Cenozoic Calcareous Nannofossils from Deep Sea Drilling Project Leg 77: Biostratigraphy and Delineation of Hiatuses

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26. CENOZOIC CALCAREOUS NANNOFOSILS FROM DEEP SEA DRILLING PROJECT LEG 77: BIOSTRATIGRAPHY AND DELINEATION OF HIATUSES

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ABSTRACT

Three of the six DSDP Leg 77 sites drilled in the western approaches to the Straits of Florida yielded thick sequences of Cenozoic sediment rich in calcareous nannofossils. Hiatuses are prominent in each of these continuously cored intervals. A prominent upper Oligocene hiatus, observed at each of these three sites, can be correlated to a large-scale "global" regression event. Other disconformable horizons present in the study area cannot be positively related to sea-level fluctuations and may be caused by a number of factors including local tectonic activity. Paleogene sections are generally marked by thick accumulations within the upper Oligocene Sphenolithus ciperoensis Zone and by a pronounced baarudospirifer-holococcolith bloom recorded in the lower Oligocene and upper Eocene. This bloom is particularly well developed at Site 540. All samples examined contain abundant nannofossils. Preservation fluctuates throughout the sections from good to poor.

INTRODUCTION

During DSDP Leg 77 (December 1980 to January 1981), 238 cores were recovered from six sites in the western approaches to the Straits of Florida (Fig. 1). The calcareous nannofossils in samples from these cores have been examined in order to provide an initial description of the abundance, diversity, preservation, and biostratigraphy of the assemblages. In addition, a special effort was made to detect and determine the extent of hiatuses in the sections. This phase of the investigation was stimulated by the recent assertion by Vail and others (1980) that they have been able to detect seismically in deep-marine Mesozoic and Cenozoic sequences of the North Atlantic a suite of 28 major and minor unconformities previously identified in nearshore sections. This was an extension of previous work along the continental margins where the principal authors had concluded that lowstands of sea level produce interregional or "global" unconformities (Vail et al., 1977).

Major Cenozoic unconformities identified in the North Atlantic by Vail and others (1980) are basal Thanetian, basal upper Ypresian, basal middle Chattian, basal Burdigalian, basal middle Tortonian, and basal Messinian. The authors suggest that the identification and seismic correlation of these unconformities are useful for building a stratigraphic framework for paleoenvironmental studies and for correlating deep-sea stratigraphy with the stratigraphy of continental shelves and interior basins. By this reasoning, it is worthwhile to look for these disconformities in other ocean basins and to attempt paleontologic verification of the dating of these surfaces. Because Leg 77 was able to continuously core a number of long Cenozoic sections, the material recovered seems particularly useful for carrying out such an investigation in the Gulf of Mexico.

At three of the six sites drilled on this leg (Sites 536, 538, and 540), holes were continuously cored and yielded significant Cenozoic sedimentary sections. Nannofossils in these sections are consistently abundant, whereas preservation fluctuates from poor to very good. The recovered sections at these three sites illustrate a history of discontinuous sedimentation from the early Paleocene to the Holocene. Many hiatuses were observed. Several are long enough to effectively package the recovered sections into sequences of distinct units (Fig. 2).

The other three sites drilled on Leg 77 (Sites 535, 537, and 539) did not yield significant Cenozoic sections. Drilling operations at the first of these (Site 535) recovered 17 cores of Cenozoic nannofossil-rich sediments, all of which are assigned to the Emiliania huxleyi Zone of the uppermost Quaternary. The sediments examined from Site 537 also contain abundant nannofossils. However, the discontinuous coring program at this site prevents a coherent biostratigraphic study. At Site 539, two attempts to spud the drill bit were unsuccessful because of the firm nature of the substratum. Three cores of Miocene to Oligocene nannofossil mud, nannofossil ooze, and nannofossil-foraminiferal ooze were recovered. These cores, as well as sediments from Sites 535 and 537, are discussed only briefly.

Three sites drilled on DSDP Leg 10 were located near the study area (Bukry, 1973; and Fig. 1). Unfortunately, discontinuous coring at two of these sites coupled with mechanical difficulties at the third prevent precise stratigraphic correlation between these and the Leg 77 sites.

Many nannofossil species identified in the sections discontinuously cored on Leg 10 also occur in Leg 77 samples. The abundance of these taxa, however, were not reported. Thus, detailed correlation of zonal boundaries and disconformities between these earlier drilled holes and holes drilled on Leg 77 are not possible at a scale necessary to further delineate disconformities in the section.

Zonal determinations for the Cenozoic core samples from Leg 77 are summarized in Figure 3. Citations for
Figure 1. Location of Leg 77 drill sites and Sites 95, 96, and 97 from DSDP Leg 10.
Figure 2. Generalized columnar sections for Holes 536, 538A, and 540. Note "packages" of middle Miocene sediment bounded by unconformities. Vertical scale: 1 cm = 4 m.
**Figure 3. Summary of the nannofossil zonation of core samples from the Cenozoic sections recovered on Leg 77.** Sample numbers designate core-section; core-section, depth in section in cm; or core section, interval in cm. Where more than one core and section are assigned to a single zone, the numbers corresponding to the highest and lowest samples in that zone are separated by a slash (/). CC = core catcher.
METHODS AND PROCEDURES

The abundance of nannofossils in the Cenozoic sediment recovered on Leg 77 permitted preparation of 301 smear slides directly from raw sediment samples. A simple staining technique was used to concentrate nannofossils in samples from the Quaternary of Sites 535, 536, and 540. These samples were then examined with a Cambridge IV Stereoscopic scanning electron microscope (SEM) to confirm the presence of the tiny upper Pleistocene zonal species, Emiliania huxleyi. Older sediment samples were examined primarily by light microscope. Abundances were calculated using a method similar to that described by Hay (1970). The one difference is in the use, here, of a higher magnification of 1560 instead of the 1000 used by Hay. The higher magnification allowed better resolution in the examination of particularly small species. Letters on the range charts indicating abundances are keyed to the number of specimens as follows:

- V = very abundant; more than 10 specimens per field of view at 1560 x;
- A = abundant; 1-10 specimens per field of view at 1560 x;
- C = common; 1 specimen per 2-10 fields of view at 1560 x;
- F = few; 1 specimen per 11-100 fields of view at 1560 x;
- R = rare; 1 specimen per 101-1000 fields of view at 1560 x.

Estimates of the preservation in a sample were made using the following outline:

- G = good, little evidence of secondary alteration via etching and/or overgrowth, identification of species not impaired;
- M = moderate, significant evidence of secondary alteration via etching and/or overgrowth, identification of species not impaired;
- P = poor; specimens typically heavily overgrown or severely etched; identification of some species significantly impaired.

