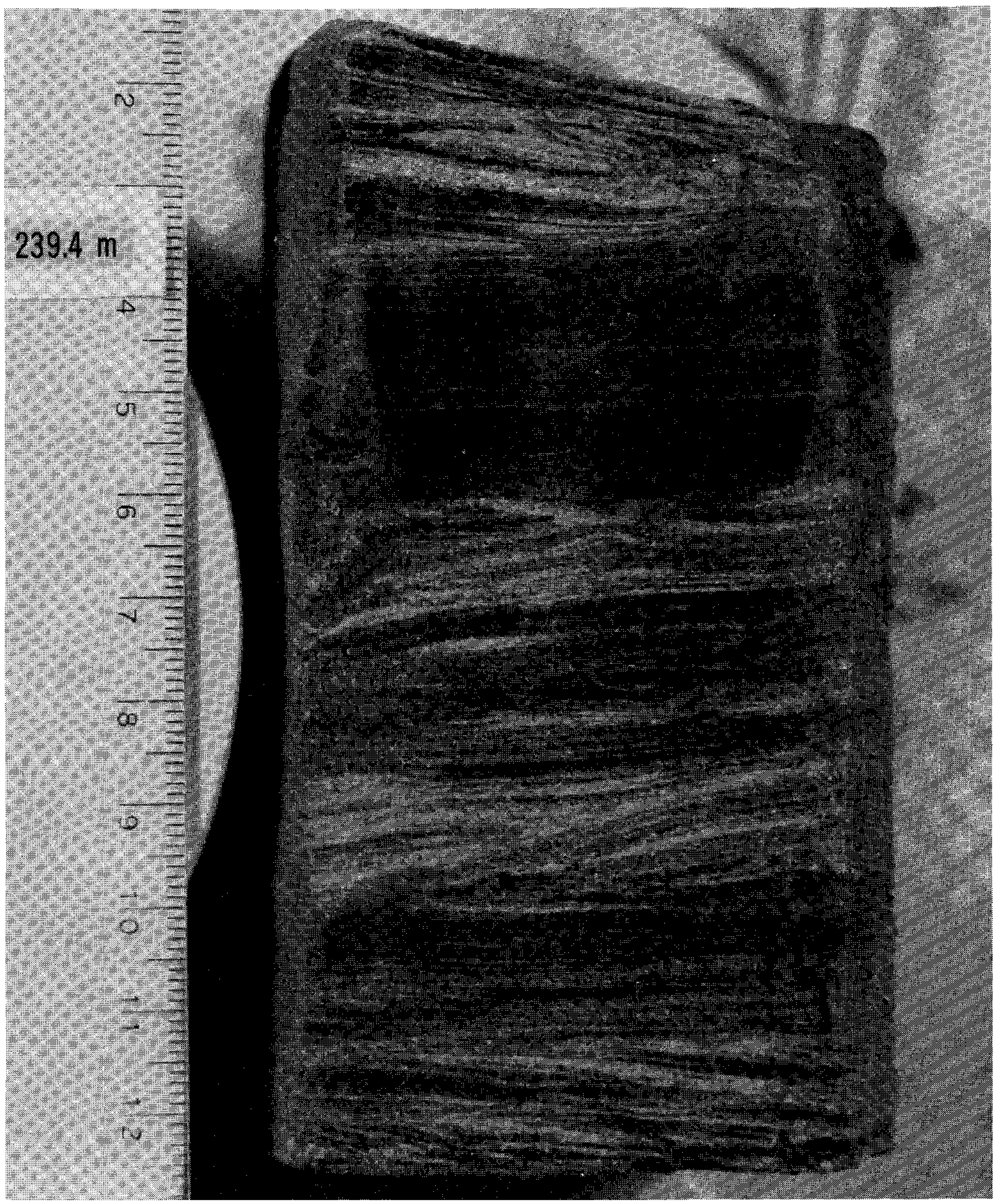
VIRGINIA DIVISION OF MINERAL RESOURCES PUBLICATION 20

GEOLOGY OF THE OAK GROVE CORE

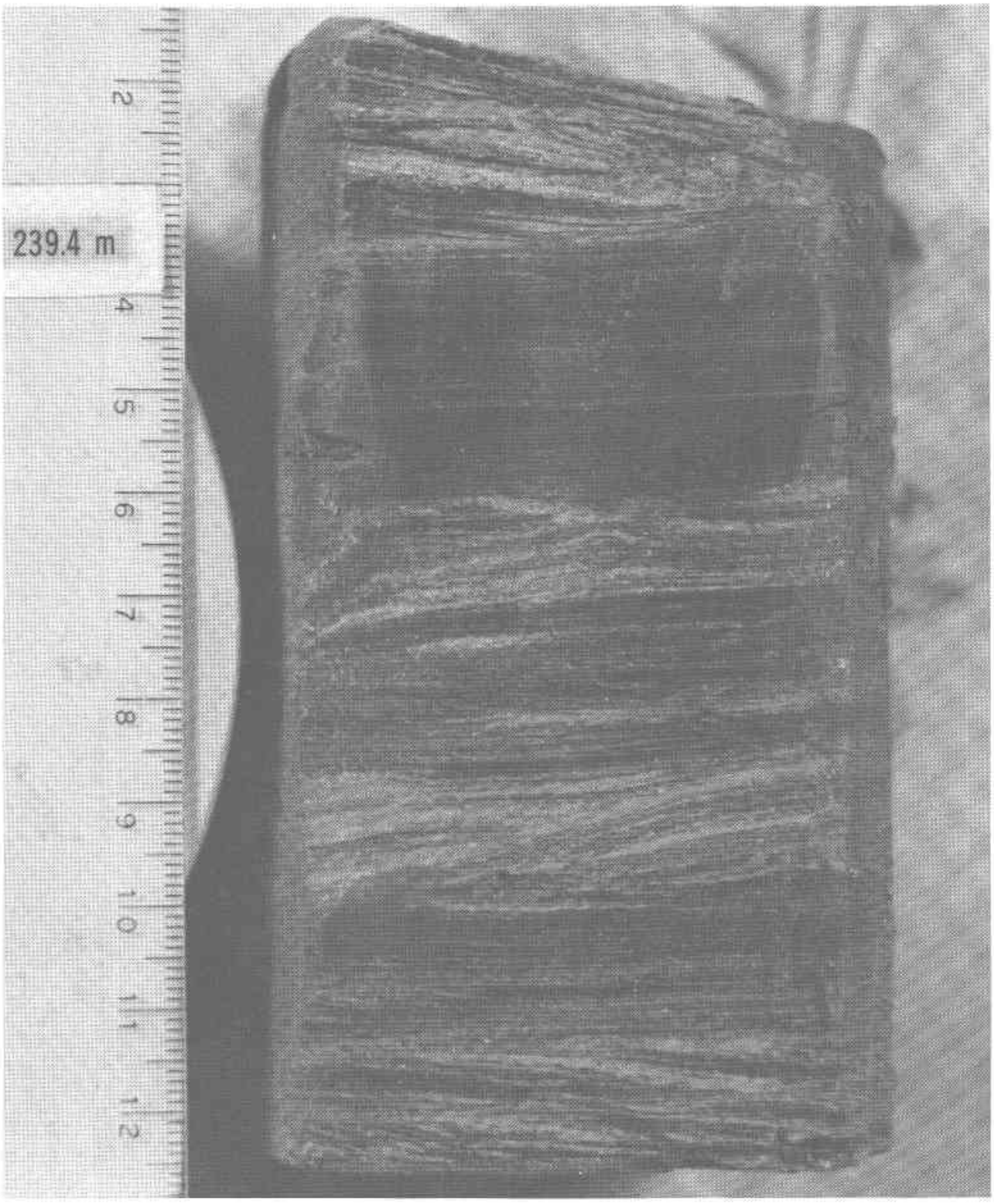


COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
Robert C. Milici, Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA
1980

VIRGINIA DIVISION OF MINERAL RESOURCES PUBLICATION 20

GEOLOGY OF THE OAK GROVE CORE



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
Robert C. Milici, Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA
1980

VIRGINIA DIVISION OF MINERAL RESOURCES PUBLICATION 20

GEOLOGY OF THE OAK GROVE CORE

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
Robert C. Milici, Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA
1980

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF PURCHASES AND SUPPLY
RICHMOND
1980

CONTENTS[1]

[1]The contents and illustrations are listed separately with each part.

PART 1
TERTIARY LITHOSTRATIGRAPHY OF THE CORE[1]

By
Juergen Reinhardt[2], W. L. Newell[2], and R. B. Mixon[2]

CONTENTS

ILLUSTRATIONS

---

[1] Portions of this publication may be quoted if credit is given to the Virginia Division of Mineral Resources. It is recommended that reference to this report be made in the following form: Reinhardt, Juergen, Newell, W. L. and Mixon, R. B., 1980, Tertiary lithostratigraphy of the core, *in* Geology of the Oak Grove core: Virginia Division of Mineral Resources Publication 20, Part 1, 88 p.

[2] U.S. Geological Survey, Reston, Virginia.

ABSTRACT

The petrologic analysis of the Tertiary part of a continuously cored stratigraphic test hole near Oak Grove, Virginia, has yielded abundant textural and mineralogical data for the Chesapeake (Miocene part) and Pamunkey (Paleocene and Eocene) groups. The general absence of primary sedimentary structures within both of these sequences, combined with the presence of burrow fabrics and shell molds, indicates deposition in shallow, low energy marine basins during early and late Tertiary.

Depositional structures and sedimentary fabrics within the Pamunkey Group (254 feet, 77.6 m, thick) indicate extremely stable and somewhat restricted shelf conditions in the Oak Grove area. The Marlboro Clay punctuates the rather homogeneous massive greensand sequence and represents the influx of an exotic mineral assemblage accompanied by a freshwater influence which probably altered the chemistry of the basin during the latest Paleocene or earliest Eocene or both.

The Chesapeake Group sediments (131 feet, 40 m, thick) reflect deposition below wave-base in a siliceous marine basin. Alternations of dominantly marine components (diatoms, sponge spicules) and immature terrigenous materials (angular quartz sand) suggest a somewhat unstable tectonic setting following the middle Eocene to early Miocene hiatus in the Salisbury embayment.

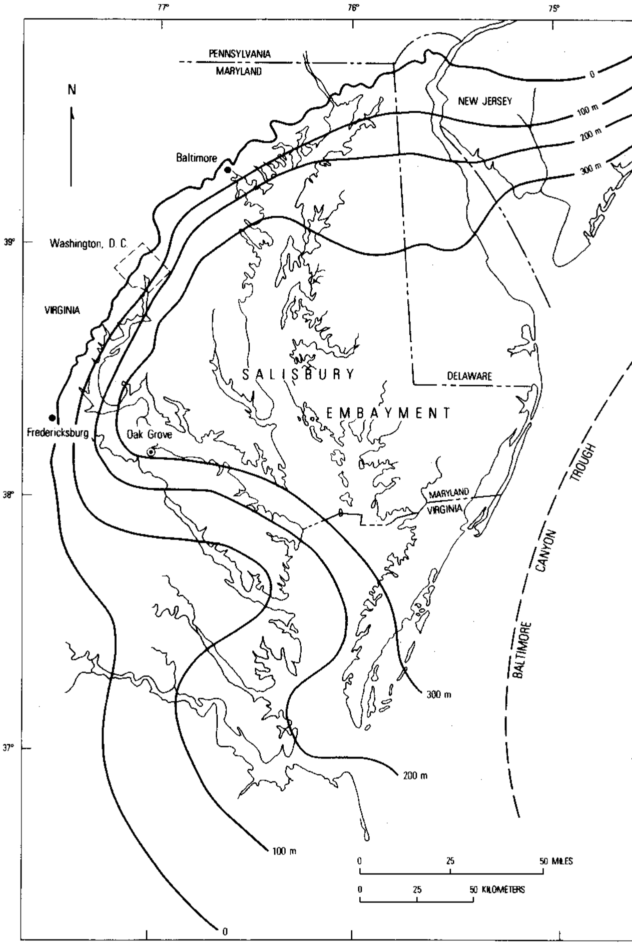


Figure 1. Map showing location of the Oak Grove core. The Salisbury embayment is delineated by isopachous thickness of Lower Cretaceous sedimentary rocks. Genaralized from Brown, Miller, and Swain (1972) and Teifke (1973).

INTRODUCTION

A stratigraphic test hole was drilled 2.2 miles (3.5 km) west-southwest of Oak Grove, Virginia, near the southern margin of the Salisbury (Baltimore-Washington) embayment (Figure 1) and 28 miles (45 km) east of the Fall Line between March 15 and May 30, 1976. The well head was at an elevation 180 feet (54.85 m), and the hole was continuously cored by the U.S. Army Corps of Engineers, under contract to the U. S. Geological Survey, from 80 to 1380 feet (24.4 to 420.6 m) or elevation + 100 to − 1200 feet (+ 30.5 to − 365.7 m). The strata cored include the lower two formations (Calvert and Choptank) of the Chesapeake Group (Miocene part)—the St. Marys and Yorktown formations are not present in the Oak Grove core; the Pamunkey Group (Paleocene and Eocene); and nearly all of the Potomac Group (Lower Cretaceous part). Less than 164 feet (50 m) of the Potomac Group appears to be missing above Triassic (?) red beds. The marine Tertiary part (upper 120 feet, 36.5 m) of the Oak Grove core is discussed in Publication 20, Parts 1 and 2. The Lower Cretaceous part of the core is discussed in Publication 20, Part 3.

The core at Oak Grove, the Clubhouse Crossroads cores No. 1-3 near Charleston, South Carolina (Gohn and others, 1977; Gohn and others 1978) and the Nantucket No. 1 core on Nantucket Island, Massachusetts (Folger and others, 1978) constitute a recent part of an ongoing effort by the U. S. Geological Survey to develop an integrated lithostratigraphic framework for the Atlantic Coastal Plain by drilling continuously cored test holes. The Oak Grove core is the only continuously cored Cretaceous and Tertiary section on the Northern Neck of Virginia and is one of the few deep cores within the entire Salisbury embayment.

The sedimentary petrology of the core has been studied in considerable detail by combining data from primary sedimentary structures, sedimentary petrography of the heavy- and light-mineral assemblages, and clay mineralogy (see sample points for petrographic analyses in Figure 2). Ad-

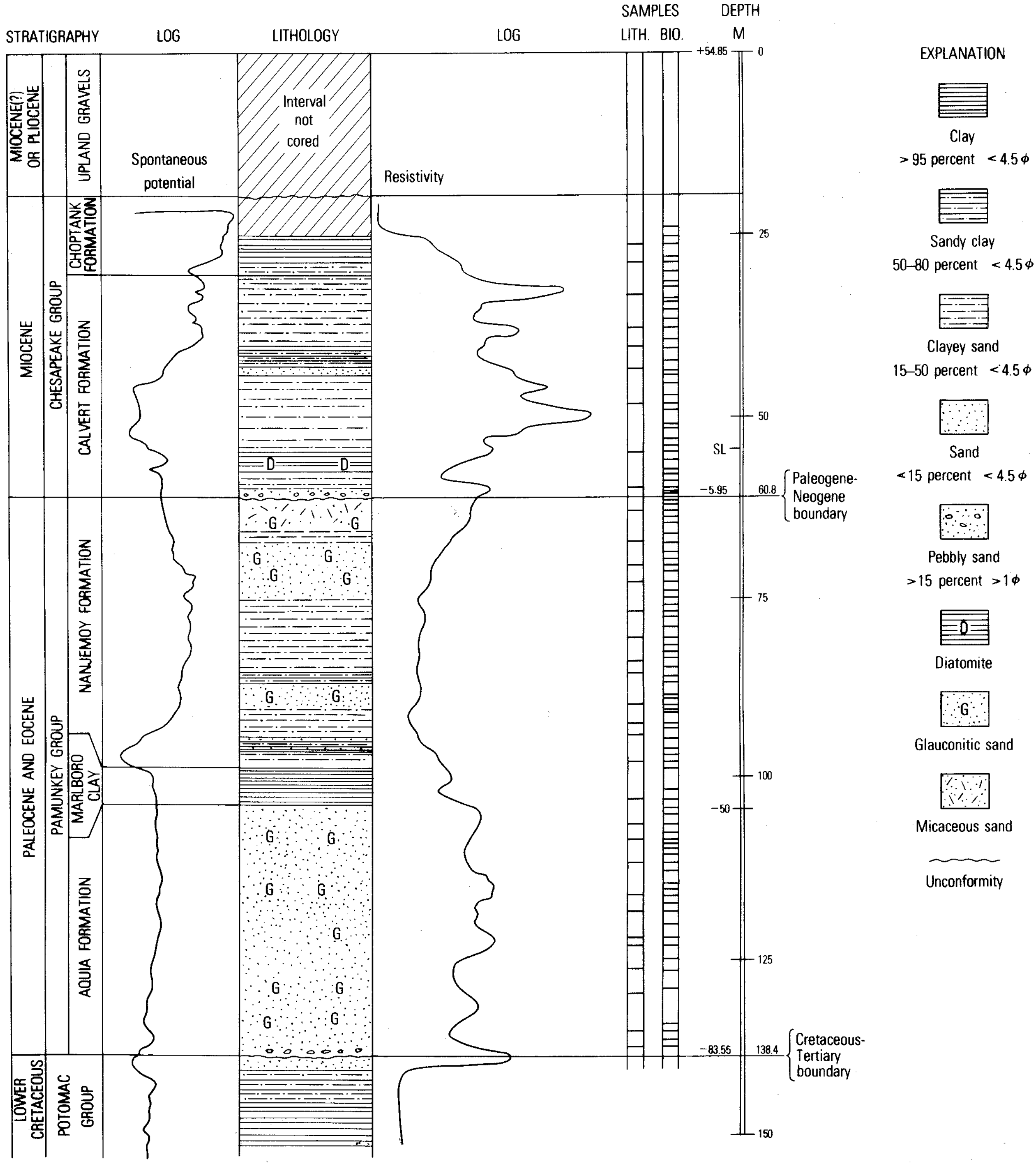


Figure 2. Generalized stratigraphy of Tertiary units of the Oak Grove core including a generalized lithologic column, geophysical logs, and sampling points for lithologic (LITH.) and biostratigraphic (BIO.) control.

ditionally, taxonomic groups including palynomorphs, dinoflagellates, diatoms, benthonic foraminifers, nannoplankton, ostracodes and bivalves have been studied to establish a coherent and comprehensive biostratigraphic as well as lithostratigraphic framework along with southern margin of the Salisbury embayment (see Publication 20, Part 2).

Previous subsurface correlations and compilations have helped to place the details of the Oak Grove core in geologic and geographic perspective. We have drawn heavily on Teifke (1973) for Virginia; Glaser (1971) and Hansen (1974) for southern Maryland; Anderson (1948) for equivalent downdip sections on the Eastern Shore of Maryland; and Brown, Miller, and Swain (1972) for a comprehensive compilation of well data throughout the Atlantic Coastal Plain north of Cape Hatteras, North Carolina.

ACKNOWLEDGMENTS

This project was part of a program to develop a stratigraphic and tectonic framework for the Rappahannock drainage basin, Virginia. James Rankin and James Dischinger were responsible for producing a detailed drilling log. James Estabrook and Melodie Hess were responsible for the textural and detailed X-ray analyses, respectively. James P. Owens provided constructive discussion and analyses of the heavy mineral assemblages. Lucy M. Force and J. P. Owens reviewed the manuscript.

An oral summary of this report was presented at the AAPG-SEPM Annual Meeting in Washington, D. C. in June 1977, (Reinhardt and others, 1977).

STRATIGRAPHY

GEOLOGIC FRAMEWORK

A generalized stratigraphic section for the Tertiary portion in the Oak Grove core is presented in Figure 2. Assignment of formational boundaries is based on lithology and confirmed by substantial biostratigraphic zonation (Publication 20, Part 2).

The absence of the entire Upper Cretaceous section and possibly a part of the basal Paleocene (see Publication 20, Part 2), in the Oak Grove core is consistent with the distribution of sediments shown by Hansen (1968) and Brown, Miller, and Swain (1972). This absence calls to question the stratigraphic usefulness of the "transition beds" and the Late Cretaceous age of the basal Mattaponi Formation of Teifke (1973) in northeastern Virginia.

The Pamunkey Group (Paleocene and Eocene) is composed of two approximately equally thick (about 120 feet; 36.5m) greensand units (Aquia and Nanjemoy formations) separated by the Marlboro Clay, a 18-foot-thick (5.5 m) massive red clay unit. Although the Marlboro Clay has traditionally been lumped with the Nanjemoy, several indicators suggest that it belongs genetically with the underlying Aquia. It should, however, be treated as a formation as was done by Glaser, 1971, and as is done here. The formational contacts (from Aquia to Marlboro and Marlboro to Nanjemoy) within the Pamunkey Group are gradational, partly as a result of biogenic reworking. Biostratigraphic arguments (Publication 20, Part 2) are consistent with an absence of, or presence of only small-scale, unconformities within the Pamunkey Group.

A major regional unconformity separates the Miocene and Lower Tertiary sediments. In tidewater Virginia the Chesapeake Group (here comprising the Calvert and Choptank formations) constitutes a fine-grained, massive and poorly fossiliferous sediment wedge that is considerably thinner at Oak Grove than in the type exposures downdip along Maryland's western shore of Chesapeake Bay (see Gernant, 1970; Andrews, 1976; Blackwelder and Ward, 1976). In the Oak Grove core, the Choptank is approximately 33 feet (10m) thick and the underlying Calvert Formation is appproximately 100 feet (30m) thick. Both of these units are about twice as thick slightly downdip and closer to the axis of the Salisbury embayment.

The upland gravels or upland deposits, discussed at length by Hack (1955) and Schlee (1957), constitute the 67 feet (20.0 m) of section at the core site. Glaser (1971, p. 29-33) presented a review of the stratigraphic problems of these and other upper Miocene (?) and Pliocene sediments in southern Maryland. These rocks were not cored and will not be discussed further in this report. Regional relationships and locally outcropping sediments indicate that the top part of the Chesapeake Group (St. Marys and Yorktown formations) is absent in the Oak Grove area.

PAMUNKEY GROUP

The Paleocene and Eocene section extends from elevation − 20 to − 274 feet (− 5.95 to − 83.55 m) (Figure 2) in the core hole. (Also see Part 4, Lithologic Log, 199-454 feet.) The units are divided into: (1) a lower greensand, the Aquia Formation, from 340 to 454 feet (103.6 to 138.4 m), (2) a compact clay unit, the Marlboro Clay, from 322 to 340 feet (98.2 to 103.6 m) and (3) an upper greensand, the Nanjemoy Formation, from 199 to 322 feet (60.8 to

98.2 m). Compositionally and texturally, the Pamunkey sediments are quite different from the overlying fine-grained siliceous Chesapeake Group or the underlying highly variable (texturally) arkosic Potomac Group. The sands in the Pamunkey Group are typically fine to medium grained; glauconite constitutes as much as 65 percent of the sand fraction.

Sediment in the Aquia Formation near the lower contact with the Potomac Group is composed largely of fine to medium glauconitic sand; however, very coarse quartz grit, small bones, and teeth are abundant in the basal 7 feet (2 m) of the unit. The lower contact was not continuously cored; a disturbed sample of Potomac Group was recovered below the basal part of the Aquia, and approximately 3 feet (1 m) of section was lost. It is unlikely that either the Paleocene Brightseat Formation or any Upper Cretaceous Monmouth Group beds are present within that interval.

Aquia Formation

The basal 115 feet (35 m) of the Pamunkey Group in the Oak Grove core is the Aquia Formation, a massive, very well-sorted greensand. In spite of the friability of the unit, only a 9-foot-part (3 m) (elevation − 256 to − 266 feet; − 78 to − 81 m) of the core was not recovered from the entire Aquia sequence. The textural and compositional characteristics of the Aquia are somewhat comparable to those of the Nanjemoy. The size, size-range, and variability of the glauconite and quartz are similar, as is the dominance of illitic clays in the matrix of both units. The Aquia contains considerably less clay, muscovite, and lignitic and shell debris than the Nanjemoy. In no analysis did total clay in the Aquia exceed 16 percent of the entire sample by weight; in most analyses, clay represented less than 10 percent. Two intervals, 6 inches (15 cm) and 9.8 inches (25 cm) thick, are carbonate cemented between elevation − 205 and − 210 feet (− 62.5 and − 64 m). Shells are more weathered in the Aquia than in the Nanjemoy; shell material is much less abundant in the Aquia. Only robust bivalves and *Turritella mortoni* Conrad (Figure 3) are preserved; most other shell material is present only as faint "ghosts" within massive greensand sequences (Figure 4).

Marlboro Clay

The contact relationships of the Marlboro Clay are interesting from the standpoint of both sedimentation and biostratigraphy. The lower

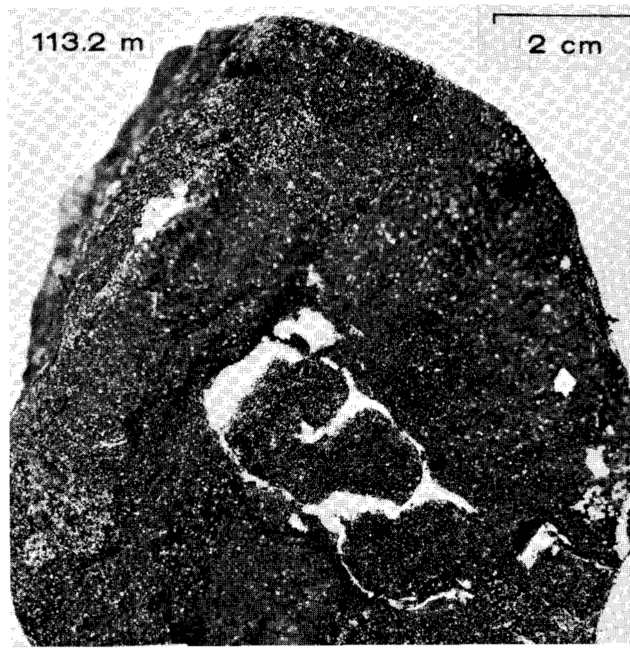


Figure 3. Leached *Turritella mortoni* Conrad (Paleocene index fossil characteristic of the Aquia Formation) floating in massive, medium-grained greensand. Sand is well sorted and contains less than 10 percent matrix. Scales shown on photographs are in centimeters, unless otherwise stated and the depth of the sample is shown on the photograph of each core segment figured (113.2 m = 371.5 feet).

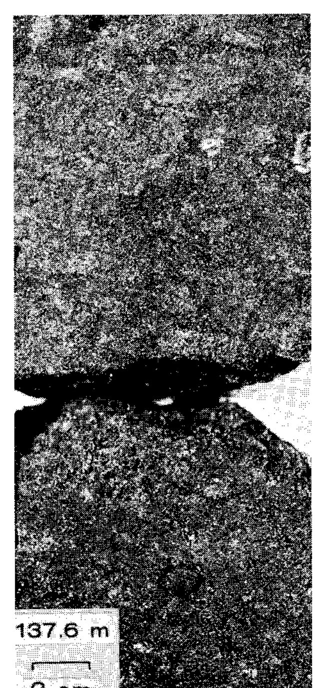


Figure 4. Massive greensand containing several "shell ghosts" near base of Aquia Formation. Biostratigraphic arguments regarding the age of this interval are presented in Gibson and other (this volume) (137.6 m = 451.5 feet).

98.2 m). Compositionally and texturally, the Pamunkey sediments are quite different from the overlying fine-grained siliceous Chesapeake Group or the underlying highly variable (texturally) arkosic Potomac Group. The sands in the Pamunkey Group are typically fine to medium grained; glauconite constitutes as much as 65 percent of the sand fraction.

Sediment in the Aquia Formation near the lower contact with the Potomac Group is composed largely of fine to medium glauconitic sand; however, very coarse quartz grit, small bones, and teeth are abundant in the basal 7 feet (2 m) of the unit. The lower contact was not continuously cored; a disturbed sample of Potomac Group was recovered below the basal part of the Aquia, and approximately 3 feet (1 m) of section was lost. It is unlikely that either the Paleocene Brightseat Formation or any Upper Cretaceous Monmouth Group beds are present within that interval.

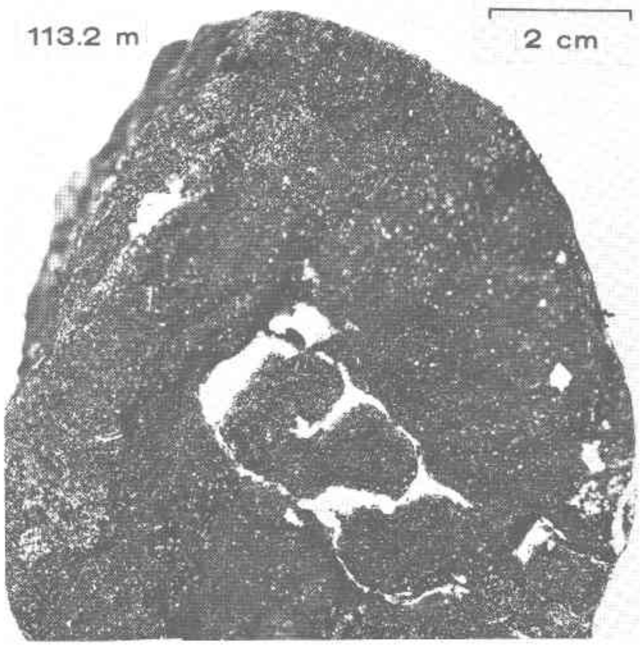


Figure 3. Leached *Turritella mortoni* Conrad (Paleocene index fossil characteristic of the Aquia Formation) floating in massive, medium-grained greensand. Sand is well sorted and contains less than 10 percent matrix. Scales shown on photographs are in centimeters, unless otherwise stated and the depth of the sample is shown on the photograph of each core segment figured (113.2 m = 371.5 feet).

Aquia Formation

The basal 115 feet (35 m) of the Pamunkey Group in the Oak Grove core is the Aquia Formation, a massive, very well-sorted greensand. In spite of the friability of the unit, only a 9-foot-part (3 m) (elevation – 256 to – 266 feet; – 78 to – 81 m) of the core was not recovered from the entire Aquia sequence. The textural and compositional characteristics of the Aquia are somewhat comparable to those of the Nanjemoy. The size, size-range, and variability of the glauconite and quartz are similar, as is the dominance of illitic clays in the matrix of both units. The Aquia contains considerably less clay, muscovite, and lignitic and shell debris than the Nanjemoy. In no analysis did total clay in the Aquia exceed 16 percent of the entire sample by weight; in most analyses, clay represented less than 10 percent. Two intervals, 6 inches (15 cm) and 9.8 inches (25 cm) thick, are carbonate cemented between elevation – 205 and – 210 feet (– 62.5 and – 64 m). Shells are more weathered in the Aquia than in the Nanjemoy; shell material is much less abundant in the Aquia. Only robust bivalves and *Turritella mortoni* Conrad (Figure 3) are preserved; most other shell material is present only as faint "ghosts" within massive greensand sequences (Figure 4).

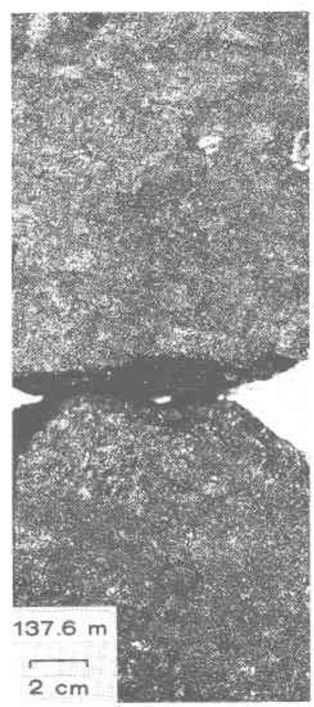


Figure 4. Massive greensand containing several "shell ghosts" near base of Aquia Formation. Biostratigraphic arguments regarding the age of this interval are presented in Gibson and other (this volume) (137.6 m = 451.5 feet).

Marlboro Clay

The contact relationships of the Marlboro Clay are interesting from the standpoint of both sedimentation and biostratigraphy. The lower contact of the 18-foot-thick (5.5 m) formation appears to be gradational. The transition from friable greensand, containing isolated clay clasts and chips, to a dense plastic clay, containing sparse sand laminae and pods, takes place over a 4 inch (10 cm) vertical distance (Figure 5A). At the upper contact is a burrowed silvery-to medium-gray (5B 7/1 to N6) (see Goddard and others, 1948) clay that grades downward to pale red (5R 6/2) within 3 feet (1 m). Several burrow types are present in the upper 7 feet (2 m) of the Marlboro, including a large (9 inch; 20 cm long) corkscrew burrow (*Gyrolithes* sp.) (Figure 5B).

5A 5B →

Figure 5. Contact relationships of the Marlboro Clay with adjoining formations. *A.* Lower contact between the Aquia Formation and the Marlboro Clay. Gradation from medium and fine glauconitic sand containing rounded clay clasts (lower segment) though clay containing sand pods and stringers (middle segment) into massive, faintly laminated red clay (top) records a gradational contact between Aquia Formation and Marlboro Clay (103.6 m = 340 feet) *B.* Upper contact between the Marlboro Clay and the Nanjemoy Formation. Burrowed and mottled light- to medium-gray clay characteristic of top of Marlboro Clay. Open-spiral burrow *(Gyrolithes)* and small vertical burrow are sand filled with sediment from the overlying Nanjemoy Formation (98.5 m = 323 feet).

The Marlboro contains only trace amounts of glauconitic sand except as burrow infills from the overlying Nanjemoy. The clay is dominantly a kaolinite-illite mixture (typically 50 percent kaolinite to 40 percent illite) and contains small amounts of illite/smectite.

Most of the formation is structureless. However, irregular pods of planar to ripple cross laminated clay are visible between mottled areas (Figure 6). Swirled bedding suggests bioturbation of the clay, and a few discrete burrows are visible within the main body of the clay unit.

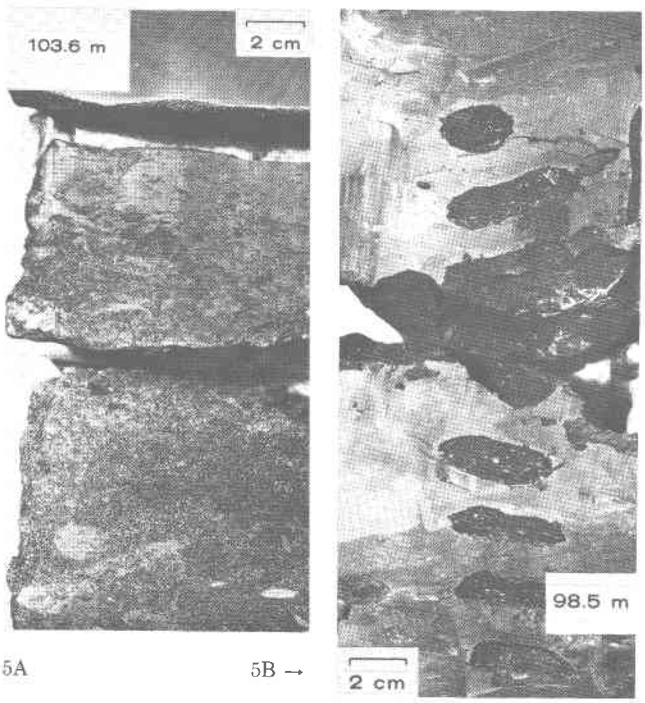
Figure 6. Massively bedded red clay in Marlboro clay is locally interrupted by laminated and cross-laminated fine silt. Soft sediment deformation of the silt and burrowing produce swirled bedding (99.7 m = 327 feet).

Nanjemoy Formation

The Nanjemoy Formation is a variably clayey greensand 124 feet (37.7 m) thick, which contains a basal clayey sand, overlain by two 33- to 49-foot-thick (10-15 m) sequences which coarsen from sandy clay to medium sand (Figure 2). Quartz, glauconite, and, to a lesser extent, muscovite and calcite (calcite as shell material) are the major framework components. The clay content varies from about 15 percent to nearly 80 percent. The clay fraction is composed mostly of illite; kaolinite increases near the contact with the Marlboro Clay. Vermiculite is present only in the upper 33 feet (10 m); clinoptilolite is found throughout, but is most abundant near the top where traces of cristobalite (low phase) also occur. Two 4- to 8-inch-thick (10 to 20 cm) calcite cemented intervals are present in the lower one-half of the unit.

The Nanjemoy is massively bedded throughout; however, sharp textural changes and oriented shell lags to thin shell beds locally define bedding (Figures 7, 8). Fish scales and lignitic debris are the other macroscopic biogenic components; pyritized foraminifers are a minor sand constituent. Con-

contact of the 18-foot-thick (5.5 m) formation appears to be gradational. The transition from friable greensand, containing isolated clay clasts and chips, to a dense plastic clay, containing sparse sand laminae and pods, takes place over a 4 inch (10 cm) vertical distance (Figure 5A). At the upper contact is a burrowed silvery-to medium-gray (5B 7/1 to N6) (see Goddard and others, 1948) clay that grades downward to pale red (5R 6/2) within 3 feet (1 m). Several burrow types are present in the upper 7 feet (2 m) of the Marlboro, including a large (9 inch; 20 cm long) corkscrew burrow (*Gyrolithes* sp.) (Figure 5B).



5A 5B →

Figure 5. Contact relationships of the Marlboro Clay with adjoining formations. *A*. Lower contact between the Aquia Formation and the Marlboro Clay. Gradation from medium and fine glauconitic sand containing rounded clay clasts (lower segment) though clay containing sand pods and stringers (middle segment) into massive, faintly laminated red clay (top) records a gradational contact between Aquia Formation and Marlboro Clay (103.6 m = 340 feet) *B*. Upper contact between the Marlboro Clay and the Nanjemoy Formation. Burrowed and mottled light- to medium-gray clay characteristic of top of Marlboro Clay. Open-spiral burrow *(Gyrolithes)* and small vertical burrow are sand filled with sediment from the overlying Nanjemoy Formation (98.5 m = 323 feet).

The Marlboro contains only trace amounts of glauconitic sand except as burrow infills from the overlying Nanjemoy. The clay is dominantly a kaolinite-illite mixture (typically 50 percent kaolinite to 40 percent illite) and contains small amounts of illite/smectite.

Most of the formation is structureless. However, irregular pods of planar to ripple cross laminated clay are visible between mottled areas (Figure 6). Swirled bedding suggests bioturbation of the clay, and a few discrete burrows are visible within the main body of the clay unit.

Figure 6. Massively bedded red clay in Marlboro clay is locally interrupted by laminated and cross-laminated fine silt. Soft sediment deformation of the silt and burrowing produce swirled bedding (99.7 m = 327 feet).

Nanjemoy Formation

The Nanjemoy Formation is a variably clayey greensand 124 feet (37.7 m) thick, which contains a basal clayey sand, overlain by two 33- to 49-foot-thick (10-15 m) sequences which coarsen from sandy clay to medium sand (Figure 2). Quartz, glauconite, and, to a lesser extent, muscovite and calcite (calcite as shell material) are the major framework components. The clay content varies from about 15 percent to nearly 80 percent. The clay fraction is composed mostly of illite; kaolinite increases near the contact with the Marlboro Clay. Vermiculite is present only in the upper 33 feet (10 m); clinoptilolite is found throughout, but is most abundant near the top where traces of cristobalite (low phase) also occur. Two 4- to 8-inch-thick (10 to 20 cm) calcite cemented intervals are present in the lower one-half of the unit.

The Nanjemoy is massively bedded throughout; however, sharp textural changes and oriented shell lags to thin shell beds locally define bedding (Figures 7, 8). Fish scales and lignitic debris are the other macroscopic biogenic components; pyritized foraminifers are a minor sand constituent. Concentrations of this biogenic material in discrete bedding planes is the strongest indication of physical sedimentation unaffected by bioturbation in portions of the Nanjemoy.

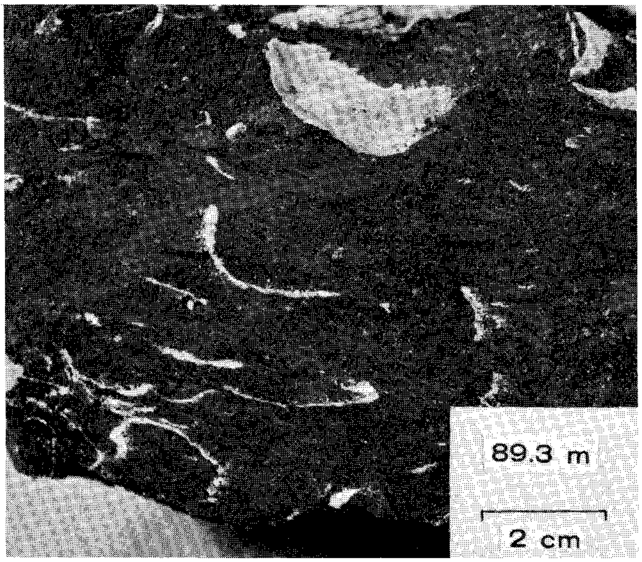


Figure 7. Oriented concave-up shell lag within the lower part of the Nanjemoy Formation. Sediment is relatively low in clay matrix (less than 10 percent), but it contains angular clay clasts (89.3 m = 293 feet).

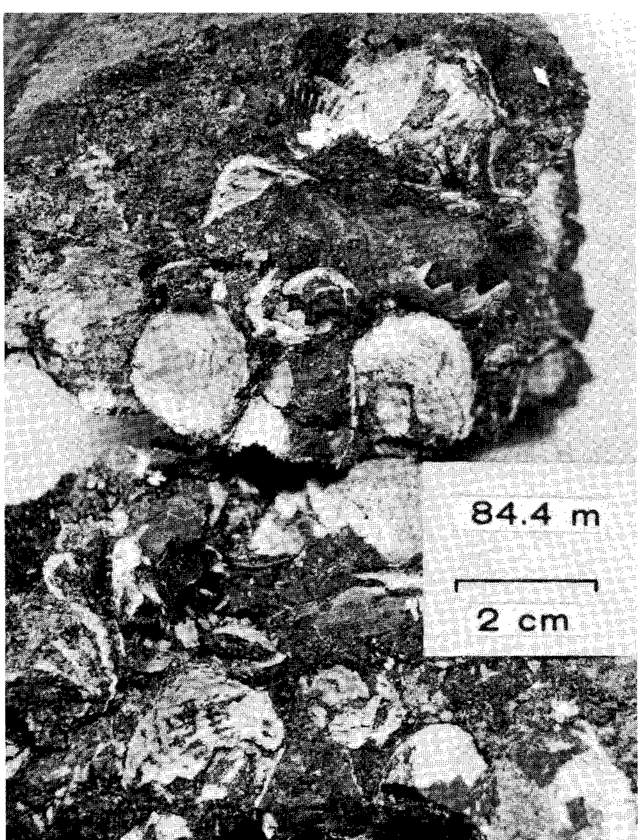


Figure 8. Shell bed composed primarily of *Cardium* sp. characteristic of the Nanjemoy Formation. Note degree of shell weathering and shell cavities filled with clay-sized material (84.4 m = 277 feet).

