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9. CENOZOIC CALCAREOUS NANNOFOSSILS FROM THE LESSER ANTILLES FOREARC REGION AND BIOSTRATIGRAPHIC SUMMARY OF LEG 110[1]

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ABSTRACT

During Leg 110 of the Ocean Drilling Program, sediment was recovered from six sites in the vicinity of the Lesser Antilles Forearc. Hole 671B, drilled near the toe of the Barbados deformation front, was the first-ever penetration of the décollement between the underthrusting Atlantic Plate and the offscraped Barbados accretionary prism. Stratigraphic repetitions in sequence associated with tectonic movement along the décollement zone, first observed on DSDP Leg 78A, were further documented at four ODP Leg 110 sites. A significant biostratigraphic inversion is present at Site 671 at 128 mbsf in which upper Miocene sediments rest atop lower Pleistocene strata. Smaller repetitions in sequence are recorded at Sites 671, 673, 674, and 676. Leg 110 sediments range from middle Eocene to early Pleistocene in age. Pliocene/Pleistocene assemblages are generally well preserved; however, Miocene assemblages have undergone extensive dissolution at all Leg 110 sites. Paleogene sediments are sometimes recrystallized and the nannofossils contained within exhibit a range in preservation from poor to good.

INTRODUCTION

Leg 110 originated in Bridgetown, Barbados, on June 26, 1986. The objectives of this Leg were to: (1) study active margin processes in the Lesser Antilles Forearc region and (2) achieve the first-ever penetration of a décollement zone between a descending crustal plate and the offscraped accretionary prism. Experience gained on DSDP Leg 78A, an earlier attempt to accomplish these goals, proved invaluable to the success of the Leg 110 mission. On July 4, 1986, the décollement separating the Barbados accretionary prism and the descending Atlantic Plate was penetrated. Reverse faulting, first recognized in Leg 78A sediments, was further documented at Leg 110 sites. Lower Pleistocene to middle Eocene sediments were recovered on Leg 110. Upper Pleistocene sediments were consistently absent from recovered sections.

Five of the six sites drilled on Leg 110 (671, 673, 674, 675, and 676) probed the deformed sediments of the Barbados accretionary prism (Fig.1) (Mascle, Moore, et al., 1988). Site 672 was drilled on the Atlantic abyssal plain as a stratigraphic reference section for sediments entering the accretionary complex. One reason the Barbados Forearc was chosen for active margin study is because equatorial Atlantic waters are characterized by a depressed calcite compensation depth (CCD), which results in improved biostratigraphic resolution. Nannofossil preservation is generally good for Pliocene/Pleistocene sediments; however, large-scale dissolution was observed in all but the uppermost Miocene assemblages. Dissolution within these sediments may have resulted from upward excursions of the CCD during the Miocene (Berger and von Rad, 1972; Van Andel, 1975). The Paleogene sequence is more deeply buried and subject to increased levels of diagenesis; its quality of preservation ranged from good to poor.

METHODS

Biostratigraphic descriptions of Leg 110 sediments were made from smear slides prepared according to standard techniques proposed by Bramlette and Sullivan (1961) and Hay (1961). One exception to the standard procedure was the use of the mounting medium Loctite so that the slides could be rapidly cured under ultraviolet light. Sediments from each Hole were routinely examined at an interval of one sample per core-section except in obviously barren sediment. Samples were observed through the light microscope at a magnification of 1000×. Both cross-polarized and phase-contrast light were used for species identification.

The relative abundance of individual species was estimated by the methods proposed by Hay (1970). Estimates of species abundance are expressed in the following manner:

V	very abundant	over 10 specimens per field of view
A	abundant	1–10 specimens per field of view
C	common	1 specimen per 2 to 10 fields of view
F	few	1 specimen per 11 to 100 fields of view
R	rare	1 to 2 specimens per slide

Lower case letters are used to represent the individual abundances of reworked species.

The overall abundance of nannofossil taxa in each sample was also estimated. The following scale was used to designate total abundance after Bergen (1984):

A	abundant	Nannofossils comprise over 50% of each slide
C	common	Betweem 10 amd 50% nannofossils
F	few	Between 1 and 10% annofossils
R	rare	Less than 1% nannofossils
B	barren	Slide totally barren of nannofossils

The overall preservation of each sample is evaluated with respect to the following criteria:

G	good	Specimens show little evidence of dissolution or overgrowth
M	moderate	Specimens are etched and show signs of overgrowth. Identification is generally not impaired except in the case of fragile forms which may be removed from the assemblage.
P	poor	Specimens appear highly dissolved and/or overgrown. Species diversity is greatly reduced.

Nannofossil Zonation

Biostratigraphic description of Leg 110 sediments is based on zonation schemes proposed by Okada and Bukry (1980), Bukry (1973, 1975), and Gartner (1977). Eocene through Pliocene sediments are zoned according to the low-latitude scheme of Bukry (1973, 1975) as modified by Okada and Bukry (1980). Pleistocene sediments are zoned using the

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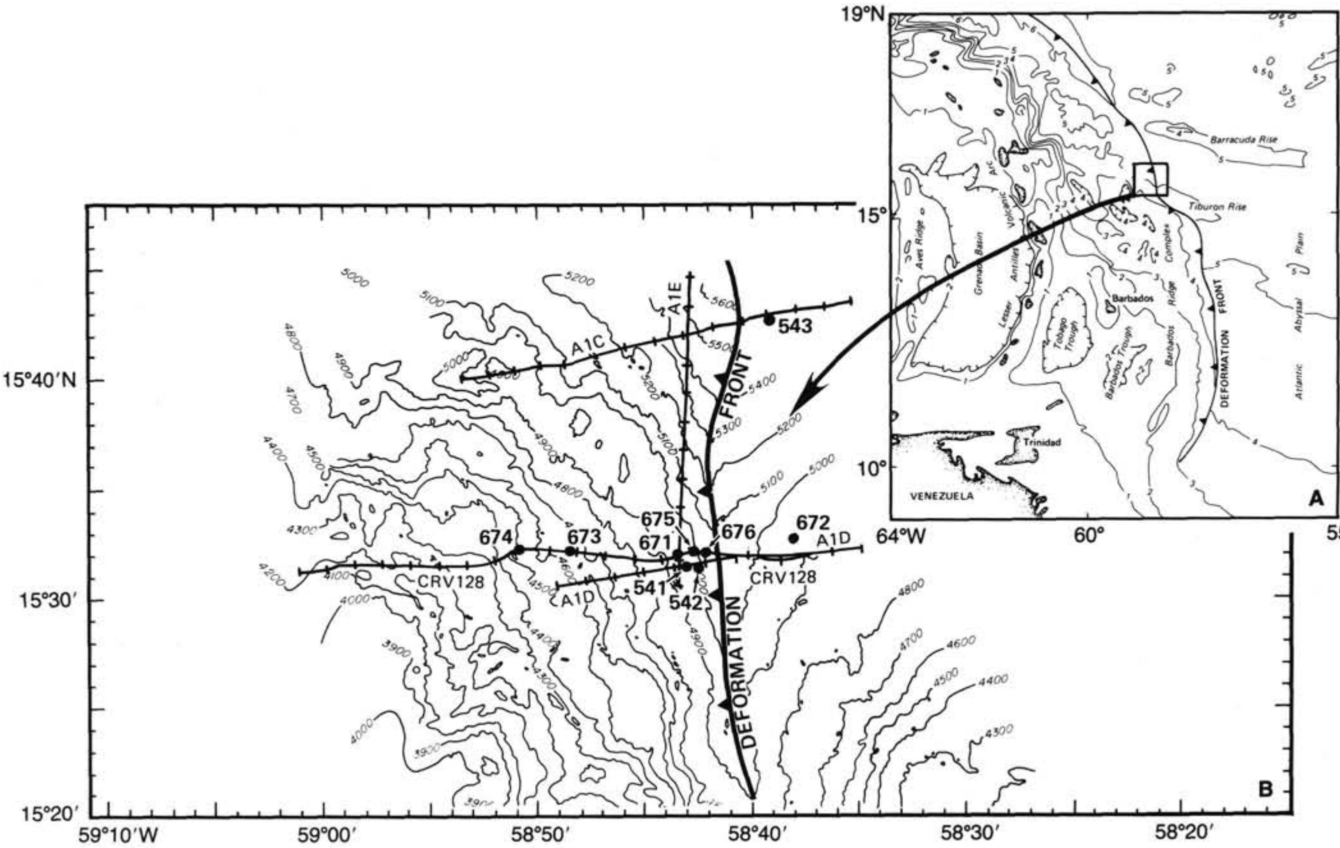

Figure 1. Location map of Leg 110 sites. Bathymetry in meters.

scheme of Gartner (1977) that affords better resolution in the Quaternary portion of the column. These two zonation schemes are easily combined because they both use the last occurrence of *Discoaster brouweri* to mark the Pliocene/Pleistocene boundary.

Emendations to the above zonation scheme are adopted in this report (Fig. 2) that conform more closely to the assemblage preserved at Leg 110 sites. Many of these changes were recommended by Bergen (1984) for samples recovered on Leg 78A.