The zonation scheme used in this study (Table 1) is that of Okada and Bukry (1980). The high degree of resolution gained from this scheme made it most suitable for the nannofossil-rich sediments encountered. Earlier zonation schemes, such as that by Martini (1971), are not as applicable as the one used here (Gartner, 1977).

SITE SUMMARIES

Site 535 (23°42.48'N; 84°30.97'W; 3450 m water depth)

Drilling at Site 535 was intended to penetrate the sedimentary column beneath a seismically prominent mid-Cretaceous unconformity (see site chapter, Site 535, this volume). Drilling at this site was primarily concerned with penetration of the older portion of the sequence below this mid-Cretaceous unconformity (MCU), whereas operations at Site 540 to the northeast were intended to penetrate the younger part above the MCU. Cenozoic sediments at Site 535 are restricted to the first 17 cores recovered, all of which contain the Quaternary species Emiliania huxleyi. Lithologies encountered included slightly calcareous muds and clays with small scattered stringers of marly clay and foraminiferal ooze. These stringers as well as light-colored burrows were selectively sampled because they showed a dramatic rise in the numbers of calcareous nannofossils within otherwise nannofossil-poor intervals. These nannofossil-rich zones are typically dominated by abundant Tertiary forms but also contain a few reworked Cretaceous species. The sparse assemblages in the surrounding nannofossil-poor intervals on the other hand are dominated by solution-resistant Cretaceous taxa.

A nannofossil-pteropod ooze in Section 535-1-1 and in Sample 535-5-4, 107-109 cm contains abundant, well-preserved nannofossils. The assemblages include E. huxleyi, Gephyrocapsa oceanica, Helicosphaera carteri, Syracosphaera pulchra, and Ceratolithus cristatus. Reworked species include the Pliocene forms Discoaster pentaradiatus and Reticulofenestra pseudoumbilica as well as several Cretaceous taxa including Micula decussata, Brionsonia parca, Eiffellithus eximius, E. turrisiellii, and Prediscosea cretacea. Another interval with abundant nannofossils occurs at 535-12-2, 63-65 cm. This sample, like the aforementioned one, contains abundant Quaternary species with reworked Cretaceous and Tertiary taxa. Nannofossils are also common in Samples 535-14-1, 104-106 cm and 535-17-2, 30-32 cm, both of which contain Emiliania huxleyi as determined by SEM observation.

Site 536 (23°29.39'N; 85°12.58'W; 2790 m water depth)

Site 536 is located in an area of the southeastern Gulf where seismic profiles show that the sedimentary cover over basement fault blocks is relatively thin. The main objective at this site was to penetrate the sedimentary cover, reach basement, and attempt to document the nature, origin, and age of the rifted basement. The site lies topographically higher than the floor of the abyssal Gulf. Sediments from this site include a Tertiary suite of gray and gray-to-yellow nannofossil oozes interrupted by numerous hiatuses. Preservation in this nannofossil-rich sequence is typically moderate to good (Fig. 4).

Of the 213 m of sediment penetrated at this site, the first nine cores contain Cenozoic sediment. The first two cores down to 536-2-2, 29-31 cm contain Emiliania huxleyi, Gephyrocapsa oceanica, G. caribbeanica, Syracosphaera pulchra, Rhabdosphaera clavigera, R. stylifera, Scapholithus fossils, Calcidiscus leptoporus, Helicosphaera carteri, and others. These samples are assigned to the E. huxleyi Zone. Samples 536-3-1, 20-22 cm to 536-3-6, 20-22 cm correspond to the Ceratolithus acutus Subzone based on the occurrence of C. acutus, Reticulofenestra pseudoumbilica, Sphenolithus abies, and an abundance of discoasters including Discoaster brouweri, D. surculus, D. pentaradiatus, and D. variabilis. These Quaternary and Pliocene sections are therefore separated by a substantial hiatus; the entire lower and middle part of the Quaternary as well as the upper Pliocene are missing. Using the absolute age assignments of Okada and Bukry (1980) (Table 1), the least possible amount of missing time represented by this hiatus can be estimated. The top of the C. acutus Subzone is at 4.4 Ma, and the base of the E. huxleyi Zone is dated at 0.2 Ma. If, as a result of this hiatus, the only sediment missing is sediment from between these two zones and not from within either, then approximately 4.2 Ma of section would not be represented. However, part of the section assigned to the upper and lower zones is almost certainly missing as well, so somewhat more than 4.2 Ma...
Table 1. Nannofossil zonation scheme used in this study (from Okada and Bukry, 1980).

<table>
<thead>
<tr>
<th>Age</th>
<th>Zone</th>
<th>Subzone</th>
<th>Martini (1971) zone</th>
<th>Duration (Ma)</th>
<th>Boundary (Ma)</th>
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</table>
of section is missing. The interval from below 536-3-6, 20-22 cm to 536-4-1, 60-62 cm is assigned to the Triquetrorhabdus rugosus Subzone.

