13. MID-CRETACEOUS CALCAREOUS NANNOPLANKTON FROM THE CENTRAL PACIFIC: IMPLICATIONS FOR PALEOCEANOGRAPHY

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ABSTRACT

Moderately well-preserved calcareous-nannoplankton assemblages from the western Mid-Pacific Mountains and Hess Rise reflect paleoceanographic conditions during the middle Cretaceous. Sediments enriched in detrital organic carbon from the Barremian (NC6) at Deep Sea Drilling Project Site 463 contain impoverished assemblages indicative of strong dissolution and adverse water conditions (e.g., high turbidity, fresh-water inflow from islands). A steady increase in the nannolith genera *Zygodiscus* and *Biscutum* and in overall diversity throughout the middle Cretaceous at Site 463 is indicative of a change to more favorable surface-water conditions, but not of highly nutrient-rich surface waters. Coccolith assemblages at Site 464 are poorly preserved and thus marginal at best for quantitative investigations. Assemblages with a high relative abundance of Coccolith species indicative of high nutrient concentrations occur on southern Hess Rise (Sites 465 and 466). Organic carbon of marine origin is commonly preserved at these sites, supporting the inferences based on coccolith assemblages. High productivity in conjunction with warm deep waters of low oxygen content seems sufficient to explain the occurrence of “black shales” in the Pacific. Injection of saline and oxygen-poor Atlantic deep water seems unlikely.

INTRODUCTION

The “middle Cretaceous anoxic event” has received much attention in the last five years. Speculations still outweigh solid information, and a consensus has not yet been achieved (see Arthur, 1979, and Berger, 1979, for reviews). This paper is an attempt to provide information based on the abundance and preservation of calcareous nannofossils, setting constraints on further speculations about tropical Pacific paleoceanography during the middle Cretaceous. A detailed discussion on the “black shale problem” and integration of sedimentological, geochemical and micropaleontological information has been attempted by Roth and Bowdler (in press). This paper treats sedimentological, geochemical, and paleoceanographic information as it applies to the preservation and distribution of calcareous nannofossils.

Equatorial deep-sea sections of middle Cretaceous age have not yet been recovered and are not likely to be cored in the Atlantic and Indian oceans, because of paleogeographic and tectonic constraints. The Pacific is thus our only hope to fill this gap. Problems of strong diagenetic effects and poor recovery have impaired an effort to study nannoliths from Pacific sections so far (Roth, 1973). However, more-complete sections recovered from the Mid-Pacific Mountains and Hess Rise during DSDP Leg 62 have provided nannolith assemblages that are well enough preserved to make a first attempt at a study of equatorial nannolith preservation and ecology in the middle Cretaceous.

ECOLOGY OF MIDDLE CRETACEOUS CALCAREOUS NANNOFOSSILS

If one assumes that Recent calcareous nannoplankton are an adequate analog for Cretaceous calcareous nannoplankton, then these organisms were largely restricted to the photic zone, i.e., the upper 50 to 200 meters of the water column. At present (a cryogenic time with cold polar seas and warm tropical waters) gradients of species diversity and nanofloral distribution patterns are largely controlled by surface-water temperature. Differences in salinity, nutrients and neritic effects are only minor factors affecting coccolithophorid distribution in the water column (Honjo, 1977). Coccolith distribution in sediments is strongly affected by carbonate dissolution at depth (McIntyre and McIntyre, 1971; Schneiderman, 1973, 1977; Roth and Berger, 1975; Roth and Coulbourn, in press). Uncertainty about the physical and chemical parameters in the ancient oceans increases with geologic age. Whereas latitude seems to have exerted the dominant control on the distribution of coccolith assemblages during the Cenozoic (Haq and Lohmann, 1976) and Late Cretaceous (H. Thierstein, pers. comm., 1979), its influence was less pronounced in the middle Cretaceous and earlier times (Roth and Bowdler, in press). This is expected for acryogenic times when global temperature gradients were reduced. Coccolith remains are greatly altered by preferential dissolution on the sea floor, which makes reconstruction of the original distribution patterns difficult. Preservation of the calcitic nannoliths (coccoliths and other nannofossils of unknown biologic affinity) is variable during the geologic history of the oceans. Dissolution of nannoliths at depth is most severe during times of great undersaturation of CaCO₃ in the deep

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1 Initial Reports of the Deep Sea Drilling Project, Volume 62.
oceans. Such times are characterized by a shallow calcite-compensation depth, resulting in sediments of low calcium carbonate content. Recent compilations of sediment distribution patterns by van Andel (1975) and Thierstein (1979) show that the CCD was shallower by about 1 km during the middle Cretaceous than during the early and latest Cretaceous. In addition, the number of sedimentary sections decreases with age, because of the age distribution of the sea floor. These restrictions allow only large-scale distribution patterns and temporal changes of nannolith patterns to be described at the present time. A first attempt to explain biogeographic patterns of the middle Cretaceous nannoliths in Atlantic and Indian ocean sediments (Roth and Bowdler, in press; Roth and Krumbach, in prep.) has shown the following:

1) Nannolith assemblages show minor changes with latitude in a wide tropical belt (about 40°N to 40°S).

2) Bipolar high latitude assemblages of largely similar composition occurred at higher latitude.

3) The dense sample distribution available in the subtropical North Atlantic demonstrates pronounced east-west gradients in the abundance of the dominant species. This is explained by upwelling in the eastern North Atlantic. Studies of the organic geochemistry (Tissot et al., 1979) and of palynomorph distribution (Habib, 1979) corroborate this finding.

4) Only high- and mid-latitude assemblages in the South Atlantic and in British epicontinental deposits show great fluctuations in the abundances of many nannolith species, in some cases almost monospecific or "bloom" assemblages.

5) Nannococids once thought to be restricted to the Tethys and to more-neritic environments (Berger and Roth, 1975) are found at latitudes as high as 55° and on oceanic plateaus (Roth, 1973, and this paper).

**SAMPLES AND METHODS**

A total of 130 samples was taken from middle Cretaceous cores recovered during Leg 62. Light-microscope slides were prepared using standard techniques, and all samples were checked for abundance, diversity, and preservation according to the semiquantitative scale of calcareous-nannoplankton assemblages. At least 300 specimens were counted in each of the 32 well-preserved samples. All samples are listed in Table 1.

**BIOGEOCHRONOLOGY**

The middle Cretaceous as defined in this paper embraces the time between about 115 and 90 m.y. ago. The four oceanic stages Canaveralian, Magellanian, Atlantician, and Tenerifian are included. They correlate more or less with the classical European stages Barremian, Aptian, Albian, Cenomanian and lower Turonian (Roth, 1978). The nannoplankton zones used in this report and the time scale are identical to the ones proposed in Roth (1978); it is preferred over van Hinte's (1976) time scale for the reasons discussed in the former paper. In addition, it results in more reasonable sedimentation rates for middle Cretaceous sediments recovered during Leg 62. The correlation of magnetostratigraphic units with the biostratigraphic scale for Site 463 differs somewhat from previous results (Roth, 1978) in that the "mixed

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472
zone at Site 263'' seems somewhat younger in its type
locality (late Albian, NC10, instead of middle Albian,
NC8), and M-0 is also slightly older at Site 463 than one
would expect from results of investigation in the Atlantic
(Sites 417 and 418).

