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Upper Cenozoic Calcareous Nannofossil Biostratigraphy Côte d'Ivoire-Ghana Margin, Eastern Equatorial Atlantic

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37. UPPER CENOZOIC CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY, CÔTE D’IVOIRE-GHANA MARGIN, EASTERN EQUATORIAL ATLANTIC

Samir Shafik, David K. Watkins, and Im Chul Shin

ABSTRACT

The distribution of calcareous nannofossils in the upper Cenozoic sections sampled at four sites in the eastern equatorial Atlantic Ocean during Ocean Drilling Program Leg 159 is documented here. A virtually complete upper Cenozoic sequence of nannofossil (sub)zones is identified at Site 959 on the shoulder of the Côte d’Ivoire-Ghana marginal ridge, with proxies for the rare marker species being employed. Hiatuses within the middle and upper Miocene are detected at two other sites on the same ridge, being more clearly defined at Site 960 on the crest of the ridge. Two of these hiatuses are of regional significance. A middle Miocene hiatus, based on a truncated Zone CN4, absent Zone CN5, and reduced Zone CN6, could probably be related to a major change in the depositional regime at Site 959, when a mid-Cenozoic series of short episodes of deposition of non-calcareous sediments ended. A late Miocene hiatus, based on the absence of Subzone CN8a in all sites on the ridge, is seemingly coeval with another one previously documented in oceanic sections elsewhere. Two other late Miocene hiatuses, based on the absence of Subzones CN7a and CN9a, coupled with a very thin Zone CN6, indicate a sediment starvation of the ridge during much of the middle and late Miocene. The timing of the hiatuses suggests a correspondence with major falls in sea level.

INTRODUCTION

The aim of this study is to document the distribution of calcareous nannofossils in the upper Cenozoic sections of four sites cored during Ocean Drilling Program Leg 159, all located in the eastern equatorial Atlantic Ocean, to determine their biostratigraphy and help interpret their geological history. Three relatively shallow sites (Sites 959, 960, and 961) are located on the Côte d’Ivoire-Ghana marginal ridge, and a fourth deeper site (Site 962) is on an associated minor ridge (Fig. 1).

One of the main objectives of Leg 159 was to improve the continuity and resolution of tropical Atlantic microfossil biostratigraphy. Site 959, being on the sheltered shoulder of the ridge where sedimentation rates were relatively high (see Mascle, Lohmann, Clift, et al., 1996), provided an almost complete upper Cenozoic section. Two holes at this site were studied: Hole 959A, which penetrated the entire upper Cenozoic including the Oligocene/Miocene transition; and Hole 959B, which provided additional information from the middle Miocene/Pliocene part.

Upper Cenozoic sections at other Leg 159 sites are significantly thinner than the one at Site 959 and were found to contain more unconformities. In oceanic sections, recognition of a hiatus (i.e., the geological time that an unconformity represents) is largely a function of the available stratigraphic resolution, which is very much dependent on the tools used (e.g., biostratigraphic, magnetostratigraphic, etc., either singularly or combined), their reliability, and the density of sampling. Calcareous nannofossils have long been acknowledged as a powerful biostratigraphic tool, with a fine resolution in most of their geological time that an unconformity represents) is largely a function of the available stratigraphic resolution, which is very much dependent on the tools used (e.g., biostratigraphic, magnetostratigraphic, etc., either singularly or combined), their reliability, and the density of sampling. Calcareous nannofossils have long been acknowledged as a powerful biostratigraphic tool, with a fine resolution in most of

METHODS

Assemblages were analyzed from smear slides prepared using either raw sediment samples (core-catcher samples) or sediment suspensions in distilled water (other samples). For each sample, two slides were prepared, one with double the number of suspension drops used for the other. Slides were examined with an optical microscope at 1250× magnification. At least one sample from every second core section was examined. The relative abundance of species was estimated for all assemblages except those in Hole 959B.

Estimates for the total nannofossil abundance in a slide were determined as follows: D (dominant) = >60% of all particles; A (abundant) = 30%-60% of all particles; C (common) = 10%-30% of all particles; F (few) = 5%-10% of all particles; R (rare) = 1%-5% of all particles; T (trace) = <1% of all particles. Estimates of nannofossil preservation are coded as follows: E (excellent) = pristine preservation with no overgrowth or dissolution; G (good) = slight dissolution and overgrowth, but all taxa are easily identifiable; M (moderate) = obvious signs of dissolution and overgrowth, but most specimens are readily identifiable; P (poor) = strong overgrowth and dissolution, and most specimens are fragmented and difficult to identify. Estimates of the relative abundances of nannofossil species were determined as follows: D (dominant) = >60% of all nannofossils; A (abundant) = 30%-60% of all nannofossils; C (common) = 10%-30% of all nannofossils; F (few) = 5%-10% of all nannofossils; R (rare) = 1%-5% of all nannofossils; vR (very rare) = <1% of all nannofossils. Where these estimates were not determined the letter X is indicated instead.
NANNOFOSSIL DISTRIBUTION AND BIOSTRATIGRAPHY

The distribution of calcareous nannofossils in the upper Cenozoic sections off the Côte d’Ivoire and Ghana is given in Tables 1–6 (back-pocket foldout, this volume). A biostratigraphic summary is presented in Figure 2 and is discussed below. We have used primarily the CN (sub)zones of Okada and Bukry (1980) because of their greater resolution, particularly in the upper Miocene. This zonation is largely based on biozones originally described by other authors (e.g. Bramlette and Wilcoxon, 1967; Gartner, 1969; Martini, 1971; Bukry, 1973, 1975), and is mostly applicable for low-latitude oceanic areas.

Zonal boundaries tended to be more confidently identified than subzonal boundaries at Site 959, the most complete upper Cenozoic record we have on the Côte d’Ivoire-Ghana marginal ridge (see below). The uncertainty usually was a result of the marker species being rare or sporadic in occurrence. This led us to either rank (sub)zonal indicators differently than originally intended by their authors or to adopt proxies for the original index species (see “Biostratigraphic Summary and Remarks,” below). As shown in Figure 2, we have used the lowest occurrence (LO) of Orthorhabdus serratus to mark the base of Subzone CN1c instead of the LO of Discoaster druggii; the highest occurrence (HO) of Discoaster bollii to mark the top of Subzone CN8a instead of the LO of Discoaster neorectus, which was originally proposed for the base of CN8b; the LO of (circular, >5 µm) Pseudoemiliania lacunosa to mark the base of Subzone CN11b instead of the advent of the acme of Discoaster asymmetricus; and the HO of Sphenolithus spp. to mark the top of Subzone CN11b in preference to the HO of Reticulofenestra pseudoumbilicus. The species Discoaster druggii, D. neorectus, and A. primus are rare or sporadic in occurrence, whereas the acme of D. asymmetricus and the HO of R. pseudoumbilicus are difficult to locate precisely.

Hole 959A (Water Depth 2090.7 m)

An almost complete succession of upper Cenozoic calcareous nannofossil (sub)zones was identified in this hole. Several barren intervals interrupt the otherwise continuous succession of upper Oligocene and lower Miocene nannofossil assemblages; and a hiatus is detected within the upper Miocene.

The Uppermost Oligocene assemblages of Subzone CN1a are found in the interval comprising Samples from 159-959A-37X-CC through 32X-5, 129–130 cm; however, several samples within this interval are barren of calcareous nannofossils, in keeping with the deposition pattern of alternating barren and nannofossil-bearing beds in both the underlying upper Oligocene (Shafik et al., Chap. 32, this volume) and overlying lower Miocene. These assemblages include abundant Cyclicargolithus abisectus, C. floridanus, Discoaster deflandrei, and Triquetrorhabdulus carinatus, and lack Sphenolithus ciperoensis, Dictyococcites bisectus, Zygrhablithus bijugatus, which are present in underlying assemblages. Cyclicargolithus abisectus is frequent, rare or even absent in similar assemblages from Samples 159-959A-31X-CC through 32X-5, 129–130 cm; however, several samples within this interval are barren of calcareous nannofossils, in keeping with the deposition pattern of alternating barren and nannofossil-bearing beds in both the underlying upper Oligocene (Shafik et al., Chap. 32, this volume) and overlying lower Miocene. These assemblages include abundant Cyclicargolithus abisectus, C. floridanus, Discoaster deflandrei, and Triquetrorhabdulus carinatus, and lack Sphenolithus ciperoensis, Dictyococcites bisectus, Zygrhablithus bijugatus, which are present in underlying assemblages. Cyclicargolithus abisectus is frequent, rare or even absent in similar assemblages from Samples 159-959A-31X-CC through 32X-5, 44–45 cm. These are assigned to the earliest Miocene Subzone CN1b.