Mottled lithologies are common throughout the Nanjemoy, especially within clayey intervals (Figure 9). Bioturbation, with or without distinct burrow infills in fine-grained sediments, results in Nanjemoy textures similar to those illustrated in the Calvert section.

The glauconite that forms the most conspicuous part of the sand fraction ranges from simple round grains to polylobate forms and accordion rods (Figure 10). Locally as much as 20 percent of the

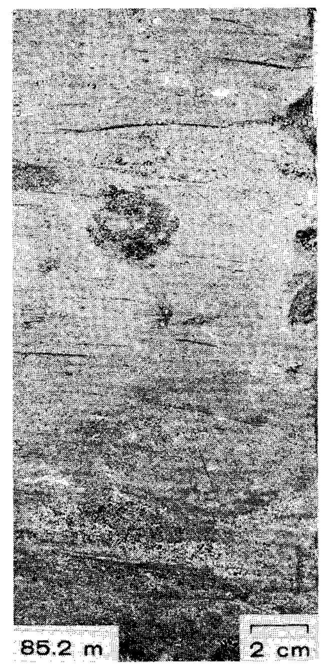


Figure 9. Textures within fine-grained part of Nanjemoy Formation. Core segment is characterized by fine sand-filled burrows (dark patches), scattered bivalve fragments, and sandy lenses. Subhorizontal streaks result from drag of fine sand grains during splitting of core (85.2 m = 279.5 feet).

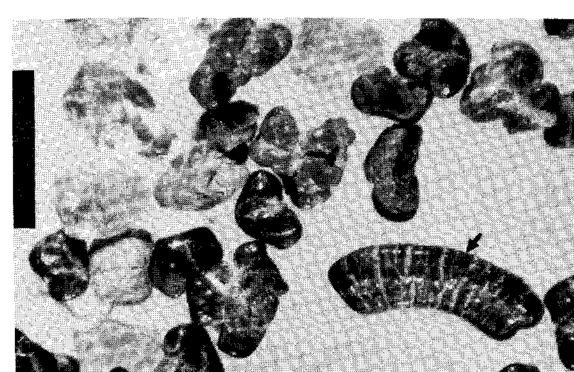


Figure 10. Macrophotograph of polylobate glauconite grains in Nanjemoy Formation. Note rare accordion form (arrow) and polished quartz grain surfaces. Sample is from 209 feet (63.7 m). The bar equals 1 mm.

centrations of this biogenic material in discrete bedding planes is the strongest indication of physical sedimentation unaffected by bioturbation in portions of the Nanjemoy.

Mottled lithologies are common throughout the Nanjemoy, especially within clayey intervals (Figure 9). Bioturbation, with or without distinct burrow infills in fine-grained sediments, results in Nanjemoy textures similar to those illustrated in the Calvert section.

The glauconite that forms the most conspicuous part of the sand fraction ranges from simple round grains to polylobate forms and accordion rods (Figure 10). Locally as much as 20 percent of the

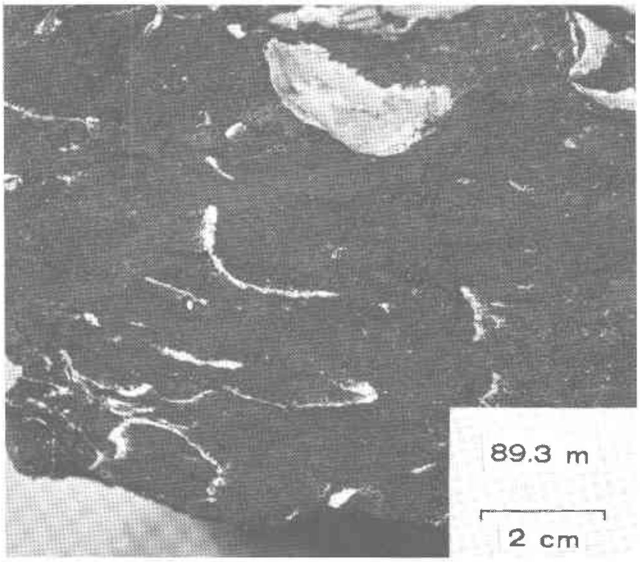


Figure 7. Oriented concave-up shell lag within the lower part of the Nanjemoy Formation. Sediment is relatively low in clay matrix (less than 10 percent), but it contains angular clay clasts (89.3 m = 293 feet).

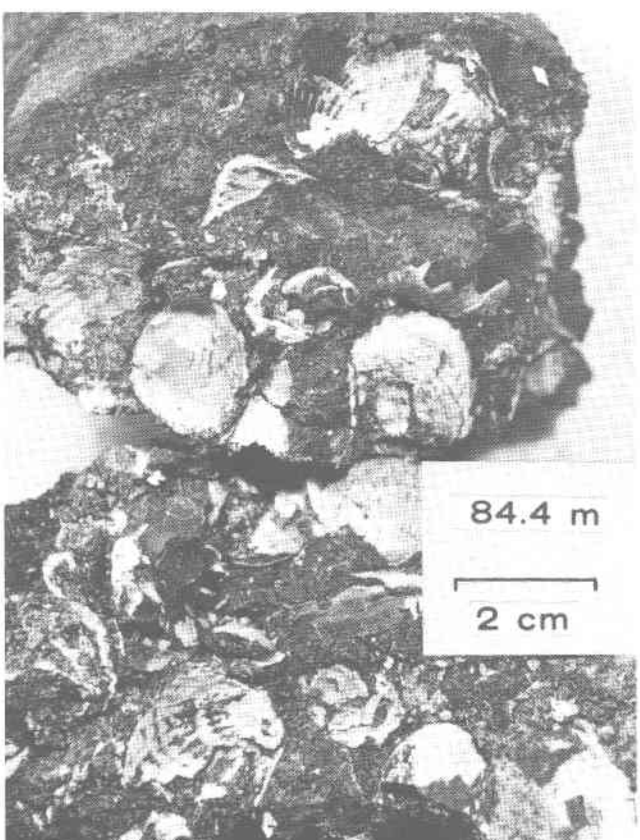


Figure 8. Shell bed composed primarily of *Cardium* sp. characteristic of the Nanjemoy Formation. Note degree of shell weathering and shell cavities filled with clay-sized material (84.4 m = 277 feet).

Figure 9. Textures within fine-grained part of Nanjemoy Formation. Core segment is characterized by fine sand-filled burrows (dark patches), scattered bivalve fragments, and sandy lenses. Subhorizontal streaks result from drag of fine sand grains during splitting of core (85.2 m = 279.5 feet).

Figure 10. Macrophotograph of polylobate glauconite grains in Nanjemoy Formation. Note rare accordion form (arrow) and polished quartz grain surfaces. Sample is from 209 feet (63.7 m). The bar equals 1 mm.

glauconite is slightly to highly weathered. Quartz grains are clear and typically polycrystalline; grains are round to subangular, and grain surfaces are highly polished. Clay clasts are a major component within the Nanjemoy. Coherent angular granules, flat chips, and burrowed-bored(?) blocks as much as 1 inch (2 cm) across are the major forms. Some clasts may be relict burrow-riddled clay laminae or thin beds. Elsewhere, the clay clasts may have an erosional origin and a history of transport and sedimentation as suggested by the association of clasts and clusters of shells (Figure 11).

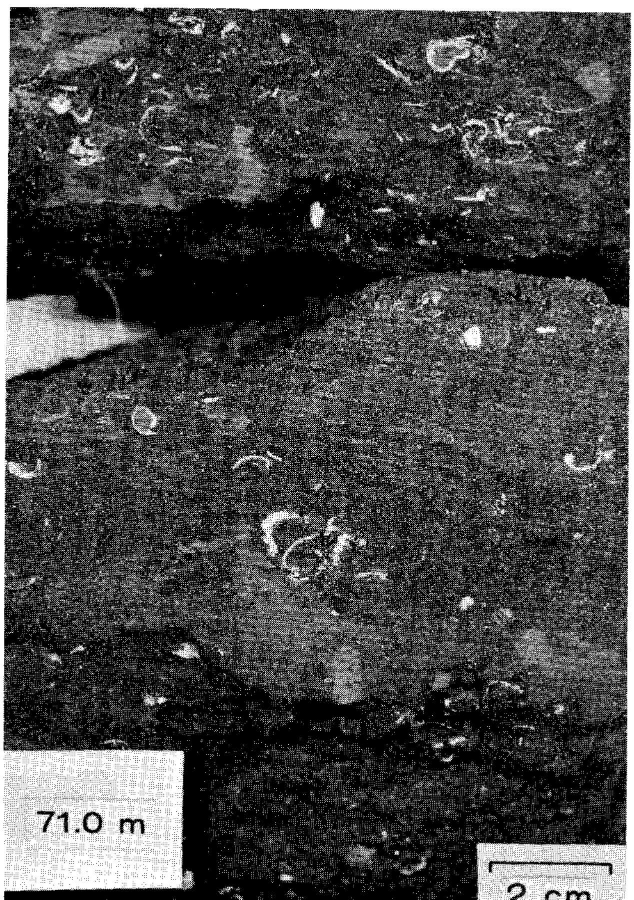


Figure 11. Interval within the Nanjemoy Formation dominated by angular clay clasts and pods of leached shell material. Note the slightly irregular sand/clay stratification near the middle of the core segment (71.0 m = 233 feet).

The Nanjemoy is somewhat weathered immediately below the Calvert contact. The top of the Nanjemoy is considerably coarser, better sorted, and more micaceous than the overlying Calvert Formation. Shell material is entirely leached from the upper 10 feet (3 m) and is not fresh anywhere within this unit in the Oak Grove core (Figures 11, 12).

Figure 12. Massive greensand within the upper part of the Nanjemoy Formation containing leached whole bivalves and shell fragments crudely oriented along bedding (66.1 m = 216 feet).

CHESAPEAKE GROUP

Calvert Formation

The Calvert is a yellow-gray, fine-grained sediment which can be divided texturally into three distinct parts. The upper part (80 feet; 24.4 m thick) is composed dominantly of very fine, angular quartz sand (as much as 60 percent) in a fine silt to clay matrix (25-45 percent); a 10-foot-thick (3 m) diatomite and a basal 10-foot-thick (3 m) highly variable clay to coarse quartz sand constitute the remainder of the 100-foot-thick (30 m) Calvert.

The basal 10 feet (3 m) of the Calvert is a poorly sorted sand containing phosphatized shell fragments and quartz granules floating in a fine-grained matrix (Figure 13). Several erosional contacts marked by coarse sediment and shell lags occur within the interval (Figure 13). The contact with the underlying Pamunkey Group is texturally and compositionally sharp.

A highly diatomaceous interval (10-foot-thick; 3 m) within the Calvert (Fairhaven Member as used by Dryden and Overbeck, 1948) occupies the interval from approximately 180 to 190 feet (54.8 to 57.8 m) (elevation 0 to − 10 feet; 0 to − 3 m). Greater than 95 percent of the diatomite is finer than coarse silt. The glauconite is slightly to highly weathered. Quartz grains are clear and typically polycrystalline; grains are round to subangular, and grain surfaces are highly polished. Clay clasts are a major component within the Nanjemoy. Coherent angular granules, flat chips, and burrowed-bored(?) blocks as much as 1 inch (2 cm) across are the major forms. Some clasts may be relict burrow-riddled clay laminae or thin beds. Elsewhere, the clay clasts may have an erosional origin and a history of transport and sedimentation as suggested by the association of clasts and clusters of shells (Figure 11).

Figure 11. Interval within the Nanjemoy Formation dominated by angular clay clasts and pods of leached shell material. Note the slightly irregular sand/clay stratification near the middle of the core segment (71.0 m = 233 feet).

The Nanjemoy is somewhat weathered immediately below the Calvert contact. The top of the Nanjemoy is considerably coarser, better sorted, and more micaceous than the overlying Calvert Formation. Shell material is entirely leached from the upper 10 feet (3 m) and is not fresh anywhere within this unit in the Oak Grove core (Figures 11, 12).

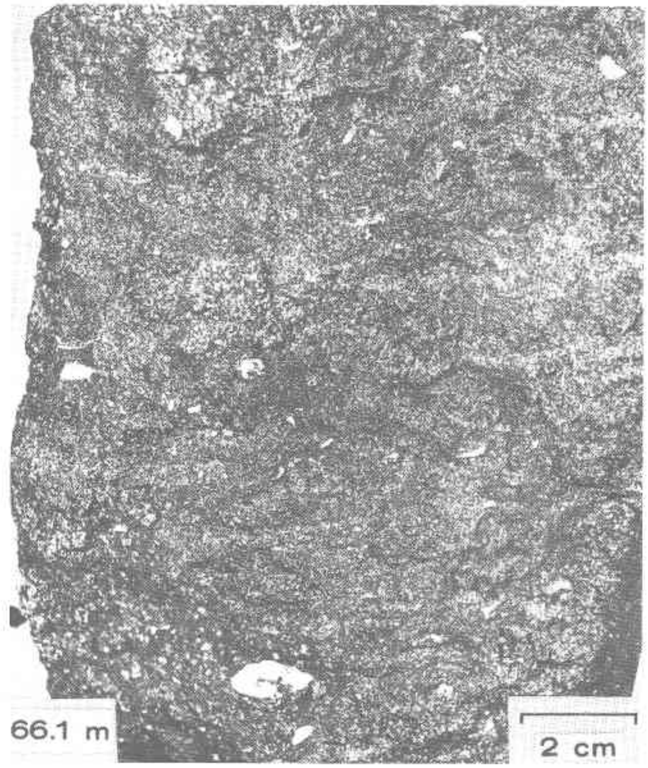


Figure 12. Massive greensand within the upper part of the Nanjemoy Formation containing leached whole bivalves and shell fragments crudely oriented along bedding (66.1 m = 216 feet).

CHESAPEAKE GROUP

Calvert Formation

The Calvert is a yellow-gray, fine-grained sediment which can be divided texturally into three distinct parts. The upper part (80 feet; 24.4 m thick) is composed dominantly of very fine, angular quartz sand (as much as 60 percent) in a fine silt to clay matrix (25-45 percent); a 10-foot-thick (3 m) diatomite and a basal 10-foot-thick (3 m) highly variable clay to coarse quartz sand constitute the remainder of the 100-foot-thick (30 m) Calvert.

The basal 10 feet (3 m) of the Calvert is a poorly sorted sand containing phosphatized shell fragments and quartz granules floating in a fine-grained matrix (Figure 13). Several erosional contacts marked by coarse sediment and shell lags occur within the interval (Figure 13). The contact with the underlying Pamunkey Group is texturally and compositionally sharp.

A highly diatomaceous interval (10-foot-thick; 3 m) within the Calvert (Fairhaven Member as used by Dryden and Overbeck, 1948) occupies the interval from approximately 180 to 190 feet (54.8 to 57.8 m) (elevation 0 to – 10 feet; 0 to – 3 m). Greater than 95 percent of the diatomite is finer than coarse silt. The

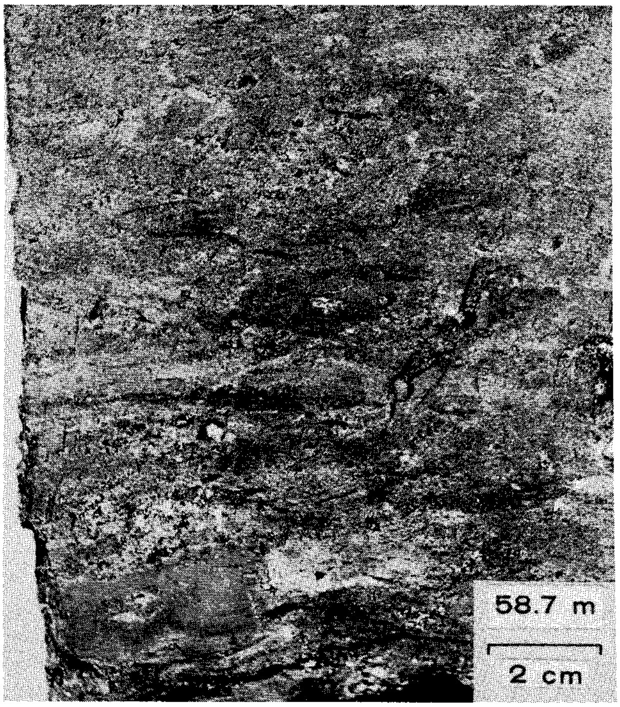


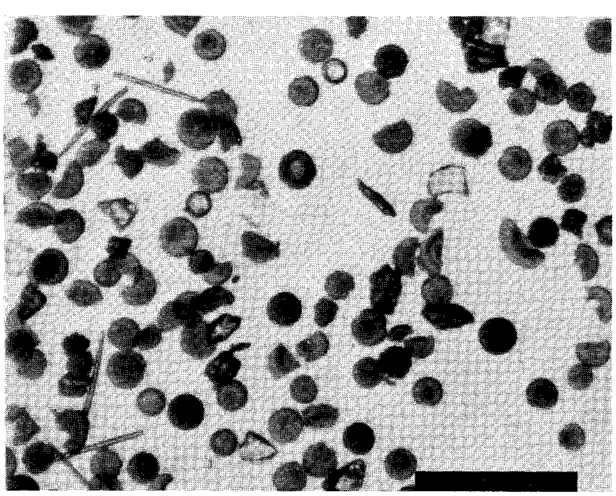
Figure 13. Upper part of basal poorly sorted sand unit of Calvert Formation contains shell molds, fragmented and leached shell material, quartz granules, and clay clasts (58.7 m = 192.5 feet).

very fine sand fraction is composed of well-rounded quartz grains, sponge spicules, and diatoms, especially *Conscinodiscus* sp. and *Cestodiscus* sp. (Figure 14A). The unit is slightly mottled and massively bedded with local relict primary sedimentary structures (Figure 14B) and becomes gradationally coarser at the base.

A substantial amount of granule-size lignitic debris is scattered throughout the Calvert, but is most abundant in the top 33 feet (10 m). Shark teeth, fish scales, small bone fragments and bivalve molds are distributed throughout the unit, but are most abundant in the lower one-half of the unit.

Relict bedding features are visible throughout much of the Calvert despite intense bioturbation. Sandy laminae are preserved in centimeter-size pods similar in scale to clay chips where bioturbation is incomplete (Figure 15). Distinct burrow structures are present throughout the unit and vary from random mottles produced by horizontal burrows to infilled vertical and back-filled U-shaped burrows (Figure 16).

The clay suite throughout the Calvert (on the basis of seven analyses) is predominantly illite (53-81 percent). Illite-smectite averages about 20 percent; kaolinite constitutes about 10 percent. Clinoptilolite is present in trace to considerable amounts in the lower one-half of the Calvert Formation, especially near the base of the unit. These data are somewhat different from the detailed mineralogy presented by Stefansson and Owens (1970) for the Baltimore Gas and Electric Company in Calvert County, Maryland. Considerably higher illite relative to illite/smectite by our analyses may result in part from the up-dip, down-dip changes in clay mineralogy within the Calvert. Additionally,



← 14A

14B

Figure 14. Textures and petrography of diatomite member of Calvert Formation. *A*. Photomicrograph of very fine sand-coarse silt fraction of diatomite (Fairhaven Member). Sample is from 182 feet (55.5 m). Note poorly rounded quartz grains, siliceous sponge spicules, and diatoms. Bar equals 1 mm. *B*. Core segment with relict primary sedimentary structures. Note componsitional change from medium silt to clayey silt near the base of this core segment. Bedding-plane view (at base of photograph) shows a dense pattern of horizontal burrows (55.3 m = 181.5 feet).

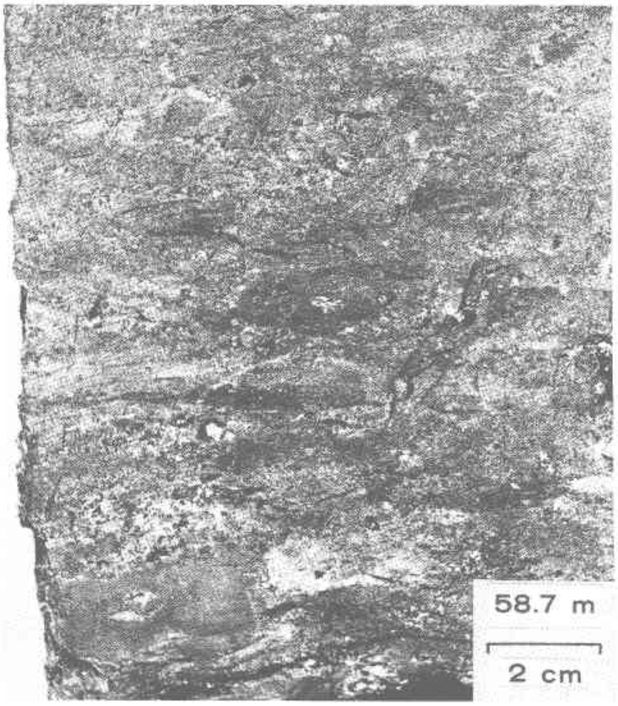


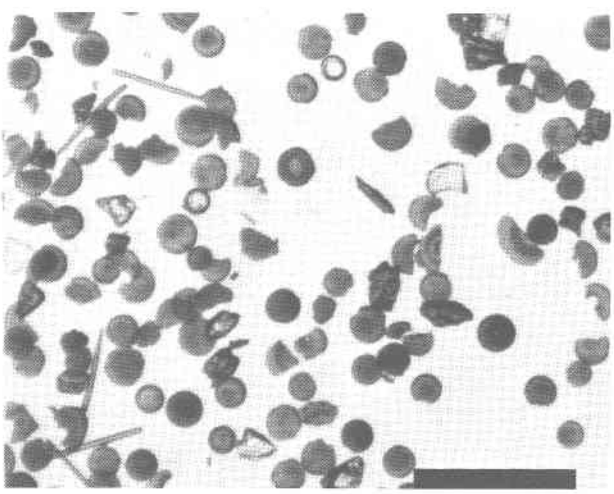
Figure 13. Upper part of basal poorly sorted sand unit of Calvert Formation contains shell molds, fragmented and leached shell material, quartz granules, and clay clasts (58.7 m = 192.5 feet).

very fine sand fraction is composed of well-rounded quartz grains, sponge spicules, and diatoms, especially *Conscinodiscus* sp. and *Cestodiscus* sp. (Figure 14A). The unit is slightly mottled and massively bedded with local relict primary sedimentary structures (Figure 14B) and becomes gradationally coarser at the base.

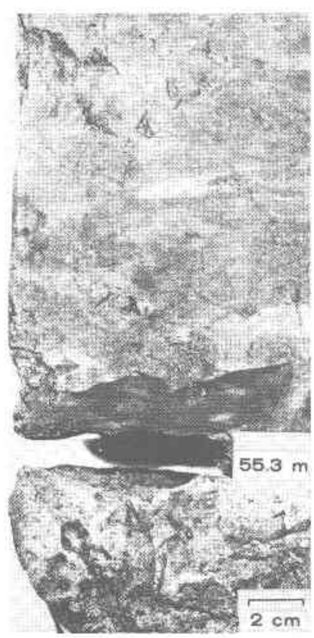
A substantial amount of granule-size lignitic debris is scattered throughout the Calvert, but is most abundant in the top 33 feet (10 m). Shark teeth, fish scales, small bone fragments and bivalve molds are distributed throughout the unit, but are most abundant in the lower one-half of the unit.

Relict bedding features are visible throughout much of the Calvert despite intense bioturbation. Sandy laminae are preserved in centimeter-size pods similar in scale to clay chips where bioturbation is incomplete (Figure 15). Distinct burrow structures are present throughout the unit and vary from random mottles produced by horizontal burrows to infilled vertical and back-filled U-shaped burrows (Figure 16).

The clay suite throughout the Calvert (on the basis of seven analyses) is predominantly illite (53-81 percent). Illite-smectite averages about 20 percent; kaolinite constitutes about 10 percent. Clinoptilolite is present in trace to considerable amounts in the lower one-half of the Calvert Formation, especially near the base of the unit. These data are somewhat different from the detailed mineralogy presented by Stefansson and Owens (1970) for the Baltimore Gas and Electric Company in Calvert County, Maryland. Considerably higher illite relative to illite/smectite by our analyses may result in part from the up-dip, down-dip changes in clay mineralogy within the Calvert. Additionally,



← 14A



14B

Figure 14. Textures and petrography of diatomite member of Calvert Formation. *A*. Photomicrograph of very fine sand-coarse silt fraction of diatomite (Fairhaven Member). Sample is from 182 feet (55.5 m). Note poorly rounded quartz grains, siliceous sponge spicules, and diatoms. Bar equals 1 mm. *B*. Core segment with relict primary sedimentary structures. Note componsitional change from medium silt to clayey silt near the base of this core segment. Bedding-plane view (at base of photograph) shows a dense pattern of horizontal burrows (55.3 m = 181.5 feet).

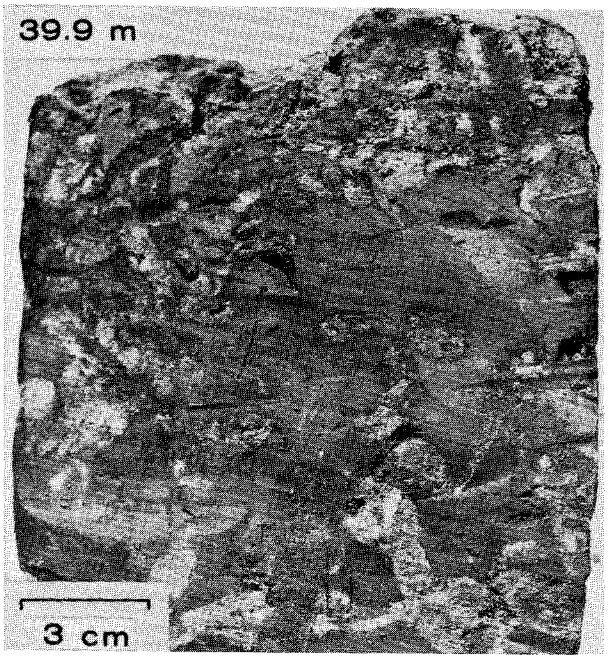


Figure 15. Burrowed clay containing sandy burrow backfills and vertical infills within dominantly sandy upper part of Calvert Formation. Locally, clay beds are fragmented by bioturbation, as in lower center of core segment (39.9 m = 131 feet).

Figure 16. U-shaped burrow with well-delineated backfills within a bioturbated fine clayey sand of the Calvert Formation (45.9 m = 150.5 feet).

differences in techniques of preparing clays for mineral analysis may have accentuated the apparent disparities (see Reynolds and Hower, 1970).

No sharp sedimentary contact between the Calvert and overlying Choptank Formation can be seen in the Oak Grove core. The contact was, in fact, first recognized biostratigraphically in this core on the basis of diatoms (G. W. Andrews, 1977, written communication). However, a change from moderately burrowed silty clay to bioturbated very fine quartz sand at a depth of approximately 100 feet (30.5 m) (elevation +82 feet; +25 m) corresponds to the Calvert-Choptank biostratigraphic zonation (Publication 20, Part 2).

Choptank Formation

The cored portion of the Choptank Formation is 20 feet (6.1 m) thick and in the Oak Grove core occupies the interval from 80 to 100 feet (24.4 to 30.5 m); the top 14 feet (4.4 m) of the unit were not cored. It is drab gray green and varies in texture from a slightly silty, dense clay (less than 5 percent coarse silt to sand) to a clayey silt in the lowermost 7 feet (2 m). The clay is composed predominantly of illite (approximately 50 percent) and contains nearly equal amounts of kaolinite and mixed-layer illite/smectite; trace amounts of vermiculite constitute the remaining clay fraction. Trace amounts of angular quartz, pyrite, and muscovite constitute the sand-coarse silt fraction. No heavy-mineral data was obtained from the Choptank Formation.

LITHOLOGIC TRENDS

Internal organization by texture, composition, or ordered sequences of sedimentary structures within most of the Tertiary interval of the Oak Grove core is not obvious from either the lithologic log or the geophysical logs (Figure 2). But within the Nanjemoy Formation two complete coarsening-upward sequences can be recognized. The Marlboro Clay constitutes the base of an additional coarsening-upward sequence.

The changes in composition from the arkosic Potomac Group (Lower Cretaceous part) to the glauconitic Pamunkey Group (Paleocene and Eocene) reflect different tectonic settings. The two groups, one continental and the other marine, are separated by more than 30 m.y. (million years). The changes from an Eocene marine greensand basin to a siliceous Miocene basin appear to be a less dramatic change in sedimentary environment. Tectonic activity during the 45 m.y. hiatus between Pamunkey and Chesapeake time is not well known

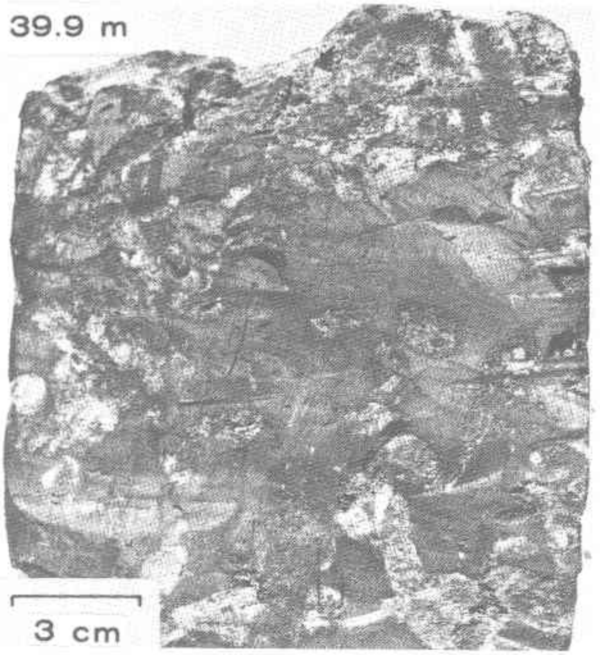


Figure 15. Burrowed clay containing sandy burrow backfills and vertical infills within dominantly sandy upper part of Calvert Formation. Locally, clay beds are fragmented by bioturbation, as in lower center of core segment (39.9 m = 131 feet).

Figure 16. U-shaped burrow with well-delineated backfills within a bioturbated fine clayey sand of the Calvert Formation (45.9 m = 150.5 feet).

differences in techniques of preparing clays for mineral analysis may have accentuated the apparent disparities (see Reynolds and Hower, 1970).

No sharp sedimentary contact between the Calvert and overlying Choptank Formation can be seen in the Oak Grove core. The contact was, in fact, first recognized biostratigraphically in this core on the basis of diatoms (G. W. Andrews, 1977, written communication). However, a change from moderately burrowed silty clay to bioturbated very fine quartz sand at a depth of approximately 100 feet (30.5 m) (elevation + 82 feet; + 25 m) corresponds to the Calvert-Choptank biostratigraphic zonation (Publication 20, Part 2).

Choptank Formation

The cored portion of the Choptank Formation is 20 feet (6.1 m) thick and in the Oak Grove core occupies the interval from 80 to 100 feet (24.4 to 30.5 m); the top 14 feet (4.4 m) of the unit were not cored. It is drab gray green and varies in texture from a slightly silty, dense clay (less than 5 percent coarse silt to sand) to a clayey silt in the lowermost 7 feet (2 m). The clay is composed predominantly of illite (approximately 50 percent) and contains nearly equal amounts of kaolinite and mixed-layer illite/smectite; trace amounts of vermiculite constitute the remaining clay fraction. Trace amounts of angular quartz, pyrite, and muscovite constitute the sand-coarse silt fraction. No heavy-mineral data was obtained from the Choptank Formation.

LITHOLOGIC TRENDS

Internal organization by texture, composition, or ordered sequences of sedimentary structures within most of the Tertiary interval of the Oak Grove core is not obvious from either the lithologic log or the geophysical logs (Figure 2). But within the Nanjemoy Formation two complete coarsening-upward sequences can be recognized. The Marlboro Clay constitutes the base of an additional coarsening-upward sequence.

The changes in composition from the arkosic Potomac Group (Lower Cretaceous part) to the glauconitic Pamunkey Group (Paleocene and Eocene) reflect different tectonic settings. The two groups, one continental and the other marine, are separated by more than 30 m.y. (million years). The changes from an Eocene marine greensand basin to a siliceous Miocene basin appear to be a less dramatic change in sedimentary environment. Tectonic activity during the 45 m.y. hiatus between Pamunkey and Chesapeake time is not well known in the Atlantic Coastal Plain (Gibson, 1970). Analysis of basin mobility during the Miocene in the Chesapeake Bay area suggests at least localized warping of the basin margins (Blackwelder and Ward, 1976).

A summary of clay and heavy-mineral data for Tertiary sediments are presented to aid discussion of the possible importance of major changes in heavy-mineral and clay suites within the two major sedimentary packages (lithostratigraphic groups) and across unconformities. The heavy-mineral data (Figure 17) result from analyses by J. P. Owens, U.S. Geological Survey. Within the Pamunkey Group unstable heavy minerals (hornblende-garnet suite) decrease from base to top. Near the Aquia-Marlboro contact is a large stable suite, dominated by well-rounded zircons and some tourmaline. In the aluminosilicate field, staurolite is dominant over sillimanite and kyanite throughout the Tertiary units in the core. The field marked "other" in Figure 17 is dominated by pyrite; in one Nanjemoy sample pyritized foraminifers constituted nearly 50 percent of the heavy-mineral separate.

The Calvert samples contain a large unstable heavy-mineral fraction dominated by garnet and epidote. Tourmaline exceeds zircon in the stable field, and chloritoid is an important "other" component. These results for heavy-mineral assemblages are generally in agreement with data presented by Glaser (1971) and Dryden and Overbeck (1948) from surface and shallow subsurface samples in nearby southern Maryland.

Semiquantitative clay analyses by M. H. Hess, U.S. Geological Survey, are presented in Figure 18. Illite is the dominant clay throughout most of the Tertiary with two notable exceptions. 1) At the top of the Nanjemoy (within the 10 foot, 3 m, leached zone), kaolinite is the dominant clay. This is attributed to clay-mineral diagenesis by fresh-water leaching. 2) The Marlboro Clay is dominantly kaolinite, although kaolinite and illite are nearly equal at the Aquia-Marlboro contact. The Marlboro kaolinite may have been formed by chemical alteration of illite by waters in the primary depositional environment (Grim, 1968) or, more likely, the clay mineral composition may be attributed to physical sorting by sediment size (see, for example, Gibbs, 1977). That the kaolinite/illite ratio in sediments decreases seaward from deposits in rivers, deltas, and estuaries has been documented (Porrenga, 1966; Edzwald and O'Melia, 1975; and others).

Data on distributions of vermiculite and clinoptilolite are presented in Figure 18.

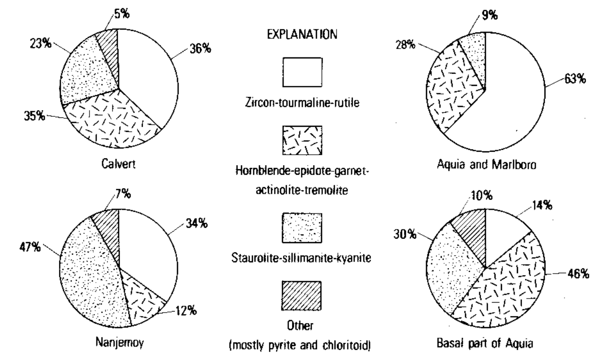


Figure 17. Compilation of heavy-mineral data from the Tertiary units in the Oak Grove core.

Arguments for a volcanic origin for these minerals and mineral associations have been made for a variety of Cretaceous and Tertiary examples (see, for example, Venkatarathnam and Biscaye, 1973; Walton, 1975). Interpretation of these minerals along with trace amounts of cristobalite found in a few samples requires further study.

DISCUSSION AND CONCLUSIONS

We have presented a variety of stratigraphic and petrologic data on the two major Tertiary sedimentary sequences in the Salisbury embayment. These data, especially when combined with biostratigraphic and paleoecological control (Publication 20, Part 2) provide a more detailed analysis than has been presented previously from cores in northeastern Virginia. Lack of physical sedimentary structures and lack of variation in the vertical sequences limit interpretations of sedimentary environments, but the absence is suggestive of stable, rather constant environments over considerable time periods. The generally mottled to massive appearance of the Tertiary sediments and the absence of sedimentary structures reflect a low rate of sedimentation, no rapid resedimentation by bottom currents, and an active infaunal population. Additionally, disseminated lignitic debris, scattered, mostly whole and occasionally imbricated shell material, and bedding plane concentrations of fish scales and mica flakes are evidence for weak bottom currents.

The Miocene sequence in the Oak Grove core is characterized by a high content of siliceous sediment both as fine-grained quartz and as diatom and sponge debris. The angularity of the sediments and the high clay content reflect a near-shore marine basin that received both terrigenous components (quartz, lignite) and marine components, especially diatoms.

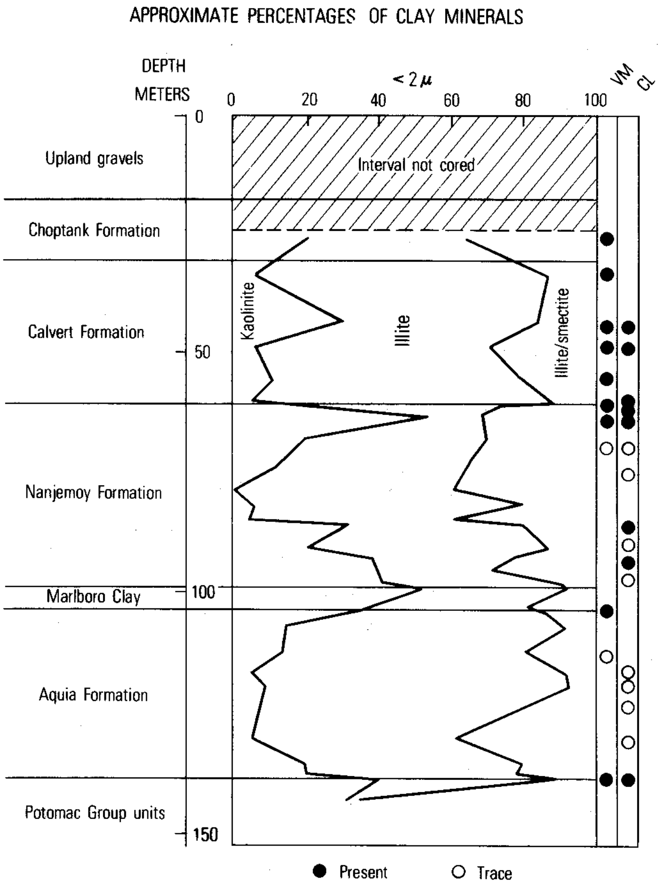


Figure 18. Clay composition of Tertiary sediments in the Oak Grove core. Semiquantitative results for major clay minerals are presented in main body of figure. Distribution of samples containing vermiculite (VM) and clinoptilolite (CL) is shown at right. Maximum dimension of clay analyzed is two microns.

A low sedimentation rate in the Pamunkey Group is suggested by the high percentage of authigenic glauconite and by the rounded, highly polished quartz grains. Except for the Marlboro Clay and thin clayey sequences within the Nanjemoy, the Pamunkey is a notably clean, well sorted sand. This may be the result of either a very low clastic input, reflecting an extremely stable and (or) protected shelf configuration, or of constant winnowing of fine sediment by bottom currents.

Except for paleoecological data, a major key to understanding the Pamunkey Group may be the character and position of the Marlboro Clay. This unit represents a considerable divergence in texture and mineralogy from the remainder of the Pamunkey Group. The key features are an abundant stable heavy-mineral suite, a high kaolinite content, and reworked Paleozoic and Late Cretaceous palynomorphs (N. O. Fredericksen, oral communication, 1977; Publication 20, Part 2). These features reflect a strong extrabasinal influence, presumably runoff from a low and deeply weathered Piedmont and inner Coastal Plain terrain immediately to the west. The geometry, consistent lithology, and thickness of the Marlboro over a considerable area are evidence that these fine sediments were ponded in a protected, low-energy basin, such as a shallow estuary or lagoon. These concepts appear to be consistent with the paleogeographic facies geometry proposed for the Aquia (Drobnyk, 1965; Hansen, 1974) and are within the framework of sedimentary features seen in the outcropping Marlboro (Glaser, 1971).

REFERENCES

Anderson, J. L., 1948, Cretaceous and Tertiary subsurface geology: Maryland Dept. Geology, Mines and Water Resources Bull. 2, 456 p.

Andrews, G. W., 1976, Miocene marine diatoms from the Choptank Formation, Calvert County, Maryland: U.S. Geol. Survey Prof. Paper 910, 26 p.

Blackwelder, B. W., and Ward, L. W., 1976, Stratigraphy of the Chesapeake Group of Maryland and Virginia: Geol. Soc. America, Northeastern-Southeastern Meeting, Arlington, Virginia, 1976, Guidebook for Field Trip 7b, 55 p.

Brown, P. M., Miller, J. A., and Swain, F. M., 1972, Structural and stratigraphic framework, and spatial distribution of permeability of the Atlantic Coastal Plain, North Carolina to New York: U.S. Geol. Survey Prof. Paper 796, 79 p.

Drobnyk, J. W., 1965, Petrology of the Paleocene-Eocene Aquia Formation of Virginia, Maryland and Delaware: Jour. of Sed. Petrology, vol. 35, no. 3, p. 626-642.

Dryden, Lincoln and Overbeck, R. M., 1948, Geology of Charles County, Maryland: Maryland Dept. Geology Mines and Water Resources, 267 p.

Edzwald, J. K., and O'Melia, C. R., 1975, Clay distribution in recent estuarine sediments: Clays and Clay Minerals, vol. 23, no. 1, p. 39-44.

Folger, D. W., and others 1978, Stratigraphic test well, Nantucket Island, Massachusetts: U.S. Geol. Survey Circular 773, 28 p.

Gernant, R. E., 1970, Paleoecology of the Choptank Formation (Miocene) of Maryland and Virginia: Maryland Geol. Survey Rept. Inv. no.12, 90 p.

Gibbs, R. J., 1977, Clay mineral segregation in the marine environment: Jour. of Sed. Petrology, vol. 47, no. 1, p. 237-243.

Gibson, T. G., 1970, Late Mesozoic and Cenozoic tectonic aspects of the Atlantic coastal margin: Geol. Soc. America Bull., vol. 1, no. 6, p. 1813-1822.

