

25. JURASSIC AND LOWER CRETACEOUS CALCAREOUS NANNOFOSSILS IN THE WESTERN NORTH ATLANTIC (SITE 534): BIOSTRATIGRAPHY, PRESERVATION, AND SOME OBSERVATIONS ON BIOGEOGRAPHY AND PALEOCEANOGRAPHY¹

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ABSTRACT

Calcareous nannofossil assemblages recovered from a long, continuous section ranging in age from Callovian to middle Albian have been described from Deep Sea Drilling Project Site 534 in the Blake-Bahama Basin in the western North Atlantic. Coccolith preservation, combined with backtracking of Site 534, indicates that the CCD (calcite compensation depth) deepened from about 2.5 km in the middle Callovian to 3.6 km in the Tithonian; the CCD remained deep (around 4 km) during the Early Cretaceous and shallowed abruptly in the Aptian to a depth of 3 km. A revised zonation for the Jurassic is used to subdivide the middle Callovian to Tithonian interval into five zones and subzones. Previously published zones for the Lower Cretaceous are used, but the ranges of important marker species are more fully documented. Lower Cretaceous coccolith and dinoflagellate zones are correlated. The relationship of calcareous nannofossil zones with magnetostratigraphic units and stages is shown. Differences in Jurassic oceanic and epicontinental coccolith assemblages are attributed mainly to preservational differences and minor paleoecological effects. Two new species, *Cruciplacolithus furtivus* n. sp. and *Polypodorhabdus harisonii* Medd n. sp., are described, and several new combinations are introduced.

INTRODUCTION

Calcareous nannofossils are one of the most important groups used for the biostratigraphy of Lower Cretaceous and Jurassic oceanic sections. A long, continuously cored section from the lower Callovian to the Upper Cretaceous at Site 534 is useful for the establishment of a new Jurassic nannofossil zonation (Roth et al., this volume) and for the correlation of calcareous nannofossil and dinoflagellate zonations for the Lower and middle Cretaceous. The distribution and variable preservation of Lower Cretaceous to Middle Jurassic nannofossils in the North Atlantic and the surrounding epicontinental areas provide some limitations on paleoceanographic interpretations of the Atlantic.

Site 534 is located near the center of the Blake-Bahama Basin at 28°26.6'N, 75°22.9'W, at a water depth of 4976 m (Fig. 1), and lies only 22 km to the northeast of Site 391 (Benson and Sheridan et al., 1978). Hole 534A was drilled to a total depth of 1666.5 m and was terminated after penetrating about 1639 m of sedimentary rocks and about 27 m of tholeiitic basalt. Five Mesozoic lithostratigraphic units were identified below about 764 m of Quaternary to middle Eocene rocks; they comprise in descending order: the Plantagenet Formation, the Hatteras Formation, the Blake-Bahama Formation, the Cat Gap Formation, and an unnamed lowermost lithostratigraphic unit (Fig. 2). The Plantagenet Formation (Cores 534A-22 to 26) consists of variegated zeolitic claystones and chert and is middle Maestrichtian (based on planktonic foraminifers). This formation is almost completely barren of coccoliths, with the exception of a sample in Core 25 that contains rare *Arkhan-*

gelskiella cymbiformis and *Micula staurophora*, together with some Tertiary forms that are all probably down-hole contaminants. The underlying Hatteras Formation (Cores 534A-27 to 48) is largely composed of gray and black carbonaceous claystones that are mostly turbidites. Three subunits have been distinguished. Black, dark gray, and greenish gray carbonaceous claystones and silty claystones with calciturbidite layers occur in the uppermost unit (Cores 534A-27 to 39). The calciturbidite units contain abundant lath-shaped carbonate particles and sparse coccoliths. The yellowish red, dark yellowish brown, to greenish gray silty claystones of the second subunit (Cores 534A-40 to 42) lack coccoliths. Carbonaceous claystones of greenish black to olive black color overlie gray calcareous claystones at the bottom of the third subunit; this lowest subunit of the Hatteras Formation grades into the underlying Blake-Bahama Formation and contains common coccoliths. The age of the Hatteras Formation is Cenomanian to late Barremian. The Blake-Bahama Formation (Cores 534A-47 to 92) consists of nannofossil-radiolarian micritic limestones, nannofossil chalks and marls, claystones, siltstones, and minor siltstones and can be subdivided into four subunits. The uppermost subunit (Cores 534A-47 to 64) contains calcareous claystones and nannofossil claystones with intercalations of calcareous siltstones and sandstones that are turbidites derived from a shallow source area. Finely laminated calcareous nannoplankton marls and chalks with interstratified bioturbated chalks and minor siltstones and sandstones dominate in the next lower subunit (Cores 534A-65 to 75). This subunit is underlain by a subunit consisting of laminated nannofossil chalks, bioturbated chalks, claystones, and siltstones (Cores 534A-75 to 84), and finally by well-cemented limestones with minor claystone partings (Cores 534A-85 to 91). The Blake-Bahama Forma-

¹ Sheridan, R. E., Gradstein, F. M., et al., *Init. Repts. DSDP*, 76: Washington (U.S. Govt. Printing Office).

Hole 534A

Age	Lithology	Description	Sedimentary unit	Formation	Core number	Sub-bottom depth (m)	Coccolith preservation		Coccolith diversity
							Etching	Overgrowth	
m. Miocene		Intraclast chalk, green mudstone	a	Great Abaco Member		545			
early Miocene			b						
			c						
			d						
late Eocene		Zeolitic-siliceous mudstone; sandstone	3	Bermuda Rise	18	696			
e. Maest.		Porcellanite, var. claystone	a	Plantagenet	22	724			
Cenom.		Black green carbonaceous claystone	4	Hatteras		764	B	B	0
Albian	B						B	0	
	2						3	32	
	B						B	0	
Aptian	2	3	30						
	B	B	0						
Barremian	1	1	46						
	2	2	24						
Hauterivian	2	2	33						
	2	2	28						
Valanginian	1	2	35						
	2	2	26						
Berriasian	2	3	24						
	1	2	38						
Tithonian	2	2	25						
	1	1	32						
Kimm.	2	3	28						
	2	3	18						
Oxfordian	2	2	30						
	2	2	26						
Callovian	2	2	25						
	2	2	24						
M-28		Basalt	8			1342	2	2	22
							2	2	18
						950	2	3	21
							2	3	14
						91	2	3	11
							2	3	7
						92	2	3	12
							2	3	21
						1342	2	2	20
							2	2	24
						1496	2	1	26
							2	2	23
						110	3	2	16
							3	3	14
						111	3	3	14
							3	2	10
						1496	2	2	17
							2	2	11
						1635	3	1	12
							3	3	6
						1666	3	2	5
							3	2	20
						1635	2	2	17
							3	2	14
						1666	3	3	13

Figure 2. Lithostratigraphy, nannofossil preservation and diversity at Site 534. (Nannofossil data are representative of complete data shown in Figs. 4 and 5. B indicates barren; for etching and overgrowth, 1 = slightly, 2 = moderately, and 3 = strongly.)

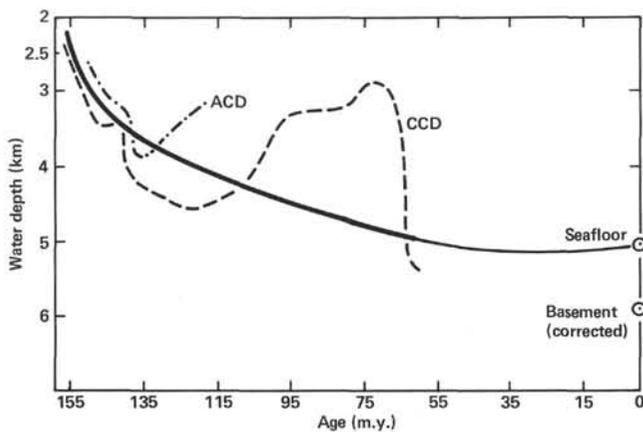


Figure 3. Lithospheric subsidence curve (solid line), calcite compensation depth (CCD), and aragonite compensation depth (ACD) during the Mesozoic for Site 534. (Sediment loading correction according to Douarane and Parsons [1982]; lithospheric subsidence curve based on Parsons and Sclater [1977].)

the Tithonian. This situation is best explained by a lowering of the CCD from about 2.5 km in the middle Callovian to below 4 km in the late Tithonian. This general trend of deepening of the CCD was interrupted in the Kimmeridgian when it shallowed somewhat, as shown by poor nanofossil preservation. The CCD was deeper than 4 km during the Early Cretaceous but gradually shallowed to a depth of around 2.5 to 3 km during the middle Cretaceous and rose to 2 km during the Late Cretaceous (Roth and Bowdler, 1981). Therefore, Site 534 was close to the CCD in the middle Aptian and below the CCD in the late Aptian to Cenomanian. The lack of preserved sedimentary rocks of the Turonian to the lower Maestrichtian at this site precludes any speculations on the exact position of the CCD during that time period. The presence of rare planktonic foraminifers in middle Maestrichtian cores is indicative of the deepening of the CCD observed elsewhere in the North Atlantic (Thierstein, 1979; Roth and Bowdler, 1981).

METHODS

Over 400 samples were investigated from the Mesozoic part of Hole 534A with the light microscope. Standard methods of sample preparation for light microscopy were used. A small amount of sediment was dispersed in distilled water and the suspension spread out on a cover glass and dried on a hot plate. An artificial mounting medium (Piccolite) was used to attach the cover glass to a microscope slide and thus enclose the sedimentary particles. A compound microscope was used for the study of all coccolith preparations. The light microscopy of the slides of Jurassic samples proved very time consuming. Several hours were spent scanning each slide to look for rare but important species. Overall abundances of coccoliths in slides were estimated by comparing the relative abundance of identifiable coccoliths with other sedimentary components. Coccoliths were called abundant (A) if their relative abundance exceeded 75% of all components, common (C) if there were more than 50% coccoliths, few (F) for more than 25% coccoliths, and rare (R) for a relative abundance of identifiable coccoliths of less than 25%. A sample was considered virtually barren (VB) if only a few coccoliths turned up in a traverse (22 mm) of a slide and barren (B) if coccoliths were absent. Rough estimates of preservation relied on the degree of etching and overgrowth. Preservation was termed good (G) for pristine samples to samples with slightly etched and/or overgrown coccoliths, moderate (M) for samples with moderate etching and/or overgrowth, and poor (P) for strongly etched and/or overgrown coccolith assemblages with reduced diversity. Estimates of the

relative abundance of various calcareous nanofossil species are semiquantitative. If at a magnification of $\times 1500$ in the light microscope more than 10^2 specimens of a species were observed, the species was termed abundant (A); if 1 to 10 specimens appeared in a field of view, it was considered common (C); if one specimen was observed in at least 10 fields of view, this species was listed as few (F); for species with no more than one specimen observed in over 10 fields of view, the connotation rare (R) was used. Photomicrographs were taken on a Zeiss photomicroscope using ordinary transmitted light, cross-polarized light, and phase contrast. Many Jurassic nanofossils are small and thus difficult to photograph. All micrographs were photographically enlarged to a magnification of about $\times 3500$.

PRESERVATION OF CALCAREOUS NANNOFOSSILS

There are three measures of preservation of calcareous nanofossils, two of which are used here because they are semiquantitative and do not require census data. The first one is the etching and overgrowth scale discussed below. The second measure is species diversity (i.e., total number of species present). Species diversity is quite sensitive to alteration of sediment assemblages by dissolution and diagenetic recrystallization, but it cannot be used to distinguish between the two processes. Thus the etching-overgrowth scale does provide additional information that species diversities do not furnish. The latter is also affected by surface water conditions that change the diversity of the original biocoenoses and by evolutionary events, but in the Mesozoic assemblages at Site 534 dissolution and diagenetic processes are the dominant factors that determine the species diversity of the nanofossil assemblages. Species diversities and the degree of etching and overgrowth are plotted on the distribution charts in Figures 4 and 5 (Fig. 5 is in the back pocket).

The semiquantitative preservation scale first proposed by Roth and Thierstein (1972) and modified by Roth (1973, 1978) was used, and the degree of etching and overgrowth is displayed on the distribution charts (Figs. 4 and 5). The categories of preservation are:

- X excellent preservation (no etching or overgrowth observed).

Etching

- E-1 slight etching (many coccoliths show serrate outlines; delicate structures have been somewhat affected by dissolution but are generally preserved).
- E-2 moderate etching (the more delicate species have been preferentially dissolved; delicate central structures have been destroyed in many specimens; irregular outlines of shields are common.)
- E-3 strong dissolution (samples contain mainly dissolution-resistant species, more delicate forms are very rare; nanofossil fragments are abundant).

Overgrowth

- O-1 slight overgrowth (irregular secondary growth of crystallites and slight thickening of central area structures).
- O-2 moderate overgrowth (delicate central structures are frequently overgrown to a degree that makes

them difficult to recognize; irregular growth of crystallites is common).

O-3 strong overgrowth (delicate species are often so much covered with secondary calcite that identification is impossible).

Frequently we observed slight to moderate etching and slight to moderate overgrowth in the same sample, which is indicative of secondary overgrowth on larger nannofossils at the expense of the more delicate ones.

Preservation of Jurassic Calcareous Nannofossils

The *Watznaurera* group, which consists of rather robust placoliths, is dominant throughout the Jurassic section at Site 534. In the upper Kimmeridgian to Tithonian interval *Conusphaera*, *Polycostella*, and small nannoconids (below 8 μm) also contribute to the robust proportion of the coccolith assemblages. Delicate genera such as *Corolithion*, *Stradnerlithus*, *Diadorhombus*, *Stephanolithion*, and even *Zygodiscus* are distinctly underrepresented in these oceanic assemblages compared to assemblages from epicontinental sea deposits of England and France (Noël, 1973; Barnard and Hay, 1974; Medd, 1982; Hamilton, 1982). This underrepresentation results in a less refined zonation at this site than the ones proposed by Barnard and Hay (1974) and Medd (1982).

Preservation of calcareous nannofossils will now be discussed in ascending order from the oldest Jurassic sediments to the youngest ones.

The sample from a mudstone intercalated in the basalt showed highly recrystallized and thus barely recognizable placoliths. The dusky brown mudstones in Core 127, especially in its lower part, contain highly dissolved assemblages with some secondary overgrowth. Preservation improves in the upper part of Core 127, and moderately etched and overgrown assemblages are found in the upper part of Core 127, in most of Core 126, and in the lower part of Core 125. The assemblages in the greenish black nannofossil claystones of the middle part of Core 125 are highly etched and of lower diversity than samples above and below. The assemblages in the uppermost part of Core 125, in Core 124, and the lower part of Core 123 are moderately well preserved and show signs of slight to moderate etching and overgrowth. The upper part of Core 123 and all of Cores 122, 121, and 120 contain poor assemblages of low diversity that consist mostly of placoliths belonging to the genus *Watznaurera*. It is possible that some of the upper ranges of the more delicate species, such as *Stephanolithion hexum* and *Ansulosphaera helvetica*, have been artificially truncated in this highly dissolved interval. Coccoliths are better preserved in Cores 117 to 119 and show only moderate dissolution and overgrowths. Diversity is also greater than in the cores below. Highly dissolved and slight to moderately overgrown coccoliths occur in the dark variegated claystones of Cores 116, 115, and 114. Diversity is slightly reduced but remains higher than in the interval including Cores 120 to 123; thus more of the original assemblage has been preserved. Cores 113 and 112 contain moderately etched and overgrown nannofossil assemblages of moderately high diversity. The gray limestones and dark claystones of Cores 111 through 105

are characterized by strongly dissolved and strongly to moderately recrystallized assemblages of reduced diversity, hence the irregular occurrence of *Vagalapilla stradneri* in these cores. This marker species is easily dissolved and occurs consistently in Core 105 and in younger cores, but it is missing in all samples from Cores 106 to 109. The core catcher of Core 110 contains fairly diverse, moderately etched and overgrown assemblages, including rare *V. stradneri*. This species is missing again in Cores 111 and 112 but occurs again in Core 113, which might contain the true first stratigraphic occurrence of *Vagalapilla stradneri* at Site 534. The scattered occurrence of this marker species complicates the nannofossil biostratigraphy of these cores. Moderately etched and slightly to moderately overgrown assemblages occur in the dark claystones and gray limestones and the grayish red calcareous claystones of the lower part of the Cat Gap Formation (Cores 104–99). Species diversity increases throughout this interval to reach its highest values in Core 99. The grayish red claystones in Cores 97 to 96 contain strongly recrystallized nannofossils. Secondary overgrowth is less pronounced in Cores 95 and 94 but is stronger again in Cores 93 and 92 and remains strong throughout the Jurassic/Cretaceous boundary interval. This secondary overgrowth contributes to a slight decline in diversity in Cores 97 to 92 compared to the diversity peak in Core 99. However, a general decline in diversity, with many of the Jurassic species becoming extinct and a relatively slow replacement by new species, seems to be very important in causing this decline in species diversity at the top of the Jurassic. Unfortunately, a general regression at the end of the Jurassic in northern France and southern England and the occurrence of highly recrystallized assemblages in southeastern France (Thierstein, 1975) precludes a comparison of species diversities at these locations with Site 534 and makes a realistic estimate of the original species diversities in upper Tithonian assemblages a difficult undertaking. Comparing nannofossil preservation in the selected number of samples studied for nannofossils with the lithology shows some general trends. There is an interval of poor preservation in upper Callovian dark claystones and olive gray limestones, but coccoliths from other samples of these units (i.e., from Cores 125, 124, or 119 through 117) are better preserved and more diverse. A second dissolution pulse occurred in the late Oxfordian to Kimmeridgian and resulted in poor nannofossil preservation in the gray limestones and dark claystones at the base of the Cat Gap Formation (Cores 105–111). Grayish red calcareous claystones and marly chalks in the lower part of the uppermost unit of the Cat Gap Formation contain among the best preserved and most diverse Jurassic nannofossil assemblages at this site. Secondary overgrowth becomes more pronounced as the limestone content increases towards the Jurassic/Cretaceous boundary. I shall come back to this factor in the last paragraph on paleoceanographic conclusions based on these nannofossil studies. In general, calcareous nannofossils show the strongest dissolution effects in the dark variegated claystone units (upper Callovian, upper Oxfordian to Kimmeridgian) and the greatest over-

growth. Species diversities are equally variable but generally high (24–35 species). The calcareous claystones and dark shales in Cores 44 and 43 contain well preserved, slightly to moderately etched and recrystallized assemblages of high species diversity. A diversity peak of 46 species is reached in Core 43. However, barren intervals or very poorly preserved assemblages also occur in this interval. Cores 42 to 39 are totally barren of nanofossils or contain only a few dissolution-resistant species. Moderately to strongly etched and recrystallized assemblages of nanofossils were found in the calciturbidite-rich calciturbidite layers within the dark gray claystone sequence of the Blake-Bahama Formation (Cores 38, 34, and 28). Barren intervals predominant and coccolith-bearing beds make up only a very small proportion of this mid-Cretaceous “black shale” unit at Site 534.

Overall, calcareous nanofossils are moderately well preserved in the Hatteras Formation, with strong overgrowth in the limestone-rich lower part of the formation and generally well preserved assemblages in the middle and upper part of this unit. The Blake-Bahama Formation contains assemblages that have been affected by dissolution, with some secondary overgrowth in the calciturbidite layers, which had a shallower source and contained sufficient reactive carbonate grains that furnished calcite to the pore waters and resulted in secondary overgrowth within the sediment. Most of the dark carbonaceous shales are barren of coccoliths. Dissolution on the seafloor or within the sediment due to CO₂ production during the catabolic breakdown of organic matter resulted in the destruction of coccoliths. The varicolored sediments of the Upper Cretaceous (Core 25) contain only a few specimens of coccoliths, and even these could have been redeposited from shallower depths.

BIOSTRATIGRAPHY

Great progress has been made in calcareous nanofossil biostratigraphy of the Mesozoic in the last decade (Thierstein, 1976; Perch-Nielsen, 1979; Lord, 1982). Cretaceous calcareous nanofossil biostratigraphy has achieved considerable stability, but Jurassic nanofossil biostratigraphy is still in a state of flux.

Jurassic Nanofossil Zonation

Several Jurassic nanofossil zonations have been proposed since 1974, when Barnard and Hay published the first comprehensive zonation. An evaluation of published zonations (Roth et al., this volume) has shown that none of them are applicable, without major modification, to the section recovered at Site 534. The reason for major changes is the scarcity or total absence at Site 534 of many of the short-ranged but delicate marker species used successfully in the epicontinental sea deposits of England and northern France. Extensive carbonate dissolution rather than biogeographic effects seems to be responsible for these differences in the Jurassic nanofossil assemblages in sediments of the western North Atlantic and the northwest European epicontinental seas. A new nanofossil zonation for the middle Callovian to Tithonian was introduced (Roth et al., this volume). This zonation should be applicable to other

oceanic sections and to epicontinental sea deposits of low to mid-latitudes, if preservation of nanofossils is moderate or good. Not enough is known about the biogeography of the latest Jurassic marker species such as *Conusphaera mexicana* and *Polycostella beckmannii* to determine the usefulness of the younger Jurassic zones at higher latitudes. Preliminary observations of Jurassic sections recovered by DSDP in the Atlantic Ocean (A. Medd, personal communication, 1982) show that the zonation is applicable to these sections. The lower part of the zonation (Callovian to Kimmeridgian) is applicable to the epicontinental deposits of England and southern France according to the range charts in Barnard and Hay (1974), Medd (1982), and Hamilton (1982).

A brief history of Jurassic calcareous nanofossil taxonomy and biostratigraphy and a correlation of other nanofossil zonations with our new nanofossil zonation are presented in Roth et al. (this volume) and will not be repeated here. In the following section, I briefly summarize the zonation from the oldest to the youngest zone.

Stephanolithion bigotii Zone

The interval from the first occurrence of *Stephanolithion bigotii* to the first occurrence of *Vagalapilla stradneri* (equals *Staurorhabdus magnus* Medd, 1979) can be subdivided into two subzones, the *Stephanolithion hexum* Subzone and the *Cyclagelosphaera margerelii* Subzone.

The *Stephanolithion bigotii* Zone as defined in Roth et al. (this volume) is neither identical to the zone of the same name by Barnard and Hay (1974) or by Hamilton (1982). These authors use different definitions for a zone of the same name. For details on the correlation of this zone with other zonations, refer to Roth et al. (this volume).

Stephanolithion hexum Subzone

This subzone (spanning the interval from the first occurrence of *Stephanolithion bigotii* to the last occurrence of *Stephanolithion hexum*) is based on the occurrence of a rare and fairly delicate species, and it might not always be possible to use it in sections with poorly preserved coccoliths. Even at Site 534 *Stephanolithion hexum* disappears just below an interval with highly dissolved assemblages and its range might have been truncated. The occurrence of *Ansulospaera helvetica* helps to recognize this interval, as this species does not seem to occur above this subzone. However, the only other record of this species is in the Callovian of Switzerland (Grün and Zweili, 1980), and further studies are required to document more completely the range of *Ansulospaera helvetica* and establish its usefulness more fully. Also, there is conflicting information on the total range of *Stephanolithion hexum*. Medd (1982) reports it in beds as young as the lower Oxfordian *Erymnoceras coronatum* Ammonite Zone. Different ranges of *Stephanolithion hexum* are given by Barnard and Hay (1974), namely, lower to upper Callovian, and by Hamilton (1982), namely, Bathonian to Callovian. Thus the total range of

Stephanolithion hexum needs to be documented more fully; reworking, paleoecological factors, and preservation seem to play an important role. The range observed at Site 534 seems to represent the acme of *Stephanolithion hexum*; its last common occurrence in England is in the *Erymnoceras cordatum* Ammonite Zone (A. Medd, personal communication, 1982). Nannofossil species that are more or less consistently present include: *Watznaueria barnesae*, *W. britannica*, *W. communis*, *W. cruci-centralis*, *Ethmorhabdus* sp. cf. *E. anglicus*, *E. gallicus*, *Stephanolithion bigotii*, *S. hexum*, *Crepidolithus cras-sus*, *Axopodorhabdus cylindricus*, *Cyclagelosphaera deflandrei*, *C. margerelii*, *Palaeopontosphaera dubia*, *Striatomarginis* sp. cf. *S. veterna*, *Ansulosphaera helvetica*, *Diazomatolithus lehmanii*, *Discorhabdus patalus*, *Crucirhabdus primulus* (rare), *Zygodiscus erectus*, *Z. salillum*, and *Proculitus* sp., *Discorhabdus* sp. (mostly the basal disc). See Figure 5 for more details. The age of the *Stephanolithion hexum* Subzone is middle Callovian.