Assemblages of Subzones CN1a and CN1b, in Samples 159-959A-31X-CC, 120–121 cm, through 32X-1, 120–121 cm (mostly diatomite with clay and minor nannofossil chalk); the lowermost sample (159-959A-32X-3, 120–121 cm), is almost barren of calcareous nannofos-
### Upper Cenozoic Calcareous Nannofossil Biostratigraphy

#### Series, Epoch, (Sub) Zones
- **Oligocene**
- **Miocene**
- **Pliocene**
- **Pleistocene**

**Table**: Core-section, interval (cm) in hole:

<table>
<thead>
<tr>
<th>Event</th>
<th>Core-section</th>
<th>Interval (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>959A</td>
<td>1H-1, 50-51</td>
<td>1H-CC</td>
</tr>
<tr>
<td>959B</td>
<td>1H-2, 100-101</td>
<td>1H-CC</td>
</tr>
<tr>
<td>960A</td>
<td>9H-1, 50-51</td>
<td>1H-CC</td>
</tr>
<tr>
<td>960C</td>
<td>9H-2, 100-101</td>
<td>1H-CC</td>
</tr>
<tr>
<td>961A</td>
<td>9H-3, 50-51</td>
<td>1H-CC</td>
</tr>
<tr>
<td>962B</td>
<td>9H-4, 50-51</td>
<td>1H-CC</td>
</tr>
</tbody>
</table>

#### Events defining (sub) zonal boundaries
- **Emiliania huxleyi**
- **Pseudoemiliania lacunosa**
- **Gephyrocapsa oceanica**
- **Gephyrocapsa caribbeaica**
- **Discoaster brouweri**
- **Discoaster pentaradiatus**
- **Discoaster surculus**
- **Discoaster tamalis**
- **Emiliania huxleyi**
- **Ceratolithus rugosus**
- **Ceratolithus armatus**
- **Tricerotaphodobulbus rugosus**
- **Discoaster quinqueramus**
- **Amauroolithus spp.**
- **Mynithula convalis**
- **Discoaster brouweri**
- **Discoaster neorectus**
- **Discoaster bollii**
- **Discoaster hamatus**
- **Catameria calyculus**
- **Discoaster hamatus**
- **Catameria coalitus**
- **Discoaster kugleri**
- **Sphenolithus heteromorphus**
- **Helicosphaera ampliaperta**
- **Sphenolithus heteromorphus**
- **Sphenolithus belemnos**
- **Orthorhabdus serratus**
- **Discoaster druggii**
- **Acme C. abisectus**
- **Sphenolithus ciperoensis**

#### Notes
- **First appearance datum/lowest occurrence in cores**
- **Last appearance datum/highest occurrence in cores**
- **(sub) zonal boundaries**
- **Questionable stratigraphic breaks**
- **Primary event for recognition of (sub) zonal boundaries**
- **Vertical extent is inherently uncertain**

**Figure 2**: Calcareous nannofossil biostratigraphic summary of the upper Cenozoic on the Côte d'Ivoire-Ghana Marginal Ridge, Leg 159.
Coccolithus eopelagicus, an impoverished/barren interval. Sample 159-959A-29X-6, 100–101 cm is barren of calcareous nannofossils. Core 159-959A-29X-5, 99–100 cm, and 29X-4, 97–98 cm, are totally barren of calcareous nannofossils. Core 159-959A-29X-2, 88–89 cm is virtually barren of calcareous nannofossils, with only traces of Discoasters (D. variabilis, D. asymmetricus, D. berggrenii, D. quinqueramus, and D. petaliformis). discoasters). The top of lower Pliocene Zone CN11 is usually drawn at the extinction of Reticulofenestra pseudoumbilicus and Sphentholithus spp. (S. neoabies and S. abies). These two events are well separated in Hole 959A; assemblies in Samples 159-959A-6H-1, 100–101 cm, through 6H-6, 100–101 cm, lack R. pseudoumbilicus, but include S. neoabies and S. abies. Recognition of the base of Subzone CN11b was based on the LO of typical Pseudoemiliania lacunosa in Sample 159-959A-6H-2, 100–101 cm, where the lowest common occurrence of D. asymmetricus is also determined. This justifies the use of the former event as a proxy for the latter in sections where the acme of D. asymmetricus is difficult to determine. Assemblages in Samples 159-959A-5H-4, 100–101 cm, through 3H-3, 100–101 cm, is based on the association of Discoaster brouwerii, Helicosphaera sellii and Pseudoemiliania lacunosa, in the absence of Sphentholithus neoabies, S. abies, and Reticulofenestra pseudoumbilicus. Subdivision of this zone was made possible by successive HOs of Discoaster tamalis, D. surculus, and D. pentaradiatus.

Assemblages in Samples 159-959A-5H-4, 100–101 cm, through 3H-3, 100–101 cm, contain Pseudoemiliania lacunosa, Helicosphaera sellii, Calcidiscus macintyrei, and Gephyrocapsa aperta. These indicate the lower Pleistocene Subzone CN13a. Gephyrocapsa caribbeanica and P. lacunosa co-occur in Samples 159-959A-2H-7, 100–101 cm,
through 1H-4, 100–101 cm, without the association of *Gephyrocapsa oceanica*, indicating Subzone CN13b.

Assemblages in Samples 159-959A-2H-2, 100–101 cm, through 2H-1, 100–101 cm, contain *Gephyrocapsa oceanica*, *G. caribbiana*, a small species of *Gephyrocapsa* (including *G. aperta*), *Pseudoemiliania lacunosa*, and *Florisphaera profunda*. This association indicates lower Pleistocene Subzone CN14a.

Nannofossils indicative of upper Pleistocene Zone CN15, including *Emiliania huxleyi*, medium sized *Gephyrocapsa* species (*G. caribbiana* and *G. oceanica*), *Calciscus leptopus*, and *Umbilicosphaera sibogae*, were found in Sample 159-959A-1H-1, 50–51 cm. This zone could not be consistently identified because of difficulty in identifying the very small *E. huxleyi* using optical microscopy where the species is not dominant. Sample 159-959A-1H-2, 100–101 cm, with questionable *E. huxleyi*, is assigned to the combined zonal interval of CN15 and CN14b.

**Hole 959B (Water Depth 2090.2 m)**

Only part of the section sampled in Hole 959A was cored in Hole 959B, with coring extending only down to the middle Miocene in Core 159-959B-20H.

The distribution of nannofossil species in Hole 959B is indicated in Table 2, without estimates of their relative abundances. It is similar to that in Hole 959A (see above) and need not be discussed in detail, except to affirm some important points: (1) a barren interval lies between the assemblages of Zones CN4 and CN5 (dark glauconitic clay beds within a clayey nanofossil chalk unit; Samples 159-959B-20H-1, 59–61 cm, and 19H-6, 59–61 cm, are without calcareous nannofossils, and Sample 159-959B-19H-CC contains only traces of *Discocysta* spp.;) (2) the base of this barren interval coincides with the tops of the stratigraphic ranges of *Sphnolithus heteromorphus*, *Discocysta petaliformis*, and *Cyclacolithus floridanus*; (3) immediately above the barren interval, a change in the populations of *Coronocyclus nitescens* occurs (circular variety has its HO and oval variety has its LO in Sample 159-959B-19H-5, 59–61 cm); (4) the LO of oval *Coronocyclus nitescens* is at about the same level as the HO of *Orthorhabdus serratus*, in Subzone CN3b; (5) *Catinaster calyculus* is scarce, with concomitant uncertainty in locating the base of Subzone CN7b; (6) assemblages assignable to Subzone CN8a are missing, and the top of Subzone CN7b is probably truncated, as suggested by the disappearance of both *Discocysta hamatus* and *D. bollii* at the same level, immediately below the LO of *Minylitha convalis* (7) most of the middle Miocene sediments and the lower part of the upper Miocene section are condensed, being relatively thin; (8) large *Reticulofenestra pseudoumbilicus* disappears in the interval from mid-Subzone CN8a to within Subzone CN9b; (9) species of *Amaurolithus* and *Ceratolithus* are sparse in Zone CN10, making it difficult to subdivide this zone and to precisely locate the CN10/CN11 boundary; (11) small gephyrocapsids (including *Gephyrocapsa aperta* are present below the Pleistocene, notably as a “bloom” within Zone CN11, in association with abundant small *Pseudoemiliania lacunosa*; (12) *Sphenolithus neoabies* and *S. abies* range higher than the HO of *Reticulofenestra pseudoumbilicus*, at the CN11/CN12 boundary; and (13) *Florisphaera profunda*, present at the top of the Pleistocene section, ranges intermittently down to within the upper Miocene Subzone CN9b.

**Hole 960A (Water Depth 2048.3 m)**

Rotary drilling in this hole severely disturbed the Pleistocene and Pliocene parts of the sequence, where core recovery rates never exceeded one section per core. In the Miocene part, recovery rates im-proved, averaging 4 sections per core. Most of the Miocene and Pliocene (sub)zones were recognized (Fig. 2; Table 3). A succession of subzones indicating middle to early late Miocene ages were identified in a single core, indicating a very condensed middle upper Miocene section. Four hiatuses are recognized within this section.

Nannofossils assignable to upper Oligocene Subzone CP19b, with *Sphnolithus ciperoensis*, are in Sample 159-960A-12R-2, 94–95 cm, Basal Miocene Subzone CN1b occurs immediately above, in Sample 159-960A-12R-2, 73–74 cm, indicating an unconformity at the top of the Oligocene in this hole. Subzone CN1b is based on the association of *Cyclicargolithus floridanus*, *Discocysta saundersii*, *D. nephados*, *D. druggii* (small form), and *Triquetrorhabdus carinatus*, in the absence of *Orthorhabdus serratus*. The latter species occurs in Sample 159-960A-1R-3, 57–58 cm, indicating Subzone CN1c. *Helicosphaera ampliaperta* has its LO in Sample 159-960A-1R-1, 120–121 cm (in Subzone CN1b).

*Sphnolithus bellemos* in Samples 159-960A-11R-1, 47–48 cm, and 10R-CC, indicates Zone CN2. *Sphnolithus heteromorphus*, together with *Helicosphaera ampliaperta*, in Samples 159-960A-10R-5, 32–33 cm, through 10R-1, 30–31 cm, indicates Zone CN3. The HO of *S. bellemos* is in Sample 159-960A-10R-CC, below the LO of *S. heteromorphus*. The top of Zone CN3 is indicated at the HO of *Helicosphaera ampliaperta* in Sample 159-960A-10R-1, 30–31 cm. *Sphnolithus heteromorphus* ranges upward through Samples 159-960A-9R-CC and 9R-2, 140–141 cm, indicating lower middle Miocene Zone CN4. Assemblages in Core 159-960A-9R are not confined to Zone CN4, but include upper Miocene Subzone CN9a (see Table 3).