Glaser, J. D., 1971, Geology and mineral resources of Southern Maryland: Maryland Geol. Survey Rept. Inv. no. 15, 84 p.

Grim, R. E., 1968, Clay mineralogy (2nd ed.): New York, McGraw-Hill, 596 p.

Goddard, E. N., and others, 1948, Rock-color chart: Washington, D.C., National Research Council, 6 p. [Republished by Geol. Soc. America, 1975].

Gohn, G. S., and others, 1977, Lithostratigraphy of the deep corehold (Clubhouse Crossroads corehole 1) near Charleston, South Carolina, Chapter E, *in* Geological, geophysical, and seismological studies related to the Charleston, South Carolina earthquake of 1886; a preliminary report: U.S. Geol. Survey Prof. Paper 1028, p. 59-70.

Gohn, G. S., and others, 1978, Preliminary report on the geology of two deep test holes, Clubhouse Crossroads #2 and #3, near Charleston, South Carolina (abs.): Geol. Soc. America Abs. vol. 10, no. 4, p. 169-170.

Hack, J. T., 1955, Geology of the Brandywine area and origin of the upland of Southern Maryland: U.S. Geol. Survey Prof. Paper 267-A, 42 p.

Hansen, H. J., III, 1968, Geophysical log cross-section network of the Cretaceous sediments of southern Maryland: Maryland Geol. Survey, Rept. Inv. no. 7, 46 p.

__________________, 1974, Sedimentary facies of the Aquia Formation in the subsurface of the Maryland Coast Plain: Maryland Geol. Survey Rept. Inv. no. 21, 47 p.

Porrenga, D. H., 1966, Clay minerals in Recent sediments of the Niger Delta: National Conference on Clays and Clay Minerals, 14th, Proceedings, vol. 26, p. 221-223.

Reinhardt, Juergen, Newell, W. L., and Mixon, R. B., 1977, Tertiary lithostratigraphy of the Oak Grove core, northeastern Virginia (abs.): Am. Association Petroleum Geologists, vol. 61, no. 5, p. 822.

Reynolds, R. C., Jr., and Hower, John, 1970, The nature of interlayering in mixed-layer illite-montmorillonites: Clays and Clay Minerals, vol. 18, no. 1, p. 25-36.

Schlee, J. S., 1957, Upland gravels of southern Maryland: Geol. Soc. America Bull., vol. 68, no. 10, p. 1371-1409.

Stefansson, Karl, and Owens, J. P., 1970, Clay mineralogy of selected samples from the middle Miocene formations of Southern Maryland, *in* Geological Survey Research 1970, chapter B: U.S. Geol. Survey Prof. Paper 700-B, p. B150-B156.

Teifke, R. H., 1973, Stratigraphic units of the Lower Cretaceous through Miocene series, *in* Geologic studies, Coastal Plain of Virginia: Virginia Division of Mineral Resources Bulletin 83, pt. 1, p. 1-78.

Venkatarathnam, Kolla, and Biscaye, P. E., 1973, Deep-sea zeolites; variations in space and time in the sediments of the Indian Ocean: Marine Geology, vol. 15, no. 1, p. M11-M17.

Walton, A. W., 1975, Zeolite diagenesis in Oligiocene volcanic sediments, Trans-Pecos Texas: Geol. Soc. America Bull., vol. 86, no. 5, p. 615-624.

PART 2
BIOSTRATIGRAPHY OF THE TERTIARY STRATA OF THE CORE[1]

By

Thomas G. Gibson[2], George W. Andrews[2], Laurel M. Bybell[2], Norman O. Frederiksen[3], Thor Hansen[4], Joseph E. Hazel[2], Dewey M. McLean[5], Roger J. Witmer[6], D. S. Van Nieuwenhuise[7].

CONTENTS

ILLUSTRATIONS

---

[1] Portions of this publication may be quoted if credit is given to the Virginia Division of Mineral Resources. It is recommended that reference to this report be made in the following form: Gibson, T.G. and others, 1980, Biostratigraphy of the Tertiary strata of the core, *in* Geology of the Oak Grove core: Virginia Division of Mineral Resources Publication 20, Part 2, 88 p.

[2] U.S. Geological Survey, Washington, D.C.
[3] U.S. Geological Survey, Reston, Virginia
[4] Yale University, New Haven, Connecticut
[5] Virginia Polytechnic Institute and State University, Blacksburg, Virginia
[6] U.S. Geological Survey, Menlo Park, California
[7] University of South Carolina, Columbia, South Carolina

ABSTRACT

Biostratigraphic and paleoenvironmental study of the Tertiary strata in a continuously cored hole near Oak Grove in northeastern Virginia utilized sporomorphs, dinoflagellates, diatoms, calcareous nannofossils, foraminifers, ostracodes, and mollusks.

The oldest Tertiary unit in the core, the Aquia Formation, has basal strata of probable early Paleocene age; a late Paleocene age is assigned the middle and upper parts of the Aquia. The upper part of the formation is thinner than equivalent strata in the type area along the Potomac River. Deposition was in slightly fluctuating water depths of inner shelf environments. The lower part of the overlying Marlboro Clay is latest Paleocene in age and the upper part is possibly earliest Eocene. This formation was deposited in brackish waters and may be the first unit found in the area to span the Paleocene-Eocene boundary. The overlying Nanjemoy Formation contains strata of early Eocene age only in the core; middle Eocene strata, found in the formation to the south, do not occur in the core. Its thickness is similar to that found in the type area along the Potomac River. Deposition was in inner to possibly middle shelf water depths; shallowing is indicated at the top of the formation. The Calvert and Choptank formations of early to middle Miocene age overlie the Paleogene strata and are of marine origin. The Calvert is considerably thinner here than at Calvert Cliffs to the northeast.

INTRODUCTION

A continuous core through 380 feet (115.9 m) of Tertiary strata in northeastern Virginia made possible the investigation of lithostratigraphic units and contact relationships which are poorly exposed or sparsely fossiliferous in area outcrops. The continuous core allowed the examination of fossil groups in a sequence of known order of superposition, in contrast to the usual outcrop pattern of small, discontinuous exposures of questionable relationship. This study gives biostratigraphic information from calcareous and organic-walled organisms in the Paleocene and Eocene strata and siliceous and some organic-walled organisms in the Miocene strata. The joint paleontologic investigation by workers in various groups of fossils led to a knowledge of the biostratigraphy which would not have been possible if based on any single group.

The Oak Grove core hole is located 6.3 miles (3.9 km) west-southwest of Oak Grove, Westmoreland County, Virginia. The well head is at an elevation of 180 feet (54.8 m), and the strata were cored from a depth of 80 to 1380 feet (24.4 to 420.6 m) below the well head. The contact between Cretaceous and Tertiary strata is 455 feet (138.6 m) below the well head at an elevation of minus 275 feet (– 83.8 m).

The biologic groups, ages of strata studied, and paleontologists are as follows: diatoms (Miocene), G.W. Andrews; calcareous nannofossils (Paleocene and Eocene), L.M. Bybell; sporomorphs (Paleocene and Eocene), N.O. Frederiksen; foraminifers (Paleocene and Eocene), T.G. Gibson; mollusks (Eocene), Thor Hansen; ostracodes (Paleocene and Eocene), J.E. Hazel and D.S. van Nieuwenhuise; and dinoflagellates (Paleocene, Eocene, and Miocene), D.M. McLean and R.J. Witmer.

SAMPLING

The core was jointly sampled for the various microfossil groups to provide results from common samples. Samples were taken at any noticeable sedimentological or megafaunal change, or in apparently uniform portions of the core at intervals of approximately 3.3 to 4.3 feet (1.0 to 1.3 m). A wafer-like sample approximately 2.4 to 3.1 inches (6 to 8 cm) thick was taken from one-half the width of the core, and this was broken into subsamples. The largest subsample was processed for foraminifers and ostracodes; another, for sporomorphs and dinoflagellates; and a smaller subsample, for calcareous nannofossils. Diatom samples were taken adjacent to those for the other microfossils. Mollusks were collected from separate, larger samples, primarily in the shelly intervals.

A total of 102 microfossil samples were taken in the Paleocene, Eocene, and Miocene sections of the core for joint use. Twenty-seven of these were from the 114 feet (34.8 m) of the Aquia Formation, four in the 18 feet (5.4 m) of the Marlboro Clay, 37 in the 123 feet (37.4 m) of the Nanjemoy Formation, and 34 in the 134 feet (40.8 m) of the Calvert and Choptank formations. In addition, 33 diatom samples were taken from the Miocene section and 20 molluscan samples from the Nanjemoy Formation.

ACKNOWLEDGEMENTS

Laboratory preparation of the fauna and flora in the samples was performed by Betsy Funk, Patricia Swain, Tony Bryant, and Orrin Oftedahl. Juergen Reinhardt and Norman Sohl critically reviewed the manuscript.

STRATIGRAPHY

Two distinctive depositional groupings of sediments were penetrated and sampled in the Tertiary part of the Oak Grove core, one composed largely of glauconitic sands and clays of the Pamunkey Group of Paleocene and Eocene age and the other of diatomaceous sands and clays of the Chesapeake Group of Miocene age. The ages and paleoenvironments represented by the two groupings will be discussed in this paper in order from oldest to the youngest unit (Figure 1).

PAMUNKEY GROUP

The Paleocene-Eocene sedimentary package includes three formations, these are, in ascending order: sparsely shelly, glauconitic sands of the Aquia Formation; gray to red compact clays of the Marlboro Clay; and shelly, glauconitic sands and clayey sands of the Nanjemoy Formation. In Maryland, near the District of Columbia, the Brightseat Formation is the basal unit of the Pamunkey Group (Hazel, 1968, 1969). Beds lithologically similar to the Brightseat Formation were not recognized in the Oak Grove core but strata provisionally placed at the base of the Aquia Formation may be time equivalent.

Aquia Formation

The Aquia Formation extends from 340 to 454 feet (103.6 to 138.4 m) in the core, and is a medium- to dark-green, massive, fine- to medium-grained glauconitic sand with sparse shelly intervals.

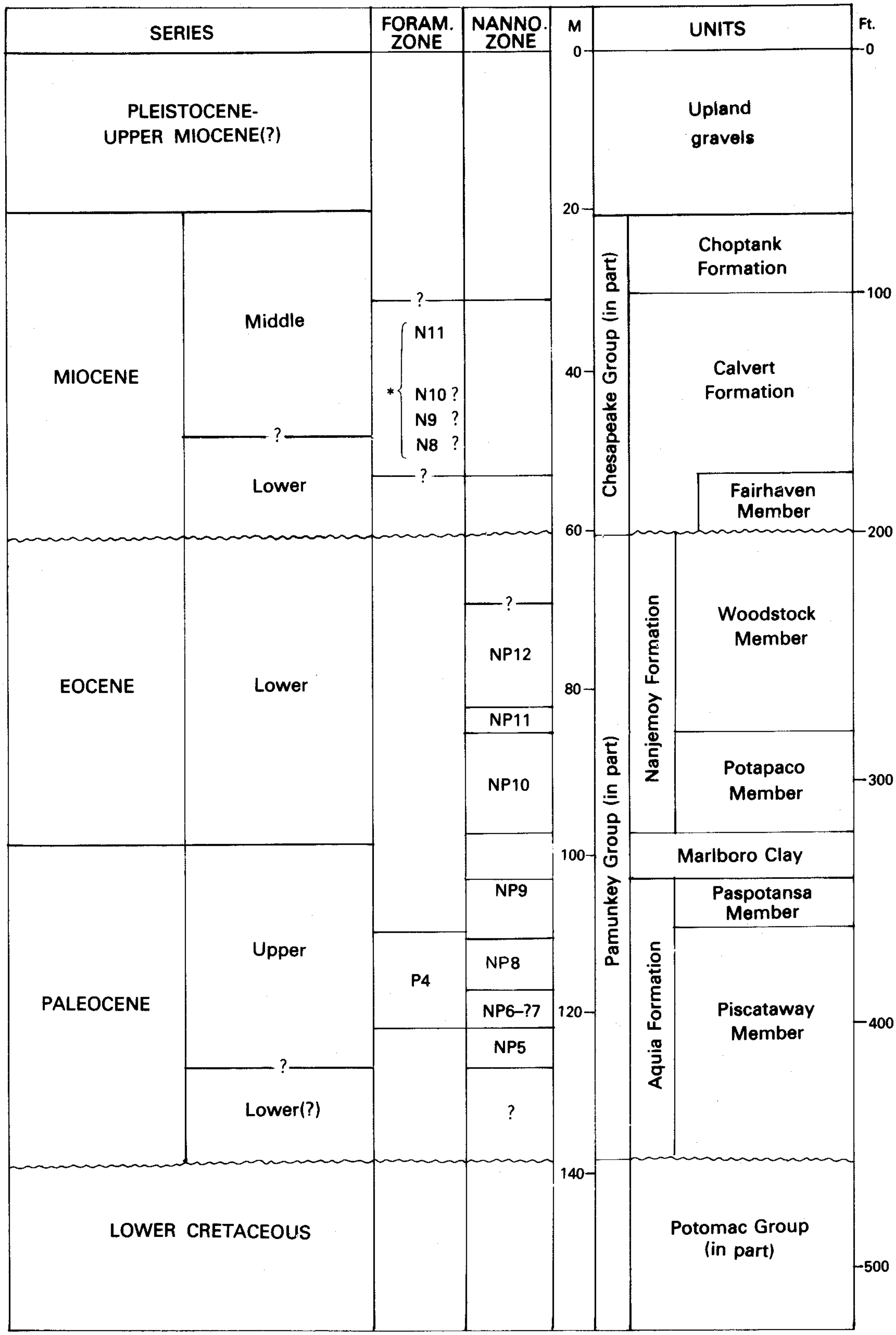
The lowest 41 feet (12.5 m) (454 to 413 feet; 138.4 to 125.9 m) of the Tertiary section in the core is assigned to the Aquia Formation on lithologic grounds. This interval does not contain calcareous fossils, but does have sporomorphs and dinoflagellates. The presence of the dinoflagellates *Danea mutabilis* Morgenroth and *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant in this interval suggests a Danian or early Paleocene age as these species have not been found in younger rocks elsewhere (Figure 2). Both species are present in the Brightseat Formation (early Paleocene) in Maryland, but are absent from the basal strata of the overlying Aquia Formation both at its type locality along the Potomac River and in outcrops near Richmond, Virginia.

Most sporomorphs from the lower 41 feet (12.5 m) of the Aquia are similar to those higher in the unit. However, four species, each represented by very rare specimens, were observed only between 451 and 421 feet (137.6 and 128.3 m) within the basal unit; each of these occurred in one sample only (except for the first species on the following list), and therefore they are not shown on the range chart (Figure 3). The species are *Pseudoplicapollis* cf. *P. endocuspis* Tschudy, *Choanopollenites* cf. *C. consanguineus* Tschudy, *Choanopollenites*? sp. and *Choanopollenites conspicuus* (Groot and Groot) Tschudy. This last species, *Choanopollenites conspicuus*, is known only from the lower Paleocene of the Gulf Coast and from the Brightseat Formation (also lower Paleocene) of Maryland. The other three species on the list are not firmly identified; their congeners have not previously been reported from the Gulf and Atlantic Coastal Plains. Most previously described species of *Choanopollenites* are confined to the Upper Cretaceous and (or) lower Paleocene on the Gulf Coast (Tschudy, 1973). On the other hand, several pollen species typical of lower Paleocene rocks in the southeastern United States, such as *Momipites dilatus* (Fairchild) Nichols and *Pseudoplicapollis serena* Tschudy, were not observed in samples from the Oak Grove core. *Carya* pollen is abundant from the lowest Tertiary sample (451 feet; 137.6 m) and upwards into the Nanjemoy; the known range base of this genus is the middle part of the upper Paleocene in the Gulf Coast in South Carolina. The fact that *Carya* occurs in abundance together with probable early Paleocene pollen and dinoflagellates means that the genus ranges much lower in the section in Virginia than it apparently does farther south in the United States.

Until investigations of fossil groups in surrounding areas are completed, the basal Aquia in the core will be considered as questionable early Paleocene in light of the conflicting evidence.

An unconformity occurs between the Brightseat Formation and the overlying Aquia Formation in outcrop sections in southern Maryland (Hazel, 1969; Bybell and Govoni, 1977). The unconformity has been recognized in the subsurface in east-central Maryland (Hansen, 1977). No lithologic evidence of it was seen in the core (Publication 20, Part 1), and the question of a time gap at this position is pending resolution of the age of the lowermost beds in the core. A maximum time interval for the unconformity of 3.5 m.y. (million years), or the upper one-half of early Paleocene (Danian) time, has been proposed (Bybell and Govoni, 1977).

The Aquia Formation, previously considered Eocene (Clark and Martin, 1901; Shifflett, 1948), was placed in the upper Paleocene on the basis of planktonic Foraminifera (Loeblich and Tappan 1957). A late early Paleocene date applied to the base of the Aquia (Nogan, 1964) was shown to be



*extrapolated from Calvert Cliffs, Maryland

Figure 1. Geologic column for Oak Grove core. (Ages and zones from Berggren, 1972. Zone symbols are: N, Neogene; P, Paleogene; NP, nannoplankton. N and P zones are based on planktonic Foraminifera.)

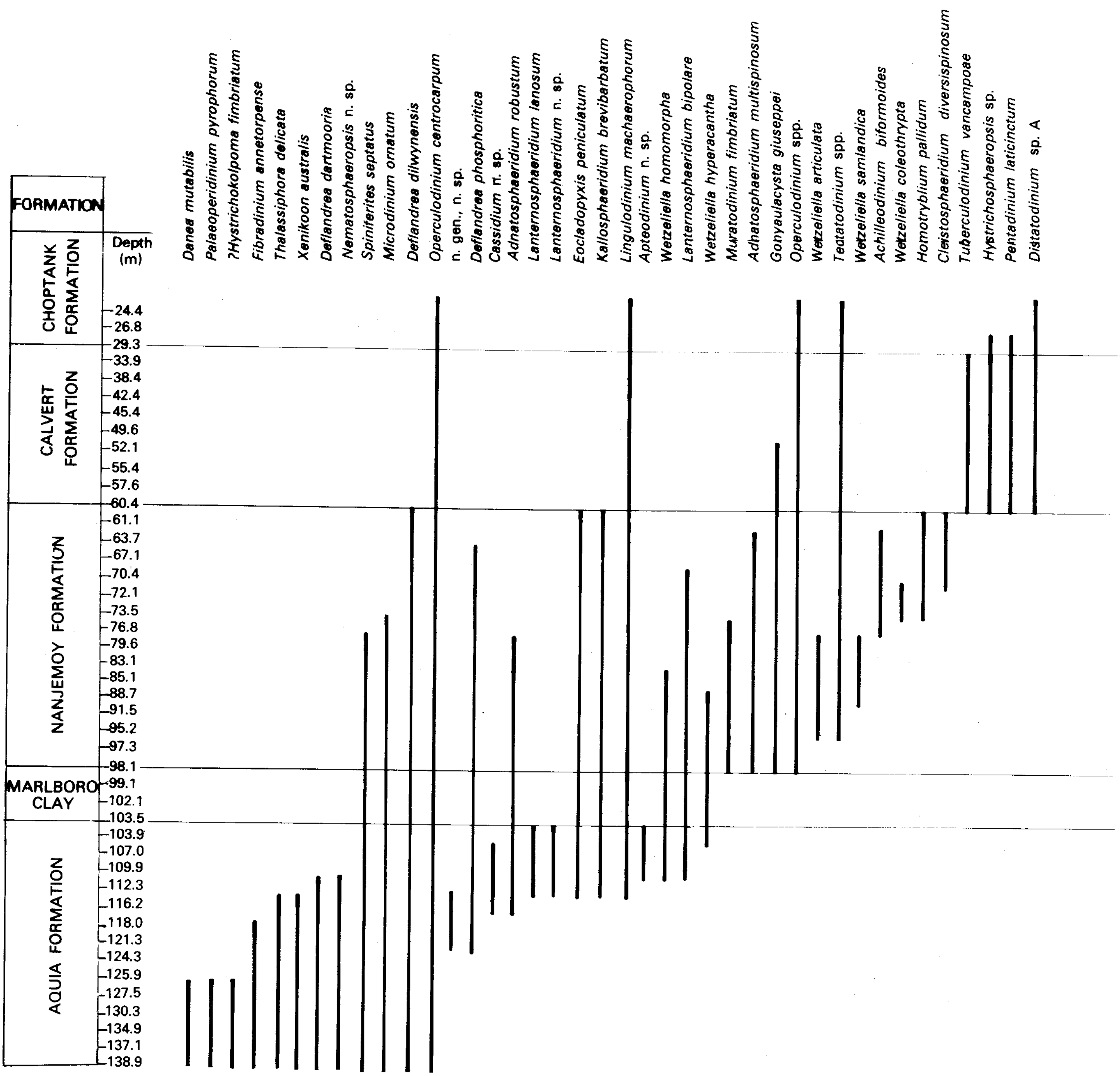


Figure 2. Distribution of selected species of dinoflagellates in the Tertiary strata of the Oak Grove core.

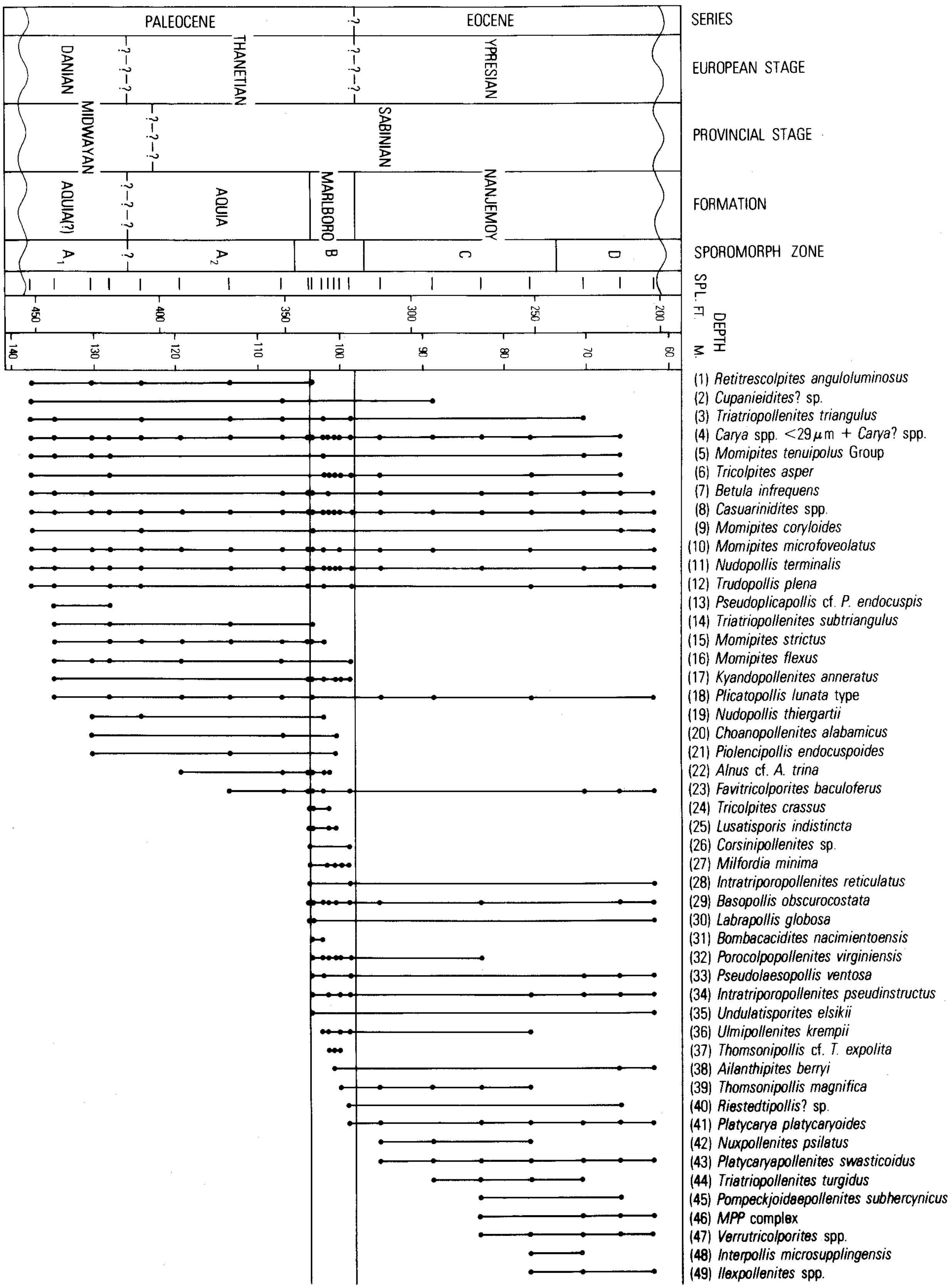


Figure 3. Distribution of sporomorphs in the Paleocene and Eocene strata of the Oak Grove core. Dots on range lines show sample locations.

incorrect (Hazel, 1969). An early late Paleocene age for the basal Aquia has been indicated (Hazel, 1969; Hansen, 1977; Bybell and Govoni, 1977).

An early Eocene age for the top of the Aquia (Nogan, 1964) was based upon an earlier assignment of the *Morozovella velascoensis* zone to the early Eocene (Olsson, 1963); this zone has been retained in the Paleocene by other workers in planktonic Foraminifera (Berggren, 1972). All outcrop samples of the Aquia Formation in northern Virginia and southern Maryland yield late Paleocene ages based upon calcareous nannofossils (L.M. Bybell, 1978, unpublished data). Some of the subsurface Aquia Formation from northern Prince Georges County, Maryland, was placed into the early Eocene on the basis of planktonic Foraminifera and potassium-argon dating of glauconite in the strata (Hansen, 1977). The potassium-argon date of 51.9 ± 2.0 m.y. could be as old as late Paleocene by its lower age limit and thus is presently inconclusive.

A late Paleocene age for all of the Aquia Formation in the Oak Grove core above the lowest 41 feet (12.5 m) is indicated by the present work (Figure 1). Calcareous nannofossils indicate the presence of zones NP 5, NP 6, NP 8, and NP 9, which comprise most of the middle and upper parts of the late Paleocene (Figure 4). Zone NP 5 extends from 413 to 402 feet (125.9 to 122.8 m), and is based upon the first occurrence of *Fasciculithus.* Zone NP 6 extends from 398 to 387 feet (121.3 to 118.0 m), its base is characterized by the first occurrence of *Heliolithus kleinpelli* Sullivan. Zone NP 7 was not recognized in the core and may not be present either because of non-deposition or very shallow water sedimentation during that time interval. Zone NP 8 extends from 384 to 372 feet (117.2 to 113.5 m); its base is marked by the first occurrence of *Heliolithus riedeli* Bramlette and Sullivan. The uppermost zone of the Paleocene, NP 9, extends from 358 to 341 feet (109.1 to 103.9 m), and its base is recognized by the first occurrence of *Discoaster multiradiatus* Bramlette and Riedel.

The presence of the planktonic foraminiferal species *Planorotalites pseudomenardii* (Bolli) and *Morozovella velascoensis* (Cushman) at 384 feet (117.2 m), and the continued presence of *P. pseudomenardii* up to 378 feet (115.4 m) place this interval in foraminiferal zone P 4 (Figure 1). This placement agrees with the assignment of calcareous nannofossil zone NP 8 for this interval.

Sporomorphs in the interval from 408 feet (124.3 m) to the top of the Aquia Formation, 340 feet (103.6 m), are similar to late Paleocene assemblages from the southeastern United States. However, all or nearly all of the species in this interval of the core range into the lower Paleocene. No early Paleocene sporomorph species were found in the core. Some dinoflagellates in the core also occur in the Aquia Formation at its type locality (McLean, 1969). Lithologic units or "zones" established at the type locality (Clark and Martin, 1901) were founded upon lithologic changes such as abundance of shells, induration, grain size, etc., and actually are lithostratigraphic units. Biostratigraphic recognition of the beds, however, is possible in many cases because of subsequent work on the faunal sequences. The lowest seven beds compose the lower, Piscataway Member of the Aquia, and beds 8 and 9 comprise the upper, Paspotansa Member. Only beds 1, 2, 4, 5 and 6 were recognized in the core. The Aquia Formation in the core below 413 feet (125.9 m) contains *Danea mutabilis* Morgenroth and *Palaeoperidinium pyrophorum* (Ehrenberg) Sargeant, characteristic of bed 1 along Aquia Creek (Figure 2). Based on the last occurrence of *Fibradinium annetorpense* Morgenroth and the first occurrences of *Deflandrea phosphoritica* Eisenack and an undescribed new genus, bed 2 extends from 413 feet (125.9 m) up to at least 398 feet (121.3 m). On the basis of the last ocurrences of *Thalassiphora delicata* Williams and Downie and *Xenikoon australis* Cookson and Eisenack and the first occurrences of *Cassisium* n. sp. and *Adnatosphaeridium robustum* (Morgenroth) DeConinck, bed 4 is present to at least 381 feet (116.2 m). The last occurrences of *Deflandrea dartmooria* Cookson and Eisenack and *Nematosphaeropsis* n. sp. and the first occurrences of *Eocladopyxis peniculatum* Morgenroth and *Lingulodinium machaerophorum* (Deflandrea and Cookson) Wall suggest that bed 5 extends up to at least 368 feet (112.3 m). Based on the first occurrences of *Apteodinium* n. sp., *Wetzeliella homomorpha* Deflandrea and Cookson, and *Lanternosphaeridium bipolare* (Cookson and Eisenack) DeConinck, bed 6 appears to begin at a depth of 360 feet (109.9 m). (The remaining strata were not assigned to beds as they lack diagnostic forms.) A similar dinoflagellate distribution was observed in Aquia strata equivalent to beds 2 to 6 near Richmond, Virginia (Witmer, 1975). The *Wetzeliella homomorpha/ W. hyperacantha* dinoflagellate zone in eastern France begins at the base of calcareous nannofossil zone NP 9 (Jan du Chene and others, 1975). The lower boundary of this dinoflagellate zone is recognized at a depth of 360 feet (109.9 m), precisely where the base of NP 9 was independently placed.

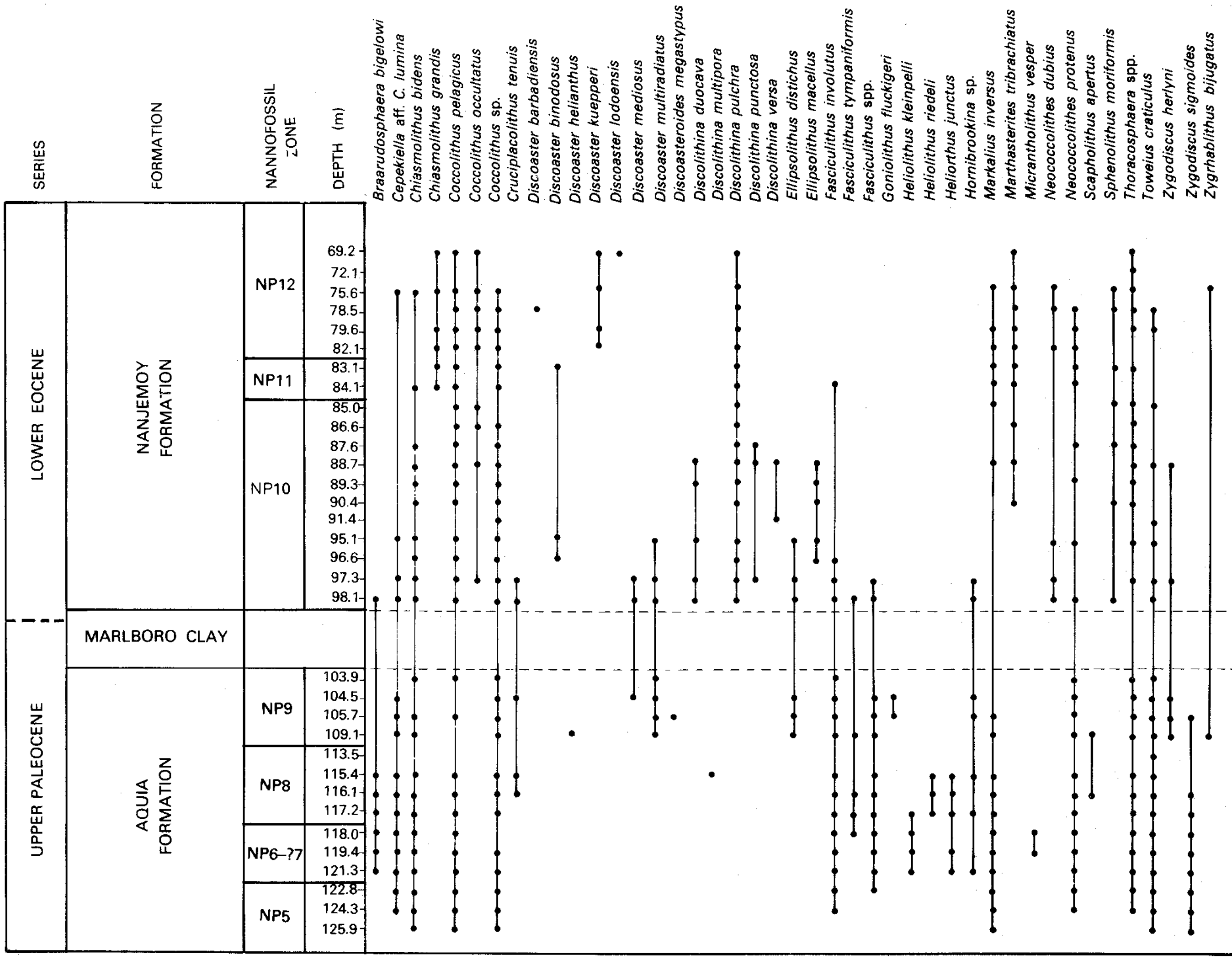


Figure 4. Distribution of calcareous nannofossils in the Paleocene and Eocene strata of the Oak Grove core. Dots on range lines show sample locations.

Ostracode assemblages from 340 to 403 feet (103.6 to 123 m) are all indicative of the range zone of *Haplocytheridea leei* (Howe and Garrett); this species occurs in the upper part of the Piscataway Member and the overlying Paspotansa Member of the Aquia Formation in the Potomac valley (Hazel, 1969). An unusual, new species of *Triginglymus* or a related genus occurs at 397 feet (121 m); the only other occurrence of this species is in a bryozoan bed of the Aquia in the area of Upper Marlboro, Maryland.

Environment of deposition: The lowest 41 feet (12.5 m) of the Aquia Formation does not contain calcareous fossils, but molluscan molds do occur. The presence of dinoflagellates indicates marine conditions for this part of the section.

The lowest sample containing Foraminifera is at 413 feet (125.9 m); it has 16 species and a planktonic proportion of 0.5 percent (Figure 5), indicating shallow marine waters probably less than 98 feet (30 m) deep (see Gibson, 1968, and Gibson and Buzas, 1973, for discussions and further references on paleoenvironmental reconstructions based on Foraminifera). That water depth was greater for deposits higher in the core to 390 feet (118.9 m) is indicated by an increase in species to 32 and by a planktonic fraction approaching 30 percent. Above this level, the water shoaled, probably reaching a minimum at a core depth of about 372 feet (113.4 m). The benthonic foraminiferal assemblage changes in this core interval (Figure 6), and nine dinoflagellate species begin and four terminate between core depths of 381 and 368 feet (116.2 and 112.3 m). This interval may include a diastem. Above 360 feet (109.7 m) the bathymetry increases slightly to water depths of 49 to 197 feet (15 to 60 m). These inner shelf conditions continue to the top of the Aquia, followed by a rapid change in the Marlboro Clay.

Dinoflagellates comprise 30 to 55 species in the Aquia Formation (of which 25 are shown in Figure 2). Generally, more species occur in the interval from 454 to 413 feet (138.4 to 125.9 m). Species of *Areoligera* are particularly abundant from 454 to 387 feet (138.4 to 118.0 m), suggesting open sea conditions (Downie and others, 1971). Great numbers of *Wetzeliella homomorpha* Deflandrea and Cookson at 341 feet (103.9 m) may indicate the onset of brackish water (Downie and others, 1971).

Marlboro Clay

This unit consists of red and gray clays and extends from east of Washington, D.C. southward to the vicinity of Richmond, Virginia, with a maximum thickness of 30 feet (9.1 m) (Glaser, 1971). The lithologic distinctiveness over a distance of approximately 100 miles led Glaser to consider the Marlboro Clay a separate formation. The unit extends from 322 to 340 feet (98.2 to 103.6 m) in the core, and consists of gray and red clays like those in outcrop.

The lower contact is gradational from glauconitic sands of the Aquia to clays containing thin sand laminae, to typical Marlboro clays over a 2.5 inch (10 cm) interval. The uppermost 7 feet (2 m) of the Marlboro is marked by extensive burrows filled with glauconitic sands and fossils, both from the overlying Nanjemoy Formation.

Calcareous fossils, consisting of small mollusks found only in the gray clays, are rare. No calcareous microfauna was found in the core, but the strata contain sporomorphs, dinoflagellates, and agglutinated Foraminifera. The Foraminifera cannot be used for correlation because their ranges in other areas are unknown.

The only abundant dinoflagellate species in the Marlboro Clay is *Deflandrea dilwynensis* Cookson and Eisenack, which continues in somewhat lesser abundance into the overlying Nanjemoy Formation, the species is also found in the Aquia (Figure 2).

Sporomorph assemblages are found throughout the Marlboro, and they provide the basis for dating the unit by correlation with assemblages from the Gulf Coast and southern Atlantic Coastal Plain. Unfortunately, detailed palynological studies with close sample spacing do not exist for the strata spanning the Paleocene-Eocene boundary either on the Gulf Coast or in South Carolina. Unconformities in this part of the column also complicate the establishment of a continuous zonation.

Seven sporomorph types first occur in the uppermost Aquia (sample from 340 feet; 103.8 m), and five more have first occurrences in the lowermost Marlboro Clay (339 feet; 103.5 m) (Figure 3). Possible explanations for the rapid introduction of new sporomorph types near the boundary are 1) some streams supplying the Marlboro sediments may have come from a different source area than previously and 2) a climatic change may have occurred at the end of Aquia time, causing migration of new plant types into the region.

Momipites sp., *Platycarya* sp. and *Platycarya swastocoida* Elsik, all members of the Juglandaceae, are important species for correlating the Marlboro Clay (see Frederiksen and Christopher, in press, for details on the distribution of these species). *Momipites* sp., which does not appear to range higher than Paleocene, is found in the Aquia and in the lower part of the Marlboro as high as 335 feet

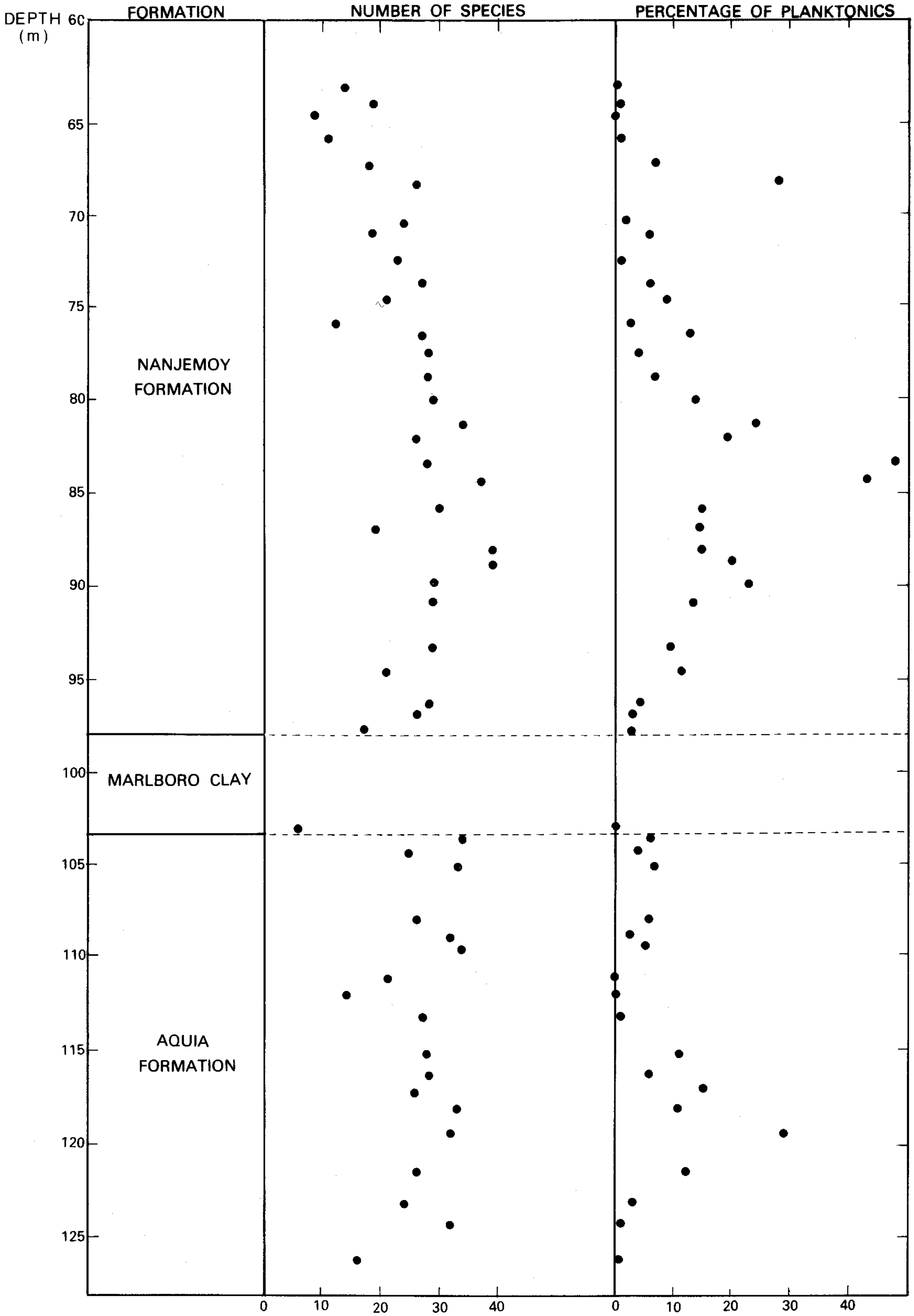


Figure 5. Numbers of species of benthonic Foraminifera and percentages of planktonic Foraminifera in Paleocene and Eocene strata of the Oak Grove Core.

