DEPARTMENT OF THE INTERIOR
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Paleogene Stratigraphy of the Solomons Island, Maryland Corehole

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This report is preliminary and has not been reviewed for conformity with U. S. Geological Survey editorial standards or with the North American Stratigraphic Code

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CONTENTS

	Page
Introduction	1
Location and Methods	1
Regional Setting and Stratigraphy	4
Lithologic Units	4
Patapsco Formation	6
Brightseat Formation	7
Aquia Formation	7
Marlboro Clay	8
Nanjemoy Formation	8
Piney Point Formation	9
Biostratigraphic Zonation	9
Patapsco Formation	9
Calcareous Nannofossil Zonal Indicators	10
Brightseat Formation	11
Aquia Formation	13
Marlboro Clay	13
Nanjemoy Formation	13
Piney Point Formation	14
Paleoenvironments	14
Brightseat Formation	16
Aquia Formation	16
Marlboro Clay	16
Nanjemoy Formation	17
Piney Point Formation	17
Acknowledgments	17
References	18
Appendix 1. On-Site Core Description	21
Appendix 2. Calcareous Nannofossil Species Listed in Paper	37

ILLUSTRATIONS

Figure 1. Location map of Solomons Island corehole and other coreholes discussed in text
Figure 2. Gamma ray and single point resistivity logs of Paleogene strata in Solomons Island corehole
Figure 3. Stratigraphic summary of Solomons Island corehole and *tau* values
Figure 4. Calcareous nannofossil occurrence chart

PALEOGENE STRATIGRAPHY OF THE SOLOMONS ISLAND, MARYLAND, COREHOLE

By THOMAS G. GIBSON and LAUREL M. BYBELL

INTRODUCTION

The Solomons Island corehole was drilled in the hope of obtaining a continuous and more nearly complete section of upper Paleocene and lower Eocene strata than are found in the discontinuous and fragmentary sections in the outcrop belt to the west. Consultation with Harry Hansen (Maryland Geological Survey) on possible drilling sites that were within the limits of our equipment and funding led to the selection of Solomons Island. A strong factor in this selection was the stratigraphic information available from the nearby Lexington Park well (Hansen and Wilson, 1984). As anticipated, all Paleogene units previously reported in the Maryland and Virginia Coastal Plain, except for the upper Eocene Chickahominy Formation and the upper Oligocene Old Church Formation, were penetrated at Solomons Island. The upper part of the Solomons Island corehole also penetrated the Calvert Formation of Miocene age and the younger Lowland Deposit. Gibson and Andrews (1994) described the lithology and biostratigraphy of these Miocene sediments. This paper describes the lithologies of the Lower Cretaceous, Paleocene, and Eocene strata that were recovered from the Solomons Island corehole and gives a brief biostratigraphic and paleoenvironmental summary of the beds penetrated there.

LOCATION AND METHODS

Dennis W. Duty, Donald G. Queen, and Cynthia M. Crampsey, of the U.S. Geological Survey (USGS), drilled the Solomons Island corehole between November 7 and November 22, 1986, with Thomas G. Gibson as the on-site geologist. The corehole (USGS Number CA Gd 60) is located on the eastern side of the Calvert Marine Museum grounds at Solomons Island, Maryland, latitude 38°19'49" N, longitude 76° 27'52" W (fig. 1). The corehole had a total depth of 636 ft. The land surface altitude at the drill site is approximately 15 ft, so the bottom of the corehole is at -621 ft. The coring procedure utilized a 10-ft core barrel that was run inside the drill pipe with a wire-line retrieval system. Intervals of no recovery were placed by convention at the bottom of each core run. The core has a diameter of one and 11/16 inches. Roger Starsoneck and Stephen Curtin (USGS) ran gamma ray and resistivity logs of the hole (fig. 2).

Calcareous nannofossil samples were taken from the center of freshly broken core surfaces. Foraminiferal assemblages were examined from approximately 2- to 3-inch-long portions of core from which the outer rind was removed to minimize contamination. The sediment was washed over a 63-μm screen. Foraminiferal assemblages were concentrated by

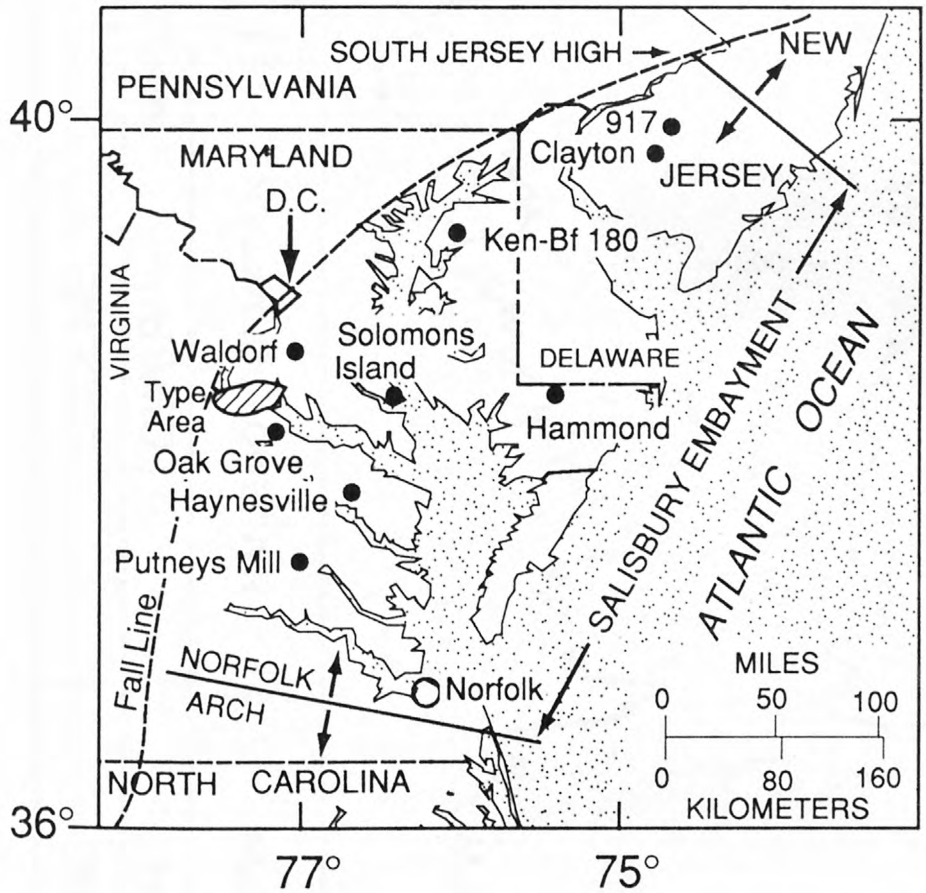

Figure 1. Map of Salisbury embayment showing location of Solomons Island corehole, other coreholes discussed in text, and type area of Aquia and Nanjemoy formations.

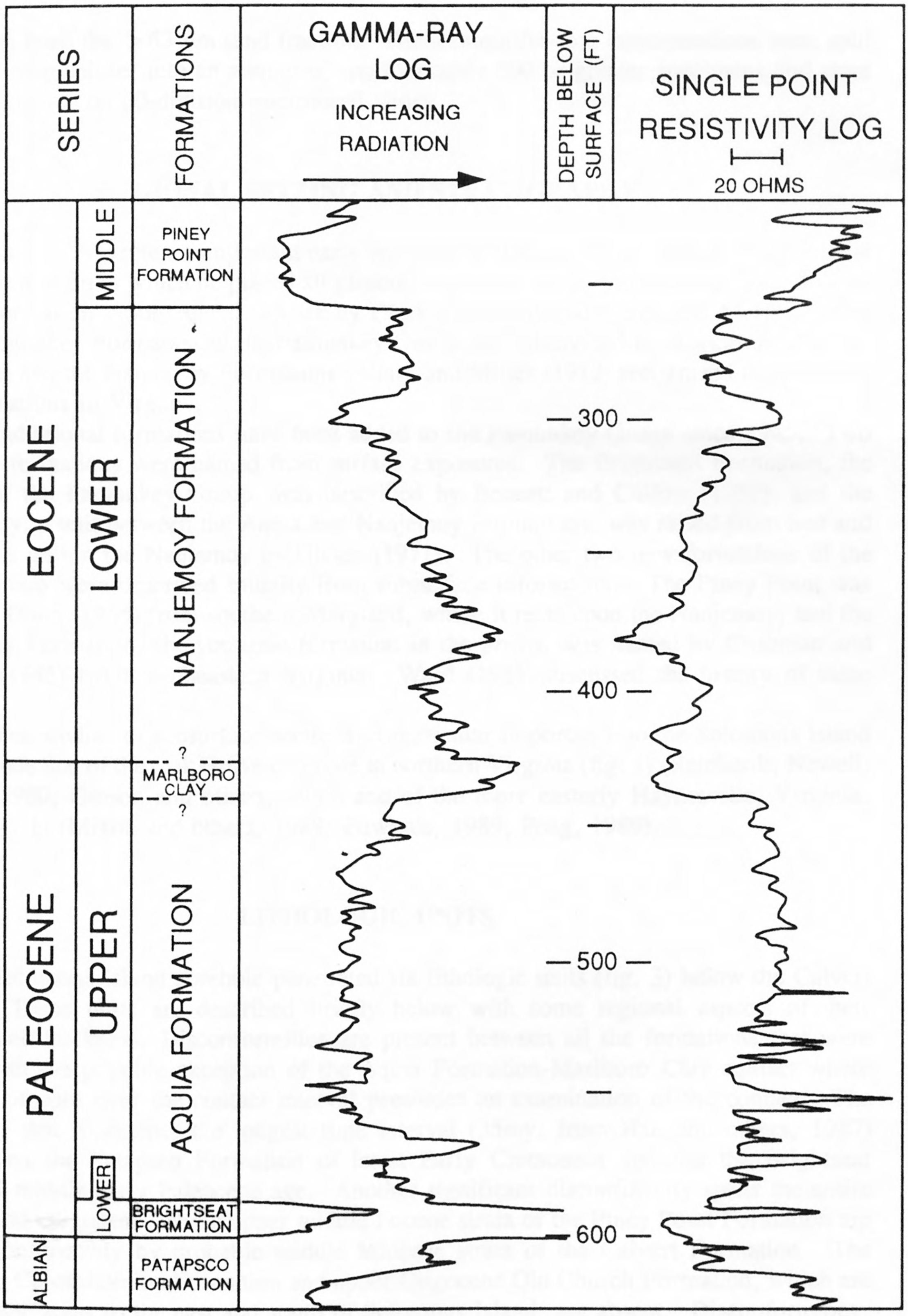

Figure 2. Gamma ray and single point resistivity log of Paleogene and Cretaceous strata in Solomons Island corehole (USGS well CA Gd 60). Altitude of ground surface is 15 ft.

soap flotation from the >63-μm sand fraction. The foraminifer-rich concentrations were split with a small microsplitter into an aliquot of approximately 300 or greater specimens and were picked and mounted on 60-division microfossil slides.