***Cyclagelosphaera margerelii* Subzone**

This interval ranges from the last occurrence of *Stephanolithion hexum* to the first occurrence of *Vagalapilla stradneri* (equals *Staurorhabdus magnus* Medd, 1979). The name-giving taxon for this subzone, *Cyclagelosphaera margerelii*, is neither restricted to this interval nor very common. The nannofossil assemblages are poorly preserved in the interval belonging to this subzone and make it impossible to subdivide this interval further. Common species in this subzone are the same as for the underlying subzone, less *Stephanolithion hexum*, *Ansulosphaera helvetica*, and *Crucirhabdus primulus*.

The only species that was first observed in this subzone is *Axopodorhabdus rahla*; however, only a single specimen was found in only one sample (530-119-1, 3 cm), probably due to poor preservation of the samples in this subzone. The range of this species in England and France would also fall into this subzone. Although *Polypodorhabdus escaigii* does not make its first appearance in the *Cyclagelosphaera margerelii* Subzone, it increases markedly in abundance and shows a more typical morphology with a larger, better developed central area in this subzone. Information on the range of this species is conflicting: according to Barnard and Hay (1974), its first occurrence is in the middle Callovian; according to Medd (1982), in the lower Bajocian. The acme of *Polypodorhabdus escaigii* is in the upper Callovian to lower Oxfordian of England (Medd, 1982). As with other species (e.g., *Stephanolithion hexum*), the range of *Polypodorhabdus escaigii* s. str. at Site 534 is comparable with the acme of this species in England rather than with its total range. The *Cyclagelosphaera margerelii* Subzone ranges from the late Callovian to the early Oxfordian.

***Vagalapilla stradneri* Zone**

This zone comprises the interval from the first occurrence of *Vagalapilla stradneri* (equals *Staurorhabdus magnus* Medd, 1979) to the first occurrence of *Conusphaera mexicana*. Considerable taxonomic problems with *Vagalapilla stradneri* do not diminish the usefulness of this species as a biostratigraphic marker. The form of *Vagalapilla stradneri* used here is that illustrated

by Barnard and Hay (1974, pl. VI, fig. 8) and described as *Staurorhabdus magnus* by Medd (1979) (see taxonomic notes for further details).

Consistently occurring species are the ones found in the underlying *Cyclagelosphaera margerelii* Subzone and the following additional species, which first appear in the *Vagalapilla stradneri* Zone: *Vagalapilla stradneri*, *Polypodorhabdus beckii*, *P. harrisonii*, *P. madingleyensis*, *Ahmuellerella ? retiformis*, *Discorhabdus exilitus*, *Zygodiscus fissus*, *Ethmorhabdus frondosus*, and *Rotelapillus radians*. The above species are moderately dissolution resistant, and their ranges at Site 534 are probably a fair representation of their total stratigraphic ranges. The following three species also first appear in this zone at Site 534, but are known to have longer ranges elsewhere (Medd, 1982): *Corollithion geometricus*, *Stradnerlithus asymmetricus*, and *S. comptus*. Only one species, *Polypodorhabdus beckii*, disappears in this zone.

The first specimens of *Parhabdolithus embergeri* with the characteristic thick multilayered wall appear near the very top of this zone. The specimens are still small; their long axis is mostly about 7.5 μm , rarely up to 9 μm . In the absence of *Conusphaera mexicana* the first occurrence of these small, but otherwise typical specimens of *Parhabdolithus embergeri* are used to approximate the top of the *Vagalapilla stradneri* Zone.

The preservation of calcareous nannofossils in the cores assigned to this zone is quite poor, which has caused a discontinuous lower range for *Vagalapilla stradneri* below Core 105, with occurrences of this species in Core 110 and a stratigraphically lowest occurrence in Core 113.

Dinoflagellate biostratigraphy indicates that Core 113 belongs to the Oxfordian and Core 105 is definitely Kimmeridgian. In the English sections, *Vagalapilla stradneri* s. str. first appears in the middle Oxfordian. Thus the lowest occurrence of *Vagalapilla stradneri* in Core 113 is in the correct stratigraphic position and appears to approximate closely the true first appearance of this species. A first appearance in Core 105 would put the base of *Vagalapilla stradneri* in the Kimmeridgian, which is too young compared to the well calibrated occurrences in England. The fact that the range of this marker species is not continuous near its base in poorly preserved sections is somewhat disconcerting. Additional markers can be found among the members of the genus *Polypodorhabdus*, which undergoes a rapid evolution in this zone. *Polypodorhabdus beckii* first appears close to the base, *P. harrisonii* in the lower part, and *P. madingleyensis* in the upper part of this zone. Medd (1982) reports a lower first occurrence for *P. madingleyensis*, that is, upper Bathonian in England. Hamilton (1982) also finds *P. madingleyensis* in slightly older beds, namely the latest Callovian. Possibly different species concepts were used by the various authors. The *Vagalapilla stradneri* Zone is middle Oxfordian to earliest Tithonian.

***Conusphaera mexicana* Zone**

This zone extends from the first occurrence of *Conusphaera mexicana* to the first occurrence of *Nannoconus colomii* s. str. and the last occurrence of *Polycostella*

beckmannii. Small nannoconids of less than 8 μm in length occur below the first occurrence of typical *Nannoconus colomii* (includes *N. steinmannii*), which is longer than 8 μm . These small nannoconids are assigned to *Nannoconus* sp. cf. *N. colomii* if they are conical; specimens with more or less parallel sides in optical sections are listed as *Nannoconus* sp. cf. *N. dolomiticus*.

At Site 534 and at other sites in the North Atlantic (A. Medd, personal communication, 1982) the lower boundary of this zone is closely approximated by the first occurrence of small (7.5–9 μm in length) *Parhabdololithus embergeri* with a well developed thick multicycle margin. Because of a gradual transition from *Zygodiscus salillum* to *Parhabdololithus embergeri* it is difficult to determine the exact first appearance surface of *P. embergeri*, and some subjective judgment by various investigators seems unavoidable. However, in sections where *Conusphaera mexicana* does not appear in the upper Kimmeridgian, for example, in England, where it is absent from Jurassic beds but found in the Hauterivian, the appearance of *Parhabdololithus embergeri* is helpful in approximating the lower boundary of the *Conusphaera mexicana* Zone.

The close proximity of the first occurrence of *Parhabdololithus embergeri* and *Conusphaera mexicana* is clearly shown by many DSDP sections in the North Atlantic (A. Medd, personal communication, 1982).

The *Conusphaera mexicana* Zone is subdivided into two subzones, the *Hexapodorhabdus cuvillieri* Subzone and the *Polycostella beckmannii* Subzone. However, the last occurrence of *Stephanolithion bigotii* that marks the boundary between the two subzones is not always easy to determine, especially in sections with poor nanofossil preservation or reworking. The first occurrence of *Polycostella beckmannii* and of small, less than 8- μm -long nannoconids helps to determine this boundary, but some variation in the first appearance of *Polycostella beckmannii* and small nannoconids with respect to the first occurrence of *Conusphaera mexicana* has been observed (A. Medd, personal communication, 1982). This would tend to make the boundary of these two subzones less stable than is desirable; thus the two subzones were not elevated to zonal level.

The *Conusphaera mexicana* Zone ranges in age from the latest Kimmeridgian or the earliest through the latest Tithonian and correlates with the Salvadorian oceanic stage.

***Hexapodorhabdus cuvillieri* Subzone**

This subzone ranges from the first occurrence of *Conusphaera mexicana* to the last occurrence of *Stephanolithion bigotii*. The first occurrence of *Polycostella beckmannii* and of small (less than 8- μm -long) nannoconids closely approximates the last occurrence of *Stephanolithion bigotii* and can thus be used to define the upper boundary of the *Hexapodorhabdus cuvillieri* Subzone. The first occurrence of small *Parhabdololithus embergeri* is, in general, somewhat below the first occurrence of *Conusphaera mexicana* (see the previous discussion of the *Conusphaera mexicana* Zone). Because the occurrence of *Stephanolithion bigotii* in the Solnhofen Lime-

stones is the only documented occurrence of this species in well-dated lower Tithonian rocks, reworking from older deposits cannot be totally ruled out (Barthel, 1976).

Hexapodorhabdus cuvillieri disappears in this subzone but is not particularly common. The following species generally occur in this subzone: *Stradnerlithus asymmetricus*, *Watznaueria barnesae*, *W. britannica*, *W. communis*, *Crepidolithus crassus*, *Hexapodorhabdus cuvillieri*, *Axopodorhabdus cylindricus*, *Octopodorhabdus decussatus*, *Cyclagelosphaera deflandrei*, *C. margerelii*, *Palaeopontosphaera dubia*, *Parhabdololithus embergeri*, *Zygodiscus erectus*, *Z. salillum*, *Polypodorhabdus escaigii*, *P. harrisonii*, *P. madingleyensis*, *Discorhabdus exilitus*, *D. patulus*, *D. tubus*, *Zygodiscus fissus*, *Ethmorhabdus frondosus*, *E. gallicus*, *Corollithion geometricum*, *Diazomatolithus lehmannii*, *Conusphaera mexicana*, *Vagalapilla quadriarcula*, *V. stradneri*, *Rotelapillus radians*, *Tetrapodorhabdus shawensis*.

Stephanolithion bigotii disappears at the top of this subzone. Three species first occur near the top of this zone, namely *Polycostella beckmannii*, *Nannoconus* sp. cf. *N. colomii*, and *N. sp. cf. N. dolomiticus*. *Stephanolithion bigotii* was found in the lower Tithonian Solnhofen Limestone of Franconia, although without *Conusphaera mexicana*, which was probably absent because of the restricted marine environment.

Thus the *Hexapodorhabdus cuvillieri* Subzone is late Kimmeridgian (*sensu gallico*) or late Kimmeridgian to early Tithonian, if a last occurrence of *Stephanolithion bigotii* in the lower Tithonian is accepted.

***Polycostella beckmannii* Subzone**

This subzone comprises the interval from the last occurrence of *Stephanolithion bigotii* to the first occurrence of *Nannoconus colomii* s. str. The first occurrence of *Polycostella beckmannii* is very close to the last occurrence of *Stephanolithion bigotii*. The last occurrence of *Polycostella beckmannii* is close to the first occurrence of typical *Nannoconus colomii* s. str. and helps to determine the position of the Jurassic/Cretaceous boundary.

Species that were observed in the majority of the samples from this subzone include the species found in the underlying subzone, without *Stephanolithion bigotii* and *Tetrapodorhabdus shawensis*. The following species first occur slightly above the lower boundary of this subzone: *Polycostella beckmannii*, *Nannoconus* sp. cf. *N. colomii*, *N. sp. cf. N. dolomiticus*.

The species *Cruciellipsis* sp. cf. *C. chiastia* and *C. sp. cf. C. cuvillieri* seem to have evolved from *Polypodorhabdus madingleyensis* near the base of this subzone because of an increase in the thickness of the arms of the central cross, a decrease of the size of the central area, and, finally, the loss of the connecting struts between the central cross and the rim (only in *Cruciellipsis* sp. cf. *C. chiastia*). Near the top of this subzone several species that are considered typical for the Cretaceous first occur; they include *Lithraphidites carniolensis*, *Rhagodiscus asper*, *Biscutum constans*, *Zygodiscus* sp. cf. *Z. diplogrammus* and *Z. sp. cf. Z. elegans*. A large number of species disappear within this zone. They include *Crepi-*

dolithus crassus, *Watznaueria crucicentralis*, *Hexapodorhabdus cuvillieri*, *Axopodorhabdus cylindratus*, *Zygodiscus fissus*, *Ethmorhabdus frondosus*, *E. gallicus*, *Polypodorhabdus harrisonii*, *Discorhabdus patulus*, *Ahmuellerella ? retiformis*, and *Disorhabdus tubus*.

The age of the *Polycostella beckmannii* Subzone is early to late Tithonian.

Remarks on the Jurassic/Cretaceous Boundary: Nannofossil Evidence

Summaries of observations on the calcareous nannofossils within the Jurassic/Cretaceous boundary interval have been presented by Thierstein (1975), Wind (1978), and A. Medd (personal communication, 1982). The section across the Jurassic/Cretaceous boundary at Site 534 contains calpionellids (Remane, this volume), dinoflagellates (Habib and Drugg, this volume), and calcareous nannofossils. Calpionellids allow correlation of the paleontological events observed in the section at Site 534 with the type and reference sections in southern France.

Early studies on the biostratigraphy of the genus *Nannoconus* (Brönnimann, 1955; Trejo, 1961; Deres and Achéritéguy, 1972) indicated the late Tithonian for the first occurrence of this genus. Thierstein (1973, 1975, 1976) studied several land and deep-sea sections and concluded that the first occurrence of *Nannoconus colomii* (which in his species concept includes *Nannoconus steinmannii*) can be correlated with the base of the Berriasian, that is, the Jurassic/Cretaceous boundary. More recent investigations by Deres and Archéritéguy (1980) showed that the genus *Nannoconus* does indeed occur in the upper Tithonian in Italy, Tunisia, and southeast Africa. This finding is supported by studies of cores from Site 534. Based on calpionellid evidence, the Jurassic/Cretaceous boundary is best placed between Cores 92 and 91. Habib and Drugg (this volume) prefer to place the Jurassic/Cretaceous boundary between Sections 2 and 3 of Core 91, on the basis of the correlation of their assemblages with assemblages from well dated land sections in France. Calcareous nannofossil evidence is consistent with the placement of this boundary at the base of Core 91, although one could argue that there is more evidence for placing it within Core 93 (e.g., at the first occurrence surface of *Lithraphidites carniolensis* and *Rhagodiscus asper*). However, a placement of the Jurassic/Cretaceous boundary at the base of Core 91 coincides with an increase in size of *Nannoconus colomii* (from less than 8 μm in length in Core 92 to 8 μm or more in length of the largest specimens in Core 91). A marked increase in the relative abundance of *Nannoconus colomii* also occurs in Core 91. Small conical and more or less cylindrical nannoconids of less than 8 μm in size and assigned to *Nannoconus* sp. cf. *N. colomii* and *N. sp. cf. N. dolomiticus* respectively occur in the upper Tithonian at Site 534 and at other North Atlantic sites (A. Medd, personal communications, 1982). Thus the first occurrence of the genus *Nannoconus* does not mark the Jurassic/Cretaceous boundary.

Another criterion used for defining the Jurassic/Cretaceous boundary is the last occurrence of *Hexalithus noelae*, a species described from beds as young as "ter-

restrial Portlandian" in Algeria by Noël (1957, 1959) and also recorded from the Bossier Shales, which are considered late Jurassic but in fact are rather poorly dated (Cooper and Shaffer, 1976). According to H. R. Thierstein (personal communication, 1982) Noël's "terminal Portlandian" contains typical Lower Cretaceous assemblages; this would also shed doubts on the dating of the Bossier shale. A single occurrence of *Hexalithus noelae* is reported from Site 391 (391C-42-5, 127 cm) by Wind (1978), who assigned this level to the Upper Jurassic. Medd (1982) found "hexaliths" in the Oxfordian and lower Kimmeridgian of England. Thierstein (personal communication, 1982) found *Hexalithus noelae* in the Berriasian section at Montsalvans. At Site 534 *Hexalithus noelae* occurs together with common large *Nannoconus colomii*, *Rhagodiscus asper*, *Lithraphidites carniolensis*, and *Polycostella senaria*; the last species is considered typical of the lowermost Cretaceous (Thierstein, 1973; Perch-Nielsen, 1979), although Thierstein (1975) did report it in one sample from just below the Jurassic/Cretaceous boundary at DSDP Site 105. *Rhagodiscus asper* and *Lithraphidites carniolensis* are thought to make their first appearance in the lowermost Cretaceous. Thus *Hexalithus noelae* appears to cross the Jurassic/Cretaceous boundary and range from the upper Jurassic to the basal Cretaceous and is *not* a marker species for the Late Jurassic.

Important occurrence surfaces of Jurassic to Lower Cretaceous calcareous nannofossils are summarized on Figure 6.

Lower Cretaceous Nannofossil Zonation

Biostratigraphic zonations of the Lower Cretaceous are generally based on Thierstein (1971, 1973). Slight modifications of the zonations were proposed by Roth (1973, 1978) and Bukry (1975), Perch-Nielsen (1979) and Taylor (1982). A zonation exclusively based on nannoconids was proposed by Deres and Achéritéguy (1980). I briefly summarize the zonation used here and refer to Figure 5 for details on the species distributions. Correlations with land and oceanic stages are based on Roth (1978). Biohorizons based on calcareous nannofossils and correlations with dinoflagellate zones are shown on Figure 6.

Nannoconus colomii Zone (NC1)

The interval spanned by this zone ranges from the first appearance of large *Nannoconus colomii* s. str. to the first occurrence of *Retecapsa neocomiana*. As discussed earlier, the base of this zone is best defined by the first occurrence of common and large specimens of *Nannoconus colomii*, more than 8 μm in length. Small nannoconids (*N. sp. cf. N. colomii*, *N. sp. cf. N. dolomiticus*) appear well below the base of this zone. At the lower boundary of this zone, or slightly below it, appear for the first time the species *Hexalithus noelae*, *Rhagodiscus asper*, *Lithraphidites carniolensis*, *Zygodiscus diplogrammus*, and *Z. elegans*. Several Jurassic species disappear just below the lower boundary of this zone, for example, *Ethmorhabdus gallicus*, *Ahmuellerella ? retiformis*, and *Zygodiscus salillum*; a longer range (Valan-

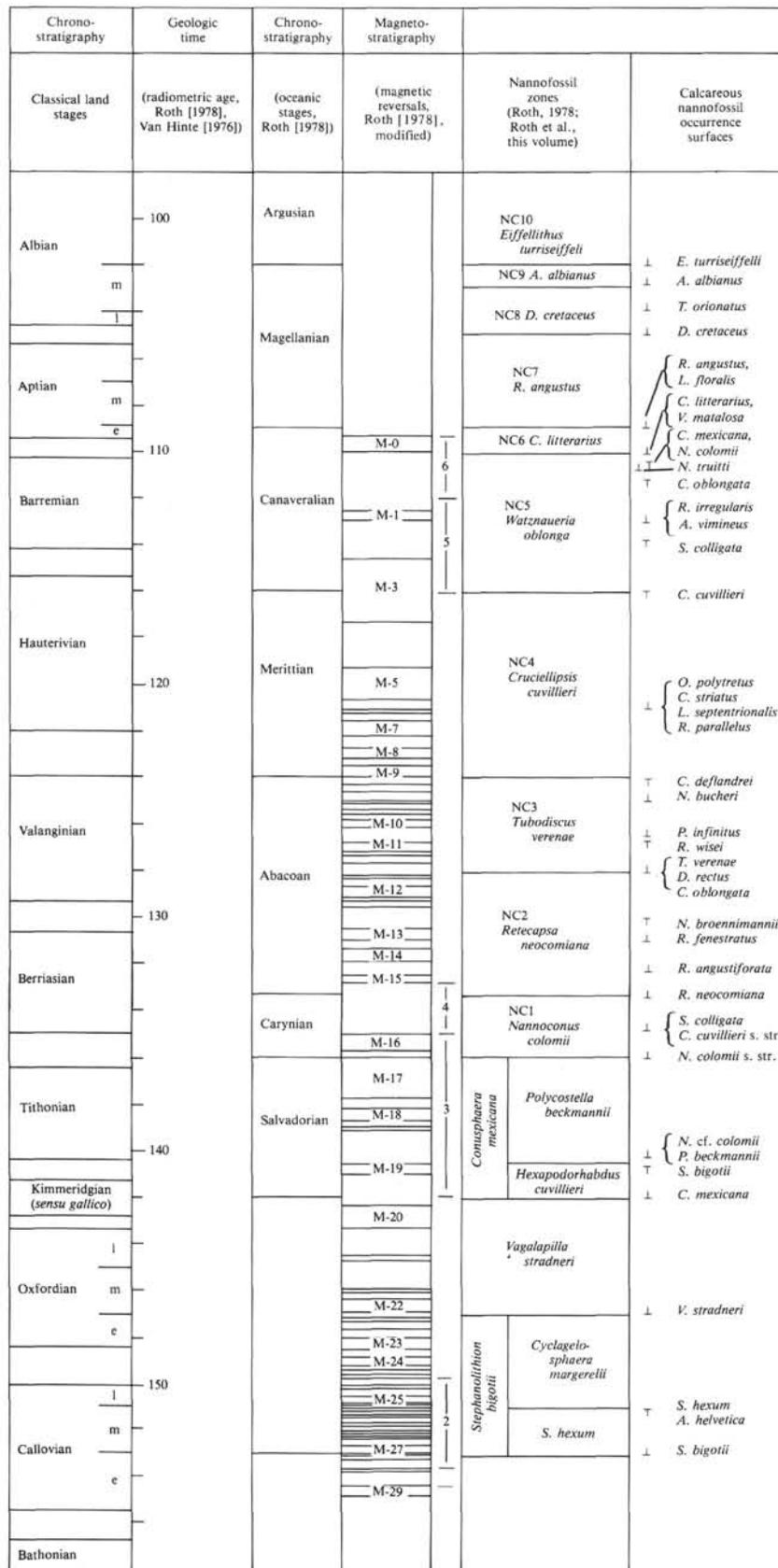


Figure 6. Jurassic and Early Cretaceous chronostratigraphy, magnetostratigraphy, and biostratigraphy, with new information from Site 534. (Some of the magnetostratigraphy data are from A. Cox [personal communication, 1982]. The magnetostratigraphic-biostratigraphic calibration points are: 1. oldest sediment at Site 534; Anomaly M-28, 2. DSDP Site 105, between M-24 and M-25 [Oxfordian basal sediments]; 3. DSDP Site 534 [Ogg, Site 534 report, this volume]; 4. DSDP Site 387, between M-15 and M-16 [basal sediment belongs to NC2]; 5. Cismone section [see Lowrie et al., 1980]; 6. DSDP Site 417 on Anomaly M-0 [oldest sediment belongs to NC6]. In the calcareous nannofossil data, T = first occurrence; ⊥ = last occurrence. The radiolarian data are from P. Baumgartner [personal communication, 1981]; Unitary associations 1 and "0" are from Baumgartner et al. [1980].

Biostratigraphy				
Dinoflagellate zones and age assignments (Habib and Drugg, this volume)	Ammonites and Aptychi (Cretaceous-Tithonian, Renz, this volume) Radiolarians (Jurassic)	Calpionellids (Remane, this volume)	Approximate position of samples	Foraminifers (Moullade, Premoli Silva, Site 534 report, this volume)
<i>Sphindium vestidum</i>				
<i>Subtilisphaera perlucida</i>				
<i>Odontochitina operculata</i>	<i>Pulchella</i> cf. <i>galeatoides</i>	Barremian		<ul style="list-style-type: none"> ⊕ <i>Clavihedbergella bizonae</i> ⊕ <i>Hedbergella sigali</i> ⊕ <i>H. infractacea</i>, <i>Clavihedbergella eocretacea</i> ⊕ <i>Dorothia ouachensis</i> ⊕ <i>Clavihedbergella eocretacea</i>
<i>Druggidium rhabdoreticulatum</i>	<i>L. angulocostatus</i>	Hauterivian		<ul style="list-style-type: none"> ⊕ <i>H. sigalia</i>, <i>C. eocretacea</i> ⊕ <i>D. ouachensis</i> ⊕ <i>Gaudryinella eichenbergi</i> ⊕ <i>Ammodiscus gaultianus</i> ⊕ <i>Pseudodosaria humilis</i> ⊕ <i>D. ouachensis</i>, <i>Gavelinella</i> sp.
<i>Druggidium deflandrei</i>	<i>L. seranonis</i>			<ul style="list-style-type: none"> ⊕ <i>Haplophragmoides vocontianus</i> (Valanginian-early late Hauterivian)
<i>Druggidium apicopaucium</i>	<i>L. subseranonis</i> <i>L. postbermudensis</i> <i>Paquiericeras</i>	Valanginian		<ul style="list-style-type: none"> ⊕ <i>Dorothia hauteriviana</i> ⊕ <i>D. praeauteriviana</i> (early late Valanginian)
<i>Biorbifera johnewingii</i>	<i>L. aplantus</i> <i>Lyticoceras</i> <i>L. herthae</i>			
"early Berriasian"	<i>L. ?bahamensis</i>	Berriasian		
		Zone B (middle)		
		Zone A?		
"Tithonian"	<i>L. beyrichi</i>	Tithonian		<ul style="list-style-type: none"> ⊕ <i>E. aff. uhligi</i>, <i>L. quenstedti</i> ⊕ <i>L. quenstedti</i>
"Kimmeridgian"	Ammonites/ aptychi			
	Radiolarians			
"Oxfordian"				<ul style="list-style-type: none"> ⊕ "G." <i>helvetojurassica</i>
m-1 "Callovian"	Zone A Unitary association			
	Unitary association "0"			

Figure 6. (Continued).

ginian) is reported for the last species by Thierstein (1973). Some species that originate in the Jurassic continue into the Cretaceous, such as *Watznaueria barnesae*, *W. britannica*, *W. communis*, *Cyclagelosphaera deflandrei*, *Parhabdolithus embergeri*, *Zygodiscus erectus*, *Palaeopontosphaera dubia* (which appears to evolve into *Biscutum constans* near the base of this zone), *Conusphaera mexicana*, *Polycostella beckmannii* (not at this Site but in other sections, such as in southeast France, according to Thierstein, 1973, 1975), and *P. senaria*.

