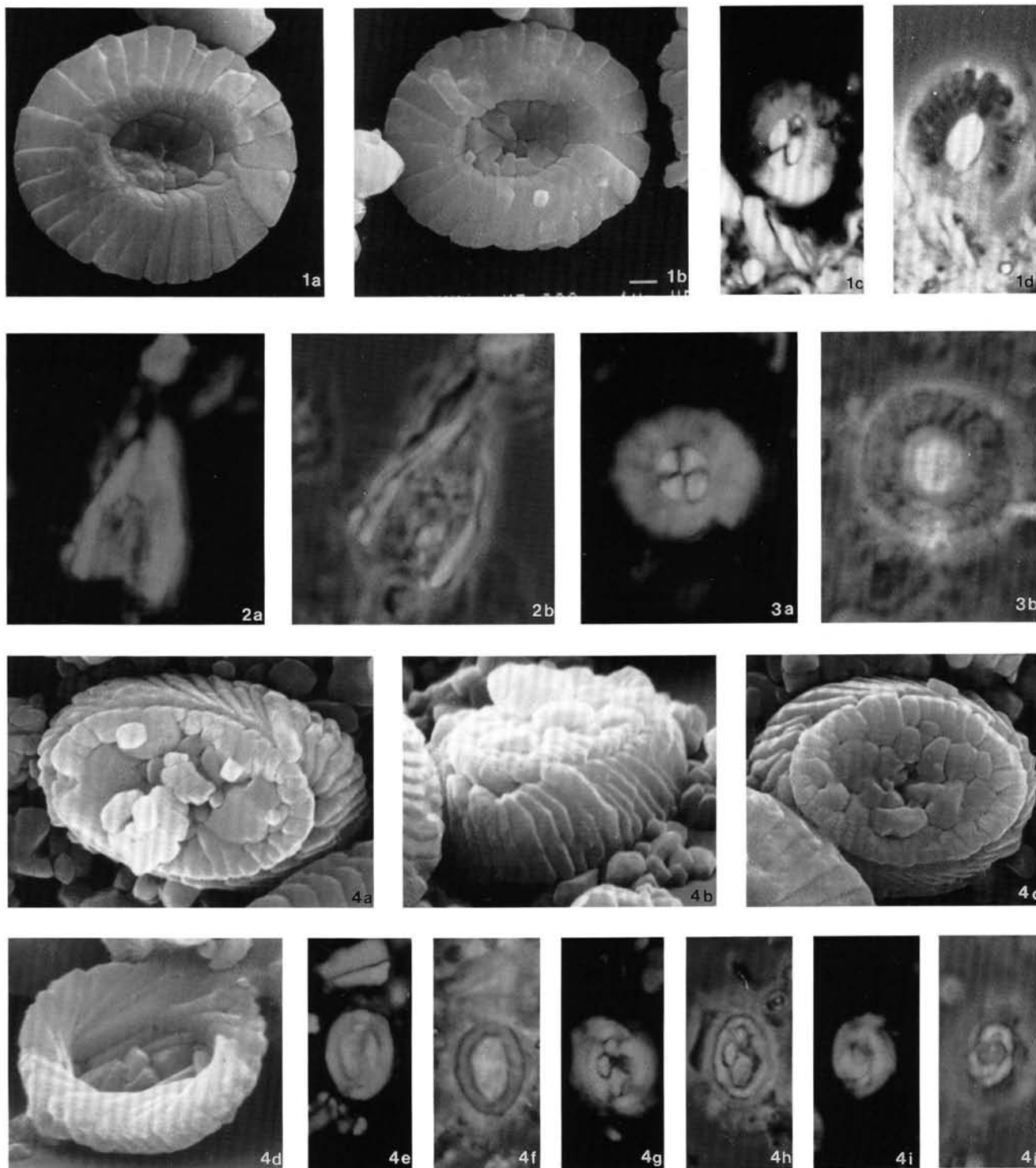


Plate 3. (Survivor assemblage) 1. *Biscutum castrorum* (a) SEM, $\times 5000$, Sample 113-690C-15X-3, 151–152 cm; (b) SEM, $\times 4900$, Sample 113-690C-15X-3, 151–152 cm; (c) Pol, $\times 2600$, Sample 113-690C-15X-4, 43–44 cm; (d) Ph. 2. *Lapideacassis* sp. (a) Pol, $\times 3500$, Sample 113-690C-15X-4, 45.3 cm; (b) Ph. 3. *Markalius inversus* (a) Pol, $\times 2200$, Sample 113-690C-15X-4, 43.8 cm; (b) Ph. 4. *Neocrepidolithus cruciatus* (a) SEM, $\times 9500$, proximal view, Sample 113-690C-15X-3, 7–8 cm; (b) side view of specimen (a); (c) SEM, $\times 9500$, proximal view, Sample 113-690C-15X-3, 7–8 cm; (d) *Neocrepidolithus* sp. SEM, $\times 7900$, Sample 113-690C-15X-4, 1–2 cm; (e) *N.