REGIONAL SETTING AND STRATIGRAPHY

Darton (1891) wrote an important early work on the lower Tertiary strata of the middle Atlantic Coastal Plain in which he placed all glauconitic, lower Tertiary strata into an undivided Pamunkey Formation. Subsequent studies by Clark (1896a,b) and Clark and Martin (1901) raised the Pamunkey Formation to the Pamunkey Group and subdivided it, in ascending order, into the Aquia and the Nanjemoy Formations. Clark and Miller (1912) recognized the presence of these formations in Virginia.

Four additional formations have been added to the Pamunkey Group since 1945. Two of these new formations were named from surface exposures. The Brightseat Formation, the oldest unit of the Pamunkey Group, was described by Bennett and Collins (1952), and the Marlboro Clay, a unit between the Aquia and Nanjemoy Formations, was raised from bed and member status within the Nanjemoy by Glaser (1971). The other two new formations of the Pamunkey Group were described initially from subsurface information. The Piney Point was described by Otton (1955) from southern Maryland, where it rests upon the Nanjemoy, and the Chickahominy Formation, the youngest formation in the group, was named by Cushman and Cederstrom (1945) from southeastern Virginia. Ward (1985) discussed the history of these units.

Previous studies of subsurface sections of particular importance to the Solomons Island corehole include that of the Oak Grove corehole in northern Virginia (fig. 1) (Reinhardt, Newell, and Mixon, 1980; Gibson and others, 1980) and of the more easterly Haynesville, Virginia, coreholes (fig. 1) (Mixon and others, 1989; Edwards, 1989; Poag, 1989).

LITHOLOGIC UNITS

The Solomons Island corehole penetrated six lithologic units (fig. 3) below the Calvert Formation. These units are described briefly below with some regional aspects of their distribution and thickness. Disconformities are present between all the formations that were examined, with the possible exception of the Aquia Formation-Marlboro Clay contact where nonrecovery of core over the contact interval precludes an examination of the contact. The disconformity that represents the longest time interval (35my, from Haq and others, 1987) occurs between the Patapsco Formation of latest Early Cretaceous age and the Brightseat Formation of middle early Paleocene age. Another significant disconformity spans the entire late Eocene and Oligocene, where upper middle Eocene strata of the Piney Point Formation are overlain disconformably by probable middle Miocene strata of the Calvert Formation. The upper Eocene Chickahominy Formation and upper Oligocene Old Church Formation, which are present in some areas to the east and south of Solomons Island, are absent. Disconformities

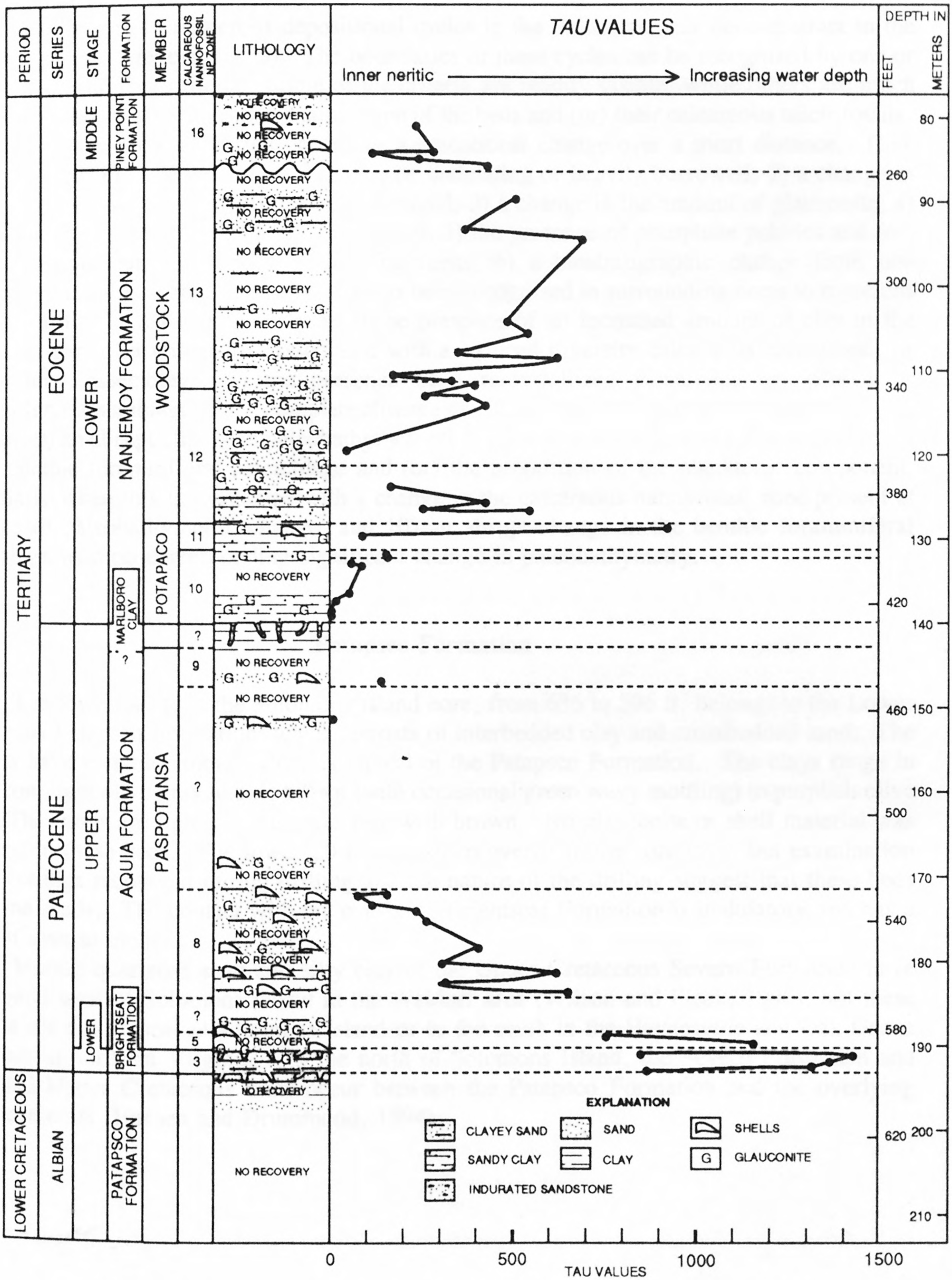

Figure 3. Stratigraphic summary of Solomons Island corehole (USGS well CA Gd 60) and *tau* values. Land surface elevation is 15 ft. Dashed lines represent cycle boundaries.

representing lesser time intervals occur in the middle part of the Paleocene and in the early middle Eocene.

We recognized numerous depositional cycles in the Paleocene and Eocene strata in the Solomons Island corehole (fig. 3). The boundaries of these cycles can be recognized by one or more of the following criteria. Some of the criteria are readily visible, while others are much more subtle and involve a detailed examination of the beds and (or) their calcareous microfossils. The criteria may show an abrupt change or a gradational change over a short distance. They include 1) a readily visible surface that may be undulating or heavily burrowed, 2) a change in lithology that may vary from abrupt to gradational, 3) a change in the amount of glauconite, 4) the presence of coarse sand and (or) fine gravel, 5) the presence of phosphate pebbles and (or) a significant amount of bone or wood fragments, 6) a biostratigraphic change from one calcareous nannofossil zone to another that has been recognized in surrounding areas to represent a disconformity or a flooding surface, 7) the presence of an increased amount of clay in the uppermost part of a unit that is associated with a reduced diversity calcareous nannofossil or foraminiferal assemblage, 8) the presence of a recrystallized calcareous nannofossil or foraminiferal assemblage or the complete absence of either or both groups in the uppermost part of a unit, 9) an abrupt change in paleobathymetry that is indicated by changes in the composition of the benthic foraminiferal assemblage and (or) the proportion of the planktonic component, particularly when this is associated with a change in the calcareous nannofossil zone present at the time of paleobathymetric change, and 10) an abrupt change in the benthic foraminiferal assemblage with no corresponding significant change in paleobathymetry.

Patapsco Formation

The lowest 40 ft of the Solomons Island core, from 636 to 596 ft, belongs to the Lower Cretaceous Patapsco Formation, which consists of interbedded clay and crossbedded sand. The deposits have variable colors, which is typical of the Patapsco Formation. The clays range in color from light olive gray to pale brown (with occasional green wavy mottling) to purplish olive gray. The sands are light olive to pale yellowish brown. No glauconite or shell material was observed in these beds. The lower 20 ft was not recovered in the core runs, but examination of the cuttings recovered during drilling and the nature of the drilling suggest that these beds were fine sands. The contact with the overlying Brightseat Formation is undulatory and has a relief of several inches.

Marine quartzose sand and silty clay of the Upper Cretaceous Severn Formation have been found west of Solomons Island in the Waldorf area (Wilson and Fleck, 1990), but these deposits are not present at Solomons Island or to the south in the Haynesville and Oak Grove coreholes in northern Virginia. To the north of Solomons Island, the Severn Formation and additional Upper Cretaceous units occur between the Patapsco Formation and the overlying Paleogene units (Hansen and Drummond, 1994).

Brightseat Formation

Nine feet of olive-black (*5 Y 2/1*) silty, clayey, very fine sand of the Brightseat Formation of early Paleocene age was penetrated from 596 to 587 ft at Solomons Island. The lower two feet of the Brightseat contain a considerable amount of pyrite, and the pyrite has had a strong diagenetic effect upon the calcareous microfossils in this interval. Foraminiferal assemblages in the lower two feet are highly corroded. Planktonic specimens, which are more highly susceptible to dissolution than benthic specimens, are few in number in the lower two feet and show more test damage than benthic specimens. Calcareous nannofossils are not present in the lowermost foot of the formation. This is the farthest east location that this lower Paleocene unit has been found in southern Maryland. At Solomons Island, the Brightseat has an undulating lower contact with the underlying Patapsco Formation and a burrowed upper contact with the overlying Aquia Formation.