The following species first appear within this zone (in ascending order): *Nannoconus colomii* (large specimens), *Cretarhabdus conicus*, *Cruciellipsis chiastia*, *Stephanolithion laffittei*, *Nannoconus globulus*, *N. broennimannii*, *Cruciellipsis cuvillieri* s. str., *Cretarhabdus crenulatus*, and finally *Retecapsa neocomiana* at the top of this zone. Several species disappear within this zone (see Fig. 5). The age of this zone is early Berriasian or Carynian.

Retecapsa neocomiana Zone (NC2)

This zone comprises the interval from the first appearance of *Retecapsa neocomiana* to the first occurrence of *Tubodiscus verenae*. The genus *Retecapsa* evolves within this zone; the first species that appears is *Retecapsa neocomiana*, a small form with a relatively small central area. *Retecapsa angustiforata* is larger, has a larger central area, and first occurs in the lower part of this zone. As used here, it includes *Retecapsa brightoni*, which is difficult to distinguish from *R. angustiforata* in the light microscope. *Reticulofenestra laevis* was not encountered until the Barremian (Zone NC5).

The following species first occur in this zone: *Crucioplacolithus salebrosus*, *Speetonia colligata*, *Reinhardtites fenestratus*, *Grantarhabdus meddii*, and *Chiastozygus bilamellus*. *Nannoconus broennimannii* disappears within this zone. Species that appear at the top of this zone will be discussed later.

Species diversity gradually increases within this zone; this increase is at least in part due to evolutionary diversification but is also caused by improved preservation. The age of this zone is late Berriasian or early Abacoan.

Tubodiscus verenae Zone (NC3)

This zone spans the interval from the first to the last occurrence of *Tubodiscus verenae*. Two additional markers for this zone are *Diadorhombus rectus* and *Calcicalathina oblongata*. Both are more susceptible to destruction by dissolution and secondary overgrowth. *Diadorhombus rectus* is much less abundant, and it has a more scattered distribution than *Tubodiscus verenae*; thus *Diadorhombus rectus* is a less reliable marker species than *Tubodiscus verenae*. However, one has to be careful to restrict the species concept of *T. verenae* to species with a well developed central tube that appears yellow in cross-polarized light. *Calcicalathina oblongata* first occurs at the same level as *Tubodiscus verenae*, but it seems to be largely restricted to the Tethyan-North Atlantic realm, including the North Sea (Perch-Nielsen, 1979). It has not been recorded in the Pacific (Roth, 1973; Bukry, 1975; 1976), nor in the British land sections (Taylor,

1982). The following additional species first occur within this zone: *Parhabdolithus infinitus*, *Nannoconus bermudezi*, *Bukryolithus ambiguus*, *Watznaueria oblonga*, *Octopodorhabdus reinhardtii*, *Haqius circumradiatus*, *Micrantholithus obtusus*, and *Rucinolithus wisei*. The last three species were reported from the lower Berriasian by Thierstein (1973, 1976). *Rucinolithus wisei* disappears in the lower part of this zone. *Nannoconus broennimannii* and *Cyclagelosphaera deflandrei* last occur near the top of this zone. This age of the zone is Valanginian or late Abacoan.

Cruciellipsis cuvillieri Zone (NC4)

This zone extends from the last occurrence of *Tubodiscus verenae* to the last occurrence of *Cruciellipsis cuvillieri*. The two species that define the underlying zone, that is, *Tubodiscus verenae* and *Diadorhombus rectus*, do not disappear suddenly at Site 534. *Tubodiscus verenae* is present in all cores and in 95% of all the samples from Cores 79 to 70. It occurs only in about half the samples in Cores 69, 68, and 67, and the last appearance surface is drawn between Sections 1 and 2 of Core 67. The single specimen of *Tubodiscus verenae* in Sample 534A-64, CC is considered reworked. *Diadorhombus rectus* occurs only in five widely spaced samples in the underlying zone; thus its disappearance seems less reliable. Scattered occurrences of *D. rectus* in this zone (NC4) and the lower part of the next zone (NC5) could be due to reworking, although no other older forms were observed in the samples that contain possibly reworked *D. rectus*. The following species first occur within this Zone NC4: *Crucioplacolithus furtivus* n. sp., *Cretarhabdus* sp. cf. *C. multiforus*, *Vagalapilla angusta*, *Rhabdolekiskus parallelus*, *Diloma placinum*, *Lithastrinus septentrionalis*, *Chiastozygus tenuis*, *C. strictus*, *Octopodorhabdus polytretus*, and *Hayesites radiatus*. Relatively few species disappear in this zone; they include *Diloma placinum* and *Polypodorhabdus madingleyensis* (the latter generally ranges into the Barremian in England) and *Cruciellipsis cuvillieri*.

Although looked for, *Lithraphidites bollii* was not found at Site 534 nor at Site 391. I suspect *L. bollii* might be an artificial fossil, that is, either a stem fragment or a heavily overgrown specimen of *Rhabdolekiskus parallelus*. The age of the *Cruciellipsis cuvillieri* Zone (NC 4) is late Valanginian to late Hauterivian or Merrittian.

Watznaueria oblonga Zone (NC5)

This zone extends from the last appearance of *Cruciellipsis cuvillieri* to the first appearance of *Chiastozygus litterarius* and/or *Vagalapilla matalosa*. The following species first appear in this zone: *Acaenolithus* sp. cf. *A. vimineus*, *Rucinolithus irregularis* (not recorded below the Aptian by Thierstein [1976] and Perch-Nielsen [1979]), *Gaarderella granulifera*, *Nannoconus truittii*, and *Radiolithus* sp. cf. *R. planus*. Species that disappear within this zone include *Speetonia colligata*, *Calcicalathina oblongata*, *Nannoconus colomii*, and *Conusphaera mexicana* (ranges into the lower Aptian, according to Thierstein [1976] and Perch-Nielsen [1979]). This zone could be subdivided into three subzones using the last

occurrence of *Speetonia colligata* and the last occurrence of *Calcicalathina oblongata*. However, these subzones would be only of a regional applicability because of the biogeographic control of the distribution of the two subzonal marker species.

The *Watznaueria oblonga* Zone extends from the upper Hauterivian to the upper Barremian; its age is early Canaveralian.

Chiastozygus litterarius Zone (NC6)

The first occurrence of *Chiastozygus litterarius* and/or *Vagalapilla matalosa* marks the beginning of this zone, and the first occurrence of *Rhagodiscus angustus* and/or *Lithastrinus floralis*, the end of this zone. Two species first appear in this zone, namely *Chiastozygus litterarius* and *Vagalapilla matalosa*. *Radiolithus* sp. cf. *R. planus* first occurs just below the base of this zone. *Nannoconus globulus* and *N. bermudezii* disappear in this zone.

The lower boundary of the next higher zone was not encountered at Site 534 due to intensive dissolution at this level. Thus it is unknown how much of this zone is present at this site.

The *Chiastozygus litterarius* Zone belongs to the lower Aptian or upper Canaveralian.

Rhagodiscus angustus Zone (NC7)

This zone extends from the first occurrence of *Rhagodiscus angustus* and/or *Lithastrinus floralis* to the first appearance of *Deflandrius cretaceus*. This interval cannot be determined at Site 534 because carbonate dissolution has removed all late Aptian to early Albian calcareous nannofossils.

Deflandrius cretaceus Zone (NC8)

This zone comprises the interval from the first occurrence of *Deflandrius cretaceus* to the first occurrence of *Axopodorhabdus albianus*. Only a few samples from Cores 38, 35, and 34 contain assemblages typical of this zone. *Deflandrius cretaceus* is present, but *Axopodorhabdus albianus* and *Eiffellithus turriseiffeli* are still absent. Because of the poor state of preservation, the assemblages are probably not complete. Refer to Figure 5 for details on the species present. The age of this Zone (NC8) is middle Albian.

Upper Cretaceous Nannofossils

Claystones barren of coccoliths lie above the last interval in a moderately rich assemblage. Only a few isolated specimens of Maestrichtian coccoliths, with *Arkhangelskiella cymbiformis* and *Micula staurophora*, occur in Core 25. The next younger core in which calcareous nannofossils are found (Core 20) contains middle Eocene assemblages.

CALCAREOUS NANNOFOSSILS AT SITE 534

The zonal definitions just presented and the range charts (Figs. 4 and 5) contain detailed information on nannofossil species distribution and zonal assignments at Site 534. Thus I shall keep this section very short and refer the reader to the charts and the earlier discussion

of zones for more details. Mudstone beds intercalated with tholeiitic basalts in Core 128 do not contain coccoliths that can be assigned to a nannofossil zone. The nannofossil assemblages in Core 127 include *Stephanolithion hexum*, *S. speciosum*, *Ansulosphaera helvetica*, *Ethmorhabdus* sp. cf. *E. anglicus*, *Watznaueria crucicentralis*, and *Crucirhabdus primulus*. The occurrence of *Stephanolithion bigotii* reported by the shipboard paleontologists of the Leg 76 extension (D. R. Watkins and J. L. Bowdler) could not be confirmed. Because of the presumed absence of *S. bigotii*, the age of this assemblage is considered early Callovian, but no formal zone is used for this short interval, which does not contain a major nannofossil occurrence surface at its base. None of the existing zones, for example, the *Stephanolithion hexum* Zone of Barnard and Hay (1974), the *Ellipsagelosphaera lucasii* Zone of Medd (1982), or the *Stephanolithion speciosum* Zone of Hamilton (1982), seem totally satisfactory, because they are based on species whose ranges have not yet been sufficiently well determined (the two former) or cover a very long time interval (the last zone). The *Stephanolithion hexum* Subzone includes Cores 126 through 123, Section 4 and is overlain by rather preserved assemblages in Core 123, Section 3 to Core 113 that are assigned to the *Cyclagelosphaera margarelii* Subzone of the *Stephanolithion bigotii* Zone. The lowest occurrence of the *Vagalapilla stradneri* in Sample 534A-113-1, 47 cm marks the lower boundary of the *Vagalapilla stradneri* Zone, which extends to Core 103, Section 3. Coccoliths are poorly preserved, and *Vagalapilla stradneri* occurs only in Sample 534A-110, CC and more or less continuously in Core 105 and above. It is not possible to determine the Oxfordian/Kimmeridgian boundary based on the nannofossils found in this interval at Site 534; this boundary is difficult to locate using nannofossils in any section (e.g., English sections, see Medd, 1982; Hamilton, 1982). Dinoflagellate evidence would favor the inclusion of the upper part of the *Vagalapilla stradneri* Zone into the Tithonian, but that would place the last occurrence of *Stephanolithion bigotii* into the middle part of the Tithonian section at Site 534, which seems to be too high. The youngest rock unit that contains *Stephanolithion bigotii*, the Solnhofen Limestone of Franconia, is early Tithonian (Keupp, 1976, 1977). All other youngest occurrences from well dated land sections are from the *Aulacostephanus autissiodorensis* Ammonite Zone Medd (1982), that is, from the uppermost Kimmeridgian (*sensu gallico*). It appears that the age of the *Vagalapilla stradneri* Zone and therefore of Core 113 (upper part) to Core 101 (lower part) is Kimmeridgian.

The interval of Core 101, Section 2 to Core 97 belongs to the *Hexapodorhabdus cuvillieri* Subzone and is latest Kimmeridgian to Tithonian. Cores 96 to 92 belong to the *Polycostella beckmannii* Subzone of the *Conusphaera mexicana* Zone. Coccolith assemblages are quite poorly preserved in the boundary interval between the *Hexapodorhabdus cuvillieri* and *Polycostella beckmannii* Subzones. Thus it is possible that *Stephanolithion bigotii* occurs in the lowermost part of Core 96 (A. Medd, personal communication, 1982). The proximity of the Ju-

rassic/Cretaceous boundary is indicated by the first occurrence of typical *Lithraphidites carniolensis* and *Rhagodiscus asper* in Core 93. The age of the *Polycostella beckmannii* Subzone (Cores 96–92) is Tithonian.

The Jurassic/Cretaceous boundary is placed between Cores 92 and 91, which seems to be its most likely position, based on information derived from the calpionellid distribution (Remane, this volume) and the increase in size and abundance of *Nannoconus colomii* (larger than 8 μm in Core 91, smaller below); dinoflagellates indicate a major change associated with this boundary at a slightly higher level (between Core 91, Sections 3 and 2). The Cretaceous section begins with the *Nannoconus colomii* Zone (NC1) recovered in Cores 91 to 87; it is early Berriasian or Carnian. The first occurrence of *Retecapsa neocomiana* in Core 86 marks the lower boundary of Zone NC2 (*Retecapsa neocomiana* Zone) that extends to Core 79, Section 5; this interval is late Berriasian to early Valanginian.

The next higher Zone NC3 (*Tubodiscus verenae* Zone) extends from Core 79, Section 4 to Core 67, Section 2. This zone is Valanginian or late Abacoan. The next higher zone, the *Crucillipsis cuvillieri* Zone (NC4), is encountered in Cores 67 (upper part) to 59 (lower part). It belongs to the lower Hauterivian. A single occurrence of *Tubodiscus verenae* in Sample 534A-64, CC is probably reworked. The assemblages in the upper part of Zone NC4 at Site 534 are rather similar to assemblages described by Wind and Čepk (1979) from Site 397 off the northwest African margin.

The *Watznaueria oblonga* Zone (NC5) was recognized in Cores 59 (upper part) to 45 (lower part). This interval belongs to the upper Hauterivian to upper Barremian or the lower Canaveralian. Assemblages recovered from Cores 45 (upper part) to 43 contain assemblages typical of the lower Aptian or upper Canaveralian Zone NC6 (*Chiastozygus litterarius* Zone). The upper boundary of this zone is not defined at Site 534, because a barren interval and layers lacking age-diagnostic nannofossils in Cores 42 to 49 are overlain by rocks that contain nannofossil assemblages assigned to Zone NC8 (*Deflandrius cretaceus*) in Cores 38, 35, 34, and 28. Only the calciturbidites rich in small carbonate components contain nannofossils in the mid-Cretaceous Black Shales (Hatteras Formation) at Site 534. Cores 36, 33, 32, 31, 30, 29, and 27 through 26 are barren of calcareous nannofossils. Core 25 contains a few specimens of *Arkhangelskiella cymbiformis* and *Micula staurophora* besides mid-Tertiary nannofossils (downhole contaminants) and is Campanian to Maestrichtian, which is also confirmed by planktonic foraminifers. Core 20 definitely contains only middle to late Eocene nannofossils.

CALCAREOUS NANNOFOSSIL ZONATION: ITS RELATIONSHIP WITH OTHER MICRO- AND MEGAFOSSIL BIOSTRATIGRAPHIES AND CHRONOSTRATIGRAPHIC UNITS

The middle Callovian to lower Aptian section recovered at Site 534 is suitable for correlating dinoflagellate and nannofossil zones. Some information derived from the study of ammonites, aptychi, calpionellids, radiolar-

ians, and foraminifers is also added. It is also possible to determine the relationship of the nannofossil zonation with classical land stages, oceanic stages, the magnetic reversal scale, and the radiometric age scale (Fig. 6). More detailed information on dinoflagellates can be found in the paper by Habib and Drugg (this volume), on calpionellids in Remane (this volume), on aptychi and ammonites in Renz (this volume), the Site 534 report presents more detailed information as well.

Such an attempt to relate biostratigraphic, magnetostratigraphic, and chronostratigraphic units with geologic time is not easy, and I shall point out the strengths and weaknesses of the various relationships. The biostratigraphy based on all fossil groups shown in Figure 6 is derived from the study of samples recovered at Site 534. The relationship of Jurassic nannofossil zones with Jurassic stages is based on studies by Barnard and Hay (1974), Medd (1982), Hamilton (1982), and Keupp (1976, 1977). Lower Cretaceous nannofossils were studied in the stratotype sections by Thierstein (1971, 1973, 1975, 1976), but considerable uncertainty remains about the exact position of many stage boundaries. Oceanic stages were thus introduced by Roth (1978). Their boundaries are based on nannofossil occurrence surfaces and are thus very suitable for oceanic sections. All but one stage were again recognized.

The Catgapan Stage was defined as having its base at the LOS (lowest occurrence surface) of *Stephanolithion bigotii* and its top at the LOS of *Conusphaera mexicana* (Roth, 1978). This definition was erroneous, because the type section has the last *Stephanolithion bigotii* at the base. It is clear from figure 3 in Roth (1978), from the stratigraphic extent of the type section, and from the correlation of the Catgapan with the upper Oxfordian and Kimmeridgian land stages that the base of the Catgapan was intended to be drawn at the last occurrence surface of *Stephanolithion bigotii*, not the first occurrence surface of this taxon. Recent studies have shown that *Stephanolithion bigotii* disappears after the first occurrence of *Conusphaera mexicana* (Wind, 1978; Medd, personal communication, 1982, and this paper). Thus the Catgapan as intended does not exist and I am herewith retracting it. A new oceanic stage covering the interval from the first occurrence of *Stephanolithion bigotii* to the first occurrence of *Conusphaera mexicana* may complete the sequence of Mesozoic oceanic stages.

The radiometric ages of chronostratigraphic units are poorly known and may be in error by as much as 10%. The time scale proposed by Roth (1978) was used for the Cretaceous and that proposed by Van Hinte (1976) for the Jurassic, although the latter is not totally satisfactory. The most serious problem appears to be the length of the Tithonian and the Kimmeridgian. The Kimmeridgian (*sensu gallico*) appears to be too short, the Tithonian too long based on calculations of sedimentation rates (Roth et al., this volume). However, this problem has only been recognized at Site 534, where sedimentation by turbidity currents was important, and changes in sedimentation rates might be responsible for the observed anomaly. Further testing at other sites is necessary before definite conclusions on the length of the vari-

ous land stages can be made. For the time being, there is no other published time scale that appears to be an improvement over the one proposed by Van Hinte (1976).

Relatively few firm ties exist between the magnetostratigraphic scale and the nannofossil zonation. Paleomagnetic studies by J. Ogg (see the Site 534 report) indicate that the magnetic anomaly pattern from M-16 to M-20 can be recognized at Site 534 between Cores 84 and 96; this interval belongs to Zone NC1 and to the *Conusphaera mexicana* Zone. More detailed studies and interpretations of the paleomagnetic results have not been completed as of the writing of this chapter. Older results of DSDP and land sites provide further tie points. Magnetic reversals M-0 to M-4 were related to nannofossil zones by Channell et al. (1979). Other dated M-anomalies are shown in Roth (1978). The age of Anomaly M-0 was also dated at Site 418 as early Aptian (NC6). At Site 166 a poor assemblage of coccoliths allows the correlation of nannofossil Zones NC5 to NC6 with the boundary between Anomalies M-7 and M-8. Reversal M-9 at Site 304 appears to be of the same age as Zones NC3 to NC4. The boundary of Magnetic Anomalies M-15 and M-16 falls within Zone NC2 as data from Site 387 show (Okada and Thierstein [1978]). All other anomalies are simply interpolated between these few fixed points, given the assumption that spreading rates were constant and that the width of the seafloor anomalies are thus proportional to the duration of the anomalies. Unpublished data compiled by A. Cox (personal communication, 1982) was very helpful in constructing the magnetostratigraphy, although I did not use his radiometric age assignments for the M-anomalies. A comparison of Figure 6 in this paper with figure 3 in Roth (1978) shows that correlations of the magnetostratigraphy with chrono- and biostratigraphic scales are still in a state of flux and are by no means final.

The biostratigraphic zonation of the calcareous nannofossils is accompanied by a list of over 40 occurrence surfaces; their relative positions in the stratigraphic framework are shown (Fig. 6). Many of these first and last occurrence surfaces would allow further refinement of the zonation. However, for the sake of stability I have refrained from defining a more detailed zonation; future biostratigraphic studies will corroborate or modify this sequence of occurrence surfaces.

The calcareous nannofossil biostratigraphy is related to the dinoflagellate biostratigraphy of Habib and Drugg (this volume). These two authors did not define any formal dinoflagellate zones for the Jurassic and thus only age assignments (stages) based on dinoflagellate ranges and some important dinoflagellate species are given. The upper Berriasian to Cenomanian is subdivided into formal dinoflagellate zones by Habib and Drugg (this volume). They can now be directly correlated with the nannofossil zones and have been related to the classical land stages directly by means of dinoflagellate studies in the stratotype sections (Habib and Drugg, this volume).

If the relationship of the dinoflagellate zones with the land stages based on dinoflagellate studies in stratotype section is compared with the relationship of stages and dinoflagellate zones achieved by means of nannofossil distributions in stratotypes and at Site 534, an amazing-

ly good agreement is seen. This agreement is a further indication that the correlation of nannofossil and dinoflagellate zones is quite reliable. Calpionellids of biostratigraphic value are only found near the Jurassic/Cretaceous boundary (Remane, this volume), but they are useful in defining that important system boundary at this Site.

Radiolarians in the Jurassic part of the section indicate that the age for the lower part of the section (Cores 120-126) is middle Callovian to Oxfordian, which is in good agreement with ages based on other fossils. Ammonites and aptychi (Renz, this volume) give ages that conflict with the ages based on coccoliths, dinoflagellates, and foraminifers. Perhaps not enough is known about the total range of these megafossils. However, the discrepancies are not major. Foraminifers were only found in selected samples and do not provide very many firm dates.

The Site 534 section has thus proven an excellent means of correlating biostratigraphies based on several microfossil groups and relating them to chrono- and magnetostratigraphic scales. Poor preservation of foraminifers is perhaps disappointing, and more detailed radiolarian studies might provide further information. However, this site did provide a key section that should be helpful for correlation with other pelagic and epicontinental sections.

OBSERVATIONS ON NANNOFOSSIL PRESERVATION AND BIOGEOGRAPHY: IMPLICATION FOR PALEOCEANOGRAPHY

Nannofossil Preservation and Its Implications for the Position of the CCD

Dissolution of coccoliths is a much more sensitive indicator of carbonate dissolution than the carbonate content of sediments, because dilution with terrigenous material can lower the carbonate content without affecting coccolith preservation. The change in the position of the CCD in the Jurassic can be traced by simply looking at etching and diversity of coccolith assemblages. Backtracking and lithospheric subsidence curves and the application of sediment loading corrections (Fig. 3) indicate that Site 534 was originally at a water depth of about 2.3 km during the early to middle Callovian. Strongly etched coccoliths in lower middle Callovian, upper Callovian, and middle Oxfordian to lower Kimmeridgian sediments at this Site are indicative of sediment accumulation close to the CCD for much of the Jurassic. The CCD probably dropped quite rapidly during the Middle and Late Jurassic to a depth of over 4 km, and it continued to drop during the Early Cretaceous. A rapid rise of the CCD in the middle Albian is well documented at Site 534 and the rest of the Atlantic (Roth and Bowdler, 1981). Thus nannofossil preservation monitors carbonate dissolution.

Biogeography and Preservation: Effects on the Distribution of Jurassic Nannofossils

Although the dominant calcareous nannofossil species in Jurassic assemblages are dissolution resistant, a cursory examination of nannofossil assemblages from

Site 534 does not reveal any major differences with epicontinental sea assemblages from England. Careful tabulation of species, however, shows that at Site 534 there is a dearth of delicate nannofossil species belonging to the genera *Corollithion*, *Diadorhombus*, and *Stradnerlithus*. Even *Zygodiscus* and *Stephanolithion* are comparatively scarce. Biogeography and paleoecology seem to be less important factors than preservation in controlling the distribution of these delicate but stratigraphically important coccoliths. The relatively shallow position of the CCD (between 2.5 and 3.5 km) in the Callovian and Oxfordian would tend to make it unlikely that truly well preserved coccolith assemblages of this age will be recovered from oceanic sites other than perhaps from shallow plateaus. The two species *Corollithion geometricus* and *Stradnerlithus asymmetricus* do occur at Site 534, but they are the only two representatives of a group that consists of 16 to 18 species in deposits of the same age in England (Medd, 1982). Unfortunately poor preservation in oceanic sections overshadows any paleogeographic patterns that might have existed.