The Pleistocene zonation of Gartner (1977) utilizes the acme of the small *Gephyrocapsa* species as a datum. Because gephyrocapsid assemblages are often adversely affected by dissolution at Leg 110 sites, this zone could not be consistently recognized and the *Pseudoemiliania lacunosa* Zone of Gartner (1977) is expanded to include this interval.

Refinements within the *Amaurolithus tricorniculatus* Zone of Okada and Bukry (1980) were possible, due to reasonably well-preserved lower Pliocene assemblages recovered from Sites 671 and 672. As suggested by Bergen (1984), the base of *Ceratolithus cristatus* proved to be coincident with the highest occurrence of *C. acutus*. Because *C. cristatus* is common in the section, its base is a useful supplement to this *C. acutus* datum. *C. ruqosus* is not used as a marker in this study because it is rare and easily misidentified when the assemblage is overgrown.

According to the Okada and Bukry zonation (1980), the position of the Miocene/Pliocene boundary is indicated by the last occurrence of *Triquetrorhabdulus ruqosus* and/or the first occurrence of *Ceratolithus acutus*. *Triquetrorhabdulus ruqosus* is consistently found above the base of *Ceratolithus acutus* in the study area and is supplanted by *C. acutus* as the boundary marker in this report. The boundary between Zones CN10 and CN11 is indicated, according to the zonation of Okada and Bukry (1980), by the coincident last occurrence of *Amaurolithus primus* and *A. tricorniculatus*. *A. tricorniculatus* is the more reliable marker and is used alone in this study to divide the lower Pliocene section. Similarly, the last appearance datum (LAD) of *Reticulofenestra pseudoumbilica* is used to distinguish lower from upper Pliocene sediments.

The first occurrences of *Discoaster surculus* and *D. berqqrenii* are used by Okada and Bukry (1980) to indicate the base of the *D. quinqueramus* Zone. The base of *D. surculus* was consistently found to occur above that of *D. berqqrenii* in Leg 110 and Leg 78A sediments (Bergen, 1984). Although the dissimilar first occurrences of these species may be an artifact of dissolution in the Barbados Forearc region, the first occurrence of *D. berqqrenii* has proven more reliable and is used here to designate the base on the *D. quinqueramus* Zone.

The revision of the early-late Oligocene boundary, as suggested by Berggren et al. (1985), will be adopted here. The *Sphenolithus distentus* Zone of Okada and Bukry (1980) is, consequently, reassigned to the early Oligocene.

SITE SUMMARIES

Site 671

Hole 671B, drilled near the toe of the Barbados Ridge complex, achieved penetration of the décollement between the descending Atlantic Plate and the offscraped Barbados accretionary prism. Sedimentological, structural, and geochemical evidence suggests that the décollement occurred between 501 and 510 mbsf (Core 110-671B-55X) within an extensive section of carbonate-poor claystones and mudstones. This interval could not be biostratigraphically zoned due to the absence of calcareous and siliceous microfossils.

Three hundred meters of calcareous mudstone and marlstone were recovered above the décollement interval. Two reverse faults were identified in this interval by means of nannofossil biostratigraphy. The largest of these emplaced an upper Miocene through lower Pleistocene section on top of a sequence spanning approximately the same age. A second fault was observed within this lower sequence, along which sediment from the early Pleistocene *Calcidiscus macintyrei* Zone was interjected into that of the late Pliocene *Discoaster brouweri* Zone.

AGE	ZONE		SUBZONE		DATUM
late Pleistocene	*Emiliania huxleyi acme*				FAD *E. huxleyi acme*
	Emiliania huxleyi				FAD *E. huxleyi*
	Gephyrocapsa oceanica				LAD *P. lacunosa*
early Pleistocene	*Pseudoemiliania lacunosa*				LAD *H. sellii*
	Helicosphaera sellii				LAD *C. macintyrei*
	Calcidiscus macintyrei				LAD *D. brouweri*
late Pliocene	CN12	*Discoaster brouweri*	CN12d	*Calcidiscus macintyrei*	LAD *D. pentaradiatus*
			CN12c	*Discoaster pentaradiatus*	LAD *D. surculus*
			CN12b	*Discoaster surculus*	LAD *D. tamalis*
			CN12a	*Discoaster tamalis*	LAD *R. pseudoumbilica*
early Pliocene	CN11	*Reticulofenestra pseudoumbilica*	CN11b	*Discoaster asymmetricus*	FAD *D. asymmetricus acme*
			CN11a	*Sphenolithus neoabies*	LAD *A. tricorniculatus*
	CN10	*Amaurolithus tricorniculatus*	CN10c	*Ceratolithus rugosus*	LAD *C. acutus* or FAD *C. cristatus*
			CN10b	*Ceratolithus acutus*	FAD *C. acutus*
late Miocene			CN10a	*Triquetrorhabdulus rugosus*	LAD *D. quinqueramus*
	CN 9	*Discoaster quinqueramus*	CN 9b	*Amaurolithus primus*	FAD *A. primus*
			CN 9a	*Discoaster berggrenii*	FAD *D. berggrenii*
	CN 8	*Discoaster neohamatus*	CN 8b	*Discoaster neorectus*	FAD *D. neorectus* or FAD *D. loeblichii*
			CN 8a	*Discoaster bellus*	LAD *D. hamatus*
	CN 7	*Discoaster hamatus*	CN 7b	*Catinaster calyculus*	FAD *C. calyculus*
middle Miocene			CN 7a	*Helicosphaera carteri*	FAD *D. hamatus*
	CN 6	*Catinaster coalitus*			FAD *C. coalitus*
	CN 5	*Discoaster exilis*	CN 5b	*Discoaster kugleri*	FAD *D. kugleri*
			CN 5a	*Coccolithus miopelagicus*	LAD *S. heteromorphus*
	CN 4	*Sphenolithus heteromorphus*			LAD *H. ampliaperta*
	CN 3	*Helicosphaera ampliaperta*			FAD *S. heteromorphus* or LAD *S. belemnos*
early Miocene	CN 2	*Sphenolithus belemnos*			FAD *S. belemnos*
	CN 1	*Triquetrorhabdulus carinatus*	CN 1c	*Discoaster druggii*	FAD *D. druggii*
			CN 1b	*Discoaster deflandrei*	LAD *C. abisectus acme*
late Oligocene			CN 1a	*Cyclicargolithus abisectus*	LAD *S. ciperoensis* or LAD *D. bisectus*
	CP 19	*Sphenolithus ciperoensis*	CP 19b	*Dictyococcites bisectus*	LAD *S. distentus*
			CP 19a	*Cyclicargolithus floridanus*	FAD *S. ciperoensis*
early Oligocene	CP 18	*Sphenolithus distentus*			FAD *S. distentus*
	CP 17	*Sphenolithus predistentus*			LAD *R. umbilica* or LAD *R. hillae*
	CP 16	*Helicosphaera reticulata*	CP 16c	*Reticulofenestra hillae*	LAD *C. formosus*
			CP 16b	*Coccolithus formosus*	LAD *C. subdistichus acme*
			CP 16a	*Coccolithus subdistichus*	LAD *D. barbadiensis* or LAD *D. saipanensis*
late Eocene	CP 15	*Discoaster barbadiensis*	CP 15b	*Isthmolithus recurvus*	FAD *I. recurvus*
			CP 15a	*Chiasmolithus oamaruensis*	LAD *C. grandis*
middle Eocene	CP 14	*Reticulofenestra umbilica*	CP 14b	*Discoaster saipanensis*	LAD *C. solitus*
			CP 14a	*Discoaster bifax*	FAD *R. umbilica*

Figure 2. Nannofossil zonation used in this study modified from Bukry (1973, 1975), Gartner (1977), Okada and Bukry (1980), and Bergen (1984). FAD = first appearance datum and LAD = last appearance datum.

Recovery of a lower to upper Oligocene section below the décollement in Core 110-671B-58X (539.2 mbsf) is biostratigrapic evidence that the descending Atlantic Plate was penetrated. The Oligocene nannofossil sequence is interrupted by many barren intervals that have a large clastic component. These intervals almost certainly correspond with periods of clastic influx from the South American continent. Biostratigraphic zonation of Site 671 sediments is recorded in Table 1 (microfiche, back pocket).

The lower Pleistocene section was observed in Samples 110-671B-lH-1, 88–90 cm, through 110-671B-5H-1, 75–77 cm. Within this interval, the *Pseudoemiliania lacunosa* Zone is recognized in Samples 110-671B-lH-1, 88–90 cm, through -3H-3, 78–80 cm.

The *Helicosphaera sellii* Zone is recognized in Samples 110-671B-3H-4, 78–80 cm, through -4H-2, 80–82 cm. Recognition of this zone is based on the presence of *Helicosphaera sellii* above the highest occurrence of *Calcidiscus macintyrei*. The first downhole occurrence of *Calcidiscus macintyrei* in Sample 110-671B-4H-3, 80–82 cm, indicates the early Pleistocene *Calcidiscus macintyrei* Zone, which extends down through Sample 110-671B-5H-1, 75–77 cm.