The Brightseat Formation is relatively thin in all known sections across southern Maryland. Measured sections from more upbasin areas show a formation thickness of 5-11 ft in outcrop sections in its type area east of Washington, D.C. (Hazel, 1968), and Wilson and Fleck (1990) reported thicknesses of 15 ft or less for the Brightseat in the Waldorf, Maryland area (fig. 1). The Brightseat Formation is not present in northern Virginia in the Oak Grove (Gibson and others, 1980) or Haynesville (Mixon and others, 1989) coreholes.

Hansen (1992) and Hansen and Drummond (1994) reported considerably thicker lower Paleocene sections (95 ft) in more northerly parts of Maryland in corehole Ken-Bf 180 (fig. 3). They assigned these beds to the Hornerstown Formation, which was named in New Jersey. The only biostratigraphic data presently available for these beds in northern Maryland (planktonic foraminiferal Zone P1a, which equals the lower part of calcareous nannofossil Zone NP 1, according to Haq and others, 1987) indicate an older age for these sediments than the Zone NP 3 age assigned to the Brightseat on the basis of calcareous nannofossils. The precise relationship between the Brightseat Formation of southern Maryland and the upper part of the "Hornerstown" beds of northern Maryland is uncertain at this time (Hansen and Drummond, 1994). Hornerstown beds placed in Zone NP 3, however, are present in southern New Jersey (Laurel M. Bybell, unpub. data).

Aquia Formation

A relatively thick, 149.4-ft-thick section of the Aquia Formation was penetrated from 587 to 437.6 ft. The Aquia is dominantly sand. The lower part is commonly a clayey, fine sand containing some silty, sandy clay intervals. The middle and upper part is somewhat coarser and contains slightly clayey, fine to medium sand. The middle and upper parts of the Aquia belong to the offshore sand bank complex facies that Hansen (1974) proposed for this area of Maryland.

Thin, shelly sandstone beds are common throughout the formation. *Oleneothyris harlani*, a brachiopod typical of the lowest Aquia beds, occurs in the basal part of the formation. Glauconite occurs throughout the formation, varying in abundance from several percent to as much as 50 percent. Goethite grains also are common in the upper part of the formation, where they may compose 10-20 percent of the sand fraction. Quartz grains may be stained green or orange. Shells, particularly thick-shelled clams, are scattered throughout the formation. The

Aquia has a burrowed contact with the underlying Brightseat Formation, and there is uncertainty about the relationship with the overlying Marlboro Clay because of no core recovery in this interval.

In northern Virginia, the Aquia Formation is 118 ft thick in the Haynesville corehole (Mixon and others, 1989), and it has a comparable thickness of 114 ft in the Oak Grove corehole (Gibson and others, 1980). Wilson and Fleck (1990) found thicknesses between 100 and 140 ft for the Aquia in the Waldorf, Maryland area.

Marlboro Clay

The Marlboro Clay, which separates unequivocally Paleocene from unequivocally Eocene strata, lacks diagnostic calcareous nannoplankton and foraminifers in most outcrop and shallow subsurface sections. The Marlboro also has a burrowed upper contact with the overlying Nanjemoy Formation that probably represents a disconformity (Reinhardt, Newell, and Mixon, 1980; Frederiksen and others, 1982; Gibson and others, 1982). At Solomons Island, the Marlboro Clay is 10.6 ft thick, extends from 437.6 to 427 ft, and consists primarily of massively bedded silty clay. Indistinct mottling and very thin silty laminae are common. Glauconite grains are scattered through the clay. The bottom 0.1 ft contains clay interlaminated with moderately glauconitic clay. The Marlboro is olive gray in the upper part and becomes pale yellowish brown at the bottom. The lower contact with the Aquia Formation was not recovered, and it could not be determined whether this contact is rapidly gradational or relatively sharp. The upper contact with the overlying Nanjemoy Formation is highly burrowed.

The areal thickness of the Marlboro is highly variable because of subsequent erosion of these beds before deposition of the overlying Nanjemoy Formation. The Marlboro is only 0.6 ft thick in the Haynesville corehole (Mixon and others, 1989), 18 ft thick in the Oak Grove corehole (Gibson and others, 1980), and 15-30 ft in the Waldorf area (Wilson and Fleck, 1990). In the type area of the Aquia and Nanjemoy Formations along the Potomac River, the formation ranges from 0.5 ft to as much as 30 ft within a few miles (Thomas Gibson, unpub. data).

Nanjemoy Formation

A relatively thick, 161-ft-thick section of the Nanjemoy was penetrated from 427 to 266 ft in the Solomons Island corehole. As in most other areas in northern Virginia and southern Maryland, the Nanjemoy can be separated into a lower, more clayey part, the Potapaco Member, and an upper, less clayey, and more sandy part, the Woodstock Member (Clark and Martin, 1901; Clark and Miller, 1912; Glaser, 1971; Ward, 1985).

The Potapaco beds are dominantly dark-greenish-black to olive-black, sandy, silty clay with some fine sand intervals. Most intervals are highly bioturbated. No molluscan shells were observed. Glauconite is abundant and may constitute most of the sand-sized portion of the sediment.

The greater portion of the Nanjemoy Formation at Solomons Island belongs to the Woodstock Member. Its dominant lithology is grayish-green, clayey, fine to medium sand with some relatively thin sandy clay intervals scattered throughout the member. The amount of glauconite ranges from less than 10 percent to as much as 50 percent. Relatively few shells are present. The beds are highly bioturbated. The upper part of the Nanjemoy contains an unusually coarse clastic component of coarse sand to fine gravel. These coarse grains are subrounded to rounded, are highly polished, and have an amber to brown coating.

The lower contact of the Nanjemoy is a highly burrowed surface into the underlying Marlboro Clay. Burrows filled with Nanjemoy sediments penetrate as deep as 1.8 ft into the Marlboro. Although we had hoped to recover a deeper water, continuous section of the Marlboro and lower part of the Nanjemoy, a disconformity between these formations also is present at Solomons Island. In addition, the basal Nanjemoy beds (those belonging to Zone NP 10) are about the same thickness and appear to represent the same time interval at Solomons Island as they do in the Oak Grove corehole to the west. No demonstrably older Eocene beds were recovered at the base of the Nanjemoy in the Solomons Island corehole. The significantly thicker Nanjemoy section at Solomons Island is due to the presence of beds of Zone NP 13 age at the top of the formation.

In contrast to the 161-ft-thick section of Nanjemoy at Solomons Island, the Nanjemoy is only 123 ft thick in the Oak Grove corehole (Gibson and others, 1980) and 90 feet thick in the Haynesville corehole (Mixon and others, 1989) in northern Virginia. Wilson and Fleck (1990) found similar thicknesses of 90 to 125 feet for the Nanjemoy in the Waldorf area.

Piney Point Formation

Interbedded, fine to medium quartzose sand and calcareous sandstone beds of the Piney Point Formation were 45 ft thick in the Solomons Island corehole, and they extended from 266 to 221 ft. The beds are light olive gray to dusky yellow green and have a bioturbated fabric. Clam shells and molds are abundant. Glauconite varies from 5-20 percent. The lower beds contain amber and brown coarse sand and fine gravel, which is probably reworked from the underlying Nanjemoy. Neither the upper nor the lower contacts of the formation was recovered in the core.

Although the Piney Point is 55 ft thick in the Haynesville corehole (Mixon and others, 1989), it has been erosionally removed from more upbasin areas. The formation is absent both at Oak Grove, Virginia (Gibson and others, 1980) and in the Waldorf, Maryland area (Wilson and Fleck, 1990).

BIOSTRATIGRAPHIC ZONATION

Patapsco Formation

The Patapsco Formation strata did not contain calcareous microfossils. However, pollen was abundant in one sample near the top of this unit and can be used for age determination.

A sample from 606.9 to 606.6 ft contained the following species (Ron Litwin, written commun., 1987): *Acyclomurus sejunctus, Appendicisporites segmentus, Asteropollis asteroides,* *Cicatricosisporites patapscoensis, Cicatricosisporites subrotundus, Cirratriradites spinulosus, Coptospora williamsii, Granulatisporites dailyi, Januasporites spinulosus, Kuylisporites lunaris, Matonisporites excavatus, Monosulcites chaloneri, Neoraistrickia robusta, Perotriletes pannuceus, Retitricolpites georgensis, Rugubivesiculites reductus, Rugubivesiculites rugosus, Stellatopollis barghoornii, Taurocusporites segmentatus, Taurocusporites spackmanii, Tricolpites minutus, Trilobosporites perverulentus*, and *Triporoletes involucratus*.

The co-occurrence of these species suggests a middle to late Albian age for the sample, which is most similar to Brenner's (1963) assemblages from Zone II [Subzone B-2] of the Patapsco Formation of the upper Potomac Group. The highest datable Patapsco Formation sample from the Oak Grove core also belongs to Zone II [Subzone B-2] (Reinhardt, Christopher, and Owens, 1980).

Calcareous Nannofossil Zonal Indicators

The biostratigraphic zonation of the Paleogene strata is based primarily upon the calcareous nannofossil zonation of Martini (1971) and secondarily upon the zonation of Bukry (1973, 1978). The calcareous nannofossil assemblages usually are sufficient in numbers of specimens, diversity of taxa, and preservational state in the Solomons corehole strata to allow dating of almost all samples (fig. 4). This contrasts with the planktonic foraminifers that occur only in small numbers in many samples, have a limited species diversity, and commonly lack the more diagnostic marker species. Deposition of these strata in shallow-marine environments is assumed to be the reason for limited planktonic foraminiferal occurrences. Planktonic foraminifera were the only fossil group used to date the Haynesville, Virginia, corehole (Mixon and others, 1989; Poag, 1989), and the resulting incomplete zonation of the strata makes detailed correlations with the Haynesville core difficult.

The following species were used to date the sediments in the core. FAD indicates a first appearance datum, and LAD indicates a last appearance datum. Zonal markers for the Martini zonation are indicated with an *, and a # indicates a zonal marker for the Bukry zonation. The remaining species are biostratigraphically useful in the Gulf and Atlantic Coastal Plains.