Nannofossils in Sample 536-4-1, 60-62 cm and all samples down to 536-4-6, 60-62 cm are characteristic of the Discoaster neorocetus Subzone. Sample 536-5-1, 120-122 cm is assigned to the D. bellus Subzone. This upper Miocene interval is marked by a very diverse discoaster assemblage that includes D. neohamatus, D. broieri, D. quinquers, D. loeblichii, D. variabilis, D. asymmetricus, D. challengeri, and others. Other taxa present include Catinaster mexicanus, Triquetrorhabdus rugosus, Helicosphaera carteri, Coccolithus pelagicus, Calcidiscus macintyrei, C. leptoporus, and several species of Scyphosphaera. The underlying sample (536-5-2, 120-122 cm) has an assemblage somewhat similar to that seen in samples from the D. neohamatus Zone, but with a few important differences. D. loeblichii, fairly prominent in the younger sediments, is absent, whereas D. hamatus and D. bollii, not seen in the younger samples, occur in substantial numbers. These differences serve to distinguish between these two assemblages, and the lower is thus assigned to the D. hamatus Zone. The upper boundary of the D. neohamatus Zone at this site is marked by a hiatus that, according to the rationale stated earlier, involves at least 1.4 Ma of section. Sample 536-6-1, 137-139 cm contains D. exilis, D. kugleri, R. pseudoumbilica, and T. rugosus. It is here assigned to the D. exilis Zone. Thus another hiatus involving at least 0.2 Ma of section occurs between these two overlying sediments assigned to the D. hamatus Zone. Samples 536-7-1, 110-112 cm through 536-8-1, 1-3 cm contain Cyclicargolithus floridanus, Sphenolithus heteromorphus, and Coccolithus pelagicus. These forms are characteristic of the S. heteromorphus Zone of the middle Miocene, and the age is assigned accordingly. The boundary between these and the underlying Oligocene sediments is also marked by a hiatus (at least 9.0 Ma). Sample 536-8-2, 7-9 cm contains D. deflandrei, S. ciperoensis, S. mortifrons, H. recta, H. euphratis, H. intermedia, H. wilcoxoni, Cyclicargolithus abisectus, S. floridanus, Pontosphera segmenta, R. bica, R. scrippsi, and Zygrhablithus bifugatus. This assemblage persists through 536-8-3, 90-92 cm. All the sediment within this interval is assigned to the Dictyococcos eodicetus Subzone of the late Oligocene. The only Eocene recovered at this site was in three clasts from the top 10 cm of Section 536-9-1. These contain an assemblage assignable to the Discoaster sublodoensis Zone. The underlying samples, 536-9-1, 11-13 cm through 536-9-3, 1-2 cm, are assigned to the Campylipsphaera eodela Subzone of the late Paleocene. Another hiatus is apparent between these and the overlying Eocene sediments. Important species present in this Paleocene interval include D. multiradiatus, Fasciculithus tymaniformis, D. robustus, D. mohleri, Chiasmolithus californicus, D. consuetus, and Torreus eminens. Sample 536-9-1, 10-12 cm has a similar assemblage but lacks D. multiradiatus and D. robustus, which are prominent in samples above this level. This sample is assigned to the D. mohleri Zone and is offset both above and below by unconformities. The interval below this (from 536-9-3, 56-58 cm to 536-9-4, 134-136 cm) contains an assemblage characteristic of the early Paleocene. Species present include C. danicus, Cruciplacolithus tenuis, Braarudosphaera bigelowii, B. discula, Neochiastozygus concinnis, Coccolithus cavus, and Zygodiscus sigmoideus. This interval is assigned to the Chiasmolithus danicus Zone. Sample 536-9-5, 50 cm contains an assemblage that includes Z. sigmoideus, Cruciplacolithus tenuis, Markallus astroporus, and Coccolithus cavus and is assigned to the Z. sigmoideus Zone of the earliest Paleocene. Detailed shipboard nannofossil and foraminiferal work identified the Cretaceous/Tertiary boundary at 536-9-5, 70 cm, where a poorly delineated burrowed zone occurs with the foraminifers, "Globigerina" eugubina in the burrows (see Premoli Silva and McNulty, this volume).

Site 537 (23º56.01’N; 85º27.62’W; 2820 m water depth)

A small knoll just north of the Campeche Escarpment near the mouth of the Catoche Tongue was chosen as the location for Site 537. This knoll stands about 300 m above the level of the flat-lying abyssal Gulf and was chosen because seismic data showed a relatively thin sediment cover overlying basement. The knoll is thought to represent the uplifted end of one of several tilted basement blocks located in the area. As at Site 536, the main objective was to investigate the nature, age, and origin of the basement rocks.

Cenozoic sediments are predominantly Pliocene to Paleocene nannofossil and foraminiferal ooze; ash and zeolitic layers are interspersed in the lower part of the section. Preservation in samples from this discontinuously cored sequence fluctuates from good to poor. Neogene samples usually show moderate preservation but several Eocene samples exhibited pronounced secondary alteration particularly by overgrowths on characteristic discoaster species. Hiatuses are also inferred for this site, though discontinuous coring does not allow us to make precise determinations.

Three cores of Cenozoic sediment were recovered from this site. Core 1 contains lower Pliocene nannofossils of the Reticulofenestra pseudoumbilica Zone and the Amauroolithus tricorniculatus Zone. Species in the upper four sections of the core include R. pseudoumbilica, Discoaster pentaradiatus, D. broueri, D. surculus, Calcidiscus macintyrei, Helicosphaera carteri, and Ceratolithus cristatus. This interval is assigned to the R. pseudoumbilica Zone. Section 537-1-5 and the core catcher contain a similar assemblage with the addition of A. tricorniculatus. This short interval is assigned to the A. tricorniculatus Zone. After recovery of Core 1, the hole was washed to 54 m, where Core 2 was cut. The interval above the core catcher contains species typical of the D. sublodoensis Zone of the middle Eocene. A sample from the core catcher contains a poorly preserved assemblage of the lower Eocene D. lodoensis Zone. A few five-rayed discoasters were found, but their size (20+ microns) was deemed too large for D. sublodoensis. Also, the common occurrence of D. lodoensis suggested placement in the zone of the same name. Other forms
present include Campylosphaera dela, Discoasteroides kuepperi, Ericsonia formosa, Discoaster barbadiensis, Chiasmolithus grandis, Coccolithus pelagicus, and Pontosphaera rimosas.

After recovery of Core 2, the hole was washed to a depth of 88 m, where Core 3 was cut. Sample 537-3-1, 27-29 cm contains D. diastypus, D. barbadiensis, D. lenticularis, D. multiradiatus, and Sphenolithus anarrhopus, but it lacks D. lodoensis. This sample is assigned to the basal Eocene D. diastypus Zone. A firm brown ooze from 537-3-1, 40 cm to 537-3-1, 95 cm contains D. multiradiatus, D. mohleri, Coccolithus pelagicus, Ellipsololithus macellus, and Toweus eminens; it is assigned to the D. multiradiatus Zone of the upper Paleocene. Samples from 537-3-1, 128 cm to 537-3-2, 5 cm contain D. mohleri, Fasciculithus tympaniformis, and Ellipsololithus macellus but lack D. multiradiatus; they are assigned to the D. mohleri Zone. The interval from 537-3-2, 18 cm to 537-3-2, 43 cm contains a heavily reworked lower Tertiary and Upper Cretaceous flora and is underlain by a white chalk interval assigned to the Chiastozygus littorarius Zone (see Watkins and Bowdler, this volume). Thus the Cretaceous/Tertiary boundary at this site lies within this reworked interval.

Site 538 (23°50.98' N; 85°10.26' W; 2820 m water depth)

Site 538 was drilled on top of Catoche Knoll, a large topographic high approximately 25 km northeast of the Campeche Escarpment. This site was originally an alternate site but the decision to drill here was made when drilling at the first two sites went faster than expected. The objective at this site was to test the basement inferred from seismic data. These data suggest that the knoll is an uplifted basement block.