Biogeochronology is summarized in Figure 1.

Table 1. (Continued).

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<tr>
<td>465A-26-1, 15</td>
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<td>465A-30-1, 24</td>
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<td>10</td>
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<td>10</td>
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<tr>
<td>465A-35-1, 63</td>
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<td>*</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>465A-37-1, 60</td>
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<td>10</td>
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<td>465A-38-2, 12</td>
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<td>3</td>
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<td>465A-39-1, 68</td>
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<td>465A-40-1, 96</td>
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<td>10</td>
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<tr>
<td>466-29-1, 25</td>
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<td>*</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>466-30-1, 65</td>
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</tr>
<tr>
<td>466-31-1, 15</td>
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<td>2</td>
<td>2</td>
<td>10</td>
</tr>
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<td>466-35-1, 25</td>
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<td>2</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>466-35-1, 81</td>
<td></td>
<td>*</td>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>

**Figure 1. Biogeochronology, radiometric ages, magnetostratigraphy, “sapropel zones,” and age assignments for mid-Cretaceous cores. Planktonic foraminifer zone assignments after Boersma (this volume).**

**LOCATION, GEOGRAPHIC POSITION, AND DEPTH OF SITES IN THE MIDDLE CRETAUCEOUS**

Site 463 is in the eastern Mid-Pacific Mountains; Site 464 is on Northern Hess Rise; and Sites 465 and 466 are on Southern Hess Rise. Reconstruction of the paleopositions of Leg 62 sites was accomplished by use of poles of rotation and rotation rates proposed by Lancelot and Larson (1975); they are summarized in Table 2.

Reconstruction of original water depths at Pacific drill sites during the middle Cretaceous poses problems (Fig. 2). If the sites are simply “back-tracked” using the ridge-subsidence curve of Parsons and Sclater (1977), three of the four sites (463, 465, and 466) would be several hundred meters above sea level before 100 m.y. ago. This exceeds the generally acceptable margin of error for the back-tracking method (200–300 m; Berger and Winterer, 1974). The oldest sediments recovered at Site 463 indicate depths of deposition of 500 meters or less. Simple back-tracking of Site 463 assuming a basement age of 130 m.y. would place it about 1000 meters
above sea level. Therefore, a mechanism to explain this discrepancy is necessary. A maximum sea-level rise of 300 meters due to rapid spreading in the middle Cretaceous (Hays and Pittman, 1973) could contribute to increased water depth, but is insufficient alone. Slower subsidence during the early Cretaceous must be invoked to obtain a reasonable sea-floor depth for Site 463 in the middle Cretaceous (Fig. 2).

The following two mechanisms could explain slow subsidence and would result in a reasonable depth of deposition for Site 463 during the later part of the early and middle Cretaceous: (1) Site 463 could be resting on old (140–150 m.y.) sea floor that had subsided to a depth of 0.5 to 1.0 km by the beginning of the middle Cretaceous; (2) sea-floor subsidence was counterbalanced by thermal uplifting associated with widespread volcanism during the early Cretaceous; once this thermal activity stopped, rapid subsidence took place; (3) post-mid-Cretaceous uplift. Magnetic anomalies (M-25) on the sea floor to the northeast of the site suggest an age of latest Jurassic. Extrapolation of basal sediment ages on the volcanic basement, expected to lie about 100 meters below the oldest sediments recovered, range from 115 m.y. to 130 m.y., depending on sedimentation rates. This volcanic basement could well be a younger edifice sitting on older sea floor. However, Site 463 is too shallow if we assume a late Jurassic to early Cretaceous basement age and subsidence along the standard age/depth curve of Parson and Sclater (1977) (Fig. 1). Preservation and composition of middle Cretaceous coccolith assemblages would be most compatible with a depth of 0.5 to 1.0 km during that time. The depositional history of Site 463 does not record drastic post-mid-Cretaceous tectonic uplifting. Therefore, reduced lithospheric subsidence due to thermal processes during the late Jurassic to early Cretaceous (hypothesis 2 above) best explains the tectonic history of Site 463. Of the Hess Rise sites, 464 does not seem to pose any problems as far as back-tracking is concerned. For Sites 465 and 466, uplift in the late Cretaceous seems necessary to obtain reasonable paleodepths for the middle Cretaceous, consistent with nannoplankton and benthic-foraminifer information.

### SEDIMENTARY FACIES OF THE DRILL CORRES

A simplified reconstruction of the middle Cretaceous sedimentary columns recovered at each drill site is shown in Figures 3 to 6. Lithology, calcium carbonate, organic carbon (determined at the University of Oslo under the supervision of J. Thiede), preservation of calcareous nannoplankton, and time-scale on Figure 1, are shown for each site.

At Site 463, the oldest sedimentary rocks (Corres 72–92) consist of interbedded clastic and pelagic limestones of white, gray, and greenish-gray color, with dark-gray cherts, turbidites and debris flows; most sediments are largely burrowed, indicating the presence of at least some dissolved oxygen in the original bottom waters. Calcium-carbonate contents are variable (3–90%). Organic-carbon contents are generally low (0.1–0.2%), with the exception of the two uppermost cores (72, 73), where values of 0.6 to 1.4% are found. The overlying gray to greenish-gray tuffaceous and carbonaceous limestones with cherts are partly laminated and

---

Table 2. Geographic position and water depth of Leg 62 sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Lat.</th>
<th>Long.</th>
<th>Depth (km)</th>
<th>Site</th>
<th>Lat.</th>
<th>Long.</th>
<th>Depth (km)</th>
<th>Site</th>
<th>Lat.</th>
<th>Long.</th>
<th>Depth (km)</th>
<th>Site</th>
<th>Lat.</th>
<th>Long.</th>
<th>Depth (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>463</td>
<td>21.3°N</td>
<td>174.6°E</td>
<td>2.4</td>
<td>16.3°S</td>
<td>150.7°E</td>
<td>0.5–1</td>
<td>20.9°S</td>
<td>146.0°E</td>
<td>0.5</td>
<td>27.3°S</td>
<td>138.0°E</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>464</td>
<td>39.9°N</td>
<td>173.9°E</td>
<td>4.6</td>
<td>2.0°N</td>
<td>153.9°E</td>
<td>2.5</td>
<td>2.9°S</td>
<td>150.4°E</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>465</td>
<td>33.8°N</td>
<td>179.3°E</td>
<td>2.2</td>
<td>2.9°S</td>
<td>148.7°E</td>
<td>0.7</td>
<td>7.5°S</td>
<td>141.1°E</td>
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<td>—</td>
<td>—</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>466</td>
<td>34.2°N</td>
<td>179.3°E</td>
<td>2.7</td>
<td>2.9°S</td>
<td>148.7°E</td>
<td>1.2</td>
<td>7.5°S</td>
<td>145.0°E</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Figure 2. Reconstruction of the paleodepths for Leg 62 sites, using the lithospheric-subsidence curve by Parsons and Sclater (1977). Thin solid lines represent tracks of sea floor without sediment-loading corrections; short dashes are tracks with sediment-loading corrections; long dashes stand for southern Hess Rise tracks without assuming tectonic uplift during the Late Cretaceous; and thick solid lines are the preferred tracks. The number symbols next to the tracks mean the following: 463 (1) basement age of 130 m.y.; 463 (2) basement age of 140 m.y.; 463 (3) basement age of 150 m.y.; 463C (4) starts at sea level, and continued volcanic buildup and uplifting largely compensate for subsidence of the site during the Early Cretaceous; Site 464, normal subsidence curve; 466 (1), 465 (1) track without assuming tectonic uplift of southern Hess Rise; 465 (2), 466 (2) initial normal subsidence, tectonic uplift in the Late Cretaceous.
partly burrowed (Cores 67-71), indicative of low or fluctuating bottom-water oxygen content. They show low calcium-carbonate contents (15–30%, with a few extremes of 1.7% to 76% and 87%), and high organic-carbon contents (maximum 10.6%, many measurements between 2.3 and 4.7%). Smear slides show a preponderance of black, coal-like organic matter, suggesting a largely terrestrial source for the organic carbon (see also Dean et al., 1979).