LAD **#Chiasmolithus solitus* - top of Zone NP 16, middle Eocene
FAD *Pemma papillatum* - within Zone NP 16, middle Eocene
LAD **Rhabdosphaera gladius* - top of Zone NP 15, middle Eocene
FAD *Pentaster lisbonensis* - within Zone NP 15, middle Eocene
FAD **#Nannotetrina fulgens* - base of Zone NP 15, base CP 13a, middle Eocene
FAD **#Discoaster sublodoensis* - base of Zone NP 14, base CP 12a, early Eocene
FAD *Reticulofenestra* spp. - within Zone NP 13, early Eocene
LAD **Rhomboaster orthostylus* - top of Zone NP 12, early Eocene
FAD *Helicosphaera lophota* - near top of Zone NP 12; has been used to approximate the NP 12/NP 13 boundary, early Eocene
FAD *Helicosphaera seminulum* - mid Zone NP 12, early Eocene
FAD **#Discoaster lodoensis* - base of Zone NP 12, base CP 10, early Eocene
FAD *Discoaster binodosus* - within Zone NP 11, early Eocene

LAD *#*Rhomboaster contortus* - top of Zone NP 10, top CP 9a, early Eocene
FAD *Rhomboaster orthostylus* - upper Zone NP 10, early Eocene
FAD #*Rhomboaster contortus* - mid Zone NP 10, base CP 9a, early Eocene; Bukry places the base of the CP 9a Zone at the base of Martini's Zone NP 10, but this is much too low according to Bybell and Self-Trail (1995) and Perch-Nielsen (1985)
FAD #*Discoaster diastypus* - mid-Zone NP 10, base CP 9a, early Eocene
LAD *Placozygus sigmoides* - lower Zone NP 10, early Eocene
LAD *Fasciculithus tympaniformis* - lower Zone NP 10, early Eocene
LAD *Hornibrookina* spp. - lower Zone NP 10, early Eocene
FAD **Rhomboaster bramlettei* - base of Zone NP 10, early Eocene
FAD *Transversopontis pulcher* sensu ampl. - upper Zone NP 9, late Paleocene
LAD *Scapholithus apertus* - upper Zone NP 9, late Paleocene
FAD *Discoaster mediosus* - within Zone NP 9, late Paleocene
FAD *Toweius occultatus* - within Zone NP 9, late Paleocene
FAD *Toweius callosus* - within Zone NP 9, late Paleocene
FAD *Lophodolithus nascens* - within Zone NP 9, late Paleocene
FAD #*Campylosphaera dela* - within Zone NP 9, base CP 8b, late Paleocene (includes *C. eodela*)
FAD *#*Discoaster multiradiatus* - base of Zone NP 9, base CP 8a, late Paleocene
FAD **Heliolithus riedelii* - base of Zone NP 8, late Paleocene
FAD #*Discoaster mohleri* - base CP 6, approximately equivalent to base of Martini's Zone NP 7, late Paleocene
FAD *Scapholithus apertus* - within Zone NP 5, late Paleocene
FAD *Toweius eminens* var. *tovae* - within Zone NP 5, late Paleocene
FAD *#*Fasciculithus tympaniformis* - base of Zone NP 5, base CP 4, late Paleocene
FAD *Toweius pertusus* - within Zone NP 4
FAD *Ellipsolithus distichus* - near base of Zone NP 4, early Paleocene
FAD **Ellipsolithus macellus* - base of Zone NP 4, early Paleocene
FAD **Chiasmolithus danicus* - base of Zone NP 3, early Paleocene

Brightseat Formation - early Paleocene, Zone NP 3

Six samples were examined from the Brightseat Formation from 595.6 ft to 588 ft. The bottom sample was barren of calcareous nannofossils, but all five upper samples contained good assemblages (fig. 4). The FAD (first appearance datum) of *Chiasmolithus danicus* marks the base of Zone NP 3 in the zonation of Martini (1971). *Chiasmolithus danicus* is present in all five Brightseat Formation samples. *Ellipsolithus macellus*, the FAD of which marks the base of Zone NP 4, is absent from these samples. Therefore, the presence of *C. danicus* and the absence of *E. macellus* indicate placement within Zone NP 3 for the Brightseat Formation in the Solomons Island core. Elsewhere in Maryland, the Brightseat Formation also is placed within Zone NP 3.

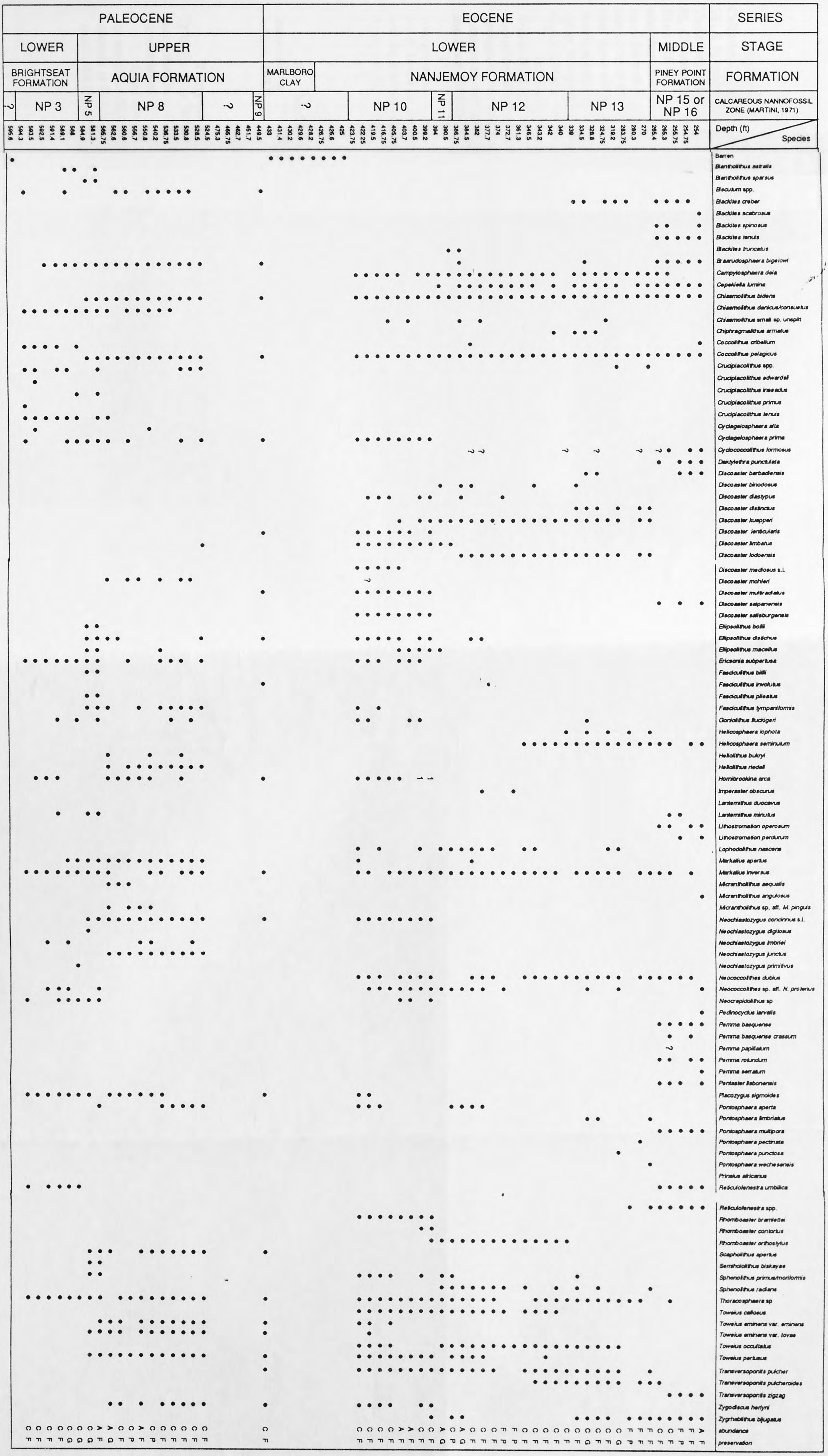

Figure 4. Distribution of calcareous nannofossil species in Solomons Island samples.
Abundance: A=abundant; C=common; F=few.
Preservation: G=good; F=fair; P=poor.

Aquia Formation - upper Paleocene, Zones NP 5, 8, and 9

Eighteen samples were examined from the Aquia Formation from 584.9 ft to 449.5 ft. Calcareous nannofossils were present in all samples. Lower Aquia samples from 584.9 ft and 581.3 ft, which are from beds that contain *Oleneothyris harlani*, are placed in Zone NP 5. These two samples contain *Fasciculithus tympaniformis* (its FAD defines the base of Zone NP 5), *Chiasmolithus bidens*, *Scapholithus apertus*, *Toweius eminens* var. *eminens* (FAD's within Zone NP 5), *Ellipsolithus macellus* (FAD defines the base of Zone NP 4), *Ellipsolithus distichus*, and *Toweius pertusus* (FAD's within Zone NP 4). The presence of *Ellipsolithus macellus* and *E. distichus* in the Solomons Island core in Zone NP 5 indicates that this genus does exist in Maryland in the Paleocene. If the Brightseat Formation were in Zone NP 4 rather than Zone NP 3, one would expect the genus *Ellipsolithus* to also be present in these samples. It thus appears that these species are absent from the Brightseat samples for evolutionary reasons rather than preservational or ecologic reasons. Zone NP 4, which is missing in the Solomons Island corehole, is also missing through most of Virginia and Maryland.

Ten Aquia samples from 565.75 ft to 528.5 ft are placed in Zone NP 8. *Heliolithus riedelii* (FAD defines the base of Zone NP 8) first appears at 565.75 ft and occurs sporadically throughout this interval. *Discoaster mohleri* (FAD near the base of Zone NP 7) also occurs throughout this interval. Zones NP 6 and NP 7 either are missing in the Solomons Island corehole or they are in the thin unrecovered interval (581.3-565.75 ft) between the Zone NP 5 and Zone NP 8 beds.

Five samples from 524.5 ft to 451.7 ft were contaminated with a significant amount of younger-aged material and could not be dated. One sample from 449.5 ft was placed in Zone NP 9, based on the presence of *Discoaster multiradiatus* (FAD defines the base of Zone NP 9) and the absence of members of the genus *Rhomboaster* (was *Tribrachiatus*, see Bybell and Self-Trail, 1995), which first appears at the base of the Eocene in Zone NP 10.