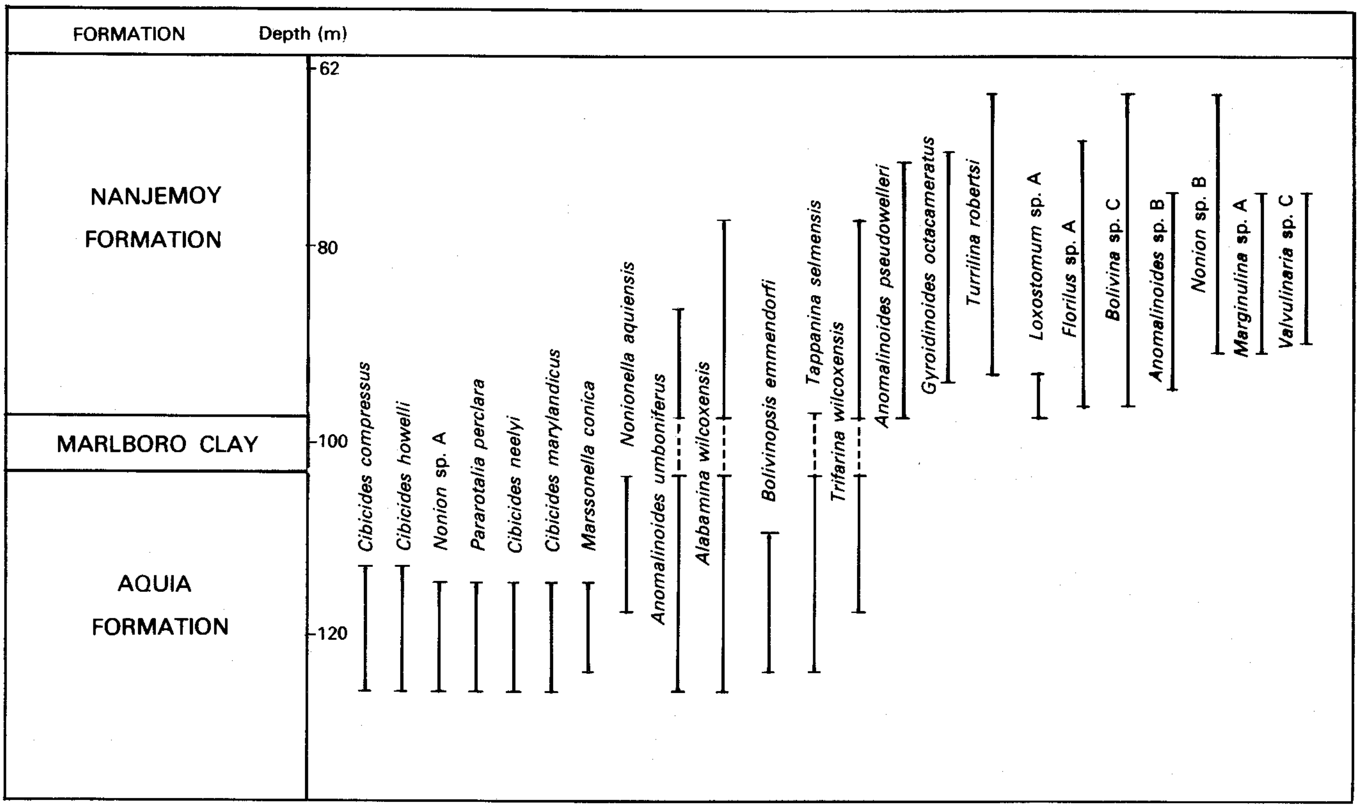


Figure 6. Range of key benthonic foraminiferal species in the Paleocene and Eocene strata of the Oak Grove core.

(102.1 m). *Platycarya* sp. occurs infrequently at the top of the Marlboro Clay both in the Oak Grove core (at 324 feet; 98.8 m) and in Maryland (Brenner and others, 1977); it has not been found below the lower Eocene either in the southeastern United States or in the Rocky Mountains, although a similar species of the genus is known from the uppermost Paleocene in South Carolina (Frederiksen and Christopher, 1978). *Platycarya swastocoida* Elsik, first appears at the base of the Nanjemoy Formation; it has not been reported from the Paleocene. These data are evidence that the lower Marlboro is Paleocene and that higher it is either uppermost Paleocene, perhaps representing slightly younger rocks than those previously studied in the southeastern United States, or else lowermost Eocene. The apparent lack of *P. swasticoida* in the sample from 324 feet (98.8 m) may result from the fact that juglandaceous pollen is rare in that sample.

Three samples of the Marlboro Clay contain the only palynomorphs recognized as reworked in the entire Paleogene portion of the core. The reworked specimens are of Paleozoic age and mostly occur in the sample from 335 feet (102.1 m) with a few in the samples from 333 and 328 feet (101.5 and 100.1 m).

Environment of deposition: The lower contact of the Marlboro exhibits a rapid, but gradational transition from the glauconitic sand of the Aquia Formation to dense clay over a 2.5 inch (10 cm) interval. The lithologic change from sand to clay is paralleled by a faunal change from a diverse foraminiferal assemblage of 34 calcareous species in the uppermost 0.3 feet (0.1 m) of the Aquia Formation to an assemblage of six agglutinated species in the basal 1 foot (0.3 m) of the Marlboro Clay (Figure 5). Nogan (1964) suggested a brackish water regime for the outcropping Marlboro on the basis of three genera of agglutinated Foraminifera. The low diversity assemblage of strictly agglutinated species in the Marlboro Clay in the Oak Grove core supports the idea of a restricted environment of less than normal salinity. Dinoflagellate diversity also drops sharply from about 50 species in the uppermost Aquia to 12 species in the Marlboro. The presence of *Wetzeliella* spp. and abundant specimens of *Deflandrea dilwynesis* Cookson and Eisenack, in addition to the low diversity, are suggestive of an estuarine environment.

Additional support for a brackish water environment of deposition is that four of the six palynological samples from the Marlboro in the Oak Grove core contain species of *Pseudoschizaea*, a freshwater alga. None of the samples from the Nanjemoy or Aquia contain this genus. An indication that the climate was moist during Marlboro time is found in the large number of fern spores which often originate in cool, shady, and moist areas.

Nanjemoy Formation

This unit contains abundant calcareous and organic-walled fossils, and biostratigraphic information from all the groups studied has been utilized in the interpretations.

The lowest part of the Nanjemoy Formation in the Oak Grove core is placed in the earliest Eocene on the basis of calcareous nannofossil data (Figures 1, 4). The assemblage indicates that the interval from 322 to 279 feet (98.1 to 85.0 m) belongs to nannofossil zone NP 10, the base of which is the first occurrence of *Marthasterites tribrachiatus* (Bramand Riedel). The earliest appearance of this species occurs a bit higher than the base of zone NP 10 in the core (Figure 4).

A progression of calcareous nannofossil zones for the early Eocene (Figures 1, 4), indicates no major breaks in sedimentation. The interval from 276 to 273 feet (84.1 to 83.1 m) is assigned to zone NP 11; its base is marked by the first occurrence of *Chiasmolithus grandis* (Bramlette and Riedel). The highest zone in the early Eocene, NP 12, is found in the interval from 269 to 227 feet (82.1 to 69.2 m) as interpreted from the first occurrences of *Discoaster barbadiensis* Tan Sin Hok, *D. lodoensis* Bramlette and Riedel, and *D. kuepperi* Stradner. The nannofossil assemblages are sparse in the upper part of zone NP 12 in the core, and nannofossils are absent in the Nanjemoy from 227 feet (69.2 cm) to its top at 199 feet (60.7 m).

Sporomorph assemblages are indicative of an early Eocene age for the Nanjemoy Formation (Figure 3). Samples from 312 to 252 feet (95.1 to 76.8 m) are placed in the lower Eocene based on the presence of *Platycarya swasticoida* Elsik and *Platycarya* sp. Sporomorph assemblages of the lower Eocene and the lowest middle Eocene on the Gulf Coast are similar except in the ratio of *Platycarya* spp. and *Plicatopollis* cf. *P. plicata* (Potonié) Krutzsch, both juglandaceous pollen types. *Platycarya* spp. is more abundant in the Gulf Coast lowest Eocene, the ratio is reversed in the middle Eocene. However, it is not known whether the change in the ratio occurs within the upper part of the lower Eocene or at the boundary between the lower and middle Eocene. Hence ratio data cannot be used to separate the two stages. In samples from the Nanjemoy Formation in the Oak Grove core, a distinctive change occurs in the ratio of the two juglandaceous types between 252 and 231 feet (76.8 and 70.4 m), with *Plicatopollis* cf. *P. plicata* dominating the juglandaceous pollen from 231 feet (70.4 m) to the top of the Nanjemoy.

Diverse dinoflagellate assemblages are found throughout the Nanjemoy Formation in the Oak Grove core (Figure 2). The following species occur together and are no younger than early Eocene; *Spiniferites septatus* (Cookson and Eisenack) McLean, *Microdinium ornatum* Cookson and Eisenack, *Deflandrea dilwynensis* Cookson and Eisenack, *Kallosphaeridium brevibaratum* DeConinck, *Muratodinium fimbriatum* (Cookson and Eisenack) Drugg, and *Cleistosphaeridium diversispinosum* Davey and others. Found with these are: *Phthanoperidinium resistente* (Morgenroth) Eisenack and Kjellstrom, *Adnatosphaeridium multispinosum* Williams and Downie, a species complex, *Gonyaulacysta giuseppei* (Morgenroth) Sarjeant, *Wetzeliella articulata* Eisenack, *W. samlandica* Eisenack, *W. coleothrypta* Williams and Downie, *Tectadodinium* spp., *Achilleodinium biformoides* (Eisenack) Eaton, and *Homotryblium pallidum* Davey and Williams, species which range no lower than early Eocene. These data are supportive of the early Eocene age assigned to the Nanjemoy on the basis of other fossils. Other species recovered in this interval that are known elsewhere only from early Eocene strata include: *Deflandrea wardenensis* Williams and Downie, *Tubidermodinium sulcatum* Morgenroth, ?*Impletosphaeridium erinaceum* Morgenroth, and ?*Eisenackia scrobiculata* Morgenroth. No dinoflagellate species diagnostic of middle Eocene were found.

Ostracode assemblages in the interval from 325 to 318 feet (99 to 97 m), the lower part of the Nanjemoy, are similar to those found in the Potopaco Member of the Nanjemoy in the Potomac River valley. The assemblage at 312 feet (95 m) contains one species each of *Brachycythere* and *Hazelina*; species of these genera have not been observed below the Bashi Member of the Hatchetigbee Formation in the eastern Gulf Coast. The Bashi is lowest Eocene in age (Berggren, 1965). The next higher sample containing ostracodes, at 287 feet (87.5 m), contains the distinctive species complex *Haplocytheridea habropapillosa s.l.*, indicative of latest Sabinian to Claibornian age; the species complex ranges to 223 feet (68 m) above which no ostracodes were found.

The mollusks from the Nanjemoy Formation were collected from shell bands ranging in thickness from less than 2 to about 8 inches (5 to 20 cm). The shells usually have random orientation, but some bands in the lower part of the Nanjemoy have flat-lying shells with generally concave-down, current-stable orientation. Bivalves, generally whole and unworn, dominate the fauna, in part because of selective leaching of the gastropods, which are present only as molds or thin white "ghosts." The softness of the shell material makes identification difficult and absolute number counts impossible; hence only relative abundances are listed (Figure 7). The taxonomy used is that of Palmer and Brann (1965).

The contact between the two members of the Nanjemoy Formation, which were erected largely on faunal grounds, was determined in the core by a comparison of the distribution of mollusks with that given in Clark and Martin (1901). The contact between the Potopaco Member (lower) and the Woodstock Member (upper) is placed at 276 feet (84.1 m) where the base of the Woodstock Member begins with the first appearance of *Saccella parva* (Rogers and Rogers), accompanied by a general increase in species number. *Turritella* sp. (*Mesalia obruta* of Clark and Martin) occurs 3 feet (0.9 m) higher in the core. The two species are characteristic of the Woodstock Member in the type area.

The Nanjemoy Formation has been considered early and middle Eocene in age (Clark and Martin, 1901; Cooke, Gardner, and Woodring, 1943). The upper part of the Nanjemoy is correlated with the middle Eocene of the Gulf Coast (Clark and Miller, 1912; Cederstrom, 1957) by the presence of oysters, including *Cubitostrea sellaeformis* (Conrad). Mature specimens of this important marker species do not occur north of central Virginia. Large, well-preserved specimens of *C. sellaeformis* in the Nanjemoy strata of the Pamunkey River valley likely prompted the juvenile oysters from the Potomac River sections of the Nanjemoy to be assigned to this species, even though the northern forms were considered as being almost indistinguishable from juveniles of "*Ostrea compressirostra*" (Clark and Martin, 1901, p. 192). The latter form is characteristic of the underlying Aquia Formation.

A study made on populations, including juveniles, of: *Ostrea* sp. from the Aquia Formation; *O. sinuosa* Rogers and Rogers (= *O. compressirostra*) from the Aquia Formation; *Cubitostrea sellaeformis* from the Nanjemoy Formation along the Pamunkey River in central Virginia; and juvenile specimens from the Oak Grove core does not establish the identity of the immature Oak Grove "oysters."

But, based on the few complete specimens of juvenile left valves present in the Oak Grove core, the early development of strong, evenly spaced ribs in each specimen and the absence of attachment scars indicate that the core specimens are more similar to *C. sellaeformis* than to *Ostrea* sp. or *O. sinuosa*. The immature oysters in the Oak Grove core could be some form intermediate between *C.*

FORMATION	UNIT	ZONE	Depth (m)	*Venericardia potapacoensis*	*Pitar ovatus*	*Pitar lenis*	*Nucula* sp.	Ostreid	*Tellina* sp.	*Vokesula aldrichi*	*Lithophaga?* sp.	*Eburneopecten dalli*	*Pitar* sp.	Naticid	*Cadulus* sp.	*Cubitostrea* sp.	*Nuculana cliftonensis*	*Saccella parva*	*Lucina uhleri*	*Tudicla* sp.	*Brachidontes potomacensis*	*Calorhadia potomacensis*	*Turritella?* sp.	*Nucula potomacensis*	*Brachidontes* sp.	*Cubitostrea* cf. *C. divaricata*	*Nucula* sp.	*Calyptraea aperta*	*Anomia marylandica*	*Turritella* sp.	*Cubitostrea* cf. *C. sellaeformis*	*Macrocallista subimpressa*	Nuculanid	Lucinid	*Turritella potomacensis*	*Gari* sp.	*Nuculana improcera*	*Nemocardium* sp.	*Anomia* sp.	*Nuculana cultelliformis*	Mitrid	*Alectryonia?* sp.	Muricid	*Venericardia* sp.	Naticid	*Teredo* sp.
NANJEMOY FORMATION	WOODSTOCK MEMBER	16–17	64.3					R		R																						A												R	R	R
			65.5					R	R																							A												R	R	
			67.0	FC					R										R					R								A	R		FR				R	FR		R	R			
			67.7	A				R	R												R			R								C								R	R					
			71.3	C						A																					R															
			71.9	C				FR	R	A										R													R						FR							
			73.8	C					R	A																					FC			R			C	R								
			74.1	R					R	C														R							FC					R										
			78.0	C						A			R																																	
			78.3	FR						A													C		FC						FC	R	R	R	R											
			80.2	A						FR			FR					R			C					C	FR	FR	R	R																
			81.4	C				R		FC			C					FC					C	FR	R																					
			82.9	A	R					A								C			C	C																								
			83.8	A		FR			FR	A			C				C	C	R	R																										
	POTAPACO MEMBER	11–15	84.4	A	C											FC																														
			86.6	A									FR	R	R																															
			89.0	A																																										
			91.7	A																																										
			94.5	A									FR																																	
			96.6	A	C	R	R	R	R	R	R	R																																		

Figure 7. Distribution of the Mollusca in the Nanjemoy Formation of the Oak Grove core. Zones are those of Clark and Martin (1901).

sellaeformis and *O. sinuosa*, such as *C. lisbonensis* (Harris). Further, the occurrence of several specimens of *Cubitostrea* cf. *C. divaricata* (Lea) suggests a middle Eocene age for the upper part of the formation, but *Vokesula aldrichi* (Meyer), a species normally confined to the lower Eocene in Alabama, also occurs in these strata, indicating an older age.

From the present state of knowledge of biostratigraphic zonation of the various groups, it appears that the lower 92 feet (28 m) of Nanjemoy Formation, core depths 322 feet (98.2 m) to at least 230 feet (70 m), ranges in age from earliest Eocene through much of the early Eocene, and that the upper 31 feet (9.4 m), core depths 230 to 199 feet (70 m to 60.8 m), is late early Eocene.

Environment of deposition: The major evidence for the interpretation of the environment of deposition of the Nanjemoy Formation is from foraminiferal species diversity and percentage of planktonic foraminiferal specimens (Figure 5). At the base of the formation, species number (17) is relatively low; three percent are planktonic forms. These values reflect deposition in inner shelf waters, at water depths probably somewhat less than 98 feet (30 m). The base of the Nanjemoy represents the beginning of a marine transgression in the area. Depth of deposition increases up-core to 291 feet (88.7 m) where it is a maximum based on number of species (39) and planktonic proportion (about 20 percent). These analyses are indicative of water depths of about 197 to 230 feet (60 to 70 m).

The assemblages from the remainder of the formation are indicative of a very gradual shallowing upward with one possible deepening pulse at 227 feet (69.2 m). The uppermost 20 feet (6.1 m) of core has about 10 foraminiferal species, and planktonic percentages approaching zero. The depth of water was probably less than 49 to 66 feet (15 to 20 m).

The number of dinoflagellate species per sample ranges from about 20 to 70 in the Nanjemoy Formation. The greatest number of species is at 279 feet (85.1 m).

CHESAPEAKE GROUP

The lower two formations, Calvert and Choptank (Miocene), of the four which compose the Chesapeake Group of Virginia and Maryland extend from about 66 to 199 feet (20 to 60.8 m) below the well head. The lithology varies from gray-green silty clays to very fine sands, with diatomaceous intervals in the lower part.

No calcareous remains were found in samples from the Miocene. Organic-walled organisms, including sporomorphs and dinoflagellates, and siliceous forms, including diatoms and radiolarians, are present. Megafossils recorded from the samples include bone fragments, shark teeth, plant fragments, and fragments of phosphatic brachiopods.

The absence of calcareous fossils is typical for diatomaceous clays of the Miocene, most of which clays are in the Fairhaven Diatomaceous Clay Member of the Calvert Formation in Maryland and Virginia. Occasional molluscan species molds may be found in the beds, but most outcrops in Virginia lack even these. Vertebrate material, including porpoise and whale bones and shark teeth, are common and, along with the marine diatoms, represent marine conditions. One would expect organisms with calcareous tests to have lived in these environments or to have been transported into them, at least. The most likely explanation for their absence is leaching. Solution must have occurred early in the depositional or post-depositional history as molluscan molds are rare to absent at most localities. All drill cores examined from the Calvert Formation in Maryland and Virginia, except one, lack calcareous fossils in the highly diatomaceous intervals of the Fairhaven Diatomaceous Clay Member. The absence in cores suggests that leaching is not due to present near-surface conditions. The only samples known to have calcareous fossils in the highly diatomaceous intervals are from the Baltimore Gas and Electric Company core hole near St. Leonards, Maryland. In this core the foraminiferal assemblages found in the highly diatomaceous intervals are similar to those found both below and above these intervals, and all the assemblages are indicative of a shallow, inner shelf, marine environment. Generalizing from this core, it seems that the absence of calcareous fossils in the Oak Grove core is related to early post-depositional diagenetic processes rather than to depositional environment.

Calvert Formation

The Calvert Formation is 99 feet (30.3 m) thick, extends from core depth 100 to 199 feet (30.5 to 60.8 m), and consists mostly of fine sand with some coarse sand, clay, and diatomaceous clay intervals. Two intervals in the core contain diatoms diagnostic of the Calvert Formation. The lower interval is 17 feet (5.1 m) thick (core depth 175 to 192 feet; 53.4 to 58.5 m) and is correlated by diatoms with bed 3, the uppermost stratum of the Fairhaven Member in the type section at Calvert Cliffs, Maryland. Diagnostic diatoms include *Delphineis ovata* Andrews, *Rhaphoneis margaritata* Andrews, *R. parvula* Andrews, *R. scalaris* Ehrenberg, and *Sceptroneis caduceus* Ehrenberg. The upper diatomaceous interval (24 feet thick, 7.3 m) extends from a depth of 107 to 131 feet (32.6 to 39.9m) and can be correlated with beds 14 and 15 of Shattuck (1904) as recognized in the Calvert Cliffs section in Maryland. This correlation is based on the following marker species: *Actinoptychus virginicus* (Grunow) Andrews, *Coscinodiscus plicatus* Grunow, *Delphineis angustata* (Pantocsek) Andrews, *D. novaecaesaraea* (Kain and Schultze) Andrews, *D. penelliptica* Andrews, *Denticula hustedtii* Simonsen and Kanaya, and *Rhaphoneis parilis* Hanna. Bed 10 of the Calvert at the type section has been placed in upper N 8 or lower N 9 of Blow (1969) (Gibson, in press). The age of underlying beds, including bed 3, is considered to be somewhere in the late part of the early Miocene. Also, bed 12 of the Calvert Cliffs section is placed in zone N 10 or N 11 of Blow (1969) and beds 14 and 15 appear to be closely following in age, hence their placement in the early to middle part of the middle Miocene.

Dinoflagellates characteristic of the Calvert include *Gonyaulacysta* spp. and *Tuberculodinium vancampoae* (Rossignol) Wall and other species shown in Figure 2.

Choptank Formation

The 34 feet (10.5 m) of silty clays and clayey silts in the interval from 66 to 100 feet (20 to 30.5 m) below well head are placed in the Choptank Formation. Only one diatomaceous sample was obtained in this interval. The sample, taken at a depth of 96 feet (29.3 m), contains a sparse diatom assemblage with three species, *Rhaphoneis diamantella* Andrews, *R. gemmifera* Ehrenberg, and *R. lancettula* Grunow, indicative of Shattuck's (1904) beds 18 and 19 of the Choptank Formation in the Chesapeake Bay area.

Dinoflagellate species are shown in Figure 2. *Operculodinium centrocarpum* (Deflandrea and Cookson) Wall is particularly abundant in this unit.

Planktonic Foraminifera are very rare in the Choptank Formation in both the Calvert Cliffs section and the Choptank River type area, and no correlation with the intercontinental planktonic zones is currently possible. A potassium-argon age determination of 12.0 $\pm$ 0.5 m.y. (late middle Miocene) for the overlying St. Marys Formation in Maryland (Blackwelder and Ward, 1976) together with the early middle Miocene age for the underlying Calvert, places the Choptank in approximately the middle part of the middle Miocene (Figure 1).

Environment of deposition: The diatom and dinoflagellate assemblages in the Choptank and Calvert Formations in the Oak Grove core, along with the presence of shark teeth, reflect marine waters.

CORRELATION AND BOUNDARY PROBLEMS

Problems in determining the Paleocene-Eocene boundary and also the lower Eocene-middle Eocene boundary in the core arise from the lack of faunal and floral control across these boundaries in adjacent areas, particularly the eastern Gulf Coastal Plain. Information gaps are due to absence of continuous deposition across the boundaries or of a marine section with fossils useful in regional and intercontinental correlation and to want of study on some fossil groups. In particular, the Paleocene-Eocene boundary is difficult to extend because the Tuscahoma Formation, considered to represent much or all of the uppermost Paleocene, is largely a restricted marine to marginal marine deposit in its upper part and lacks calcareous fossils. Higher strata, representing continuous deposition across the Paleocene-Eocene boundary, appear to be absent in the eastern Gulf Coast. And in the Atlantic Coastal Plain transitional deposits may be present, as, for example, the Marlboro Clay in Virginia, but are of non-marine or marginal marine origin.

Similarly, strata representing the lower Eocene-middle Eocene boundary are not present in the eastern Gulf Coast. The basal beds of the Tallahatta Formation, usually considered lowermost middle Eocene, generally rest upon the Bashi Marl Member of the Hatchetigbee Formation (of earliest Eocene age); the middle or upper part of the lower Eocene is not usually present. This gap extends into the Atlantic Coastal Plain as determined in the core from Clubhouse Crossroads, South Carolina (Hazel and others, 1977). If strata of late early Eocene age exist in the eastern United States, they are mainly of non-marine origin and not readily correlated with units elsewhere.

From the work to date, it appears that stratigraphic gaps in the Lower Tertiary of the eastern Gulf Coast are also present in the Atlantic Coastal Plain. Whether these be eustatic or tectonic is not now known.

AREAL RELATIONSHIPS OF THE FORMATIONS

The Aquia Formation in the Potomac River valley consists of the Piscataway Member, beds 1 through

7, and the overlying Paspotansa Member, beds 8 and 9. The thicknesses of these units as given in Clark and Martin (1901) for the Potomac valley are from 30 feet (9.1 m) to an estimated 60 feet (9.1 to 18.3 m) for bed 1, 40 feet (12.2 m) for the remaining portion of the Piscataway Member, and 47 feet (14.3 m) for beds 8 and 9 of the Paspotansa Member. Dinoflagellate species enable recognition of beds 1, 2, 4, 5 and 6 in the Oak Grove core (Figure 2). These data enable the following comparisons between type Aquia and the Oak Grove core. The equivalent of bed 1 extends from 454 to 413 feet (138.4 to 125.9 m) in the core, the 41 feet (12.5 m) thickness comparing similarily with the Potomac section; beds 2 through 6 extend from 413 to at least 360 feet (125.9 to 109.8 m), the 53 feet (16.3 m) thickness also being similar to the Potomac sections; but beds 8 and 9 together have a maximum thickness of 20 feet (6.2 m) in the core compared with 47 feet (14.3 m) in the Potomac sections, indicating considerable thinning of the Paspotansa Member southeastward from the Potomac or missing strata and disconformity.

Both members of the Nanjemoy Formation, recognized in the Oak Grove core on the basis of molluscan assemblages (Figure 7), are of early Eocene age in this area. The boundary between the members is placed at 276 feet (84.1 m), and each has similar thickness as they also do in sections along the Potomac River. This contrasts with the marked thinning in the upper Aquia and in the Calvert formations. Thickness change in the Nanjemoy Formation suggests either a longer duration of the depositional basin to the south or greater subsequent erosion in northern Virginia. It is possible that a middle Eocene part of the Nanjemoy has been eroded from the area of the Oak Grove core, but the shoaling toward its top reflects a regressive phase, possibly representing the final Eocene sea in this area.

The Calvert Formation is only 100 feet (30.5 m) thick in the Oak Grove core, and it is 196 feet (59.7 m) thick in the Baltimore Gas and Electric Company core at Calvert Cliffs, Maryland. The thickness of the Plum Point Marl Member of the Calvert Formation in the BG & E core is 84 feet (25.6 m) and in the Oak Grove core this interval, all the Calvert above the strata correlated by diatoms with Shattuck's (1904) bed 3, is 36 feet (10.9 m) thick. (The shelly sands so characteristic of the Plum Point Marl Member at Calvert Cliffs are not recognizable in the Oak Grove core.) Similarly, the Fairhaven Diatomaceous Clay Member of the Calvert Formation, recognizable both lithologically and biostratigraphically in the Oak Grove core, thins from 111 feet (33.8 m) to 25 feet (7.6 m) southward. This southerly thinning of the Calvert was noted earlier (Gibson, 1970, fig. 3).

SUMMARY

The 380 feet (115.9 m) of cored Tertiary strata in the Oak Grove core hole are placed in the following units with the accompanying age and paleoenvironment determinations. 1) The lower 41 feet (12.5 m), the glauconitic sands of the Aquia Formation, is probably early Paleocene (Danian) in age and is of marine origin. The remaining 73 feet (22.3 m) of the Aquia ranges through much of the late Paleocene, and was deposited in inner shelf environments with water depths of less than 98 feet (30 m) to as much as 328 feet (100 m). The upper member of the Aquia, the Paspotansa, is thinner at Oak Grove than farther north. 2) The overlying Marlboro Clay is composed of 18 feet (5.4 m) of compact red and gray clays. The lower part of the unit is of late Paleocene age, and the upper part is either latest Paleocene or earliest Eocene. The fauna and flora indicate a brackish water environment. 3) The 123-foot-thick (37.4 m) shelly glauconitic sands and clayey sands of the Nanjemoy Formation spans most of early Eocene time; the middle Eocene strata found in other areas in the Nanjemoy apparently are absent here. The base of the Nanjemoy represents a transgression with water depths reaching about 197 feet (60 m) in the lower part of the section. The upper part reflects a shallowing of and the possible end to Eocene marine deposition in the area. 4) Strata referable to the Calvert Formation are 99 feet (30.3 m) thick and are marine. Calcareous fossils are absent, but diatoms correlate with the Calvert Cliffs type section where ages range from late early to early middle Miocene. The Calvert Formation at Oak Grove is considerably thinner than at the Calvert Cliffs. Deposition occurred in marine environments. 5) The uppermost 34 feet (10.5 m) of cored strata are placed in the Choptank Formation, dated elsewhere as of middle Miocene age. The clays and silts were deposited in marine environments.

REFERENCES

Berggren, W .A., 1965, Some problems of Paleocene-lower Eocene planktonic foraminiferal correlations: Micropaleontology, vol. 11, no. 3, p. 278-300.

________________, 1972, A Cenozoic time-scale; some implications for regional geology and paleobiogeography: Lethaia, vol. 5, no. 2, p. 195-215.

Blackwelder, B.W., and Ward, L.W., 1976, Stratigraphy of the Chesapeake Group of Maryland and Virginia: Geol. Soc. America, Northeastern-Southeastern Meeting, Arlington, Virginia, 1976 Guidebook for Field Trip 7b, 55p.

Blow, W.H., 1969, Late middle Eocene to Recent planktonic foraminiferal biostratigraphy: Proc. First International Conf. Planktonic Microfossils, Geneva, p. 199-422.

Brenner, G.J., Patricelli, Judith, and Rachele, Linda, 1977, Palynology of the Paleocene-Eocene sediments from PGDf-35 well, Prince Georges County, Maryland (U.S.A.) (abs.): Am. Assoc. Strat. Palynologists 10th Ann. Mtg., Abstracts with Program, p. 5-6.

Bybell, L.M., and Govoni, D.L., 1977, Preliminary calcareous nannofossil zonation of Brightseat and Aquia formations (Paleocene) of Maryland and Virginia—stratigraphic implications (abs.): Am. Assoc. Petroleum Geologists, vol. 61, no. 5, p. 773-774.

Cederstrom, D.J., 1957, Geology and ground-water resources of the York-James Peninsula, Virginia: U.S. Geol. Survey Water-Supply Paper 1361, 237 p.

Clark, W.B., and Martin, G.C., 1901, The Eocene deposits of Maryland: Maryland Geol. Survey, Eocene, p. 19-92.

Clark, W.B., and Miller, B.L., 1912, The physiography and geology of the Coastal Plain province of Virginia: Virginia Geol. Survey, Bull. 4, p. 13-222.

Cooke, C.W., Gardner, Julia, and Woodring, W.P., 1943, Correlation of the Cenozoic formations of the Atlantic and Gulf Coastal Plain and the Caribbean region: Geol. Soc. America, Bull., vol. 54, no. 11, p. 1713-1724.

Cushman, J.A., and Cederstrom, D.J., 1945, An upper Eocene foraminiferal fauna from deep wells in York County, Virginia: Virginia Geol. Survey, Bull. 67, 58 p.

Downie, Charles, Hussain, M.A., and Williams, G.L., 1971, Dinoflagellate cyst and acritarch associations in the Paleogene of southeast England: *in* Am. Assoc. Strat. Palynologist, Proc., second, Geoscience and Man, vol. 3, p. 29-35.

Frederiksen, N.O., and Christopher, R.A., 1978, Taxonomy and biostratigraphy of Late Cretaceous and Paleogene triatriate pollen from South Carolina: Palynology, vol. 2., p. 113-145.

Gibson, T.G., 1968, Stratigraphy and paleoenvironment of the phosphatic Miocene strata of North Carolina: Reply: Geol. Soc. America Bull., vol. 79, no. 10, 1437-1447.

__________ 1970, Late Mesozoic-Cenozoic tectonic aspects of the Atlantic coastal margin: Geol. Soc. America Bull., vol. 81, no. 6, p. 1813-1822.

__________ in press, Miocene and Pliocene Pectinidae (Bivalvia) from the Lee Creek Mine, North Carolina, and adjacent areas: Smithsonian Contr. Paleobiology.

Gibson, T.G., and Buzas, M.A., 1973, Species diversity; patterns in modern and Miocene Foraminifera of the eastern margin of North America: Geol. Soc. America Bull., vol. 84, no. 1, p. 217-238.

Glaser, J.D., 1971, Geology and mineral resources of southern Maryland: Maryland Geol. Survey, Rept. Inv. no. 15, 84 p.

Hansen, H.J., 1977, Geologic and hydrologic data from two core holes drilled through the Aquia Formation (Eocene-Paleocene) in Prince Georges and Queen Anne's Counties, Maryland: Maryland Geol. Survey, Misc. Open File Report, 77 p.

Hazel, J.E., 1968, Ostracodes from the Brightseat Formation (Danian) of Maryland: Jour. Paleontology, vol. 42, no. 1, p. 100-142.

__________ 1969, Faunal evidence for an unconformity between the Paleocene Brightseat and Aquia formations (Maryland and Virginia): U.S. Geol. Survey Prof. Paper 650-C, p. C58-65.

Hazel, J.E., and others, 1977, Biostratigraphy of the deep corehole (Clubhouse Crossroads corehole 1) near Charleston, South Carolina: U.S. Geol. Survey Prof. Paper 1028F., p. 71-89.

Jan du Chene, Roger, Gorin, Georges, and Van Stuijvenberg, Jan, 1975, Etude geologique et stratigraphique (Palynologie et Nannofossiles calcaires) des Gres de Voirons (Paleogene de Haute-Savoie, France): Geol. Alpine, vol. 51, p. 51-78.

Loeblich, A.R. Jr., and Tappan, H.N., 1957, Planktonic Foraminifera of Paleocene and early Eocene age from the Gulf and Atlantic Coastal Plains: U.S. National Mus. Bull. 215, p. 173-198.

McLean, D.M., 1969, Organic-walled phytoplankton from the Lower Tertiary Pamunkey Group of Virginia and Maryland: Unpublished Ph.D. thesis, Stanford University, 165 p.

Nogan, D .S., 1964, Foraminifera, stratigraphy, and paleoecology of the Aquia Formation of Maryland and Virginia: Cushman Foundation Foram. Research, Spec. Pub. 7, 50 p.

Olsson, R.K., 1963, Latest Cretaceous and earliest Tertiary stratigraphy of New Jersey Coastal Plain: Am. Assoc. Petroleum Geologists Bull., vol. 47, no. 4, p. 643-665.

Palmer, K.V.M., and Brann, D.C., 1965, Catalogue of the Paleocene and Eocene Mollusca of the southern and eastern United States-Pts. 1 and 2: Bulls. Amer. Paleontology, vol. 48, no. 218, 1057 p.

Shattuck, G.B., 1904, Geological and paleontological relations, with a review of earlier investigations, *in* Miocene: Maryland Geol. Survey, p. 33-137.

Shifflett, F.E., 1948, Eocene stratigraphy and Foraminifera of the Aquia Formation: Maryland Dept. Geol., Mines and Water Resources, Bull. 3, p. 1-93.

Tschudy, R.H., 1973, *Complexiopollis* pollen lineage in Mississippi embayment rocks: U.S. Geol. Survey Prof. Paper 743-C, 15 p.

Witmer, R.J., 1975, Taxonomy and biostratigraphy of Lower Tertiary dinoflagellate assemblages from the Atlantic Coastal Plain near Richmond, Virginia: Unpublished M.S. thesis, Virginia Polytech. Inst. and State Univ., 168 p.

PART 3
LOWER CRETACEOUS STRATIGRAPHY OF THE CORE[1]

By
Juergen Reinhardt[2], Raymond A. Christopher[2],
and James P. Owens[2]

CONTENTS

ILLUSTRATIONS

[1] Portions of this publication may be quoted if credit is given to the Virginia Division of Mineral Resources. It is recommended that reference to this report be made in the following form: Reinhardt, Juergen, Christopher, R.A., and Owens, J.P., 1980, Lower Cretaceous stratigraphy of the core, *in* Geology of the Oak Grove core: Virginia Division of Mineral Resources Publication 20, Part 3, 88 p.
[2] U.S. Geological Survey, Reston, Virginia

TABLES

ABSTRACT

A continuous core nearly 1000 feet (300 m) long through Potomac Group (Lower Cretaceous) strata was studied petrographically and palynologically in order to reach a better understanding of the fluvio-deltaic system that dominates clastic fill of the Salisbury embayment. Characteristics of sediments from the lower part of the Potomac Group (Aptian-Barremian?) in the core are suggestive of derivation from a drainage basin of limited extent. The drainage system was near the southern limit of the embayment and deposition was near a marine environment. The Potomac Group in the Oak Grove core (Albian) is dominated by fining-upward sequences and highly disrupted red clay beds indicating deposition in a fluvial channel-floodplain complex.

The vertical sequence of Potomac Group deposits records delta building near the southern limit of the Salisbury embayment during Early Cretaceous time. The distribution of progressively younger sediments to the north within both the Salisbury and Raritan embayments is indicative of the migration of major fluvio-deltaic lobes during Aptian to Cenomanian time, immediately prior to the "world-wide" Cenomanian marine transgression.

INTRODUCTION

The Potomac Group (Lower Cretaceous part) constitutes the basal outcropping sedimentary wedge in the Atlantic Coastal Plain from southern New Jersey to Virginia. These sediments are composed of laterally and vertically variable packages of quartzose to quartzo-feldspathic sand and kaolinitic to montmorillonitic clay. The distribution of these sediments is coincident with the Salisbury (Chesapeake-Delaware) embayment which locally contains more than 6500 feet (2000 m) of Cretaceous and Tertiary sediment immediately west of the Baltimore Canyon trough and as much as 46,000 feet (14,000) of sediment within the trough (Minard and others, 1974; Mattick and others, 1974).

This paper reports on the Lower Cretaceous portion of a continuously cored stratigraphic test hole drilled between March 15 and May 30, 1976, in the southwestern part of the Salisbury embayment near the village of Oak Grove, Virginia (Figure 1). The Lower Cretaceous sand and clay formed in a fluvio-deltaic depositional system. As a direct consequence, biostratigraphic calibration of the Lower Cretaceous sediments is more limited than with the Tertiary sediments in the core. Further, the local hydrologic and petrologic variability of the major fluvial system evident in these Cretaceous sediments tends to preclude basinwide correlation based on the physical characteristics of the sediments.

The purpose of this paper is to tie outcropping sediments and sedimentary structures studied near the Fall Line (Glaser, 1969; Owens, 1969; Reinhardt and Cleaves, 1978) to depositional models for Lower Cretaceous sediments downdip (Hansen; 1968; Minard and others, 1974). Pollen zones are recognized in each of the two major Cretaceous sedimentary sequences within this test hole. Data obtained here are extrapolated to define the timing and pattern of sedimentation within the Salisbury embayment for Early Cretaceous and a portion of Late Cretaceous times.

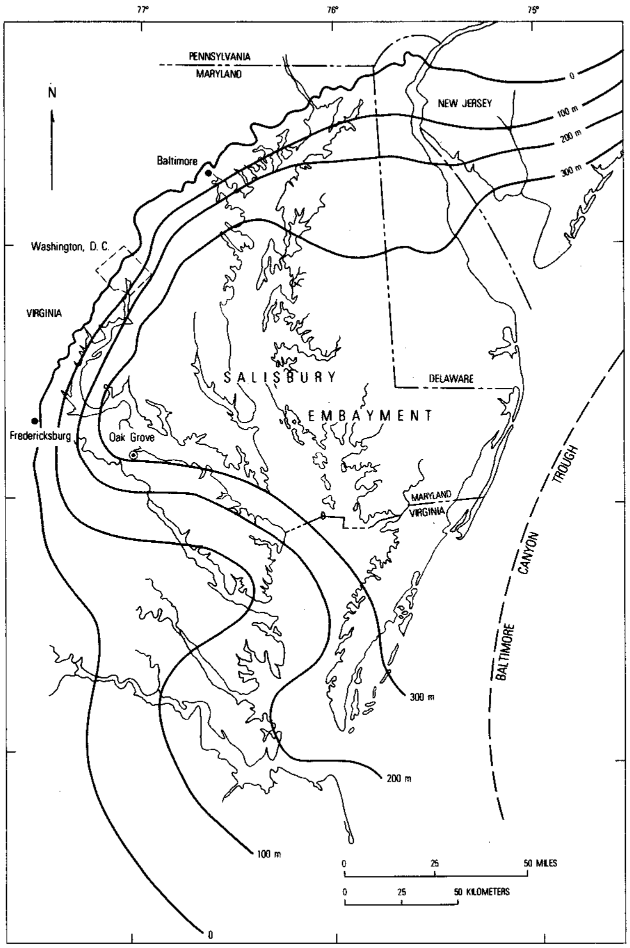


Figure 1. Location map of the Oak Grove stratigraphic test well. Isopachous lines delineate the thickness of Lower Cretaceous sedimentary rocks in the Salisbury embayment (generalized from Teifke, 1973; Brown and others, 1972).

ACKNOWLEDGEMENTS

We thank James Estabrook and Melodie Hess for their care and patience in preparing and compiling textural and X-ray analyses, respectively, for this study. The comments and reviews by R.B. Mixon, W.L. Newell, A.J. Froelich, C.C. Smith, E.K. Rader, and J.D. Glaser of earlier versions of this paper have all been constructive and are gratefully acknowledged.

STRATIGRAPHIC AND PALYNOLOGIC FRAMEWORK

The Potomac Group in the Oak Grove core occupies the 926 feet (282.2 m) between the friable Paleocene greensands of the Aquia Formation and the bottom of the hole at 1380 feet (420.6 m) (elevation −1200 feet, −365.75 m) (see Figure 2). The stratigraphic relationships within the Oak Grove hole and other deep holes in the area sugest that the bottom of Oak Grove No. 1 is probably not more than 164 feet (50 m) above a thick red bed sequence. Well cuttings of the red bed interval in northeastern Virginia have been placed in the Cretaceous to Late Jurassic by Brown and others (1972; see for example section N-N′). The age of Lower Cretaceous pre-Potomac Group "red beds" in the Salisbury embayment is more fully treated in Doyle and Robbins (1977, p. 68-70). A trough of magnetically low material below Oak Grove on the aeromagnetic map of Virginia (Zietz and others, 1978) suggests that a buried "Triassic" basin may also underlie the Lower Cretaceous sequence at Oak Grove.

Age assignments within sedimentary rocks of the Potomac Group have been based on vertebrate remains (Marsh, 1896; Gilmore, 1939), plant megafossils (Newberry, 1895; Berry, 1906, 1911; Dorf, 1952), and, more recently, on palynomorphs (Groot and Penny, 1960; Brenner, 1963, 1967; Doyle, 1969; Wolfe and Pakiser, 1971; Doyle and Robbins, 1977).