The middle part of the mid-Cretaceous section at Site 463 (Cores 52–66) consists of multicolored limestones and cherts (various shades of white, greenish-gray, green, pink, and brown), indicating a change to more-oxidizing conditions. Calcium-carbonate contents are high, generally above 50%, and as high as 100%. Intervals of high organic-carbon content are found in Cores
62 (1.3%) and 56 (3.5%). The uppermost part of the middle Cretaceous section (Cores 65 to 38) is composed of massive foraminifer chalks that extend to the lower Maastrichtian. They are off-white with light pink and green shades and contain abundant chert, which resulted in low core recovery. Carbonate contents are high, and organic-carbon values are very low. Thus, there is a slight indication of a “sapropel event” at Site 463 in the upper Magellanian (NC8), but no indication of a Tenerifian (NC11) anoxic event at this site.

The middle Cretaceous sedimentary sections recovered from Hess Rise cover a stratigraphic interval restricted to the upper part of the middle Cretaceous (Atlantian and Tenerifian). At Site 464, the recovery of middle Cretaceous rocks was very poor. Only three of the 23 cores recovered more than 1 meter of sediments. The predominant rock type is gray and reddish to dark-brown chert. Some of the chert vugs are filled with red and tan chalk that contains coccoliths of moderate to poor preservation. Dark-red and brown limestones, marlstones, and claystones occur in Cores 21, 29, 30 and 32. The hole bottomed in basalt. Calcium-carbonate contents are relatively low (max. 40%), but few measurements have been made. Organic-carbon contents are low (0-0.1%), except for one value of 4.3% in Core 32. Conditions of sedimentation were largely oxidizing at this deep site.

The middle Cretaceous section at Site 465 (Hole 465A) consists of laminated olive-gray limestones with black chert and some ash-rich beds at the base which represent distal turbidites. Carbonate contents are generally high (70-90%). In most intervals where organic-carbon values are high, carbonate values are low (11-33%). Organic-carbon contents fluctuate, but many values between 2 and 3% were measured; peak values reach 6.1 to 8.6%. The organic carbon appears to have a largely marine source (Dean et al., 1979) in this part of the Tenerifian (NC11/NC12) sapropel cycle.

At Site 466, middle Cretaceous beds consist of olive-gray, faintly laminated nannoplankton chalk and limestone with black chert, very similar to the sediments recovered nearby at Site 465. They are also interpreted as distal turbidites.

The sedimentology and organic chemistry of the pelagic sediments in Cores 69 and 70 at Site 463 indicate an increased influx and preservation of terrestrial, rapidly buried organic debris. Other sediments rich in organic carbon in the Albian at Site 463, and the organic-rich sediments from Sites 465 and 466, seem to be related to increased productivity, causing reduced oxygen content in the waters (see also Dean et al., 1979). As discussed later, coccolith assemblages seem to corroborate this hypothesis.

**PRESERVATION OF CALCAREOUS NANNOPLANKTON**

Nannoliths exhibit moderate to severe dissolution (“etching”) in samples from sites at water depths close to or below the CCD (e.g., in the western Pacific). Secondary calcite overgrowths are more prevalent in shallow plateau sequences. Poor recovery in the chalky sections compounds the problem, because the most strongly lithified parts of the section are preferentially recovered; coccoliths from these lithologies are often recrystallized beyond recognition. The middle Cretaceous nannoplankton assemblages recovered during Leg 62, although not pristine, are among the best-preserved from the Pacific Ocean. The state of preservation of middle Cretaceous coccolith assemblages is expressed in the semi-quantitative visual preservation scale of Roth and Thierstein (1972), as modified by Roth (1973) for the Mesozoic.

The following degrees of etching are distinguished: E1: slightly jagged margins among delicate forms, delicate central structure damaged in some but not all specimens; E2: more-jagged outlines, delicate central structures frequently affected, more-delicate forms slightly fragmented; E3: only the more-robust forms are preserved, assemblages are enriched in *Watznaueria* and *Cretarhabdus*.

The following degrees of overgrowth are distinguished: O1: slight overgrowth on central structures and shield elements; O2: increased overgrowth, some of the more-delicate forms are sufficiently masked to make identification more difficult; O3: only robust forms preserved; diversity reduced because of removal of delicate forms that serve as the source material for secondary calcite overgrowths and cements.
Rarity is expressed in these terms: VB: virtually barren; only occasional coccoliths and fragments of coccoliths, often barely recognizable, mostly micrite grains; B: total absence of recognizable coccoliths.

Coccolith preservation at the various sites is listed in Table 1 and is graphically depicted in Figures 3 through 6. None of the samples show pristine preservation. All of them show at least moderate overgrowth, with the exception of a strongly etched sample at Site 464. In general, the samples from Leg 62 cores are affected more by overgrowth than by etching. At Site 463, the most-etched samples correlate with low calcium-carbonate content and unusually high organic-carbon content (Core 70, Section 5). Overgrowths are most pronounced in deeply buried multicolored and tuffaceous limestones (Cores 55–87).

At Site 463, virtually barren samples, with only a few poorly preserved specimens of Watznaueria barnesae, and totally barren samples occur in parts of the tuffaceous and carbonaceous limestone sequence (Core 70) and in the clastic and detrital limestones (Cores 79–82, 89 to 91,CC). Dilution of the coccolith remains with detrital and volcanogenic matter resulted in low total concentration of coccoliths in the sediments. Decay of organic matter and diagenesis was responsible for the alteration and occasional total destruction of nannoliths in these intervals. At Site 464 (Cores 79–82, 89–91,CC) recovery was virtually restricted to strongly lithified rocks, such as cherts, with calcareous vug fillings, and also silicified limestones.