Marlboro Clay

Five Marlboro Clay samples were examined, and all were barren of calcareous nannofossils. The Marlboro may be of latest Paleocene or earliest Eocene age (Frederiksen and others, 1982).

Nanjemoy Formation - early Eocene, Zones NP 10-13

Thirty-one samples were examined from the Nanjemoy Formation between 426.75 ft and 270 ft. The bottom two samples from 426.75 ft and 426.6 ft are barren of calcareous nannofossils. The remaining samples contain fairly abundant calcareous nannofossil assemblages.

Eight samples from 423.75 ft to 399.2 ft can be placed in Zone NP 10 by the presence of the genus *Rhomboaster*. *Rhomboaster bramlettei* (FAD marks the base of Zone NP 10) first appears at 423.75 ft and continues throughout the interval, while *Rhomboaster contortus* (LAD marks the top of Zone NP 10) occurs in the upper two samples in this interval. *Rhomboaster* *orthostylus* (FAD in the upper part of Zone NP 10) first appears in the uppermost sample in this Zone NP 10 interval.

Two samples from 394 ft and 390.5 ft are placed in Zone NP 11 by the presence of *Discoaster binodosus* (FAD in Zone NP 11) and the absence of *Rhomboaster contortus* and *Discoaster lodoensis* (FAD marks the base of Zone NP 12).

Eleven samples from 386.75 ft to 340 ft were placed in Zone NP 12 by the presence of *Discoaster lodoensis* throughout this interval. *Helicosphaera seminulum* (FAD within Zone NP 12) also first appears in this interval. *Rhomboaster orthostylus* (LAD marks the top of Zone NP 12) last appears at 340 ft, and thus defines the top of Zone NP 12.

Eight samples from 339 ft to 270 ft were placed in Zone NP 13 by the absence of *R. orthostylus* and the presence of *Helicosphaera lophota* (FAD just below the base of Zone NP 13).

Piney Point Formation - middle Eocene, upper Zone NP 15 or lower Zone NP 16

Calcareous nannofossils were present in all five samples that were examined from the Piney Point Formation from 265.4 ft to 254 ft. There are several species that are known to appear either in the uppermost part of Zone NP 14 or the lowermost part of Zone NP 15. These include *Lanternithus minutus* and *Daktylethra punctulata*, which both occur within the Piney Point Formation in the Solomons Island core. *Pentaster lisbonensis*, which occurs through this interval, first appears in the upper part of Zone NP 15. It is very difficult to determine the Zone NP 15/16 boundary because the defining species, *Rhabdosphaera gladius* (LAD defines the top of Zone NP 15) often is missing. *Reticulofenestra umbilica*, using a definition that includes specimens larger than 12 microns, first occurs either in the upper part of Zone NP 15 or the lower part of Zone NP 16. Large specimens of this species first appear in the base of the Piney Point. *Cribrocentrum reticulatum* and *Pemma papillatum* (FAD's within Zone NP 16) were not observed in the Piney Point Formation. Therefore, it appears to be most likely that the Piney Point Formation in the Solomons Island core is in either uppermost Zone NP 15 and (or) lowermost Zone NP 16, and all of Zone NP 14 and the lower part of Zone NP 15 are missing. In Virginia, the Piney Point can be placed in Zones NP 16 and NP 17 (Bybell and Gibson, 1994).

PALEOENVIRONMENTS

Most of the information used in paleoenvironmental interpretations of Solomons Island corehole strata is gained from the foraminiferal assemblages that occur abundantly in most cored intervals. The primary parameters used to evaluate the foraminiferal assemblages include the species diversity of the benthic component and the relative abundances of planktonic and benthonic specimens. In addition, particular genera and species have been shown to have environmental limits in terms of paleobathymetry, salinity, temperature, and other complexes of environmental parameters. These taxa will be noted where appropriate.

A generalized paleobathymetric history of the Paleogene formations in the Solomons Island corehole is constructed from the foraminiferal assemblages. The paleobathymetric trends are shown (fig. 3) by the use of the *tau* index (Gibson, 1988). *Tau* values are the mathematical product of the number of benthic foraminiferal species times the percentage of planktonic specimens in the total foraminiferal assemblage in a sample.

Buzas and Gibson (1969) and Gibson and Buzas (1973) showed that although the number of benthic species exhibits a general increase from inner neritic depths into abyssal depths along the U.S. Atlantic margin, the increase is not necessarily a continually progressive one. The number of species in a sample generally increases from inner neritic to outer neritic depths, but the number of species in samples from the upper continental slope may be lower than those found on outer parts of the shelf. An increase in the number of species begins again on the middle and lower parts of the slope, and this increase continues into abyssal regions. This pattern places limits on the use of the number of species for interpretation of slope paleoenvironments.

The planktonic proportion of the foraminiferal assemblage, however, generally continues to increase across the shelf and through upper and middle slope environments (Grimsdale and Van Morkhoven, 1955; Gibson, 1989). Gibson (1988) proposed the index *tau*, which is the product of the number of benthic species times the percentage of planktonic specimens in the total foraminiferal assemblage of a sample. The values of this index increase across the shelf, down the slope, and into abyssal regions. Gibson (1988, fig. 11) showed that Parker's (1954) data from the northeastern Gulf of Mexico region gives *tau* values of 1-100 in waters less than 130 ft deep. The *tau* values continue a general increase with increasing depth and reach 10,000 in water depths around 3,000 ft. There is no exact correlation between any particular *tau* value and a particular water depth, but various depth interval categories and paleobathymetric trends can be recognized. The *tau* values also may vary between different sedimentary basins because of particular environmental conditions, but the plotting of *tau* values through a section in a single sedimentary basin normally follows the paleobathymetric trends (fig. 3).

Because the species, as well as genera, composing the foraminiferal assemblages vary both in their proportions and in their presence or absence with changes in bathymetry and other environmental complexes, the taxonomic composition of the assemblages is an additional valuable tool for the interpretation of the paleoenvironmental changes. Van Morkhoven and others (1986), Olsson and Wise (1987), and Poag (1989) discussed the paleoenvironmental significance of Paleocene and Eocene taxa, many of which occur in the Solomons Island deposits. Gibson is preparing a much more extensive paleontologic manuscript that contains detailed lists and illustrations of the foraminiferal taxa from the Paleogene formations in the Solomons Island corehole and discussions of their paleoenvironmental significance.

Brightseat Formation

The Brightseat sediments were deposited in the deepest marine waters of any Cenozoic unit in Maryland. This time of deep water agrees well with the sea-level curves of Haq and others (1987), who showed higher sea levels in the middle early Paleocene than at any other time during the Cenozoic. Diverse benthic assemblages and abundant planktonic specimens are present in the samples. The benthic assemblages are dominated by *Gavelinella* spp. and *Gyroidinoides* spp., and they contain abundant *Tappanina selmensis*. The *tau* values approach 1500, which suggest middle to outer neritic environments with water depths of 300-400 ft.

Aquia Formation

Inner middle to middle neritic faunas, containing moderately high species diversities and moderate to abundant planktonic specimens, are characteristic of the lower part of the Aquia Formation. In sandier sediments in the middle and upper parts of the formation, the species diversities are lower, and there are relatively few planktonic specimens. The foraminiferal assemblages in the upper beds suggest deposition in inner neritic depths of less than 100 ft, in contrast to assemblages in the lowermost beds that suggest depths approaching 300 ft.

Marlboro Clay

No calcareous microfossils were found in the Marlboro beds at Solomons Island. Previously, Gibson and others (1980) considered that the Marlboro Formation in the Oak Grove corehole had been deposited in brackish or estuarine environments of less than normal salinity. This interpretation was based upon the presence in the Marlboro of a low-diversity, agglutinated foraminiferal assemblage, a low-diversity dinoflagellate assemblage, and freshwater algae.

Recently, we have found several Marlboro samples that contain calcareous foraminifers in the Waldorf, Maryland, and Putneys Mill, Virginia, cores (fig. 1) (Gibson and Bybell, in press). The foraminiferal assemblages in these samples suggest that the Marlboro Clay was deposited in middle shelf environments during a period of unusual climatic and hydrographic conditions similar to those documented by Gibson and others (1993) in coeval deposits of the Manasquan Formation in New Jersey. The benthic foraminiferal assemblages in both the Marlboro and Manasquan Formations suggest low-oxygen bottom conditions. These conditions may have influenced either the preservation of calcareous specimens or the suitability of the environment for the existence of calcareous specimens.

Nanjemoy Formation

The Nanjemoy contains several depositional sequences. The relatively low benthic diversity and few planktonics found in the lowest clayey interval suggest that it was deposited in inner neritic environments of less than 100 ft in depth. The dominance of these benthic assemblages by ***Buliminella virginiana, Epistominella minuta***, and *Pulsiphonina prima* indicates that the bottom waters had low-oxygen levels and that environmental conditions were similar to those found in coeval beds in New Jersey (Gibson and others, 1993).

Most of the overlying Nanjemoy sequences were deposited in inner to middle neritic environments with water depths varying from 60 to 300 ft. The deepest water deposits are represented in the sequence of Zone NP 11 clays that contain assemblages with high benthic species diversity and abundant planktonic specimens. The deepest water deposits in the Nanjemoy Formation in the Oak Grove (Gibson and Bybell, in press) and Putneys Mill (Bybell and Gibson, 1994) cores also occurred during this time, and this period represented a high sea-level stand across the central and southern Salisbury embayment.

Piney Point Formation

The Piney Point contains a diverse benthic assemblage and a small to moderate assemblage of planktic specimens. The assemblages are dominated by species of *Asterigerina, Cibicides,* and *Cibicidoides.* The *tau* values are between 105 and 426. The Piney Point assemblages suggest quite warm, well-oxygenated, inner to possibly inner middle neritic environments about 60-150 ft deep.

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APPENDIX 1. On-Site Core Description of Paleogene and Cretaceous Strata

The sediment and rock colors are from the Geological Society of America's "Rock Color Chart."

Depth (ft):

RUN 21, 216-226 ft:

10-ft core run, 3-ft recovery.

216-217.5 ft:
SAND, contains bimodal sediment distribution with abundant medium to coarse sand and fine quartz gravel mixed with some clay; massively bedded; has less than 1 percent glauconite, some shell material; forms basal part of Calvert Formation; dusky-yellow-green (*5 GY 5/2*).