Samples 159-960A-9R-2, 110 cm, and 9R-2, 90 cm, contain common *Catinaster coali tus*, *C. mexicana*, and *Discocysta bollii* This asso-ociation, in the absence of *Discocysta hamatus*, characterizes middle Miocene Zone CN6. An unconformity is evident between Samples 159-960A-9R-2, 140–141 cm (Zone CN4), and 159-960A-9R-2, 110 cm (Zone CN6): the top of Zone CN4 is probably truncated, Zone CN5 is missing, and Zone CN6 is very thin (less than 1 m in thickness). Truncation of the top of Zone CN4 (Sample 159-960A-9R-2, 140–141 cm) is suggested because the species *Coronocyclus nitescens*, *Cyclicargolithus floridanus*, *Discocysta deflandrei*, and *Triquetrorhabdus milowii* all have their HOs simultaneously at the level of the unconformity. Consistent with the absence of Zone CN5 and a thin Zone CN6 is the absence of *Coccolithus miopelagicus* at the unconformity. The base of Zone CN6 contains evidence of mixing and/or reworking; several older species (such as *Reticulofenestra lockerti*, *Sphnolithus heteromorphus*, and *Triquetrorhabdus carinatus*, derived from Zone CN4 and older sediments) are present in Sample 159-960A-9R-2, 110 cm. A reduced Zone CN6 is also indicated by the LOs of both *Discocysta sanniquelensis* and *D. exilis* be-ing at its base.

Subzone CN7a was not identified, and the assemblage in a sample a few centimeters above the top of Zone CN6 (i.e., Sample 159-960A-9R-2, 60–61 cm) contains *Discocysta hamatus*, *D. bollii*, and *D. pseudovariabilis*, in association with *Catinaster calyculus*, *C. coali tus* and *C. mexicana*, indicating Subzone CN7b. Similarly, Subzone CN8a was not identified, and the assemblage in a sample a few centimeters above the top of Subzone CN7b (i.e., Sample 159-960A-9R-1, 29–30 cm), contains *Minylitha convalis*, *Discocysta neoreuctus*, *D. calcaris*, *D. surculus*, and *D. pentaradiatus*, indicating Subzone CN8b. Once more the pattern is being repeated, Subzone CN9a was not identified, and the assemblage in a sample, a few centimeters above Subzone CN9b (i.e., Sample 159-960A-9R-1, 3–4 cm), contains abundant *Discocysta quinqueramus* and very rare *Amaurolithus delicatus*, but lacks *Minylitha convalis*, indicating Subzone CN9b. The virtual absence of *Discocysta berggreni* from Subzone CN9b, particularly from its basal part (Table 3), is consistent with the absence of Subzone CN9a. *Discocysta quinqueramus* ranges through-
out Subzone CN9b, and its HO (at the top of the subzone) is in Sample 159-960A-7R-3, 130–131 cm. This indicates that Subzone CN9b is about 16 m thick, which contrasts sharply with the underlying thin upper Miocene divisions (the combined Subzone CN7b and CN6 is less than 2.5 m thick).

Species of Amaurolithus are rare and sporadic in Subzone CN9b. An isolated occurrence of common Minyolitha convallis in Subzone CN9b (Sample 159-960A-8R-CC), is difficult to explain.

Recognition of Subzone CN10b was based on rare Ceratolithus armatus and C. acutus in Sample 159-960A-6R-CC, above the HO of both Triquetrorhabdus rugosus and T. farnsworthii. Species of Amaurolithus co-occur with Ceratolithus rugosus in the short interval of Samples 159-960A-6R-1, 104–105 cm, through 6R-1, 10–11 cm, indicating lower Pliocene Subzone CN10c. This is unlike the record in Hole 960C, where Amaurolithus spp. were not found with C. rugosus, and separation of Subzones CN11a and CN10c was not possible. Consistent occurrences of rare Discaster asymmetricus in Samples 159-960A-6R-1, 34–35 cm, and 6R-1, 10–11 cm, make identification of the rarely used Subzone CN10d (Bukry, 1981) seem possible.

Lower Pliocene Zone CN11 assemblages were identified in Cores 159-960A-5R and 4R. In these assemblages, Discaster asymmetricus is rare or even absent, but becomes common in Samples 159-960A-4R-1, 50–52 cm, and 159-960A-3R-CC, above the HO of Reticulofenestra pseudoumbilicus. Typical (5 µm, circular) Pseudoequimiliaciona lacunosa has its LO in Sample 159-960A-4R-1, 50–52 cm, indicating Subzone CN11b. Both Sphenolithus neobases and S. abies have their HO in Sample 159-960A-3R-CC. The assemblages in Section 159-960A-4R-1 contain abundant small Gephyrocapsa spp. (including G. aperta). This is about the same level as the Plocamium ‘bloom’ of small Gephyrocapsa spp. at Site 959.

Assemblages of Zone CN12 were identified in Core 159-960A-3R. Subzone CN12a, in Sample 159-960A-3R-1, 100–101 cm, contains Discaster asymmetricus, D. brouweri, D. pentaradiatus, D. sursalis, D. tamalis, Helicosphaera sellii, and small Pseudoequimiliaciona lacunosa. A similar association, minus both D. tamalis and D. asymmetricus, was identified a few centimeters above (Sample 159-960A-3R-1, 95–96 cm), indicating Subzone CN12b. Both Discaster brouweri and D. pentaradiatus occur in Sample 159-960A-3R-1, 7–8 cm, together with normal sized P. lacunosa, H. sellii, and Florisphaera profunda, indicating Subzone CN12c. The apparent absence of Subzone CN12d (Fig. 2) is probably an artifact of inadequate sampling and very poor core recovery. Sample 159-960A-2R-CC lacks the large to medium-sized Gephyrocapsa spp. (G. caribbeanica and G. oceanica) as well as Discaster spp., and contains Calcisidiscus macintyrei, Helicosphaera sellii, P. lacunosa, and Florisphaera profunda, suggesting lower Pleistocene CN13a. Assemblages from the top of the hole in Core 159-960A-1R are assigned to lower Pleistocene Subzone CN13a. This is based on the presence of Gephyrocapsa oceanica, G. caribbeanica, Helicosphaera inversa, Umbilicosphaera sibogae, Pseudoequimiliaciona lacunosa, and small Gephyrocapsa spp.

Hole 960C (Water Depth 2034.9 m)

Core recovery in this hole contrasted sharply with that from Hole 960A, being 100% in the upper Cenozoic sequence. The distribution of nanofossil species in this hole (Table 4) is generally similar to that in Hole 960A. Differences are minor, largely attributable to sampling and the general rarity of several key species, particularly the ammocritoids and ceratolithids. The middle Miocene and lower upper Miocene section is thick and broken by four unconformities.

An assemblage assignable to the basal Miocene Subzone CN1b was recovered from Sample 159-960C-14H-2, 34–36 cm. This is strongly etched and impoverished and contains common to frequent Cyclicargolithus floridanus, small Discoaster druggii, D. saundersii, Triquetrorhabdus carinatus, Reticulofenestra lockeri, and rare Cyclicargolithus absectus. Neither Orthorhabdus serratus nor Discoaster druggii (15 µm or more) are present. Nanofossils from immediately below in Sample 159-960C-14H-3, 34–36 cm, are indicative of the upper Oligocene Subzone CP19b, with Sphenolithus ciperoensis, Helicosphaera truempyi, and common Cyclicargolithus absectus being present. Subzone CN1a is missing, and an unconformity at the top of the Oligocene is deduced.

Samples 159-960C-14H-1, 34–36 cm, and 13H-CC, are barren of calcareous nanofossils. This barren interval separates the impoverished assemblage in Sample 159-960C-14H-2, 34–36 cm (Subzone CN1b), from abundant, moderately well preserved assemblage in Sample 159-960C-13H-7, 34–36 cm (Subzone CN1c).

Helicosphaera ampliaperta occurs in conjunction with several other species in Samples 159-960C-13H-7, 34–36 cm, through 11H-5, 140–141 cm: (1) with Orthorhabdus serratus in Samples 159-960C-13H-7, 34–36 cm, through 13H-5, 130–131 cm, indicating lower Miocene Subzone CN1c; (2) with Zone CN2 marker Sphenolithus helennos in Samples 159-960C-13H-4, 34–36 cm, through 12H-7, 34–36 cm; and (3) with S. heteromorphus in Sample 159-960C-12H-6, 34–36 cm, through 11H-5, 140–141 cm, indicating lower Miocene Zone CN3. Chiasmolithus solitus was found in Sample 159-960C-12H-3, 130–131 cm, indicating minor reworking. Abundant Sphenolithus heteromorphus, Cyclicargolithus floridanus, Reticulofenestra pseudoumbilicus, Discoaster sanmiguelensis, D. exilis, and Helicosphaera carteri/ampiperti in Sample 159-960C-11H-4, 34–36 cm, through 10H-7, 34–36 cm, indicate middle Miocene Zone CN4.