The stratigraphic palynological studies of Brenner (1963), Wolfe and Pakiser (1971), and Doyle and Robbins (1977) suggest that two major zones occur within the Potomac Group of the Salisbury embayment, and that the upper zone can be divided into three subzones. In ascending stratigraphic order, the zones are referred to as zone I and II, and the subzones as II-A, II-B, and II-C (Figure 3). Brenner's (1963) zone I included the Patuxent and Arundel formations and zone II comprised the Patapsco Formation. These formational names are not used in describing the stratigraphic sequence in the Oak Grove core, but zones I and II are used.

Habib (1977) presented two palynologic zonations, one based on sporomorphs and the other on dinoflagellate cysts; these parallel the zonation of Brenner (1963) and Doyle and Robbins (1977) for the Lower and basal Upper Cretaceous. Habib's work, based on samples from the Deep Sea Drilling Project site 105 in the North Atlantic, allows correlation of zones in the nonmarine section with those in the downdip marine section. A comparison of the zonations described by Brenner (1963) and Doyle and Robbins (1977) with those of Habib (1977) and with those in the Oak Grove core is presented in Figure 3. Age assignments for the zones are based on similarities of microfloral assemblages in both North American and European strata which have been independently dated by marine invertebrates (see, for example, Doyle, 1969; Wolfe and Pakiser, 1971; Christopher, 1977; Doyle and Robbins, 1977).

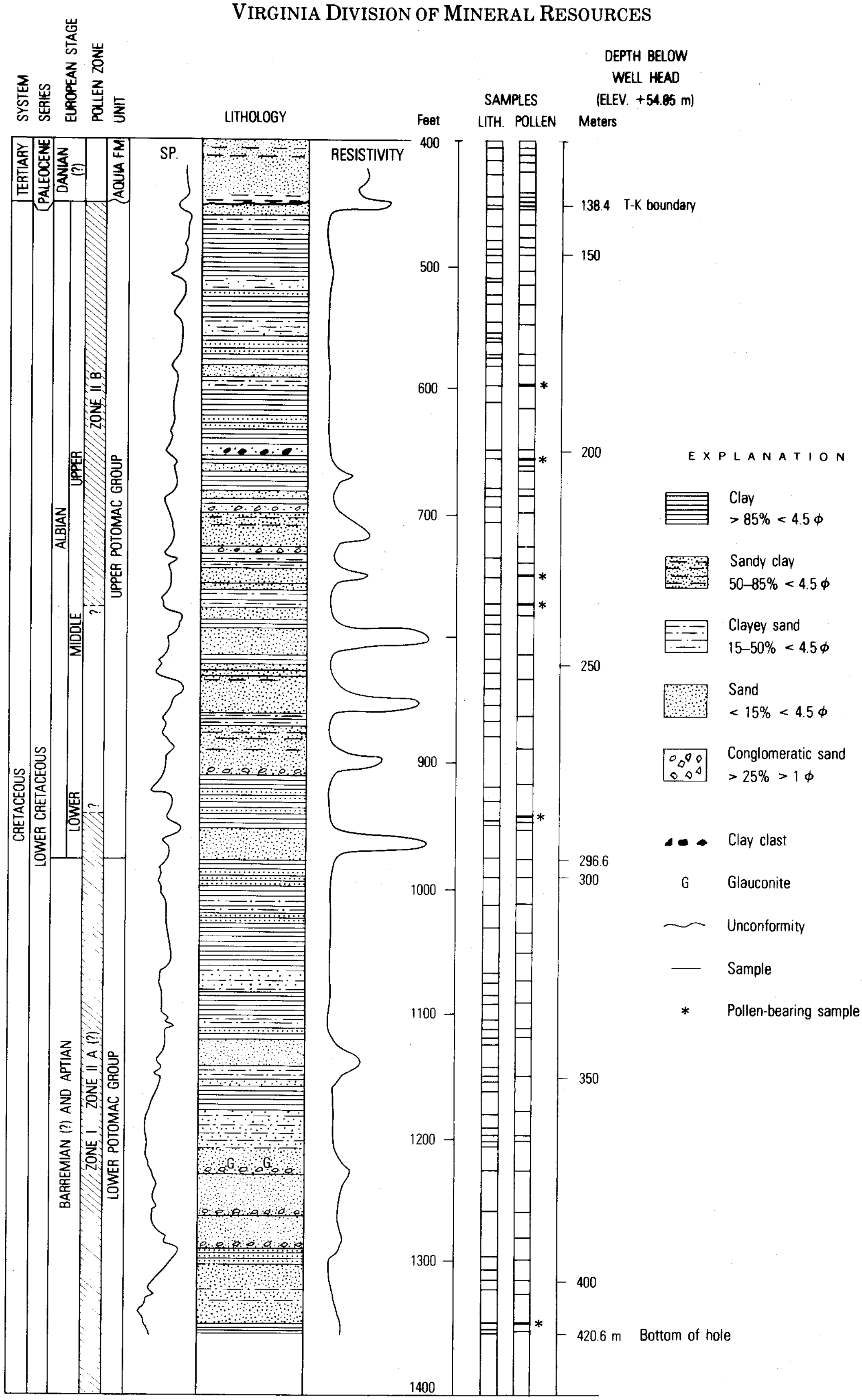


Figure 2. Lower Cretaceous stratigraphy in the Oak Grove core. Lithologic control from petrographic samples and geophysical logs (in washed intervals). Pollen-bearing samples lead to the zonation and European stage assignments.

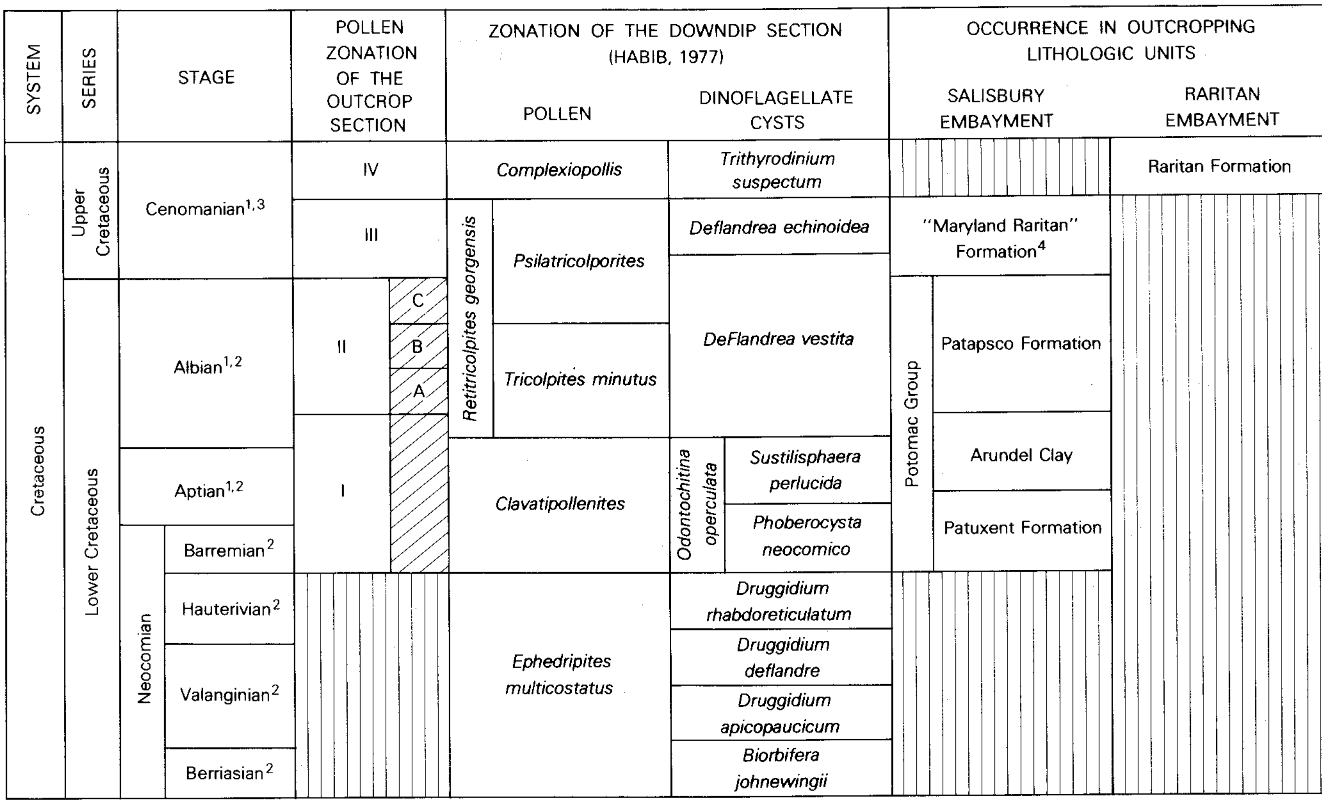


Figure 3. Summary of pollen zonation of the Lower Cretaceous and basal Upper Cretaceous as used in this paper and their occurrence in outcrop sections. Hachured pattern indicates portions of pollen zones preserved in Oak Grove core.

STRATIGRAPHY

A summary of the stratigraphic framework, lithologies, geophysical logs, and relevant sampling points in the Lower Cretaceous portion of the Oak Grove core is presented in Figure 2. These sediments can be organized into two major fining-upward sequences, each is more than 330 feet (100 m) thick, and is composed of numerous second-order, fining-upward sequences typically about 33 feet (10 m) thick. The Potomac Group in the Oak Grove core is here informally divided into "lower" and "upper" Potomac Group at the boundary between the two major fining-upward sequences. The textural break at 973 feet (296.6 m) below the top of the core is accompanied by changes in the representative logs (Figure 2; note especially the resistivity log contrast between "lower" and "upper" Potomac Group). In both the "lower" and "upper" portions of the Potomac Group, the dominantly clay-silt intervals, which top each fining-upward sequence, are sharply delineated by geophysical logs. Figure 2 also shows the coincidence of zone I and zone IIA(?) pollen samples with the lithologic interval defined as "lower" Potomac and the coincidence of younger zone II pollen associations with the "upper" Potomac interval. The two intervals are described below.

SAMPLING AND ANALYSES

X-ray analysis of the clay fraction and site analysis by standard wet-sieve techniques were performed on each of 71 samples. Selected light- and heavy-mineral separates were studied petrographically. Nineteen samples were collected, processed, and examined for palynomorphs; only six of these samples contained spores and pollen (Figure 2). The pollen-bearing samples came from two separate carbonaceous clay units that occur at depths from 596.5 to 781 feet (181.8 to 238.0 m), and from 950.5 feet (289.7 m) to the bottom of the core at 1380 feet (420.6 m). The six productive samples yielded an abundant and diverse microflora, containing a total of 87 species of spores and pollen; the distribution of these in the Oak Grove core is presented in Table 1. Miospore species are shown in Figure 25.

Table 1. Distribution of palynomorphs in samples from the Oak Grove core.

Palynomorph	Sampled Depth					
	410.9 m (1348 ft)	289.7 m (950.5 ft)	238.0 m (781 ft)	230.4 m (756 ft)	201.2 m (660 ft)	181.8 m (596.5 ft)
Pteridophyte spores						
Acanthotriletes cf. *A. varispinosus*		X				X
Aequitriradites spinulosus (Cookson & Dettmann) Cookson & Dettmann 1961		X	X	X	X	X
Alsophillidites pannuceus Brenner 1963		X				
Apiculatisporis asymmetricus Cookson & Dettmann 1958				X		X
Apiculatisporis babsae Brenner 1963						X
Appendicisporites potomacensis Brenner 1963		X		X	X	X
Appendicisporites tricornitatus Weyland & Greifeld 1953						X
Biretisporites sp.						X
Cicatricosisporites australiensis (Cookson) Potonié 1956					X	
Cicatricosisporites brevilaesuratus Couper 1958			X	X	X	X
Cicatricosisporites hallei Delcourt & Sprumont	X	X	X	X	X	X
Cicatricosisporites patapscoensis Brenner 1963				X		
Cicatricosisporites potomacensis Brenner 1963		X				
Cicatricosisporites subrotundus Brenner 1963					X	
Cicatricosisporites spp.		X				
Cingulatisporites distaverrucosus Brenner 1963			X			X
Concavissimisporites punctatus (Delcourt & Sprumont) Brenner 1963						X
Concavissimisporites variverrucatus (Couper) Brenner 1963	X					
Converrucosisporites proxigranulatus Brenner 1963		X				
Cyathidites australis Couper 1953		X				X
Cyathidites minor Couper 1953	X	X	X	X	X	X
Deltoidospora hallii Miner 1935		X				
Densoisporites perinatus Couper 1958	X					
Dictyophyllidites sp.						X
Heliosporites sp.					X	
Klukisporites pseudoreticulatus Couper 1958		X				
Klukisporites variegatus Couper 1958	X		X			
Kuylisporites lunaris Cookson & Dettmann 1958	X					
Laevigatosporites gracilis Wilson & Webster 1946		X	X	X		X
Laevigatosporites ovatus Wilson & Webster 1946		X				
Lycopodiacidites ambifoveolatus Brenner 1963		X				
Lycopodiacidites triangularis Brenner 1963		X	X		X	X
Lycopodiumsporites austroclavatidites (Cookson) Potonié 1956					X	
Matonisporites sp.			X			
Neoraistrickia robusta Brenner 1963					X	
Osmundacidites wellmanii Couper 1953			X			
Patellaesporites tavardensis Groot & Groot 1962					X	
Peromonolites allenensis Brenner 1963		X	X	X		
Polycingulatisporites reduncus (Bolchovitina) Playford & Dettmann 1965	X	X			X	X
Rouseisporites reticulatus Pocock 1962		X				X
Rouseisporites sp.				X	X	
Todisporites minor Couper 1958	X				X	
Trilobosporites marylandicus Brenner 1963						X
Trilobosporites minor Pocock 1962				X		
Undulatisporites undulapolus Brenner 1963						X

Table 1. Distribution of palynomorphs in samples from the Oak Grove core (Continued).

Palynomorph	Sampled Depth					
	410.9 m (1348 ft)	289.7 m (950.5 ft)	238.0 m (781 ft)	230.4 m (756 ft)	201.2 m (660 ft)	181.8 m (596.5 ft)
Gymnosperm pollen						
Abietineaepollenites microreticulatus Groot & Penny 1960		X	X		X	X
Alisporites bilateralis Rouse 1959	X	X	X	X	X	X
Araucariacites australis Cookson 1947		X	X	X		X
Circulina parva Brenner 1963						X
Classopollis torosus (Reissinger) Couper 1958	X	X	X	X	X	X
Decussosporites cf. D. *microreticulatus* Brenner 1963				X	X	X
Ephedripites multicostatus Brenner 1963	X					
Eucommiidites troedssonii Erdtman 1948				X	X	X
Exesipollenites tumulus Balme 1957	X	X		X	X	X
Ginkgocycadopites nitidus (Balme) Srivastava 1966		X	X	X		
Inaperturopollenites dubius (Potonié & Venitz) Thomson & Pflug 1953		X	X	X	X	X
Monosulcites epakros Brenner 1963						X
Monosulcites glottus Brenner 1963				X		
Parvisaccites radiatus Couper 1958	X	X	X	X	X	X
Podocarpidites potomacensis Brenner 1963			X	X		X
Sequoiaepollenites sp.			X			
Taxodiaceaepollenites hiatus (Potonié) Kremp 1949		X	X	X	X	X
Vitreisporites pallidus (Reissinger) Brenner 1963		X				X
Welwitschiapites sp.				X		
Angiosperm pollen						
Ajatipollis sp. A of Doyle & Robbins 1977						X
Clavatipollenites hughesii Couper 1958		X			X	X
Clavatipollenites minutus Brenner 1963		X		X	X	
"Foveotricolpites" concinnus Singh 1971					X	X
Liliacidites sp. F of Doyle & Robbins 1977					X	X
Retimonocolpites dividuus Pierce 1961				X	X	X
Retimonocolpites peroreticulatus (Brenner) Doyle 1975				X		X
"Retitricolpites" fragosus Hedlund & Norris 1968			X			
"Retitricolpites" geranioides (Couper) Brenner 1963				X		
"Retitricolpites" prosimilis Norris 1967				X		
"Retitricolpites" vermimurus Brenner 1963			X		X	X
Stellatopollis barghoornii Doyle 1973			X	X		X
Tricolpites albiensis Kemp 1968			X	X	X	X
Tricolpites crassimurus (Groot & Penny) Singh 1971		X	X		X	X
Tricolpites micromunus (Groot & Penny) Burger 1970			X	X	X	X
Tricolpites sagax Norris 1967				X	X	
Tricolpites sp. A of Doyle & Robbins 1977		X				
Tricolpites spp.		X				
Palynomorphs incertae sedis						
Callialasporites dampieri (Balme) Suk Dev 1961		X				X
Monosulcites chaloneri Brenner 1963		X				
Monosulcites spinosus Brenner 1963						X
Perinopollenites elatoides Couper 1958	X	X	X	X	X	X
Spheripollenites psilatus Couper 1958	X			X		

"LOWER" POTOMAC GROUP

Petrographic characteristics: The "lower" Potomac group is 412 feet (125.6 m) thick, occupying the interval from 973 feet (296.6 m) to the base of the Oak Grove core; it is composed of a lower series of thick beds containing mostly sand with associated clay-clast conglomerates and an upper series composed of sand beds interbedded with laminated carbonaceous clays.

The sandy intervals are typically composed of medium to very coarse subangular quartz, potassium feldspar, and plagioclase. Framework grains, determined from stained thin sections, varied from 45 to 60 percent quartz, 30 to 40 percent potassium feldspar and 5 to 14 percent plagioclase. The potassium feldspar grains are typically rather fresh, but the plagioclase feldspar grains are pitted to deeply weathered. The non-opaque heavy-mineral assemblages in the "lower" Potomac Group are dominated by staurolite, garnet, and zircon, constituting relatively balanced full suites (using the terminology of Dryden and Dryden, 1956). Hyacinth-colored zircon occurs between 984 and 1149 feet (300 and 350 m), and apatite comprises up to 40 percent of the heavy mineral separates in most "lower" Potomac samples. Additionally, small amounts of well-rounded, crystalline, very fine sand-size glauconite grains constitute as much as 10 percent of the heavy-mineral fraction in samples below 1148 feet (350 m) (Figure 4).

No systematic study of the opaque heavy minerals was undertaken. The opaque minerals above 1148 feet (350 m) are mostly hematite and ilmenite; below this zone relatively high percentages of pyrite and siderite were noted. A single pyritized foraminiferal test was found in the sample taken at 1070.5 feet (372.6 m).

The well-bedded clays in the "lower" Potomac are typically mixed-layer illite/smectite containing a high percentage of expandable layers. Interstitial clay in sandy intervals or in laminated sand and clay is dominantly kaolinitic. Illite typically constitutes less than 20 percent of the clays. In several samples collected at depths between 1214 and 1279.5 feet (370 and 390 m), however, illite constitutes 40 to nearly 80 percent of the total clays. Vermiculite is a minor component in several "lower" Potomac samples; only trace amounts of cristobalite (low phase) and clinoptilolite are present.

Sedimentary structures: Sand units and clay-clast conglomerates are thickly bedded and are either poorly stratified internally (Figure 5) or crudely bedded to well stratified (Figure 6). Three major clay-clast conglomerate intervals, each ap-

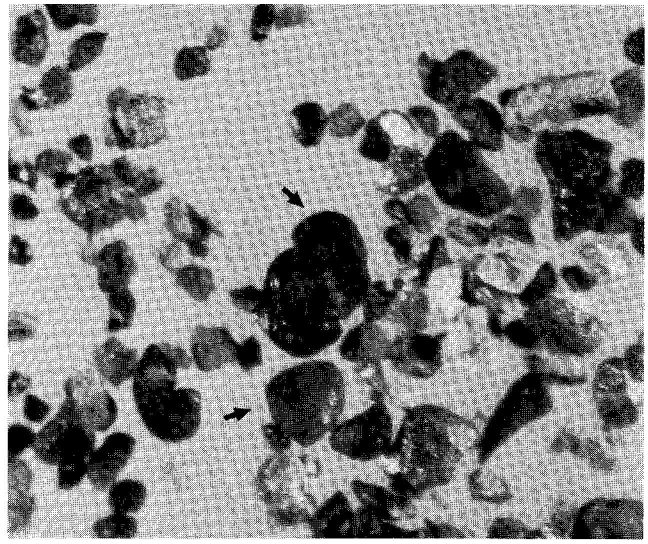


Figure 4. Photomicrograph of heavy-mineral separate from the "lower" Potomac Group; arrows point to glauconite grains from 122.5 feet, (372.6 m) below well head. Bar = 1.0 mm.

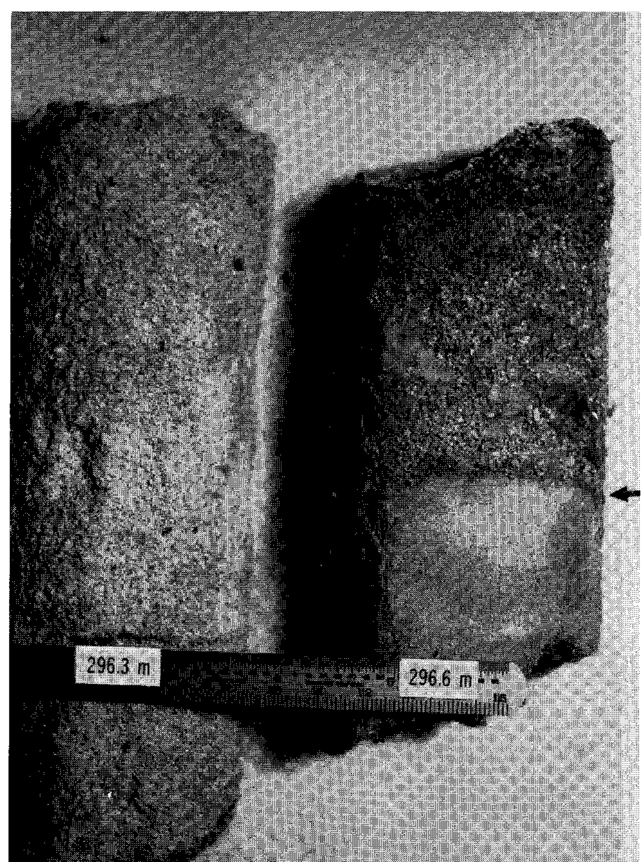


Figure 5. Massive, poorly stratified arkosic sands in the "lower" Potomac Group. Note the sharp contact (arrow) between medium clayey sand and very coarse conglomeratic sand in core segment at right.

"LOWER" POTOMAC GROUP

Petrographic characteristics: The "lower" Potomac group is 412 feet (125.6 m) thick, occupying the interval from 973 feet (296.6 m) to the base of the Oak Grove core; it is composed of a lower series of thick beds containing mostly sand with associated clay-clast conglomerates and an upper series composed of sand beds interbedded with laminated carbonaceous clays.

The sandy intervals are typically composed of medium to very coarse subangular quartz, potassium feldspar, and plagioclase. Framework grains, determined from stained thin sections, varied from 45 to 60 percent quartz, 30 to 40 percent potassium feldspar and 5 to 14 percent plagioclase. The potassium feldspar grains are typically rather fresh, but the plagioclase feldspar grains are pitted to deeply weathered. The non-opaque heavy-mineral assemblages in the "lower" Potomac Group are dominated by staurolite, garnet, and zircon, constituting relatively balanced full suites (using the terminology of Dryden and Dryden, 1956). Hyacinth-colored zircon occurs between 984 and 1149 feet (300 and 350 m), and apatite comprises up to 40 percent of the heavy mineral separates in most "lower" Potomac samples. Additionally, small amounts of well-rounded, crystalline, very fine sand-size glauconite grains constitute as much as 10 percent of the heavy-mineral fraction in samples below 1148 feet (350 m) (Figure 4).

No systematic study of the opaque heavy minerals was undertaken. The opaque minerals above 1148 feet (350 m) are mostly hematite and ilmenite; below this zone relatively high percentages of pyrite and siderite were noted. A single pyritized foraminiferal test was found in the sample taken at 1070.5 feet (372.6 m).

The well-bedded clays in the "lower" Potomac are typically mixed-layer illite/smectite containing a high percentage of expandable layers. Interstitial clay in sandy intervals or in laminated sand and clay is dominantly kaolinitic. Illite typically constitutes less than 20 percent of the clays. In several samples collected at depths between 1214 and 1279.5 feet (370 and 390 m), however, illite constitutes 40 to nearly 80 percent of the total clays. Vermiculite is a minor component in several "lower" Potomac samples; only trace amounts of cristobalite (low phase) and clinoptilolite are present.

Sedimentary structures: Sand units and clay-clast conglomerates are thickly bedded and are either poorly stratified internally (Figure 5) or crudely bedded to well stratified (Figure 6). Three major clay-clast conglomerate intervals, each ap-

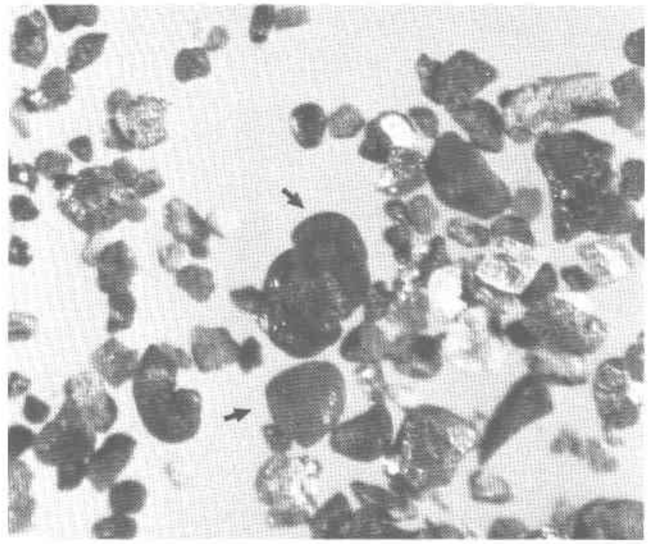


Figure 4. Photomicrograph of heavy-mineral separate from the "lower" Potomac Group; arrows point to glauconite grains from 122.5 feet, (372.6 m) below well head. Bar = 1.0 mm.

Figure 5. Massive, poorly stratified arkosic sands in the "lower" Potomac Group. Note the sharp contact (arrow) between medium clayey sand and very coarse conglomeratic sand in core segment at right.

Figure 6. Planar bedding—horizontal stratification of conglomeratic sands in the "lower" Potomac Group. Note the variation in clay clast size and color (composition) in the core segment on the left. Stratification in the core segment on the right may be slightly inclined.

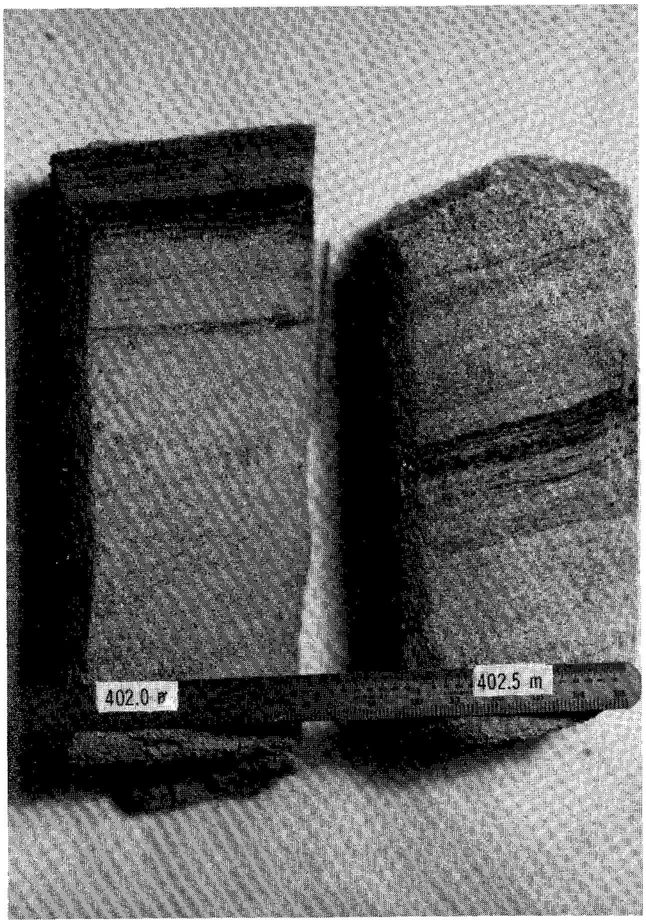


Figure 7. Ripple cross-laminated medium-to fine-miceous sand in the "lower" Potomac Group. Dark laminae are composed of carbonaceous debris (mostly charred wood). On the left-hand specimen, note the change in stratification angle from the right (lower) to the left segment (higher) and the corresponding decrease in sediment size.

proximately 3 feet (1 m) thick, are present between 1198 and 1280 feet (365 and 390 m) (see Figure 2). The clay clasts tend to be compact and somewhat rounded; clast to clast contacts are rare. Many fining-upward sequences, characterized by sharp lower contacts, occur throughout the "lower" Potomac strata (arrow in Figure 5).

Large-scale inclined bedding is rare. It should be noted, however, that core recovery was poor in thick friable sands (possibly crossbedded?) from several intervals in the "lower" Potomac. Small-scale inclined bedding is common in medium- to fine-grained sand (Figure 7) and in interbedded sand and clay units (Figure 8). Carbonaceous debris is a common component in ripple cross-laminated sand.

The clay intervals within the "lower" Potomac Group vary from massive sandy clay to finely laminated carbonaceous clay. Similar laminated to cross-laminated clay intervals are present in the "upper" Potomac Group. Both well-bedded carbonaceous clay and carbonaceous clay clasts have yeilded pollen within the "lower" Potomac, or zone I, interval.

Palynological characteristics: Two samples 398 feet (121.2 m) apart in the lower Potomac produced spores and pollen. The basal pollen sample (1398 feet; 410.9 m) from the Oak Grove core yielded well preserved moderately abundant palynomorphs. The assemblage is dominated by pollen of the gymnosperms *Classopollis torosus* (Reissinger) Couper 1958, and *Exesipollenites tumulus* Balme 1957. Other gymnosperm pollen and pteridophyte spores constitute a minor element of the microflora. No angiospermous pollen were observed from this sample.

The only biostratigraphically significant sporomorph recovered from the basal sample of the Oak Grove core is *Kuylisproites lunaris* Cookson and Dettmann 1958 (Figure 25a).

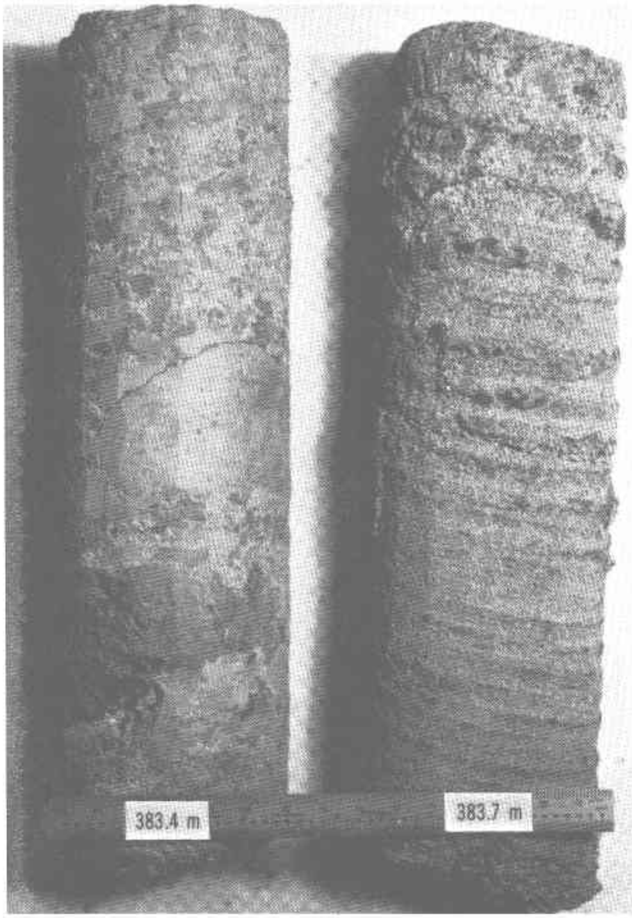


Figure 6. Planar bedding—horizontal stratification of conglomeratic sands in the "lower" Potomac Group. Note the variation in clay clast size and color (composition) in the core segment on the left. Stratification in the core segment on the right may be slightly inclined.

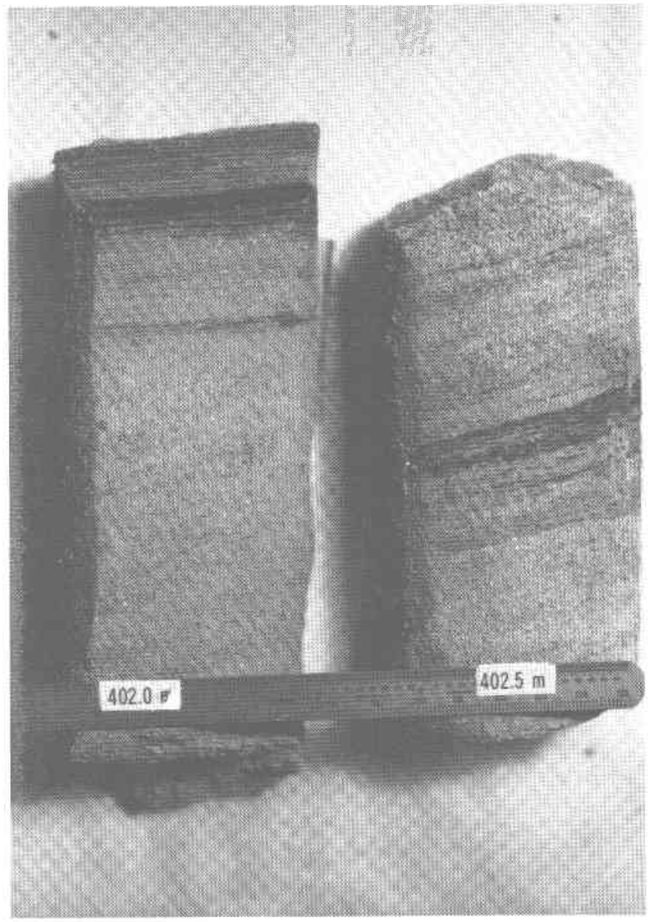


Figure 7. Ripple cross-laminated medium-to fine-miceous sand in the "lower" Potomac Group. Dark laminae are composed of carbonaceous debris (mostly charred wood). On the left-hand specimen, note the change in stratification angle from the right (lower) to the left segment (higher) and the corresponding decrease in sediment size.

proximately 3 feet (1 m) thick, are present between 1198 and 1280 feet (365 and 390 m) (see Figure 2). The clay clasts tend to be compact and somewhat rounded; clast to clast contacts are rare. Many fining-upward sequences, characterized by sharp lower contacts, occur throughout the "lower" Potomac strata (arrow in Figure 5).

Large-scale inclined bedding is rare. It should be noted, however, that core recovery was poor in thick friable sands (possibly crossbedded?) from several intervals in the "lower" Potomac. Small-scale inclined bedding is common in medium- to fine-grained sand (Figure 7) and in interbedded sand and clay units (Figure 8). Carbonaceous debris is a common component in ripple cross-laminated sand.

The clay intervals within the "lower" Potomac Group vary from massive sandy clay to finely laminated carbonaceous clay. Similar laminated to cross-laminated clay intervals are present in the "upper" Potomac Group. Both well-bedded carbonaceous clay and carbonaceous clay clasts have yeilded pollen within the "lower" Potomac, or zone I, interval.

Palynological characteristics: Two samples 398 feet (121.2 m) apart in the lower Potomac produced spores and pollen. The basal pollen sample (1398 feet; 410.9 m) from the Oak Grove core yielded well preserved moderately abundant palynomorphs. The assemblage is dominated by pollen of the gymnosperms *Classopollis torosus* (Reissinger) Couper 1958, and *Exesipollenites tumulus* Balme 1957. Other gymnosperm pollen and pteridophyte spores constitute a minor element of the microflora. No angiospermous pollen were observed from this sample.

The only biostratigraphically significant sporomorph recovered from the basal sample of the Oak Grove core is *Kuylisproites lunaris* Cookson and Dettmann 1958 (Figure 25a).

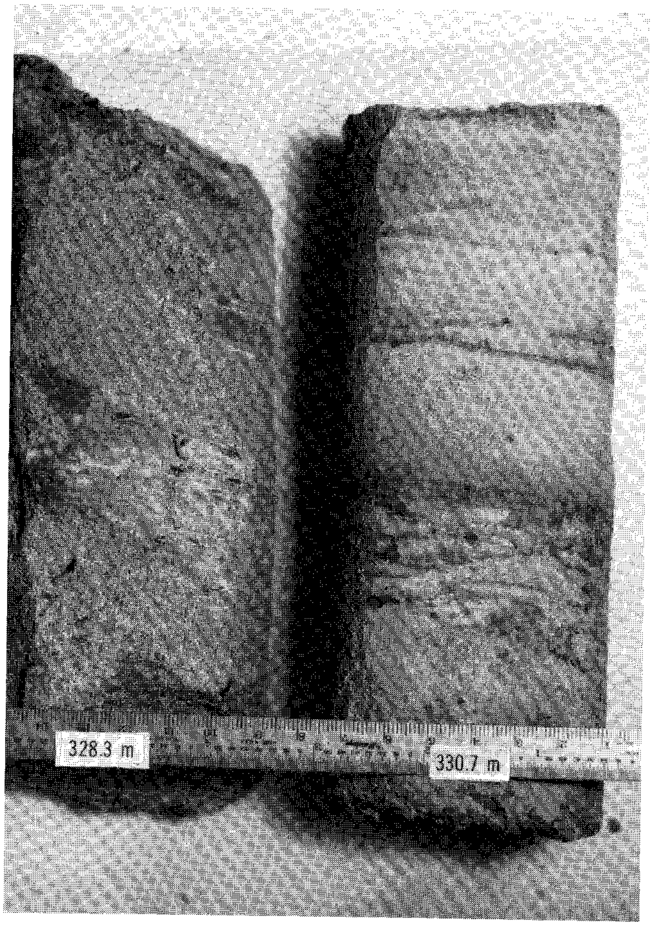


Figure 8. Interbedded sand and clay intervals in the "lower" Potomac Group showing moderate to slight disruption of primary stratification. Note the irregular distribution of sand in both core segments.

Brenner (1963) cited this spore as one of only four species restricted to zone I. On the basis of its presence and the abundance of *Classopollis torosus* and *Exesipollenites tumulus* (also cited by Brenner as typical of samples from zone I), the basal Oak Grove sample is assigned to zone I.

The *Ephedripites multicostatus* zone, defined as the interval from the first appearance of the nominative species up to the first occurrence of *Clavatipollenites*, was estabalished in a palynological study of the Lower Cretaceous of the Deep Sea Drilling Project site 105 in the North Atlantic (Habib, 1977). The *Ephedripites multicostatus* zone was considered to be older than zone I. The presence of *Ephedripites multicostatus* Brenner 1963 and the absence of *Clavatipollenites* in the basal sample from the Oak Grove core are evidence that this sample belongs to the *Ephedripites multicostatus* zone; however, many of the guide sporomorphs for a particular zone are rare, and should by no means be expected in every sample from that zone (Doyle and Robbins, 1977). Therefore, until more detailed sampling and examination of the basal sediments of the Oak Grove core help to confirm the absence of *Clavatipollenites* within them, we will consider the Oak Grove core to bottom in sediments of zone I age.

The relatively high abundance of *Classopollis* might also have paleoecologic importance. On the basis of the distribution of the remains of plants believed to have produced *Classopollis* pollen (Family Cheirolepidiaceae), together with the lithologies associated with varying *Classopollis* abundances, it was concluded that species of Cheirolepidiaceae inhabited upland slopes of warm, arid regions (Vakhrameev, 1970). Because of their abundance on upland slopes, it was further concluded that dominance of an assemblage by *Classopollis* pollen indicates transgressive marine conditions. An advancing sea would flood the coastal regions, causing a sharp decrease in the pollen of plants growing in coastal areas and an increase in the pollen from plants of the upland slopes (Vakhrameev, 1970). The reported occurrence of dinoflagellate cysts from downdip subsurface zone I samples (Doyle and Robbins, 1977, p. 71-72) and the presence of glauconite in zone I from the Oak Grove core support Vakhrameev's conclusion.

The other "lower" Potomac Group sample containing palynomorphs was from 950 feet (287.7 m) and yielded an abundance of well preserved palynomorphs. Inaperturate pollen types dominate the assemblage with *Inaperturopollenites dubius* (Potonié and Venitz) Thomson and Pflug 1953 and *Taxodiaceaepollenites hiatus* (Potonié) Kremp 1949 being most common. *Classopollis torosus* is also common, as are a variety of pteridophyte spores.

None of the sporomorphs listed as being restricted to either zone I or II by Brenner (1963) or Doyle and Robbins (1977) were observed in the Oak Grove core sample at 950 feet (289.7 m). However, several very rare tricolpate angiosperm pollen grains were observed (Figure 25), among which is *Tricolpites* aff. *T. crassimurus* (Groot and Penny) Singh 1971. The first appearance of angiosperm pollen was used to define the base of zone II, and the complete absence of pollen with angiospermous affinities was used as a characteristic of zone I (Brenner, 1963). Subsequent studies (Doyle, 1973; Wolfe, Doyle, and Page, 1975; Doyle, van Campo, and Lugardon, 1975; Doyle and Hickey, 1976; and Doyle and Robbins, 1977) have shown that: 1) some of the reticulate monosulcate pollen of zone I probably represents early angiosperm pollen; and 2)

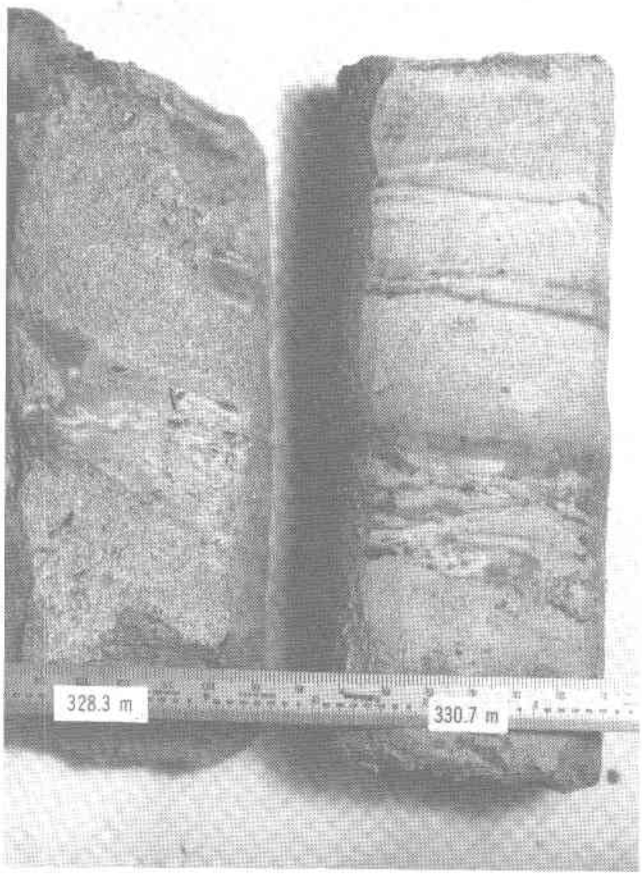


Figure 8. Interbedded sand and clay intervals in the "lower" Potomac Group showing moderate to slight disruption of primary stratification. Note the irregular distribution of sand in both core segments.