Thus, the material is mostly poorly preserved, and the assemblages have to be considered marginal at best for quantitative investigation. Preservation of nannoliths is considerably better at Sites 465 and 466. In Hole 465A, preservation is poor in the limestones recovered in Core 26 and in Section 1 of Core 27, where carbonate contents are 90%, and in the limestones from Cores 33, 38, and 40. Moderate preservation was observed in the remaining cores and in all samples from Site 466.

Carbonate content in the middle Cretaceous intervals of Holes 465A and 466 is generally high (55–99%), with the exception of organic-carbon-rich intervals, where it drops to values as low as 6 to 30%. Somewhat poorer preservation is associated with the most-organic-carbon-rich laminated limestone sections at these sites.

**COCCOLITH ASSEMBLAGES: LATITUDINAL, PRESERVATIONAL, AND TEMPORAL CHANGES**

The relative abundance of all species and some groups only identified to genus in the 32 samples studied are shown in Figures 7 through 10. Species concepts are summarized in the appendix. Closer inspections of these charts show that of the more than 60 species (and genera) observed, only 10 to 12 occur more or less consistently in an abundance over 2% of the total assemblage. Because moderate to severe preservational changes have affected the nannolith assemblages, 2% was used as a lower limit for generalized nannoflora analysis. The more abundant forms and their maximum and minimum relative abundances at each site are as follows:

<table>
<thead>
<tr>
<th>Site</th>
<th>Species</th>
<th>Site 463</th>
<th>Site 464</th>
<th>Site 465</th>
<th>Site 466</th>
</tr>
</thead>
<tbody>
<tr>
<td>463</td>
<td>Watznaueria barnesae</td>
<td>80-65%</td>
<td>34-68%</td>
<td>2-9%</td>
<td>18-30%</td>
</tr>
<tr>
<td>464</td>
<td>Biscutum constans</td>
<td>0-35%</td>
<td>0-39%</td>
<td>22-36%</td>
<td>31-49%</td>
</tr>
<tr>
<td>465</td>
<td>Discorhabus ignotus</td>
<td>1-9%</td>
<td>0-2%</td>
<td>1-8%</td>
<td>1-3%</td>
</tr>
<tr>
<td>466</td>
<td>Zygodiscus erectus</td>
<td>1-20%</td>
<td>0-5%</td>
<td>23-28%</td>
<td>9-30%</td>
</tr>
<tr>
<td></td>
<td>Z. elegans</td>
<td>1-2%</td>
<td>1%</td>
<td>1-3%</td>
<td>1-3%</td>
</tr>
<tr>
<td></td>
<td>Z. diploogrammus</td>
<td>0-3%</td>
<td>0-2%</td>
<td>1-2%</td>
<td>1-5%</td>
</tr>
<tr>
<td></td>
<td>Eiffelithus turrisellifellus</td>
<td>3-16%</td>
<td>0-4%</td>
<td>6-16%</td>
<td>2-4%</td>
</tr>
<tr>
<td></td>
<td>Parhabdolithus asper</td>
<td>1-10%</td>
<td>1%</td>
<td>0-1%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>Parhabdolithus swinnertonii</td>
<td>1-12%</td>
<td>2-7%</td>
<td>2-6%</td>
<td>2-4%</td>
</tr>
<tr>
<td></td>
<td>Prediscosphaera cretacea</td>
<td>1-8%</td>
<td>0-3%</td>
<td>1-3%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>Cretarhabdus crenulas</td>
<td>2-11%</td>
<td>1-2%</td>
<td>1-2%</td>
<td>1-2%</td>
</tr>
</tbody>
</table>

Species that occur in low to moderate abundance (but do not exhibit consistent patterns) and their total range in all sections include the following:

- **Lithraphidites carniolensis**: 1-14%
- **Cruciellipsis chasta**: 0-4%
- **Cyclogelosphaera margaritii**: 0-12%
- **Vagapolita matalota**: 0-5%
- **Watznaueria supracretacea**: 0-9%
- **Parhabdolithus swinnertonii**: 0-4%
- **Nannoconus spp.**: 0-3%
- **Rucinolithus sp.**: 0-7%

All other species do not exceed 5% in any sample and are generally in the 0 to 3% range, or occur only in scattered samples.

The list of abundant species and genera agrees well with observations from the Atlantic and Indian Oceans. A possible interpretation of distribution patterns for these predominant species has been determined for the Atlantic (Roth and Bowdler, in press). In order to facilitate the interpretation of middle Cretaceous nannoplankton distribution and the implication for paleoceanography, nannoplankton distribution in the Atlantic is outlined briefly, and species important for paleoceanographic interpretation are identified. A profile of species abundance in the best-preserved samples from sites along the eastern margin of the North Atlantic and continuing through the South Atlantic for the interval NC10/NC11 is shown in Figure 11. An east–west profile of species abundances from Texas across the North Atlantic is shown on Figure 12.

The north–south profile starts with a sample from the Gault Clay that contains some high-latitude species (Serbiscutum primitivum and Zygodiscus cf. Z. spiralis). The next station (Site 400) contains more Watznaueria barnesae, possibly because of some post-depositional dissolution during diagenesis of these organic-matter-rich shelf sediments. The samples from Sites 398 to 367 show little change in the overall abundance of the major species. Abundance of Watznaueria barnesae is low; Biscutum constans and Zygodiscus spp. abundances are high. In the largely isolated northern South Atlantic, Biscutum constans can totally dominate the nannolith assemblages. A peak of 59% Biscutum constans was observed at Site 364 in the sam-

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Figure 7. Relative abundance of nannoliths at Site 463 in percent of the total assemblage. The plus sign stands for abundances of less than 1%, the minus sign for species that were not observed in the particular sample during counting.
ple used for the profile; other samples show lower values, similar to the ones found at Site 363. Assemblages of the Falkland Plateau are dominated by high-latitude forms (Seribiscutum primitivum, Zygodiscus spiralis, and Transolithus orionatus). However, changes in nannoplankton assemblages in a wide tropical zone between 40°N and about 40°S seem relatively minor compared to changes we observe in an east–west profile across the North Atlantic (Fig. 12). The east–west profile, on the other hand, shows pronounced nanofloral trends. Epicontinental assemblages from Texas contain relatively abundant Biscutum constans and Eifellithus turriseiffeli, but relatively low abundances of Zygodiscus spp. At the Blake Nose (Site 390), Biscutum con-
(upwelling) forms: particular paleoceanographic conditions: 

voking differences in preservation. 

per part of the middle Cretaceous of the Atlantic allows 
latter site. 

and on the Blake Nose and at Site 391, where they are 
and noconus 

are observed in Texas 

Braarudosphaera, Parhabdolithus splendens 

are more abun-

P. asper 

466-29-1, 25 cm 

for the nannofloral distribution patterns simply by in-

on the eastern and western margins of the North Atlan-

the best-preserved assemblages from the shallowest sites 

reduced abundances in the western North Atlantic. 

Zygodiscus erectus, Z. 

is fairly abundant, but 

ygodiscus erectus, Z. 
elegans, and Z. diplogrammatus are much less common. 