Hole 538 was drilled on the northwestern flank of the Catoche Knoll. A single core of reworked Pliocene to Oligocene sediment was recovered from this hole before relocation.

Hole 538A was drilled on top of a northwest-trending ridge near the crest of the Catoche Knoll. The Cenozoic section recovered included sediments from each epoch of the Tertiary. Sediments younger than middle Pliocene were absent. Only the first sample examined (538A-1-1,
0–1 cm) contains Pliocene species including *Discoaster brouweri*, *D. surculus*, *D. pentaradiatus*, *Reticulofenestra pseudoumbilica*, *Helicosphaera carteri*, and *Coccolithus pelagicus*. The presence of these forms in the absence of older taxa such as the species of *Amaurolithus* places this sample within the *Reticulofenestra pseudoumbilica* Zone. The five samples immediately downhole are Miocene in age indicating a hiatus between these and the overlying sediments involving at least 7.0 Ma of section. These three samples from Core 1 (538A-1-1, 144–145 cm through 538A-1-2, 62–63 cm) contain *D. hamatus*, *D. neohamatus*, *Catinaster coalitus*, and *D. bollii*, which indicate an age equivalent to that of the *D. hamatus* Zone of the middle Miocene. Samples 538A-2-1, 19–20 cm and 538A-2-1, 94–95 cm have assemblages similar to those found in the previous interval but lacking the distinctive *D. hamatus*, which implies an older age. These are placed in the *C. coalitus* Zone (Fig. 5).

Samples from 538A-3-1, 121–122 cm through 538A-6-3, 56–57 cm are placed in the upper Oligocene *Sphenolithus ciperoensis* Zone. The assemblage includes the characteristic upper Oligocene species *S. ciperoensis*, *Cyclacargolithus abisectus*, *H. euphratis*, and *Triquetrorhabdulus carinatus*. A hiatus of at least 10.8 Ma is evident between these samples and those from the overlying Core 2. Samples 538A-6-3, 100–102 cm to 538A-11-2, 100–102 cm show a lack of *S. ciperoensis* and an abundance of *S. distentus*. This interval is assigned to the *S. distentus* Zone. The boundary between the *S. distentus* Zone and the underlying *S. predistentus* Zone is difficult to delineate precisely because of a number of sphenoliths with intermediate construction. The boundary has been placed above 538A-12-1, 90–92 cm. Samples below this boundary down to 538A-13-2, 90–92 cm are placed within the *S. predistentus* Zone. Species commonly in the assemblage include *H. compacta*, *Bramlettieus serraculoides*, *Zygrhablithus bijugatus*, *Braarudosphaera bigelowii*, and *Peritrichelina joidesa*. Sample 538A-14-1, 74–76 cm was placed in the *H. reticulata* Zone based on the absence of any Eocene discoasters and the presence of *R. umbilica*, *R. hillae*, and *Ericsonia formosa*.

The youngest Eocene sediment was encountered in the interval from 538A-15-1, 34–35 cm to 538A-17-3, 69–71 cm. Samples from this interval are assigned to the *R. umbilica* Zone. Another hiatus (at least 4.0 Ma) oc-
Figure 5. Distribution of Cenozoic calcareous nanofossils in samples from Hole 336A. Wavy lines in age and zone columns represent hiatuses.
Figure 5. (Continued).
curc in the section at the upper boundary of this interval. Samples assigned to this zone contain some of the most diverse assemblages encountered at this site. Forms usually present include *D. barbadiensis*, *D. saipanensis*, *R. bisecta*, *R. umbilica*, *Chiasmolithus grandis*, and *Rhabdosphaera tenuis*. B. bigelowi, *B. discula*, and debris derived from these become very abundant in this interval as well. Samples 538A-17-4, 111-113 cm and 538A-17-5, 75-77 cm contain a similar assemblage but lack *Reticulofenestra umbilica* and are assigned the Nannotetra quadrata Zone.

The *D. sublodoensis* Zone encompasses Samples 538A-17-6, 44-46 cm to 538A-19-4, 50-52 cm. This assemblage is composed, in part, of *D. sublodoensis*, *D. barbadiensis*, *E. formosa*, and *Campylosphaera dela*. The presence of *Rhabdosphaera inflata* in samples from the top of this interval down to 538A-18-6, 52-54 cm places these within the *Rhabdosphaera inflata* Subzone. The lowest four samples in the interval lack *R. inflata* but otherwise contain the same assemblage, which clearly delimits a second subzone, the *Discosasteroides kuepperi* Subzone. Two underlying samples (538A-19-5, 112-114 cm and 538A-20-1, 14-16 cm) contain nannofossils characteristic of the *Discosaster lodoensis* Zone. Species present include *D. lodoensis*, *D. lenticularis*, *D. barbadiensis*, and *R. tenuis*. A hiatus (at least 2 Ma) separates this interval from the underlying sample (538A-20-2, 9-12 cm), which is assigned to the *D. diastypus* Zone on the basis of the presence of *D. multiradiatus*, *D. diastypus*, and *Trirachiatous orthosystis*. *D. lodoensis* is conspicuously absent from this sample.

Sample 538A-20-4, 97-99 cm is assigned to the upper Paleocene *Campylosphaera eodela* Subzone of the *D. multiradiatus* Zone, because it contains *C. eodela* and lacks *D. diastypus*, *T. orthosystis*, and any other species characteristic of younger Eocene sediments. Sample 538A-20-6, 7-9 cm is the only sample assigned to the lower Paleocene *Zygodiscus sigmoides* Zone. The sample contains *Z. sigmoides*, *Markallus astroporus*, *Cruciplusolithus tenuis*, and other forms common to sediments of that age. Beneath this lower Paleocene section occurs a short interval in which the sediments show a pronounced age reversal. Sample 538A-21-1, 39-41 cm, contains an assemblage virtually identical to that found in samples assigned to the Eocene *D. diastypus* Zone. This reversal was interpreted by shipboard scientists as a small slump deposit generated sometime in the early to middle Eocene. All samples below this interval contain *D. sublodoensis*, *D. diastypus*, and *Trirachiatous orthosystis*.

The entire first core recovered from Hole 539 contains typical upper Quaternary taxa, including *Emiliania huxleyi*, *Gephyrocapsa oceanica*, *G. caribbeana*, and *Ceratolithus cristasinus*. All samples from this core fall within the *E. huxleyi* Zone. At 539A-2-2, 132 cm, Paleocene discoasters occur, including *Discosaster brouweri*, *D. bentiradiatus*, and others. Also present are other Pliocene species: *Calciscus macintyrei*, *C. leptopus*, and *Helicosphaera carteri*. Samples below this level down to the termination of drilling are placed in the upper Pliocene *D. brouweri* Zone.