* sp., Pol, $\times 2900$, Sample 113-690C-15X-4, 43.8 cm; (f) Ph; (g) *N. cruciatus*, Pol, $\times 2200$, Sample 113-690C-15X-4, 44.7 cm; (h) Ph; (i) Pol, $\times 2500$, Sample 113-690C-15X-4, 43.8 cm; (j) Ph.

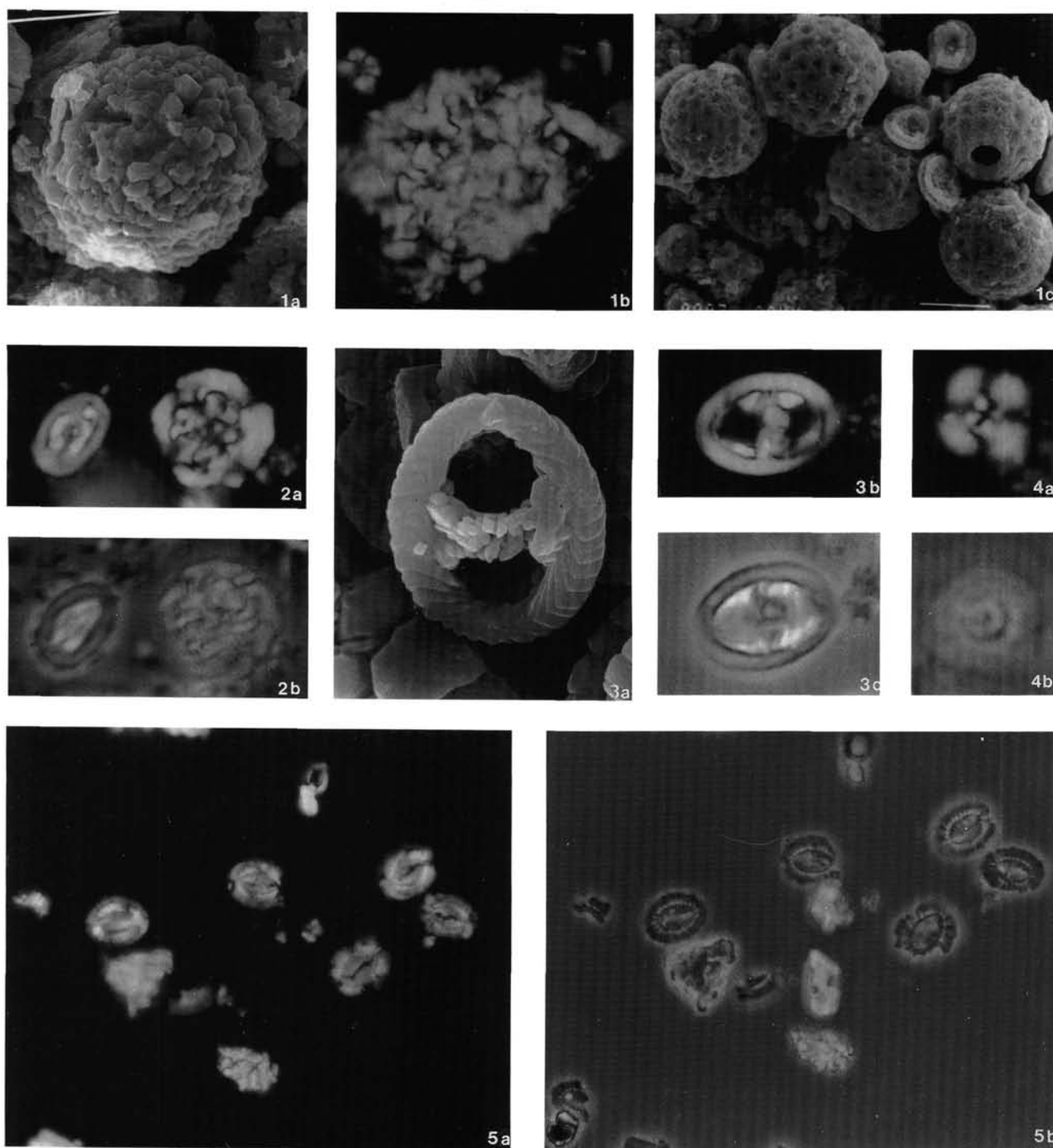


Plate 4. (Survivor assemblage) 1. *Thoracosphaera* sp. (a) SEM, $\times 2000$, Sample 113-690C-15X-3, 151–152 cm; (b) Pol, $\times 2900$, Sample 113-690C-15X-4, 50.8 cm; (c) SEM, $\times 1100$, Sample 113-690C-14X-3, 28–30 cm. 2. *Neocrepidolithus* sp. and *Thoracosphaera* operculum (a) Pol, $\times 2300$, Sample 113-690C-15X-4, 41.4 cm; (b) Ph. 3. *Zygodiscus sigmoides* (a) SEM, $\times 6000$, Sample 113-690C-15X-3, 151–152 cm; (b) Pol, $\times 