The Callovian species *Anusphaera helvetica* has been described from the Jura Mountains of Switzerland; it also occurs in the North Atlantic, and an attempt should be made to find it in other Jurassic sections to better document its biostratigraphic and biogeographic distribution. Better indications of the effect of nearshore conditions on coccolith assemblages can be found. The Upper Jurassic of England and northern France shows the influence of a great regression. Upper Kimmeridgian (*sensu anglico*) coccolith assemblages from the *Pectinatites elegans* Ammonite Zone to the *Palovia rotunda* Ammonite Zone of England show a decreased diversity and lack many of the "Tethyan" species such as *Conusphaera mexicana*, *Polycostella beckmannii*, *Hexalithus noelae*, and *Nannoconus* ssp. Some or all these species are well known from the Tethyan realm, including the Austroalpine Nappes of Austria (Flügel and Keupp, 1979), southern France (Thierstein, 1975), northern Italy (Canuti and Marucci, 1969), Algeria (Noël, 1957, 1959; 1965), and the Atlantic Ocean (Wilcox, 1972; Thierstein, 1975; Čepik, 1978; Wind, 1978; and Medd, this volume, and Mexico (Trejo, 1961, 1969). *Conusphaera mexicana* occurs in the Hauterivian in the Speeton Clay (Taylor, 1982) and is thus not excluded from Britain because of high latitude but probably because of nearshore conditions during the latest Jurassic. *Conusphaera mexicana* is also missing from the lower Tithonian of Solnhofen Limestone (Franconia) and thus seems to be intolerant of neritic conditions. Nannoconids are also present in the British Cretaceous (Hauterivian, Aptian, Cenomanian-Campanian), although diversity is low (Perch-Nielsen, 1979; Taylor, 1982; Crux, 1982); thus they seem to be missing from the uppermost Jurassic and basal Cretaceous because of nearshore conditions (variable and unusual salinities, water turbidity, fluctuating temperature, etc.) rather than high latitudes and the associated lower temperatures in Britain. Nearshore effects rather than biogeographic or preservational effects are responsible for the differences between the latest Jurassic nannoflora at

Site 534 and those in England. The great similarity of Tithonian nannofossils at Site 534 with Tethyan assemblages is due to the fact that fairly open-marine conditions existed in both places rather than that good connections existed between the Jurassic Atlantic, the Tethys, and the Pacific Ocean. Indirect connections between ocean basins are perfectly sufficient for nannoplankton dispersals, if there are no temperature or salinity "barriers" that would prevent such an exchange. Quite a few instances of coccolith dispersal by rather circuitous routes are known. A good example are the Aptian sediments from the South Atlantic that contain very similar assemblages to the ones in the North Atlantic, although the first established direct connection is the middle Albian (Roth and Bowdler, 1981).

Thus our knowledge of the paleobiogeography is very meager; and preservational changes distorted the nannofossil thanatocoenosis to a considerable extent, making our task even more complicated.

Paleoceanographic Conclusions Based on Calcareous Nannofossil Distributions

Moderately diverse calcareous nannoplankton assemblages populated the surface waters of the early North Atlantic during the Jurassic. Calcareous nannoplankton productivity cannot be estimated because dissolution and dilution with terrigenous sediment was high and thus it is difficult to calculate flux rates of pelagic carbonate. Assuming that all calcium carbonate in these cores was derived from coccoliths and using a sedimentation rate of 17 m/m.y., I calculated a sediment flux of about 4 g/cm² per thousand years. Calcium carbonate concentrations in Cores 127 to 100 vary between 10 and 90% but are in general between 20 and 50%. Using bulk densities and porosities determined in the laboratory as well as GRAPE data (Shipley, this volume) we can calculate carbonate fluxes of 0.8 to 3.6 g/cm² per thousand years. Such carbonate fluxes would be moderately high to high for the pelagic environment. However, the shipboard sedimentologists suspect large-scale mass transport from shallower regions to this Site, and these mass accumulation rates may not reflect purely pelagic fluxes. Thus they may be rather meaningless.

The Tithonian part (Cores 100-92) shows high carbonate accumulation rates (up to 4.2 g/cm² per thousand years). Estimates of absolute ages for the sediments recovered at Site 534 are insufficiently accurate to calculate more precise flux rates. The Early Cretaceous was also characterized by fairly high flux rates of pelagic carbonate (up to 4 g/cm² per thousand years), but once again much of it could be redeposited and little can be said about actual surface water productivity. Because dissolution was higher in the Jurassic than in the Early Cretaceous, pelagic carbonate fluxes and thus nannoplankton production in the surface water appears to have been as high or higher in the Jurassic than in the Early Cretaceous.

The high degree of dissolution in the upper Middle Jurassic and lower Upper Jurassic indicates a close proximity of Site 534 to the calcite compensation depth. In the latest Jurassic and the Lower Cretaceous (until the

early Aptian), the CCD was considerably deeper than the water depth at Site 534. The CCD shallowed abruptly in the Albian and stayed above the site of deposition until the end of the Cretaceous, with possibly a slight dip in the Maestrichtian (rare planktonic foraminifers and coccoliths occur in Core 25).

Calcareous nannoplankton distribution does not help very much in understanding Jurassic paleoceanography of the Atlantic. Impoverished assemblages of the late Middle Jurassic and early Late Jurassic at Site 534 are indicative of carbonate dissolution rather than paleoecological conditions in the surface water during the time of coccolith production. The Tethyan aspects of the Tithonian nannofossil assemblages mainly result from a lack of many species in English assemblages. Thus little can be said about connections of the early Atlantic with the Tethys, Pacific Ocean, and boreal seas based on coccolith occurrences.

Biogeographic distribution patterns do not provide any constraints on surface or bottom-water circulation patterns in the late Middle and Late Jurassic Atlantic. The position of the continents provides some constraints on surface-water circulation. A strong tropical Tethys current flowing in an east-west direction for the late Middle Jurassic and possibly the development of a clockwise gyre system in the Late Jurassic and Early Cretaceous are reasonable assumptions (Roth, 1978) that need to be substantiated by more precise information. Bottom-water circulation was rather sluggish in the Callovian, as indicated by organic carbon-rich shales. These bottom currents were probably also haline-driven with a high salinity water flux from marginal seas (e.g., the Gulf Coast region where large evaporite deposits of about the right age exist). Speculations on Jurassic paleoceanography remain vague because of the lack of sufficient information. However, coccoliths do provide a good means of biostratigraphy of Jurassic and Lower Cretaceous sediments.

NOTES ON SPECIES

Species of Jurassic and Cretaceous nannofossils cited in this report are listed in alphabetical order according to the species epithet. For each species, the species epithet is followed by the original author(s), by the possible subsequent author(s) who proposed the preferred combination, and by one or more references to illustrations that most closely approximate the species concepts used in this study. Reference to the illustrations in this paper (Plates 1-6) are added in parentheses. Remarks are added to clarify species concepts, especially with respect to the light optical identification of species.

Complete synonymy lists have not been prepared, and the interested reader is referred to the recent taxonomic literature, such as Grün and Zweili (1980) and Medd (1979) for the Jurassic, and Black (1971, 1973, 1975), Grün and Allemann (1975), Hill (1976), and Verbeek (1977) for more detailed taxonomic discussions. A detailed taxonomic treatment by Deres and Achéritéguy (1980) deals with nannocoids. Also, not all taxonomic references are listed in the reference list; they can be found in the "Annotated Index and Bibliography of the Calcareous Nannoplankton" by Loeblich and Tappan (1966-1973) and the "Bibliography and Taxa of Calcareous Nannoplankton" by Van Heck (1979-1982).

Parhabdolithus achlyostaurion Hill, 1976, p. 145, pl. 9, figs. 24-29. Taylor, 1982, pl. 4.5, fig. 11; pl. 4.8, figs. 2, 3. Crux, 1982, pl. 5.6, fig. 5; pl. 5.8, figs. 14, 15.

Corollithion achylosum (Stover, 1966) Thierstein, 1971. Stover, 1966, p. 137, pl. 6, fig. 26; pl. 7, fig. 20. Thierstein, 1971, p. 480, pl. 7, figs. 12-16. Hill, 1976, pp. 129-130, pl. 4, figs. 11-18; pl. 13, figs. 18, 19.

Braarudosphaera africana Stradner, 1961, p. 82, text-fig. 44. Hill, 1976, p. 124, pl. 2, figs. 10-13, fig. 15.

Hayesites albiensis Manivit, 1971, p. 138, pl. 14, figs. 1-7. Hill, 1976, pp. 142-143, pl. 7, figs. 19-20; pl. 14, figs. 11-12.

Bukryolithus ambiguus Black, 1971, p. 416, pl. 33, fig. 6. Taylor, 1982, pl. 4.5, fig. 2.

Ethmorhabdus sp. cf. *E. anglicus* Rood, Hay, and Barnard, 1971, p. 263, pl. 3, fig. 8. Grün and Zweili, 1980 p. 272, pl. 8, figs. 1-3.

Remarks. This species differs from *E. gallicus* in having fewer perforations in its central area. I have assigned small specimens of *Ethmorhabdus* with relatively few holes in the central area to *E. sp. cf. E. anglicus*. Because only light microscopy was used, it was sometimes difficult to determine with certainty that the observed specimens were identical to the ones described by the original authors as *Ethmorhabdus anglicus*.

Vagalapilla angusta (Stover, 1966) Roth, 1981. Stover, 1966, p. 147, pl. 3, figs. 14, 15; pl. 8, fig. 22. Roth, 1981, p. 486.

Retecapsa angustiforata Black, 1971, p. 409, pl. 33, fig. 3. Roth, 1978, p. 748, pl. 1, figs. 3-5.

Remarks. Unless preservation is excellent it is difficult to distinguish this species from *Retecapsa brightoni* Black, 1971 and thus the two species are here lumped under *R. angustiforata*. However, *R. angustiforata* is readily distinguishable from *Re. neocomiana* by its larger central area and better-developed struts and pores.

Rhagodiscus asper (Stradner, 1963) Reinhardt, 1967. Stradner, 1963, p. 11, pl. 2, figs. 4, 5. Reinhardt, 1967, p. 167. Roth and Thierstein, 1972, pl. 7, figs. 7-17.

Stradnerolithus asymmetricus (Rood, Hay, and Barnard, 1971) Medd, 1979. Rood, Hay, and Barnard, 1971, p. 255, pl. 1, fig. 7. Medd, 1979, p. 47, pl. 3, fig. 5. Barnard and Hay, 1974, pl. 2, fig. 12; pl. 5, fig. 11.

Watznaueria barnesae (Black, 1959) Perch-Nielsen, 1968. Black, 1959, p. 325, pl. 9, figs. 1-2. Perch-Nielsen, 1968, p. 69, pl. 22, figs. 1-7; pl. 23, figs. 1, 4, 5, 16; text-fig. 32. Hill, 1976, pp. 159-160, pl. 12, figs. 16-18; pl. 15, figs. 21-24. (Plate 2, Figs. 3-4.)

Remarks. Although many authors claim that *Watznaueria barnesae* is restricted to the Cretaceous I have observed forms that are optically indistinguishable from the Cretaceous *Watznaueria* in sediments as old as middle Callovian. The presence or absence of an inner cycle of elements surrounding the central area in the proximal shield could be caused by variations in the degree of secondary calcite overgrowth. I use this species for specimens of *Watznaueria* that have a more or less closed central area; they behave optically identically in the Jurassic and Cretaceous; I see no reason for using a different species or genus for the Jurassic forms.

Polypodorhabdus sp. cf. *P. beckii* Medd, 1979, p. 66, pl. 6, fig. 6. (Plate 3, Figs. 23-24.)

Remarks. A small polypodorhabdid with a central area filled with a central cross supported by a small number of struts was observed in the light microscope. It is very similar to *Polypodorhabdus beckii*, which has only been illustrated in the electron microscope.

Polycostella beckmannii Thierstein, 1971, p. 483, pl. 2, figs. 5-16.

Nannoconus bermudezii Brönnimann, 1955, p. 37, pl. 2, fig. 1, 24. Deres and Achéritéguy, 1980, p. 18, pl. 2, fig. 12; pl. 3, fig. 8.

Braarudosphaera bigelowii (Gran and Braarud, 1935) Deflandre, 1947. Gran and Braarud, 1935, p. 389, text-fig. 67. Deflandre, 1947, p. 439, text-figs. 1-5. Manivit, p. 125, pl. 3, figs. 13-16.

Stephanolithion bigotii Deflandre, 1939, p. 1332, figs. 1-9. Deflandre and Fert, p. 146, pl. 15, figs. 1-6. (Plate 1, Figs. 18, 19.)

Chiastozygus bilamellus Worsley, 1971, p. 1306, pl. 1, figs. 8-10.

Watznaueria biporta Bukry, 1969, p. 32, pl. 10, figs. 8-10. Worsley, 1971, p. 1314, pl. 2, figs. 23-25 (as *W. cynthae*).

Bipodorhabdus biradiatus (Worsley, 1971) Thierstein, 1973. Worsley, 1971, p. 1311, pl. 1, figs. 51-52. Thierstein, 1973, p. 42, pl. 6, figs. 7-11.

Nannoconus boletus Deflandre and Deflandre-Rigaud, 1962, p. 2639, figs. 6-8. Deres and Achéritéguy, 1980, pp. 26-27, pl. 6, fig. 4.

- Nannoconus bonetii* Trejo, 1959, p. 131, fig. 2a-f. Deres and Achéritéguy, 1980, pp. 18-19, pl. 2, fig. 11.
- Watznaueria britannica* (Stradner, 1963) Reinhardt, 1964. Stradner, 1963, p. 10, pl. 1, fig. 7. Reinhardt, 1964, p. 753, pl. 2, fig. 3, text-fig. 5. Thierstein, 1976, pl. 4, figs. 24-25.
- Remarks.** I only assign specimens to this species that show a clear and relatively highly birefringent double bridge crossing an open central area. Specimens with a low birefringent bridge or a platelike central area structure are assigned to *Watznaueria communis*.
- Nannoconus broennimannii* Trejo, 1959, p. 130, fig. 1a-f. Deres and Achéritéguy, 1980, p. 15, pl. 2, figs. 6, 13. (Plate 6, Fig. 12.)
- Amphizygus brooksii* Bukry, 1969, p. 47, pl. 25, figs. 1-3. Hill, 1976, pp. 121-122, pl. 1, figs. 1-11. (Plate 4, Figs. 9-11.)
- Nannoconus bucheri* Brönnimann, 1955, p. 39, pl. 1, figs. 1-3, 5-7. Deres and Achéritéguy, 1980, p. 20, pl. 3, fig. 6.
- Lithraphidites carniolensis* Deflandre, 1963, p. 3486, text-figs. 1-10. Hill, 1976, pp. 19-20, pl. 8, figs. 8-9; pl. 14, figs. 15-16.
- Proculithus charlotteii* Medd, 1979, pp. 55-56, pl. 10, fig. 11; pl. 11, fig. 9.
- Cruciellipsis chiastia* (Worsley, 1971) Thierstein, 1972. Worsley, 1971, p. 1310, pl. 1, figs. 42-44. Thierstein, in Roth and Thierstein, 1972, p. 437, pl. 6, figs. 8-13. Thierstein, 1976, pl. 4, figs. 28-29.
- Hagius circumradiatus* (Stover, 1976) Roth, 1978. Stover, 1966, p. 138, pl. 5, figs. 2-4; pl. 9, fig. 10. Roth, 1978, pp. 746, 748.
- Speetonia colligata* Black, 1971, p. 413, pl. 34, fig. 10. Thierstein, 1976, pl. 3, figs. 7, 8.
- Stradnerolithus comptus* Black, 1971, p. 415, pl. 31, fig. 10. Medd, 1979, p. 49, pl. 3, figs. 7, 8.
- Nannoconus colomii* (de Lapparent, 1931) Kamptner, 1938. de Lapparent, 1931, p. 223. Thierstein, 1971, p. 483, pl. 3, fig. 16. Deres and Achéritéguy, 1980, pp. 15-16, pl. 2, figs. 2, 8; pl. 3, fig. 3 (as *N. steinmanni*) and p. 17, pl. 2, figs. 4, 9; pl. 3, fig. 1.
- Remarks.** I consider the small increase in width of the basal part of the central cavity as not significant enough to warrant the separation of *N. colomii* and *N. steinmanni* and consider the two species synonymous. Small specimens of *N. colomii*, less than 8 μm in total length, appear together with *Conusphaera mexicana* in the Tithonian. They are quite comparable with *Nannoconus steinmanni minor* of Deres and Achéritéguy (1980); they are here assigned to *Nannoconus* sp. cf. *N. colomii*.
- Watznaueria communis* Reinhardt, 1964, p. 756, pl. 2, fig. 5; text-fig. 6. Thierstein, 1976, pl. 2, figs. 12, 13. (Plate 2, Figures 17-18).
- Remarks.** Specimens of *Watznaueria* that have a relatively small central area with a low-birefringent bridge or plate are assigned to this species. Often, the central area structure is missing, possibly because of dissolution; specimens without central area structures become almost indistinguishable from *W. ovata*, which generally has thicker shields and a relatively larger central area. Medd (1979) included specimens here assigned to *W. communis* in *W. britannica*, which I used in a more restricted sense. *Ellipsagelosphaera keftalrempti* Grün and *E. fossacinta* Black appear to be junior subjective synonyms of *Watznaueria communis*.
- Vagalapilla compacta* Bukry, 1969, p. 57, pl. 31, figs. 10-12. Roth, 1981, p. 486.
- Cretarhabdus conicus*. Bramlette and Martini, 1964, p. 299, pl. 3, figs. 5-9. Hill, 1976, p. 132, pl. 4, figs. 25-30; pl. 13, figs. 23-24. Taylor, 1982, pl. 4.3, figs. 11, 12; pl. 4.7, fig. 18.
- Remarks.** Specimens with a pronounced central cross and more than one cycle of perforations in the central area were included in this species. It differs from *Cretarhabdus* cf. *multiforus* in having a brighter central area under crossed nicols and less regular pore patterns. Variability in this species is large, and a detailed study of this group in the light and electron microscopes could result in a finer subdivision of the group. Previous attempts (e.g., Black, 1971, 1972, 1973) were not satisfactory as far as light microscopy is concerned.
- Hemipodorhabdus conjugatus* Medd, 1979, p. 62, pl. 5, figs. 4, 8, 9, 12.
- Biscutum constans* (Gorka, 1957) Black, 1967, Gorka, 1957, p. 279, pl. 4, fig. 7. Black, 1967, p. 139. Roth and Thierstein, 1972, pl. 8, figs. 13-18.
- Tetrapodorhabdus coptensis* Black, 1971, p. 411, pl. 31, fig. 7. Taylor, 1982, pl. 4.1, figs. 4, 8; pl. 4.7, fig. 2.
- Nannoconus cornutus* Deres and Achéritéguy, 1980, pp. 17-18, pl. 1, fig. 3.
- Grantarhabdus coronadventis* (Reinhardt, 1966) Grün, 1975. Reinhardt, 1966, p. 26, pl. 23, figs. 29, 30. Grün, in Grün and Allemann, 1975, p. 184. Stover, 1966, p. 149, pl. 5, figs. 15, 16; pl. 9, fig. 15 (as *Cretarhabdus unicornis*). Roth and Thierstein, 1972, pl. 5, figs. 1-9.
- Crepidolithus crassus* (Deflandre, 1954) Noël, 1965. Deflandre, in Deflandre and Fert, 1954, p. 144, pl. 15, figs. 12-13. Noël, 1965, p. 85, pl. 2, figs. 3-7, pl. 3, figs. 1-5. Thierstein, 1976, pl. 2, figs. 6, 7.
- Cretarhabdus crenulatus* Bramlette and Martini, 1964, p. 300, pl. 2, figs. 21-24. Hill, 1976, p. 133, pl. 4, figs. 31-42; pl. 13, figs. 25-26.
- Remarks.** Small specimens of a cretarhabdid with a relatively small central area filled with a perforate central structure that appears coarsely granular in the light microscope are the oldest true cretarhabdids that appear in the Cretaceous. They are assigned to *Cretarhabdus* sp. cf. *C. crenulatus*. More typical specimens with a larger central area with 8 or more perforations appear in Zone NC2 and are found throughout the Cretaceous.
- Deflandrius cretaceus* (Arkhangelski, 1912) Bramlette and Martini, 1964. Arkhangelski, 1912, p. 410, pl. 6, figs. 12-13. Bramlette and Martini, p. 301, pl. 2, figs. 11-12.
- Remarks.** As pointed out by Tappan (1980) *Prediscosphaera* Vekshina, 1959 is invalid and the genus *Deflandrius* Bramlette and Martini, 1964 is the earliest available genus. I consider the shape of the basal disc in this species as variable because the whole range of shapes from circular to elliptical is observed. Thus forms assigned to *Deflandrius columnatus* Stover by other authors are included in *Deflandrius cretaceus*.
- Watznaueria crucicentralis* (Medd, 1971) Thierstein, 1976, Medd, 1971, p. 829, p. 829, pl. 1, figs. 1-2. Thierstein, 1976, pl. 2, figs. 8, 9. (Plate 3, Figs. 15-16.)
- Remarks.** This species has a bright *Watznaueria*-like rim. Some specimens with a more irregular cross that fills the central area more completely have been assigned to *Watznaueria* sp. cf. *W. crucicentralis*.
- Cruciellipsis cuvillieri* (Manivit, 1966) Thierstein, 1971. Manivit, 1966, p. 268, figs. 2, 3. Thierstein, 1971, p. 478, pl. 5, figs. 4-8. Wind and Čeppek, 1979, p. 228, pl. 2, figs. 11-13 (Plate 5, Figs. 4-7.)
- Remarks.** I only include specimens with a shield showing the individual elements well even in the light microscope in ordinary light and with a well developed fibrous cross with tapering arms; specimens that do not show these characteristic features such as Wind (1978), p. 764, pl. 1, figs. 6, 7 are assigned to *Cruciellipsis* sp. cf. *C. cuvillieri* (pl. 3, figs. 20-22). *Cruciellipsis cuvillieri* appears to evolve from *Polyopodorhabdus madingleyensis* in the earliest Cretaceous, with transitional forms commonly appearing in the uppermost Tithonian. An increase in the thickness of the cross bars is noticed in many upper Tithonian specimens of *P. madingleyensis*; it seems to precede the thickening of the shield elements that is not completed until the Berriasian.
- Hexapodorhabdus cuvillieri* Noël, 1965, p. 105, pl. 9, figs. 4-6. Barnard and Hay, 1974, pl. 2, fig. 9; pl. 5, fig. 8. Hamilton, 1982, pl. 3.3, fig. 1, pl. 3.4, fig. 11.
- Axopodorhabdus cylindratus* (Noël, 1965) Wind and Wise, 1976. Noël, 1965, p. 103, pl. 9, figs. 3, 7; text-fig. 30. Wise and Wind, 1976, p. 297, pl. 80, figs. 5, 6; pl. 81, figs. 1-4, pl. 88, figs. 5, 6. Thierstein, 1976, pl. 2, figs. 10, 11. (Plate 1, Fig. 14.)
- Octopodorhabdus decussatus* (Manivit, 1961) Rood, Hay, and Barnard, 1971. Manivit, 1971, p. 344, pl. 1, fig. 7. Rood, Hay, and Barnard, 1971, p. 262, pl. 3, fig. 4. Stradner, Adamiker, and Maresch, 1968, p. 29, pl. 13, figs. 1, 2; pl. 14, figs. 1-6. Medd, 1979, p. 64, pl. 5, figs. 5-7; pl. 6, fig. 1.
- Cyclagelosphaera deflandrei* (Manivit, 1966) Roth, 1973. Manivit, 1966, p. 268, fig. 1a-c. Roth, 1973, pp. 723-724, pl. 26, fig. 7. Thierstein, 1976, pl. 2, figs. 20-21. (Plate 2, Figs. 1, 2.)
- Remarks.** Large, highly birefringent placoliths that are circular to slightly subcircular occur in the middle Callovian to Valanginian interval at this site. They are assigned to this species. The exact relationship of *Cyclagelosphaera deflandrei* (Manivit) Roth and *Actinosphaera deflandrei* Noël, the latter being distinctly elliptical, needs further study. Optically Jurassic and Cretaceous specimens assigned to *C. deflandrei* are indistinguishable.
- Axopodorhabdus dietzmannii* (Reinhardt, 1965) Wind and Wise, 1977. Reinhardt, 1965, p. 30, pl. 1, fig. 1; text-fig. 1. Wind and Wise, in Wise and Wind, 1977, p. 297, pl. 58, figs. 3, 4. Thierstein,