The stratigraphic ranges of several species (Coccolithus miope- lagicus, Discoaster petaliformis, Discoaster sanmiguelensis, Cyclicargolithus floridanus, circular Coronocyclus nitescens, together with Sphenolithus heteromorphus) appear truncated at the top of Zone CN4 in Sample 159-960C-10H-7, 34–36 cm. In the same sample, reworking is evident in the presence of the undeniable (rare Eocene) Chiasmolithus solitus. The overlying assemblage, in Sample 159-960C-10H-6, 34–36 cm, is assigned to Zone CN6, based on the occurrence of frequent Catimaster coxalis, rare C. mexicana, together with common Discoaster bollii, D. exitis, and D. variabilis, and the absence of D. hamatus. A substantial hiatus is indicated: Zone CN 4 is truncated. Zone CN5 is missing, and Zone CN6 is reduced.

Both Discoaster hamatus and D. bollii are present, along with very rare Catimaster calyculus, in Samples 159-960C-10H-5, 34–36 cm, and 10H-4, 34–36 cm, indicating upper Miocene Subzone CN7b. Subzone CN7a is missing.

Samples 159-960C-10H-3, 34–36 cm, through 9H-7, 64–65 cm, contain consistent Minyolitha convallis, Discoaster pentaradiatus, D. neohamatus, D. calcaris, and D. variabilis, as well as sporadic D. neorectus, D. loeblichii, and Triquetrorhabdus rugosus, indicating upper Miocene Subzone CN8b. Subzone CN8a is missing.

Assemblages in Samples 159-960C-9H-6, 34–36 cm, through 8H-5, 130–131 cm, are assignable to upper Miocene Subzone CN9b; Subzone CN9a is missing. In these assemblages Discoaster quinqueraumus is common and consistent in distribution, but D. berggrenii and species of Amaurolithus are rare, occurring sporadically. There is virtually no gap between the HO of Minyolitha convallis in Sample 159-960C-9H-7, 64–65 cm, and the LO of Amaurolithus spp. (in this case A. bizzarus) in Sample 9H-6, 34–36 cm.

Subzone CN10a, in Samples 159-960C-8H-3, 130–131 cm, and 8H-1, 130–131 cm, was recognized by the presence of Triquetrorhabdus rugosus and/or T. farnsworthi in the absence of Discoaster quinqueraumus. Subzone CN10b was identified in Samples 159-960C-7H-CC through 159-960C-7H-5, 130–131 cm; the assemblage in the upper sample is particularly noteworthy because of the presence of rare Ceratolithus armatus, Amaurolithus bizzarus, and Discoaster asymmetricus. Assemblages in the overlying interval, comprising Samples 159-960C-7H-1, 130–131 cm, through 5H-5,
130–131 cm, are broadly assigned to the combined Subzones CN10c/CN11a. These assemblages contain *Ceratolithus rugosus*, *Discoaster brouweri*, *D. pentaradiatus*, *D. surculus*, *R. pseudoumbilicus*, *S. neo-abies*, and *S. abies*, without any species of *Amaurolithus*. *Discoaster asymmetricus* is virtually absent, being present only in the lowermost sample of the interval, Sample 159-960C-7H-1, 130–131 cm. A small oval form of *P. lacunosa* and small *Gephyrocapsa* spp. occur in the uppermost sample of this interval (i.e., Sample 159-960C-5H-5, 130–131 cm). Subzone CN11b is indicated by the presence of common *Discoaster asymmetricus*, *Pseudoeomilinia lacunosa*, *Sphenolithus neoabies*, *S. abies*, and frequent *D. tamalis* in Samples 159-960C-5H-3, 129–130 cm, through 4H-5, 130–131 cm. *Reticulofenestra pseudoambulibicus* is absent from Samples 159-960C-4H-CC and 4H-5, 130–131 cm, but occurs in Core 159-960C-5H and below. Small *Gephyrocapsa* species (including *G. aperta*) occur abundantly in the assemblages of Subzone CN11b.

Upper Pliocene Zone CN12 is identified in the interval comprising Samples 159-960C-4H-3, 130–131 cm, through 2H-CC, with all its subzones being represented. Assemblages readily assignable to Subzone CN12a occur in samples from Core 159-960C-4H. These contain *Discoaster tamalis*, *D. brouweri*, *D. pentaradiatus*, *Calcis-
cus macintyrei*, *C. leptoporus*, *Helicosphaera sellii*, *Pseudoeomilinia lacunosa*, and *Florisphaera profunda*, without *Reticulofenestra pseudoambulibicus*, *Sphenolithus neoabies*, or *S. abies*.

Lower Pleistocene Zone CN13 occurs in Samples 159-960C-2H-6, 35–37 cm, through 2H-3, 10–11 cm, and could easily be subdivi-
ded. The assemblage in Sample 159-960C-2H-6, 35–37 cm, con-
tains *Calcisicus macintyrei*, *Helicosphaera sellii*, *Pseudoeomilinia lacunosa*, and *Florisphaera profunda*, and is assigned to Subzone CN13a. Assemblages in Samples 159-960C-2H-5, 10–11 cm, and 2H-3, 10–11 cm, contain *Gephyrocapsa carribeanica*, without *G. oceanica*, indicating Subzone CN13b. The Samples 159-960C-2H-1, 10–11 cm, through 1H-5, 29–30 cm, contain *C. leptoporus*, *G. oceanica*, *G. carribeanica*, *F. profunda*, *Umbilicosphaera sibogae*, and *P. lacunosa*, which indicate Subzone CN14a. A similar association of species, but minus *P. lacunosa* and with the addition of both *Emil-
iania huxleyi* and *U. irregularis*, occurs in Samples 159-960C-1H-3, 30–31 cm, through 1H-1, 17–19 cm. Identification of *E. huxleyi* is somewhat uncertain, but suggests the interval of Subzone CN14b and Zone CN15.

### Hole 961A (Water Depth 3292 m)

Core recovery from the upper Cenozoic section in this hole, particularly the Miocene part, was very poor, hence the apparent stratigraphic breaks in Figure 2. In most of the Miocene section, each core is confined to a single zone (or even subzone).

Sample 159-961A-15R-CC contains an assemblage indicative of Subzone CN1c. In this assemblage, *Orthorhabdus serratus*, small *Discoaster dragui*, *Sphenolithus compactus*, *S. dissimilis*, *D. flan-
drei*, *D. adamanteus*, *Coronocyclus nitescens*, and several species of the genus *Helicosphaera* are present. Sample 159-961A-16R-CC lacks calcareous nannofossils, but contains a lower Miocene radiolarian fauna. The first downhole sample with calcareous nannofossils (Sample 159-961A-17R-CC) contains an association of species indicative of the early Eocene age (Shafik et al., Chap. 32, this volume).

The interval comprising Samples 159-961A-15R-1, 36–37 cm, through 11R-CC, contains assemblages characterized by the presence of the key species *Sphenolithus heteromorphus*, (Zones CN3 and CN4); Zone CN2 was not identified. Assemblages in the lower samples (Samples 159-961A-15R-1, 36–47 cm, through 12R-1, 39–40 cm) include *H. ampliaperta*, indicating Zone CN3. The Zone CN4 assemblage in Sample 159-961A-11R-CC is impoverished and almost barren of nannofossils, having a few specimens of *Cyclicar-golithus floridanus*, *Reticulofenestra pseudoambulibicus*, *Discoaster sammiguelensis*, *D. exilis*, and *Helicosphaera kampferi*. Core 159-961A-10R had no recovery.

Main elements of the assemblages in Core 159-961A-9R include *Discoaster hamatus*, *D. bollii*, *D. calcaris*, *D. variabilis*, *Catinaster coaliatus*, *C. mexicana*, *Triquetrorhabdulus rugosus*, and *Calcisicus macintyrei*, together with rare *Catinaster calcarus*, indicating upper Miocene Zone CN17b.

Core 159-961A-8R contains abundant, well-preserved nannofossils including *Minyliitha convalis*, *Discoaster pentaradiatus*, *D. neo-
hamatus*, *D. calcaris*, *D. variabilis*, and *Triquetrorhabdulus rugosus*, but lacks *Discoaster hamatus*, *D. bollii*, *D. calcaris*, and *Pseudoemilinia lacunosa*, indicating Subzone CN18a. This association indicates upper Miocene Subzone CN9b. The lower Subzone CN8a is not represented in this hole; a likely hiatus separates Cores 159-961A-9R and 8R.

Well-preserved assemblages of upper Miocene Zone CN9 were identified in Cores 159-961A-7R through 5R. Those in Samples 159-961A-5R-CC through 6R-CC contain several extremely rare but undeniably distinct species of *Amaurolithus* (mainly represented by either *A. primus* or *A. delicatus*), and are assigned to Subzone CN9b. Species of *Amaurolithus* are absent in Sample 159-961A-7R-CC, but *Mi-
nyliitha convalis* is present instead, in association with abundant *Discoaster brouweri* and *D. quinqueramus*, indicating Subzone CN9a.

Core 159-961A-4R contains assemblages indicative of Zone CN10. Rare *Amaurolithus delicatus* in Sample 159-961A-4R-1, 89–91 cm, together with rare *Ceratolithus rugosus*, *Discoaster asymmetricus*, and *Helicosphaera sellii* suggests Subzone CN10c: *A. delicatus* is the only species of *Amaurolithus* found in Core 159-961A-4R, and only in one sample; *D. asymmetricus* occurs at lower levels, in Zone CN9, and could not be used to indicate Subzone CN10d.