Brenner (1963) cited this spore as one of only four species restricted to zone I. On the basis of its presence and the abundance of *Classopollis torosus* and *Exesipollenites tumulus* (also cited by Brenner as typical of samples from zone I), the basal Oak Grove sample is assigned to zone I.

The *Ephedripites multicostatus* zone, defined as the interval from the first appearance of the nominative species up to the first occurrence of *Clavatipollenites*, was estabalished in a palynological study of the Lower Cretaceous of the Deep Sea Drilling Project site 105 in the North Atlantic (Habib, 1977). The *Ephedripites multicostatus* zone was considered to be older than zone I. The presence of *Ephedripites multicostatus* Brenner 1963 and the absence of *Clavatipollenites* in the basal sample from the Oak Grove core are evidence that this sample belongs to the *Ephedripites multicostatus* zone; however, many of the guide sporomorphs for a particular zone are rare, and should by no means be expected in every sample from that zone (Doyle and Robbins, 1977). Therefore, until more detailed sampling and examination of the basal sediments of the Oak Grove core help to confirm the absence of *Clavatipollenites* within them, we will consider the Oak Grove core to bottom in sediments of zone I age.

The relatively high abundance of *Classopollis* might also have paleoecologic importance. On the basis of the distribution of the remains of plants believed to have produced *Classopollis* pollen (Family Cheirolepidiaceae), together with the lithologies associated with varying *Classopollis* abundances, it was concluded that species of Cheirolepidiaceae inhabited upland slopes of warm, arid regions (Vakhrameev, 1970). Because of their abundance on upland slopes, it was further concluded that dominance of an assemblage by *Classopollis* pollen indicates transgressive marine conditions. An advancing sea would flood the coastal regions, causing a sharp decrease in the pollen of plants growing in coastal areas and an increase in the pollen from plants of the upland slopes (Vakhrameev, 1970). The reported occurrence of dinoflagellate cysts from downdip subsurface zone I samples (Doyle and Robbins, 1977, p. 71-72) and the presence of glauconite in zone I from the Oak Grove core support Vakhrameev's conclusion.

The other "lower" Potomac Group sample containing palynomorphs was from 950 feet (287.7 m) and yielded an abundance of well preserved palynomorphs. Inaperturate pollen types dominate the assemblage with *Inaperturopollenites dubius* (Potonié and Venitz) Thomson and Pflug 1953 and *Taxodiaceaepollenites hiatus* (Potonié) Kremp 1949 being most common. *Classopollis torosus* is also common, as are a variety of pteridophyte spores.

None of the sporomorphs listed as being restricted to either zone I or II by Brenner (1963) or Doyle and Robbins (1977) were observed in the Oak Grove core sample at 950 feet (289.7 m). However, several very rare tricolpate angiosperm pollen grains were observed (Figure 25), among which is *Tricolpites* aff. *T. crassimurus* (Groot and Penny) Singh 1971. The first appearance of angiosperm pollen was used to define the base of zone II, and the complete absence of pollen with angiospermous affinities was used as a characteristic of zone I (Brenner, 1963). Subsequent studies (Doyle, 1973; Wolfe, Doyle, and Page, 1975; Doyle, van Campo, and Lugardon, 1975; Doyle and Hickey, 1976; and Doyle and Robbins, 1977) have shown that: 1) some of the reticulate monosulcate pollen of zone I probably represents early angiosperm pollen; and 2) tricolpates do, in fact, occur as rare elements in the uppermost part of zone I. Biostratigraphic precision was obtained from detailed inspection of the angiosperm pollen in these zones (Doyle and Robbins, 1977). Accordingly, with the exception of the basal sample at 1348 feet (410.0 m), zonation of the Lower Cretaceous sediments of the Oak Grove core is based primarily on the distribution of angiosperm pollen. Therefore, primarily on the basis of the occurrences of rare tricolpate forms, the Oak Grove sample at 950 feet (289.7 m) is considered to belong to either the uppermost part of zone I or the basal part of II-A.

"UPPER" POTOMAC GROUP

Petrographic characteristics: The "upper" Potomac Group is 418 feet (127.4 m) thick and is composed of a lower sand-dominant interval and an upper clay-dominant interval. The lower 317 feet (96.6 m) (from 973 to 655 feet; 296.6 to approximately 200 m) is characterized by fining-upward sequences; seven such sequences are apparent on the resistivity log (Figure 2). Within a vertical distance of 33 to 66 feet (10 to 20 m), these sequences grade from coarse sand, commonly containing clay clasts, to laminated or massive clay. The upper 101 feet (30.8 m) of the "upper" Potomac Group is characterized by highly sheared and locally mottled montmorillonitic red clay.

The lower portion of the "upper" Potomac Group is poorly represented; only cuttings of washed portions are available for several 10-16.5 foot (3-5 m) intervals between 754.5 and 853 feet (230 and 260 m). From the cuttings and the resistivity log it is inferred that these intervals are composed of coarse to very coarse sand, probably dominated by angular quartz and microcline. The light mineral sand fraction in the "upper" Potomac Group is similar in composition to that in the "lower" Potomac. Quartz percentages are marginally higher in the "upper" Potomac (55-70 versus 40-65 percent) and plagioclase is slightly lower (5-8 versus 5-14 percent).

The heavy-mineral separates in the "upper" Potomac are characterized by a limited suite of heavy minerals dominated by a very stable zircon assemblage. Apatite is rare above 738 feet (225 m) and glauconite was not observed in the "upper" Potomac. Staurolite, tourmaline, epidote, and garnet are present and locally common in the heavy mineral suites.

Composition of the major clays in the "upper" Potomac Group is similar to that of the "lower" Potomac. Most samples are mixed kaolinite and highly expandable illite/smectite. Illite typically constitutes less than 15 percent of the total clay fraction. Cristobalite occurs in the clay-dominant part of the "upper" Potomac at depths between 460 and 656 feet (140 and 200 m).

Sedimentary structures: Primary stratification throughout the "upper" Potomac Group is poor; bedding appears to be disrupted by both physical deforming agents (liquifaction, shearing, and folding) and biological mottling (rooting or burrowing). Most of the sand and clay intervals between 454 and 656 feet (138.4 and 200 m) appear to be massive to thick-bedded.

Cross-stratification occurs within the coarse-grained intervals where sand containing sparse clay clasts is succeeded by clay-clast conglomerate (Figure 9) or where sandy clay grades into micaceous clayey sand (Figure 10). These examples are perhaps the best defined primary structures in the "upper" Potomac. Resolution of framework-

Figure 9. Conglomeratic medium sand in the "upper" Potomac Group showing clast roundness decreasing upward in the section. Note the abundant round, granule-size clay clasts in the lower one-half of the core segment and the clast supported framework in the upper one-half.

tricolpates do, in fact, occur as rare elements in the uppermost part of zone I. Biostratigraphic precision was obtained from detailed inspection of the angiosperm pollen in these zones (Doyle and Robbins, 1977). Accordingly, with the exception of the basal sample at 1348 feet (410.0 m), zonation of the Lower Cretaceous sediments of the Oak Grove core is based primarily on the distribution of angiosperm pollen. Therefore, primarily on the basis of the occurrences of rare tricolpate forms, the Oak Grove sample at 950 feet (289.7 m) is considered to belong to either the uppermost part of zone I or the basal part of II-A.

"UPPER" POTOMAC GROUP

Petrographic characteristics: The "upper" Potomac Group is 418 feet (127.4 m) thick and is composed of a lower sand-dominant interval and an upper clay-dominant interval. The lower 317 feet (96.6 m) (from 973 to 655 feet; 296.6 to approximately 200 m) is characterized by fining-upward sequences; seven such sequences are apparent on the resistivity log (Figure 2). Within a vertical distance of 33 to 66 feet (10 to 20 m), these sequences grade from coarse sand, commonly containing clay clasts, to laminated or massive clay. The upper 101 feet (30.8 m) of the "upper" Potomac Group is characterized by highly sheared and locally mottled montmorillonitic red clay.

The lower portion of the "upper" Potomac Group is poorly represented; only cuttings of washed portions are available for several 10-16.5 foot (3-5 m) intervals between 754.5 and 853 feet (230 and 260 m). From the cuttings and the resistivity log it is inferred that these intervals are composed of coarse to very coarse sand, probably dominated by angular quartz and microcline. The light mineral sand fraction in the "upper" Potomac Group is similar in composition to that in the "lower" Potomac. Quartz percentages are marginally higher in the "upper" Potomac (55-70 versus 40-65 percent) and plagioclase is slightly lower (5-8 versus 5-14 percent).

The heavy-mineral separates in the "upper" Potomac are characterized by a limited suite of heavy minerals dominated by a very stable zircon assemblage. Apatite is rare above 738 feet (225 m) and glauconite was not observed in the "upper" Potomac. Staurolite, tourmaline, epidote, and garnet are present and locally common in the heavy mineral suites.

Composition of the major clays in the "upper" Potomac Group is similar to that of the "lower" Potomac. Most samples are mixed kaolinite and highly expandable illite/smectite. Illite typically constitutes less than 15 percent of the total clay fraction. Cristobalite occurs in the clay-dominant part of the "upper" Potomac at depths between 460 and 656 feet (140 and 200 m).

Sedimentary structures: Primary stratification throughout the "upper" Potomac Group is poor; bedding appears to be disrupted by both physical deforming agents (liquifaction, shearing, and folding) and biological mottling (rooting or burrowing). Most of the sand and clay intervals between 454 and 656 feet (138.4 and 200 m) appear to be massive to thick-bedded.

Cross-stratification occurs within the coarse-grained intervals where sand containing sparse clay clasts is succeeded by clay-clast conglomerate (Figure 9) or where sandy clay grades into micaceous clayey sand (Figure 10). These examples are perhaps the best defined primary structures in the "upper" Potomac. Resolution of framework-

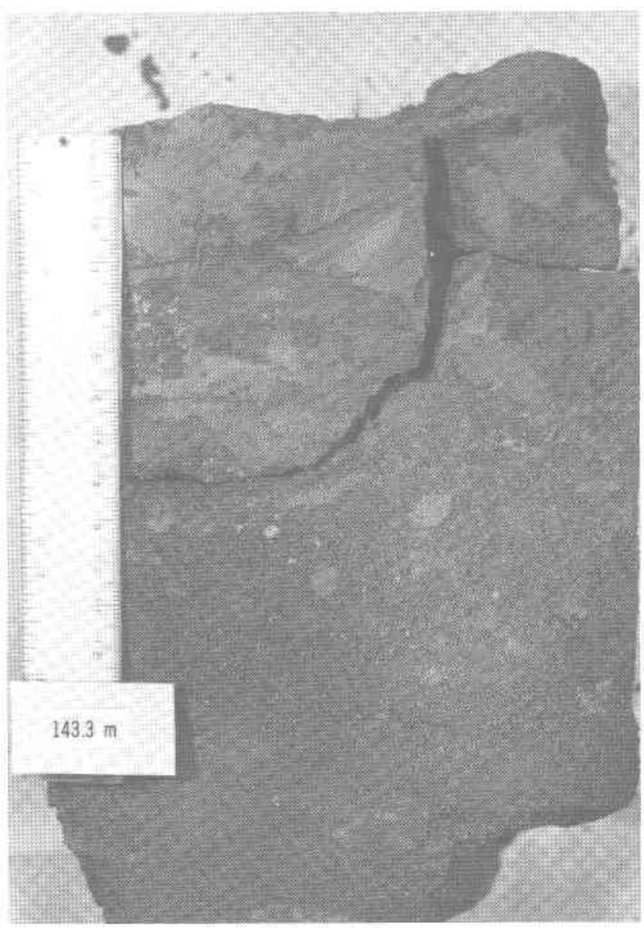


Figure 9. Conglomeratic medium sand in the "upper" Potomac Group showing clast roundness decreasing upward in the section. Note the abundant round, granule-size clay clasts in the lower one-half of the core segment and the clast supported framework in the upper one-half.

Figure 10. Transition from sandy, poorly laminated silt and clay to laminated(?) micaceous fine sand in the "upper" Potomac Group.

matrix relationship or lithologic contacts are much less clear in other stratigraphic intervals. Recognition of primary clay clast boundaries is difficult where coarse sand is absent (Figure 11). Load structures occur at boundaries between sand and clay or between coarse sand and clayey sand (Figure 12). The injected clayey interval as well as the interval below the contact appears to be highly disrupted. Some intervals initially logged as crossbedded sand (Figure 13) may have been formed by clay flow along shear surfaces (Figure 14). Note the circular compact clay mottles in both the apparently crossbedded sand and the sheared clay (Figures 13 and 14).

Primary sedimentary features are preserved in planar to cross-laminated carbonaceous clay and micaceous silt (Figures 15, 16). These structures and lithologies are similar to the laminated clay intervals in the "lower" Potomac, but contrast sharply with overlying, poorly bedded clay intervals. The clays are crudely laminated and contain subvertical tubular disruptions (Figure 17), and interbedded, massive clays, which contain submillimeter scale radiating tubules (Figure 18). Both tubular structures appear to be the result of biological agents. Plant rootlets are probably responsible for the small tubules (Figure 18), and the larger shallow curving, nonbranching structures may be worm borrows.

Mechanical disruption of the sediment appears to have taken place both within the primary depositional environment and in later diagenetic environments. Penecontemporaneous disruption may have been produced either by clay injection, induced by loading, or by transportation of mechanically "rolled-up" laminated clay at the sediment-water interface. The result is juxtaposition of tightly folded laminated clay and silt with planar to cross-laminated silt to very fine sand (Figure 19). The highly fractured clays so pervasive in the "upper" Potomac Group (Figure 20) must have been deformed after dewatering, as watered clay deforms plastically. The pattern of fractures in these clays (Figures 14, 20) is unlike structures produced by either subaerial mudcracks (suncracks) or subaequeous mudcracks produced by contraction during clay transformations (syneresis cracks). These intervals of fractured clays presently consist of mixtures of kaolinite, mixed layer illite/smectite, and illite; this mixture is evidence that clay is predominantly detrital and that diagenesis has not played a major role in the sediment disruption.

Palynological characteristics: The four pollen-bearing samples taken at depths between 596 and 781 feet (181.8 and 238.0 m) have all been assigned to subzone II-B because of the presence of numerous guide fossils including: *Neoraistrickia robusta* Brenner 1963, *Cicatricosisporites subrotundus* Brenner 1963, and *C. patapscoensis* Brenner 1963. Each of these species was recorded from one or more of the four samples (Table 1), and each is cited by Brenner (1963) as being restricted to subzone II-B. In addition, a wide variety of monosulcate, tricolpate, and tricolporoidate pollen were recovered from these samples, the concurrent ranges of which are suggestive of a subzone II-B age for all four samples (Figure 21).

The basal three samples assigned to subzone II-B yielded only a moderately abundant, moderately well preserved palynomorph flora. Abundant carbonized matter was present in these samples and angiosperm pollen, although common, was generally less abundant than were pteridophyte spores, or gymnosperm pollen, or the sum of these.

In contrast, the uppermost sample assigned to subzone II-B (596 feet; 181.8 m) contained abundant, well preserved palynomorphs, and little carbonized organic matter. The assemblage was dominated by

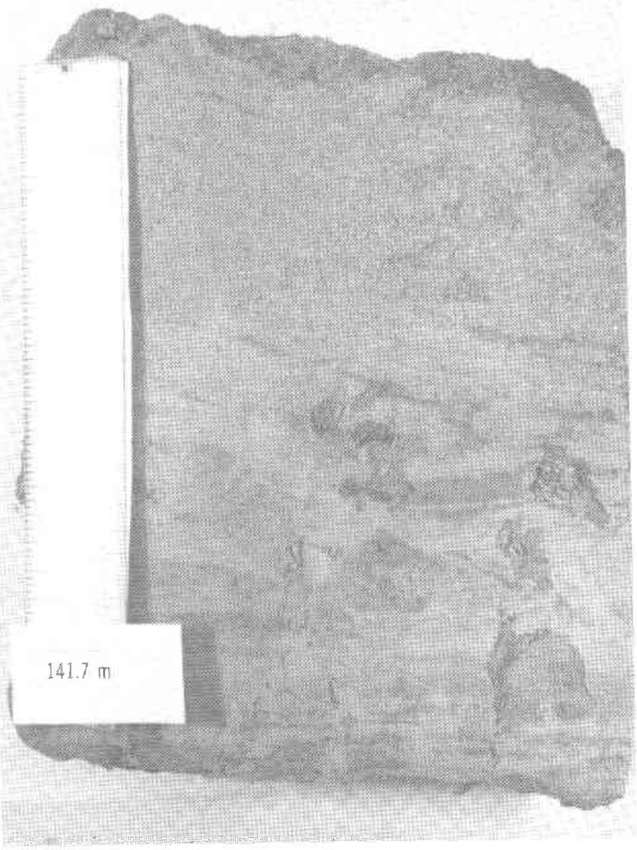


Figure 10. Transition from sandy, poorly laminated silt and clay to laminated(?) micaceous fine sand in the "upper" Potomac Group.

matrix relationship or lithologic contacts are much less clear in other stratigraphic intervals. Recognition of primary clay clast boundaries is difficult where coarse sand is absent (Figure 11). Load structures occur at boundaries between sand and clay or between coarse sand and clayey sand (Figure 12). The injected clayey interval as well as the interval below the contact appears to be highly disrupted. Some intervals initially logged as crossbedded sand (Figure 13) may have been formed by clay flow along shear surfaces (Figure 14). Note the circular compact clay mottles in both the apparently crossbedded sand and the sheared clay (Figures 13 and 14).

Primary sedimentary features are preserved in planar to cross-laminated carbonaceous clay and micaceous silt (Figures 15, 16). These structures and lithologies are similar to the laminated clay intervals in the "lower" Potomac, but contrast sharply with overlying, poorly bedded clay intervals. The clays are crudely laminated and contain subvertical tubular disruptions (Figure 17), and interbedded, massive clays, which contain submillimeter scale radiating tubules (Figure 18). Both tubular structures appear to be the result of biological agents. Plant rootlets are probably responsible for the small tubules (Figure 18), and the larger shallow curving, nonbranching structures may be worm borrows.

Mechanical disruption of the sediment appears to have taken place both within the primary depositional environment and in later diagenetic environments. Penecontemporaneous disruption may have been produced either by clay injection, induced by loading, or by transportation of mechanically "rolled-up" laminated clay at the sediment-water interface. The result is juxtaposition of tightly folded laminated clay and silt with planar to cross-laminated silt to very fine sand (Figure 19). The highly fractured clays so pervasive in the "upper" Potomac Group (Figure 20) must have been deformed after dewatering, as watered clay deforms plastically. The pattern of fractures in these clays (Figures 14, 20) is unlike structures produced by either subaerial mudcracks (suncracks) or subaequeous mudcracks produced by contraction during clay transformations (syneresis cracks). These intervals of fractured clays presently consist of mixtures of kaolinite, mixed layer illite/smectite, and illite; this mixture is evidence that clay is predominantly detrital and that diagenesis has not played a major role in the sediment disruption.

Palynological characteristics: The four pollen-bearing samples taken at depths between 596 and 781 feet (181.8 and 238.0 m) have all been assigned to subzone II-B because of the presence of numerous guide fossils including: *Neoraistrickia robusta* Brenner 1963, *Cicatricosisporites subrotundus* Brenner 1963, and *C. patapscoensis* Brenner 1963. Each of these species was recorded from one or more of the four samples (Table 1), and each is cited by Brenner (1963) as being restricted to subzone II-B. In addition, a wide variety of monosulcate, tricolpate, and tricolporoidate pollen were recovered from these samples, the concurrent ranges of which are suggestive of a subzone II-B age for all four samples (Figure 21).

The basal three samples assigned to subzone II-B yielded only a moderately abundant, moderately well preserved palynomorph flora. Abundant carbonized matter was present in these samples and angiosperm pollen, although common, was generally less abundant than were pteridophyte spores, or gymnosperm pollen, or the sum of these.

In contrast, the uppermost sample assigned to subzone II-B (596 feet; 181.8 m) contained abundant, well preserved palynomorphs, and little carbonized organic matter. The assemblage was dominated by angiosperm pollen; particularly abundant were small, reticulate tricolpates and tricolporoidates, specimens of the latter were assigned to *Tricolpites micromunus* (Groot and Penny) Burger 1970 (Figure 25aa-dd). This sample probably represents the uppermost part of subzone II-B, a conclusion concurred with by J.A. Doyle (personal communication, 1977).

Assignment of the four samples 596 to 781 feet (181.8 and 238.0 m) subzone II-B is also supported by the numerous occurrences of tricolporoidate forms of several species, notably *Tricolpites micromunus* and *T. albiensis* Kemp 1968 (Figure 25). Doyle and Robbins (1977) observed the first occurrence of tricolporoidate apertures among a few species at the base of subzone II-B; higher in the subzone, many normally tricolpate species are tricolporoidate. Subzone II-A has not been observed in the Oak Grove core nor has any zone or subzone younger than II-B. This might be the result of the numerous palynologically barren samples, rather than the absence of deposits.

ANALYSIS OF SEDIMENTARY TRENDS AND DEPOSITIONAL ENVIRONMENTS

Changes in mineralogy from the "lower" Potomac to "upper" Potomac sediments are small for the major clays and the light-mineral fraction, but notable changes occur in the accessory clays and in the heavy-mineral fraction. The heavy-mineral data in Figure 22 contrast the highly varied assemblage in the "lower" Potomac Group with the stable suite in the "upper" Potomac sands. Similar well-defined stratigraphic differences have been recognized farther north and along the Fall Line (Anderson, 1948; Bennett and Meyer, 1952; and Groot, 1955). Regional variations in heavy-mineral composition within the Salisbury embayment have been documented (Glaser, 1969; Owens and others, 1977).

The vertical increase in the stable heavy-mineral suite at Oak Grove, noted throughout the basin in the works cited above, is accompanied by a slight increase in quartz relative to feldspar. Possible interpretations of these data are that during "up-

Figure 11. Interbedded clay clasts, sand, and clay clasts(?) from the base to the top ("upper" Potomac Group). Note the variability of clay clast margins from well-defined and ragged in the lower portion of core segment to ill-defined at the top.

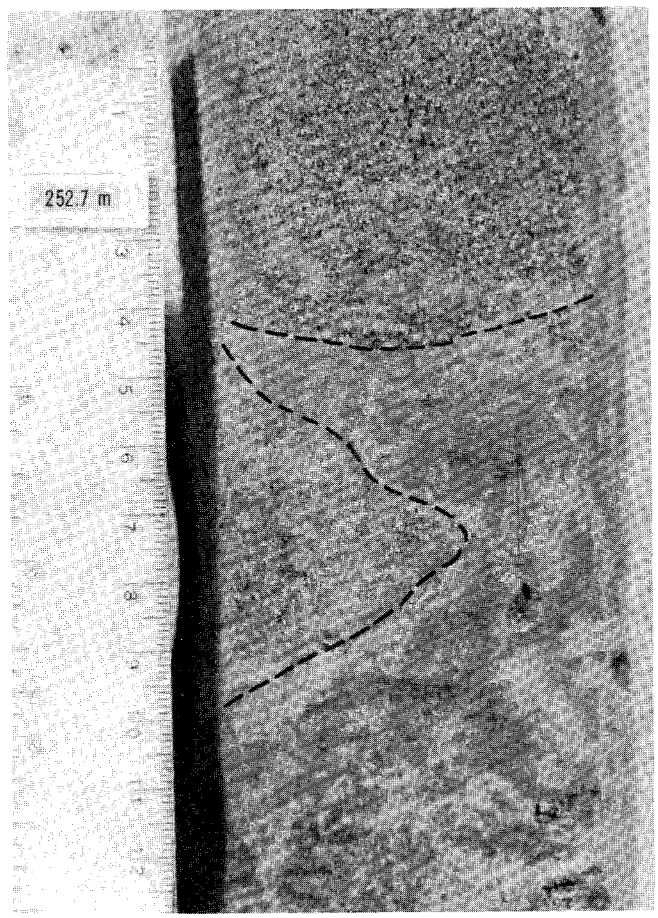


Figure 12. Injection(?) structure in the "upper" Potomac Group defined by sharp to gradational changes from silty to medium sand. Note the disrupted (wavy) bedding within the clay; sand is massive throughout this interval.

angiosperm pollen; particularly abundant were small, reticulate tricolpates and tricolporoidates, specimens of the latter were assigned to *Tricolpites micromunus* (Groot and Penny) Burger 1970 (Figure 25aa-dd). This sample probably represents the uppermost part of subzone II-B, a conclusion concurred with by J.A. Doyle (personal communication, 1977).

Assignment of the four samples 596 to 781 feet (181.8 and 238.0 m) subzone II-B is also supported by the numerous occurrences of tricolporoidate forms of several species, notably *Tricolpites micromunus* and *T. albiensis* Kemp 1968 (Figure 25). Doyle and Robbins (1977) observed the first occurrence of tricolporoidate apertures among a few species at the base of subzone II-B; higher in the subzone, many normally tricolpate species are tricolporoidate. Subzone II-A has not been observed in the Oak Grove core nor has any zone or subzone younger than II-B. This might be the result of the numerous palynologically barren samples, rather than the absence of deposits.

ANALYSIS OF SEDIMENTARY TRENDS AND DEPOSITIONAL ENVIRONMENTS

Changes in mineralogy from the "lower" Potomac to "upper" Potomac sediments are small for the major clays and the light-mineral fraction, but notable changes occur in the accessory clays and in the heavy-mineral fraction. The heavy-mineral data in Figure 22 contrast the highly varied assemblage in the "lower" Potomac Group with the stable suite in the "upper" Potomac sands. Similar well-defined stratigraphic differences have been recognized farther north and along the Fall Line (Anderson, 1948; Bennett and Meyer, 1952; and Groot, 1955). Regional variations in heavy-mineral composition within the Salisbury embayment have been documented (Glaser, 1969; Owens and others, 1977).

The vertical increase in the stable heavy-mineral suite at Oak Grove, noted throughout the basin in the works cited above, is accompanied by a slight increase in quartz relative to feldspar. Possible interpretations of these data are that during "up-

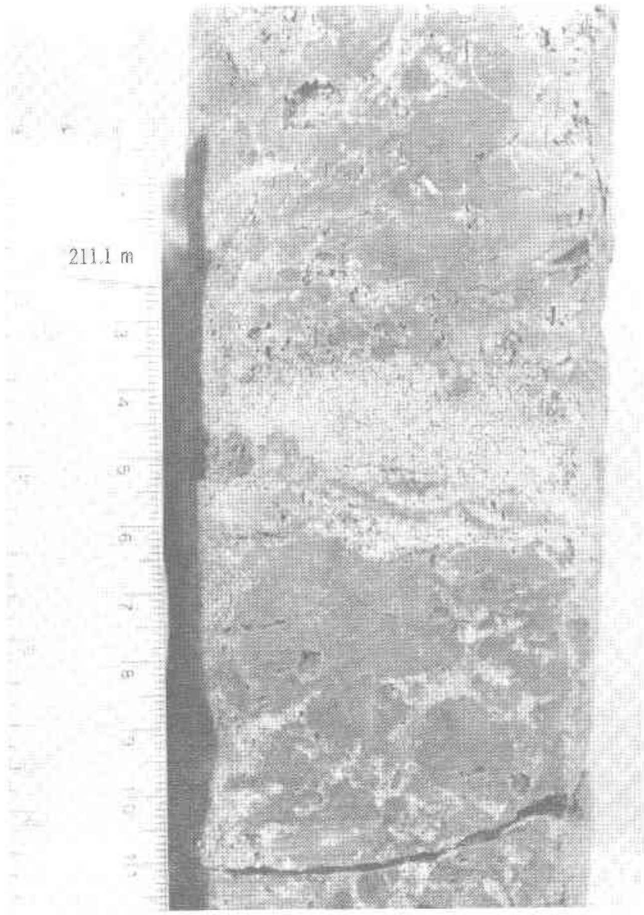


Figure 11. Interbedded clay clasts, sand, and clay clasts(?) from the base to the top ("upper" Potomac Group). Note the variability of clay clast margins from well-defined and ragged in the lower portion of core segment to ill-defined at the top.

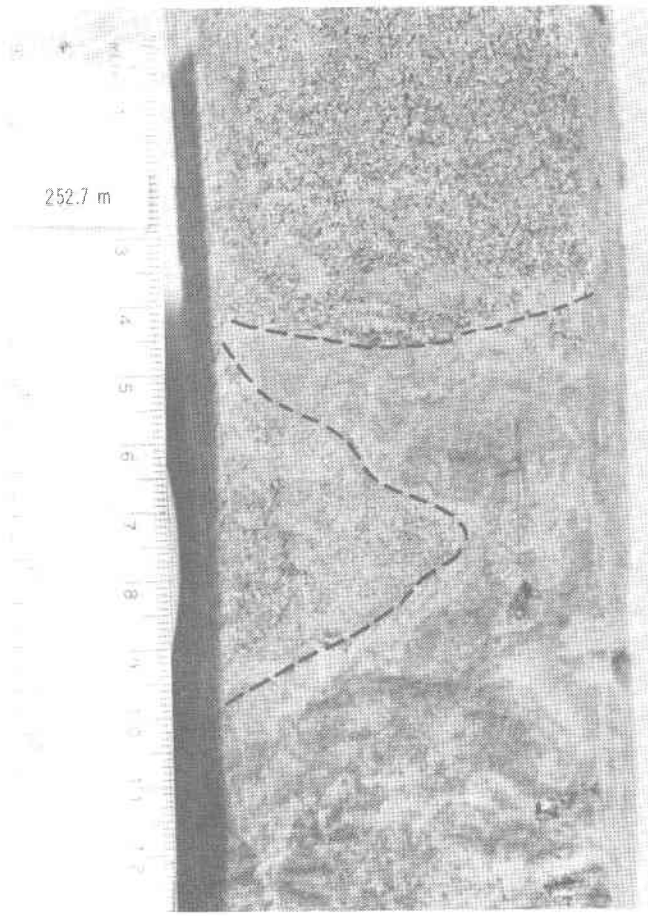


Figure 12. Injection(?) structure in the "upper" Potomac Group defined by sharp to gradational changes from silty to medium sand. Note the disrupted (wavy) bedding within the clay; sand is massive throughout this interval.

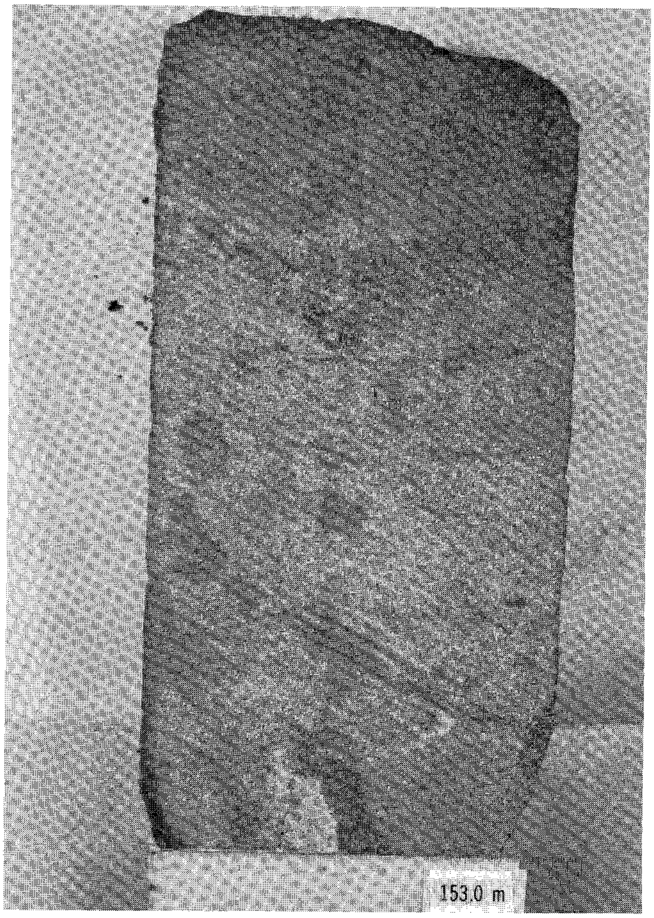


Figure 13. Crossbedded or sheared sand within the "upper" Potomac Group. Inclined surfaces are defined by clay-rich laminae. Note also the clay-rich (cm-size, circular) mottles and small clay clasts.

Figure 14. Highly sheared sandy clay in the "upper" Potomac Group containing irregular cm-size clay patches. Inclination angles typically exceed 50°.

per" Potomac (Albian) time: 1) updip "lower" Potomac sediments were being reworked; 2) an increased percentage of second cycle grains were being derived from farther west, or 3) the primary source rocks in the adjacent Piedmont were more deeply weathered. A combination of factors 2 and 3 may have produced a greater proportion of mature sediments in the Patapsco Formation, which is equivalent to a portion of the "upper" Potomac Group (Glaser, 1969). The change from a heavy-mineral suite containing abundant apatite to one dominated by zircons (some hyacinth-colored), however, is indicative of an increase in the size of the drainage basin and a commensurate increase in types of source rocks during Albian time.

The source area for the abundant apatite in the "lower" Potomac is probably the Fredericksburg Complex approximately 31 miles (50 km) to the west (L. Pavlides, oral communication, 1977); the hyacinth-colored zircons indicate a Precambrian source rock (D. Gottfried, oral communication, 1977), probably granitic basement in the Blue Ridge approximately 62 miles (100 km) to the west.

Glauconite occurrences in the "lower" Potomac at the Oak Grove core help to delineate the northwestern limit of marine influence during Aptian-Barremian(?) time and places constraints on the geometry of the fluvio-deltaic model generally used in discussing the depositional framework for the Potomac Group (Clark and Bibbins, 1897; Groot, 1955; Glaser, 1969; and others). It should be noted that the occurrence of glauconite, an indicator of marine conditions, is accompanied by a slight increase in illite (Figure 23). Glauconite abundance increases in the Potomac Group in subsurface samples from areas farther south (Cederstrom, 1945; Teifke, 1973).

Results of the 53 clay analyses throughout the Potomac Group (Figure 23) show no clear stratigraphic trends. It is noted that outcrop samples are dominantly kaolinite north of the Potomac River and dominantly illite/smectite south

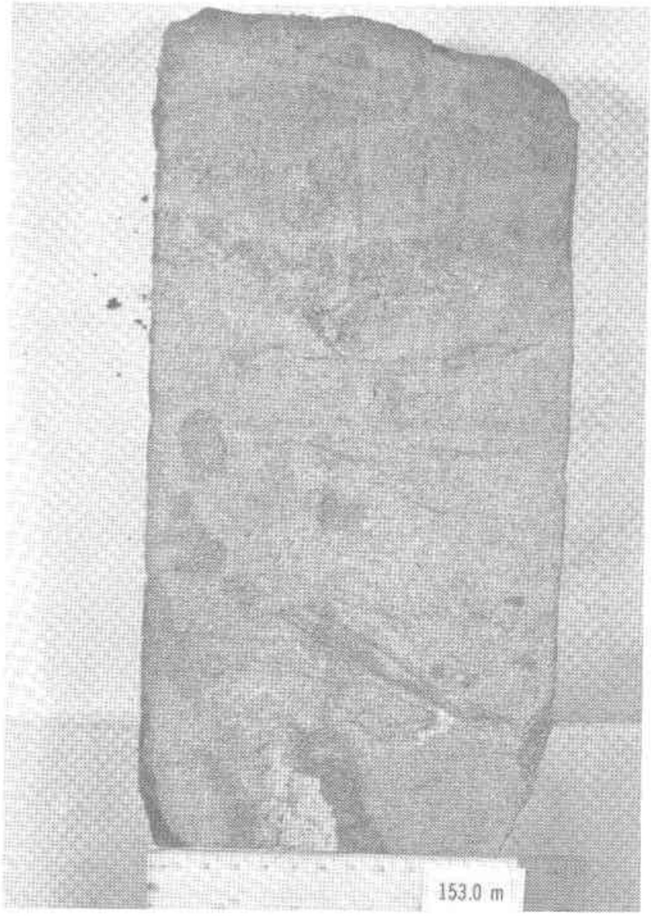


Figure 13. Crossbedded or sheared sand within the "upper" Potomac Group. Inclined surfaces are defined by clay-rich laminae. Note also the clay-rich (cm-size, circular) mottles and small clay clasts.

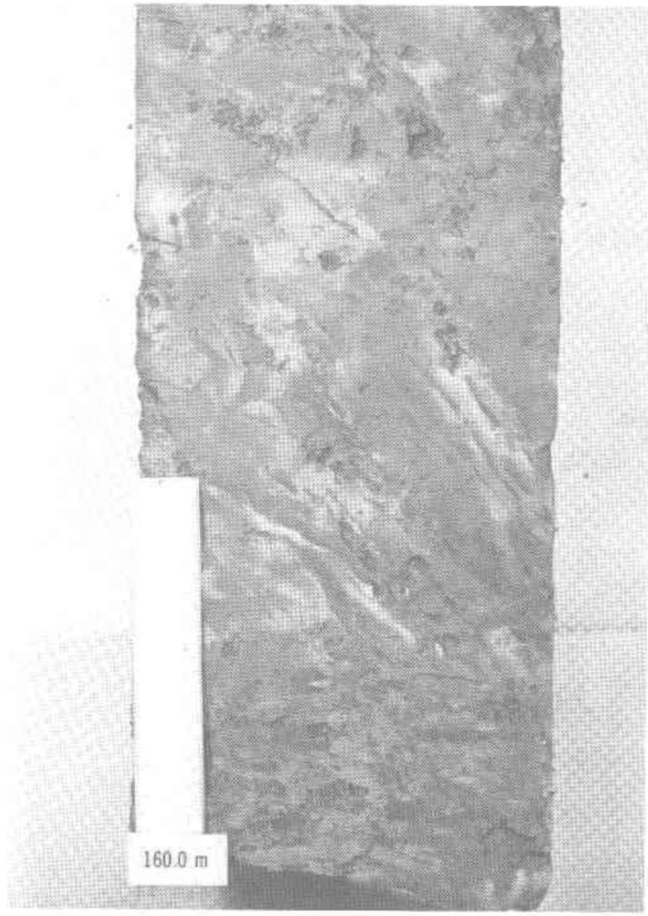


Figure 14. Highly sheared sandy clay in the "upper" Potomac Group containing irregular cm-size clay patches. Inclination angles typically exceed 50°.

per" Potomac (Albian) time: 1) updip "lower" Potomac sediments were being reworked; 2) an increased percentage of second cycle grains were being derived from farther west, or 3) the primary source rocks in the adjacent Piedmont were more deeply weathered. A combination of factors 2 and 3 may have produced a greater proportion of mature sediments in the Patapsco Formation, which is equivalent to a portion of the "upper" Potomac Group (Glaser, 1969). The change from a heavy-mineral suite containing abundant apatite to one dominated by zircons (some hyacinth-colored), however, is indicative of an increase in the size of the drainage basin and a commensurate increase in types of source rocks during Albian time.

The source area for the abundant apatite in the "lower" Potomac is probably the Fredericksburg Complex approximately 31 miles (50 km) to the west (L. Pavlides, oral communication, 1977); the hyacinth-colored zircons indicate a Precambrian source rock (D. Gottfried, oral communication, 1977), probably granitic basement in the Blue Ridge approximately 62 miles (100 km) to the west.

Glauconite occurrences in the "lower" Potomac at the Oak Grove core help to delineate the northwestern limit of marine influence during Aptian-Barremian(?) time and places constraints on the geometry of the fluvio-deltaic model generally used in discussing the depositional framework for the Potomac Group (Clark and Bibbins, 1897; Groot, 1955; Glaser, 1969; and others). It should be noted that the occurrence of glauconite, an indicator of marine conditions, is accompanied by a slight increase in illite (Figure 23). Glauconite abundance increases in the Potomac Group in subsurface samples from areas farther south (Cederstrom, 1945; Teifke, 1973).

Results of the 53 clay analyses throughout the Potomac Group (Figure 23) show no clear stratigraphic trends. It is noted that outcrop samples are dominantly kaolinite north of the Potomac River and dominantly illite/smectite south

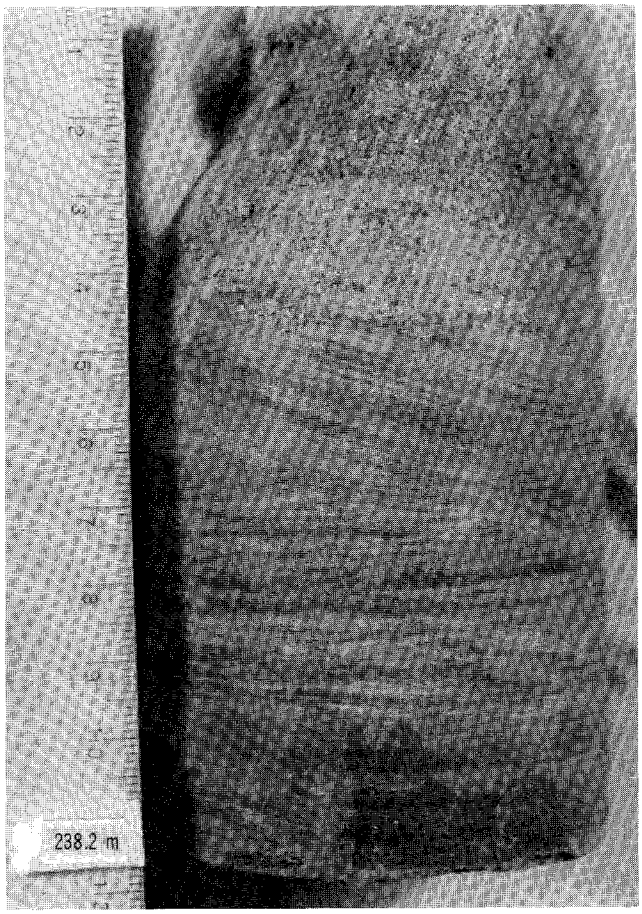


Figure 15. Transition from planar-laminated clay through ripple cross-laminated clay and silt to massive micaceous fine sand, "upper" Potomac Group.