- 1971, p. 478, pl. 8, figs. 1–8. Hill, 1976, pp. 149–150, pl. 10, figs. 31–33; pl. 11, figs. 1–2; pl. 15, fig. 5.
- Zygodiscus diplogrammus* (Deflandre, 1954) Gartner, 1968. Deflandre, in Deflandre and Fert, 1954, p. 148, pl. 10, fig. 7; text-fig. 57. Gartner, 1968, p. 32, pl. 21, fig. 2; pl. 22, fig. 7. Hill, 1976, p. 161, pl. 12, figs. 25–27; pl. 15, figs. 25–26.
- Nannoconus dolomiticus* Cita and Pasquare, 1959, pp. 426–431, pl. 28, figs. 3–5; text-figs. 6(7–10). Deres and Achéritéguy, 1980, p. 14, pl. 2, fig. 2.
- Palaeopontosphaera dubia* Noël, 1965, p. 76, pl. 7, figs. 1–13. Barnard and Hay, 1974, p. 2, fig. 2, pl. 5, fig. 1.
- Remarks.** *Palaeopontosphaera dubia* seems to be the ancestor of the Cretaceous genus *Biscutum*. The transition between *Palaeopontosphaera dubia* and *Biscutum constans* is observed in the lowermost Berriasian at Site 534; the most pronounced change is a thickening of the rim, an overall increase in size, and an enlargement of the central area.
- Rhagodiscus eboracensis* Black, 1971, p. 419, pl. 33, fig. 9. Wind and Cepek, 1979, p. 231, pl. 5, figs. 11–13.
- Remarks.** This species is similar to *Rhagodiscus asper* but has a wider margin, lacks perforation, and never has a stem.
- Zygodiscus elegans* Gartner, 1968, p. 32, pl. 10, figs. 3–6; pl. 12, figs. 3–4; pl. 27, fig. 1. Roth and Theirstein, 1972, p. 437, pl. 10, figs. 16–20.
- Parhabdololithus embergeri* (Noël, 1959) ex Hill, 1976 Noël, 1959, p. 164, pl. 1, figs. 5, 6, 7, 8. Hill, 1976, pp. 147–148, pl. 9, figs. 30–31; pl. 10, figs. 1–5.
- Remarks.** This species evolves from *Zygodiscus salillum* in the Upper Jurassic. First a thick, multilayered wall develops, but the specimens remain largely in the 7.5 to 9 μm size range. In the uppermost Tithonian, specimens of 9 μm to 10 μm were observed. Specimens reaching the size specified by Noël in the original description, namely 12 to 24 μm , are not found below the Cretaceous at Site 534. I used the change from a more narrow wall to a multilayer wall as the main criterion for separating this species from its ancestor. Because of variable species concepts for this species, its range as reported in the literature is not commonly reliable.
- Zygodiscus erectus* (Deflandre, 1954) Manivit, 1971. Deflandre, in Deflandre and Fert, 1954, p. 150, pl. 15, figs. 14–17; text-figs. 60–62. Manivit, 1971, pp. 78–79, pl. 29, figs. 1–3, 5–8. Medd, 1979, p. 46, pl. 2, figs. 7, 8; pl. 9, fig. 10, pl. 10, figs. 1–3.
- Remarks.** *Zygrhabdotus noelae* Rood, Hay, and Barnard, 1971 is a junior subjective synonym of this species. I assigned small specimens of *Zygodiscus* with a single bar and a small stem or knob to this species. Somewhat larger specimens with a narrower rim assigned to *Zygrhabdotus bussoni* (Noes) by Medd (1979) have also been included in *Zygodiscus erectus*.
- Palaeopontogphaera erismatica* Wind and Wise, 1976, p. 303, pl. 78, figs. 4–6.
- Remarks.** This species is distinguished from *P. dubia* in the light microscope by a well developed central knob. The crosslike structure is only visible in the electron microscope.
- Polypodorhabdus escaigii* Noël, 1965, p. 109, pl. 10, figs. 6–8; text-fig. 32. Thierstein, 1976, pl. 2, figs. 22–25. (Plate 3, Figs. 4–6, 25–27.)
- Discorhabdus exilitus* Noël, 1965, pp. 147–148, pl. 13, fig. 1.
- Proculithus expansus* Medd, 1979, p. 56, pl. 11, figs. 1, 5, 6.
- Reinhardtites fenestratus* (Worsley, 1971) Thierstein, 1972. Worsley, 1971, p. 1305, pl. 1, figs. 33–35. Thierstein, in Roth and Thierstein, 1972, p. 437, pl. 8, figs. 1–12.
- Zygodiscus fissus* (Grün and Zweili, 1980) n. comb. **Basionym:** *Zygrhabdotus ? fissus* Grün and Zweili, 1980, *Jahrb. Geol. Bundesanst.* 123, p. 269, pl. 15, figs. 9–12. (Plate 1, Figs. 23–24).
- Remarks.** This species is easily recognizable in the light microscope because of its split double bridge, with the greatest separation of the two laths making up the bridge in the center and a diminishing distance between them toward the rim.
- Lithastrinus floralis* Stradner, 1962 ex Bukry, 1969. Stradner, 1962, p. 370, pl. 2, figs. 6–11. Bukry, 1969, p. 43, pl. 21, figs. 1–2. Hill, 1976, partim, p. 143, pl. 7, figs. 21–35; pl. 14, figs. 13–14 (non pl. 7, figs. 36–39; pl. 8, figs. 1–7).
- Remarks.** I do not include *Radiolithus planus* in this species and reserve *L. floralis* for specimens with a floor within the tube, giving them an H-shaped cross section.
- Ethmorhabdus frondosus* Wind and Wise, 1976, in Wise and Wind, 1976, p. 300, pl. 76, figs. 1, 2.
- Cruciplacolithus furtivus* n. sp. (Plate 6, Figs. 1–4.)
- ?*Cruciplacolithus hayi* Black, Hill, 1976, p. 136, pl. 11, figs. 27–28. (Non *Cruciplacolithus hayi* Black, 1973, p. 66, pl. 23, figs. 9–10.)
- ?*Cruciplacolithus hayi* Black, Köthe, 1982, partim, p. 31, pl. 7, fig. 15 (non fig. 14).
- Definition.** A species of *Cruciplacolithus* with a delicate rim, composed of two cycles and a central cross that may have a grill connecting the cross arms with the rim.
- Description.** Study of this new species under ordinary light, phase contrast, and polarized light show that the shield elements are thin and not highly imbricate. In ordinary light and phase contrast illumination the rim appears faint and delicate. In cross-polarized light the rim displays an extinction cross with slightly counterclockwise-inclined arms that are narrow near the center and flare towards the periphery. The extinction figure is reminiscent of the one observed in the Tertiary genus *Reticulofenestra*. Thus the rim appears to be composed of a wide outer cycle of nonimbricate to slightly imbricate elements and a narrower inner cycle surrounding the central area.
- A cross in the central area is built of narrow laths and tapers from the center to the rim. A sheetlike, perforate structure connects the crossarms and the rim in some specimens. The cross appears to be slightly asymmetrical in some specimens but not in others. Occasionally the cross bars in the long axis are missing and only a slightly oblique bridge subparallel to the short axis of the elliptical central area is present. It is not known if the long arms of the cross are broken or if this is a primary feature of some specimens.
- Remarks.** Although *Cruciplacolithus hayi* was originally described in the electron microscope, it seems quite certain that its sturdy and imbricate elements would produce a rim structure that appears less delicate in the light microscope. Specimens assigned to *Cruciplacolithus hayi* Black by Hill and Köthe are quite similar to *Cruciplacolithus furtivus* n. sp. but have a narrower rim. These specimens illustrated by Hill (1976) and Köthe (1982) are definitely more similar to *Cruciplacolithus furtivus* n. sp. than to *Cruciplacolithus hayi* Black.
- Holotype.** Specimen illustrated on Plate 6, Figs. 1–2, DSDP 534A-61-2, 76 cm.
- Paratype.** Specimen illustrated on Plate 6, Figs. 3–4, DSDP 534A-61-2, 76 cm.
- Dimensions**
- Holotype.** Maximum diameter: 9 μm . Maximum diameter of central area: 3.5 μm . Eccentricity: 1.2
- Paratype.** Maximum diameter: about 10 μm . Maximum diameter of central area: 4.3 μm . Eccentricity: about 1.4 (based on eccentricity of the central area).
- Distribution.** In Hole 534A this species ranges from Zone NC4 to Zone NC5, with a single occurrence in Zone NC8, upper Hauterivian–Barremian, middle Albian, or Merititan to Magellanian oceanic stages. Closely related forms have been described as *Cruciplacolithus hayi* (not *Cruciplacolithus hayi* of Black, 1973) from the upper Hauterivian to lower Barremian of northern Germany (Köthe, 1982) and the middle to upper Albian of Texas (Hill, 1976).
- This species is quite rare, but easily recognizable and thus potentially useful for biostratigraphy.
- Tranolithus gabalus* Stover, 1966, p. 146, pl. 4, fig. 22; pl. 9, fig. 5. Hill, 1976, p. 156, pl. 11, figs. 36–41; pl. 15, fig. 13.
- Ethmorhabdus gallicus* Noël, 1965, p. 110, pl. 10, figs. 1, 2, 5; text-figs. 33–34. Thierstein, 1976, pl. 2, figs. 15–18.
- Corollithion geometricum* (Gorka, 1957) Manivit, 1971. Gorka, 1957, p. 259, pl. 4, fig. 8. Manivit, 1971, p. 109, pl. 5, figs. 4–5. Barnard and Hay, 1974, pl. 3, fig. 7; pl. 6, fig. 6. Hill, 1976, pl. 30, figs. 19, 20; pl. 13, fig. 20.
- Nannoconus globulus* Brönnimann, 1955, p. 37, pl. 2, figs. 13, 18, 23; text-fig. 3a–b. Deres and Achéritéguy, 1980, p. 16, pl. 2, figs. 5, 15; pl. 3, fig. 7. (Plate 6, Fig. 16.)
- Gaarderella granulifera* Black, 1973, p. 65, pl. 19, figs. 6, 10–13. Roth, 1981, pl. 1, fig. 5a, b. Taylor, 1982, pl. 4.7, fig. 13.
- Podorhabdus grassei* Noël, 1965, p. 103, pl. 9, figs. 1, 2. Grün and Zweili, 1980, pp. 264–265, pl. 5, figs. 3–8.
- Remarks.** Wise and Wind (1976) demonstrated that *P. grassei* has only two perforations rather than four. Noël (1965) gives only side

views of this species, and it seems possible that *Hemipodorhabdus conjugatus* Medd, 1979 is a subjective junior synonym of *P. grassei*.

Also *Discorhabdus biperforatus* Rood, Hay, and Barnard of Hamilton (1982, pl. 3.2, fig. 17) appears to be a distal view of *Podorhabdus grassei* Noël with the stem broken off. This group of podorhabdids with only two perforations in the center needs careful study, including a restudy of topotype material. I assigned specimens with a thick stem and two pores to *P. grassei*, specimens with a thinner stem (or a central hole, if the stem was broken off) to *Hemipodorhabdus conjugatus*, but this assignment might not be totally satisfactory as there is a great variability among these forms.

Anfractus harrisonii Medd, 1979, p. 38, pl. 1, figs. 1-4.

Remarks. This species is difficult to recognize in the light microscope. Coccoliths with a narrow rim, a granular center, a central knob, or elliptical hole were assigned to this species. If a central knob or big hole was absent, they were assigned to *Ahmuellerella ? retiformis* Reinhardt. A study of topotype material for Reinhardt's and Medd's species is needed to clarify their relationship.

Polypodorhabdus harrisonii Medd n. sp. (Plate 3, Figs. 7-9)

? *Cretarhabdus quadratus* (Black) Wind, 1978, p. 764, pl. 1, figs. 8-9.
Retecapsa schizobrachiata (Gartner) Grün, in Grün and Zweili, 1980, pp. 273-274, pl. 8, figs. 10-12; text-fig. 28 (non text-fig. 29b). Non
Vekshinella schizobrachiata Gartner, 1968, p. 31, pl. 13, figs. 10-11; pl. 20, fig. 5.

Definition. A species of *Polypodorhabdus* with a central cross composed of relatively few broad laths connected to the rim by trifurcate terminations.

Description. This elliptical coccolith is composed of two shields, a proximal shield and a slightly larger, closely appressed distal shield. The distal shield consists of two cycles of elements of almost equal width. The outer cycle contains about 30 tabular elements that are separated by essentially radial suture lines and show slightly dextral imbrication. The inner cycle consists of an about equal number of tabular elements with also essentially radial sutures. The proximal shield also consists of two cycles of about equal width composed of about 30 tabular elements. The elliptical central area is about two-thirds the size of the distal shield. It is spanned by a cross structure with arms in the long and short axis of the ellipse. The cross arms are composed of about three to four rather long and broad laths. A central knob composed of about eight elements and a central perforation or a rarely preserved hollow stem of about the same number of long laths forms the center of the distally convex cross structure. On the proximal side the cross bars display a distinctive central depression, and a deep central depression exists in the center of the whole cross structure. The terminations of the cross bars in the long axis consist of a tapered central branch and two flat side branches at an angle of about 70° with the axis of the main cross arm and separated from it by small triangular perforations. The terminations of the cross bars in the short axis are broadly flaring, with only slight indications of trifurcation but lacking pores between the side branches and the main branch. In the light microscope this species displays the typical relatively highly birefringent "cretarhabdid" rim, with a diffuse extinction cross and a stout central cross with trifurcate or broadly flaring terminations. The four large pores in the central area are clearly visible in the light and electron microscopes; the small perforation between the cross bar and their terminal side branches are triangular and only visible in the electron microscope.

Remarks. This species differs from *Retecapsa schizobrachiata* (Gartner) Grün in that it has a central cross composed of fewer and relatively larger crystallites and thus a less fibrous composition. *Polypodorhabdus harrisonii* Medd n. sp. resembles *Polypodorhabdus madingleyensis* in the rim structure, but the central cross is composed of a bundle of thick laths and is connected to the rim by a trifurcate structure of short struts. There are no additional laths connecting the rim and the cross in the four holes between cross arms and the rim. Specimens with less well developed trifurcate cross arm tips but a coarse, stout cross have been assigned to *Polypodorhabdus* sp. cf. *P. harrisonii*. Only specimens that show additional struts in the areas between cross bars were assigned to *Polypodorhabdus madingleyensis* or *Polypodorhabdus* sp. cf. *P. madingleyensis* (see *P. madingleyensis* for further discussion).

Holotype. The specimen illustrated by Grün and Zweili, 1980, pl. 8, fig. 10, Oxfordian, lower Renggeri-Clays (p. 3), Liesberg, Switzerland.

Paratypes. The specimens illustrated by Grün and Zweili, pl. 8, figs. 11, 12; this chapter, Pl. 3, Figs. 7-9.

Dimensions

Holotype. Maximum diameter: 4.5 μm . Maximum of central area: 3.0 μm . Eccentricity: 1.2.

Paratypes. Maximum diameter: 4.4 to 6.7 μm .

Distribution. This species occurs in Oxfordian Renggeri-Tonen of the Clay Pits South of Liesberg, Switzerland (holotype), in the *Vagalpilla stradneri* and *Conusphaera mexicana* Zones (Oxfordian-Tithonian) at Site 534, Blake-Bahama Basin, and in the Oxfordian of England (Medd, personal communication, 1982).

Cruciplacolithus hayi Black, 1973, p. 66, p. 23, figs. 9, 10. Köthe, 1982, partim, p. 31, pl. 7, fig. 14 (non fig. 15).

Remarks. This species was originally described only in the electron microscope. Two different forms have been assigned to this species by Köthe (1982): namely, a form with a delicate margin with a diffuse extinction cross (pl. 7, fig. 15a, b), similar to the illustrations given by Hill (1976, pl. 11, figs. 27, 28), which does not seem to agree with the original description and illustrations for *Cruciplacolithus hayi* by Black, 1973; the other form illustrated by Köthe, 1982 (pl. 7, fig. 14a, b) seems to be identical to *Cruciplacolithus hayi* Black as far as one can compare electron and light micrographs without the use of topotype material and a study of the same specimens in both microscopes. Thus I assigned small coccoliths with a highly birefringent margin and a relatively small central area with a well developed central cross to *Cruciplacolithus hayi* Black. Forms with delicate rims and cross structures such as specimens illustrated as *Cruciplacolithus hayi* by Hill (1976) and Köthe (1982 partim, pl. 15a, b) do not belong to *Cruciplacolithus hayi* but should be assigned to *Cruciplacolithus* sp. cf. *C. furtivus* n. sp.

Ansulospaera helvetica Grün and Zweili, 1980, pp. 261-262, pl. 4, figs. 6-11; text-fig. 19. (Plate 1, Figs. 4-7, 11-13.)

Remarks. This species was originally described in the electron microscope but is easily recognizable in the light microscope in side view. It is composed of an upper shield that protrudes beyond the outer limits of the lower columnar part. It appears that the upper shield and the lower columnar part are optically continuous, and it seems likely that the elements making up the shield and the column are also continuous. The central cavity is narrow and widens towards the base of the columnar lower part of the coccolith. Top or bottom views of this species appear to be difficult to recognize in the light microscope. Its restricted range (lower to middle Callovian, if confirmed by future observation) could make it an important stratigraphic marker. So far it has only been described from the "Callovien-Tone," lower Callovian of the Liesberg Clay Pit, Jura Mountains and the lower Callovian to middle Callovian of DSDP Hole 534A in the western Atlantic.

Stephanolithion hexum Rood and Barnard, 1972, p. 329, pl. 1, figs. 3, 4, 9, 10; text-fig. 1. Barnard and Hay, 1974, pl. 3, fig. 1; pl. 5, fig. 12. Hamilton, 1982, pl. 3.2, fig. 3; pl. 3.4, fig. 16. (Plate 1, Figs. 1-3, 8-10.)

Sollasites horticus (Stradner, Adamiker, and Maresch, 1966) Čepel and Hay, 1969. Stradner, Adamiker, and Maresch, 1968, p. 337, pl. 2, fig. 4; text-figs. 1-2. Čepel and Hay, 1969, pp. 325, 327, fig. 2 (8). Hill, 1976, pp. 154-155, pl. 11, figs. 24-26; pl. 15, fig. 10.

Discorhabdus ignotus (Gorka, 1957) Perch-Nielsen, 1968. Gorka, 1957, p. 248, pl. 2, fig. 9. Perch-Nielsen, 1968, p. 81, pl. 28, figs. 6-8; text-figs. 41-42. Hill, 1976, pp. 137-138, pl. 6, figs. 12-18; pl. 14, figs. 4-5.

Parhabdololithus infinitus (Worsley, 1971) Thierstein, 1972, Worsley, 1971, p. 1311, pl. 1, figs. 48-50. Thierstein, in Roth and Thierstein, 1972, p. 437, pl. 9, figs. 7-16. Wise and Wind, 1976, pl. 56, figs. 4-6.

Assipetra infracretacea (Thierstein, 1973) Roth, 1973. Thierstein, 1973, p. 46, pl. 1, figs. 1-19. Roth, 1973, p. 729, pl. 25, figs. 5, 7. *Rucinolithus irregularis* Thierstein, 1972. Thierstein, in Roth and Thierstein, 1972, p. 438, pl. 2, figs. 10-19. Thierstein, 1973, p. 45, pl. 3, figs. 1-14.

Discorhabdus jungii Noël, 1965, p. 144, pl. 22, fig. 5. Hamilton, 1982, partim, pl. 3.2, fig. 14; pl. 3.4, fig. 25 (non fig. 24).

Remarks. Only specimens with a thick, flaring stem are assigned to *D. jungii*. Specimens with a relatively narrow stem that flares at the upper end belong to *D. patulus* (see Medd, 1979).

Watznaueria sp. cf. *W. jurapelagicus* Worsley, 1971, p. 1315, pl. 2, figs. 29–31. Roth, 1973, pl. 26, fig. 6a–c (as *Tubodiscus jurapelagicus* (Worsley) Roth).

Remarks. In the uppermost Tithonian I observed a few specimens that resemble *Watznaueria* sp. cf. *jurapelagicus*; they have a relatively narrow rim but do not have a high collar surrounding the central area; thus I did not assign them to *Tubodiscus* and prefer Worsley's original combination. The specimens are too rare and too much recrystallized to warrant further study.

Nannoconus kamptneri Brönnimann, 1955, p. 37, pl. 2, figs. 14, 16, 20, 21, text-fig. 2i–m. Deres and Achéritéguy, 1980, p. 19, pl. fig. 10; pl. 3, fig. 4.

Stephanolithon laffittei Noël, 1957, p. 318, pl. 2, fig. 5 (non fig. 6). Hill, 1976, p. 155, pl. 11, figs. 30–32; pl. 15, figs. 11–12.

Diazomatholithus lehmannii Noël, 1965, p. 96, pl. 6, figs. 6–10; text-figs. 25–27. Thierstein, 1971, p. 479, pl. 3, figs. 11–15.

Retecapsa levis Black, 1971, p. 41, pl. 33, fig. 1. Hill, 1976, pp. 152–153, pl. 5, figs. 15–19.

Chiastozygus litterarius (Gorka, 1957) Manivit, 1971. Gorka, 1957, p. 251, 274, pl. 3, fig. 3. Manivit, 1971, p. 92, pl. 4, fig. 1 (non figs. 2–5). Roth and Thierstein, 1972, pl. 1, figs. 1–6. Hill, 1976, p. 128, pl. 3, figs. 31–40; pl. 13, figs. 15–16.

Discorhabdus longicornis Medd, 1979, p. 70, pl. 7, figs. 9–10. Grün and Zweili, 1980, partim, pp. 251–252, pl. 1, figs. 10–11 (non fig. 9) (as *Discorhabdus patulus* (Deflandre) Noël).

Remarks. This species was used for discorhabdids with a relatively long slender stem with a flaring termination. *Discorhabdus exilitus* Noël is very similar but has a relatively larger basal disc and a more tapering stem with a less pronounced flaring portion at its end.

Cretarhabdus loriei Gartner, 1968, p. 21, pl. 24, figs. 9–10. Hill, 1976, p. 134, pl. 5, figs. 7–14.

Remarks. I assigned specimens of *Cretarhabdus* to this species that clearly show extinction of diagonally opposite quadrants as shown by Gartner (1968) in the original illustration. Stradner's species *Arkhangelskiella striata* Stradner, 1963 was described using very schematic drawings and an all-too-brief description. Although Stradner, Adamiker, and Maresch (1968) illustrated *A. striata* using electron micrographs (of two unrelated species!) and light micrographs (phase contrast only) the species concept of *A. striata* has not stabilized. Thus I avoid it (using Stafleu et al., 1972, *International Code of Botanical Nomenclature*, Article 69 as a justification) and assign specimens with the characteristic extinction pattern to *C. loriei*, older forms that are morphologically similar but lack the characteristic "diagonal" extinction pattern to *Cretarhabdus* sp. cf. *C. multiforus* Black.

Sollasites lowei (Bukry, 1969) Rood, Hay, and Barnard, 1971. Bukry, 1969, p. 44, pl. 22, figs. 5, 6. Rood, Hay, and Barnard, 1971, p. 264, pl. 4, fig. 1. Goy, 1981, p. 48, pl. 17, figs. 2–6. (Plate 6, Figs. 9–11.)

Remarks. In the light microscope *Sollasites lowei* has the characteristic *Sollasites* rim (i.e., a dark gray appearance in phase-contrast illumination and in cross-polarized light, a bright rim around the central area, and a gray outer rim with rather diffuse extinction cross). The central area structure is seen in both phase-contrast and cross-polarized high illumination as a faint cross and a superimposed elliptical ring.

Polypodorhabdus madingleyensis Black, 1968, p. 806, pl. 150, fig. 2. Black, 1972, p. 41, pl. 10, fig. 4. Medd, 1979, p. 66, pl. 6, figs. 4, 5. (Plate 3, Figs. 1–3, 12–14).

Remarks. In the light microscope one sees a well developed cross with slightly tapering arms and about four struts connecting the cross arms with the rim. *Polypodorhabdus escaigii* has a less sturdy cross and more numerous connecting struts, giving its central area a granular appearance under cross nicols at an angle of 30–45° to the direction of the analyzer or polarizer. However, poorly preserved and transitional specimens are often difficult to assign to either one of the two species with certainty. *Polypodorhabdus madingleyensis* is more common in Oxfordian to Tithonian beds but also occurs in the Lower Cretaceous. *P. escaigii* appears to be its ancestor and is more common in the upper Callovian and lower Oxfordian.