The Pliocene/Pleistocene boundary is delineated between Samples 110-671A-5H-1, 75–77 cm, and 110-671B-5H-2, 75–77 cm, by the last occurrence datum of *Discoaster brouweri*. The late Pliocene *D. brouweri* Zone (CN12) is present between Samples 110-671B-5H-2, 75–77 cm, and 110-671B-10H-1, 79–81 cm. Within this interval each of the four subzones proposed by Okada and Bukry (1980) are recognized. The *Calcidiscus macintyrei* Subzone (CN12d) extends from the highest occurrence of *Discoaster brouweri* down to the highest occurrence of *D. pentaradiatus* in Sample 110-671B-6H-2, 80–82 cm. *D. triradiatus* reaches its peak abundance near the middle of this interval. The *D. pentaradiatus* Subzone (CN12c) is recognized from the highest occurrence of *D. pentaradiatus* down to the highest occurrence of *D. surculus* in Sample 110-671B-6H-6, 80–82 cm. The *D. surculus* Subzone (CN12b) is present in Sample 110-671B-6H, 80–82 cm, down through Sample 110-671B-7H-3, 79–81 cm.

The *D. tamalis* Subzone (CN12a) extends from the highest occurrence of *D. tamalis* in Sample 110-671B-7H-3, 79–81 cm, down to the last occurrence of *Reticulofenestra pseudoumbilica* in Sample 110-671B-10H-2, 79–81 cm. A four-rayed discoaster with bifurcate tips occurs within the upper Pliocene section, resembling *D.* tamalis, particularly under conditions of increased dissolution. This form is discussed in detail in the Appendix.

Samples 110-671B-10H-2, 79–81 cm, through 110-671B-11X-6, 79–81 cm, are assigned to the the early Pliocene *Reticulofenestra* pseudoumbilica Zone (CN11). Further subdivision of this zone was not possible because the beginning of the acme of *D. asymmetricus* could not be established.

All three subzones of the *Amaurolithus tricorniculatus* Zone (CN10) are recognized for Samples 110-671B-11X, CC, to -12X, CC. The *Ceratolithus ruqosus* Subzone (CN10c), which coincides at this site with the range of *Amaurolithus tricorniculatus*, is determined for Samples 110-671B-11X, CC, and 110-671B-12X-1, 80–83 cm. The early Pliocene *C. acutus* Subzone (CN10b) is designated by the rare but consistent occurrence of *C. acutus* in Samples 110-671B-12X-2, 80–83 cm, through 110-671B-12X-5, 80–83 cm. Sample 110-671B-12X, CC, is assigned to the late Miocene *Triquetrorhabdulus ruqosus* Subzone (CN10a) because both *Ceratolithus acutus* and *Discoaster* quinqueramus are absent.

Samples 110-671B-13X-1, 80–82 cm, through 110-671B-14X-6, 74–76 cm, are placed within the *Amaurolithus primus* Subzone (CN9b) of the *Discoaster quinqueramus* Zone. The assemblage, although poorly preserved, includes *Discoaster quinqueramus, D. surculus, D. pentaradiatus, D. variabilis, Amaurolithus primus*, and *Reticulofenestra pseudoumbilica*.

Below Sample 110-671B-14X-6, 74–76 cm, a thrust fault is evident and has placed upper Miocene sediment in Core 110-671B-14X atop lower Pleistocene age sediment. Samples 110-671B-14X, CC, through 110-671B-19X-1, 83–85 cm, are assigned to the early Pleistocene *Pseudoemiliania lacunosa* Zone of Gartner (1977). The lower Pleistocene section below the fault is thicker but less complete than the same interval above. In the lower section, the sediment of the *P. lacunosa* Zone appears to rest unconformably on top of that of the *Calcidiscus macintyrei* Zone. The intervening *Helicosphaera sellii* Zone was not identified. The *Calcidiscus* macintyrei Zone is determined for Samples 110-671B-19X, CC, through -23X-CC. A small interval of upper Pliocene sediment (containing *Discoaster brouweri* and *D. triradiatus*) is present within this interval (Samples 110-671B-22X-3, 79–81 cm, through 110-671B-22X-6, 79–81 cm). This assemblage is indicative of the late Pliocene *Calcidiscus macintyrei* Subzone of Okada and Bukry (1980) and was very likely emplaced by additional reverse faulting.

The late Pliocene *Calcidiscus macintyrei* Subzone (CN12d) is again recognized in Samples 110-671B-24X-1, 80–82 cm, through 110-671B-25X-1, 80–82 cm. Between Samples 110-671B-24X-1, 80–82 cm, and 110-671B-29X-3, 80–82 cm, all four late Pliocene subzones of Okada and Bukry (1980) are observed. These subzones are differentiated by the successive downhole highest occurrences of *Discoaster* pentaradiatus in Sample 110-671B-25X-2, 80–82 cm, *D. surculus* in Sample 110-671B-26X-1, 79–81 cm, and *D. tamalis* in Sample 110-671B-27X-1, 80–82 cm.

Samples 110-671B-29X, CC, through -33X, CC, are assigned to the *Reticulofenestra pseudoumbilica* Zone (CN11) of early Pliocene age. The *Discoaster asymmetricus* (CN11b) and *Sphenolithus neoabies* (CN11a) Subzones are readily discernible within this interval. The two subzones are separated by the base of the acme of *D. asymmetricus*, which occurs in Sample 110-671B-30X, CC. Samples 110-671B-31X-1, 80–82 cm, through -33X, CC, contain only rare specimens of *D. asymmetricus*.

Samples 110-671B-34X-1, 79–81 cm, through -37X-CC, are assigned to the *Amaurolithus tricorniculatus* Zone (CN10), which spans the Miocene/Pliocene boundary. All three of the Okada and Bukry (1980) subzones are recognized in this interval. The *Ceratolithus ruqosus* Subzone (CN10c) extends from the highest occurrence of *Amaurolithus tricorniculatus* down through Sample 110-671B-35X-6, 79–81 cm. The presence of *Ceratolithus acutus* in Sample 110-671-35X, CC, separates Subzone CN10c from the *C. acutus* Subzone (CN10b). The base of *C. acutus* in Sample 110-671B-37X-1, 79–81 cm, designates the bottom of the *C. acutus* Subzone, which has been correlated with the Miocene/Pliocene boundary. The *Triquetrorhabdulus ruqosus* Subzone (CN10a) of late Miocene age extends from the base of *C. acutus* down through Sample 110-671B-37X, CC.

Preservation declines sharply in Samples 110-671B-38X-1, 78–81 cm, through -42X, CC, which are assigned to the *Amaurolithus primus* Subzone (CN9b) of the *Discoaster quinqueramus* Zone. This interval contains an assemblage composed largely of discoasters. *D. quinqueramus, D. surculus, D. brouweri, D. variabilis*, and *D. pentaradiatus* are the principal assemblage components along with infrequent specimens of *Amaurolithus primus*. The abundance of placolith species may be selectively reduced by dissolution.

Samples 110-671B-43X-1, 79–81 cm, through -58X-5, 81–83 cm, are largely barren of nannofossils with the exception of two poorly fossiliferous intervals. The first of these occurs between Samples 110-671B-46X-4, 77–80 cm, and -46X, CC. This interval contains an assemblage which is indicative of the *Discoaster berqqrenii* Subzone (CN9a) of the late Miocene *D. quinqueramus* Zone. This assignment is based on the presence of *D. berqqrenii* without any *Amaurolithus primus*. Because *A. primus* is moderately susceptible to dissolution (Bergen, 1984), the absence of this species could be an artifact of sample preservation.

A second fossiliferous interval occurs between Samples 110-671B-47X, CC, and -48X-2, 80–82 cm, and contains rare specimens of *D. hamatus*, whose total range defines the *D. hamatus* Zone (CN7). No subzone designation could be made from the poorly preserved assemblage. *D. bollii* is present within this interval as well as in Sample 110-671B-48X-6, 80–82 cm. The *D. neohamatus* Zone (CN8) is absent from the section.

The late Oligocene *Dictyococcites bisectus* Subzone (CP19b) of the *Sphenolithus ciperoensis* Zone is recognized in Samples 110-671B-58X, CC, through -60X, CC. This portion of the section is punctuated by barren intervals which alternate with well-preserved nannofossiliferous sediment. Common *Sphenolithus ciperoensis* and *Cyclicarqolithus abisectus* occur within the assemblage as well as very abundant *Cyclicarqolithus floridanus*. Because the ranges of *Sphenolithus ciperoensis* and *S. distentus* were not observed to overlap at this site, the *Cyclicarqolithus floridanus* Subzone (CP19a) is assumed to be absent.

Sphenolithus distentus is encountered below the base of *S. ciperoensis* in Sample 110-671B-61X-4, 80–82 cm. The *S. distentus* Zone (CP18) of early Oligocene age is recognized in Samples 110-671B-61X-4, 80–82 cm, through -71X-4, 26–28 cm. This interval has been expanded by the influx of clastic sediment which corresponds with barren portions of the section. Sample 110-671B-71X, CC, contains no *S. distentus* or *Reticulofenestra umbilica* and is, therefore, assigned to the *Sphenolithus predistentus* Zone (CP17).

Samples 110-671B-72X-3, 120–122 cm, through -72X, CC, contain few to rare specimens of *Reticulofenestra umbilica* and rare *Coccolithus formosus*. Although these species define the *Coccolithus formosus* Subzone (CP16b) of the *Helicosphaera reticulata* Zone, the low abundance of these forms is unusual and suggests that alternative zonations for the interval are possible. Cores 110-671B-73X and -74X are barren of nannofossils.