Many rare forms occur at Site 390, so that only 65% of 

the assemblage is expressed by the species shown on the 

profile. Watznaueria barnesia is more abundant at Site 

390 and remains high at Sites 391, 418, 386, and 137. 

Parhabdolithus splendens and P. asper are more abun-

dant in eastern basin and central North Atlantic sites 

than along the eastern and western continental margins. 

These relatively solution-resistant species show much-

reduced abundances in the western North Atlantic. 

Relative abundances of the major nannolith species in 

the best-preserved assemblages from the shallowest sites 

on the eastern and western margins of the North Atlan-

tic differ considerably—by as much as a factor of ten 

(Fig. 12). This seems to indicate that one cannot account 

for the nannofloral distribution patterns simply by in-

ducing differences in preservation. 

Indicators of more-neritic conditions, such as Nan-

noconus and Braarudosphaera, are observed in Texas 

and on the Blake Nose and at Site 391, where they are 

possibly redeposited in part from shallower water at the 

latter site. 

This brief discussion of nannofloral trends in the upper 

part of the middle Cretaceous of the Atlantic allows 

us to identify the following species that are indicative of 

particular paleoceanographic conditions: 

1) High-latitude forms: 

Seribiscutum primitivum 

Zygodiscus cf. spiralis 

Tranolithus orionatus 

2) High-productivity/high-surface-water-fertility 

(“upwelling”) forms: 

Biscutum constans 

Zygodiscus erectus 

(or total Zygodiscus spp.) 

3) Indicators of neritic conditions: (continental mar-

gin, shallow plateaus) 

Nannoconus spp. 

Braarudosphaera 

Broinsonia spp. 

4) Dissolution residual assemblages (excluded from 

our Atlantic profiles): 

Watznaueria barnesia 

5) Restricted sea assemblage (South Atlantic): highly 

variable assemblages with almost monospecific assem-

blages of Biscutum constans, Zygodiscus spp., Cor-

rolithon spp. 

With this knowledge of how ecologic preference and 

preservational aspects affect nannoplankton assem-

blages, it is now possible to interpret the nannolith dis-

tribution in a north-south profile in the tropical Pacific 

(Leg 62 sites) for the interval late NC10 to early NC11 

(Fig. 13) in order to detect possible latitudinal trends. 

The major difference between the assemblages at Sites 

463 and 465 is a much greater abundance of Zygodiscus 

erectus and a low abundance of Discochabdis ignitus at 

the latter site. The relative abundance of Biscutum const-

ans is almost the same at all the sites; this indicates its 

relatively great resistance to dissolution and diagenetic 

alteration. A decrease in the relative abundances of 

Watznaueria barnesae, Eiffellithus turrieseifelii, and 

Prediscophaera cretacea seems of minor significance 

and is probably largely due to differences in preserva-

tion. The major differences in nannolith assemblages at 

Sites 463 and 465 are best explained by more-fertile sur-

face water at the latter site; a very small difference in 

surface-water temperature might have had some influence 

also. 

The comparison of coccolith assemblages at Sites 465 

and 466 is most interesting because the two sites are only 

50 km apart and the sedimentary facies are almost iden-
Figure 11. Plot of late mid-Cretaceous (NC10/NC11) nannolith ratios versus latitude in a north-south transect from southeastern England along the eastern continental margin of the North Atlantic and through the South Atlantic to the Falkland Plateau. The following samples with the best preservation were used: 6 = Gault Clay; 400 = DSDP 400A-62-1, 56 cm; Bed XII, Copt Point, SE England; 398 = DSDP 398D-57-3, 50 cm; 370 = DSDP 370-24-2, 60 cm; 369A = DSDP 369A-41-2, 96 cm; 367 = DSDP 367-20-2, 100 cm; 364 = DSDP 364-28-1, 55 cm; 363 = DSDP 363-28-2, 98 cm; 327 = DSDP 327-15-2, 87 cm.

The changes in relative abundance of the major nannolith species at these two sites was likely caused by differences in preservation; it seems highly improbable that a major water-mass boundary passed between the two sites and caused the differences in observed species composition. The most drastic change is an increase in the abundance of *Watznaueria barnesae* (a solution-resistant form) at Site 466. The ratios of *Biscutum constans*, *Eiffellithus turriseiffeli*, *Zygodiscus elegans* + *Z. diplogrammus*, and *Parhabdolithus splendens* + *P. asper* remain almost unchanged. However, *Zygodiscus erectus* decreases drastically in relative abundance. The best-preserved sample at Site 464 has a composition very similar to Site 466, with somewhat more-abundant *Biscutum constans* and less-abundant *Zygodiscus erectus* at Site 464. Again, these small differences in nannofloral composition are largely attributed to differences in preservation, the assemblages at Site 464 being much more poorly preserved than the ones at Site 466, because of greater water depth of the former and hence greater preservational changes. A comparison of the well-preserved assemblages at Sites 465 and 466 with assemblages in the Atlantic shows that *Biscutum constans* is a little more abundant in the tropical Pacific than it is in the Atlantic along the eastern margin (off Africa) or in epicontinental samples from Texas. *Zygodiscus erectus* is as abundant at Site 465 as in samples from the eastern basin of the Atlantic. This is indicative of high-productivity, possibly along an equatorial divergence. Common radiolarians in these sediments and high sedimentation rates support this hypothesis.

In order to find how nannolith assemblages changed through time, ratios of the dominant species were plotted against age for each site (Fig. 14). The temporal species plot at Site 463 shows interesting trends. Lower middle Cretaceous assemblages (NC6 and NC7) show unusually abundant *Watznaueria barnesae* and relatively abundant *Parhabdolithus splendens* and *P. asper*. Such assemblages are indicative either of low original
diversity because of unfavorable surface-water conditions, or of the effect of preservational changes. The beds rich in detrital organic carbon from terrestrial sources are particularly rich in *Watznaueria barnesae*. Perhaps the highly turbid surface water near the islands that furnished the detrital matter was an unfavorable habitat for other species. Also, carbon dioxide production by disintegrating organic matter in the sediment might be partly responsible for secondary differential dissolution of coccolith species. Samples just above this interval contain very abundant *Lithraphidites carniolensis*, a species whose ecological preference is not clearly understood at the present time. In zone NC8 (middle Albian) *Watznaueria barnesae* reaches a second peak in abundance and then steadily declines until the top of the middle Cretaceous. This decrease of *Watznaueria barnesae* is accompanied by a steady increase in *Biscutum constans*. *Parhabdolithus splendens* and *P. asper* increase in the lower and middle Albian and decrease in the upper Albian. *Eiffellithus turrisseiffeli* increases rapidly after its first appearance and fluctuates in abundance near the top of the section. *Zygodiscus* spp. do not increase very much in that interval (NC10); therefore we cannot attribute the temporal changes in nannolith assemblages solely to changes in preservation. Closer sample spacing in the uppermost middle Cretaceous zone NC11 (Tenerifian or lower Cenomanian) results in greater fluctuations in abundance of important nannoliths. *Biscutum constans* and *Zygodiscus* spp. seem to display the greatest variability. Whether such changes are cyclic and are caused by changes in surface-water conditions or preservation could be tested by taking more closely spaced samples. The overall nannofloral assemblage change at Site 463 between 100 m.y. and 95 m.y. reflects a trend from more-neritic conditions to better-preserved assemblages deposited under oxygenated deep water during the late part of the middle Cretaceous. The presence of *Nannoconus* during the middle Cretaceous at the Mid-Pacific Mountains and Hess Rise shows clearly that this species did occur in shallow regions of
the tropical oceans far from land. It was also found in the lowermost Cretaceous at the Magellan Rise (Site 167) by Roth (1973).