Well-preserved assemblages, assignable to the lower Pliocene Subzone CN11b, occur in Core 159-961A-3R. These contain *Reticulofenestra pseudoambulibicus*, *Sphenolithus neoabies*, *S. abies*, and *Pseudoeomilinia lacunosa*: *R. pseudoambulibicus* and *S. neoabies* are present up to Sample 159-961A-3R-2, 34–35 cm; *S. abies* persists up to Sample 3R-1, 34–35 cm. *Discoaster asymmetricus* occurs in most of the core, but *P. lacunosa* is more common, appearing first (up-section) in the core-catcher sample. The seeming absence of Subzone CN11a is probably an artifact of inadequate sampling.

Core 159-961A-2R recovered only a 4-cm section (in the core catcher). This yielded an assemblage with *Discoaster tamalis*, *D. pentaradiatus*, and *D. brouweri*, indicative of mid-Pliocene Subzone CN12a. The assemblage in Sample 159-961A-1R-CC lacks *Discoaster*, and contains an association indicative of lower Pleistocene Subzone CN13a: *Pseudoeomilinia lacunosa*, *Helicosphaera sellii*, *Florisphaera profunda*, *Calcisicus macintyrei*, and *C. leptoporus*. The assemblage in Sample 159-961A-1R-1, 3–5 cm, is dominated by *Emiliania huxleyi*, *Gephyrocapsa oceanica*, *C. carribeanica*, and *Florisphaera profunda*, indicating Zone CN15. The Pleistocene section is condensed, being about 3.4 m thick (Core 159-961A-1R), and probably contains a hiatus.

### Hole 962B (Water Depth 4637 m)

Site 962 is on a minor ridge associated with the Côte d’Ivoire-Ghana marginal ridge. Upper Cenozoic calcareous nannofossil-bearing sediments in Hole 962B are restricted to a thin, predominantly barren, Pliocene and upper Pleistocene section (the upper three cores), which overlies a much thicker section entirely barren of cal-
areous nannofossils (the underlying six cores). This section recalls the general pattern of deposition on the main ridge during the Paleogene: a nannofossil-bearing sequence interrupted by episodes of non-calcareous deposition, condensed sedimentation or stratigraphic gaps, overlying a thick section barren of calcareous nannofossils (Shafik et al., Chap. 32, this volume).
There is a significant lithologic change between Cores 159-962B-3H and 4H, separating zeolitic clay (below) from nannofossil clay (above). A few specimens of Discoaster pentaradiatus, Sphenolithus abies, Reticulofenestra pseudoumbilicus, and R. minutula were found in Sample 159-962B-4H-1, 50–52 cm. Except for this, samples from Cores 159-962B-4H through 159-962B-9H are barren of calcareous nannofossils. Albian nannofossils were found in Core 159-962B-10H.

The interval comprising Samples 159-962B-3H-CC and 159-962B-3H-3, 50–52 cm, contains assemblages indicative of lower Pliocene Subzone CN1a. These include Discoaster asymmetricus, D. brouweri, D. penraradiatus, Ceratolithus rugosus, Reticulofenestra pseudoumbilicus, Sphenolithus neoabies, and S. abies. Intervening Samples 159-962B-3H-6, 51–53 cm, and 3H-5, 50–52 cm, are barren of calcareous nannofossils. Sample 159-962B-3H-2, 50–52 cm, contains abundant, moderately well-preserved nannofossils. These include Pseudoemiliania lacunosa, Sphenolithus neoabies, and S. abies, but not R. pseudoumbilicus, indicating the upper part of Subzone CN1b. Sample 159-962B-3H-1, 130–131 cm, lacks calcareous nannofossils, and Sample 3H-1, 53–55 cm, contains abundant, moderately well-preserved nannofossils indicative of upper Pliocene Subzone 12b. These include Discoaster brouweri, D. pentaradiatus, D. surculus, Calcidiscus magnyrei, C. leptoporus, Helicosphaera sellii, and Pseudoemiliania lacunosa. Sample 159-962B-2H-CC contains rare, poorly preserved nannofossils lacking Discoaster spp. and including Gephyrocapsa caribbeana, G. aperta, and G. margerelli, indicating lower Pleistocene Subzone CN13b.

In the barren interval between Subzones CN11b and CN12b, concentrations of glauconite were identified as hardgrounds, based on lithologic criteria (see Maske, Lohmann, Clift et al., 1996). A long hiatus is identified between Samples 159-962B-3H-1, 53–55 cm, and 2H-CC because of the absence of Subzones CN12c, CN12d, and CN13a.

Sample 159-962B-2H-7, 50–52 cm, is barren of calcareous nannofossils. Samples 159-962B-2H-6, 50–52 cm, and 2H-5, 50–52 cm, contain assemblages of variable preservation. Main elements of these assemblages include Gephyrocapsa oceanica and G. caribbeana, with Pseudoemiliania lacunosa indicating lower Pleistocene Subzone CN14a. In Sample 159-962B-2H-5, 50–52 cm, trace amounts of reworked Eocene taxa (e.g., Chiasmolithus solitus) were found. No calcareous Eocene sediments of Eocene age were cored at the site, although they are known from the shallower Sites 959 and 960.

The interval comprising Samples 159-962B-2H-3, 130–131 cm, through 2H-1, 50–52 cm, is barren of calcareous nannofossils. In contrast, Sample 159-962B-1H-CC contains abundant, moderately well-preserved nannofossils including G. aperta, G. oceanica, G. caribbeana and Helicosphaera inversa, indicating upper Pleistocene Subzone CN14b. Sample 159-962B-1H-1, 78–80 cm, is barren, but abundant, moderately well-preserved nannofossils occur in Sample 1H-4, 133–134 cm. These are dominated by G. oceanica and G. caribbeana. Samples 159-962B-1H-4, 50–52 cm, through 1H-3, 130–131 cm, are barren of calcareous nannofossils, and only a residual assemblage was found in Sample 159-962B-1H-3, 96–97 cm. This consists mainly of G. omega, G. caribbeana, C. leptoporus, and Helicosphaera carteri, indicating upper Pleistocene Subzone CN14b. Rare, strongly etched nannofossils mostly of G. omega and F. profunda occur in Sample 159-962B-1H-2, 25–26 cm. The assemblage in Sample 159-962B-1H-1, 1–2 cm, is strongly affected by dissolution, but is assignable to Zone CN15. It contains Emiliania huxleyi, Calcidiscus leptoporus, Ceratolithus sp., Umbilicosphaera si-bogae, Florisphaera profunda, and several species of Gephyrocapsa, including G. omega and G. oceanica, in addition to reworked Calcith...

**BIOSTRATIGRAPHIC SUMMARY AND REMARKS**

Sediment accumulation rates for the Neogene sequences on the Côte d’Ivoire-Ghana marginal ridge (Maske, Lohmann, Clift, et al., 1996) suggest a relatively more expanded sequence at Site 959, on the shoulder of the ridge, compared with that at Site 960, on the crest of the ridge. Sites 960 and 961 were sediment-starved during much of the Neogene, receiving much less sediment and having more hiatuses than was the case at Site 959. Species ranges at Site 959 are longer than at the other two sites, with the attendant result that a gap between a pair of HO and LO events at Site 959 may not exist at the other two sites. The relationship between the HO of Sphenolithus belemnos and the LO of Sphenolithus heteromorphus discussed below is a case in point.

**Oligocene/Miocene Transition**

The Oligocene/Miocene boundary occurs at a disconformity at Site 960, and within a barren interval at Site 959: the uppermost Oligocene Subzone CN1a is missing at Site 960; while the end of acme of Cyclicargolithus abicetus (top of Oligocene/Subzone CN1a), was reasonably distinct, being immediately below a barren interval in Hole 959A.

**Lower Miocene**

We use the LO of *Orthorhabdus serratus* as the primary determinant of the base of Subzone CN1c, rather than the LO of the poor stratigraphic indicator *Discoaster druggii*. Originally, both *D. druggii* and *O. serratus* were included in the definition of the CN1b/CN1c subzonal boundary (see Bukry, 1973), but the former species was ranked as the primary criterion, being perceived as more cosmopolitan. Problems in determination of the LO of *D. druggii* (e.g., because the species is overgrown with calcite or rare) have necessitated combining Subzones CN1b with CN1c, but occasionally a substitute was used (see, for example, Olafsson, 1989, who also used the LO of *O. serratus* in nearby Hole 667A). On the Côte d’Ivoir-Ghana marginal ridge, a small form of *D. druggii* occurs well below the LO of *O. serratus* and the normal sized (>15 µm) *D. druggii* is very rare. It is worthy of note that in Berggren et al. (1995b) the numerical age of the LO of *D. druggii* was first used in biostratigraphy, it was recognized above the LO of *O. serratus*—between the LO of *Helicosphaera ampliaperta* (below), and the LO of *Sphenolithus heteromorphus* (above) (see Theodoridis, 1984).

The LO of *Sphenolithus belemnos* (base of Zone CN2) is a sharp, easily identifiable event in sections on the Côte d’Ivoir-Ghana marginal ridge. Evidence from elsewhere is emerging to suggest that this event is very useful in correlation, and probably is synchronous over low- and mid-latitude areas (see Fornaciari et al., 1990, 1993; Olafsson, 1991; Fornaciari and Rio, 1996).

*Sphenolithus heteromorphus* occurs consistently over its range on the Côte d’Ivoir-Ghana marginal ridge, and its LO (base of Zone CN3) is easily detectable. In Hole 959A, there is a gap between the HO of *Sphenolithus belemnos* and the LO of *Sphenolithus hetero-
morphus. But in Hole 960A, there is virtually no gap between these two levels. The HO of Helicosphaera ampliaperta (top of Zone CN3) is a neat, easily identifiable event. Most of the assemblages of Zone CN3 are characterized by common H. ampliaperta, and abundant S. heteromorphus.