Site 672

Site 672 was drilled on the Atlantic abyssal plain, 6 km east of the Barbados deformation front (Fig 1). This site was selected as a biostratigraphic reference section for Leg 110 holes drilled into the more deformed sediments of the accretionary complex (Table 2, microfiche). One hundred sixty meters of Miocene to lower Pleistocene hemipelagic muds and claystones were recovered in the upper portion of this section. These deposits blanket nearly 340 m of lower Eocene through lower Miocene sediment. This lower portion is characterized by cyclical alternations between terrigenous influx from the South American continent and redeposited sediments from the vicinity of the Tiburon Rise. Because the sequence of clastic and redeposited material is overprinted by intervals of normal hemipelagic sedimentation, a rudimentary zonation of these sediments is possible.

Pliocene/Pleistocene assemblages are well preserved at Site 672 and show little effect from dissolution even at an estimated water depth of greater than 4000 m. This is consistent with estimates for the modern CCD in this region placed at 5200 m by Wright (1984). Conversely, Miocene assemblages appear highly dissolved and may have experienced increased levels of dissolution due to an elevation of the CCD (Berger and von Rad, 1972; Van Andel, 1975). Intervals barren of carbonate within the Miocene section have been identified as lower Miocene by radiolarian assemblages (Mascle, Moore, et al., 1988). Oligocene assemblages are moderately well preserved, although the Oligocene sequence is punctuated by unfossiliferous redeposited sediment layers. Middle to upper Eocene carbonate sediments are highly indurated and yield nannofossil assemblages of poor to moderate quality. Overgrowth and recrystallization of specimens is common in the Eocene section.

Samples 110-672A-lH-1, 71–73 cm, through -4H, CC, belong to the early Pleistocene *Pseudoemiliania lacunosa* Zone. The nominative species occurs within this interval above the highest occurrence of *Helicosphaera sellii*. *Calcidiscus macintyrei* and *Helicosphaera sellii* are first observed downhole in Sample 110-672A-5H-1, 80–82 cm. The coincident highest occurrences of these two species indicates that the *H. sellii* Zone is missing. The *Calcidiscus macintyrei* Zone extends from Sample 110-672A-5H-1, 80–82 cm, through -5H-3, 80–82 cm, based on the presence of *C. macintyrei* above the highest occurrence of *Discoaster brouweri*.

The Pliocene/Pleistocene boundary is indicated by the first downhole occurrence of *D. brouweri* in Sample 110-672A-5H-4, 80–82 cm. The four late Pliocene subzones of Okada and Bukry (1980) are again recognized. This suggests that a complete upper Pliocene section was recovered at Site 672. The highest consistent occurrence of *D. pentaradiatus* in Sample 110-672A-6H-4, 98–100 cm, marks the top of the *D. pentaradiatus* Subzone (CN12c), which extends down through Sample 110-672A-6H-6, 98–100 cm. Rare reworked specimens of *D. pentaradiatus* were noted in the *Calcidiscus macintyrei* Subzone (CN12d) above (Samples 110-672A-5H-4, 80–82 cm, to 110-672A-6H-4, 98–100 cm). The *D. surculus* Subzone (CN12b) is recognized in Samples 110-672A-6H, CC, through -7H-3, 80–82 cm, above the highest occurrence of *D. tamalis*.

D. tamalis is first observed downhole in Sample 110-672A-7H-4, 80–82 cm, where it defines the top of the *D. tamalis* Subzone (CN12a). This is a relatively thick interval (27 m) that extends down through Sample 110-672A-10H-3, 80–82 cm. Four rayed forms similar in appearance to *D. tamalis* (as seen at Site 671) occur in the *Discoaster surculus* Subzone above. The upper boundary of the *D. tamalis* Subzone is conservatively placed and could perhaps have been extended upward had samples been well preserved.

The lower Pliocene section at Site 672 is also complete. The top of the lower Pliocene is marked by the highest occurrence of *Reticulofenestra pseudoumbilica* in Sample 110-672A-10H-4, 80–82 cm. The *R. pseudoumbilica* Zone (CN11), which extends down through Sample 110-672A-12H-1, 82–84 cm, is divided into subzones on the acme of *Discoaster asymmetricus*. A sharp decline in the abundance of *D. asymmetricus* below Sample 110-672A-11H-1, 76–78 cm, serves to separate the *D. asymmetricus* Subzone (CN11b) from the *Sphenolithus abies* Subzone (CN11a).

Samples 110-672A-12H-2, 82–84 cm, through -13H-3, 97–99 cm, are assigned to the *Amaurolithus tricorniculatus* Zone (CN10). The top of this zone is designated by the highest occurrence of *A. tricorniculatus*. Within this interval three subzones are recognized. The *Ceratolithus ruqosus* Subzone (CN10c) is defined by the presence of *Amaurolithus tricorniculatus* above the highest occurrence of *Ceratolithus acutus* in Samples 110-672A-12H-2, 82–84 cm, through 110-672A-12H-5, 82–84 cm. The *C. acutus* Subzone (CN10b) is defined by the range of *C. acutus*. This species is rare but very well preserved in Samples 110-672A-12H-6, 82–84 cm, through 13H-2, 87–89 cm. The base of *Ceratolithus acutus* defines the position of the Miocene/Pliocene boundary.

The *Triquetrorhabdulus ruqosus* Subzone (CN10a) of latest Miocene age is an interval zone between the first occurrence of *Ceratolithus acutus* and the last occurrence of *Discoaster quinqueramus*. These criteria are met in Sample 110-672A-13H-3, 97–99 cm, which alone represents Subzone CN10a of Okada and Bukry (1980).

Discoaster quinqueramus and *Amaurolithus primus* are present in Samples 110-672A-13H-4, 97–99 cm, through -15X-2, 70–72 cm. These species identify the *A. primus* Subzone (CN9b) of the *Discoaster quinqueramus* Zone. Preservation within this interval is poor to moderate and deteriorates rapidly downhole. Samples 110-672A-15X-3, 70–72 cm, through 17X-2, 110–112 cm, are totally barren of nannofossils. The *Discoaster berqqrenii* Subzone (CN9a) is identified in Samples 110-672A-17X-3, 110–112 cm, through -18X-4, 39–41 cm, from a poorly preserved assemblage that contains *D. berggrenii* without *Amaurolithus primus* or *Discoaster quinqueramus*. Most placoliths were absent from the assemblage due to the effects of dissolution.

Samples 110-672A-18X-4, 50–52 cm, and -18X-CC, contain a poorly preserved Miocene assemblage that includes rare specimens of *D. hamatus*. This interval is assigned to the *D. hamatus* Zone (CN7); no subzone designation could be determined from the sparse assemblage. The fact that the *Discoaster neohamatus* Zone (CN8) was not observed at Site 672 may suggest the presence of a hiatus. Below Sample 110-672A-18X, CC, a long interval exists that is barren of calcareous microfossils.

Samples 110-672A-26X-1, 86–88 cm, through -28X, CC, contain a well-preserved late Oligocene assemblage in which common *Sphenolithus ciperoensis* are observed without *S. distentus*. This suggests an age assignment for this interval within the *S. ciperoensis* Zone (CP19b). No sample at this site contains both *S. ciperoensis* and *S. distentus*; therefore, Subzone CP19a is probably missing from the section.

S. distentus first appears downhole in Sample 110-672A-29X-1, 85–87 cm, and is present through a lengthy carbonate section (76 m) interspersed with clastic deposits. As at Site 671 the expanded nature of the *S. distentus* section may be explained by the influx of sediment from the South American coast and from the nearby Tiburon Rise. The base of the early Oligocene *S. distentus* Zone (CP18) is placed directly below Sample 110-672A-37X-1, 67–69 cm. This sample also contains specimens of *Reticulofenestra umbilica* and *Coccolithus formosus* that have been reworked from older deposits.

An interval predominantly barren of nannofossils occurs in Samples 110-672A-37X-2, 67–69 cm, through -38X, CC. These samples separate the *S. distentus* Zone (CP18) and the Eocene deposits at the base of the section. Sample 110-672A-37X-6, 67–69 cm contains a poor assemblage of early Oligocene nannofossils that includes *Reticulofenestra umbilica* without *Sphenolithus distentus*. Due to its poor state of preservation, this sample is tentatively placed within the *Helicosphaera reticulata* Zone (CP16). The *Sphenolithus predistentus* Zone (CN17) was not observed in the section.

Poor to moderately preserved Eocene assemblages are observed in Samples 110-672A-39X-2, 26–28 cm, through -49X-2, 70–72 cm. This section is well indurated and somewhat recrystallized. The *Discoaster barbadiensis* Zone (CP15) occurs in Samples 110-672A-39X-2, 26–28 cm, through -40X-5, 13–15 cm, due to the presence of *D. barbadiensis* and *D. saipanensis* within the interval.