Cyclagelosphaera margerelii Noël, 1965, p. 130, pl. 17, figs. 4–9; pl. 18, figs. 1, 2; pl. 20, figs. 2–4. Roth and Thierstein, 1972, pl. 16, figs. 19–20. (Plate 5, Figs. 8–10.)

Parhabdololithus marthae Deflandre, 1954. Deflandre, in Deflandre and Fert, 1954, p. 163, pl. 15, figs. 22, 23; text-fig. 101 (non 102). Bar-

nard and Hay, 1974, pl. 1, fig. 12; pl. 4, fig. 12. Grün and Zweili, 1980, pp. 290–291, pl. 13, figs. 11, 12.

Vagalapilla matallosa (Stover, 1966) Thierstein, 1973, Stover, 1966, p. 139, pl. 2, figs. 1–2; pl. 8, fig. 10. Thierstein, 1973, p. 37, pl. 3, figs. 15–18. Hill 1976, p. 159, pl. 12, figs. 7–15.

Grantarhabdus meddii Black, 1971, p. 403, pl. 33, fig. 7. Taylor, 1982, pl. 4.3, fig. 7.

Conusphaera mexicana Trejo, 1969, p. 6, pl. 1, figs. 1–7; pl. 2, figs. 1–8; text-figs. 1–4. Thierstein, 1971, p. 483, pl. 3, figs. 2–5 (as *Cretaturbella rothii* Thierstein). Thierstein, 1976, pl. 2, figs. 26, 27. (Plate 2, Figs. 11, 12.)

Remarks. Two different sizes were observed. In some samples, especially from the uppermost Tithonian, large specimens around 8 μm dominate. The earliest specimen in the uppermost Kimmeridgian (*sensu gallico*) *Hexapodorhabdus cuvillieri* subzone is about 3 to 4 μm in length. Thus there appears to be an evolutionary increase in size in this species.

Cretarhabdus sp. cf. *C. multiforus* Black, 1971, p. 402, pl. 31, fig. 1.

Remarks. *Cretarhabdus* coccoliths that display a large central area with a regular pore pattern similar to *C. loriei* but lack the "diagonal" extinction pattern are assigned to *C. sp. cf. C. multiforus*. They appear to be the ancestors of *C. loriei* and range to the Aptian. Typical *C. loriei* does not appear until the late Aptian. Both Sissingh (1977, 1978) and Taylor (1982) appear to have lumped *C. loriei* s. str. and *C. sp. cf. C. multiforus* and called them either *C. loriei* or *C. striatus* (Sissingh, 1977, 1978; Taylor, 1982). Because the two separate forms provide good biostratigraphic control if used properly it seems worthwhile to separate them, although it appears to be possible only in the light microscope.

Retecapsa neocomiana Black, 1971, p. 410, pl. 33, fig. 2. Roth, 1978, p. 749, pl. 1, fig. 1a–c.

Hexalithus noelae Loeblich and Tappan, 1964. Noël, 1957, p. 329, pl. 5, figs. 39, 40a–c. Loeblich and Tappan, 1964, p. 44. Cooper and Shaffer, 1976, pl. 1, figs. 6, 7. (Plate 2, Figs. 13–16.)

Remarks. Although it was originally described as a Tithonian form and its last occurrence was used to define the Jurassic-Cretaceous by both Cooper and Shaffer (1976) and Wind (1978), I have observed this species mostly in the basal Berrasian at Site 534. H. R. Thierstein (personal communication, 1982) found *H. noelae* in the Berriasian of Montsalvans and, after a restudy of the coccolith assemblages, considers Noël's original Portlandian samples as Lower Cretaceous.

Watznaueria oblonga Bukry, 1969, p. 33, pl. 11, figs. 8–10. Thierstein, 1973, p. 41, pl. 5, figs. 1–12 (as *Flabellites biforaminis* Thierstein).

Remarks. I have not observed any asymmetrical specimens at this site. Early forms have scattered occurrences in the Aptian to Hauterivian with less typically developed forms, and specimens were assigned to *W. sp. cf. W. oblonga* in the Valanginian. The well developed forms with the typical x-shaped cross are most common in the upper Barremian, Aptian, and Albian to Cenomanian part of the section.

Calicalathina oblongata (Worsley, 1971) Thierstein, 1971. Worsley, 1971, p. 1312, pl. 2, figs. 32–33. Thierstein, 1971, p. 475, pl. 4, figs. 6–10.

Micrantholithus obtusus Stradner, 1963, p. 11, pl. 6, fig. 11. Thierstein, 1976, pl. 3, figs. 37–38.

Tranolithus orionatus (Reinhardt, 1966) Perch-Nielsen, 1968. Reinhardt, 1966, p. 42, pl. 23, figs. 22, 31–33. Perch-Nielsen, 1968, p. 35, pl. 4, figs. 15–19, text-fig. 9. Thierstein, 1976, pl. 4, figs. 11–12.

Watznaueria ovata Bukry, 1969, p. 33, pl. 11, figs. 11, 12. Hill, 1976, p. 160, pl. 12, figs. 19–22.

Rhabdolekiskus parallelus Wind and Čepek, 1979, p. 232, pl. 3, figs. 3–6.

Discorhabdus patulus (Deflandre, 1954) Noël, 1965. Deflandre, in Deflandre and Fert, 1954, p. 162, pl. 15, figs. 40–45; text-figs. 97, 98. Noël, 1965, p. 141, pl. 21, figs. 6–8, 10–11; pl. 22, figs. 1, 2, 7, 9, 10. Barnard and Hay, 1974, pl. 3, fig. 12; pl. 6, fig. 11. Medd, 1979, p. 69, pl. 7, figs. 4, 5.

Manivitiella pemmatoidea (Deflandre, in Manivit, 1965). Thierstein, 1971. Manivit, 1965, p. 192, pl. 2, fig. 8. Thierstein, 1971, p. 480, pl. 3, figs. 11–15. Roth and Thierstein, 1972, pl. 11, figs. 6–13.

Crepidolithus perforatus (Medd, 1979) Grün and Zweili, 1980. Medd, 1979, p. 57, pl. 11, figs. 2, 3, 4. Grün and Zweili, 1980, pp. 289–290, pl. 13, figs. 6–9.

Diloma placinum Wind and Čepek, 1979, p. 228, pl. 8, figs. 2–3.

- Radiolithus* sp. cf. *R. planus* Stover, 1966, p. 160, pl. 7, figs. 22–24; pl. 9, fig. 23. Hill, 1976, partim, p. 143, pl. 7, figs. 36–39; pl. 8, figs. 1–7 (non pl. 7, figs. 21–35, 40–41; pl. 14, figs. 13–14; as *Lithastrinus floralis*).
- Remarks.** I was able to distinguish the thin, more discolith-shaped *Radiolithus* sp. cf. *R. planus* from the more cylindrical *Lithastrinus floralis*. The former appears earlier than the latter and is already present in the lower Aptian (Zone NC6).
- Octopodorhabdus polytretus* Wind and Čepek, 1979, pp. 230–231, pl. 4, figs. 1–5. (Plate 5, Figs. 1 and 2.)
- Crucirhabdus primulus* Prins ex Rood, Hay, and Barnard, 1973. Prins, 1969, p. 548, pl. 1, fig. 1; pl. 2, figs. 1–3. Rood, Hay, and Barnard, 1973, p. 367, pl. 1, figs. 1, 2. Barnard and Hay, 1974, pl. 1, fig. 7; pl. 4, figs. 7, 8. Thierstein, 1976, pl. 2, figs. 1, 2. (Plate 1, Figs. 20, 21.)
- Remarks.** This species does appear to range as high as the Callovian or Oxfordian as shown by Medd (1979) and is not restricted to the Liassic.
- Nannoconus quadriangulus* Deflandre and Deflandre-Rigaud, 1962, p. 2639, figs. 11–12. Deres and Achéritéguy, 1980, p. 28, pl. 6, fig. 13.
- Vagalapilla quadriarcula* (Noël, 1965) n. comb. **Basionym:** *Discolithus quadriarculus* Noël, 1965, *Coccolithes Jurassique. Essai de Classifications des Coccolithes Fossiles*, p. 74, pl. 1, figs. 14–15; pl. 2, figs. 1, 2; text-fig. 7. Also Barnard and Hay, 1974, pl. 1, fig. 3; pl. 4, fig. 3. Medd, 1979, p. 36, pl. 1, fig. 5; pl. 2, fig. 4. Goy, 1981, p. 20, pl. 2, figs. 1–7; pl. 3, figs. 1–4 (as *Staurorhabdus magnus*). (Plate 1, Figs. 17, 22.)
- Remarks.** I do not consider *Vekshinella* available (see Bukry, 1969) and consider *Staurorhabdus* Noël, 1973 a subjective junior synonym of *Vagalapilla* Bukry. In the light microscope *V. quadriarcula* differs from *V. stradneri* by having strongly tapering cross arms and a depression in the center of the cross.
- Rotelapillus radians* Noël, 1973, pp. 107–108, pl. 4, figs. 1–3, text-fig. 5. Non Grün and Zweili, 1980, pl. 11, fig. 2.
- Hayesites radiatus* (Worsley, 1971) Thierstein, 1976. Worsley, 1971, p. 1311, pl. 1, figs. 53, 54. Roth and Thierstein, 1972, p. 438, pl. 2, figs. 20–23 (as *Hayesites bulbus* Thierstein). Thierstein, 1976, p. 352, pl. 3, figs. 29, 30.
- Axopodorhabdus rahla* (Noël, 1965) Grün and Zweili, 1980. Noël, 1965, p. 105, pl. 9, fig. 8. Grün and Zweili, 1980, p. 267, pl. 6, figs. 5–8, text-fig. 23. Barnard and Hay, 1974, pl. 3, fig. 3; pl. 6, fig. 2.
- Diadorhombus rectus* Worsley, 1971, p. 1307, pl. 1, figs. 14–20. Wind and Čepek, 1979, pl. 3, figs. 7–8. (Plate 4, Figs. 4–8.)
- Remarks.** Specimens that displayed a narrow rim with less well defined elements were assigned to *D.* sp. cf. *D. rectus*. The range of this species appears to be longer than was originally thought (Thierstein, 1976; Roth, 1978). It does appear to range into the Hauterivian or even the basal Barremian. This fact in combination with its scattered distribution make it a less useful marker than was once thought.
- Braarudosphaera regularis* Black, 1973, p. 91, pl. 28, fig. 10. Taylor, 1982, pl. 4.8, fig. 22.
- Watznaueria reinhardtii* Rood, Hay, and Barnard, 1971, p. 267, pl. 5, fig. 6. Medd, 1979, pp. 72–73, pl. 8, figs. 7–8.
- Ahmuelerella ? retiformis* Reinhardt, 1965, p. 39, pl. 3, fig. 2. Reinhardt, 1966, pl. 4, figs. 2, 4.
- Remarks.** This species appears rarely in the Upper Jurassic at Site 534. It somewhat resembles the older form *Anfractus harrisonii* in that it also consists of a perforate disc surrounded by a narrow margin. However, it does not have a central knob, dome, or large hole. It is not possible to determine the ultrastructure of this form in the light microscope nor assign it with absolute certainty to *A. retiformis*, but the species was too rare at Site 534 to make a more thorough study of this group of perforate disc-shaped coccoliths.
- Cruciplacolithus salebrosus* Black, 1971, p. 397, pl. 30, fig. 4. Taylor, 1982, pl. 4.2, figs. 17–18. (Plate 5, Figs. 8–10.)
- Remarks.** An intermediate-size to small placolith with a highly birefringent rim and a rather delicate cross is similar to the forms described in the electron microscope from the Speeton Clay, especially as illustrated by Taylor (1982).
- Zygodiscus salillum* (Noël, 1965) Thierstein, 1975. Noël, 1965, p. 72, pl. 1, figs. 8–12; text-figs. 5, 6. Thierstein, 1975, p. 86. Grün and Zweili, 1980, p. 298, pl. 16, figs. 6–9.
- Polycostella senaria* Thierstein, 1971, p. 484, pl. 1, figs. 1–6.
- Lithastrinus septentrionalis* Stradner, 1963, p. 177, pl. 2, figs. 7, 7a. Reinhardt, 1966, pl. 21, fig. 10. Köthe, 1982, p. 37, p. 37, pl. 5, figs. 1–6; text-fig. 33.
- Tetrapodorhabdus shawensis* Medd, 1979, p. 63, pl. 6, figs. 9–12; text-fig. 4c. (Plate 2, Figs. 5–7.)
- Stephanolithion speciosum* Deflandre, 1954. Deflandre, in Deflandre and Fert, 1954, p. 146, pl. 15, figs. 7–8. Barnard and Hay, 1974, pl. 2, fig. 8; pl. 5, fig. 7. Thierstein, 1976, pl. 2, fig. 14. Hamilton, 1982, pl. 3.2, fig. 1; pl. 3.4, fig. 14.
- Broinsonia signata* (Noël, 1969) Noël, 1970. Noël, 1969, p. 197, pl. 2, figs. 3–4. Noël, 1970, p. 78, pl. 25, figs. 4–6. Roth and Thierstein, 1972, pl. 13, figs. 12–20; pl. 14, figs. 1–5.
- Corollithion signum* Stradner, 1963, p. 11, pl. 1, fig. 13. Hill, 1976, pp. 131–132, pl. 4, figs. 21–24; pl. 13, fig. 22.
- Zygodiscus* sp. cf. *Z. spiralis* Bramlette and Martini, 1964, p. 303, pl. 4, figs. 4–6. Hill, 1976, p. 162, pl. 12, figs. 28–37.
- Remarks.** As Hill (1976) showed, a zygodiscid that is very similar to *Z. spiralis* but somewhat smaller than the typical Late Cretaceous forms occurs already in the middle Cretaceous; it was also observed at Site 534, as well as in mid-Cretaceous rocks in Texas, the Atlantic Indian and Pacific Oceans (Hill, 1976; Roth and Bowdler, 1981; Roth, 1981).
- Braarudosphaera stenorheta* Hill, 1976, pp. 125–126, pl. 2, figs. 26–31; pl. 13, figs. 7–9.
- Tegumentum stradneri* Thierstein, 1972, in Roth and Thierstein, 1972, p. 437, pl. 1, figs. 7–15.
- Vagalapilla stradneri* (Rood, Hay, and Barnard, 1971) Thierstein, 1973. Rood, Hay, and Barnard, 1971, p. 249, pl. 1, fig. 2. Barnard and Hay, 1974, pl. 3, fig. 9; pl. 6, fig. 8. Medd, 1979, p. 35, pl. 10, figs. 6, 7, 10 (as *Staurorhabdus magnus*), Medd, 1979, p. 46, pl. 9, fig. 12 (as *Zygrhabdotus salillum* [Noël] Rood, Hay, and Barnard). Grün and Zweili, 1980, pp. 291–292, pl. 14, fig. 12; pl. 15, figs. 1–5 (as *Vekshinella dibrachiata* [Gartner]). Non Goy, 1981, p. 21, pl. 3, figs. 1–4 (as *Staurorhabdus magnus* Medd). (Plate 1, Figs. 15, 16.)
- Remarks.** This is a fairly large species of *Vagalapilla*, about 6 μ m, that often shows slightly thickened terminations of the central cross. The cross does not have a central depression on the proximal side but sometimes a small central hole. The taxonomy of this stratigraphically useful species has been complicated by the use of poorly defined species (e.g., *Zygodiscus crux* Deflandre and Fert), unnecessary creation of new species (*Staurorhabdus magnus* Medd, 1979), and too much lumping (Grün and Zweili, 1980). This species, as used here, begins in the Oxfordian and is found as high as the Upper Cretaceous. In the Cretaceous it becomes highly variable and it could possibly be subdivided into several different species.
- Chiastozygus striatus* Black, 1971, p. 416, pl. 34, fig. 7. Taylor, 1982, pl. 4.4, figs. 11, 12. (Plate 6, Figs. 7, 8.)
- Remarks.** This species of *Chiastozygus* has a sturdy bright rim and a fairly thick x-shaped central structure composed of several laths. It first occurs in the Hauterivian.
- Watznaueria supracretacea* (Reinhardt, 1965) Wind and Wise, 1976. Reinhardt, 1965, p. 40, pl. 2, figs. 7, 8. Wind and Wise, in Wise and Wind, 1976, p. 308, pl. 50, fig. 8.
- Parhabdololithus swinnertonii* (Black, 1971) Wind and Čepek, 1979. Black, 1971, p. 418, pl. 34, fig. 4. Wind and Čepek, 1979, p. 231, pl. 11, figs. 8–16. Roth, 1981, p. 488, pl. 1, fig. 10.
- Chiastozygus tenuis* Black, 1971, p. 416, pl. 34, fig. 8. Taylor, 1982, pl. 4.4, figs. 9, 10; pl. 4.7, fig. 23. (Plate 6, Figs. 5, 6.)
- Remarks.** This species is characterized by its rather delicate rim and x-shaped cross with cross bars that are closer to the short axis of the ellipse; the cross does not divide the central area into more equidimensional segments as in *C. striatus* or *C. litterarius*. This is also an early species of *Chiastozygus* but the occurrence at Site 534 shows that it is not restricted to the boreal realm.
- Nannoconus truitii* Brönnimann, 1955, p. 38, pl. 2, figs. 2–5, 7. Deres and Achéritéguy, 1980, p. 24, pl. 5, fig. 10.
- Discorhabdus tubus* Noël, 1965, p. 145, pl. 21, figs. 4, 15. Medd, 1979, p. 69, pl. 1, fig. 9.
- Braarudosphaera turbinea* Stradner, 1963, p. 10, pl. 6, figs. 8, 8a.
- Remarks.** Although this species was originally described from the Danian, I have observed rare specimens of a *Braarudosphaera*, with

curved structures, that very closely resemble Stradner's original description and illustration in Lower to middle Cretaceous rocks at Site 534.

Anfractus variabilis Medd, 1979, p. 38, pl. 1, fig. 6.

Remarks. Rare specimens of a disclike coccolith with a single row of perforations and a granular central area were observed at Site 534 and assigned to this species.

Tubodiscus verena Thierstein, 1973, p. 42, pl. 2, figs. 1-3, 4-7. Thierstein, 1976, pl. 3, figs. 11-14. (Plate 4, Figs. 1, 2.)

Remarks. This species was narrowly defined to include only specimens with a high collar around the central area that looks yellow in cross-polarized light. If narrowly defined, this is a good marker species. I do not agree with Grün and Alleman (1975) who define it so broadly that it becomes useless; none of their electron micrographs belong to this species.

Striatomarginis veteranae (Prins, ex Rood, Hay, and Barnard, 1973) Wind and Wise, 1976. Prins, 1969, pl. 2, fig. 9. Rood, Hay, and Barnard, 1973, pp. 378-379, pl. 3, figs. 2-3. Wind and Wise, in Wise and Wind, 1976, p. 306. Barnard and Hay, 1974, pl. 2, fig. 4; pl. 5, fig. 3. Grün, Prins, and Zweili, 1974, p. 261, text-fig. 18; pl. 3, fig. 12; pl. 4, figs. 1, 2 (as *Lotharingus sigillatus* [Stradner] Prins). Grün and Zweili, 1980, pl. 3, fig. 12; pl. 4, fig. 1, 2 (as *Lotharingus sigillatus* [Stradner] Prins). Goy, 1981, pp. 66-67, pl. 30, figs. 5, 6 (as *Lotharingus sigillatus* [Stradner] Prins).

Remarks. The emended description of *Discolithus sigillatus* Stradner by Prins (in Grün et al., 1974) and its transfer to *Lotharingus* seems another case of a resurrection of a rather poorly described species that is bound to lead to confusion. There are a number of Liassic coccoliths Stradner (1963) could have described as *Discolithus sigillatus*. Unless all species in topotype material are thoroughly described and illustrated, it seems better to use the species *Striatomarginis veteranae*.

Acaenolithus sp. cf. *A. vimineus* Black, 1973, p. 59, pl. 20, figs. 6, 8, 11, 12, 15, 16; pl. 21, fig. 3 (Plate 6, Figs. 13-15.)

Remarks. This small coccolith has a bright shield surrounded by a narrow rim and a central area with a double-cross that flares where the cross-arms meet the rim. The narrow laths filling the area between the cross bars described by Black (1973) for *A. vimineus* would be invisible in the light microscope; thus I only tentatively assign the forms illustrated here to Black's species. *A. sp. cf. A. vimineus* first appears in the middle of Zone NC5 and seems stratigraphically useful.

Corollithion virgatum (Medd, 1979) n. comb. **Basionym:** *Millbrookia virgata* Medd, 1979, *Eclogae Geol. Helv.*, 72, pp. 57-58, pl. 11, figs. 7, 8.

Remarks. Grün and Zweili (1980) have transferred *Millbrookia perforata* Medd, 1979, the holotype of the genus *Millbrookia*, to *Crepidolithus* and indicated the close similarity of *M. virgata* with *Corollithion silvaradion* Filewicz, Wind and Wise. I do not want to go so far as to consider *Millbrookia virgata* Medd, 1979 a subjective junior synonym of *Corollithion silvaradion* Filewicz, Wind and Wise, 1976, but I do consider a transfer to the genus *Corollithion* justified. This species is very rare and only a few specimens have been observed at Site 534. The numerous radial laths in the center of this coccolith are quite clearly visible in the light microscope.

Rucinolithus wisei Thierstein, 1971, p. 482, pl. 4, figs. 11-15. Thierstein, 1976, pl. 3 figs. 21-22.

Remarks. A few more specimens of *Rucinolithus* that are quite similar to *R. wisei* occur in the late Tithonian (Plate 2, Fig. 8.)

Forms Not Assigned to Species

Diloma sp. Specimens very similar to *Diloma* sp. Wind and Čepek, 1979, p. 228, pl. 8, figs. 8-17 were also observed at Site 534.

Discorhabdus sp. 2. A few specimens of a sturdy discorhabdid, very similar to *Discorhabdus* sp. 2 of Medd, 1979, p. 70, pl. 7, figs. 6-8 were observed in samples from Site 534.

Proculithus sp. A few specimens of coccoliths with a narrow margin, surrounded by a bright inner cycle and a central hole that is often partly obstructed have been tentatively assigned to *Proculithus* sp. Medd, 1979. (Plate 2, Figs. 9, 10.)

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REFERENCES

Barnard, T., and Hay, W. W., 1974. On Jurassic coccoliths: a tentative zonation of the Jurassic of Southern England and North France. *Eclogae Geol. Helv.*, 67:563-585.

Barthel, K. W., 1976. Coccolithen, Flugstaub und Gehalt an organischen Substanzen in Oberjura-Plattalkalken Bayerns und SE-Frankreichs. *Eclogae Geol. Helv.*, 69:627-739.

Baumgartner, P. O., De Wever, P., and Kocher, R., 1980. Correlation of Tethyan Late Jurassic-Early Cretaceous radiolarian events. *Cah. Micropaleontol.*, 7(2):23-72.

Benson, W. E., Sheridan, R. E., et al., 1978. *Init. Repts. DSDP*, 44: Washington (U.S. Govt. Printing Office).

Black, M., 1967. New names for some coccolith taxa. *Proc. Geol. Assoc. London*, 1640:139-145.

_____, 1971. Coccoliths of the Speeton Clay and Sutterby Marl. *Proc. Yorks. Geol. Soc.*, 38:381-424.

_____, 1972, 1973, 1975. British Lower Cretaceous coccoliths 1. Gault Clay. *Palaeontogr. Soc. Mono.*, 126:1-48 (Pt. 1); 127:49-112 (Pt. 2); 129:113-142 (Pt. 3).

Black, M., and Barnes, B., 1959. The structure of coccoliths from the English Chalk. *Geol. Mag.*, 96:321-328.

Bramlette, M. N., and Martini, E., 1964. The great change in calcareous nannoplankton between the Maastrichtian and the Danian. *Micropaleontology*, 10:291-322.

Brönnimann, P., 1955. Microfossils incertae sedis from the Upper Jurassic and Lower Cretaceous of Cuba. *Micropaleontology*, 1:28-51.

Bukry, D., 1969. Upper Cretaceous coccoliths from Texas and Europe. *Univ. Kans. Paleontol. Contrib. Pap.*, Article 51 (Protista 2):1-79.

_____, 1975. Coccolith and silicoflagellate stratigraphy, northwestern Pacific Ocean, Deep Sea Drilling Project Leg 32. In Larson, R. L., Moberly, R., et al., *Init. Repts. DSDP*, 32: Washington (U.S. Govt. Printing Office), 677-701.

_____, 1976. Coccolith stratigraphy of Manihiki Plateau, Central Pacific, Deep Sea Drilling Project, Site 317. In Schlanger, S. O., Jackson, E. D., et al., *Init. Repts. DSDP*, 33: Washington (U.S. Govt. Printing Office), 493-501.