Middle and Upper Miocene

The HO of Sphenolithus heteromorphus (top of Zone CN4) is a sharp event, and is probably truncated at Sites 959 and 960. This event is immediately below an unconformity at Site 960. At Site 959, it is immediately below the base of a barren interval where other species have their highest occurrences as well. At Site 961, Zone CN4 was identified in almost barren sediments.

The LO of Discoaster kugleri is used to identify the base of Subzone CN5b, although the species in Hole 959B is very rare and sporadic in its lower range, because of a lack of any other, clearer, event in the interval of Zone CN5. The HO of Cyclacargolithus floridanus, which was suggested originally by Bukry (1973) as a possible alternative event to the HO of D. kugleri, is probably only a short distance above the top of Zone CN4 at low latitudes (see Raffi et al., 1995) or above the LO of D. kugleri at middle latitudes (Site 139: Roth and Thierstein, 1972). In any case, at Site 959, the HO of C. floridanus coincides with the base of a barren interval, which is immediately below Zone CN5 assemblages. The HO of Coronocyclyus nitescens, along with the HO of Orthonhambus serratissus, are considered to be good biostratigraphic events, useful for subdividing the Zone CN5 interval (see Raffi et al., 1995). This is partially supported in this study. At Site 959, two varieties of C. nitescens were distinguished, a circular variety (the typical form), and an oval one. Both varieties were found together in one sample only, at the base of Zone CN5, with the oval variety disappearing higher within Subzone CN5b. The HO of oval C. nitescens is very close to the HO of O. serratus in both Holes 959A and 959B, but the range of O. serratus is disjunct. In Hole 959A, this species is virtually absent in Zones CN3 and CN4, and its upper range is short. Such a distribution pattern, although not unknown for other species (e.g., Ischnolithus recurvus in southern Australia; Shafik, 1996) may lend itself to interpretation of reworking (i.e., the upper range of the species may be considered displaced occurrences). However, the distribution pattern of O. serratus in equatorial eastern Pacific Holes 575B, 806B, 845B, and 846D and at tropical Indian Ocean site 714 (as shown in Raffi et al., 1995; Raffi and Flores, 1995) is not dissimilar to that at Site 959, in that the species is absent in the interval of Zones CN4 and CN3. At Site 289 in equatorial western Pacific, the reappearance of O. serratus in the section is in Zone CN5, and after a short, continuous range, it disappears abruptly in the upper part of Zone CN5 (data in Shafik, 1975). More documentation of the stratigraphic range of O. serratus is needed to ascertain its biostratigraphic potential, including the species LO at the base of Subzone CN1c, the zonal CN3–CN4 gap in its range, and its HO in upper Zone CN5 (or as a possible approximation of the top of Subzone CN5a).

Catinaster coaititus is consistent throughout its range at Sites 959 and 960. Its LO (the base of Subzone CN6) is a sharp, easily identifiable event. Similarly, the LO of Discoaster hamatus (the base of Subzone CN7) is an easily detectable event, but the LO of Catinaster calyculus (the base of Subzone CN7b) was determined only tentatively because the species is scarce. This is generally true for all events based on rare species at Site 959.

Evidence is mounting to suggest that the LO of C. calyculus is at or below the LO of Discoaster hamatus (Peleo-Alamay and Wei, 1995; Raffi et al., 1995). Nevertheless, the distribution of both species in Holes 959A and 959B is in agreement with Bukry’s (1973, 1975) results, indicating that the LO of C. calyculus is younger than the LO of D. hamatus. This is very important because detection of the hiatus immediately above Zone CN6 at Site 960 (Fig. 2) hinges on the LO of C. calyculus being above the LO of D. hamatus.

The upper Miocene Subzone CN8a is missing in all sections cored on the Côte d’Ivoire-Ghana marginal ridge, and recognition of Subzone CN8b was based primarily on consistent occurrences of Minylitha convalis without the association of Discoaster bollii, or D. berggrenii. Bukry (1973) used the LO of D. neorectus and D. loehlichii to indicate the base of Subzone CN8b. Both species are rare, only intermittently occurring in the upper Miocene of the Côte d’Ivoire-Ghana marginal ridge. Also, D. bellus was not found, but this is not inconsistent with the absence of its name-bearing subzone (the D. bellus Subzone of Bukry, 1973), and probably suggests a reduced Subzone CN8b.

The LO of Discoaster quinqueramus is well above the LO of D. berggrenii at Site 959, but at Site 960, D. quinqueramus occurs at the base of Zone CN9, without D. berggrenii. This is consistent with Subzone CN9a being missing at Site 960.

Amaurolithids are rare in the upper Miocene and Pliocene on the Côte d’Ivoire-Ghana marginal ridge, occurring mostly intermittently. This is true in Zone CN9. We use the HO of Minylitha convalis as a proxy for the LO of Amaurolithus primus, which defines the base of Subzone CN9b, to determine the top of Subzone CN9a at Site 959. At nearby Site 667, on the Sierra Leone Rise, amaurolithids are also rare, as indicated by Manivit (1989), who estimated the amaurolithid/total assemblage ratio there to be <1:10,000; with this low abundance, the LO of A. primus may easily escape detection. Minylitha convalis is usually common to abundant throughout its stratigraphic range, making its HO easy to determine. However, A. primus (or Amaurolithus spp. in general) may be rare and sporadic near the base of its stratigraphic range. Relying on the LO of Amaurolithus spp., without regard to the HO of M. convalis, can lead to discrepancies in age determination and uncertainties in correlation. Gartner (1992) assigned an age of about 6.4 Ma to the LO of species of Amaurolithus at mid-latitude North Atlantic Site 608, while acknowledging that it has a significantly older age at lower latitudes. In its lower range at Site 608, Amaurolithus spp. are rare. In contrast, M. convalis has a good top at the same site, to which Gartner (1992) assigned an age of 6.7 Ma.

One argument against the biostratigraphic use of Minylitha convalis is that it is often overlooked or confused with Florisphaera profunda, which ranges down into the upper Miocene. Raffi et al. (1995) questioned the reliability of the HO of M. convalis for long-distance correlations, while conceding some of the problems in precisely locating the LO of Amaurolithus primus.

The HO of Discoaster quinqueramus (top Zone CN9) may be difficult to determine. Near this level the species develops spurs at its tips, and becomes somewhat similar to a variety of D. pentarradiatus, which has very small bifurcations at the tips and is common at about the same level. Under crossed nicols, however, the two can be separated, with D. pentarradiatus being partially birefringent, showing a characteristic figure.

Upper Miocene Interval Without Reticulofenestra pseudomobillicus

The upper Miocene record on the Côte d’Ivoire-Ghana marginal ridge shows large (>7 µm) Reticulofenestra pseudomobillicus temporarily disappearing during the interval from (?mid) Subzone CN8b to within Subzone CN9b. Concomitant with this disappearance is a notable increase in the abundance of small placoliths, which probably
include small *Gephyrocapsa* spp.: the smaller species of *Reticulofenestra*, particularly *R. minutula*, dominate the reticulofenestrids after a seemingly initial sharp decline in its abundance. This distribution pattern of reticulofenestrids is particularly evident at Site 959, but is also discernible, though less clearly, in the condensed sections at Site 960.

Only in recent studies has the upper Miocene interval without *Reticulofenestra pseudoumbilicus* been given prominence (Río et al., 1990a, Gartner, 1992; Raffi and Flores, 1995), even though it can be discerned in distribution charts of earlier studies (e.g., Shafik, 1975). The reason for its recently acquired prominence is the realization that it occupies the same stratigraphic position (Zone CN8–CN9) across the three principal oceans (Raffi et al., 1995; this study), obviously with important oceanographic and biostratigraphic implications. The interval has been identified mainly in low-latitude sections. Río et al. (1990a) described the interval (their *R. pseudoumbilicus* paracme) from four eastern tropical Indian Ocean sites, and Raffi and Flores, (1995) recorded it (their absence interval of *R. pseudoumbilicus*) at eight sites in the eastern equatorial Pacific. Based on distribution charts in Shafik (1975), the interval is also detectable in the western equatorial Pacific, at the Ontong Java Plateau Site 289, the same stratigraphic position (mid-Zone CN8 to within Subzone CN8b) as Site 959.

In the mid-latitude North Atlantic Site 608, Gartner (1992) identified the base of the interval at an abrupt size decrease in the reticulofenestrids, and interpreted it as a major change in productivity. We accept that the interval was a high-productivity event.

Correlation of the interval without *R. pseudoumbilicus* to magnetostratigraphy (Raffi et al., 1995) indicates that it extends from the upper part of Chron 4An to the lower part of Chron 3Ar, which, in terms of the timescale of Berggren et al. (1995b), spans about 2 m.y. (from about 8.8 Ma to about 6.8 Ma).