Drilling in Hole 539A recovered a single core. This single core contains sediments that range in age from the Holocene to the Oligocene. Sediment from 539A-1-1, 0-2 cm through 539A-1-2, 90-92 cm contains *E. huxleyi* and the upper Quaternary assemblage typically found with that species. These sediments are placed in the *E. huxleyi* Zone. Samples 539A-1-2, 93 cm through 539A-1-3, 92 cm contain a Miocene assemblage that includes both *D. quinqueramus* and *Amaurolithus primus*, limiting the interval to the upper Miocene *A. primus* Subzone. The rest of the core contains typical Oligocene forms found at the other sites, including *Sphenolithus ciperoensis*, *Cyclicargolithus abisectus*, *C. floridanus*, *Reticulofenestra bisecta*, and *S. moriformis*.

**Site 540 (23°49.73' N; 84°22.25' W; 2926 m water depth)**

Site 540 was drilled about 20 km northeast of Site 535 and on the flank of a prominent erosional valley. The main objectives at this site were to determine the nature and age of the prominent mid-Cretaceous? unconformity (MCU) seen on seismic records and to determine the nature and age of the sedimentary section between this MCU and an underlying horizon, Unconformity 1. The Cenozoic sequence recovered from this site consisted in part of gray marls and light-colored oozes and chalks of Quaternary to Paleocene age. The sequence here, as at the other sites, is cut by numerous hiatuses. Preservation of nannofossils is generally moderate to good in samples from this site (Figs. 6–7).

Pliocene sediments are missing from the section recovered at this site, but all other epochs of the Tertiary are represented. Samples 540-1-1, 4–6 cm through 540-1-1, 145–147 cm contain *Emiliania huxleyi* plus species of *Gephyrocapsa* and are placed in the upper Quaternary *E. huxleyi* Zone.
Samples 540-1-2, 75-77 cm through 540-2-6, 90-92 cm contain discosasters including *Discaster quinqueramus*, *D. variabilis*, *D. brouweri*, *D. surculus*, *D. challengeri*, and other taxa such as *Amaurolithus primus* and *A. amplificus*. Sediments in this interval are assigned to the *A. primus* Subzone (Fig. 6). Thus, a hiatus involving at least 5.4 Ma of section separates these Mio- cene sediments from the overlying Holocene sediments.

Samples 540-3-1, 90-92 cm through 540-5-1, 101-103 cm are assigned to the *D. neohamatus* Zone. The assem- blage in this interval characteristically contains a wide variety of discosasters including *D. neohamatus*, *D. va- riabilis*, *D. pentaradiatus*, *D. surculus*, and *D. loebli- chii*. The base of this interval is marked by a hiatus (at least 2 Ma); the older *D. neohamatus*, *D. va- riabilis*, *D. brouweri*, *D. calcaris*, *D. challengeri*, and *D. intercalcaris* are observed in Sample 540-26-1, Ericsonia formosa, *Gephyrocapsa caribbeanica* permit further subdivi- sion of the *H. reticulata* Zone at this site into at least two subzones, the upper *R. hillae* Subzone and the lower *E. formosa* Subzone. The lowermost subzone, the *Coc- colithus subdistichus* Subzone, cannot be definitively iden- tified at this site because the original description of the subzone utilizes an acme that was not observed here.

Populations within the *H. reticulata* Zone show a slight change in character from the younger overlying inter- vals. The sequential extinction datums of *R. umbilica* val also contains a relatively diverse *Helicosphaera* population.

The interval from 540-15-1, 100-102 cm to 540-21-1, 133-135 cm, is placed within the *S. distentus* Zone. Samples in this interval show a lack of *S. ciperoensis* and an abundance of *S. distentus*. This interval is also marked by an abundance of braarudosphaerids. Species present in this zone are similar to those from the overlying *S. ci- peroensis* Zone, but *S. ciperoensis* is absent. The bound- ary between this zone and the underlying *S. predistentus* Zone is more difficult to place because of the presence of specimens of intermediate construction. The bound- ary has been placed between Samples 540-21-2, 133–135 cm and 540-22-1, 10–12 cm. The *S. predistentus* Zone includes samples from this level down to 540-24-5, 96– 98 cm.

In the lower Oligocene, the distinctive *Reticulofenes- tra umbilica* is observed in Samples 540-25-1, 67–69 cm through 540-26-2, 124–126 cm. This interval is assigned to the *H. reticulata* Zone on this basis. The cosmopoli- tan *Ericsonia formosa* is observed in Sample 540-26-1, 12–14 cm. These two extinction datums, that of *R. um- bilica* and that of *E. formosa*, permit further subdivi- sion of the *H. reticulata* Zone at this site into at least two subzones, the upper *R. hillae* Subzone and the lower *E. formosa* Subzone. The lowermost subzone, the *Coc- colithus subdistichus* Subzone, cannot be definitively iden- tified at this site because the original description of the subzone utilizes an acme that was not observed here.

Populations within the *H. reticulata* Zone show a slight change in character from the younger overlying inter- vals. The sequential extinction datums of *R. umbilica*
Figure 7. Distribution of Paleogene calcareous nannofossils in samples from Hole 540. Wavy lines in Age and Zone columns represent hiatuses. See Figure 4 for key. See Figure 6 for Neogene calcareous nannofossils, Hole 540.
CENOZOIC CALCAREOUS NANNOSILS

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<th>D. nobilis</th>
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<th>Ellipsolithus distichus</th>
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and *E. formosa* are prominent, as are the extinction levels of *Brumlethetis serraculoides* and *H. reticulata*. However, the braarudosphaerids that are prominent in the earlier samples are abundant throughout this interval as well.

Eocene discoasters are encountered in Sample 540-26-3, 101–103 cm, which is assigned to the upper Eocene *D. barbadiensis* Zone. The boundary between this sample and the overlying Oligocene section may be marked by an unconformity, as is common in all the Cenozoic sections drilled on Leg 77. However, the uncertainty concerning the presence of the lowermost subzone of the *H. reticulata* Zone precludes unequivocal identification of the boundary as a hiatus, though one is strongly suspected. This highest Eocene sample, 540-26-3, 101–103 cm, has an assemblage composed of *D. barbadiensis, D. saipanensis, B. serraculoides, H. compacta, S. pseudoradians*, and others. Samples 540-27-1, 140–142 cm to 540-28-2, 10–12 cm contain species characteristic of the *Nannotetraquina quadra* Zone of the middle Eocene. A disconformity involving at least 3.0 Ma of section separates this interval from the overlying one. A striking feature of the assemblage is the presence of a tremendous number of *N. quadra*ta. Included in this assemblage are common *D. barbadiensis, D. saipanensis, E. formosa*, and *Braarudosphaera bigelowii*. Eocene sediments in this hole, as in Hole 538A, show the highest diversity of any interval in the Cenozoic section at this site.