2500$, Sample 113-690C-15X-3, 151–152 cm; (c) Ph. 4. *Cyclagelosphaera reinhardtii* (a) Pol, $\times 3750$, Sample 113-690C-13X-3, 129–131 cm; (b) Ph. 5. *Hornibrookina* group photo (a) Pol, $\times 1400$, Sample 113-690C-15X-3, 151–152 cm; (b) Ph.

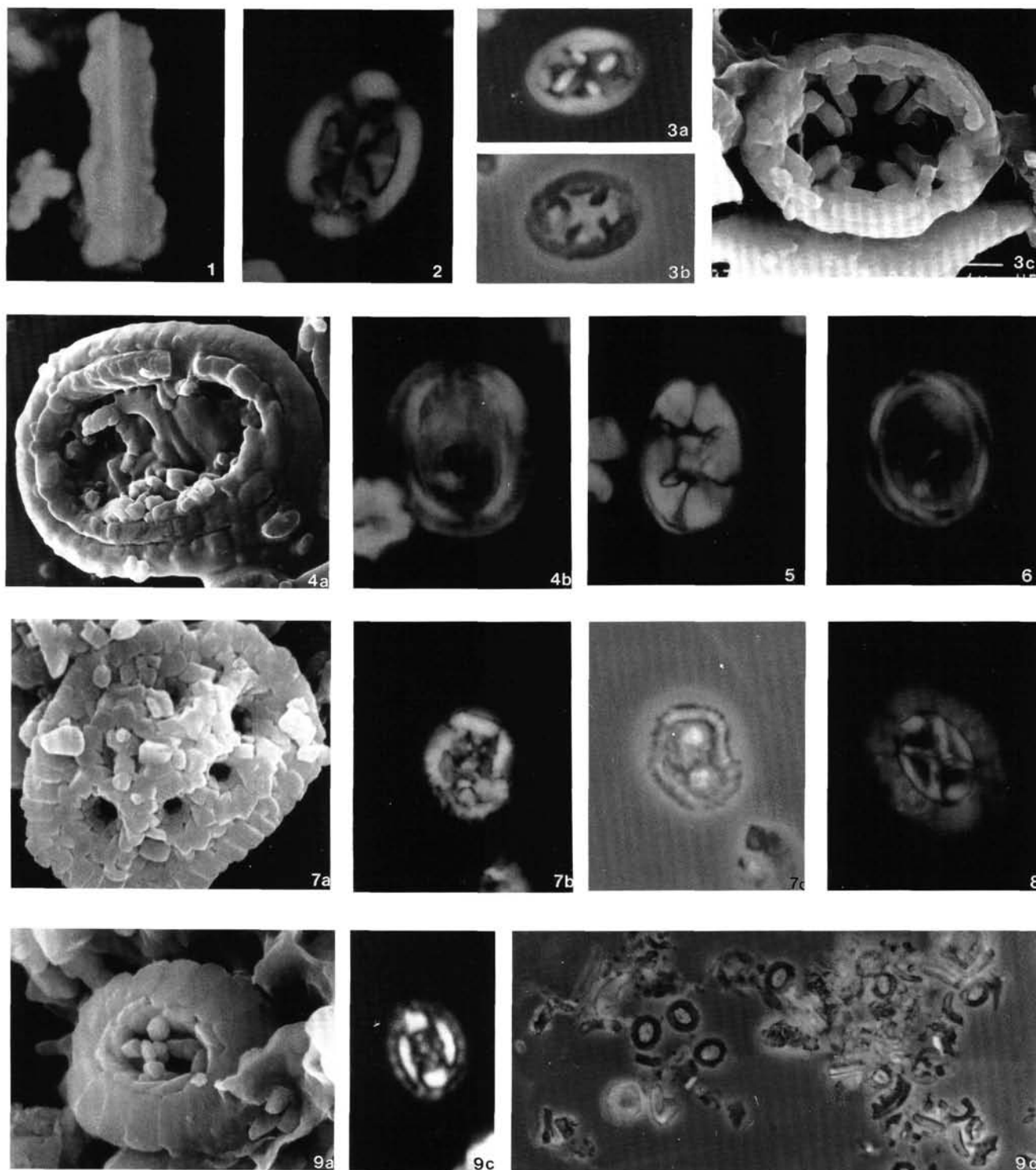


Plate 5. (Cretaceous assemblage) 1. *Acuturris scotus* Pol, $\times 2600$, Sample 113-690C-15X-3, 151-152 cm. 2. *Arkhangelskiella cymbiformis* Pol, $\times 2100$, Sample 113-690C-15X-3, 151-152 cm. 3. *Chiastozygus* sp. (a) Pol, $\times 3100$, proximal view, Sample 113-690C-15X-3, 151-152 cm; (b) Ph; (c) SEM, $\times 6700$, Sample 113-690C-15X-4, 49-50 cm. 4. *Cribrosphaerella daniae* (a) SEM, $\times 4100$, Sample 113-690C-15X-4, 72-73 cm; (b) Pol, $\times 2300$, Sample 113-690C-15X-3, 151-152 cm. 5. *Eiffellithus turriseiffeli* Pol, $\times 2100$, Sample 113-690C-15X-3, 151-152 cm. 6. *Kamptnerius magnificus* Pol, $\times 1900$, Sample 113-690C-15X-3, 151-152 cm. 7. *Nephrolithus frequens frequens* (a) SEM, $\times 5700$, Sample 113-690C-15X-4, 66-67 cm; (b) *N. f. miniporus* Pol, $\times 2250$, Sample 113-690C-15X-4, 151-152 cm; (c) Ph. 8. *Prediscosphaera cretacea* Pol, $\times 2300$, Sample 113-690C-15X-3, 151-152 cm. 9. *Prediscosphaera stoveri* (a) SEM, $\times 8200$, Sample 113-690C-15X-4, 49-50 cm; (b) Pol, $\times 3500$, Sample 113-690C-19X-4, 130-132 cm; (c) Ph, $\times 1100$, group photo, Sample 113-690C-15X-4, 41.8 cm.