217.5-221 ft: No recovery.

-----MAJOR LITHOLOGIC CHANGE at 221 ft.

221-222.5 ft:
SANDSTONE, fine-to medium-grained quartzose; contains 10-20 percent glauconite, abundant clam shell molds; hard bed is top of Piney Point Formation; light-olive-gray (*5 Y 6/1*).

222.5-226 ft: No recovery.

RUN 22, 226-236 ft:

10-ft core run, 0.3-ft recovery.

226-226.3 ft:
SANDSTONE, fine- to medium-grained quartzose; contains 5-10 percent glauconite, phosphate grains, abundant clam shells and molds; appears to have dolomitic cement, bioturbated fabric with some more clayey areas; greenish-gray (*5 GY 6/1*).

226.3-236 ft: No recovery. Appears to be an interval of alternating indurated beds and very loose sands.

RUN 23, 236-246 ft:

10-ft core run, 0.5-ft recovery.

236-236.5 ft:
SANDSTONE and SAND; sandstone is fine grained, massively bedded with 5 percent glauconite, grayish yellow green (*5 GY 7/2*); sand is fine to medium, very slightly clayey with 5-10 percent glauconite, fairly abundant fine shell hash; dusky yellow green (*5 GY 5/2*).

236.5-246 ft: No recovery. Appears to be interval of alternating indurated beds and very loose sands.

RUN 24, 246-256 ft:

10-ft core run, 1.9-ft recovery.

246-247.9 ft:
SAND and SANDSTONE; sand is mostly fine with some medium grains, slightly clayey, massively bedded; contains 5-10 percent glauconite, fairly abundant fragmental shells, and some large oysters; grayish olive-green (*5 GY 3/2*); several 0.2-ft-thick sandstone beds in this interval.

247.9-256 ft: No recovery. Appears to be interval of alternating indurated beds and very loose sands.

RUN 25, 256-266 ft:

10-ft core run, 1-ft recovery.

256-257 ft:
SANDSTONE, fine-grained, clayey in places; contains some coarse sand and gravel of which some grains are amber coated and others are brown like goethite; massively bedded with bioturbated texture; 5 percent glauconite; pale-olive (*10 Y 6/2*); is near or at base of the Piney Point Formation.

257-266 ft: No recovery.

-----MAJOR LITHOLOGIC CHANGE

RUN 26, 266-276 ft:

10-ft run, 6.7-ft recovery

266-272.7 ft:

SAND, fine to medium, clayey with abundant medium to coarse sand and some fine gravel of which many grains have a yellow-stained surface; medium to coarse quartz grains are highly polished; contains dark-gray clay layers that are 1-3 inches thick and thinner discontinuous clay lenses that have many burrows filled with light-gray-green sand; contains 5-20 percent glauconite, 10-20 percent polished brown phosphate; is highly bioturbated with no visible shell; dark-grayish-green; is near or at top of Nanjemoy Formation.

272.7-276 ft: No recovery.

RUN 27, 276-286 ft:

10-ft core run, 6-ft recovery.

276-280 ft:

SAND, fine to medium, clayey; is interspersed with sandy clay intervals and highly burrowed, more olive clay laminae about 1/2 inch thick; contains abundant medium to coarse sand and fine gravel clasts that are polished and subrounded to rounded, commonly with amber to brown coating, 10 percent glauconite, 5 percent phosphate, several pieces of lignitized wood, no visible shell; is highly bioturbated; dark-grayish-green.

280-282 ft:

CLAY, sandy; is interspersed with highly burrowed clay laminae; amber to brown-stained quartz gravel are more abundant than in above interval; gravel is polished and subrounded to rounded; contains 5-10 percent glauconite, 5-10 percent phosphate, no visible shell; dark-grayish-green.

RUN 28, 286-296 ft:

10-ft core run, 0.3-ft recovery.

286-286.3 ft:.

SAND, fine to coarse, clayey with some fine gravel, no visible shell; dark-grayish-green.

286.3-296 ft: No recovery.

RUN 29, 296-301 ft:

5-ft core run, 0.2-ft recovery.

296-296.2 ft:
SAND and SANDSTONE, fine to medium, clayey with 5-10 percent glauconite; highly bioturbated;dark-grayish-green.

296.2-301 ft: No recovery.

RUN 30, 301-309 ft:

8-ft core run, no recovery.

RUN 31, 309-316 ft:

7-ft core run, 3-ft recovery.

309-312 ft:
SAND, fine to medium with some coarse, clayey sand, mostly massively bedded, but contains some 1/2-inch-thick clay laminae that are burrowed; medium to coarse quartz sand is polished and has yellow to yellow-brown coating; contains 10-15 percent glauconite, no visible shell; medium-dark-grayish-green.

312-316 ft: No recovery.

RUN 32, 316-322 ft:

6-ft core run, 4.5-ft recovery.

316-320.5 ft:
SAND, fine to medium, clayey with some coarse sand and fine gravel, massively bedded with some 1/2-inch-thick burrowed clay lenses, 10-20 percent glauconite, no visible shell; dark-grayish-green.

320.5-322 ft: No recovery.

RUN 33, 322-326 ft:

4-ft core run, 2-ft recovery.

322-324 ft:

SAND, fine to medium, clayey with some quartzose coarse sand and fine gravel that is yellow to brown coated, some 1/2-inch-thick burrowed clay lenses, 10-20 percent glauconite, no visible shell; dark-grayish-green.

324-326 ft: No recovery.

RUN 34, 326-331 ft:

5-ft core run, 4.5-ft recovery.

326-327.5 ft:

SAND, clayey; same as that in above run with no visible shell.

327.5-330.5 ft:

SAND, fine to medium, clayey with some burrowed thin clay laminae, polished coarse sand and fine gravel, 5 percent glauconite, some glauconite staining of particles, no visible shell; this run is a coarser sand with less clay than in above run; dark-grayish-green.

330.5-331 ft: No recovery.

RUN 35, 331-336 ft:

5-ft core run, 3-ft recovery.

331-334 ft:

SAND, fine, clayey with some coarse sand and fine gravel; contains common burrowed clay laminae, 10-20 percent glauconite with glauconite more abundant in lower 0.3 ft where it is associated with glauconitic staining of burrows and sediment; dark-grayish-green; this run is a finer sand with more clay and less coarse sand and gravel than above run.

334-336 ft: No recovery.

RUN 36, 336-341 ft:

5-ft core run, 4-ft recovery.

336-340 ft:

SAND, clayey with some coarse sand and a little fine gravel; contains abundant burrowed clay laminae, 20-30 percent glauconite; quartz grains stained green (not yellow), no visible shell; more abundant clay laminae, more glauconitic, and less coarse-grained material than in above runs; dark-green with more olive clay intervals than above.

340-341 ft: No recovery.

RUN 37, 341-346.5 ft:

5.5-ft run, 5.5-ft recovery.

341-346.5 ft:

SAND, clayey with small amount of coarse sand; contains abundantly burrowed silty clay laminae, highly bioturbated fabric with medium-olive-grayish-green clay and dark-greenish-black glauconitic sands that may contain 50 percent glauconite; no visible shell.

RUN 38, 346.5-356 ft:

9.5-ft run, 2.7-ft recovery.

346.5-349.2 ft:

SAND, fine, clayey with a few coarse sand grains; contains abundant burrowed clay laminae, of which some are discontinuous; has highly bioturbated fabric with glauconite more than 50 percent in sandier portions, glauconitic staining of quartz grains; few scattered shell fragments; dark-greenish-black.

349.2-356 ft: No recovery.

RUN 39, 356-359 ft:

3-ft core run, 1-ft recovery.

356-357 ft:

SAND, fine to medium, clayey with some coarse sand; contains discontinuous clay laminae, bioturbated fabric with dark-greenish-black glauconitic sand and medium-olive-green clay; glauconite exceeds 50 percent in sand; glauconite comprises fine sand and quartz comprises the medium sand; very few scattered shell fragments.

357-359 ft: No recovery.

RUN 40, 359-366 ft:

7-ft core run, 3-ft recovery.

359-362 ft:

SAND, fine, clayey with some medium to coarse sand, discontinuous clay lenses, bioturbated fabric of dark-greenish-black, highly glauconitic sand and medium-olive-grayish-green clay; glauconite may be greater than 50 percent in sands; very few shell fragments.

362-365 ft:

SAND, fine to medium, quite clayey with few medium to coarse sand grains and fine gravel, bioturbated fabric of dark-greenish-black sand and medium-olive-grayish-green clay; very few shell fragments.

365-366 ft: No recovery.

RUN 41, 366-373 ft:

7-ft core run, 7-ft recovery.

366-373 ft:

SAND, fine to medium, quite clayey with some medium to coarse sand and fine gravel, bioturbated fabric of dark-greenish-black sand and medium-olive-grayish-green clay; glauconite may be more than 50 percent in sands; very few shell fragments.

-----RAPID GRADATIONAL CHANGE to more clayey and less glauconitic beds

RUN 42, 373-376 ft:

3-ft core run, 3-ft recovery.

373-374.5 ft:

CLAY, fine, sandy with bioturbated fabric, 2 percent glauconite, very little shell; medium-grayish-green.

374.5-376 ft:

SAND, fine, silty, very clayey with bioturbated fabric of medium-grayish-green sand and darker olive-grayish-green clay; contains 5-10 percent glauconite, no visible shell.

RUN 43, 376-86 ft:

10-ft core run, 9-ft recovery.

376-379 ft:
CLAY, very fine, sandy, silty, and SAND, very fine, silty, very clayey; olive-gray (*5 Y 3/2*); clayey intervals are dominant; contains discontinuous clay laminae, bioturbated fabric, 5-10 percent glauconite, scattered carbonaceous debris, few small shells.

379-385 ft:
CLAY, silty with discontinuous clay and glauconitic sand laminae in some intervals; remainder has bioturbated fabric of clay and sand, 5 percent medium to coarse glauconite, scattered small clam shells; grayish-olive-green (*5 GY 3/2*).

385-386 ft: No recovery.

-----GRADATIONAL CHANGE to much more glauconitic beds

RUN 44, 386-396 ft:

10-ft core run, 10-ft recovery.