Site 463 did not reach the equatorial high-productivity zone during the middle Cretaceous (Table 2). *Biscutum constans* and *Zygodiscus* spp. are not as abundant at Sites 463 in zones NC10/NC11 as at equatorial Sites 465, 466, and 464. Also, sedimentation rates are not as high at Site 463 as at Sites 465 and 466, and the latest mid-Cretaceous "sapropel cycle" is missing at Site 463. This is an indication that Site 463 had not reached the equatorial region of high productivity by the late middle Cretaceous; it did not reach it until the Maastrichtian.

At Sites 465 and 466, temporal changes in species abundance are relatively small. *Biscutum constans* and *Zygodiscus* spp. remain high throughout zones NC10 and NC11. High content of organic-carbon largely of marine origin (Dean et al., 1979) seems a further indication of fairly high production in the surface water, associated with high nutrient content possibly caused by an equatorial divergence.

Temporal changes at Site 464 are largely due to changes in preservation that seem to mask all primary changes in nannoplankton biocoenoses.

Although equatorial middle Cretaceous sections have not yet been sampled in other ocean basins, it is possible to interpret the large-scale nannofloral patterns in the equatorial Pacific middle Cretaceous. A zone of high productivity did exist, and we can assume that, although surface circulation was more sluggish because of smaller temperature gradients, a system of gyres and an equatorial convergence existed during the middle Cretaceous, at least in the Pacific Ocean.

**SUMMARY AND CONCLUSIONS**

Calcareous-nannoplankton assemblages from the equatorial Pacific, although affected by preservational changes, have retained the major original spatial and temporal nannofloral trends. Dissolution and overgrowth result in an increase in the abundance of *Watznaueria barnesae* and a decrease in the abundance of one of the high-fertility indicators, *Zygodiscus erectus*, but they hardly affect the abundance of *Biscutum con-
stans, the other indicator species of high surface-water fertility. Equatorial Pacific middle Cretaceous assemblages contain both of these indicator species of high surface-water fertility in great abundance during the interval NC10/NC11 (Argusian and Tenerifian or late Albian–Cenomanian). This indicates surface-water currents in the form of two gyres and an equatorial divergence that resulted in high surface-water productivity. The increased production of organic matter in an ocean with warm, intermediate and deep waters that contained little original dissolved oxygen was probably sufficient to cause mid-water anoxia in the tropical Pacific during the middle Cretaceous. Injection of oxygen-depleted deep water from the Atlantic into the Pacific at a depth of 1 to 2 km seems unnecessary and also unlikely, because of the lack of cold, dense bottom waters in the Pacific which could have been denser than the more-saline waters injected from the Atlantic (Table 3). Middle Cretaceous organic-carbon-rich sediments are very localized in their occurrence in the Pacific and are generally associated with high sedimentation rates in the equatorial zone or in proximity to island chains. There is a need for detailed investigations of assemblages from additional drill sites, and also for a combination of micropaleontological, sedimentological, and geochemical studies of such sections in order to obtain a more complete picture of the middle Cretaceous paleoceanography of the Pacific.

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REFERENCES


APPENDIX

Notes on Species

All species of calcareous 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 combination, and by one or more references to illustrations that most closely approximate species concepts used in this study. Reference to the illustrations in this paper are added in parentheses. Remarks are added for variable species concepts, or for species difficult to identify under
the light microscope. Some forms originally described by use of the electron microscope and some that are generally rare were grouped in genera listed at the end.

Complete synonym lists have not been prepared, and the interested reader is referred to the recent taxonomic literature, such as Black (1971, 1973, 1975), Hill (1976), and Verbeek (1977), for more-detailed taxonomic discussions. Also, not all taxonomic references are listed in the reference list. They can be found in the index and bibliography of calcareous nanoplankton by Loeblich and Tappan (1966–1971) and by van Heek (1979a, b).

Lithraphidites alatus Thierstein in Roth and Thierstein, 1972. Thierstein, 1976, pl. 4, figs. 26, 27.

Remarks. It is important that only specimens with distinctly flaring blades are included in this species, and not irregularly overgrown specimens of *L. carniolensis*. Specimens that could be assigned to *Lithraphidites acutus* Verbeek and Manivit (in Manivit et al., 1977, pl. 1, figs. 7, 8) were not observed.


Remarks. Strongly overgrown specimens tend to display almost completely filled central areas with a broad central cross composed of two plates that flare towards the periphery.

Vagalapilla angusta (Stover, 1966) n. comb. (Basionym: *Zygolithus angustus* Stover, 1966, pl. 3, figs. 14, 15, pl. 8, fig. 22).

Remarks. This species displays a cross that is not exactly aligned with the major and minor axes of the ellipse. As Verbeek (1976) has shown, this could be the ancestor of *Eiffelliites turrisellii*.

Parhabdolithus angustus (Stradner, 1963) Stradner, Adamik, and Maresch, 1968. Stover, 1966, pl. 6, figs. 16–19. (as *Parhabdolithus elongatus* Stover = junior subjective synonym of *P. angustus*).

Remarks. Only specimens with a total length equal to or larger than twice its width have been included.


Remarks. Specimens with and without an obvious stem are included. Transitions exist between *P. asper* and *P. splendidus*, the latter being more narrowly elliptical and more abundant in the latter part of the middle Cretaceous. The two species are often combined, since they appear to have the same ecological preference and are closely related.

Watznaueria barnesae (Black, 1959) Perch-Nielsen, 1968. Stover, 1966, pl. 1, figs. 10, 11 (as *Coccolithus paenepelagicus* Stover = junior subjective synonym of *W. barnesae*).


Remarks. This species has a well-developed bridge, frequently made up of two elements. Specimens with a floor or a weakly birefringent bridge belong to *Watznaueria communis* Reinhardt, 1964.


Crucellipsis chiastia (Worsley, 1971) Thierstein in Roth and Thierstein, 1972, pl. 6, figs. 8–13.

Haquis circumradiatus (Stover, 1966) Roth 1978. Stover, 1966, pl. 5, figs. 2–4 (as *Coccolithites circumradiatus*); Hill, 1976, pl. 8, figs. 20–27 (as *Markalites circumradiatus*).

Vagalapilla compacta Bukry, 1969, pl. 31, figs. 10, 11.

Remarks. This species shows a characteristic clover-leaf pattern in the center under the light microscope.


Remarks. This species is used in a very broad sense for cretarhabdids with a distinctive central cross.


Remarks. This species was used for species of *Biscutum* that do not show a central-area structure. Specimens of *Biscutum* with a small central knob are assigned to *Biscutum* sp. cf. *B. gartneri* Black, 1973.