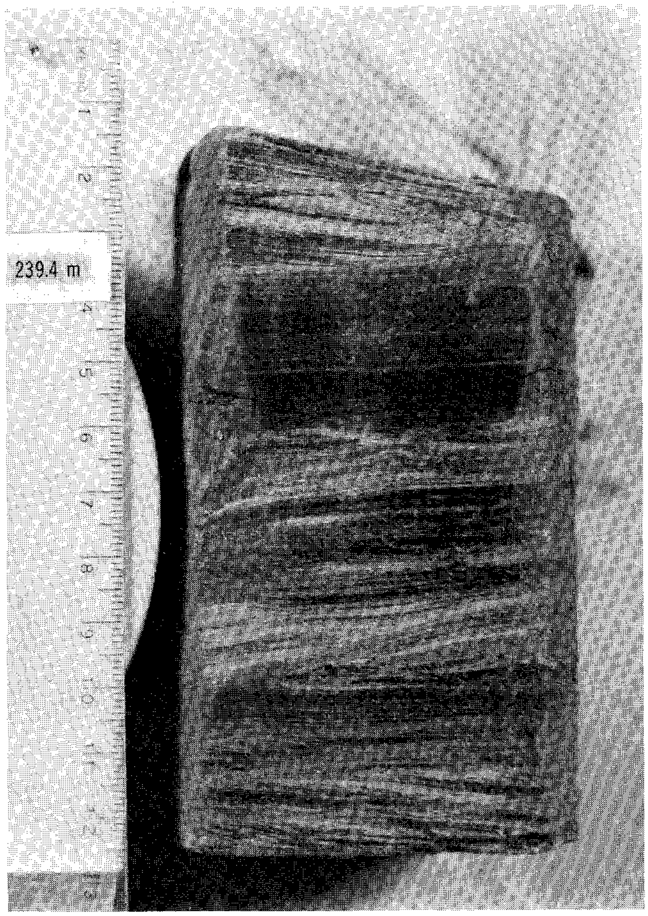


Figure 16. Low-energy bedforms and associated carbonaceous clays, which are palynologically productive lithologies in both the "upper" Potomac Group (shown here) and in similar lithologies of the "lower" Potomac.

of the Potomac River (Moncure and Force, 1976; Owens and others, 1977). At Oak Grove, the clay-dominant portions of the "upper" Potomac Group display mottled, highly oxidized clays suggestive of deposition on a subaerial floodplain. Mottles created by burrowing organisms or plant roots are predictable associations in such an environment, and these agents may explain the structures illustrated in Figures 17 and 18.

The clay deformation fabrics seem to be more ubiquitous. The fractures and shears (Figures 14 and 20) are not simple desiccation features (mud-cracks). The likely alternatives are: 1) an origin due to clay mineral diagenesis; 2) tectonic disruption of the massively bedded clays; or 3) differential loading and overconsolidation of the mixed mineralogy clays.

If the unidirectional shear patterns seen in some clay beds (Figure 14) and the highly fractured clays in other intervals (Figure 20) result from a common origin, brittle tectonics are the most likely alternative. This tentative conclusion is supported by synsedimentary and post-sedimentary faulting in the Potomac Group near the Fall Line about 30 miles to the west (Mixon and Newell, 1977).

Cristobalite associated with sheared and fractured clays of the "upper" Potomac group might be explained as silica freed during the transformation of montmorillonite (illite/smectite) to kaolinite in a weathering profile within the primary environment (see Altschuler and others, 1963). Such associations may also indicate volcanism (Venkaratham and Biscaye, 1973; Walton, 1975; and others).

The Potomac Group sediments in the Salisbury embayment represent deposition in fluvial (updip) to deltaic (downdip) environments. Deposition by braided streams has been postulated for Patuxent sediments (our zone I) and meandering streams for the Patapsco (our zone II) sediments (Glaser, 1969). Within the Oak Grove core, "lower" Potomac sediments are dominated by coarse sediments which consist largely of intraformational carbonaceous

Figure 15. Transition from planar-laminated clay through ripple cross-laminated clay and silt to massive micaceous fine sand, "upper" Potomac Group.

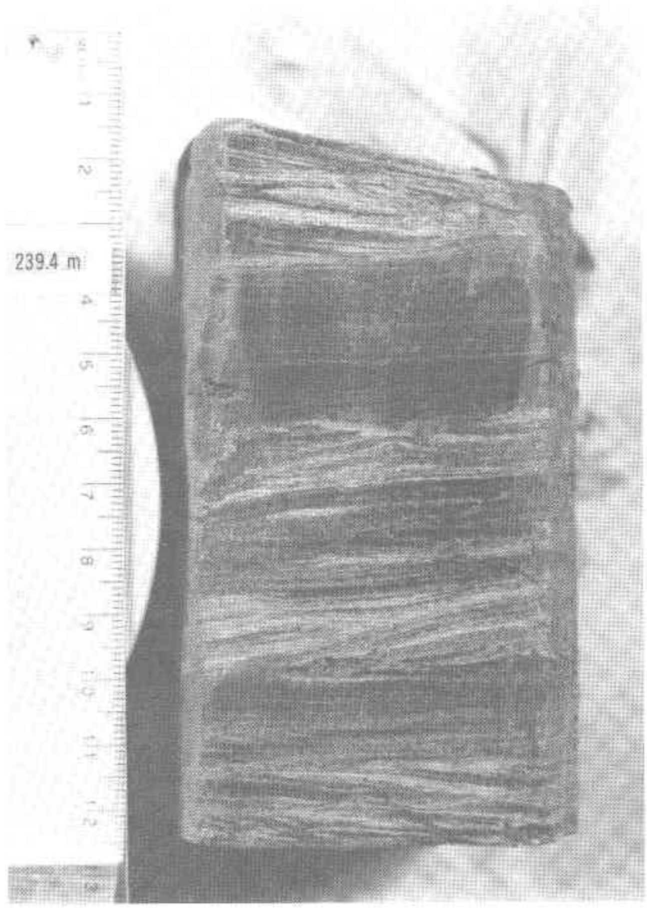


Figure 16. Low-energy bedforms and associated carbonaceous clays, which are palynologically productive lithologies in both the "upper" Potomac Group (shown here) and in similar lithologies of the "lower" Potomac.

of the Potomac River (Moncure and Force, 1976; Owens and others, 1977). At Oak Grove, the clay-dominant portions of the "upper" Potomac Group display mottled, highly oxidized clays suggestive of deposition on a subaerial floodplain. Mottles created by burrowing organisms or plant roots are predictable associations in such an environment, and these agents may explain the structures illustrated in Figures 17 and 18.

The clay deformation fabrics seem to be more ubiquitous. The fractures and shears (Figures 14 and 20) are not simple desiccation features (mudcracks). The likely alternatives are: 1) an origin due to clay mineral diagenesis; 2) tectonic disruption of the massively bedded clays; or 3) differential loading and overconsolidation of the mixed mineralogy clays.

If the unidirectional shear patterns seen in some clay beds (Figure 14) and the highly fractured clays in other intervals (Figure 20) result from a common origin, brittle tectonics are the most likely alternative. This tentative conclusion is supported by synsedimentary and post-sedimentary faulting in the Potomac Group near the Fall Line about 30 miles to the west (Mixon and Newell, 1977).

Cristobalite associated with sheared and fractured clays of the "upper" Potomac group might be explained as silica freed during the transformation of montmorillonite (illite/smectite) to kaolinite in a weathering profile within the primary environment (see Altschuler and others, 1963). Such associations may also indicate volcanism (Venkaratham and Biscaye, 1973; Walton, 1975; and others).

The Potomac Group sediments in the Salisbury embayment represent deposition in fluvial (updip) to deltaic (downdip) environments. Deposition by braided streams has been postulated for Patuxent sediments (our zone I) and meandering streams for the Patapsco (our zone II) sediments (Glaser, 1969). Within the Oak Grove core, "lower" Potomac sediments are dominated by coarse sediments which consist largely of intraformational carbonaceous

Figure 17. Laminated silty clay in "upper" Potomac Group containing short clay-filled vertical to horizontal burrows(?). Bedding is only slightly disturbed in the vicinity of the structures.

Figure 18. Bedding-plane view of massive "speckled" silty clay showing radiating pattern of tubules in the "upper" Potomac Group

clay clasts. The presence of glauconite and illitic clays in these beds are strongly suggestive of proximity to a marine environment. These lithologic associations reflect the transition from an alluvial environment to a subaerial deltaic plain in which low gradient meandering streams are undercutting carbonaceous marsh and point bar deposits. A possible modern counterpart of this sedimentary system is within the transition zone of the Brazos River alluvial and delta plain complex (Bernard and others, 1970).

The sand and clay in the "upper" Potomac Group appear to represent two distinct sedimentary environments. The lower, sand-dominant part is characterized by fining-upward sequences as are

Figure 19. Synsedimentary deformation in the "upper" Potomac Group shown here in transition from isoclinally folded clays (probably the termination of an injection structure) through a structureless clay and clayey sand to planer- and ripple-cross-laminated silt.

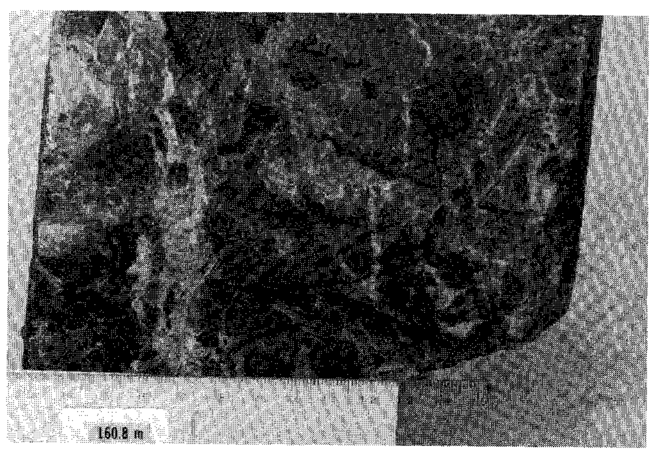


Figure 20. Brittle deformation of massive kaolinitic clay in the "upper" Potomac Group. Apparent fracture fills are compositionally similar to the host sediment.

point bar systems in meandering streams (Visher, 1965; Allen, 1970; and many others). The upper, clay-

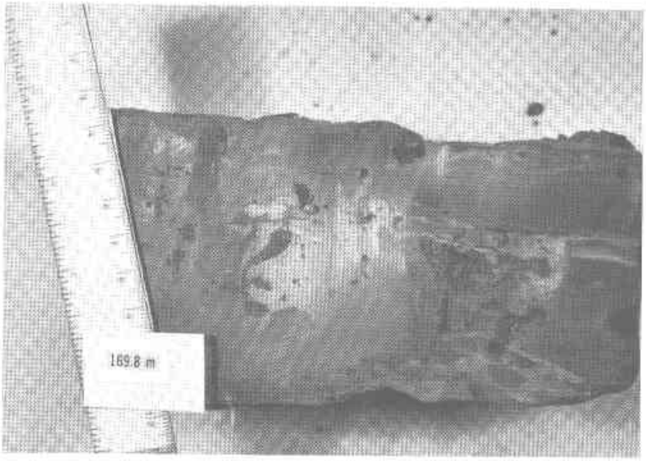


Figure 17. Laminated silty clay in "upper" Potomac Group containing short clay-filled vertical to horizontal burrows(?). Bedding is only slightly disturbed in the vicinity of the structures.

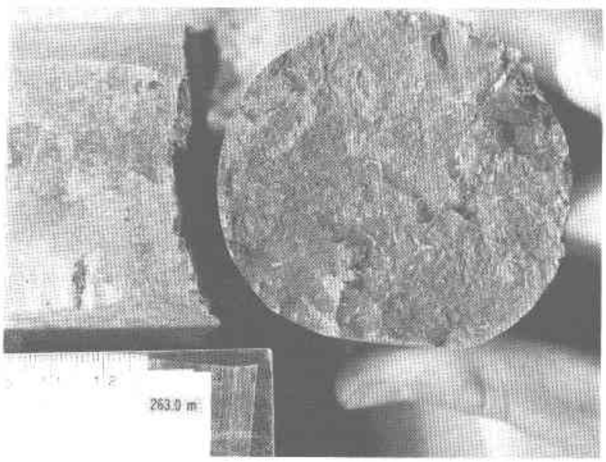


Figure 18. Bedding-plane view of massive "speckled" silty clay showing radiating pattern of tubules in the "upper" Potomac Group

clay clasts. The presence of glauconite and illitic clays in these beds are strongly suggestive of proximity to a marine environment. These lithologic associations reflect the transition from an alluvial environment to a subaerial deltaic plain in which low gradient meandering streams are undercutting carbonaceous marsh and point bar deposits. A possible modern counterpart of this sedimentary system is within the transition zone of the Brazos River alluvial and delta plain complex (Bernard and others, 1970).

The sand and clay in the "upper" Potomac Group appear to represent two distinct sedimentary environments. The lower, sand-dominant part is characterized by fining-upward sequences as are

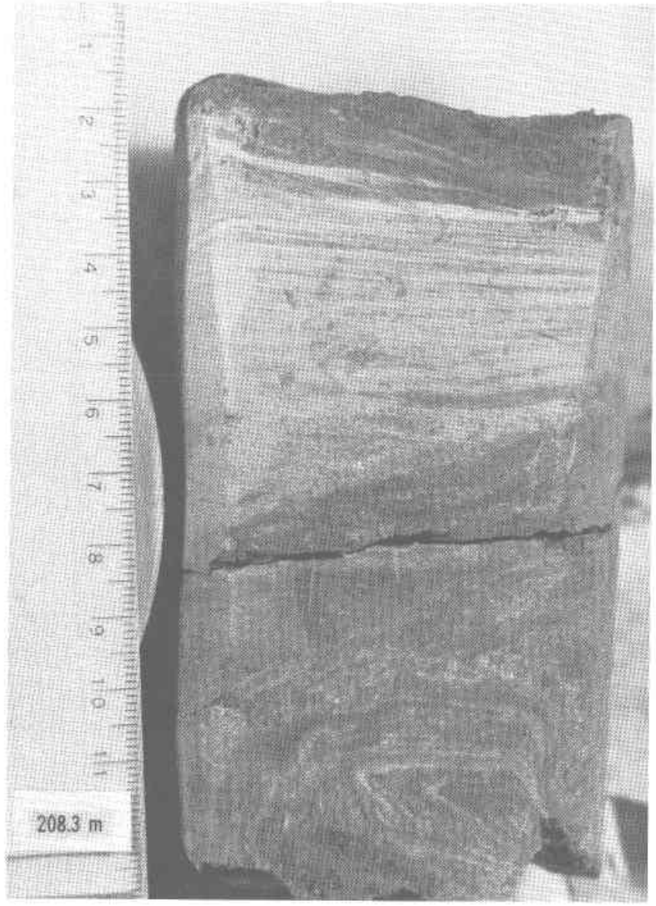


Figure 19. Synsedimentary deformation in the "upper" Potomac Group shown here in transition from isoclinally folded clays (probably the termination of an injection structure) through a structureless clay and clayey sand to planer- and ripple-cross-laminated silt.

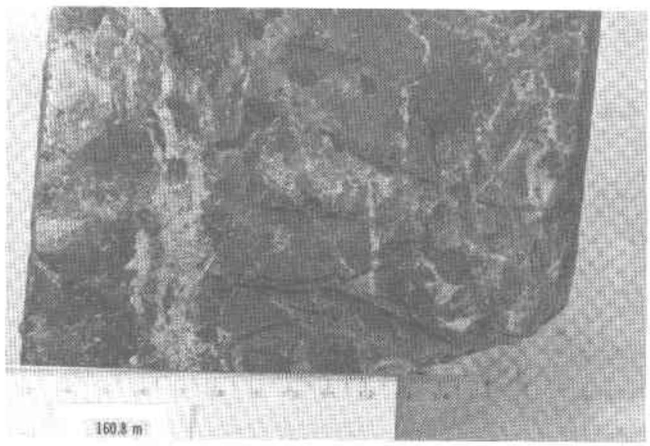


Figure 20. Brittle deformation of massive kaolinitic clay in the "upper" Potomac Group. Apparent fracture fills are compositionally similar to the host sediment.

point bar systems in meandering streams (Visher, 1965; Allen, 1970; and many others). The upper, clay-

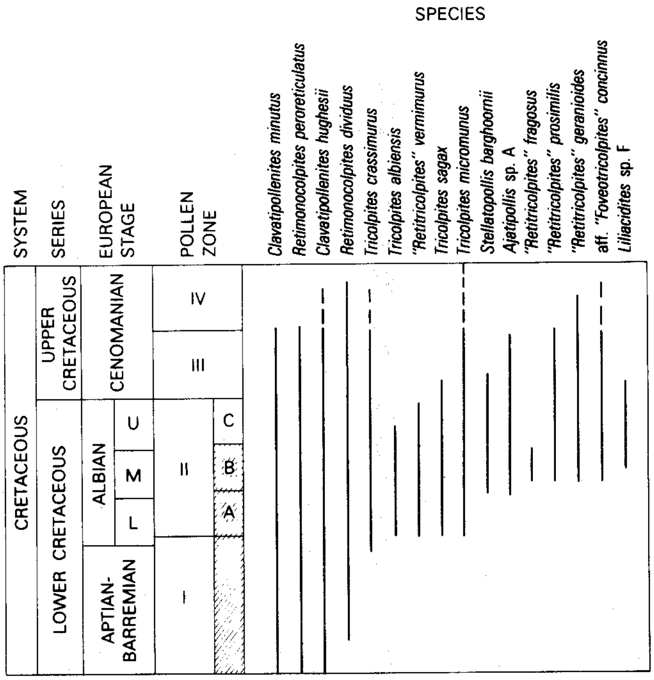


Figure 21. Distribution of key palynomorph species within Cretaceous pollen zones I-IV. Note the appearance of tricolpates at or near the zone I-IIA boundary.

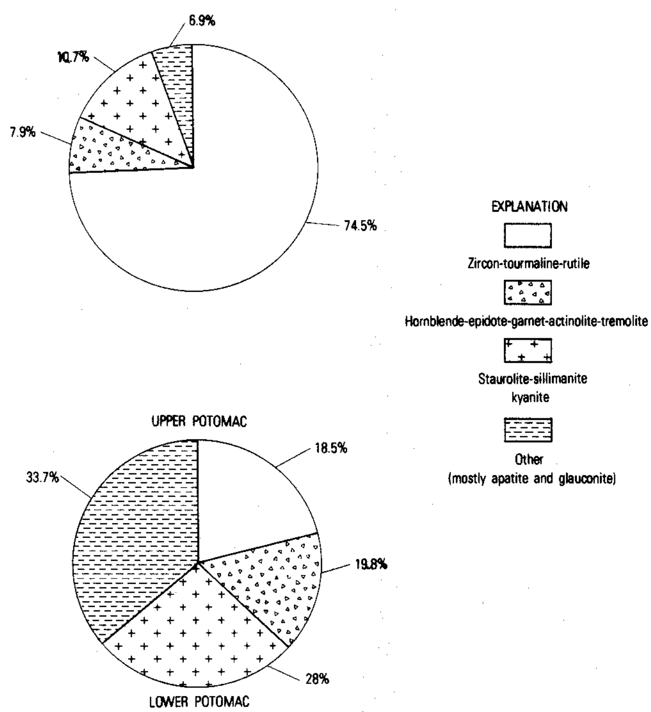


Figure 22. Distribution of heavy-mineral suites within the Potomac Group in the Oak Grove core. Note the high "other" component in the "lower" Potomac and the dominance of a stable suite in the "upper" Potomac.

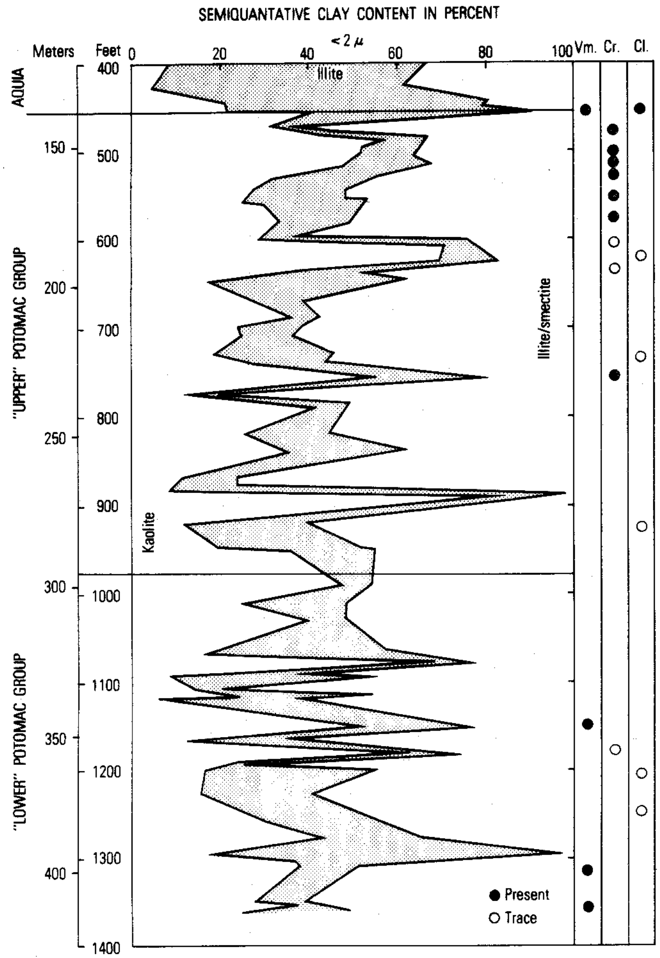


Figure 23. Distribution of major clay species with grain-size less than 2 microns in the Oak Grove core. The occurrence of vermiculite (VM), cristobalite (CR), and clinoptilolite (CL) is shown at the right.

dominant portion is the product of overbank deposition modified by weathering, diagenesis and (or) diastrophism. These backswamp or flood basin deposits are distinctly continental in the Oak Grove core.

The "lower" and "upper" Potomac units, when viewed as a whole, appear to represent the construction of a delta lobe. Depositional environments change from a subaerial delta plain to a fluvial floodplain. Within this framework, fluvial channel systems contributed sediment, organic debris, and moisture and controlled sedimentary structures and textures. Regional tectonics controlled sedimentation rate and lithology.

REGIONAL SEDIMENTATION PATTERNS

Pollen assignable to zones I and II and to Upper Cretaceous zones III and IV have been collected at a number of outcrop and subsurface localities in the Salisbury and Raritan embayments. However, available data indicate that the zones are not contiguous over the entire area of these embayments. Rather each zone occurs in a geographically restricted location (Figure 24). Beginning with zone I in the Salisbury embayment to the south, each successive zone appears to be displaced northward. As a result, zones I and IV are geographically isolated from one another. The localization of the zones and sediment accumulation sites through time are evidence that the sediments assigned to each zone represent distinct deltaic lobes.

From the geographic distribution of the palynological zones presented in Figure 24, it would appear that strata representing only zones I and II should be found at Oak Grove, as was observed. Zone I(?) pollen occurs near the bottom of the core at 1348 feet (410.9 m); the upper most part of zone I or the basal part of zone II-A occurs at 950 feet (289.7 m), and zone II-B occurs above 787 feet (240 m).

Within the Oak Grove core a more seaward assemblage of sediments and sedimentary structures is overlain by a more landward series. Integration of this sequence with regional biostratigraphy enables analysis of sedimentary dynamics within the Salisbury embayment. The southern limit of the subaerial part of the Potomac delta was near Oak Grove during Aptian-Barremian(?) time. The composition of sediments within the Salisbury embayment is evidence that: the drainage basin is somewhat restricted, fluvial gradients were high, and streams were contributing immature sediments during lower Potomac time. The drainage basin broadened and stream gradients lessened during Albian time.

The systematic northward migration of the Potomac fluvio-deltaic system and the geometry and timing of the basin fill lend support to the idea that the Potomac Group was a Mississippi-type delta

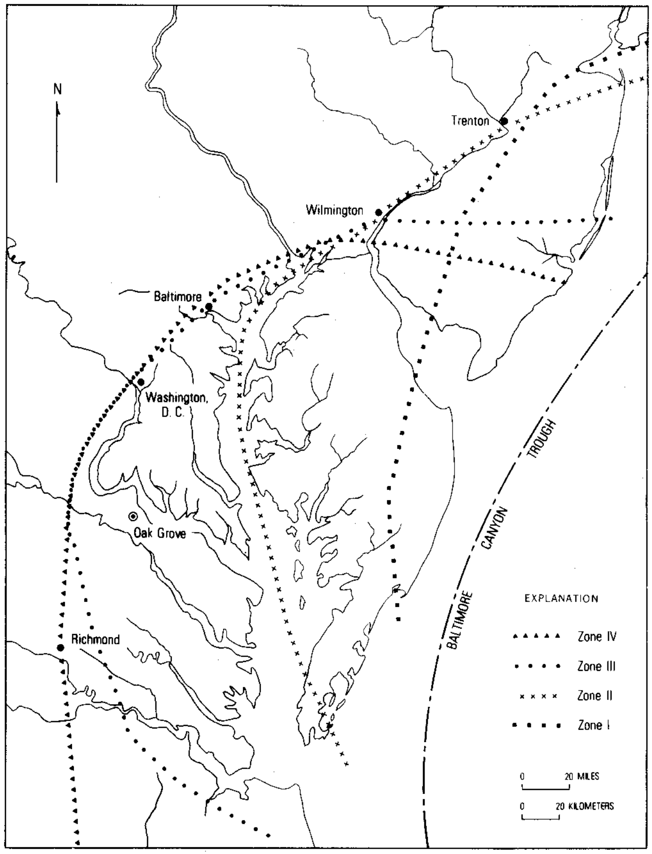


Figure 24. Map showing general distribution of palynological zones I throuth IV in the Salisbury and Raritan embayments. Distribution of pollen zones is schematic and based on data from hundreds of surfact and subsurface pollen-bearing samples north of Oak Grove and tens of samples south of Oak Grove. Data sources are: U.S. Geological Survey files, Brenner (1963), Christopher (1977), Doyle (1969), Doyle and Robbins (1977), and Wolfe and Pakiser (1971).

characterized by rapid subsidence controlled primarily by sediment compaction (Morgan, 1970). Although the analogy is imcomplete and subsurface control inadequate, the similarities of scale, progradation and lateral shifting, plus overlapping delta lobes, are suggestive of similar systems.

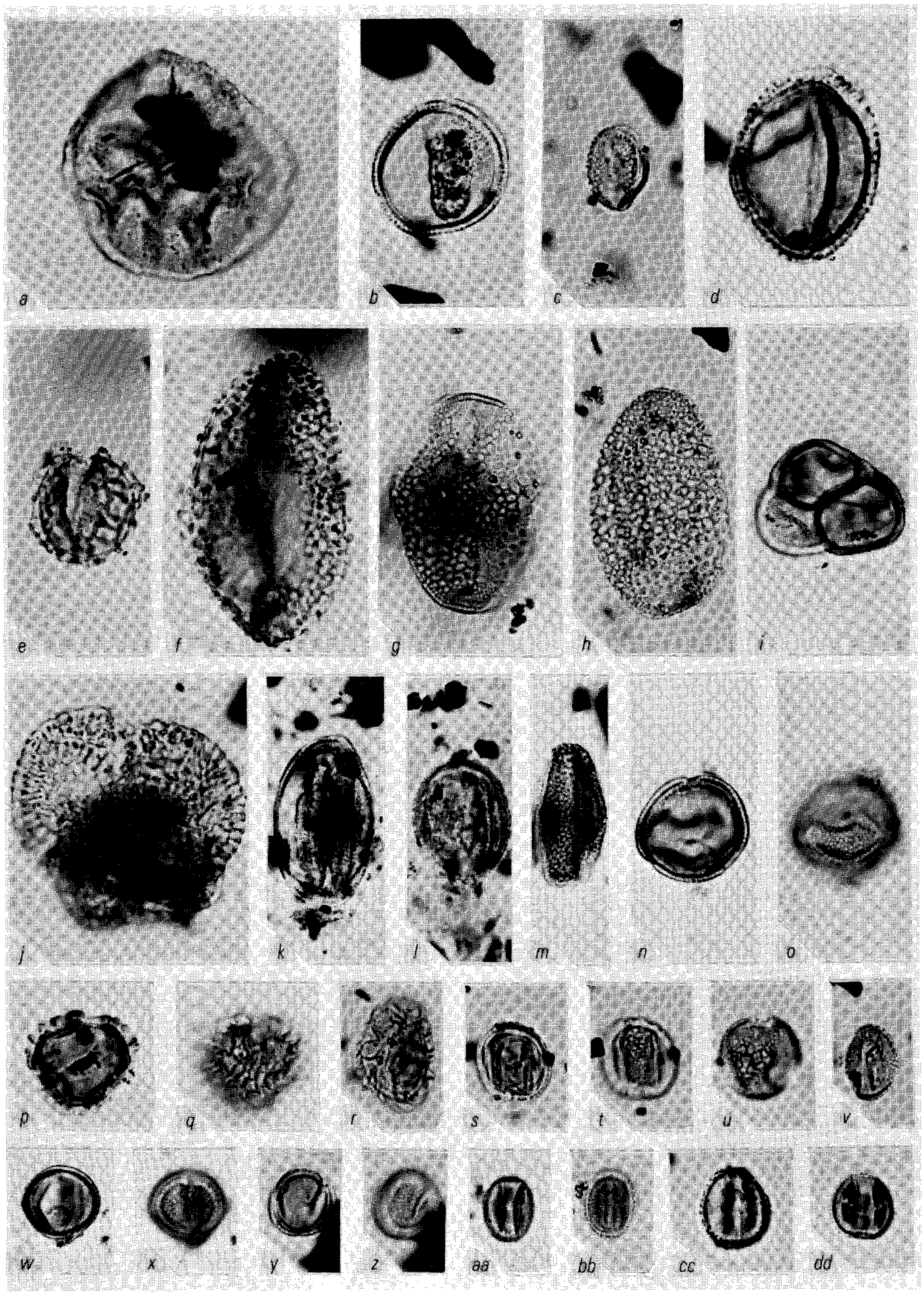


Figure 25. Miospore species, their sample depth in the Oak Grove core, and the pollen zone assigned to that sample. Citation of binomen follows Doyle and Robbins (1977). All illustrations x1000. See key.

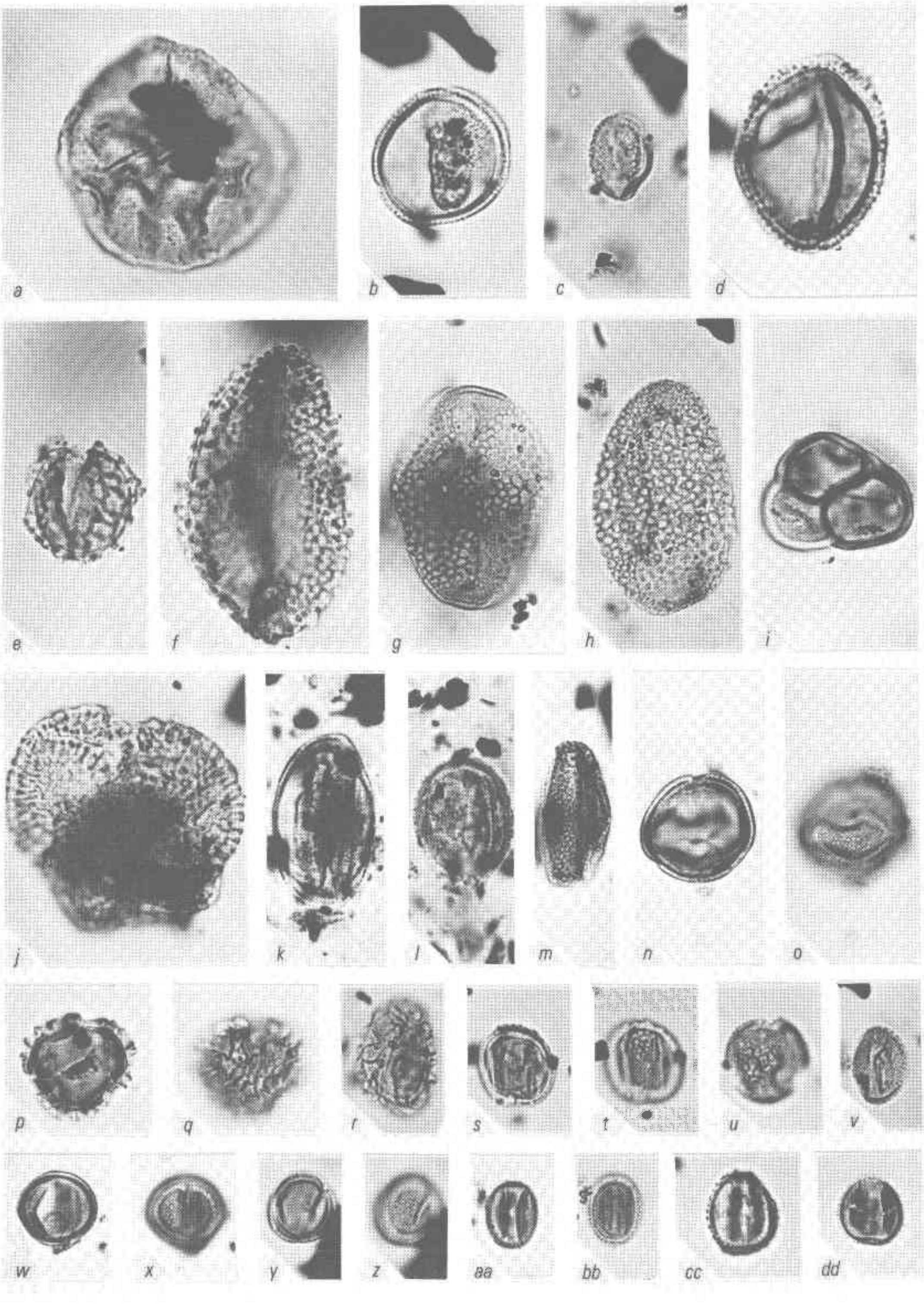


Figure 25. Miospore species, their sample depth in the Oak Grove core, and the pollen zone assigned to that sample. Citation of binomen follows Doyle and Robbins (1977). All illustrations x1000. See key.

Figure 25 key.

Specimen	Species	Sample depth (m)	Pollen zone
a	*Kuylisporites lunaris* Cookson & Detmann 1958	410.9	I
b	*Clavatipollenites hughesii* Couper 1958	201.2	II-B
c	*Clavatipollenites minutus* Brenner 1963	230.4	II-B
d	*Retimonocolpites dividuus* Pierce 1961	181.8	II-B
e	*Retimonocolpites peroreticulatus* (Brenner) Doyle 1975	181.8	II-B
f	*Stellatopollis barghoornii* Doyle 1973	181.8	II-B
g	*Liliacidites* sp. F of Doyle and Robbins 1977	181.8	II-B
h	*Liliacidites* sp. F of Doyle and Robbins 1977	181.8	II-B
i	*Ajatipollis* sp. A of Doyle and Robbins 1977	181.8	II-B
j	*"Retitricolpites" geranioides* (Couper) Brenner 1963	230.4	II-B
k	aff. *Tricolpites crassimurus* (Groot & Penny) Singh 1971	289.7	I or II-A
l	unidentified tricolpate	289.7	I or II-A
m	aff. *"Foveotricolpites" concinnus* Singh 1977	201.2	II-B
n,o	*Tricolpites sagax* Norris 1967	230.4	II-B
p,q	*"Retitricolpites" vermimurus* Brenner 1963	181.8	II-B
r	*"Retitricolpites" vermimurus* Brenner 1963	181.8	II-B
s,t	*"Retitricolpites" fragosus* Hedlund & Norris 1968	238.0	II-B
u	*"Retitricolpites" fragosus* Hedlund & Norris 1968	238.0	II-B
v	aff. *"Retitricolpites" prosimilis* Norris 1967	230.4	II-B
w,x	*Tricolpites albiensis* Kemp 1968	230.4	II-B
y,z	*Tricolpites albiensis* Kemp 1968	230.4	II-B
aa,bb	*Tricolpites micromunus* (Groot & Penny) Burger 1970	181.8	II-B
cc	*Tricolpites micromunus* (Groot & Penny) Burger 1970	238.0	II-B
dd	*Tricolpites micromunus* (Groot & Penny) Burger 1970	181.8	II-B

REFERENCES

Allen, J.R.L., 1970, Studies in fluviatile sedimentation—A comparison of fining-upwards cyclothems, with special reference to coarse-member composition and interpretations: Jour. Sed. Petrology, v. 40, no. 1, p. 298-323.

Altschuler, Z.S., Dwornik, E.J., and Kramer, Henry, 1963, Transformation of montmorillonite to kaolinite during weathering: Science, vol. 141, p. 148-152.

Anderson, J.L., 1948, Cretaceous and Tertiary subsurface geology: Maryland Dept. Geology, Mines and Water Resources, Bull. 2, 456 p.

Balme, B.E., 1957, Spores and pollen grains from the Mesozoic of western Australia: Comm. Sci. Ins. Res. Org., Coal Res. Sect., Ref. 25, 48 p.

Bernard, H.A. and others, 1970, Recent sediments of Southeast Texas—a field guide to the Brazos alluvial and deltaic plains and the Galveston barrier island complex: Texas Bur. Econ. Geol. Guidebook 11, 31.

Bennett, R.R., and Meyer, R.R., 1952, Geology and ground water resources of the Baltimore area: Maryland Dept. Geology, Mines and Water Resources, Bull. 4, 573 p.

Berry, E.W., 1906, The flora of the Cliffwood Clays: New Jersey Geol. Survey, Bull. 3, 233 p.

Brenner, G.J., 1963, The spores and pollen of the Potomac Group of Maryland: Maryland Dept. Geology, Mines, and Water Resources, Bull. 27, 215 p.

__________ 1967, Early angiosperm pollen differentiation in the Albian to Cenomanian deposits of Delaware (U.S.A.) *in* Palacophytic and Mesophytic palynology Internat. Conf. Palynology, 2d, Utrecht, 1966: Palaeobotany and Palynology, vol. 1, nos. 1-4, p. 219-227.

Brown, P.M., Miller, J.A., and Swain, F.M., 1972, Structural and stratigraphic framework, and spatial distribution of permeability of the Atlantic Coastal Plain, North Carolina to New York: U.S. Geol. Survey, Prof. Paper 796, 79 p.

Burger, Dennis, 1970, Early Cretaceous angiospermous pollen grains from Queensland: Bur. Min. Res., Geol. Geophysics, Canberra, Bull., vol. 16, p. 1-10.

Cederstom, D.J., 1945, Selected well logs in the Virginia Coastal Plain north of the James River: Virginia Geol. Survey Circ. 3, 82 p.

Christopher, R.A., 1977, Selected Normapolles pollen genera and age of the Raritan and Magothy Formations (Upper Cretaceous) of northern New Jersey, *in* Owens, J.P., Sohl, N.F., and Minard, J.P., A field guide to Cretaceous and Lower Tertiary beds of the Raritan and Salisbury embayments, New Jersey, Delaware, and Maryland: Guidebook AAPG-SEPM Annual Mtg. Washington, D.C., June 12-16, 1977, p. 58-69.

Clark, W.B. and Bibbins, A.B., 1897, The stratigraphy of the Potomac Group in Maryland: Jour. Geology, vol. 5, p. 479-506.

Cookson, I.C., and Dettmann, M.E., 1958, Some trilete spores from Upper Mesozoic deposits in the eastern Australian region: Roy. Soc. Victoria Proc., vol. 70, pt. 2, p. 95-126.

Couper, R.A., 1958, British Mesozoic microspores and pollen grains; a systematic and stratigraphic study: Palaeontographica, Abt. B, vol. 103, p. 75-174.

Dorf, Erling, 1952, Critical analysis of the Cretaceous stratigraphy and paleobotany of the Atlantic Coastal Plain: Am. Assoc. Petroleum Geologists Bull., vol. 36, no. 11, p. 2161-2184.

Doyle, J.A., 1969, Cretaceous angiosperm pollen of the Atlantic Coastal Plain and its evolutionary significance: Harvard Univ., Arnold Arboretum Jour., vol. 50, no. 1, p. 1-35.

Doyle, J.A., and Hickey, L.J., 1976, Pollen and leaves from the mid-Cretaceous Potomac Group and their bearing on early angiosperm evolution, *in* Beck, C.B., ed., Origin and early evolution of angiosperms: New York, Columbia Univ. Press p. 139-206.

Doyle, J.A., and Robbins, E.I., 1977, Angiosperm pollen zonation of the continental Cretaceous of the Atlantic Coastal Plain and its application to deep wells in the Salisbury embayment *in* Proc. of 8th Annual Meeting of Am. Assoc. of Strat. Palynologists: Palynology, vol. 1, p. 43-78.

Doyle, J.A., van Campo, Madeleine, and Lugardon, B., 1975, Observations on exine structure of *Eucommiidites* and Lower Cretaceous angiosperm pollen: Pollen et Spores, vol. 17, no. 3, p. 429-486.

Dryden, A.L. Jr., and Dryden, Clarissa, 1956, Coastal plains and heavy minerals (abs.): Internat. Geol. Cong., 20th, Mexico City, Resumenes de los trabajos presentandos, p. 279-280.

Gilmore, C.W., 1939, A review of recent progress in reptilean paleontology: Geol. Soc. America Bull., vol. 50, no. 3, p. 337-348.

Glaser, J.D., 1969, Petrology and origin of Potomac and Magothy (Cretaceous) sediments, middle Atlantic Coastal Plain, Maryland Geol. Survey Rept. Inv. no. 11, 101 p.

Groot, J.J., 1955, Sedimentary petrology of the Cretaceous sediments of northern Delaware in relation to paleographic problems: Delaware Geol. Survey Bull. 5, 157 p.

Groot, J.J., and Penny, J.S., 1960, Plant microfossils and age of non-marine Cretaceous sediments of Maryland and Delaware: Micropaleontology, vol. 6, no. 2, p. 225-236.

Habib, Daniel, 1977, Comparison of Lower and Middle Cretaceous palynostratigraphic zonations in the western North Atlantic, *in* Swain, F.M., ed., Stratigraphic micropaleontology of Atlantic Basin and borderlands: Amsterdam, Elsevier, p. 341-367.

Hansen, H.J., 1968, Geophysical log cross-section network of the Cretaceous sediments of southern Maryland: Maryland Geol. Survey Rept. Inv. no. 7, 46 p.