386-396 ft:
CLAY, sandy, silty with some medium to coarse quartz grains that are highly polished; contains few discontinuous laminae; bioturbated fabric dominates with grayish-olive-green (*5 GY 3/2*) clayey areas and greenish-black (*5 G 2/1*) glauconitic sandy clay areas; up to 30 percent fine to coarse glauconite.

RUN 45, 396-406 ft:

10-ft core run, 10-ft recovery.

396-406 ft:
CLAY, sandy; most of sand component is glauconite; contains some polished, green-stained, fine to medium quartz, bioturbated fabric, 30-50 percent glauconite or more in some places, no visible shell; grayish-olive-green (*5 GY 3/2*).

RUN 46, 406-416 ft:

10-ft core run, 0.5-ft recovery.

406-406.5 ft:

SAND, fine to medium with a few coarse grains, clayey with bioturbated fabric; contains 50 percent glauconite, green-stained quartz grains, no visible shell; dark-greenish-black (*5 G 2/1*).

406.5-416 ft: No recovery.

RUN 47, 416-419 ft:

3-ft core run, 3-ft recovery.

416-419 ft:

SAND, fine with some medium sand, clayey with bioturbated fabric, 50 percent glauconite, no visible shell; olive-black (*5 Y 2/1*).

RUN 48, 419-426 ft:

7-ft core run, 7-ft recovery.

419-426 ft:

CLAY, fine, sandy with few medium to coarse sand grains and thin, discontinuous clay laminae; becomes more clayey in lower 2 ft; contains bioturbated fabric, 50 percent glauconite, green-stained quartz grains, no visible shell; olive-black (*5 Y 2/1*).

RUN 49, 426-436 ft:

10-ft core run, 10-ft recovery.

426-427 ft:

CLAY, fine to very fine, sandy with 5-10 percent glauconite, 1/2-inch clay clasts in lower 0.5 ft; no visible shell; dark-greenish-gray (*5 GY 4/1*).

-----MAJOR LITHOLOGIC CHANGE, burrowed surface with 1-inch-diameter burrows of lowermost Nanjemoy Formation extending as much as 1.8 ft into underlying Marlboro Clay.

427-436 ft:

CLAY, silty, massively bedded with very faint mottling in upper 2 ft; has some very thin (1/16 inch) more silty laminae in otherwise mottled beds; olive-gray (*5 Y 4/1*) in upper part, becoming somewhat pinkish near the bottom.

RUN 50, 436-446 ft:

10-ft core run, 1.7-ft recovery.

436-437.6 ft:
CLAY, silty with some glauconite sand floating in clay in upper part; contains differing colored indistinct laminae 1 to 2 inches thick in bottom 1 ft; lenticular pods 1/2 inch wide by 1 inch high in lower 1 ft have 10 percent glauconite and yellow-stained coarse sand and fine gravel; bottom 0.1 ft has interlaminated clay and glauconitic clay with 10-15 percent glauconite; brownish-gray (*5 YR 4/1*) at top, grading to pale-yellowish-brown (*10 YR 6/2*) at bottom; bottom is base of Marlboro.

-----MAJOR LITHOLOGIC CHANGE

437.6-437.7 ft:
SAND, fine to medium, massively bedded, glauconitic; "pistachio" green.

437.7-446 ft: No recovery.

RUN 51, 446-452 ft:

6-ft core run, 3-ft recovery.

446-449 ft:
SAND, fine to medium, slightly clayey, massively bedded; contains 20-40 percent glauconite, 10-20 percent goethite, abundant clam shell fragments; grayish-olive (*10 Y 4/2*).

449-452 ft: No recovery.

RUN 52, 452-456 ft:

4-ft core run, 0-ft recovery.

452-456 ft: No recovery; appears to be loose sands.

RUN 53, 456-462 ft:

6-ft core run, 0-ft recovery.

456-462 ft: No recovery; appears to be loose sands.

RUN 54, 462-466 ft:

4-ft core run, 4-ft recovery.

462-466 ft:

SAND, fine to medium, slightly clayey, massively bedded with 10-20 percent glauconite with some colored orange-brown; many quartz grains are orange or green stained; contains scattered, small to medium clam shells; grayish-olive (*10 Y 4/2*).

RUN 55, 466-476 ft:

10-ft core run, 0.7-ft recovery.

466-466.7 ft:

SAND, fine to medium, slightly clayey, massively bedded; contains 10-20 percent glauconite with some colored orange-brown, scattered small clam shells; grayish-olive (*10 Y 4/2*).

466.7-476 ft: No recovery.

RUN 56, 476-486 ft:

10-ft core run, 0.2-ft recovery.

476-476.2 ft:

SANDSTONE, fine- to medium-grained, massively bedded with some coarse quartz and goethite grains, 20 percent glauconite, green-stained quartz, abundant clam shells; very light gray (*N 8*).

476.2-486 ft: No recovery.

RUN 57, 486-496 ft:

10-ft core run, 0.2-ft recovery.

486-486.2-ft:

SANDSTONE, fine- to medium-grained, massively bedded with some coarse quartz and goethite grains, 15 percent glauconite, abundant clam shells; very light gray (*N 8).*

486.2-496 ft: No recovery.

RUN 58, 496-506 ft:

10-ft core run, 0-ft recovery.

496-506 ft: No recovery, except loose slurry of fine to medium glauconitic sand.

RUN 59, 506-516 ft:

10-ft core run, 0.9-ft recovery.

506-506.5 ft:
SANDSTONE, fine- to primarily medium-grained, massively bedded with 10-20 percent glauconite, orange-colored grains, some shell fragments; light-gray (*N 7*).

506.5-506.9 ft:
SANDSTONE, mostly fine- to some medium-grained, massively bedded with 20-30 percent glauconite; olive-gray (*5 Y 4/1*).

506.9-516 ft: No recovery.

RUN 60, 516-526 ft:

10-ft core run, 3-ft recovery.

516-517.5 ft:
SANDSTONE, fine- to medium-grained, massively bedded with 10-20 percent glauconite, about 10 percent yellow and orange grains; contains green-stained quartz, some scattered shell; olive-gray (*5 Y 4/1*).

517.5-518 ft:
SAND, mostly fine to medium, moderately clayey, massively bedded with 10-15 percent glauconite; olive-gray (*5 Y 4/1*).

518-519 ft:
SANDSTONE, fine-grained with some medium-grained, massively bedded with 10-15 percent glauconite; light-gray (*N 7*).

519-526 ft: No recovery.

RUN 61, 526-536 ft:

10-ft core run, 8.5-ft recovery.

526-527.3 ft:
SAND, fine to medium, clayey, massively bedded with 10-15 percent glauconite, abundant large clams, large bryozoan colonies; grayish-olive-green (5 *GY 3/2*).

527.3-531.6 ft:
SAND, fine, clayey, massively bedded with 2-3 percent glauconite, some shell, 0.3-ft-thick indurated zone; light-olive-gray (*5 Y 5/2*).

-----GRADATION CHANGE over 530.6-531.6 ft to more glauconitic and darker colored beds.

531.6-533.1 ft:
SAND, fine with some medium sand and small amounts of coarse, clayey, massively bedded sand with 10-20 percent glauconite, scattered shells; olive-gray (*5 Y 3/2*).

533.1-534.5 ft:
SANDSTONE, fine, massively bedded with bioturbated fabric, 10-40 percent glauconite; light-gray (*N 7*).

534.5-536 ft: No recovery.

RUN 62, 536-546 ft:

10-ft core run, 7-ft recovery.

536-541 ft:
SAND, grayish-olive-green (*5 GY 3/2*), fine, clayey with moderate amount of medium to coarse sand; is massively bedded with 20 percent glauconite, scattered shell; light-gray (*N 7*).

541-543 ft:
SAND, fine, some coarse, fairly clayey, massively bedded with 10-15 percent glauconite, some shell; olive-gray (*5 Y 4/1*).

543-546 ft: No recovery.

RUN 63, 546-556 ft:

10-ft core run, 6-ft recovery.

546-546.9 ft:

SANDSTONE, fine-grained, clayey, massively bedded with 2 percent glauconite; light-gray (*N 7*).

546.9-549.5 ft:

SAND, fine, clayey, massively bedded with 3 percent glauconite, common scattered shell; olive-gray (*5 Y 4/1*).

549.5-550.2 ft:

SAND, fine, clayey, massively bedded with 2 percent glauconite; light-gray (*N 7*).

550.2-552 ft:

SAND, very fine, silty, clayey, massively bedded with bioturbated fabric, 1 percent glauconite, moderate amounts of scattered shell; olive-gray (*5 Y 4/1*).

552-556 ft: No recovery.

RUN 64, 556-566 ft:

10-ft core run, 10-ft recovery.

556-561 ft:

CLAY, silty, very fine, sandy, massively bedded with bioturbated fabric, 1 percent glauconite, moderate scattered shell, some scattered carbonaceous debris; gradational change to underlying unit; olive-gray (*5 Y 4/1*).

561-565 ft:

CLAY, silty, very fine sandy, massively bedded with 3- 5 percent glauconite, some phosphate grains, moderate amounts of scattered shell; gradational change to underlying unit; olive-gray (*5 Y 4/1*).

565-566 ft:

SAND, fine to some medium, clayey, massively bedded with 20 percent glauconite at top of interval to 50 percent at bottom; moderate amount of scattered shell; olive-gray (*5 Y 4/1*).

RUN 65, 566-576 ft:

10-ft core run, 0-ft recovery.

566-576 ft: No recovery.

RUN 66, 576-586 ft:

10-ft core run, 6-ft recovery.

576-582 ft:

SAND, fine with some medium sand, clayey, massively bedded with 20-50 percent glauconite, abundant thick-shelled clams and probable *Oleneothyris; dark-greenish-gray (5 GY 4/1)*.

582-586 ft: No recovery.

RUN 67, 586-596 ft:

10-ft core run, 10-ft recovery.

586-587 ft:

SANDSTONE, fine-grained with some medium- and coarse-grained, massively bedded with 10-15 percent glauconite, many thick-shelled clams in random orientations; olive-gray (*5 Y 3/2*); base of Aquia Formation.

-----MAJOR LITHOLOGIC CHANGE AND FORMATIONAL CHANGE, burrowed contact with burrows filled from overlying unit, extending 0.1- 0.2 ft into underlying unit.