Canuti, P., and Marcucci, M., 1969. Osservazioni al microscopi elettronico sui "Diaspini" dei Monti del Chianti settentrionale. *Bol. Soc. Geol. Ital.*, 88:1-13.

Čepek, P., 1978. Mesozoic calcareous nannofossils of the Eastern North Atlantic, Leg 41. In Lancelot, Y., Seibold, E., et al., *Init. Repts. DSDP*, 41: Washington (U.S. Govt. Printing Office), 667-687.

Čepek, P., and Hay, W. W., 1969. Calcareous nannoplankton and biostratigraphic subdivisions of the Upper Cretaceous. *Trans. Gulf Coast Assoc. Geol. Soc.*, 19:323-336.

Channell, J. E. T., Lowrie, W., and Medizza, F., 1979. Middle and Early Cretaceous magnetic stratigraphy from the Cismone section, northern Italy. *Earth Planet. Sci. Lett.*, 42:153-166.

Cita, M. B., and Pasquare, G., 1959. Studi stratigrafici sul sistema cretaceo in Italia. Nota IV. Osservazioni micropaleontologiche sul cretaceo delle Dolomiti. *Riv. Ital. Paleontol. Stratigr.*, 65:231-250.

Cooper, W. W., and Shaffer, B. L., 1976. Nannofossil biostratigraphy of the Bossier Shale and the Jurassic-Cretaceous boundary. *Trans. Gulf Coast Assoc. Geol. Soc.*, 16:178-184.

Crux, J. A., 1982. Upper Cretaceous (Cenomanian to Campanian) calcareous nannofossils. In Lord, A. R. (Ed.), *A Stratigraphical Index of Calcareous Nannofossils*: Chichester (Ellis Horwood Ltd.), pp. 81-135.

Deflandre, G., 1939. Les stéphanolithes, représentants d'un type nouveau de coccolithes du jurassique supérieur. *C. R. Hebd. Seances Acad. Sci. Ser. D.*, 208:1331-1333.

- _____, 1947. *Braarudosphaera* nov. gen., type d'une famille nouvelle de Coccolithophoridés actuels à éléments composites. *C. R. Hebd. Seances Acad. Sci. Ser. D.*, 225:439-441.
- _____, 1963. Sur les microrhabdulidés, famille nouvelle de nanofossils calcaires. *C. R. Hebd. Seances Acad. Sci. Ser. D.*, 256:3484-3486.
- Deflandre, G., and Deflandre-Rigaud, M., 1962. Remarques sur l'évolution des nannoconidés à propos quelques nouveaux types du Crétacé inférieur de Haute-Provence. *C. R. Hebd. Seances Acad. Sci. Ser. D.*, 255:2638-2640.
- Deflandre, G., Fert, C., 1954. Observations sur les coccolithophoridés actuels et fossiles en microscopie ordinaire et électronique. *Ann. Paleontol.*, 40:115-176.
- Deres, F., and Achéritéguy, J., 1972. Contributions à l'étude des Nannoconidés dans le Crétacé inférieur du Bassin d'Aquitaine. *Mem. Bur. Rech. Geol. Min.*, 77:153-159.
- Deres, F., and Achéritéguy, J., 1980. Biostratigraphie des Nannoconidés. *Bull. Cent. Rech. Explor. Prod. Elf-Aquitaine*, 4:1-53.
- Douarane, S. le, and Parsons, B., 1982. A note on the correction of ocean floor depths for sediment loading. *J. Geophys. Res.*, 87:4715-4722.
- Flügel, E., and Keupp, H., 1979. Coccolithen-Diagenese in Malmkalken (Solnhofen/Frankenalb, Oberalm/Salzburg). *Geol. Rundsch.*, 68:876-893.
- Gartner, S., 1968. Coccoliths and related calcareous nanofossils from Upper Cretaceous deposits of Texas and Arkansas. *Univ. Kans. Paleontol. Contrib. Pap.*, Article 48 (Protista):1-56.
- Gorka, H., 1957. Les Coccolithophoridés du Maestrichtien supérieur de Pologne. *Acta Palaeontol. Polonica*, 2:235-284.
- Goy, G., 1981. Nannofossiles calcaires des schistes carton (Toarcien inférieur) du Bassin de Paris. *Documents RCP495*, n. 1, Paris, p. 86.
- Gran, H. H., and Braarud, T., 1935. A quantitative study of the phytoplankton in the Bay of Fundy and the Gulf of Maine (including observations on hydrography, chemistry, and turbidity). *J. Biol. Board Can.*, 1:279-467.
- Grün, W., and Allemann, F., 1975. The Lower Cretaceous of Caravaca (Spain); Berriasian calcareous nannoplankton of the Miravetes Section (Subbetic Zone, Prov. of Murcia). *Eclogae Geol. Helv.*, 68:147-211.
- Grün, W., Prins, B., and Zweili, F., 1974. Coccolithophoriden aus dem Lias epsilon von Holzmaden (Deutschland). *Neues Jahrb. Geol. Palaeontol., Abh.*, 147:294-328.
- Grün, W., and Zweili, F., 1980. Das kalkige Nannoplankton der Dogger-Malm-Grenz im Berner Jura bei Liesberg (Schweiz). *Jahrb. Geol. Bundesanst.*, 123:231-341.
- Hamilton, G. B., 1982. Triassic and Jurassic nanofossils. In Lord, A. R. (Ed.), *A Stratigraphic Index of Calcareous Nanofossils*: Chichester (Ellis Horwood Limited), pp. 17-39.
- Hill, M. E., 1976. Lower Cretaceous calcareous nanofossils from Texas and Oklahoma. *Palaeontographica B*, 156:103-179.
- Keupp, H., 1976. Kalkiges Nannoplankton aus den Solnhofener Schichten (Unter-Tithon, Südliche Frankenalb). *Neues Jahrb. Geol. Palaeontol. Monatsh.*, 1976:361-381.
- _____, 1977. Ultrafazies und Genese der Solnhofener Plattenkalke (Oberer Malm, Südliche Frankenalb). *Abh. Naturhist. Ges. Nürnberg*, 37:1-128.
- Köthe, A., 1982. Kalkiges Nannoplankton aus dem Unter-Hauterivium bis Unter-Barremium der Tongrube Moorberg/Sarstedt. *Mitt. Geol. Palaeontol. Inst. Univ. Hannover*, 21:1-95.
- Loeblich, A. R., and Tappan, H., 1963. Type fixation and validation of certain calcareous nannoplankton genera. *Proc. Biol. Soc. Washington*, 76:191-196.
- _____, 1966. Annotated index and bibliography of the calcareous nannoplankton. *Phycologia*, 5:81-216.
- _____, 1968. Annotated index and bibliography of the calcareous nannoplankton II. *J. Paleontol.*, 42:584-598.
- _____, 1969. Annotated index and bibliography of the calcareous nannoplankton III. *J. Paleontol.*, 43:568-588.
- _____, 1970a. Annotated index and bibliography of the calcareous nannoplankton IV. *J. Paleontol.*, 44:558-574.
- _____, 1970b. Annotated index and bibliography of the calcareous nannoplankton V. *Phycologia*, 9:157-174.
- _____, 1971. Annotated index and bibliography of the Calcareous nannoplankton VI. *Phycologia*, 10:315-339.
- _____, 1973. Annotated index and bibliography of the calcareous nannoplankton VII. *J. Paleontol.*, 47:715-759.
- Lord, A. R. (Ed.), 1982. *A Stratigraphical Index of Calcareous Nanofossils*: Chichester (Ellis Horwood Ltd.), p. 192.
- Lowrie, W., Channell, J. E. T., and Alvarez, W., 1980. A review of magnetic stratigraphy investigations in Cretaceous pelagic carbonate rocks. *J. Geophys. Res.*, 85:3597-3605.
- Manivit, H. 1965. Nannofossiles calcaires de l'Albo-Aptien. *Rev. Micropaleontol.*, 8:189-201.
- _____, 1966. Sur quelques coccolithes nouveaux du Néocomien. *C. R. Somm. Seances Soc. Geol. Fr.*, 1966:267-269.
- _____, 1971. Les nannofossiles calcaires du Crétacé Français (Aptien-Maestrichtien). Essai de biozonation appuyée sur les stratotypes (thèse). Université de Paris.
- Medd, A. W., 1971. Some Middle and Upper Jurassic Coccolithophoridae from England and France. *Proc. Second Planktonic Conf. Roma 1970*, 2:821-844.
- _____, 1979. The Upper Jurassic coccoliths from the Haddenham and Gamlingay boreholes (Cambridgeshire, England). *Eclogae Geol. Helv.*, 72:19-109.
- _____, 1982. Nannofossil zonation of the English Middle and Upper Jurassic. *Mar. Micropaleontol.*, 7:73-95.
- Noël, D., 1957. Coccolithes des terrains jurassiques de l'Algérie. *Publ. Serv. Carte Geol. Alger. Ser. 2 Bull.*, 8:303-345.
- _____, 1959. Etude de coccolithes du Jurassique et du Crétacé inférieur. *Publ. Serv. Carte Geol. Alger. Ser. 2 Bull.*, 20:155-196.
- _____, 1965. *Sur les Coccolithes du Jurassique Européen et d'Afrique du Nord. Essai de Classification des Coccolithes Fossiles*: Paris (Editions du Cent. Nat. Rech. Sci.), p. 209.
- _____, 1969. *Arkhangelskiella* (Coccolithes Crétacés) et formes affines du Bassin de Paris. *Rev. Micropaleontol.*, 11:191-204.
- _____, 1970. *Coccolithes Crétacés. La Craie Campanienne du Bassin de Paris*: Paris (Editions du Cent. Nat. Rech. Sci.), p. 129.
- _____, 1973. Nannofossiles calcaires des sédiments jurassiques finement laminés. *Bull. Mus. Nat. Hist. Nat. 3^e Ser.*, 75 (Sci. Terre 14):95-156 (for 1972).
- Okada, H., and Thierstein, H. R., 1978. Calcareous nannoplankton—Leg 43, Deep Sea Drilling Project. In Tucholke, B. E., Vogt, P. R., et al., *Init. Repts. DSDP*, 43: Washington (U.S. Govt. Printing Office), 507-573.
- Parsons, B., and Sclater, J. G., 1977. An analysis of the variation of ocean floor bathymetry and heat flow with age. *J. Geophys. Res.*, 82:803-827.
- Perch-Nielsen, K., 1968. Der Feinbau und die Klassifikation der Coccolithen aus dem Maestrichtien von Dänemark. *Det Kongelige Danske Videnskabernes Selskab, Biologiske Skrifter*, 16:1-96.
- _____, 1979. Calcareous nanofossils from the Cretaceous between the North Sea and the Mediterranean. In Wiedmann, J. (Ed.), *Aspekte der Kreide Europas*, Int. Union Geol. Sci. Ser. A, 6 Stuttgart (Schweizerbart), pp. 223-272.
- Prins, B., 1969. Evolution and stratigraphy of Coccolithinids from the Lower and Middle Lias. *Proc. First Int. Conf. Planktonic Microfossils, Geneva*, 2:547-558.
- Reinhardt, P., 1964. Einige Kalkflagellaten-Gattungen (Coccolithophoriden, Coccolithinen) aus dem Mesozoikum Deutschlands. *Monatsber. Dtsch. Akad. Wiss. Berlin*, 6:749-759.
- _____, 1965. Neue Familien für fossile Kalkflagellaten (Coccolithophoriden, Coccolithineen). *Monatsber. Dtsch. Akad. Wiss. Berlin*, 7:30-40.
- _____, 1966. Zur Taxonomie und Biostratigraphie des fossilen Nannoplanktons aus dem Malm, der Kreide und dem Alttertiär Mitteleuropas. *Freiberg. Forschungsh. C*, 196:5-109.
- _____, 1967. Fossile Coccolithen mit rhagoideem Zentralfeld (Fam. Ahmuellerellaceae, Subord. Coccolithineae). *Neues Jahrb. Geol. Palaeontol. Monatsh.*, 1967:163-178.
- Rood, A. P., and Barnard, T., 1972. On Jurassic coccoliths: *Stephanolithion*, *Diadozygus*, and related genera. *Eclogae Geol. Helv.*, 65:327-342.
- Rood, A. P., Hay, W. W., and Barnard, T., 1971. Electron microscope studies of Oxford clay coccoliths. *Eclogae Geol. Helv.*, 64:245-272.
- _____, 1973. Electron microscope studies of Lower and Middle Jurassic coccoliths. *Eclogae Geol. Helv.*, 66:365-382.
- Roth, P. H., 1973. Calcareous nanofossils—Leg 17, Deep Sea Drilling Project. In Winterer, E. L., Ewing, J. I., et al., *Init. Repts. DSDP*, 17: Washington (U.S. Govt. Printing Office), 695-795.
- _____, 1978. Cretaceous nannoplankton biostratigraphy and oceanography of the northwestern Atlantic Ocean. In Benson, W.

- E., Sheridan, R. E., et al., *Init. Repts. DSDP*, 44: Washington (U.S. Govt. Printing Office), 731-759.
- _____, 1981. Mid-Cretaceous calcareous nannoplankton from the central Pacific: implications for paleoceanography. In Thiede, J., Vallier, T. L., et al., *Init. Repts. DSDP*, 62: Washington (U.S. Govt. Printing Office), 471-489.
- Roth, P. H., and Bowdler, J. L., 1981. Middle Cretaceous calcareous nannoplankton biogeography and oceanography of the Atlantic Ocean. *Soc. Econ. Paleontol. Mineral. Spec. Publ.*, 32:517-546.
- Roth, P. H., and Thierstein, H. R., 1972. Calcareous nannoplankton: Leg 14 of the Deep Sea Drilling Project. In Hayes, D. E., Pimm, A. C., et al., *Init. Repts. DSDP*, 14: Washington (U.S. Govt. Printing Office), 421-486.
- Sissingh, W., 1977. Biostratigraphy of Cretaceous calcareous nannoplankton. *Geol. Mijnbouw*, 56:37-65.
- _____, 1978. Microfossil biostratigraphy and stage-stratotypes of the Cretaceous. *Geol. Mijnbouw*, 57:433-440.
- Stafleu, F. A., Bonner, C. E. B., McVaugh, R., Meikle, R. D., Rollins, R. C., et al., 1972. *International Code of Botanical Nomenclature*: Utrecht, Netherlands (Oosthoek's Uitgeversmaatschappij), p. 426.
- Stover, J. E., 1966. Cretaceous coccoliths and associated nannofossils from France and the Netherlands. *Micropaleontology*, 12:133-167.
- Stradner, H., 1961. Vorkommen von Nannofossilien im Mesozoikum und Alttertiär. *Erdoel-Z. Bohr-Foerdertech.*, 77:77-88.
- _____, 1962. Über neue und wenig bekannte Nannofossilien aus Kreide und Alttertiär. *Verh. Geol. Bundesanst. Wien*, 1962(2): 363-377.
- _____, 1963. New contributions to Mesozoic stratigraphy by means of nannofossils. *Proc. Sixth World Pet. Congr.*, Section 1, Paper 4 (preprint):167-184.
- Stradner, H., and Adamiker, D., 1966. Nannofossilien aus Bohrkernen und ihre elektronenmikroskopische Bearbeitung. *Erdol-Erdgas-Z.*, 82:330-341.
- Stradner, H., Adamiker, D., and Maresch, O., 1968. Electron microscope studies on Albian calcareous nannoplankton from the Delft 2 and Leidschendam 1 Deepwells, Holland. *Verh. K. Ned. Akad. Wet. Afd. Natuurk. Reeks 1*, 24:1-107.
- Tappan, H., 1980. *The Paleobiology of Plant Protists*: San Francisco (Freeman), p. 1028.
- Taylor, R., 1982. Lower Cretaceous (Ryazanian to Albian) calcareous nannofossils. In Lord, A. R. (Ed.), *A Stratigraphical Index of Calcareous Nannofossils*: Chichester (Ellis Horwood Ltd.), pp. 40-80.
- Thierstein, H. R., 1971. Tentative Lower Cretaceous calcareous nannoplankton zonation. *Eclogae Geol. Helv.*, 64:459-488.
- _____, 1973. Lower Cretaceous calcareous nannoplankton zonation. *Abh. Geol. Bundesanst. (Wien)*, 29:1-52.
- _____, 1975. Calcareous nannoplankton biostratigraphy at the Jurassic-Cretaceous boundary. *Colloque sur la limite Jurassique-Crétacé*. Mem. BRGM, 86:84-94.
- _____, 1976. Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. *Mar. Micropaleontol.*, 1:325-362.
- _____, 1979. Paleoceanographic implications of organic carbon and carbonates in Mesozoic deep-sea sediments. In Talwani, M., Hay, W., and Ryan, W. B. F. (Eds.), *Deep Drilling in the Atlantic Ocean*: Washington (Am. Geophys. Union), Maurice Ewing Series, 3:249-274.
- Trejo, M. H., 1961. La Familia Nannoconidae y su alcance estratigráfico en América (Protozoa, Incertae sedis). *Bol. Asoc. Mex. Geol. Pet.*, 12:259-314.
- _____, 1969. *Conusphaera mexicana*, un nuevo coccolitoforido del Jurásico Superior de México. *Rev. Inst. Mex. Pet.*, 1:5-15.
- Van Heck, S. E., 1979a. Bibliography and taxa of calcareous nannoplankton. *INA Newsletter*, Proc. Int. Nannoplankton Assoc., 1(1):ABI-ABV, A-1-A-12, B-1-B-27.
- _____, 1979b. Bibliography and taxa of calcareous nannoplankton. *INA Newsletter*, 1(2):AB VI, A 13-A 28, B 28-B 42.
- _____, 1980a. Bibliography and taxa of calcareous nannoplankton. *INA Newsletter*, 2(1):5-34.
- _____, 1980b. Bibliography and taxa of calcareous nannoplankton. *INA Newsletter*, 2(2):43-81.
- _____, 1981a. Bibliography and taxa of calcareous nannoplankton. *INA Newsletter*, 3(1):4-41.
- _____, 1981b. Bibliography and taxa of calcareous nannoplankton. *INA Newsletter*, 3(2):51-86.
- _____, 1982. Bibliography and taxa of calcareous nannoplankton. *INA Newsletter*, 4(1):7-50.
- _____, 1982. Bibliography and taxa of calcareous nannoplankton. *INA Newsletter*, Proc. Int. Nannoplankton Assoc., 4(2):65-96.
- Van Hinte, J. E., 1976. A Jurassic time scale. *Bull. Am. Assoc. Pet. Geol.*, 60:489-497.
- Verbeek, J. W., 1977. Calcareous nannoplankton biostratigraphy of Middle and Upper Cretaceous deposits in Tunisia, southern Spain, and France. *Utrecht Micropaleontol. Bull.*, 16:1-157.
- Wilcoxon, J. A., 1972. Upper Jurassic-Lower Cretaceous calcareous nannoplankton from the western North Atlantic Basin. In Hollister, C. D., Ewing, J. I., et al., *Init. Repts. DSDP*, 11: Washington (U.S. Govt. Printing Office), 427-458.
- Wind, F. H., 1978. Western North Atlantic Upper Jurassic calcareous nannofossil biostratigraphy. In Benson, W. E., Sheridan, R. E., et al., *Init. Repts. DSDP*, 44: Washington (U.S. Govt. Printing Office), 761-773.
- Wind, F. H., and Cepek, P., 1979. Lower Cretaceous calcareous nannoplankton from DSDP Hole 397A (northwest African margin). In von Rad, U., Ryan, W. B. F., et al., *Init. Repts. DSDP*, 47, Pt. 1: Washington (U.S. Govt. Printing Office), 221-255.
- Wise, W. W., and Wind, F. H., 1977. Mesozoic and Cenozoic calcareous nannofossils recovered by DSDP Leg 36 drilling on the Falkland Plateau, southwest Atlantic sector of the Southern Ocean. In Barker, P. F., Dalziel, I. W. D., et al., *Init. Repts. DSDP*, 36: Washington (U.S. Govt. Printing Office), 269-492.
- Worsley, T. R., 1971. Calcareous nannofossil zonation of Upper Jurassic and Lower Cretaceous sediments from the western Atlantic. *Proc. Second Planktonic Conf. Roma 1970*, 2:1301-1321.

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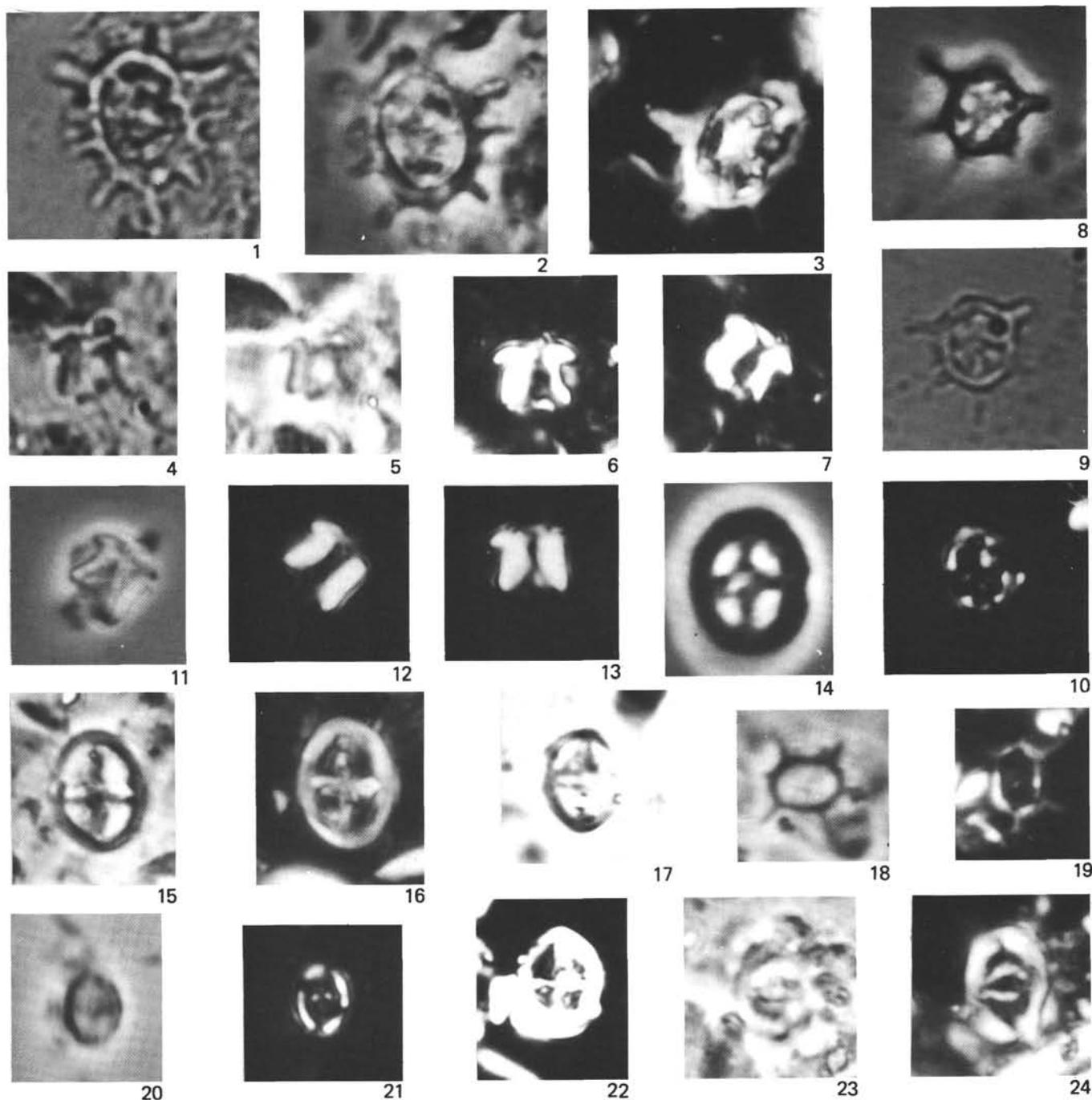


Plate 1. Jurassic and basal Cretaceous calcareous nannofossils. (Magnification approximately $\times 3500$ [XN: cross-polarized light; PH: phase contrast; OL: ordinary light].) 1-3. *Stephanolithion hexum*. Sample 534A-125-2, 45 cm. (1) OL, (2) PH, (3) XN. 4-7. *Ansulosphaera helvetica*. Sample 534A-125-2, 45 cm. (4) OL, (5) PH, (6-7), XL. 8-10. *Stephanolithion hexum*. Sample 534A-125-2, 45 cm. (8) PH, (9) OL, (10) XN. 11-13. *Ansulosphaera helvetica*. Sample 534A-126-1, 86 cm. (11) PH, (12-13) OL. 14. *Axopodorhabdus cylindricus*. Sample 534A-99-3, 66 cm. PH. 15-16. *Vagalapilla stradneri*. Sample 534A-99-2, 130 cm. (15) PH, (16) XN. 17, 22. *Vagalapilla quadriarcula*. Sample 534A-105-5, 31 cm. (17) PH, (22) XN. 18-19. *Stephanolithion bigotii*. Sample 534A-110, CC. (18) PH, (19) XN. 20-21. *Crucirhabdus* sp. cf. *C. primulus*. Sample 534A-123-3, 131 cm. (20) PH, (21) XN. 23-24. *Zygodiscus fissus* n. comb. Sample 534A-99-1, 8 cm. (23) PH, (24) XN.