### Pliocene

Ceratolithids are rare in the Pliocene and Pleistocene on the Côte d’Ivoire-Ghana marginal ridge, occurring mostly intermittently. In the lowermost Pliocene assemblages, they are dominated by *Ceratolithus armatus* rather than *C. acutus*. The base of Subzone CN10b, approximating the Miocene/Pliocene boundary, is relatively easy to determine, but only by using the combination of the LO of *Ceratolithus armatus/acutus* and the HO of *Triquetrorhabdulus rugosus*. In Hole 959A, *Ceratolithus rugosus* is virtually absent above the HO of *R. pseudoumbilicus*, and its presence below the HO of *Amaurolithus* spp. allowed determination of Subzone CN10c. Manivit (1989) indicated that *R. pseudoumbilicus* is very close to the HO of *R. pseudoumbilicus*, below the HO of *Sphenolithus* spp. (*S. neoabies* and *S. abies*), suggesting that the beginning of the acme of *D. asymmetricus* is diachronous. In the area immediately to the west of the Côte d’Ivoire-Ghana marginal ridge, Manivit (1989) reported a similar distribution pattern for *D. asymmetricus* at Sites 665 and 666. The LOs of small (<5 µm, oval) *Pseudoemiliania lacunosa*, *Discocysta tamalis*, typical *P. lacunosa* (circular, <5 µm), and common *D. asymmetricus* are very close in Zone CN11 at Sites 959 and 960. The LO of typical *P. lacunosa* was easier to determine than the lowest common *D. asymmetricus* at Site 961, suggesting the former is a more useful biostratigraphic marker.

A normal succession of Pliocene discocysters permitted easy recognition of the subzones of Zone CN12 at Sites 959 and 960, although both *Discocysta pentaradiatus* and *D. surculus* were particularly rare towards the end of their indicated ranges.

### Mid-Pliocene Interval of Small Gephyrocapsa

An interval with abundant small placoliths, characteristically including <3.5-µm gephyrocapsids, is recognizable within mid-Pliocene Zone CN11 at Sites 959, 960, 961, and elsewhere. At nearby Site 366, on the Sierra Leone Rise, small gephyrocapsids have been recorded in Zone CN11 (Samtleben, 1980). At low-latitude sites in the western Indian Ocean, abundant gephyrocapsids have been recognized as confined to a distinct short interval within Zone CN11 (Young, 1990). At middle latitudes, however, more than one acme interval of Pliocene small gephyrocapsids has been described (Driever, 1988). *Our Zone CN11 interval of small gephyrocapsids probably correlates with Subzone NN14-15B of Driever (1988) in the Mediterranean region, which corresponds to the middle of his lower long interval of dominance of gephyrocapsids (this subzone contains *Sphenolithus* spp. and *Reticulofenestra pseudoumbilicus*, without *Amaurolithus* spp., the latter being present in the underlying Subzone NN14–15A; Driever, 1988).

Concentrations of small gephyrocapsids have also been recorded in other parts of the upper Cenozoic. Upper Miocene gephyrocapsids have been recorded in association with abundant small placoliths, at mid-latitude sites in the North Atlantic Ocean (Gartner, 1992; de Kaenel and Villa, 1996); these are confined to a short interval within Zone CN9. A possible low-latitude correlative with this middle-latitude acme of small placoliths is the upper Miocene interval without large *Reticulofenestra pseudoumbilicus* recognized at Sites 959 and
As discussed above, this interval contains abundant small placoliths, which may include small Gephyrocapsa spp. In the Pleistocene, dominance of small gephyrocapsids (the so-called small Gephyrocapsa Zone of Gartner, 1977) occurs within a short interval in Subzone CN14a. This is the best-known interval of dominance of small gephyrocapsids; it has been recorded more widely than the older ones.

Gartner (1992) suggested that the upper Miocene acme of small placoliths at middle latitude signal an important change in surface-water properties that enhance productivity. Earlier, Driever (1988) showed that acmes of small gephyrocapsids in Pliocene sections in the Mediterranean coincide with intervals when surface water temperatures were relatively low. The geographic scale of these changes in surface waters must have been wide to account for the numerous occurrences of abundant small gephyrocapsids. Small gephyrocapsids (and associated small placoliths) are easily overlooked, and more work is needed to determine properly their geographic distribution in pre-Pleistocene sections, especially at low latitudes. This would ultimately help in determining whether these low-latitude occurrences are synchronous.

**Pleistocene**

The HO of typical Pseudoemiliania lacunosa is a distinct, easily identified event compared with the LO of Emiliania huxleyii, and it was necessary to combine Zone CN15 with Subzone CN14b, where gephyrocapsids and not E. huxleyii dominate the assemblage. Small- and medium-sized gephyrocapsids are abundant in the Pleistocene on the Côte d’Ivoire-Ghana marginal ridge, and the populations of Gephyrocapsa oceanica and G. caribbeanica are easily separated.

In the absence of both Discoaster brouweri and G. caribbeanica (the criteria defining the limits of the short Subzone CN13a), the association of Fliriosphaera sellii, and Calcidiscus macintyreii was used as evidence for recognition of Subzone CN13a.

Common to abundant Fliriosphaera profunda occurs in most Pleistocene samples of Site 959 and 960. Fliriosphaera profunda ranges down into the upper Miocene at Sites 959 and 960, similar to its range in equatorial Pacific Site 289 (see Okada, 1983).

**MIOCENE HIATUSES**

In oceanic sections, hiatuses may not only be recognized by a discontinuity in ages, but also by an abrupt decrease in average sediment accumulation rates below that typical for the sediment type recovered in the interval (Rona, 1973). In this study, hiatuses were detected at breaks in the nanofossil biostratigraphic sequence, and condensed sections were identified where average sediment accumulation rates are relatively low. A break or a hiatus in the nanostратigraphic sequence is most likely to be easily recognized where a whole (sub)zone or a number of (sub)zones are missing, but not necessarily where only parts of (sub)zones are missing. In studies employing two or more integrated stratigraphic systems (see, for example, Keller and Barron, 1983; Aubry, 1995), the cumulative stratigraphic resolution may allow detection of short hiatuses, equivalent to a part of a subzone.

In Figure 2, most stratigraphic breaks, which fall between cores, are considered questionable, because such breaks are likely to be a result of incomplete core recovery rather than hiatuses (see also Moore et al., 1978). This is exemplified by the two breaks in the Pliocene–Pleistocene section in Hole 960A (see Fig. 2), where core recovery was exceedingly poor (1.2 m of sediment recovered from a cored interval of 18.7 m). These two breaks have no counterparts in Hole 960C, where core recovery was almost complete.

**The Miocene Record on the Côte d’Ivoire-Ghana Marginal Ridge**

The Miocene section (about 210 m thick) at Site 959, on the shoulder of the Côte d’Ivoire-Ghana marginal ridge, is more than three times the thickness of its counterpart (less than 60 m thick) at Site 960 on the crest of the ridge; the latter is largely condensed. Preservation of calcareous microfossils in the lower Miocene units (diameter interbedded with nanofossil chalk, clayey chalk, and clays) at Site 959 is highly variable, with barren and nanofossil-bearing beds alternating. The youngest barren interval lies between nanofossil assemblages of Zones CN4 and CN5. This suggests repeated episodes of severe carbonate dissolution during much of the early and middle Miocene. Earlier, during the late Paleogene, a similar sedimentation history at the site also resulted in the formation of alternating non-calcareous (biosiliceous) and calcareous (nanofossil-bearing) sediments (Shafik et al., Chap. 32, this volume). In most of the middle and upper Miocene units (nanofossil ooze/chalk) at Site 959, preservation of calcareous microfossils is generally poor, with abundant unidentifiable nanofossil debris, as well as evidence of partial dissolution of recognizable nanofossil specimens. This part of the section contains a hiatus which corresponds to the upper Miocene Subzone CN8a. Sediments marking the end of this hiatus were found to contain evidence of minor reworking from Cretaceous and Paleocene sources.

The largely condensed Miocene contains four hiatuses in its middle and upper parts and one barren interval in its lowermost part (Fig. 2). The temporal extent of these hiatuses are shown in Figure 3. The only Miocene hiatus present at Site 959 (CN8a hiatus), is present also at Site 960, and probably in Hole 961A as well. Evidence of very minor reworking from Eocene sources was found at the erosional surface marking the start (probably late Zone CN4) and the end (probably within Zone CN6) of the CN5 hiatus. This hiatus partly corresponds with the barren interval between Zones CN4 and CN5 at Site 959.

**The Sierra Leone Rise and Nearby Sites**

Data combined from Olafsson (1989) and Manivit (1989) suggest that the middle Miocene CN5 hiatus, which was identified on the crest of the Côte d’Ivoire-Ghana marginal ridge (Sites 960), is detectable at nearby Site 667 on the Sierra Leone Rise. There, Olafsson (1989) recorded the LO of S. heteromorphus (top of Zone CN4) in Sample 108-667A-18H-1, 135–136 cm, and Manivit (1989) showed that the LO of Catinastrinus coalitus (base of Zone CN6) is immediately above, in Sample 108-667A-17H-CC. This suggests a regional extent for this middle Miocene hiatus.

The interval corresponding to the late Miocene CN7a hiatus through the late Miocene CN8a hiatus at Site 960 has no diagnostic species (except perhaps for Discoaster pentaradiatus), and contains evidence of reworking (Coronocyclus nitescens, Cyclicargolithus floridanus, and Heliosphaera granulata) at Site 667 (based on data in Manivit, 1989). In nearby Hole 366A, also on the Sierra Leone Rise, Bukry (1977) recorded Subzone CN7b immediately above Zone CN6 and immediately below Zone CN9. Although this may be a good indication of a condensed section, it cannot be taken as clear evidence for the absence of Subzone CN7a and Zone CN8 because Bukry (1977) based his study largely on one sample per core. Interestingly, data in Manivit (1989) present more compelling evidence for the absence of Subzone CN7a in Hole 659A to the north of Site 366.