Samples 540-29-1, 38–40 cm and 540-29-2, 19–21 cm are placed in the *D. subdoensis* Zone. Both samples contain *D. barbadiensis, D. subdoensis, Chiasmolithus grandis, Rhabdosphaera tenuis*, and *Campylosphaera dela*. Only the upper sample of the two contains *R. inflata* and rare *D. lodoensis*, whereas the lower lacks the former and has common *D. lodoensis*. This may support the separation of the two samples into the *R. inflata* Subzone and the Discoasteroides kuepperi Subzone.

A disconformity (at least 4.0 Ma) lies between the above samples and Sample 540-30-1, 14–16 cm, which contains *Discoaster multiradiatus, Toweius eminis, C. eodela, Chiasmolithus bidens, C. californicus, C. conuates*, and *Zygodiscus sigmoides* and is assigned to the upper Paleocene *D. multiradiatus* Zone. Samples 540-30-2, 28–30 cm and 540-30-2, 31–32 cm have similar assemblages but lack the distinctive *D. multiradiatus*, placing them in the *D. mohleri* Zone. *D. nobilis* was not observed, so another hiatus is inferred between these two samples and the overlying sample. These samples also contain well-preserved *Fasciculithus tympaniformis* and *S. anarrhopus*. Other forms present include *Ellipsolithus macellus, Cruciplocolithus tenuis*, and *Coccolithus cavus*.

Sample 540-30-2, 81–83 cm, lacks discoasters of any kind but contains *Heliolithus kleinpellii, F. tympaniformis, C. tenuis*, and *E. subpertusa*. There also occur a few reworked Cretaceous species such as *Micula decussata* and *Microrhabdulus decoratus*. This sample is placed within the lower Paleocene *H. kleinpellii* Zone. All samples examined below Core 31 contain a thoroughly reworked Tertiary and Cretaceous assemblage, which is underlain by definite Cretaceous sediments. Thus the Cretaceous/Tertiary boundary at this site is obscured by this intensively reworked interval.

### SUMMARY AND CONCLUSIONS

Two significant features (one paleontologic, the other depositional) have been observed through study of the nannofossils in the Cenozoic sediment recovered on Leg 77. The first is the occurrence of anomalous braarudosphaerid accumulations in the lower Eocene and upper Eocene at Site 540. The second, and most important, is the detection of numerous disconformities, the most prominent of which is related to a widespread Oligocene regressive interval.

#### Braarudosphaerids

Sections 540-22-1 to 540-28-2 span the upper Eocene to lower Oligocene at Site 540. Braarudosphaerids are common to abundant in this interval. This abundance is anomalously high in relation to the rest of the Oligocene section, where braarudosphaerids are generally few to rare. The isolated rhomb-shaped laths that in union compose the braarudosphaerids are also extremely abundant in this interval, a fact that is not reflected in the abundances plotted on the range charts. This abundance of pentaliths and pentalith debris is notable in itself but becomes more intriguing when one considers the relation that appears to exist between this group and certain holococcoliths. The well-known holococcoliths *P. joide-sa, Lanthernithus minutus*, and *Zygrhablithus bijugatus* are also found in the lower Oligocene and upper Eocene portions of the section drilled at Site 540. The abundance of these holococcoliths seems to parallel the fluctuating abundances of the braarudosphaerids. *P. joide-sa*, in particular becomes much more prominent in the samples with the highest numbers of braarudosphaerids. At least three mechanisms could explain this anomalous accumulation of braarudosphaerids: (1) shallowing of the seaway, (2) selective dissolution of other nannofossil species, or (3) an increase in productivity of these taxa.

The presence of holococcoliths implies a departure from normal pelagic sedimentation to more shallow-pelagic conditions (Bukry, 1970; Roth, 1970), so the cause of this braarudosphaerid accumulation could lie in a decrease in water depth. This shoaling effect could be generated by a prolonged sea-level drop or by local tectonic uplift of the sea floor. However, the sea-level fluctuation curve of Vail and Hardenbol (1979) for the Tertiary (Fig. 8) shows no such prolonged drop in sea level at the time of the deposition of these early Oligocene braarudosphaerid concentrations. Unfortunately, tectonic uplift of the area, on the other hand, cannot be independently confirmed.

If selective dissolution of other nannofossil taxa were the cause, the highly solution-susceptible holococcoliths would not remain intact. In this interval, however, they not only remain intact, but their numbers increase as well.

An increase in productivity among braarudosphaerids, on the other hand, has been logically invoked to
explain similar accumulations elsewhere (Maxwell, von Herzen, et al., 1970; Fischer and Arthur, 1977). This same mechanism is invoked for the Gulf of Mexico. Another work on sediments from the Gulf (Bukry, 1973) describes the same braarudosphaerid and holococcolith species in the same stratigraphic interval as those in Leg 77 sediments. Although the abundances of these taxa are not reported in the Bukry (1973) report, their presence is significant.

Thus, of the three mechanisms proposed, the most reasonable seems to be that a productivity increase among braarudosphaerids in the southeastern Gulf of Mexico during the Oligocene is responsible for the generation of this braarudosphaerid-holococcolith concentration.

**Hiatuses**

The most obvious depositional features of the Cenozoic sections at these sites are the numerous hiatuses, which essentially package the sections into sequences of distinct units. The extent of these hiatuses represented by missing nannofossil zones is sometimes very large, as in the case of Site 536. Here, the only Eocene found was in a few clasts in the top 10 cm of one core, whereas both Holes 538A and 540 contain ample Eocene sediment. Similarly, the Pliocene interval, represented in both Holes 536 and 538A, is completely missing from the Site 540. In general, hiatuses were found throughout the Cenozoic of every hole drilled on Leg 77.

Accelerated bottom-current activity during periods of global cooling and/or marine regression has been used to explain hiatuses in other deep-sea sections (Johnson, 1972; Rona, 1973; Davies, et al., 1975; Moore, et al., 1978; Barron and Keller, 1982). In this study, the same mechanism is invoked for the generation of at least the major upper Oligocene unconformity observed in the southeastern Gulf of Mexico. This upper Oligocene horizon correlates fairly well with the Chattian hiatus observed by Vail and others (1980) in sections from both the continental shelf off West Africa and the Blake continental slope off the southeastern United States. Those authors relate the horizon to the pronounced sea-level drop shown on their curves.