The co-occurrence of *Chiasmolithus qrandis* and *Reticulofenestra umbilica* defines the middle Eocene *Reticulofenestra umbilica* Zone (CN14) in Samples 110-672A-40X-6, 44–46 cm, through -49X-2, 70–72 cm. *Chiasmolithus qrandis* is rare and occurs sporadically throughout the upper portion of this zone due to poor sample preservation and reduced nannofossil abundances. The fairly consistent occurrence of *C. solitus* in Samples 110-672A-44X-3, 59–61 cm, through -49X-2, 70–72 cm, suggests that Subzone CP14a of the *Reticulofenestra umbilica* Zone is present. Subzone CP14b is recognized at this site between the highest occurrence of *Chiasmolithus qrandis* and the highest consistent occurrence of *C. solitus*. The subzone boundary between Subzones CP14a and CP14b is dashed in Table 2 due to the poor sample preservation throughout the middle Eocene interval.

Site 673

Site 673 was drilled in a highly deformed portion of the accretionary prism located 12 km west of the deformation front. The 330 m of sediment recovered at Hole 673B consists of a Miocene sequence of siliceous rich clays overlain by a thin package of Pliocene/Pleistocene carbonates (Table 3, microfiche, back pocket). Nannofossiliferous sediments are confined almost exclusively to Cores 110-673B-lH through -4H.

No upper Pleistocene sediments are observed at this site. Samples 110-673B-lH-1, 80–82 cm, through -3H-4, 80–82 cm, contain *Pseudoemiliania lacunosa* without *Helicosphaera sellii* and are assigned to the early Pleistocene *Pseudoemiliania lacunosa* Zone. This sequence is interrupted by two barren intervals within Core 110-673B-2H.

The *Helicosphaera sellii* Zone, also of early Pleistocene age, was recognized in Samples 110-673B-3H-5, 80–82 cm, through -4H-2, 80–82 cm by the presence of *H. sellii* above the highest occurrence of *Calcidiscus macintyrei*. This zone is absent in the lower repeated sequence at Site 671 perhaps due to the effects of dissolution. The basal Pleistocene section represented by the *Calcidiscus macintyrei* Zone is present in Samples 110-673B-4H-3, 80–82 cm, through -4H-5, 80–82 cm.

The Pliocene/Pleistocene boundary is marked just above Sample 110-673B-4H-6, 80–82 cm, which contains *Discoaster brouweri*. Although the lower Pleistocene section appears continuous, only an incomplete record of the upper Pliocene section was recovered at this site. Samples 110-673B-4H-6, 80–82 cm, through -5H-1, 79–82 cm, are latest Pliocene in age and are placed within the *Calcidiscus macintyrei* Subzone (CN12d) of the *Discoaster brouweri* Zone. Sample 110-673B-5H-2, 79–81 cm, contains *D. tamalis*, *D. surculus*, and *D. pentaradiatus* as important assemblage components and is therefore assigned to the *D. tamalis* Subzone (CN12a). The simultaneous downhole appearance of these species is strongly indicative of missing sections. The *D. fentaradiatus* (CN12c) and *D. surculus* (CN12b) Subzones were not observed in the Site 673 sequence. This interval may have been removed by dissolution or as a result of faulting within the accretionary prism.

Below Sample 110-672A-5H-2, 79–81 cm, sediments are nearly barren of calcareous microfossils. Samples 110-673B-8X-2, 142–144 cm, through -8X-3, 29–31 cm, and -17X-4, 127–130 cm, through -18X-3, 30–32 cm, do, however, contain a moderately well-preserved assemblage of early Miocene nannofossils. The coincident occurrence of *Sphenolithus heteromorphus* and *Helicosphaera ampliaperta* places these samples within the *H. ampliaperta* Zone (CN3).

Radiolarian assemblages indicate an early Miocene age for the interval from Core 110-672A-8X down through -35X. Multiple reversals in radiolarian biostratigraphy define numerous thrust faults in this portion of the section.

Site 674

Hole 674 is located on the lower slope of the Barbados accretionary complex. At this location intensely deformed sediments were recovered that facilitated the study of accretionary deposits arcward of the deformation front. The biostratigraphy at this site is understandably complex (Table 4, microfiche) and is influenced by at least two reverse faults. Barren intervals and missing zones frequently interrupt the biostratigraphic sequence.

Samples 110-674A-lH-1, 68–70 cm, through -2H-2, 86–88 cm, occur within the early Pleistocene *Pseudoemiliania lacunosa* Zone due to the presence of *P. lacunosa* above the highest occurrence of *Helicosphaera sellii*. A long barren interval, presumably of early Pleistocene age, is observed between Samples

110-674A-2H-4, 86–88 cm, and -5X-3, 99–101 cm. Two samples within this interval contain a poor assemblage of nannofossils that could not be reliably zoned. Lower Pleistocene sediments are recognized below the barren interval in Samples 110-674A-5X-4, 99–101 cm, through -6X-2, 80–82 cm. These sediments are assigned to the *Calcidiscus macintyrei* Zone based on the presence of *C. macintyrei* and *Helicosphaera sellii* above the highest consistent occurrence of *Discoaster brouweri*. *Discoaster* species are present in this interval and are almost certainly the result of reworking. The *Helicosphaera sellii* Zone was not detected within the early Pleistocene section at Site 674; this zone was also missing at Site 672.

The highest consistent occurrence of *Discoaster brouweri* designates the top of the Pliocene in Sample 110-674A-6X-3, 80–82 cm. The four subzones of the *D. brouweri* Zone are recognized in the section between Sample 110-674A-6X-3, 80–82 cm, and -7X, CC. This zone is quite thin when compared with the same interval at the other Leg 110 sites. The *Calcidiscus macintyrei* Subzone (CN12d) is recognized down through Sample -6X, CC. Sample 110-674A-7X-1, 78–80 cm, contains *Discoaster pentaradiatus* above the highest occurrence of *D. surculus* and is assigned to the *D. pentaradiatus* Subzone (CN12c). Sample 110-674A-7X-2, 78–80 cm, is assigned to the *D. surculus* Zone (CN12b) due to the presence of the nominative species above the last occurrence of *D. tamalis*. The *D. tamalis* Subzone (CN12a) extends from Sample 110-674A-7X-3, 78–80 cm, down through -7X, CC.

In Sample 110-674A-8X-1, 85–87 cm, the *Discoaster pentaradiatus* Subzone (CN12c) is repeated. Below this the *D. tamalis* Subzone (CN12a) also recurs in the section in Samples 110-674A-12X-1, 70–72 cm through -13X-4, 80–82 cm. These subzones are separated by a barren interval of unknown age. Repetition of these late Pliocene subzones indicates the presence of a reverse thrust fault below Sample 110-674A-7X, CC.

The early Pliocene is represented only by Sample 110-674A-14X-1, 13–15 cm, which is placed within the *Discoaster asymmetricus* Subzone (CN11b) of the *Reticulofenestra pseudoumbilica* Zone. Assignment to the *D. asymmetricus* Subzone is based on the common occurrence of *D. asymmetricus* within the interval. Below this sample a long barren interval persists down to Sample 110-674A-28X-3, 4–7 cm, at which point Eocene sediments are encountered. The intervening barren interval is Miocene in age based on radiolarian biostratigraphy.

Samples 110-674A-28X-3, 4–7 cm, through 31X-2, 107–109 cm, are placed within the *Discoaster bifax* Subzone (CP14a) of the *Reticulofenestra umbilica* Zone, which is middle Eocene in age. *Chiasmolithus qrandis*, *C. solitus*, and *Reticulofenestra umbilica* indicate the above age designation. Preservation is poor to moderate in these samples, and overgrowth of *Chiasmolithus* and *Discoaster* species is common.

Samples 110-674A-31X, CC, through -48X, CC, are barren of nannofossils with the exception of a poorly preserved assemblage observed in Samples 110-674A-33X-2, 50–52 cm, through -674A-33X-3, 68–70 cm. Although the age of these samples appears to be Miocene, exact zonation was not possible. Late Miocene species such as *Discoaster quinqueramus* occur together with early to middle Miocene species such as *Sphenolithus heteromorphus* in Sample 110-674A-33X-2, 50–52 cm. The presence of a Miocene assemblage below Eocene sediments is indicative of additional thrust faulting at this point in the section.

Site 675

Site 675 was drilled on the lower slope of the Barbados Forearc (Fig. 1). After a mudline core was taken, the hole was washed to a depth of 363 mbsf where 67 m of sediment were cored. The mudline core was found to be early Pleistocene in age due to the presence of an assemblage that contained *Calcidiscus macintyrei*, *Helicosphaera sellii*, and *Pseudoemiliania lacunosa* in the core-catcher sample. Cores 110-675A-2X through -8X recovered from the bottom of the hole were barren of calcareous microfossils.

Site 676

Hole 676A was drilled at the toe of the Barbados accretionary wedge, 250 m arcward of the deformation front (Fig. 1). Three hundred ten meters of sediment were cored that ranged from early Pleistocene to middle Miocene in age (Table 5, microfiche). Preservation is moderate to good throughout the Pliocene/Pleistocene section but deteriorates markedly downhole as Miocene sediments become progressively depleted in carbonate.

Reverse faults are recognized within the lower Pleistocene and upper Miocene sections by the repetition of portions of the biostratigraphic sequence. The section appears to be otherwise complete with the exception of a small biostratigraphic gap that occurs near the Miocene/Pliocene boundary.

Samples 110-676A-lH-1, 66–68 cm, through -3H-5, 84–86 cm, are placed within the *Pseudoemiliania lacunosa* Zone of early Pleistocene age. No upper Pleistocene sediments were encountered at this site.