587-596 ft:

SAND, very fine, silty, clayey, massively bedded; contains bioturbated fabric with burrow fills of more shelly, silty, clayey, very fine sand mixed with more clayey areas; 2 percent fine-grained glauconite; is slightly micaceous; lower 2 ft become increasingly rich in pyrite; contains some small to medium mollusk shells; olive-black (*5 Y 2/1*); Brightseat Formation.

RUN 68, 596-606 ft:

10-ft core run, 5.6-ft recovery.

596-596.2 ft:

SAND, very fine with some fine and medium sand, silty, clayey, massively bedded with a little glauconite, no visible shells; base of Brightseat Formation; olive-black (*5 Y 2/1*).

-----MAJOR LITHOLOGIC CHANGE AND FORMATIONAL CHANGE, undulating contact with relief of 0.1 ft.

596.2-596.4 ft:
CLAY, sandy, massively bedded; light-olive-gray (*5 Y 6/1*); top of Patapsco Formation.

596.4-597.9 ft:
SAND, fine, clayey, cross-bedded; pale-yellowish-brown (*10 YR 6/2*).

597.9-598.4 ft:
CLAY, massively bedded; pale-brown (*5 YR 5/2*).

598.4-600.4 ft:
SAND, fine to medium, crossbedded; pale-yellowish-brown (*10 YR 6/2*).

600.4-601.1 ft:
CLAY, pale-brown (*5 YR 5/2*) with green wavy mottling.

601.1-601.3 ft:
SAND, fine, crossbedded; pale-yellowish-brown (*10 YR 6/2*).

601.3-601.6 ft:
CLAY, pale-brown (*5 YR 5/2*) with green wavy mottling.

601.6-606 ft: No recovery

RUN 69, 606-616 ft:

10-ft core run, 5.2-ft recovery.

606-607.3 ft:
CLAY, silty, massively bedded, slightly micaceous; purplish-olive-gray.

607.3-608.2 ft:
CLAY, silty; red and greenish-gray mottled.

608.2-611.2 ft:
SAND, fine, crossbedded; light-olive (5 Y 6/1).

611.2-616 ft: No recovery.

RUN 70, 616-626 ft:

10-ft core run, 0-ft recovery.

616-626 ft: No recovery, but appears to be a fine, well-sorted sand from drill cuttings.

RUN 71, 626-636 ft:

10-ft core run, 0-ft recovery.

626-636 ft: No recovery, but appears to be a fine, well-sorted sand from drill cuttings.

-----TOTAL DEPTH OF HOLE -636 FT; bottomed in Patapsco Formation

APPENDIX 2. Complete Names for Calcareous Nannofossil Species Mentioned in Paper

Biantholithus astralis Steinmetz & Stradner, 1984
Biantholithus sparsus Bramlette & Martini, 1964
Blackites creber (Deflandre *in* Deflandre and Fert, 1954) Stradner & Edwards
Blackites scabrosus (Deflandre *in* Deflandre and Fert, 1954) Roth, 1970
Blackites spinosus (Deflandre & Fert, 1954) Hay & Towe, 1962
Blackites tenuis (Bramlette & Sullivan, 1961) Sherwood, 1974
Blackites truncatus (Bramlette & Sullivan, 1961) Varol, 1989
Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre, 1947
Campylosphaera dela (Bramlette & Sullivan, 1961) Hay & Mohler, 1967
Cepekiella lumina (Sullivan, 1965) Bybell, 1975
Chiasmolithus bidens (Bramlette & Sullivan, 1961) Hay & Mohler, 1967
Chiasmolithus consuetus (Bramlette & Sullivan, 1961) Hay & Mohler, 1967
Chiasmolithus danicus (Brotzen, 1959) Hay & Mohler, 1967
Chiasmolithus solitus (Bramlette & Sullivan, 1961) Hay, Mohler, & Wade, 1966
Chiphragmalithus armatus Perch-Nielsen, 1971
Coccolithus cribellum (Bramlette & Sullivan, 1961) Stradner, 1962
Coccolithus pelagicus (Wallich, 1877) Schiller, 1930
Cribrocentrum reticulatum (Gartner & Smith, 1967) Perch-Nielsen, 1971
Cruciplacolithus edwardsii Romein, 1979
Cruciplacolithus inseadus Perch-Nielsen, 1969
Cruciplacolithus primus Perch-Nielsen, 1977
Cruciplacolithus tenuis (Stradner, 1961) Hay & Mohler *in* Hay and others, 1967
Cyclagelosphaera alta Perch-Nielsen, 1979
Cyclagelosphaera prima (Bukry, 1969) Bybell & Self-Trail, 1995
Cyclococcolithus formosus Kamptner, 1963
Daktylethra punctulata Gartner *in* Gartner and Bukry, 1969
Discoaster barbadiensis Tan Sin Hok, 1927
Discoaster binodosus Martini, 1958
Discoaster diastypus Bramlette & Sullivan, 1961
Discoaster distinctus Martini, 1958
Discoaster kuepperi Stradner, 1959

Discoaster lenticularis Bramlette & Sullivan, 1961
Discoaster limbatus Bramlette & Sullivan, 1961
Discoaster lodoensis Bramlette & Riedel, 1954
Discoaster mediosus Bramlette & Sullivan, 1961
Discoaster mohleri Bukry & Percival, 1971
Discoaster multiradiatus Bramlette & Riedel, 1954
Discoaster saipanensis Bramlette & Riedel, 1954
Discoaster salisburgensis Stradner, 1961
Discoaster sublodoensis Bramlette & Sullivan, 1961
Ellipsolithus bollii Perch-Nielsen, 1977
Ellipsolithus distichus (Bramlette & Sullivan, 1961) Sullivan, 1964
Ellipsolithus macellus (Bramlette & Sullivan, 1961) Sullivan, 1964
Ericsonia subpertusa Hay & Mohler, 1967
Fasciculithus billii Perch-Nielsen, 1971
Fasciculithus involutus Bramlette & Sullivan, 1961
Fasciculithus pileatus Bukry, 1973
Fasciculithus tympaniformis Hay & Mohler *in* Hay and others, 1967
Goniolithus fluckigeri Deflandre, 1957
Helicosphaera lophota (Bramlette & Sullivan, 1961) Locker, 1973
Helicosphaera seminulum Bramlette & Sullivan, 1961
Heliolithus bukryi Wei, 1988
Heliolithus riedelii Bramlette & Sullivan, 1961
Hornibrookina arca Bybell & Self-Trail, 1995
Imperiaster obscurus (Martini, 1958) Martini, 1970
Lanternithus duocavus Locker, 1967a
Lanternithus minutus Stradner, 1962
Lithostromation operosum (Deflandre *in* Deflandre and Fert, 1954) Bybell, 1975
Lithostromation perdurum Deflandre, 1942
Lophodolithus nascens Bramlette & Sullivan, 1961
Markalius apertus Perch-Nielsen, 1979
Markalius inversus (Deflandre *in* Deflandre and Fert, 1954) Bramlette & Martini, 1964
Micrantholithus aequalis Sullivan, 1964
Micrantholithus angulosus Stradner, 1961
Micrantholithus pinguis Bramlette & Sullivan, 1961
Nannotetrina fulgens (Stradner, 1960) Achuthan & Stradner, 1969
Neochiastozygus concinnus (Martini, 1961) Perch-Nielsen, 1971
Neochiastozygus digitosus Perch-Nielsen, 1971
Neochiastozygus imbriei Haq & Lohmann, 1975
Neochiastozygus junctus (Bramlette & Sullivan, 1961) Perch-Nielsen, 1971
Neochiastozygus primitivus Perch-Nielsen, 1981
Neococcolithes dubius (Deflandre *in* Deflandre and Fert, 1954) Black, 1967
Neococcolithes protenus (Bramlette & Sullivan, 1961) Black, 1967
Pedinocyclus larvalis Bukry & Bramlette, 1971
Pemma basquense (Martini, 1959) Bybell & Gartner, 1972

Pemma basquense crassum (Bouche, 1962) Bybell & Gartner, 1972
Pemma papillatum Martini, 1959
Pemma rotundum Klumpp, 1953
Pemma serratum (Chang, 1969) Bybell & Gartner, 1972
Pentaster lisbonensis Bybell & Gartner, 1972
Placozygus sigmoides (Bramlette & Sullivan, 1961) Romein, 1979
Pontosphaera aperta (Perch-Nielsen, 1971) Aubry, 1986
Pontosphaera fimbriata (Bramlette & Sullivan, 1961) Romein, 1979
Pontosphaera multipora (Kamptner ex Deflandre, 1959) Roth, 1970
Pontosphaera pectinata (Bramlette & Sullivan, 1961) Sherwood, 1974
Pontosphaera punctosa (Bramlette & Sullivan, 1961) Perch-Nielsen, 1984
Pontosphaera wechesensis (Bukry & Percival, 1971) Aubry, 1986
Prinsius africanus Perch-Nielsen, 1981
Reticulofenestra umbilica (Levin, 1965) Martini & Ritzkowski, 1968
Rhabdosphaera gladius Locker, 1967
Rhomboaster bramlettei (Brönnimann & Stradner, 1960) Bybell & Self-Trail, 1995
Rhomboaster contortus (Stradner, 1958) Bybell & Self-Trail, 1995
Rhomboaster orthostylus (Shamrai, 1963) Bybell & Self-Trail, 1995
Scapholithus apertus Hay & Mohler, 1967
Semihololithus biskayae Perch-Nielsen, 1971
Sphenolithus moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967
Sphenolithus primus Perch-Nielsen, 1971
Sphenolithus radians Deflandre in Grasse, 1952
Toweius callosus Perch-Nielsen, 1971
Toweius eminens var. *eminens* (Bramlette & Sullivan, 1961) Bybell & Self-Trail, 1995
Toweius eminens (Bramlette & Sullivan, 1961) Gartner, 1971 var. *tovae* Perch-Nielsen, 1971
Toweius occultatus (Locker, 1967) Perch-Nielsen, 1971
Toweius pertusus (Sullivan, 1965) Romein, 1979
Transversopontis pulcher (Deflandre *in* Deflandre and Fert, 1954) Perch-Nielsen, 1967
Transversopontis pulcheroides (Sullivan, 1964) Baldi-Beke, 1971
Transversopontis zigzag Roth & Hay *in* Hay and others, 1967
Zygodiscus herlyni Sullivan, 1964
Zygrhablithus bijugatus (Deflandre *in* Deflandre and Fert, 1954) Deflandre, 1959