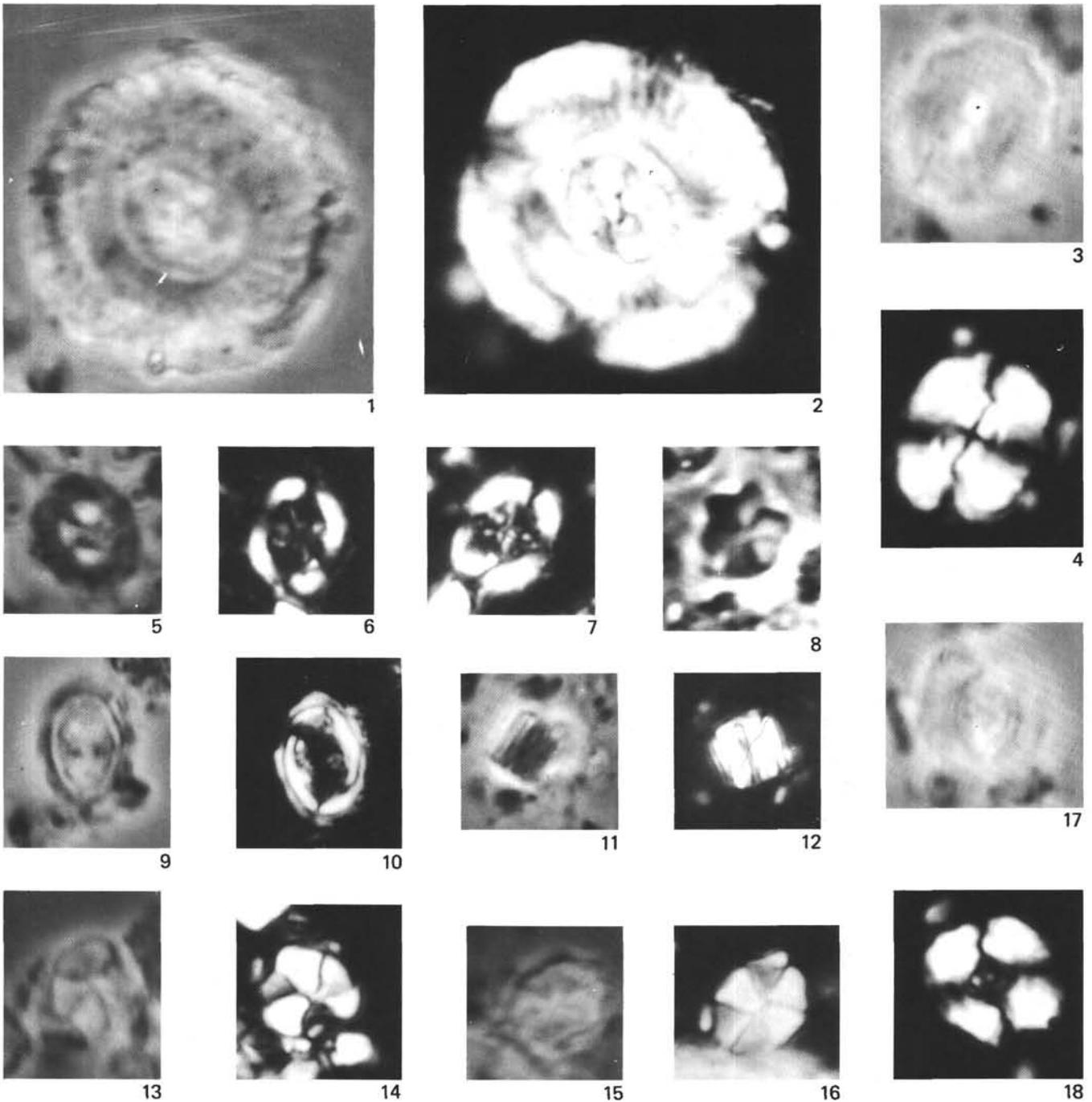


Plate 2. Jurassic calcareous nannofossils. (Magnification approximately $\times 3500$ [XN: cross-polarized light; PH: phase contrast; OL: ordinary light].) 1-2. *Cyclagelosphaera cuvillieri* Sample 534A-110, CC. (1) PH, (2) XN. 3-4. *Watznaueria barnesae*. Sample 534A-110, CC. (3) PH (4) XN. 5-7. *Tetrapodorhabdus shawensis*. Sample 534A-99-2, 130 cm. (5) PH, (6-7) XN. 8. *Rucinolithus cf. wisei*. Sample 534A-95, CC. PH. 9-10. *Proculithus* sp. Sample 534-127-4, 8 cm. (9) PH, (10) XN. 11-12. *Conusphaera mexicana*. Sample 534A-99-2, 130 cm. (11) PH, (12) XN. 13-14. *Hexalithus noelae*. Sample 534A-91-5, 42 cm. (13) PH, (14) XN. 15-16. *Hexalithus noelae*. Sample 534A-91-4, 106 cm. (15) PH, (16) XN. 17-18. *Watznaueria communis*. Sample 534A-110, CC. (17) PH, (18) XN.

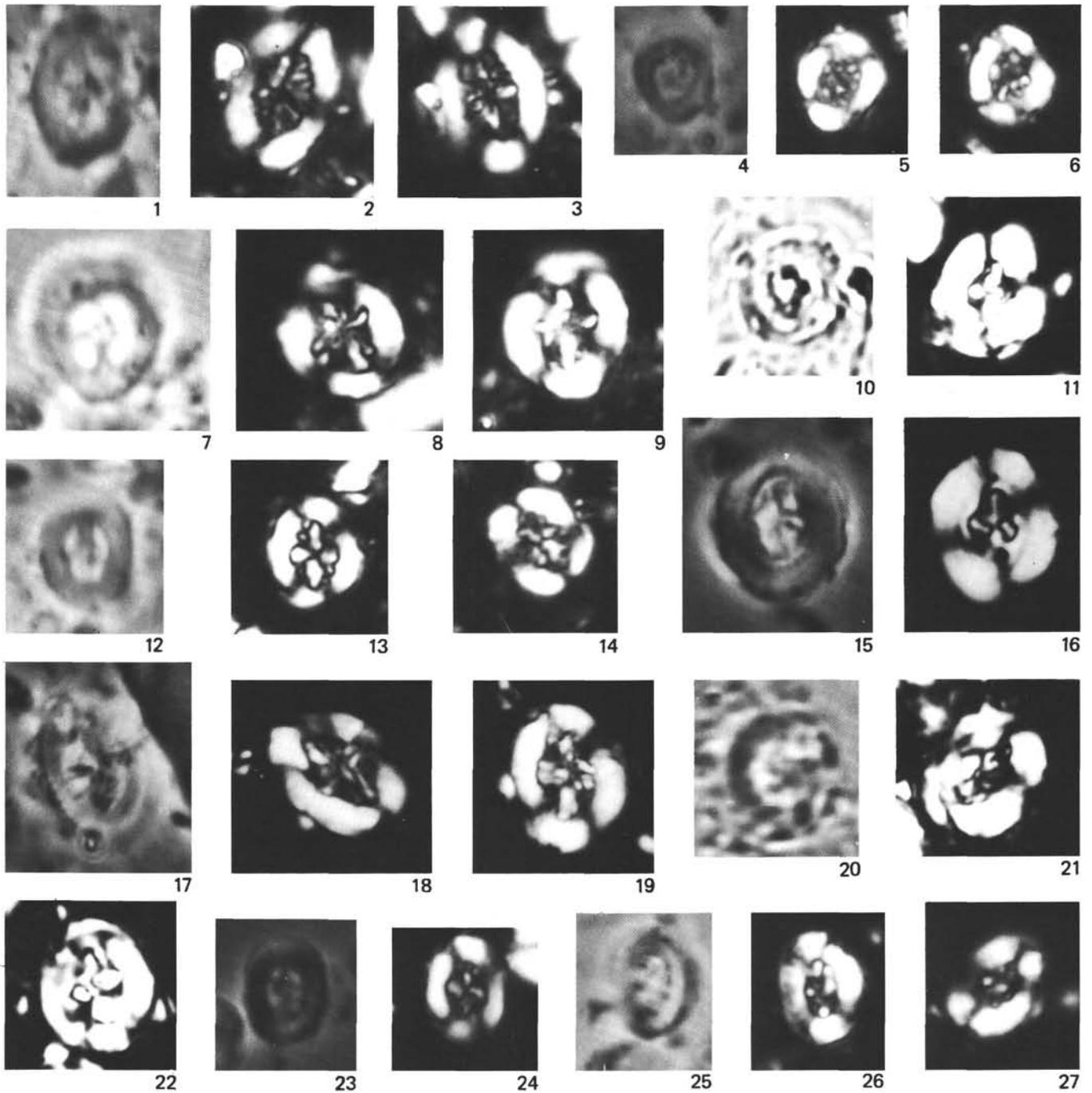


Plate 3. Jurassic calcareous nannofossils. (Magnification approximately $\times 3500$ [XN: cross-polarized light; PH: phase contrast; OL: ordinary light].) 1-3. *Polypodorhabdus madingleyensis*. Sample 534A-117-1, 14 cm. (1) PH, (2-3) XN. 4-6. *Polypodorhabdus escaigii*. Sample 534A-117-1, 14 cm. (4) PH, (5-6) XN. 7-9. *Polypodorhabdus harrisonii*. Sample 534A-100-1, 15 cm. Paratype. (7) PH, (8-9) XN. 10-11. *Crucellipsis* sp. cf. *C. chiasia*. Sample 534A-96-5, 15 cm. (10) OL, (11) XN. 12-14. *Polypodorhabdus madingleyensis*. Sample 534A-110, CC. (12) PH, (13-14) XN. 15-16. *Watznaueria crucicentralis*. Sample 534A-123-4, 82 cm. (15) PH, (16) XN. 17-19. *Polypodorhabdus* sp. cf. *P. harrisonii*. Sample 534A-99-2, 130 cm. (17) PH, (18-19) XN. 20-22. *Crucellipsis* sp. cf. *C. cuvillieri*. Sample 534A-96-3, 15 cm. (20) PH, (21-22) XN. 23-24. *Polypodorhabdus* cf. *beckii*. Sample 534A-91-4, 106 cm. (23) PH, (24) PH. 25-27. *Polypodorhabdus escaigii*. Sample 534A-110, CC. (25) PH; (26-27) XN.

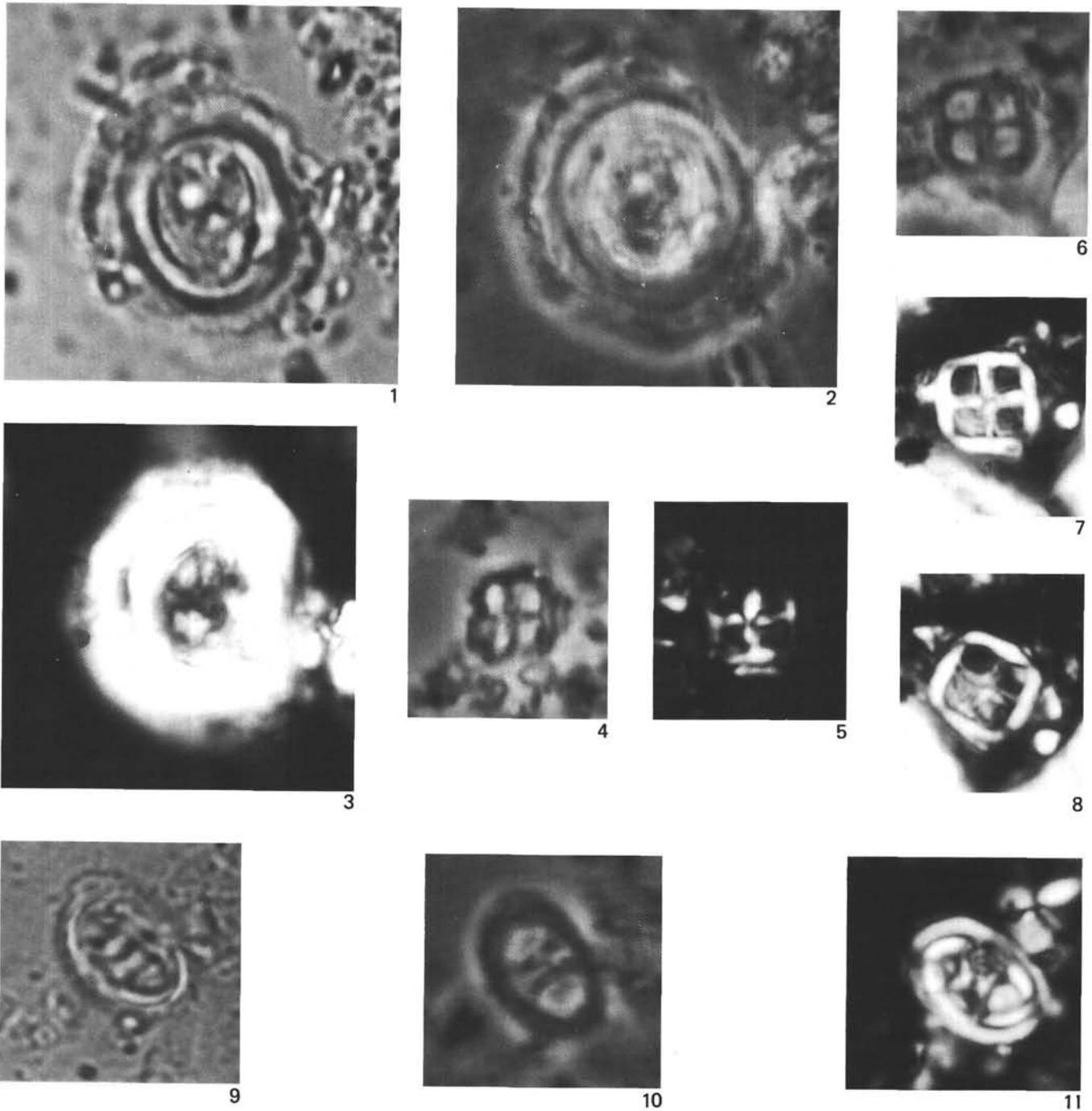


Plate 4. Lower Cretaceous calcareous nannofossils. (Magnification approximately $\times 3500$ [XN: cross-polarized light; PH: phase contrast; OL: ordinary light].) 1-3. *Tubodiscus verena*. Sample 534A-70-4, 60 cm. (1) OL, (2) PH, (3) XN. 4-5. *Diadorhombus rectus*. Sample 534A-56-2, 79 cm. (4) PH, (5) XN. 6-8. *Diadorhombus rectus*. Sample 534A-60-3, 73 cm. (6) PH, (7-8) XN. 9-11. *Amphizygus brooksii*. Sample 534A-60-3, 73 cm. (9) OL, (10) PH, (11) XN.

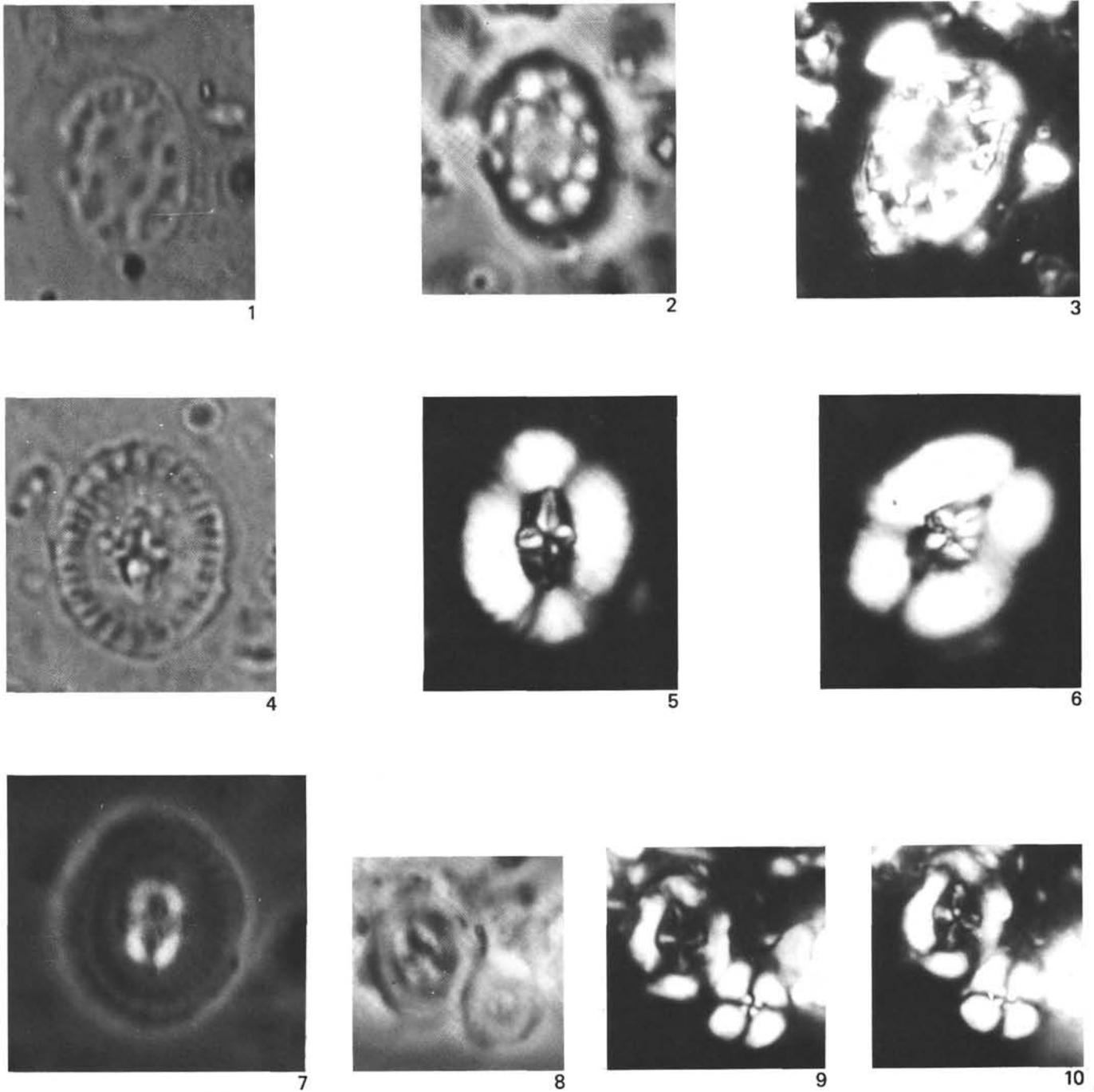


Plate 5. Lower Cretaceous calcareous nannofossils. (Magnification about $\times 3500$ [XN: cross-polarized light; PH: phase contrast; OL: ordinary light].) 1-3. *Octopodorhabdus polytretus*. Sample 534A-61-2, 76 cm. (1) OL, (2) PH, (3) XN. 4-7. *Cruciellipsis cuvillieri*. Sample 534A-76, CC. (4) OL; (5-6) XN, (7) PH. 8-10. *Cruciplacolithus salebrosus* (specimen in the upper left) and *Cyclagelosphaera margerelii* (lower right). Sample 534A-83-3, 53 cm. (8) PH, (9-10) XN.

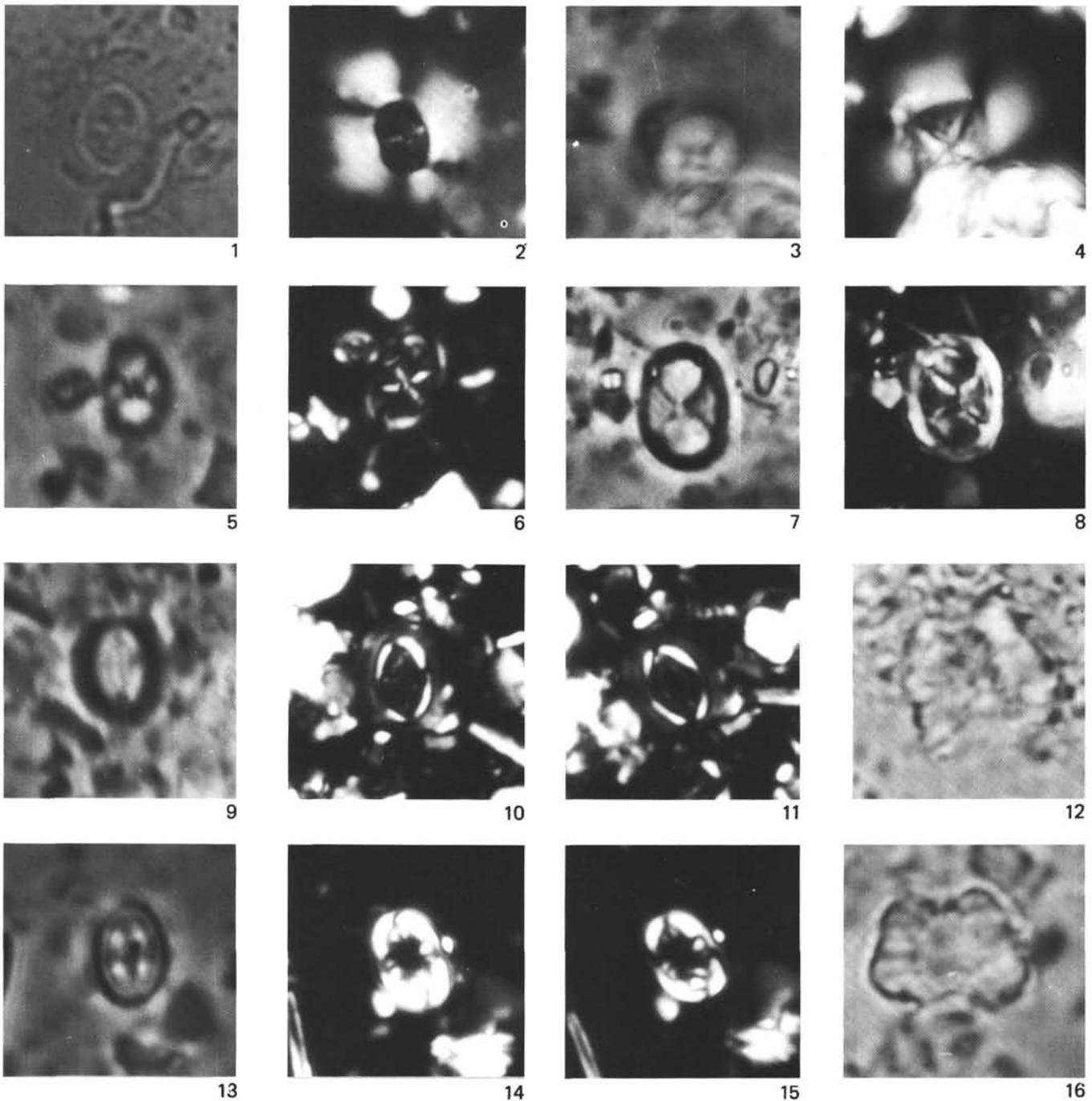


Plate 6. Lower Cretaceous calcareous nannofossils. (Magnification about $\times 3500$ [XN: cross-polarized light; PH: phase contrast; OL: ordinary light].) 1-4. *Cruciaplacolithus furtivus* n. sp. (1 and 2) Holotype (1) OL, (2) XN. Sample 534A-61-2, 76 cm. (3 and 4) Paratype (3) PH, (4) XN. Sample 534A-61-2, 76 cm. 5, 6. *Chiastozygus tenuis*. Sample 534A-45-2, 32 cm. (5) PH, (6) XN. 7-8. *Chiastozygus striatus*. Sample 534A-61-3, 53 cm. (7) PH, (8) XN. 9-11. *Sollasites lowei*. Sample 534A-49,CC. (9) PH, (10-11) XN. 12. *Nannoconus broennimannii*. Sample 534A-87-3, 142 cm. OL. 13-15. *Acaenolithus cf. vimineus*. Sample 534A-50,CC. (13) PH. (14-15) XN. 16. *Nannoconus globulus*. Sample 534A-69-4, 74 cm. PH.