Due to the presence of *Helicosphaera sellii*, the interval between Samples 110-676A-3H-6, 84–86 cm, and -4H-6, 80–82 cm, is assigned to the early Pleistocene *H. sellii* Zone. In Sample 110-676A-4H, CC, through -6H-2, 81–83 cm, *H. sellii* is absent from the assemblage, and repetition of the *Pseudoemiliania lacunosa* Zone is indicated. The recurrence of the *Helicosphaera sellii* Zone in Samples 110-676A-6H-3, 81–83 cm, through -6H, CC, further supports the presence of at least one reverse fault at this point in the section. Large specimens of *Calcidiscus leptoporus* occur within the *Helicosphaera sellii* Zone that are very similar to *C. macintyrei*. *C. macintyrei* is distinguished on the basis of an open central area and a well-developed collar.

Samples 110-676A-7H-1, 80–82 cm, through 7H-6, 80–82 cm, are assigned to the early Pleistocene *Calcidiscus macintyrei* Zone. *C. macintyrei* is common to abundant in this well-preserved section. *Helicosphaera sellii* is present but less abundant than *Calcidiscus macintyrei*.

The Pliocene/Pleistocene boundary occurs between Samples 110-676A-7H-6, 80–82 cm, and 7H-7, 60–62 cm. Infrequent specimens of *Discoaster brouweri* and an increase in the abundance of *D. triradiatus* downhole signal the top of the Pliocene section in Sample 110-676A-7H-7, 60–62 cm. Because Samples 110-676A-7H-7, 60–62 cm, through -9H-1, 80–82 cm, do not consistently contain *D. pentaradiatus*, they are placed within the *Calcidiscus macintyrei* Subzone (CN12d) of the *Discoaster brouweri* Zone. *D. brouweri* is consistently reworked into the Pleistocene sediments of Site 676 as are specimens of *D. pentaradiatus*, *D. surculus*, and *D. variabilis*. *Sphenolithus abies* and *Cyclicarqolithus floridanus* are commonly reworked throughout the section.

Two samples, 110-676A-9H-2, 80–82 cm, and 110-676A-9H-3, 80–82 cm, contain *Discoaster pentaradiatus* without *D. surculus* and are assigned to the *D. pentaradiatus* Subzone (CN12c) of the *D. brouweri* Zone. *D. surculus* occurs in Sample 110-676A-9H-4, 80–82 cm, and designates the top of the *D. surculus* Subzone (CN12b) that extends through Sample 110-676A-10-5, 16–18 cm.

The *Discoaster tamalis* Subzone (CN12a) is recognized in Samples 110-676A-10H-6, 16–18 cm, through -13X-5, 80–82 cm. The top of this interval is defined by the highest consistent occurrence of *D. tamalis* due to the fact that rare specimens of *D. tamalis* are reworked into the *D. surculus* Subzone.

The boundary between the upper and lower Pliocene is indicated by the highest occurrence of *Reticulofenestra pseudoumbilica* in Sample 110-676A-13X-6, 80–82 cm. The *R. pseudoumbilica* Zone (CN11) of early Pliocene age extends from Sample 110-676A-13-6, 80–82 cm, through -15X, CC. The boundary between Subzones CN11a and CN11b is designated by the beginning of the acme of *Discoaster asymmetricus* between Samples 110-676A-13X, CC, and -14X-1, 8–10 cm.

Samples 110-676A-16X-1, 80–82 cm, through -16X, CC, contain *Amaurolithus tricorniculatus* and *Ceratolithus cristatus* without *C. acutus* and are assigned to Subzone CN10c of the *Amaurolithus tricorniculatus* Zone. Subzone CN10b, which is defined by the total range of *Ceratolithus acutus*, was not observed at this site. The absence of *C. acutus* is indicative of missing section at the Miocene/Pliocene boundary. Subzone CN10a is recognized in Sample 110-676A-17X-1, 100–102 cm, by the absence of *C. acutus*, *C. cristatus*, *Amaurolithus tricorniculatus*, and *Discoaster quinqueramus*. Preservation within Zone CN10 is noticeably poorer than in the Pliocene/Pleistocene section above.

Discoaster quinqueramus is well represented in Samples 110-676A-17X-2, 100–102 cm, through -18X-6, 30–32 cm, although preservation of the overall assemblage is poor. This interval is assigned to the *Amaurolithus primus* Subzone (CN9b) of the *Discoaster quinqueramus* Zone due to the co-occurrence of *D. quinqueramus* and *Amaurolithus primus*.

The *Discoaster quinqueramus* Zone contains an interval between Samples 110-676A-18X-7, 30–32 cm, and -20X, CC, that is barren of calcareous microfossils. The *Discosater berqqrenii* Subzone (CN9a) of the *D. quinqueramus* Zone is recognized in Samples 110-676A-21X-1, 50–52 cm, through -21X-3, 50–52 cm, below the barren interval. The CN9a assemblage has undergone selective removal of all but the most dissolution-resistant species. *Discoaster berqqrenii*, *D. brouweri*, *D. pentaradiatus*, and *D. variabilis* are the dominant assemblage components that remain. It is possible that the amauroliths have also been removed from the assemblage by dissolution; however, the presence of this group in dissolved sediments slightly higher in the section indicates otherwise. Very large specimens of *D. braarudii* (20 μm) are outstanding in the interval. In this report *D. braarudii* and *D. brouweri* are combined on range charts because overgrowth and dissolution in many portions of the Leg 110 section does not allow the consistent differentiation of these species.

Samples 110-676A-21-4X, 50–42 cm, through -22X-1, 80–82 cm, contain few nannofossils and were not assigned to a specific zone. Samples 110-676A-22X-2, 80–82 cm, through -22X-5, 80–82 cm, contain a poorly preserved and depauperate assemblage assigned to the *Discoaster neohamatus* Zone (CN8). This zonal designation is based on the common occurrence of *D. neohamatus* in the absence of *D. berqqrenii* and *D. hamatus*. The *D. hamatus* Zone (CN7) is identified in Sample 110-676A-22X, CC, by the presence of *D. neohamatus*, *D. bollii*, and six-rayed specimens of *D. hamatus*. Due to poor sample preservation a more refined zonation of this sample could not be obtained.

The *D. berqqrenii* Subzone (CN9a) is again encountered in the section between Samples 110-676A-23X-7, 80–82 cm, and 24X-5, 80–82 cm. This assemblage occurs below a barren interval between Samples 110-676A-23X-1, 80–82 cm, and 23X-6, 80–82 cm, and is indicative of reverse faulting. Samples 110-676A-24X, CC, through -25X-2, 70–72 cm, are part of the repeated sequence as well, and are assigned to the *D. neohamatus* Zone (CN8) based on the absence of *D. berqqrenii* and *D. hamatus*. This interval is very poorly preserved and most of the easily dissolved assemblage components have been selectively removed.

Below Sample 110-676A-25X-2, 70–72 cm, the section is barren or contains so few specimens that zonation is indeterminate.

CORRELATIONS

Hole 672A was drilled as a reference section for the deformed sediments of the Barbados accretionary prism. A nearly complete section was recovered at this site between the early Pleistocene *Pseudoemiliania lacunosa* Zone down through the late Miocene *Discoaster bergqrenii* Subzone (CN9a) of the *D. quinqueramus* Zone. Only the early Pleistocene *Helicosphaera sellii* Zone was not recognized in the section. This sequence is representative of Neogene sediments at Sites 671, 676, and at Site 541 (recovered on Leg 78A to the Lesser Antilles Forearc region). Although the *H. sellii* Zone was absent from Site 672, as it was in the Pleistocene section at Site 671 below the fault and at Site 674, it is present at Sites 673, 676, 541, and in the Pleistocene section above the fault at Site 671 (Fig. 3). Sites 673 and 674 have undergone intense deformation and contain Pliocene/Pleistocene sediments that exhibit numerous gaps in the biostratigraphic sequence so that comparisons with the reference site are difficult.

Preservation is significantly reduced for Neogene sediments at all Leg 110 sites below the *Discoaster quinqueramus* Zone (CN9). Only the *D. hamatus* Zone (CN7) is recognized at Site 672 between The *D. quinqueramus* Zone (CN9) and the top of the Oligocene section. The *D. neohamatus* (CN8) and *D. hamatus* (CN7) Zones were recognized at Site 676 and the *Helicosphaera ampliaperta* Zone (CN3) was recognized at Site 673 from a middle to lower Miocene sequence otherwise barren of calcareous microfossils. Radiolarians provide more detailed biostratigraphic information at Sites 672, 673, 675, and 676 for this interval (Fig. 3) and establish an early Miocene age for sediments in this highly dissolved portion of the column (Mascle, Moore, et al., 1988).