Cretarhabdus coronadventis (Reinhardt, 1966) n. comb. (Basionym: *Cretarhabdus coronadventis* Reinhardt, 1966, p. 26, pl. 23, figs. 29, 30; Stover, 1966, pl. 5, figs. 15, 16; (as *Cretarhabdus unicorns* Stover = junior subjective synonym of *T. coronadventis* (Reinhardt)). Hill, 1976, pl. 7, figs. 1–5 (as *Gephyrorhabdus coronadventis*).

Remarks. This species has buttresses in the diagonal direction and a distal shield consisting of two cycles. Under the light microscope, the shields of *T. coronadventis* show higher birefringence than shields of *Axopodorhabdus*. The genus *Gephyrorhabdus* Hill, 1976 is a junior subjective synonym of *Tetrapodorhabdus* Black, 1973.

Cretarhabdus crenulatus Bramlette and Martini, 1964. Bramlette and Martini, 1964, pl. 2, figs. 23, 24. (Plate 1, Fig. 2).

Remarks. This species is used in a broad sense for specimens having more than eight struts in the central area and frequently showing more than one cycle of perforations between the struts. *Cretarhabdus surirellus* (Deflandre, 1954) Reinhardt, 1970 is a species whose structure is not known with certainty.

Prediscosphaera cretacea (Arkhangelsky, 1912) Gardner, 1968, pl. 2, figs. 10–14, pl. 3, figs. 10–14, pl. 3, figs. 8a–c, pl. 4, figs. 19–24; pl. 6, figs. 13–15, pl. 9, figs. 1–4, pl. 12, figs. 1a–c, pl. 14, figs. 20–22, pl. 18, fig. 8, pl. 22, figs. 1–3, pl. 23, figs. 4–6, pl. 25, figs. 12–14, pl. 26, fig. 2. (Plate 1, Fig. 1)

Remarks. Early forms of this species are almost circular in outline and very small. *Prediscosphaera cretacea columnata* (Stover, 1966) Hill, 1976 was not distinguished from *P. cretacea cretacea*, because transitions between the small circular form and the slightly larger elliptical form exist and the projections on the stem described in the former subspecies (Hill, 1976) are impossible to recognize consistently under the light microscope. Certainly a distinction of the two forms at the species level does not seem warranted.


Remarks. This species differs from *T. coronadventis* in having two small pores in the short axis and two larger pores in the long axis of the ellipse.

Cyclagelasphaera deflandrei (Manivit, 1966) Roth, 1973, pl. 26, fig. 7.

Axopodorhabdus dietzmannii (Reinhardt, 1965) Wind and Wise, 1977, Hill, 1976, pl. 10, figs. 31–33, pl. 11, figs. 1, 2, pl. 15, fig. 5 (as *Podorhabdus dietzmannii*).

Remarks. This species differs from *A. albius* in its more robust, broader central cross and its oblong shape, with parallel sides rather than a regularly elliptical outline as observed in *A. albius*.

Zygolithus diplogrammus (Deflandre in Deflandre and Fert, 1954) Gartner, 1968, Stover, 1966, pl. 4, figs. 2–5, (as *Zygolithus ponticus* = junior subjective synonym of *Z. diplogrammus*); Hill, 1976, pl. 12, figs. 25–27, pl. 15, figs. 5–26. (Plate 1, Fig. 3).

Remarks. All specimens with a bridge composed of two optically continuous elements that are not optically continuous with the wall are included in this species.

Cribrospirellina ehrenbergii (Arkhangelsky, 1912) Deflandre, 1952. Stover, 1966, pl. 3, figs. 12, 13 (as *Discolithus venatus* = junior subjective synonym of *C. ehrenbergii*); Hill, 1976, pl. 5, figs. 20–32. (Plate 1, Fig. 4)

Remarks. Early forms of this species are elliptical, rather than oblong with parallel sides. The regular arrangement of crystallites and the relatively low birefringence of the shield margin are well developed in specimens as far back as zone NC10.
Discorhabdus ignotus (Gorka, 1957) Perch-Nielsen, 1968. Hill, 1976, the latter species also shows a more regular arrangement of the crystallites in the central area.


Remarks. This species shows a double bridge that is interrupted in the middle by a central knob-like structure composed of four elements. My species concept follows the emended definition and illustrations of Bukry, 1969, as the original illustrations by Gartner, 1968 do not show sufficient ultra-structural detail, and more than one species might have been included. *Zygodiscus* sp. cf. *Z. spiralis* Bramlette and Martini, 1964 differs from *Z. ignotus* by the presence of a slightly asymmetrical bridge with asymmetrically flaring attachment plates that are larger on opposite sides of the bridge where it attaches to the wall, and by strongly spiral extinction figures under crossed nics.


Remarks. Under the light microscope this species of *Broinsonia* is difficult to separate from other species of *Broinsonia*, especially forms with delicate grill structures such as *Z. dentata* Bukry, and from many species belonging to the genera *Acantholithus* Black and *Cibcricalithus* Black. Specimens that lack a distinctive cross and appear to have a completely filled central area are included in this species.


Remarks. This species is small and has a single bridge with a central knob. The grill structure that generally fills the central area between the bridge and the margin is not visible under the light microscope.

Reinhardtites fenestratus (Worsley, 1971) Thierstein, in Roth and Thierstein, 1972, pl. 8, figs. 1-12.


Remarks. This species is used in a broad sense, and includes specimens with high and low walls that seem to grade into each other. The single bridge is interrupted in the center, but is optically continuous with the margin.

Tranolithus gabalus Stover, 1966, pl. 4, fig. 22.

Remarks. The single bridge is interrupted in the center, but is optically continuous with the margin.

Gaarderella granulifera Black, 1973. Part II, pl. 19, fig. 6, 10-13. (Plate 1, Fig. 5)

Remarks. This species differs from *Cretarhabdus crenulatus* s. ampl. in having a central area composed of irregular small blocks and a cretarhabdoidal margin that shows higher birefringence than *Cribrospheeraiah ehrenbergii*; the latter species also shows a more regular arrangement of the crystallites in the central area.

Cruceplactolithus hayi Black, 1973, Part II, pl. 23, figs. 9, 10; Hill, 1976, pl. 11, figs. 27, 28.

Remarks. Small specimens with a cocolithid rim and a cross aligned in the long and short axes of the ellipse are assigned to this species.


Remarks. The rim of the species shows low birefringence, much like *Biscutum*, with the exception of a narrow bright ring around the central area. The characteristic structure in the central area is best observed under the light microscope with phase optics.

Discochorhabdus ignotus (Gorka, 1957) Perch-Nielsen, 1968. Hill, 1976, pl. 6, figs. 12-18. (Plate 1, Fig. 6)

Remarks. This species is sometimes referred to as *C. rotatorius* (e.g., Thierstein, 1973).


Remarks. This species show dextral imbrication and has a larger number of elements (9-11) than *R. wii*, which has always 6 elements and is sinistraly imbricated.