A slight discrepancy exists, however, between the age placed on this regression (Vail et al., 1980) and the apparent age of the late Oligocene hiatus in Leg 77 Cenozoic sections. The hiatus seen in Holes 536, 538A, and 540 (Figs. 2 and 8) is slightly younger. The precise dating of this horizon in the southeastern Gulf would be best achieved at some point where the disconformity approaches conformity. Unfortunately, that would require more precise correlation of regional seismic reflection lines and biostratigraphic work on a reasonable number of other sections, all of which is therefore beyond the
scope of this initial report. For gross correlation purposes, however, the disconformity and the large scale sea-level drop become tantalizingly coincident.

Most other hiatuses in the Leg 77 Cenozoic sections do not correlate well with the unconformities identified elsewhere by Vail and his co-authors (1980). A possible exception is the minor disconformity in the basal Serravalian dated at 15.5 Ma. The disconformity at the bottom of the Sphenolithus heteromorphus Zone in Hole 536 is of a similar age and could conceivably be tied to that minor event. However, because of the lack of correlation between the major unconformities, a correlation between this minor Serravalian horizon and a horizon of similar age at the Leg 77 sites is highly tenuous.

If intensified bottom-current activity during marine regressions can explain hiatuses, then the fading effects of these currents during a subsequent transgression should allow normal accumulation of sediments. Vail and Hardenbol (1979) depict a middle Miocene transgression after the pronounced late Oligocene regression (Fig. 8). Lowered current velocities during this transgression should have allowed deposition of sediments at that time and preservation of these deposits. This, then, can explain the presence of the only Miocene sediment found on Leg 77 and its age, which is middle Miocene.

Future studies may show that factors other than sea-level oscillations caused disconformities in the Cenozoic section of the southeastern Gulf of Mexico. At this point, however, the remarkable concurrences of “global” regressions with hiatuses and of transgressions with preserved sections cannot be ignored.

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REFERENCES


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APPENDIX

Nannofossil Species Considered (alphabetical by species name)

Sphenolithus abies Deflandre, 1953

Cycligagotholithus absectus (Müller) Wise, 1973

Chiplagatholithus acanthodes Bramlette and Sullivan, 1961

Ceratolithus acutus (Bukry) Gartner and Bukry, 1974
CENOZOIC CALCAREOUS NANNOFOSSILS

Discoaster adamanicus Bramlette and Wilcoxon, 1967
Zygodicoccus adamanicus Bramlette and Sullivan, 1961
Chiasmolithus altus Bukry and Percival, 1976
Amaurolithus amplificus (Bukry and Percival) Gartner and Bukry, 1974
Sphenolithus ananzipus Bukry and Bramlette, 1966
Pontosphaera anisostoma (Kamptner) Backman, 1980
Markallus asteroideus (Stradner) Hay and Mohler, 1967
Discoaster asymmetricus Gartner, 1969
Micrantholithus attenuatus Bramlette and Sullivan, 1961
Orthoxygys aureus (Stradner) Bramlette and Wilcoxon, 1967
Discoaster barbadiensis Tian, 1972
Sphenolithus belemnus Bramlette and Wilcoxon, 1967
Discoaster bellii Bukry and Percival, 1971
Discoaster bergrensi Bukry, 1971
Chiasmolithus bidens (Bramlette and Sullivan) Hay and Mohler, 1967
Braarudosphaera bigelowii (Gras and Braarud) Deflandre, 1947
Zygohabitatous bifigitas (Deflandre) Deflandre, 1959
Reticulofenestra bisecon (Hay, Mohler, and Wade) Roth, 1970
Printhus bialeeus (Stradner) Hay and Mohler, 1967
Discoaster bellii Martini and Bramlette, 1963
Helicosphaera bremlieni (Müller) Jafar and Martini, 1975
Discoaster brouweri Tan, 1972
Discoaster calcites Gartner, 1967
Chiasmolithus californiensis (Bramlette and Sullivan) Hay and Mohler, 1967
Catalanaster calcys Martini and Bramlette, 1963
Gephyrocapsa caribbeanica Boudreaux and Hay, 1967
Trirugorhabdulus carinatus Martini, 1965
Helicosphera carriera (Wallace) Kappmier, 1954
Coccocystis cavus Hay and Mohler, 1967
Discoaster challenger Gartner and Riedel, 1954
Sphenolithus ciperoensis Gartner and Wilcoxon, 1967
Catalanaster coxilithus and Bramlette, 1963
Helicosphaera compacta Haq, 1966
Neochiasmolithus concinns (Martini) Perch-Nielsen, 1971
Chiasmolithus conicus Bukry, 1971
Chiasmolithus constrictus (Bramlette and Sullivan) Hay and Mohler, 1967
Toweius critaculus Hay and Mohler, 1967
Rhabdosphaera crebra (Deflandre) Bramlette and Sullivan, 1961
Clausioecoccus cribeilum (Bramlette and Sullivan) Prins, 1979
Nannotetritina cristata (Martini)
Catalanaster cristatus Gartner, 1958
Discoaster cricoforus Martini, 1958
Chiasmolithus criscus (Brotzen) Hay and Mohler, 1967
Discoaster deflandre i Bramlette and Riedel, 1954
Campylosphaera dela (Bramlette and Sullivan) Hay and Mohler, 1967
Amaurolithus delicatus Gartner and Bukry, 1975
Discoaster diastyper Bramlette and Sullivan, 1961
Braarudosphaera discula Bramlette and Riedel, 1954
Sphenolithus distentus (Martini) Bramlette and Wilcoxon, 1967
Chiasmolithus distichus (Bramlette and Sullivan) Sullivan, 1964
Discoaster distinctus Martini, 1958
Neochiasmolithus dubius (Deflandre) Black, 1967
Discoaster elegans Bramlette and Sullivan, 1961
Campylosphaera eodusa Bukry and Percival, 1971
Coccocystis eogelapogus (Bramlette and Riedel) Bramlette and Sullivan, 1961
Toweius eminens (Bramlette and Sullivan) Perch-Nielsen, 1971
Helicosphaera ephrathis Haq, 1966
Discoaster exilis Martini and Bramlette, 1963
Chiasmolithus expansus (Bramlette and Sullivan) Gartner, 1970
Clausioecoccus ferus (Deflandre and Bert) Prins, 1979
Cyclarolithus floridus (Roth and Hay) Bukry, 1971
Micrantholithus floridus Deflandre, 1950
Erociona formosa (Kamptner) Romein, 1979
Scapholithus fossils Deflandre, 1954
Chiasmolithus gigas (Bramlette and Sullivan) Gartner, 1970
Sphenosphaera globulata Bukry and Percival, 1971
Chiasmolithus grandis (Bramlette and Riedel) Gartner, 1970
Helicosphaera granulata (Bukry and Percival) Jafar and Martini, 1975
Discoaster humatus Martini and Bramlette, 1963
Helicosphaera heezeni (Bukry) Jafar and Martini, 1975
Sphenolithus heteromorphus Deflandre, 1953