Oligocene sediments were identified only at Sites 671, 672, and 674. At Site 672 the *Sphenolithus ciperoensis* Zone (CP19), the *S. distentus* Zone (CP18), and the *Helicosphaera reticulata* Zone (CP16), are present. The *Sphenolithus predistentus* Zone (CP17) is not recognized in the Site 672 section but is observed in the more complete Oligocene sequence recovered at Site 671. At both sites the *S. distentus* section is expanded by clastic influx from the South American continent. The *Cyclicarqolithus floridanus* Subzone (CP19a) was not observed at either Site 671 or 672 and may be missing from the section. Oligocene nannofossil zonations are coroborated by planktonic foraminifer ages at Site 672 (Mascle, Moore, et al., 1988). Radiolarian biostratigraphy at Site 674 indicates that early Oligocene-aged sediments were interjected into the sequence in Cores 110-674A-10X, -11X, -28X, -31X to -33X, and -38X to -41X, probably by reverse faulting (Mascle, Moore, et al., 1988).

A middle to upper Eocene sequence occurs at Site 672 that extends from the *Discoaster barbadiensis* Zone (CP15) down through the *Discoaster bifax* Subzone (CP14a) of the *Reticulofenestra umbilica* Zone. A middle Eocene age for this portion of the sequence is supported by planktonic foraminifer biostratigraphy. Middle to early Eocene radiolarian zones are recognized near the base of the hole at Site 672 (Mascle, Moore, et al., 1988). Eocene sediments are also observed from the *Discoaster bifax* Subzone (CP14a) at Site 674. Radiolarian biostratigraphy indicates that discrete intervals of middle to upper Eocene sediment alternate with sediment of Oligocene age in Cores 110-674A-29X through -43X (Mascle, Moore, et al., 1988).

FAULTING

Reverse faulting associated with crustal underthrusting was detected at Sites 671, 674, and 676 through repetition of calcareous nannofossil and planktonic foraminifer zones, and at Sites 673, 674, and 676 through reversals in radiolarian biostratigraphy (Fig. 3) (Mascle, Moore, et al., 1988). The most obvious fault is indicated by calcareous nannofossils and planktonic foraminifers at Site 671, where an upper Miocene through lower Pleistocene sequence occurs atop a section of approximately the same age. In the lower sequence an additional reverse fault is detected through the repetition of the *Calcidiscus macintyrei* Zone.

At Site 674 the *Discoaster tamalis* (CN12a) and the *D. pentaradiatus* (CN12c) Subzones occur twice in the section, which is evidence that at least one reverse fault is present. In Cores 110-674A-10X through -11X, radiolarian Zone 15 of early Oligocene age is detected above late Oligocene Zone R13 \ 14. This reversed sequence is emplaced within an interval of upper Pliocene sediment and may indicate as many as three thrust faults. Two additional thrust faults are indicated by repetition of radiolarian zones in the lower Oligocene through middle Eocene section at the bottom of the hole (Fig. 3) (Mascle, Moore, et al., 1988).

Two reverse faults are detected at Site 676 through the repetition of nannofossil zones that interrupt the upper Miocene through lower Pleistocene sequence. The upper fault is indicated by the repetition of the *Pseudoemiliania lacunosa* Zone and the lower one is detected by the repetition of the *Discoaster quinqueramus* (CN9) through *D. neohamatus* (CN8) Zones. A reverse fault is indicated in the lower Miocene sequence between Cores 110-676A-31X and -32X by the repetition of radiolarian Zones 9 and 10 (Mascle, Moore, et al., 1988).

At Site 673, frequent repetition of radiolarian zones indicates that the lower Miocene sequence (Cores 110-673B-8X through -35X) has been tectonically expanded, probably by reverse faulting (Mascle, Moore, et al., 1988).

CONCLUSIONS

Five of the six sites drilled on Leg 110 explored the deformed sediments of the Barbados Ridge complex. Sites 671, 675, and 676 were drilled at the toe of the accretionary prism whereas Sites 673 and 674 penetrated intensely disturbed sediments upslope from the deformation front. Site 672 investigated the relatively undisturbed sediments of the abyssal plain to document the sedimentary sequence entering the subduction zone. The main objective of this leg was realized at Site 671 when the décollement between the descending Atlantic Plate and the offscraped accretionary prism was penetrated. Conclusive evidence was obtained at four Leg 110 sites for reverse faulting of sediments within the accretionary prism due to tectonic movements along the décollement zone. At Site 671 the most obvious example of reverse thrust faulting emplaced a lower Pleistocene through upper Miocene section above sediments of early Pleistocene age.

Nannofossiliferous sediments were recovered on Leg 110 that ranged in age from middle Eocene to early Pleistocene. Numerous gaps occur in the sedimentary sequence that may be a result of episodes of increased dissolution or of tectonic disturbance. Miocene sediments were particularly affected by dissolution at all Leg 110 Sites. Early to middle Miocene assemblages were rare to absent and all but the uppermost Miocene sediments were represented by intensely etched, low-diversity assemblages. Episodic rises in the Miocene CCD may be responsible for the patterns of preservation observed in these sediments. Although Pliocene/Pleistocene sediments are generally well preserved at Leg 110 sites, no record of late Pleistocene sedimentation was recovered. Paleogene sediments were often recrystallized and ranged in preservation from good to poor.

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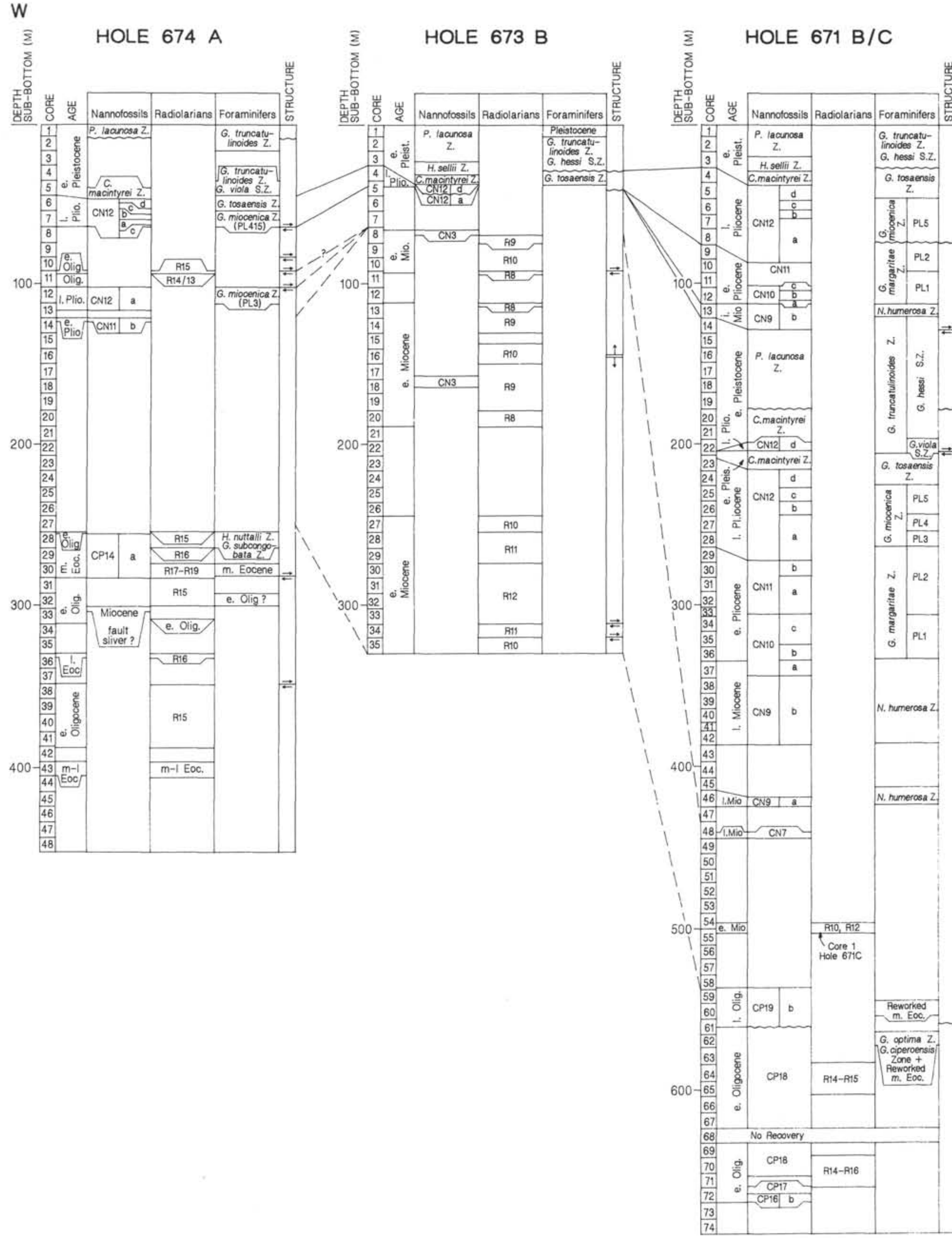

Figure 3. Biostratigraphic summary and correlation of Leg 110 sites. The nannofossil zonation used in this study is modified from Bukry (1973, 1975), Gartner (1977), Okada and Bukry (1980), and Bergen (1984). Radiolarian biostratigraphy is based on the zonation schemes of Riedel and Sanfilippo (1978) and Saunders et al. (1984). Planktonic foraminifer zones employed are those of Berggren (1977) and Bolli and Premoli-Silva (1973).