**Stephanolithion lassifiei** Noel, 1956. Stover, 1966, pl. 7, figs. 25-27 (as Stephanolithion crenulatum = junior subjective synonym of *S. lassifiei*).


**Chiaustoxys littorarius** (Gorka, 1957) Manivit, 1971, Thierstein, 1976, pl. 3, figs. 31, 32; Stover, 1966, pl. 4, fig. 18. (as *Zygolithus cf. conicus*). Plate 1, Fig. 7

Remarks. Under the light microscope, this species can be distinguished from *Vagapipiia strudneri* by its straight arms that show symmetrical extinction figures.

**Cretarhabdus toriei** Gartner, 1968, pl. 24, figs. 9, 10.

Remarks. This species shows extinction of its central area by segments and is only present as typical specimens in the uppermost part of the middle Cretaceous.

**Tetralithus multicus** Worsley, 1971, pl. 2, figs. 9-11.

**Cyclagelosphera margerelli** Noel, 1965. Hill, 1976, pl. 14, fig. 3.


Remarks. The rim of this species is eff follicithid, and the cross broadens towards the rim.

**Watsonniera oblonga** Bukry, 1969, pl. 11, figs. 8-10; Thierstein, 1973, pl. 5, figs. 1-12 (as *Flabellites biforaminis*).

Remarks. Few if any specimens assigned to this species show a distinctly flaring margin. Thus, I prefer to assign them to *W. oblonga* Bukry, 1969, rather than to *Flabellites biforaminis* Thierstein, 1973.


Remarks. Specimens with a broad double bridge that is optically continuous with the wall belong to this species. Etched forms sometimes assigned to *T. exiguus* Stover by other authors were included in *T. orionatus*, as suggested by Thierstein, 1974.


Remarks. This species has relatively large open central area.

**Manivitella pemmatoidea** (Deflandre ex Manivit, 1965) Thierstein, 1971, pl. 5, figs. 1-3.


Remarks. This small species with about 8 bulbous arms has been assigned to *Hayesites atlanticus* Wilcoxon, 1972 and *H. bulbus* Thierstein, 1973; both are junior subjective synonyms of *H. radiatus*.

Remarks. This small *Broinsonia* has a distinctive cross in the center and differs from *Vagalapilla stradneri* in having a bright "*Broinsonia*-type" rim.

*Corolithion signum* Stradner, 1963. Hill, 1976, pl. 4, figs. 21-24, pl. 13, fig. 22.


Remarks. This species occurs more commonly and is more typically developed in the upper Cretaceous, but specimens with strongly spiral extinction figures found in the middle Cretaceous, especially at high latitudes, are assigned to this species. See remarks for *Z. elegans* for further discussion.


Remarks. This unusual species of *Broinsonia*, first described from Texas, is found as rare specimens in the central Pacific. It is included in *Broinsonia* sp. on the range charts.

*Tegumentum stradneri* Thierstein in Roth and Thierstein, 1972. (Plate 1, Fig. 8, 9)

Remarks. Under the light microscope, this species shows asymmetrical extinction figures on its cross arms. A gray outer cycle of plates is faintly visible in well-preserved specimens.


Remarks. This species is used in a broad sense and includes all specimens of *Vagalapilla* with a relatively narrow central cross, with its arms aligned in the long and short axis of the ellipse. Several species possibly could be distinguished in a detailed taxonomic study.


*Parhabdolithus swinnertonii* (Black, 1971) Wind and Čepok, 1979. Black, 1971, pi. 34, fig. 4; Wind and Čepok, 1979, pl. 11, figs. 8-16. (Plate 1, Fig. 10)

Remarks. This species differs from *P. splendens* by the presence of a strongly inflated stem that fills almost the whole central area.

*Eiffellithus trabeculatus* (Gorka, 1957) Reinhardt and Gorka, 1967. Stover, 1966, pi. 11, figs. 7-18 (as Discolithus dissectatus = junior subjective synonym of *E. trabeculatus*). Roth and Thierstein, 1972, pi. 12, figs. 34-36.


Remarks. Specimens with a large diagonal double cross and specimens with a small cross that does not reach the wall are included in this species.


A number of rare small forms with a "*Broinsonia*-type" rim and a central cross of complex structure surmounted by a knob or stem were observed. They appear to be most similar to the genus. No attempt was made to identify these forms on the species level.

*Broinsonia* spp.

Species of *Broinsonia* not assigned to either *B. enormis* or *B. signata* were included in this category.

*Braarudosphaera* spp.

All species of *Braarudosphaera* and *Micrantholithus*.

*Nannoconus* spp.

The species of *Nannoconus* belong predominantly to the group with open central cavity (*N. bucheri*, *N. truitti*, etc.). In the lower part of Site 465, *N. colomi* is present.

*Rucinolithus* spp.

Irregular specimens of *Rucinolithus* with fewer rays than *R. irregularis* are included. There was some indication of transitions from well-preserved *Discorhabdus ignotus* to more highly birefringent forms with jagged outlines, and finally to forms that resemble *Rucinolithus*.


Spec. nov. A

Dart-shaped objects that seem to be composed of four blades which are possibly holococcoliths were observed in Hole 465A. These are possibly related to *Lucinorhabdus compactus* (Verbeeck) Prins and Sissingh, 1977, reported from the Cenomanian. Because of considerable overgrowths, its structural details are somewhat obscured, and no detailed description is given here.
Plate 1. Magnification 2000× except for Figure 9 (2150×); XN: cross-polarized light; PH: phase contrast; OL: ordinary light.

Figure 1. *Prediscosphaera cretacea* (Arkhangelsky) Gartner: Sample 463-43-2, 10 cm; la: XN, lb: PH, lc: OL.

Figure 2. *Cretarhabdus crenulatus* Bramlette and Martini; Sample 463-43-2, 10 cm; XN.

Figure 3. *Zygodiscus diplogrammus* (Deflandre in Deflandre and Fert) Gartner; Sample 258-20-1, 80 cm (Indian Ocean) 3a, 3b: XN; 3c: PH.

Figure 4. *Cribrosphaerella ehrenbergii* (Arkhangelsky) Deflandre, Sample 463-43-2, 10 cm; 4a, 4b: XN; 4c: PH.

Figure 5. *Garderella* sp. cf. *G. granulifera* Black; Sample 465A-29-1, 133 cm; 5a, 5b: XN.

Figure 6. *Discorhabdus ignotus* (Gorka) Perch-Nielsen; Sample 463-48-1, 75 cm; 6a: XN; 6b: PH; 6c: OL.

Figure 7. *Chiastozygus litterarius* (Gorka) Manivit; Sample 465A-27, CC; 7a, b: XN; 7c: PH.

Figure 8. *Tegumentum stradneri* Thierstein in Roth and Thierstein; Sample 465A-27, CC; XN.

Figure 9. *Tegumentum stradneri* Thierstein in Roth and Thierstein; Sample 258-20-1, 80 cm (Indian Ocean); 9a: XN; 9b: PH.

Figure 10. *Parhabdolithus swinnertonii* (Black) Wind and Čepek; Sample 465A-29-1, 133 cm; XN.