Reticolophenestra hillae Bukry and Percival, 1971
Emiliania huxleyi (Lohmann) Hay and Mohler in Hay, Mohler, Roth, Schmidt, and Boudreaux, 1967
Braarudosphaera imbricata Manivit, 1966
Rhabdosphaera inflata Bramlette and Sullivan, 1961
Discoaster intercalaris Bukry, 1971
Helicosphaera intermedia Martini, 1965
Triquetrorhabdulus inversus Bukry and Bramlette, 1969
Fasciculosla involutus Bramlette and Sullivan, 1961
Pontosphaera japonica (Tanaka)
Peritrachelia jovidis Bukry and Bramlette, 1969
Calcidiscus kingii (Roth) Lettelich and Tappan, 1978
Helicotolithus kleinpellensis Sullivan, 1964
Discoasteroides leptocephaloides (Stradner) Bramlette and Sullivan, 1961
Discoaster lugrideri Martini and Bramlette, 1963
Pseudoellipsolithus lacunosa (Kamptner) Gartner, 1969
Leptodiscus larvalis Bukry and Bramlette, 1969
Discoaster lodoensis Bramlette and Riedel, 1954
Discoaster loeblichii Bukry, 1971
Helicosphaera lophota (Bramlette and Sullivan) Jafar and Martini, 1975
Ellipsolithus macellus (Bramlette and Sullivan) Sullivan, 1964
Calcidiscus macintyre (Bukry and Bramlette) Lettelich and Tappan, 1978
Catalyaster mexicanus Bukry, 1971
Lanheinithus minutus Stradner, 1962
Umbilicosphaera mirabilis Lohmann, 1902
Locitholithus mochlophorus Deflandre in Deflandre and Riedel, 1954
Discoaster mochlophorus Bukry and Percival, 1971
Sphenolithus moriformis (Brönnimann and Stradner) Bramlette and Wilcoxon, 1967
Discoaster multiradiatus Bramlette and Riedel, 1954
Lopholithus nasces Bramlette and Sullivan, 1961
Sphenolithus neubies Bukry and Bramlette, 1969
Discoaster neumatus Bukry and Bramlette, 1969
Coronococcus niesceri (Kamptner) Bramlette and Wilcoxon, 1967
Discoaster nobilis Martini, 1961
Sphenolithus noeticus Martini and Bramlette, 1967
Peritrichia orygenensis (Bukry) Backman, 1980
Trirugohabitatous orthostylus (Bramlette and Riedel) Shamrai, 1963
Pontosphaera pectinata (Bramlette and Sullivan)
Coccolithus pelagicus (Wallrich) Schiller, 1930
Discoaster pentameradius Tian, 1927
Pontosphaera plana (Bramlette and Sullivan) Romien, 1979
Zygodicoccus plectopora Bramlette and Sullivan, 1961
Sphenolithus predistentus Bramlette and Wilcoxon, 1967
Discoaster prevalentus Bukry and Percival, 1971
Amaurolithus primus (Bukry and Percival) Gartner and Bukry, 1975
Cyclarolithus pseudogemmation (Bouche) Bukry, 1973
Sphenolithus pseudoradians Bramlette and Wilcoxon, 1967
Syrochiasilla pulchra Lohmann, 1902
Nannotetritina quadrata (Bramlette and Sullivan) Bukry, 1973
Discoaster quinqueramus Gartner, 1969
Sphenolithus radians Deflandre, 1952
Helicosphaera recta (Haq) Jafar and Martini, 1975
Ishimolithus recurvus (Deflandre) Deflandre and Riedel, 1954
Helicosphaera reticulata Bukry and Wilcoxon, 1967
Pontosphaera rimosa (Bramlette and Sullivan)
Rhabdosphaera rudis (Bramlette and Sullivan) Sullivan, 1964
Triquetrorhabdulus rugosus (Bukry and Percival) Jafar and Martini, 1975
Discoaster saipanensis Bukry and Percival, 1971
Helicosphaera seminulum (Bukry and Percival) Martini and Bramlette, 1975
Sphenolithus sellii (Bukry and Bramlette) Jafar and Martini, 1975
Zygodiscus seminulum (Bukry and Bramlette) Jafar and Martini, 1975
Bramletteus serruloides Gartner, 1969
Zygodicoccus sigmoideus Bramlette and Sullivan, 1961
Chiasmolithus solitarius (Bramlette and Sullivan) Locke, 1964
Briishilosphaera sparsa Bramlette and Martini, 1964
Sphenolithus spiceri Bukry, 1971
Chiasmolithus staurion (Bramlette and Sullivan)
Rhabdosphaera stylifera Lohmann, 1902
Discoaster sublodoensis Bramlette and Sullivan, 1961
Ericsonia subpertusa Hay and Mohler, 1967
Discoaster surculus Bramlette and Martini, 1963
Discoaster tamalis Kampnner, 1967
Discoaster tani Bramlette and Riedel, 1954
Discoaster tani nodifer Bramlette and Riedel, 1954
Ceratolithus telesmus Norris, 1965
Cruciplacolithus tenuis Bramlette and Sullivan, 1961

Rhabdosphaera tenuis Bramlette and Sullivan, 1961
Chiasmolithus titus (Bramlette and Sullivan) Gartner, 1970
Amaurolithus tricorniculatus (Gartner) Gartner and Bukry, 1975
Helicosphaera truncata Bramlette and Wilcoxon, 1967
Discosphaera tubifera (Murray and Blackman) Kampnner, 1944
Fasciculithus tympaniformis Hay and Mohler, 1967
Reticulofenestra umbilica (Levin) Martini and Ritzkowski, 1968
Discoaster variabilis Bramlette and Martini, 1963
Micrantholithus vesper Deflandre, 1950
Helicosphaera wilcoxonii (Gartner) Jafar and Martini, 1975