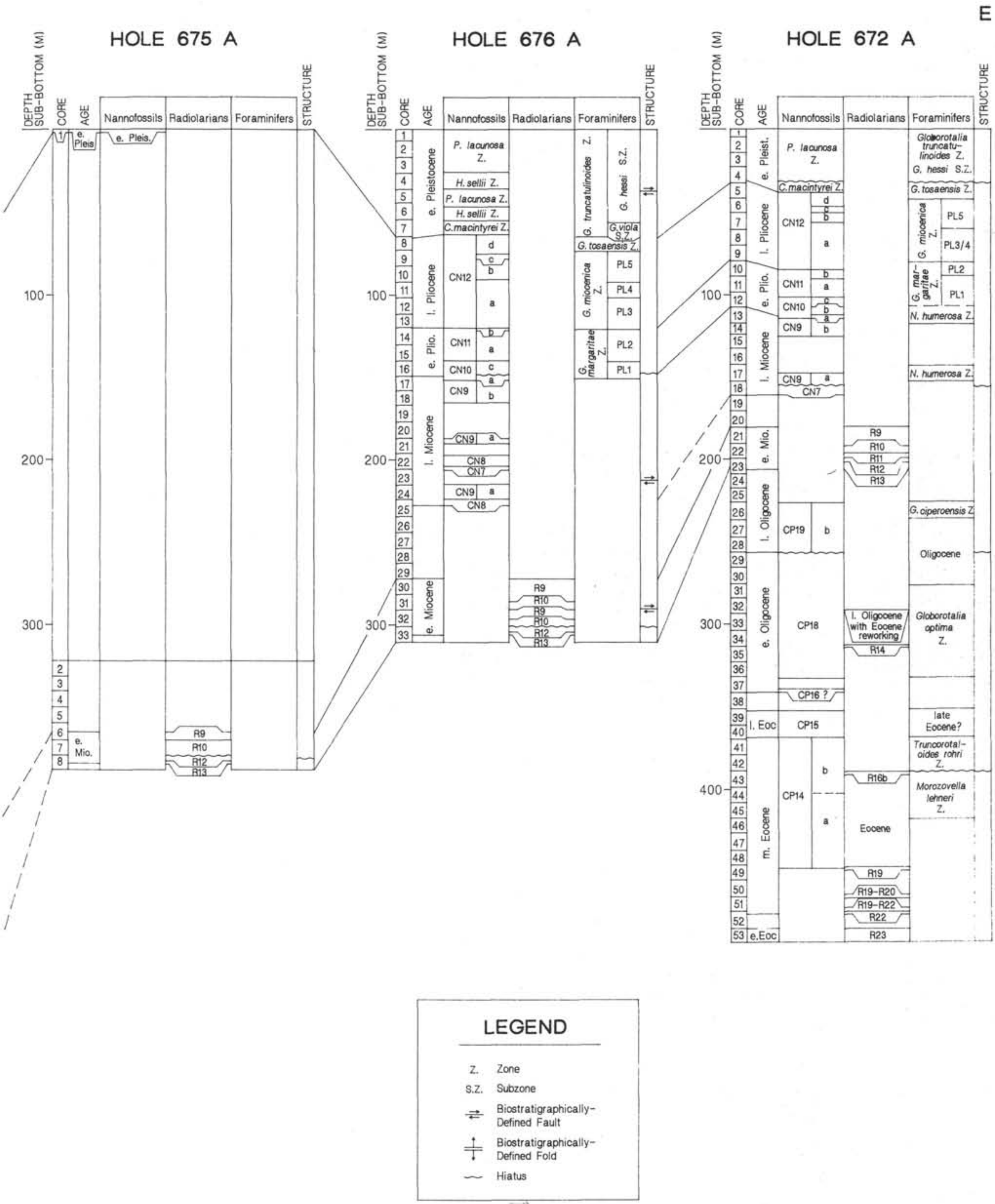

Figure 3 (Continued).

APPENDIX

Calcareous nannofossil species considered in this study are listed below.

Sphenolithus abies Deflandre, 1953
Cyclicarqolithus abisectus (Muller) Bukry, 1973
Ceratolithus acutus, Gartner and Bukry, 1974 *Helicosphaera ampliaperta* Bramlette and Wilcoxon, 1967
Amaurolithus amplificus (Bukry and Percival) Gartner and Bukry, 1975
Ceratolithus armatus Muller, 1974
Discoaster asymmetricus Gartner, 1969
Discoaster barbadiensis Tan Sin Hok, 1927
Discoaster berqqrenii Bukry, 1971
Chiasmolithus bidens (Bramlette and Sullivan) Hay and Mohler, 1967
Braarudosphaera biqelowi (Gran and Braarud) Deflandre, 1947
Zyqrhablithus bijuqatus (Deflandre) Deflandre, 1959
Reticulofenestra bisecta (Hay Mohler and Wade) Roth, 1973
Discoaster bollii Martini and Bramlette, 1963
Discoaster brouweri Tan Sin Hok, 1927
Gephyrocapsa caribbeanica Boudreaux and Hay, 1969
Triquetrorhabdulus carinatus Martini, 1965
Helicosphaera carteri (Wallach) Kamptner, 1954
Discoaster challenqeri Bramlette and Riedel, 1954
Sphenolithus ciperoensis Bramlette and Wilcoxon, 1967
Rhabdosphaera claviqera Murray and Blackmann, 1898
Helicosphaera compacta Bramlette and Wilcoxon, 1967
Ceratolithus cristatus Kamptner, 1950

Discoaster deflandrei Bramlette and Riedel, 1954
Campylosphaera dela (Bramlette and Sullivan) Hay and Mohler, 1967
Amaurolithus delicatus Gartner and Bukry, 1975
Sphenolithus distentus (Martini) Bramlette and Wilcoxon, 1967
Crenalithus doronicoides (Black and Barnes) Roth, 1973
Coccolithus eopelaqicus (Bramlette and Riedel) Bramlette and Sullivan, 1961
Cyclicarqolithus floridanus (Roth and Hay) Bukry, 1971
Micrantholithus flos Deflandre, 1954
Coccolithus formosus (Kamptner) Wise, 1973
Scapholithus fossilis Deflandre, 1954
Gephycapsa sp. small
Chiasmolithus qrandis (Bramlette and Riedel) Radomski, 1968
Discoaster hamatus Martini and Bramlette, 1963
Sphenolithus heteromorphus Deflandre, 1953
Reticulofenestra hillae Bukry and Percival, 1971
Pontosphaera laponica (Takayama) Burns, 1973
Pseudoemiliania lacunosa (Kamptner) Gartner, 1969
Calcidiscus leptoporus (Murray and Blackman) and Loeblich and Tappen, 1978
Calcidiscus macintyrei (Bukry and Bramlette) and Loeblich and Tappen, 1978
Sphenolithus moriformis (Bronnimann and Stradner) Bramlette and Wilcoxon, 1967
Discoaster neohamatus Bukry and Bramlette, 1969
Coronocyclus nitescens (Kamptner) Bramlette and Wilcoxon, 1967
Gephyrocapsa oceanica Kamptner, 1943
Coccolithus pelaqicus (Wallich) Schiller, 1930
Discoaster pentaradiatus Tan Sin Hok, 1927
Hayaster perplexus (Bramlette and Riedel) Bukry, 1973
Pontosphaera spp.
Sphenolithus predistentus Bramlette and Wilcoxon, 1967
Amaurolithus primus (Bukry and Percival) Gartner and Bukry, 1975
Sphenolithus pseudoradians Deflandre, 1952
Reticulofenestra pseudoumbilica (Gartner) Gartner, 1969
Discoaster quinqueramus Gartner, 1969
Cribrocentrum reticulatum (Gartner and Smith) Perch-Nielsen, 1971
Helicosphaera reticulata Bramlette and Wilcoxon, 1967
Ceratolithus ruqosus Bukry and Bramlette, 1968
Triquetrorhabdulus ruqosus Bramlette and Wilcoxon, 1967
Discoaster saipanensis Bramlette and Riedel, 1954
Helicosphaera sellii (Bukry and Bramlette) and Jafar and Martini, 1975
Umbilicosphaera siboqae (Weber-van-Bysse) Gaardner, 1970
Chiasmolithus solitus (Bramlette and Sullivan) Lycker, 1968
Discoaster surculus Martini and Bramlette, 1963
Discoaster tamalis Kamptner, 1967
Thoracosphaera spp. *Amaurolithus tricorniculatus* (Gartner) Gartner and Bukry, 1975
Discoaster tanii Bramlette and Riedel, 1954
Reticulofenestra umbilica (Levin) Martini and Ritzkowski, 1968
Discoaster variabilis Martini and Bramlette, 1963

Taxonomic Notes

Discoaster sp. cf. *D. tamalis*

Description. *Discoaster* sp. cf. *D. tamalis* is a form that has four rays intersecting at right angles with bifurcations at the tips of each ray. No ornamentation is apparent in the central area. This form is easily confused with *D. tamalis* when dissolution has removed the delicate bifurcations. Under conditions of increased dissapation, *D. tamalis* is distinguished by the thicker appearance of its rays.

Occurrence. *Discoaster* sp. cf. *D. tamalis* occurs at Sites 671, 672, and 676 and extends above the range of *D. tamalis* into the *D. surculus* Zone. Under conditions of increased sample dissolution the upper boundary of the *D. tamalis* Zone is obscured by this similar form.