It appears from the above discussion that the middle and upper Miocene section on the Sierra Leone Rise is largely condensed; Zone CN5 is absent at Site 667 and Subzones CN7a and CN8a were not recorded at either Sites 336 or 667, while at the latter site, evidence for a reworking episode was identified.
At Site 661, to the north of the Sierra Leone Rise, Manivit (1989) recorded a succession of biohorizons in a single core (Core 108-661A-10H) indicative of upper Miocene Subzones CN7b through CN9a, above a barren interval in the same core: top of barren interval in Sample 108-661A-10H-4, 140 cm; Subzone CN7b in Samples 108-661A-10H-4, 45–46 cm, and 108-661A-10H-3, 150–151 cm; Subzone CN8a in Sample 108-661A-10H-3, 130–131 cm; Subzone CN8b in Sample 108-661A-10H-1, 110–111 cm; and Subzone CN9a in Sample 108-661A-10H-1, 70–71 cm. In contrast, all of the overlying core (Core 108-661A-9H) is assigned to Subzone CN9b. *Mnlythisa convalis* was not recorded by Manivit (1989), but it is still reasonable to suggest that the ~5-m-thick upper Miocene section (representing Subzones CN7b through to CN9a) is condensed. Subzone CN9a is particularly thin, and the rate of accumulation for the combined Zone CN8 and Subzone CN9a, is <0.8 per 1 m.y. (using the timescale of Berggren et al., 1995b), suggesting a possible hiatus.

**Correlation with Deep-Sea Hiatuses**

As shown in Figure 3, the middle and late Miocene hiatuses, detected on the Côte d’Ivoire-Ghana marginal ridge, correspond with four described by Keller and Barron (1983, 1987; see also Keller et al., 1987). According to Keller and Barron (1983), these Neogene hiatuses coincided with climatic cooling, sea level falls, and increased carbonate dissolution. Evidence of pronounced carbonate dissolution in the middle and lower upper Miocene section on the ridge have already been noted above, and Figure 3 seems to support a correlation between the hiatuses and falls in sea level. The CN5 hiatus on the crest of the ridge (Site 960) is longer than NH3, but seems to coincide with a period of progressively lowering global sea level, with two major sea level falls (a 55-m drop followed by a 60-m drop). The CN5 hiatus probably began as an erosional event which left rare Eocene nannofossils at Site 960 and terminated with the deposition...
of reworked nannofossils from Zone CN4 and older sediments at the same site. Modern deep-current circulation probably was established by the time of this hiatus. The CN7a hiatus at Site 960, which corresponds well with NH4 of Keller and Barron (1983, 1987), was probably a consequence of the drastic sea level fall (a 125-m drop) that occurred late in Zone CN6 time.

The CN8a hiatus, on different parts of the Côte d’Ivoire-Ghana marginal ridge, neatly fits with the well-documented, widespread NH5 of Keller and Barron (1983, 1987). The erosional intensity of this event, which was probably greater than any other hiatus during the middle and late Miocene (Keller and Barron, 1983), is evident at Site 959 where reworked Cretaceous and Paleocene nannofossils were found in the sediments marking its termination. The CN9a hiatus at Site 960 may have started earlier than the NH6 of Keller and Barron (1983, 1987), but both probably terminated at about the same time. Coincidently with this hiatus is the high-productivity event that temporarily eliminated large Reticolotenestra pseudambulicus from low-latitude areas.

Interestingly, Figure 3 shows that both the CN5 hiatus and CN8a hiatus began at the highs on the sea-level curve and ended at the lows, whereas the CN7a hiatus began at a low on the curve, and ended at a high and the CN9a hiatus began and ended at lows on the sea-level curve.

CONCLUSIONS

An almost complete upper Cenozoic sequence of nannofossil (sub)zones was identified in Hole 959A, with proxies for the rare marker species being employed. Only Subzone CN8a was missing, but this subzone was also missing from other holes on the ridge, indicating a widespread hiatus off the Côte d’Ivoire and Ghana. Three other hiatuses were recognized in the largely condensed middle and upper Miocene section at Site 960. During the oldest of these hiatuses a series of short episodes of increased dissolution of calcareous microfossils and an influx of siliceous fossils at Site 959 ended. The four hiatuses correlate well with other oceanic hiatuses known in the middle and late Miocene stratigraphic record in the Atlantic Ocean.

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APPENDIX

Calcareous Nannofossils Considered in This Chapter

(in alphabetical order of generic epithets)

Neogene and Pleistocene species

*Amauroolithus amplificus* (Bukry and Percival, 1971) Gartner and Bukry, 1975
*Amauroolithus bizzarri* (Bukry, 1973) Gartner and Bukry, 1975
*Amauroolithus delicatus* Gartner and Bukry, 1975
*Amauroolithus primus* (Bukry and Percival, 1971) Gartner and Bukry, 1975
*Amauroolithus tricoronculatus* (Gartner, 1967) Gartner and Bukry, 1975
*Calidicus leptopus* (Murray and Blackman, 1898) Loeblich and Tappan, 1978
*Calidicus mucintrei* (Bukry and Bramlette, 1969) Loeblich and Tappan, 1978
*Catniaster calyculus* Martini and Bramlette, 1969
*Catniaster coelitus* Martini and Bramlette, 1969
*Catniaster mexicanus* Bukry, 1971
*Ceratolithus acutus* Gartner and Bukry, 1974
*Ceratolithus armatus* Müller, 1974
*Ceratolithus armatus/rugosus* (a transitional form between the two species)
*Ceratolithus cristatus* Kamptner, 1950
*Ceratolithus rugosus* Bukry and Bramlette, 1968
*Ceratolithus separatus* Bukry, 1979
*Ceratolithus simplex* Bukry, 1979
*Clausioecus fenestratus* (Deflandre and Fert, 1954) Prins, 1979
*Coccolithus eopelagicus* (Bramlette and Riedel, 1954) Bramlette and Sullivan, 1961
*Coccolithus miopelagicus* Bukry, 1971
*Coccolithus pelagicus* (Wallich, 1877) Schiller, 1930
*Cyclicargolithus abisicus* (Müller, 1970) Wise, 1973
*Cyclicargolithus floridanus* (Roth and Hay in Hay et al., 1967) Bukry, 1971
*Discoaster adamantheus* Bramlette and Wilcoxon, 1967
*Discoaster asymetricus* Gartner, 1969
*Discoaster berggrenii* Bukry, 1971
*Discoaster blackstockae* Bukry, 1973
*Discoaster bollii* Martini and Bramlette, 1969
*Discoaster braarudii* Bukry, 1971
*Discoaster burowi* Tan, 1927 emend. Bramlette and Riedel, 1954
*Discoaster calcitris* Gartner, 1967
*Discoaster challenger* Bramlette and Riedel, 1954
*Discoaster decorus* (Bukry, 1971) Bukry, 1973
*Discoaster deflandrei* Bramlette and Riedel, 1954
*Discoaster dragii* Bramlette and Wilcoxon, 1967
*Discoaster exilis* Martini and Bramlette, 1963
*Discoaster hamatus* Martini and Bramlette, 1963
*Discoaster icarus* Stradner, 1973
*Discoaster intercalaris* Hay in Hay et al., 1967
*Discoaster kugleri* Martini and Bramlette, 1963
*Discoaster loeblichii* Bukry, 1971
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*Discoaster neohamatus* Bukry and Bramlette, 1969
*Discoaster neorheicus* Bukry, 1971
*Discoaster nephodis* Hay in Hay et al., 1967
*Discoaster obilusus* Gartner, 1969
*Discoaster pansus* (Bukry and Percival, 1971) Bukry, 1973
*Discoaster pentaradatus* Tan, 1927 emend. Bramlette and Riedel, 1954
*Discoaster petaliformis* Moskhvitz and Ehrlich, 1980
*Discoaster preterminalis* Bukry and Percival, 1971
*Discoaster pseudovariabilis* Martini and Worsley, 1971
*Discoaster quadramus* Bukry, 1973
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*Discoaster samiquinas* Bukry, 1981
*Discoaster saundersi* Hay in Hay et al., 1967
*Discoaster signus* Bukry, 1971
*Discoaster subsarcolus* Gartner, 1967
*Discoaster surculus* Martini and Bramlette, 1963
*Discoaster talaris* Kamptner, 1967
*Discoaster trivittatus* Ellis, Lohmann, and Wray, 1972
*Discoaster triassicus* Tan, 1927
*Discoaster tristellifer* Bukry, 1976
*Discoaster variabilis* Martini and Bramlette, 1963
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<td>Sphenolithus neobabies Bukry and Bramlette, 1969</td>
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<tr>
<td>Syracosphaera pulcra Lohmann, 1902</td>
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<tr>
<td>Tetrailithoides symeonidesii Theodordis, 1984</td>
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<tr>
<td>Triquetrorhabdulus auritus Stradner and Allram, 1982</td>
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<tr>
<td>Triquetrorhabdulus milowii Bukry, 1971</td>
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<tr>
<td>Triquetrorhabdulus carinatus Martini, 1965</td>
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<tr>
<td>Triquetrorhabdulus farnsworthii Gartner, 1967</td>
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<tr>
<td>Triquetrorhabdulus rugosus Bramlette and Wilcoxon, 1967</td>
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<tr>
<td>Umbilicosphaera irregularis Paasche, 1955</td>
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<tr>
<td>Umbilicosphaera sibogae (Weber-van Bosse, 1901) Gaarder, 1970</td>
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<td>Older species</td>
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<td>Chiasmolithus solitus (Bramlette and Sullivan, 1961)</td>
<td>Locker, 1968</td>
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<tr>
<td>Cruciplacolithus tenax (Stradner, 1961) Hay and Mohler in Hay et al., 1967</td>
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<td>Gartnerago obliquum (Stradner, 1963) Noel, 1970</td>
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<td>Isthmolithus recurvus Deflandre, 1954</td>
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