Kemp, E.M., 1968, Probable angiosperm pollen from British Barremian to Albian strata: Palaeonotology, vol. 11, no. 3, p. 421-434.

Kremp, G.O.W., 1949, Pollenanalystische Untersuchung des Miozanen Braunkohlenlagers von Konin an der Warthe: Palaeontographica, Abt. B, vol. 90, p. 53-93.

Marsh, O.G., 1896, The Jurassic formation on the Atlantic Coast: Amer. Jour. Sci., 4th Ser., vol. 2, p. 433-447.

Mattick, R.E., and others, 1974, Structural framework of United States Atlantic Outer Continental Shelf north of Cape Hatteras: Am. Assoc. Petroleum Geologists Bull., vol. 58, p. 1179-1190.

Minard, J.P., and others, 1974, Preliminary report on geology along Atlantic continental margin of the northeastern United States: Am. Assoc. Petroleum Geologists Bull., vol. 58, no. 6, 1169-1178.

Mixon, R.B., and Newell, W.L., 1977, Stafford fault system: structures documenting Cretaceous and Tertiary deformation along the Fall Line in northeastern Virginia: Geology, vol. 5, p. 437-440.

Moncure, G.K., and Force, L.M., 1976, Potomac Group clays (abs.): Geol. Soc. America Abs., vol. 8, no. 2, p. 232-233.

Morgan, J.P., 1970, Depositional processes and products in the deltaic environment, *in* Morgan, J.P. and Shaver, R.H., eds. Deltaic sedimentation, modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 31-47.

Newberry, J.S., 1895, The flora of the Amboy Clays: U.S. Survey Monograph 26, 260 p.

Owens, J.P., 1969, Coastal Plain rocks of Harford County, *in* The geology of Harford County, Maryland: Maryland Geol. Survey, p. 77-103; 123-127.

Owens, J.P., Sohl, N.F., and Minard, J.P., 1977, A field guide to Cretaceous and Lower Tertiary beds of the Raritan and Salisbury embayments, New Jersey, Delaware, and Maryland: Guidebook AAPG-SEPM Annual Mtg., Washington, D.C., June 12-16, 1977, 113 p.

Reinhardt, Juergen, and Cleaves, E.T., 1978, Load structures at the sediment-saprolite boundary, Fall Line, Maryland: Geol. Soc. America Bull., vol. 89, p. 307-313.

Singh, Chaitanya, 1971, Lower Cretaceous microfloras of the Peace River area: northwestern Alberta: Research Council Alberta Bull., vol. 28, 310 p.

Teifke, R.H., 1973, Stratigraphic units of the Lower Cretaceous through Miocene series, *in* Geologic studies, Coastal Plain of Virginia: Virginia Division Mineral Resources, Bulletin 83, pts. 1 and 2, 78 p.

Thomson, P.W., and Pflug, H.D., 1953, Pollen and Sporen des Mitteleuropaischen Tertiars: Palaentographica, Abt. B, vol. 94, 138 p.

Vakhrameev, V.A., 1970, Range and paleoecology of Mesozoic conifers, the Cheirolepidiaceae: Paleont, Zhur., 1970, no. 1, p. 19-34.

Venkatarathnam, Kolla, and Biscaye, P.E., 1973, Deep sea zeolites; variations in space and time in the sediments of the Indian Ocean: Marine Geology, vol. 15, p. M11-M17.

Visher, G.S., 1965, Fluvial processes as interpreted from ancient and Recent fluvial deposits, *in* G.V. Middleton, Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontogists and Mineralogists, Spec. Pub. 12, p. 116-132.

Walton, A.W., 1975, Zeolite diagenesis in Oligocene volcanic sediments, Trans-Pecos Texas: Geol. Soc. America Bull., vol. 86, p. 615-624.

Wolfe, J.A., and Pakiser, H.M., 1971, Stratigraphic interpretations of some Cretaceous microfloras of the Middle Atlantic States: U.S. Geol. Survey Prof. Paper 750-B, p. B35-B47.

Wolfe, J.A., Doyle, J.A., and Page, V.M., 1975, The bases of angiosperm phylogeny: Paleobotany: Annals Missouri Bot. Garden, vol. 62, no. 3, p. 801-824.

Zietz, Isidore, and others, 1978, Aeromagnetic map of Virginia: U.S. Geol. Survey Geophys. Invest. Map GP-907, 1:500,000.

PART 4
LITHOLOGIC LOG OF THE CORE[1]

By
James Estabrook[2] and Juergen Reinhardt[2]

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

The Oak Grove core was taken as part of a multifaceted project to develop a stratigraphic and tectonic framework for the Rappahannock drainage basin, northeastern Virginia[3]. This core is the only continuously cored Cretaceous and Tertiary section on the Northern Neck of Virginia and is one of the few deep cores in the Salisbury embayment. The strata cored include the Chesapeake Group (Miocene), the Pamunkey Group (Paleocene and Eocene) and the Potomac Group (Lower Cretaceous) (see Table 1; Figure 1).

The hole was drilled near the southern margin of the Salisbury (Baltimore-Washington) embayment about 28 miles (45 km) east of the Fall Line. More specifically the hole is located in the Rollins Fork 7.5-minute quadrangle, 2.2 miles (3.5 km) west-southwest of Oak Grove, Virginia. The well head was at 180 feet (54.85 m) above sea level and the hole was continuously cored from (+ 100 to − 1195.5 feet) (+ 30.5 m to − 364.4 m).

The coring operation by the U.S. Army Corps of Engineers under contract to the U.S. Geological Survey began on March 23, 1976 and terminated on May 26, 1976. The loss of a core barrel and the inability of the drill crew to retrieve it during the next ten days forced hole abandonment. Subsequently, electric logs (single point resistance, resistivity, and spontaneous potential), and caliper logs of the hole (Figure 1) were run by the U.S. Geological Survey, Water Resources Division, Richmond District Office.[4] The water well was completed on June 8, 1976 and continues as an observation well.

The core was logged on-site by James Rankin and James Dischinger, U.S. Geological Survey (U.S.G.S.). After preliminary logging was completed, the entire core was transported to the U.S.G.S. core storage facility in Herndon, Virginia for more

---

[1] Portions of this publication may be quoted if credit is given to the Virginia Division of Mineral Resources. It is recommended that reference to this report be made in the following form: Estabrook, James and Reinhardt, Juergen, 1980, Lithologic log of the core, *in* Geology of the Oak Grove core: Virginia Division of Mineral Resources Publication 20, Part 4, 88 p.

[2] U.S. Geological Survey, Reston, Virginia

[3] U.S. Geological Survey Open-file report 78-855.

[4] Copies of the well logs can be obtained from District Chief, Water Resources Division, U.S. Geological Survey, 200 West Grace St., Room 304, Richmond, Virginia 23220.

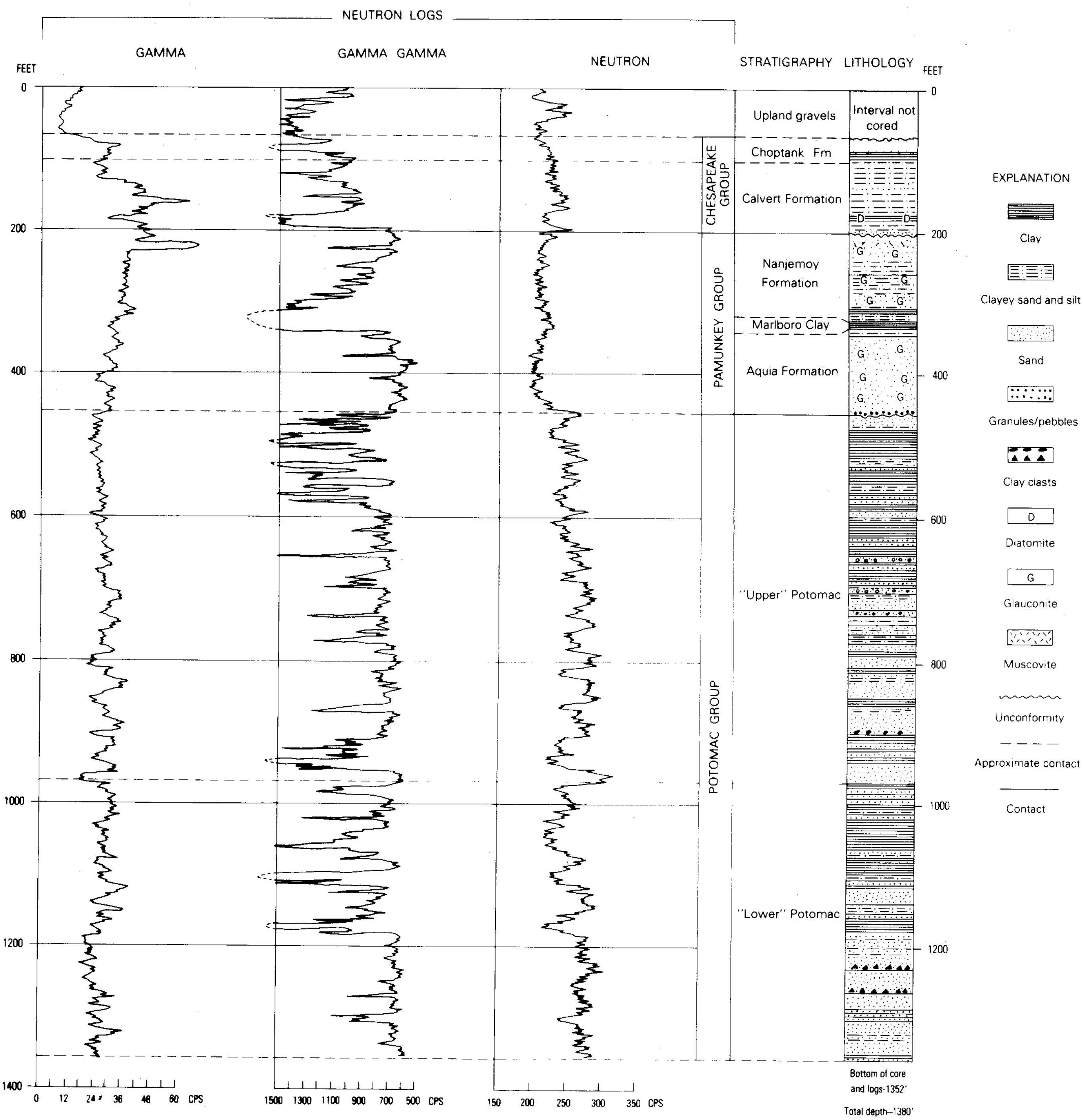


Figure 1. Lithostratigraphic summary and geophysical logs of the Oak Grove core.

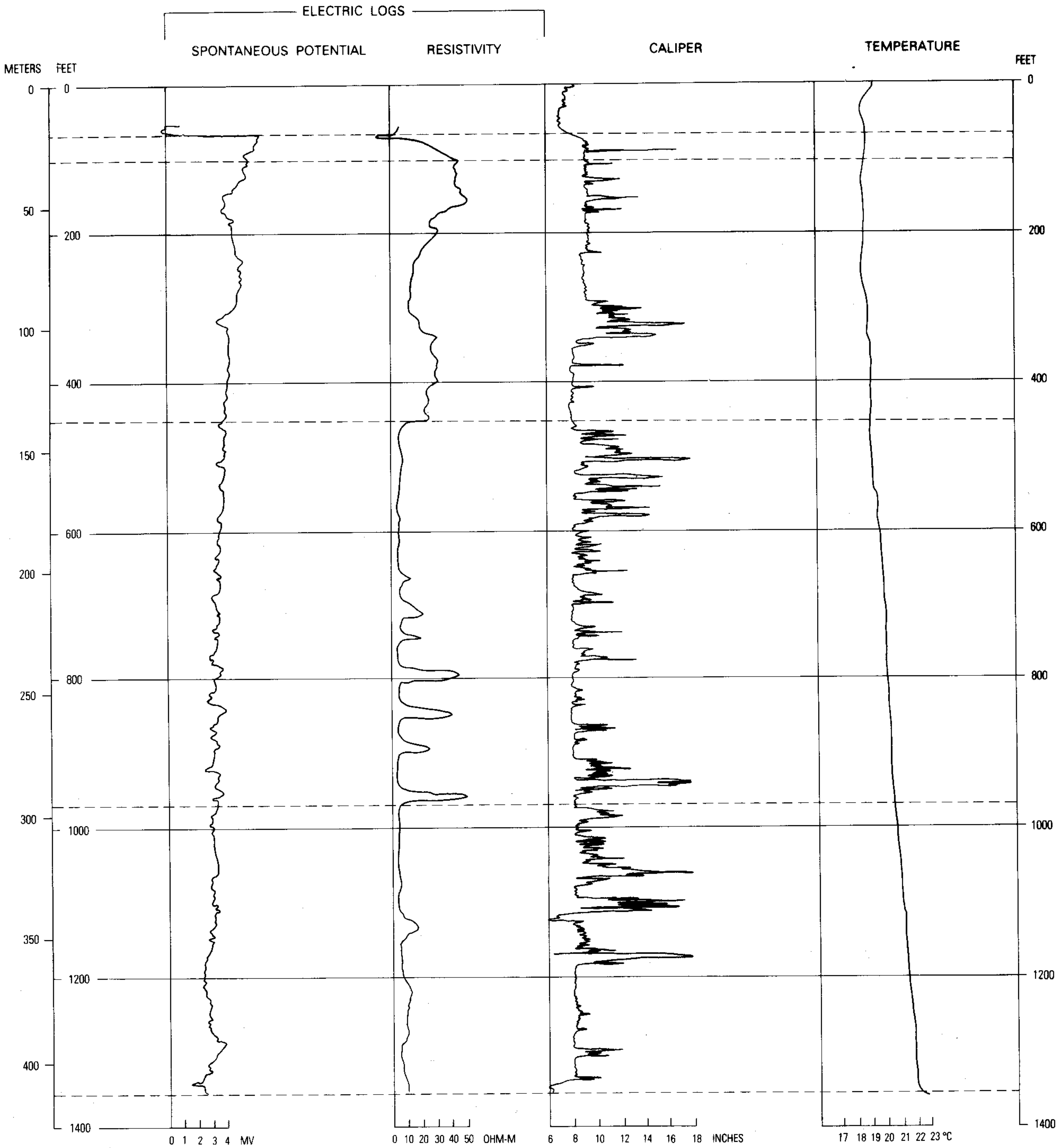

ELECTRIC LOGS
SPONTANEOUS POTENTIAL
RESISTIVITY
CALIPER
TEMPERATURE
METERS
FEET
0
50
100
150
200
250
300
350
400
0
200
400
600
800
1000
1200
1400
0 1 2 3 4 MV
0 10 20 30 40 50 OHM-M
6 8 10 12 14 16 18 INCHES
17 18 19 20 21 22 23 °C

Table 1. Stratigraphic summary

Period	Epoch	Group	Formation	Thickness of Penetrated Section m	Top of Formation Depth Relative to: Well head ft	m	Sea level ft	m
Tertiary	Miocene?-Pliocene		Upland Gravels	20.5	0	0	+ 180	+ 54.85
	Miocene	Chesapeake	Choptank	10.0	67	20.5	+ 113	+ 34.4
			Calvert	30.3	100	30.5	80	24.4
		unconformity						
	Eocene and Paleocene	Pamunkey	Nanjemoy	37.4	199	60.8	- 20	- 6.0
			Marlboro Clay	5.4	322	98.2	- 143	- 43.6
			Aquia	34.8	340	103.6	- 160	- 48.7
		unconformity						
Cretaceous	Lower Cretaceous	"Upper" Potomac		158.2	454	138.4	- 274	- 83.5
		"Lower" Potomac		124.0	973	296.6	- 793	- 241.7
			Total Depth		1380	420.6	- 1200	- 365.7

detailed inspection and sampling. Photography and lithologic sampling of the core were completed during July 1976. The aid of W.L. Newell and Stephen Perlman, U.S.G.S., in photographing the core is acknowledged.

A total of 122 samples were taken for petrographic and clay analysis; 40 from selected Tertiary portions of the core and 82 from the Cretaceous section. Heavy mineral separates were identified petrographically by J.P. Owens, U.S.G.S.; clay mineral analysis was performed by Melodie M. Hess, U.S.G.S. The results of the lithologic analyses are presented in Appendices 1 and 2. A preliminary report on the core was presented by Reinhardt, Newell, and Mixon (1977).

The core was jointly sampled for various microfossil groups from common samples. Wafers 2.4 to 3.1 inches thick (6 to 8 cm) were taken at intervals from one-half of the core. The largest sub-sample was washed for foraminifers and ostracodes, another for sporomorphs and dinoflagellates, and the smallest for calcareous nannofossils. Samples for diatoms were taken adjacent to those of the other microfossils. Additionally, mollusks were collected from separate, larger samples in the shelly intervals. Samples for fossils were as follows: 135 microfossil samples in the Tertiary section; 20 molluscan samples from the Nanjemoy Formation; and 25 samples for palynomorphs from the Cretaceous section. The biostratigraphic work on the core was coordinated by T.G. Gibson, U.S.G.S. The Cretaceous palynological studies by Raymond Christopher are in Publication 20, Part 3. A preliminary report of the biostratigraphy has been presented (Andrews and others, 1977).

Core chips from the full length of the Oak Grove core are reposited with the Virginia Division of Mineral Resources under number W-4938.

LITHOLOGIC LOG

Explanation of Log Format, Headings and Symbols

DEPTH: All measurements including run lengths and on-site core logging were made in feet. Accordingly all depths are given in feet in the lithologic log.

Conversion from feet to meters can be obtained by multiplying by 0.3048.

RUN-BOX: Numbers indicate run and core storage boxes. Occasionally the same box was used to hold core material from portions of two consecutive runs. Core from a single run was typically placed in three or four boxes. Percentage of recovery for each run is recorded in the "run-box" column.

BEDDING: Gross bedding characteristics are recorded; detailed observations of bedding style may be given under "comments".

Thin	$<$	5 cm thick
Thick		5-30 cm thick
Massive	$>$	30 cm thick

TEXTURE: Textural terminology corresponds to standard Wentworth scale terms and results largely from hand lens inspection of the core. More detailed textural analyses are presented in Appendix 1.

major grain size(s) secondary grain size(s)

MINERALOGY: The dominant macroscopic mineralogical characteristics of each five-foot interval are given. Where no mineral is noted, the texture was too fine to allow hand lens determination. The major minerals noted were: quartz (Q), feldspar (F), glauconite (G), micas—muscovite (M), and biotite (B), phosphate (P), and heavy minerals (H) (especially magnetite and ilmenite).

The clay analysis column indicates the stratigraphic position (*) of those samples studied for clay mineralogy. Results of these analyses appear in Appendix 2.

COLOR: This information is based on color chart comparison with freshly recovered core at the drilling site. These observations were made by Rankin and Dischinger. Subsequent drying and oxidation of the core has altered the color of some core intervals.

BIOLOGY/FOSSILS: Macroscopic fragments to whole specimens of bivalve shells (or molds), wood, teeth, bone and fish scales are recorded in these columns. Additional information about trace fossils, including bioturbation, is recorded here:

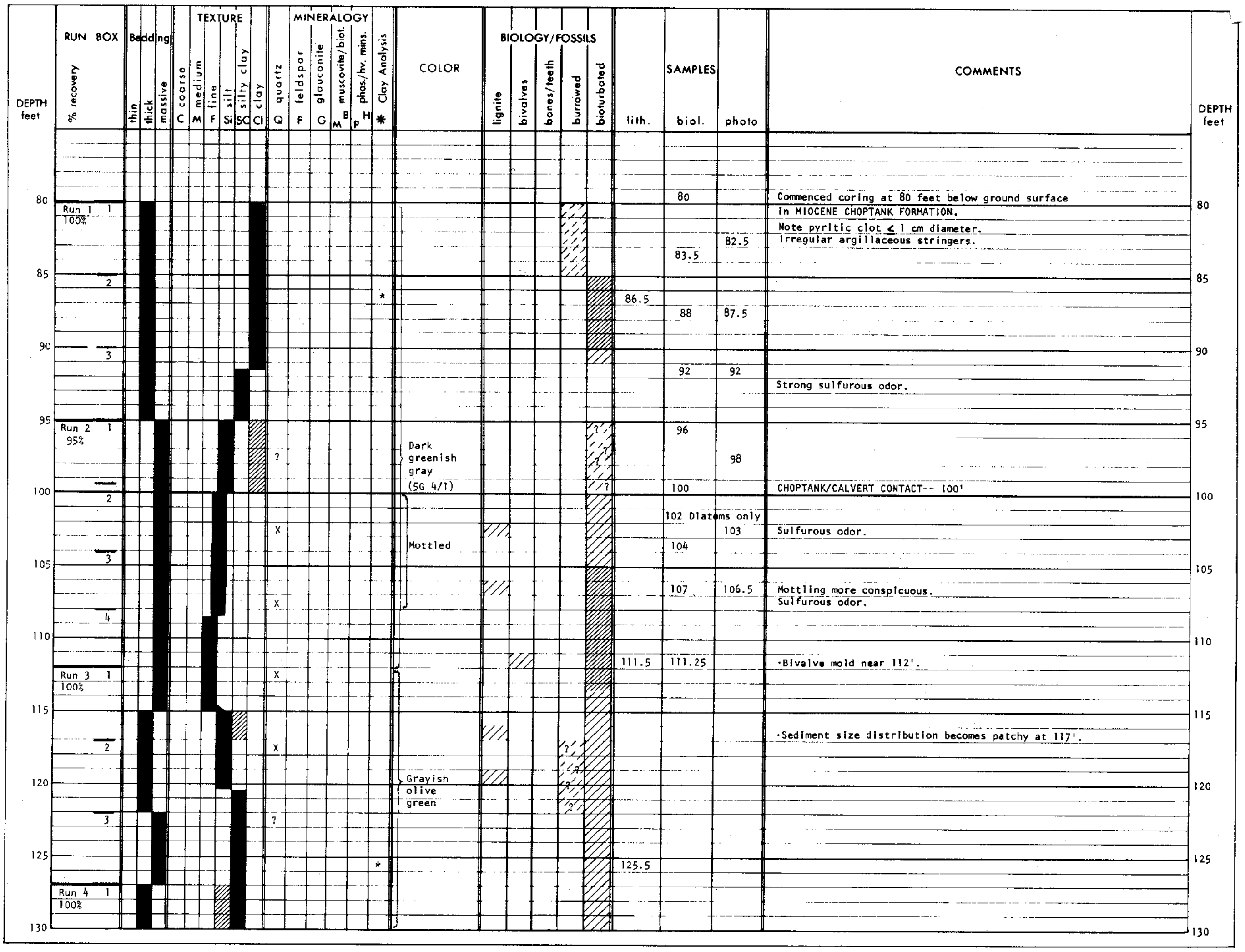
abundant sparse

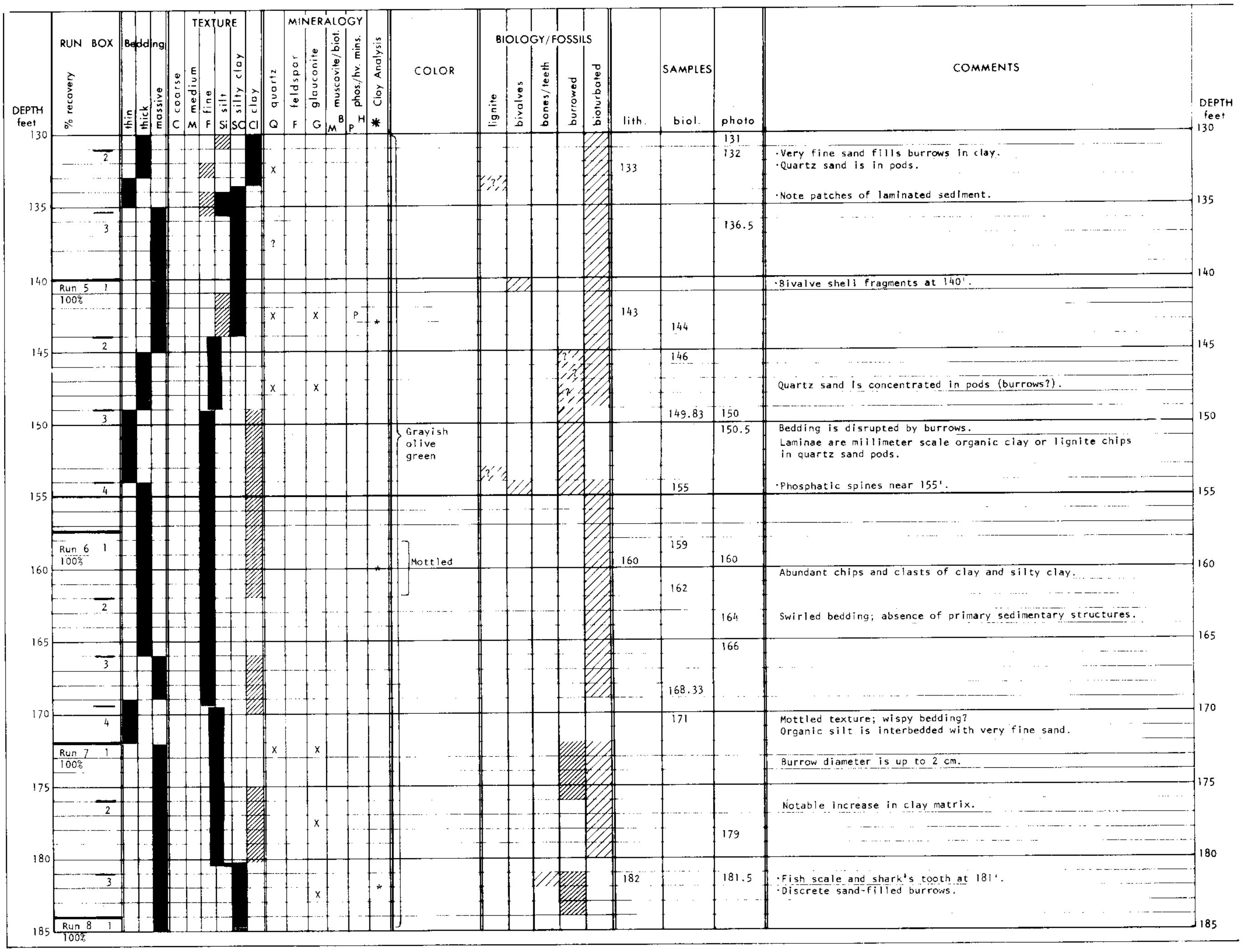
common shell layer

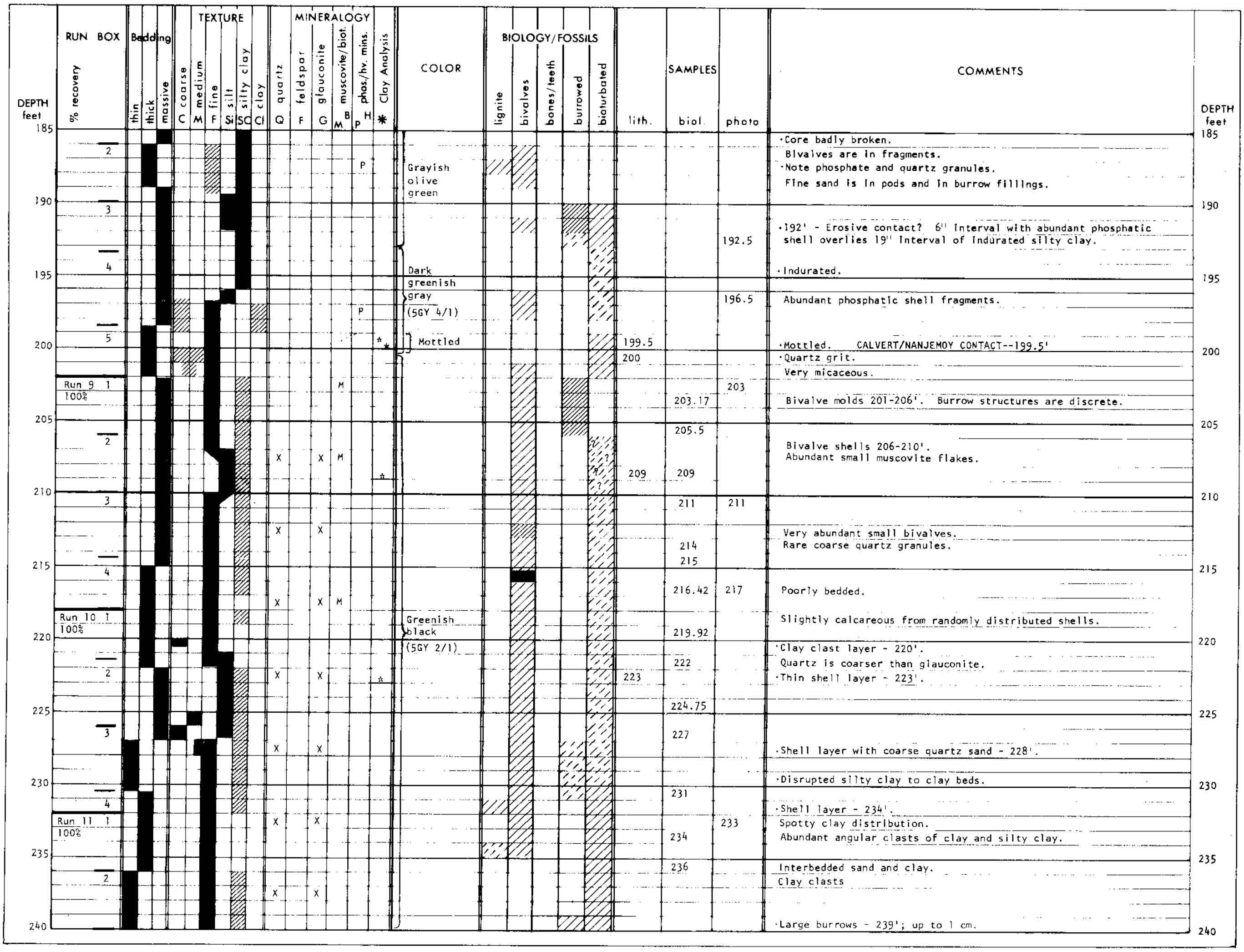
rare or possible

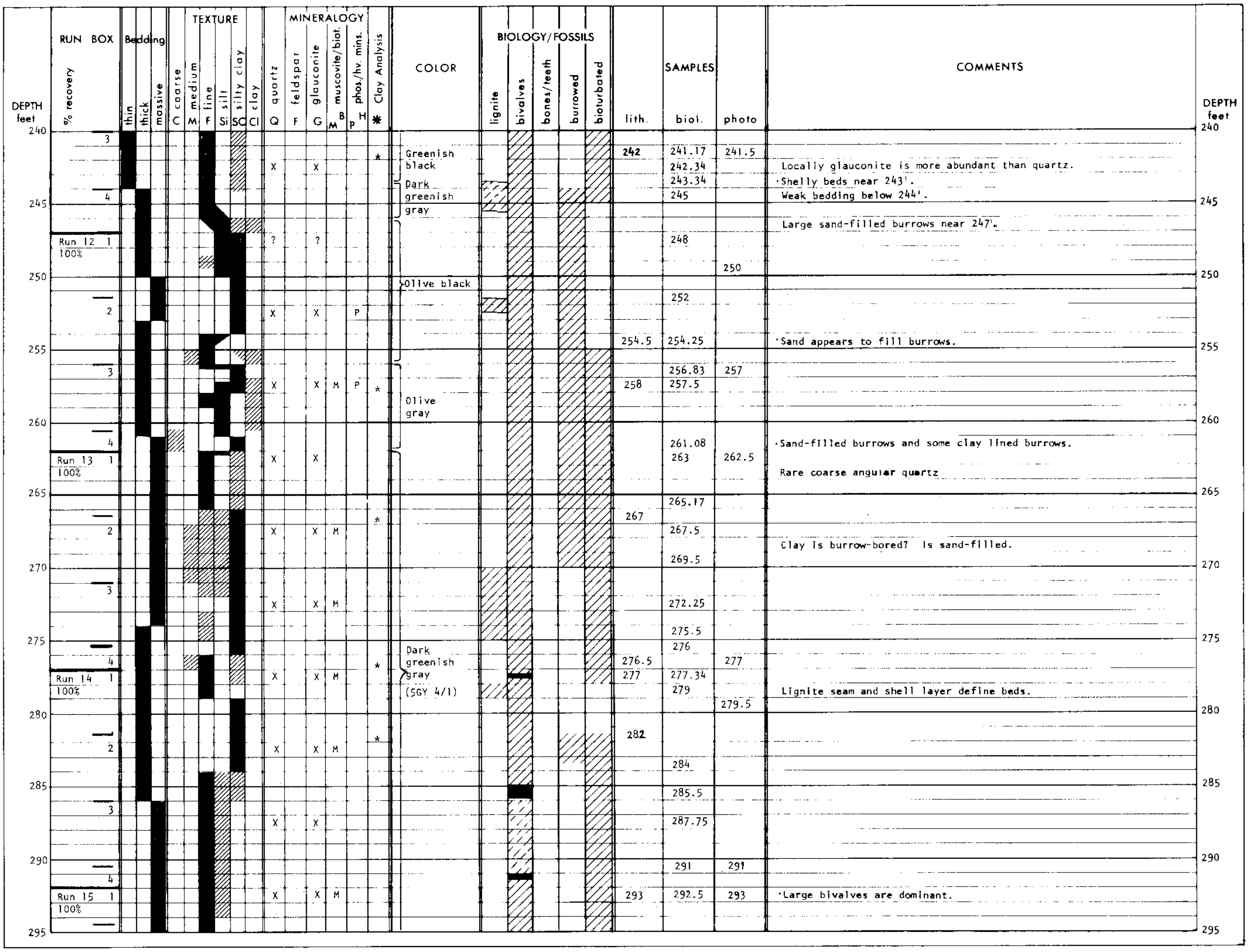
SAMPLES: The depths recorded indicate the top of the sampled or photographed interval. Most lithologic and biostratigraphic samples were 5 to 15 cm (2 to 6 inches) long. The procedure for dealing with lithologic and biostratigraphic samples is explained elsewhere.

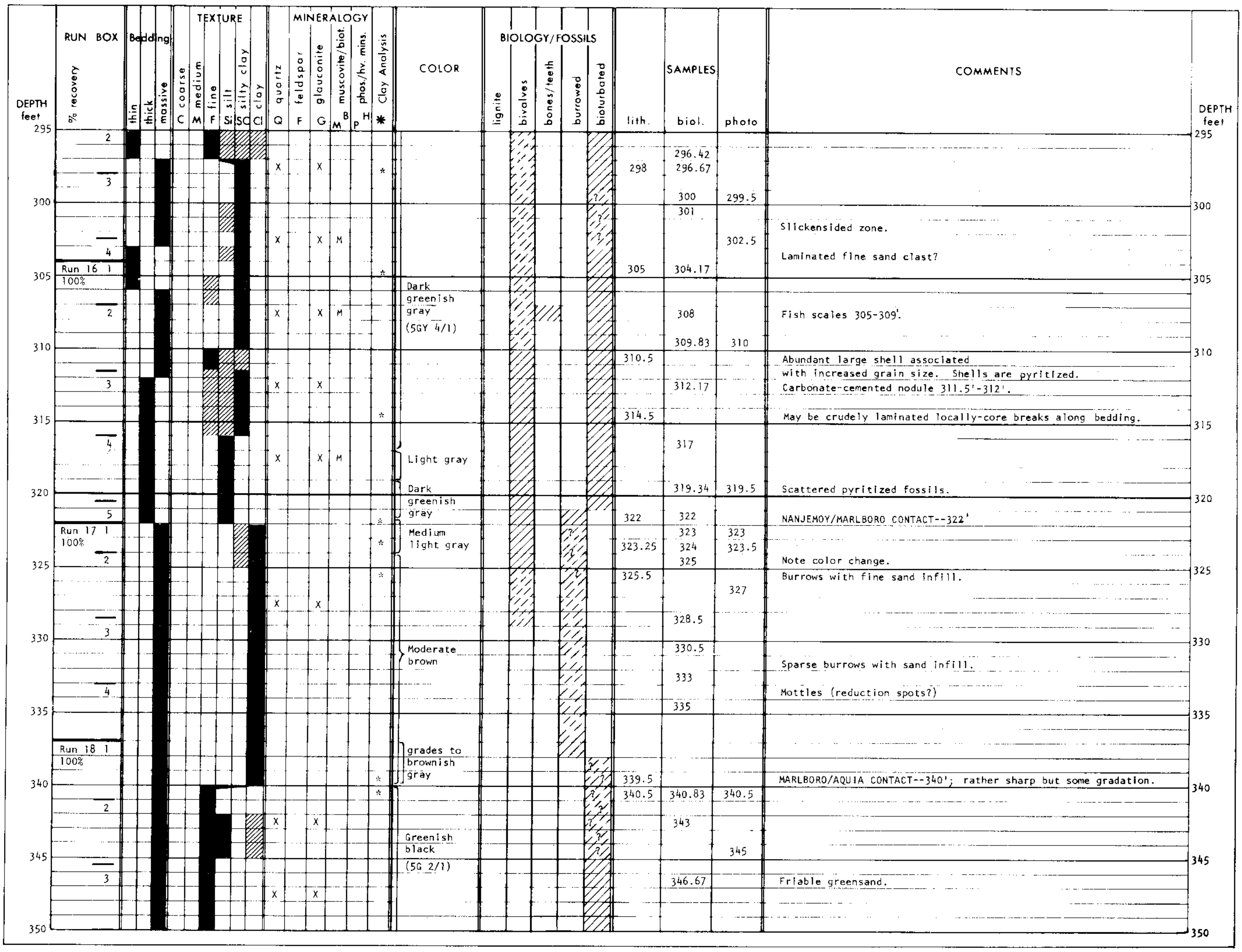
COMMENTS: Information not easily recorded in the preceding columns is entered here. A dot (•) preceding a comment applies to the core interval only at that specific depth. Where there is no dot and no qualifying depth given in the comment, the remark generally refers to a core interval up to 7 feet (2 m) thick.

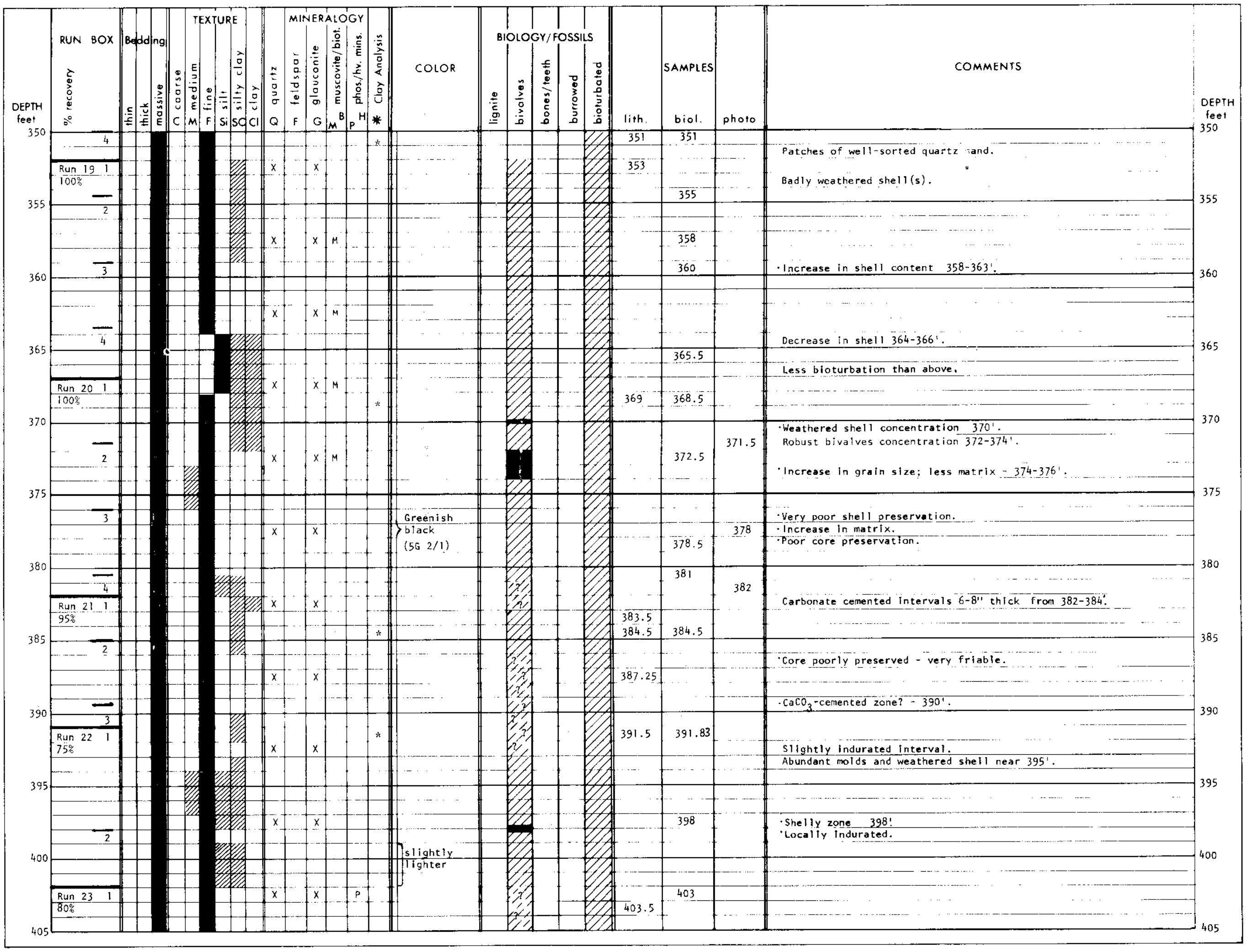

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
C coarse
M medium
F fine
Si silt
SC silty clay
Cl clay
MINERALOGY
Q quartz
F feldspar
G glauconite
M B muscovite/biot.
P H phos/hv. mins.
* Clay Analysis
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
80
85
90
95
100
105
110
115
120
125
130
Run 1 1
100%
2
3
Run 2 1
95%
2
3
4
Run 3 1
100%
2
3
Run 4 1
100%
Dark greenish gray (5G 4/1)
Mottled
Grayish olive green
86.5
111.5
125.5
80
83.5
88
92
96
100
102 Diatoms only
104
107
111.25
82.5
87.5
92
98
103
106.5
Commenced coring at 80 feet below ground surface in MIOCENE CHOPTANK FORMATION.
Note pyritic clot ≤ 1 cm diameter.
Irregular argillaceous stringers.
Strong sulfurous odor.
CHOPTANK/CALVERT CONTACT-- 100'
Sulfurous odor.
Mottling more conspicuous.
Sulfurous odor.
·Bivalve mold near 112'.
·Sediment size distribution becomes patchy at 117'.

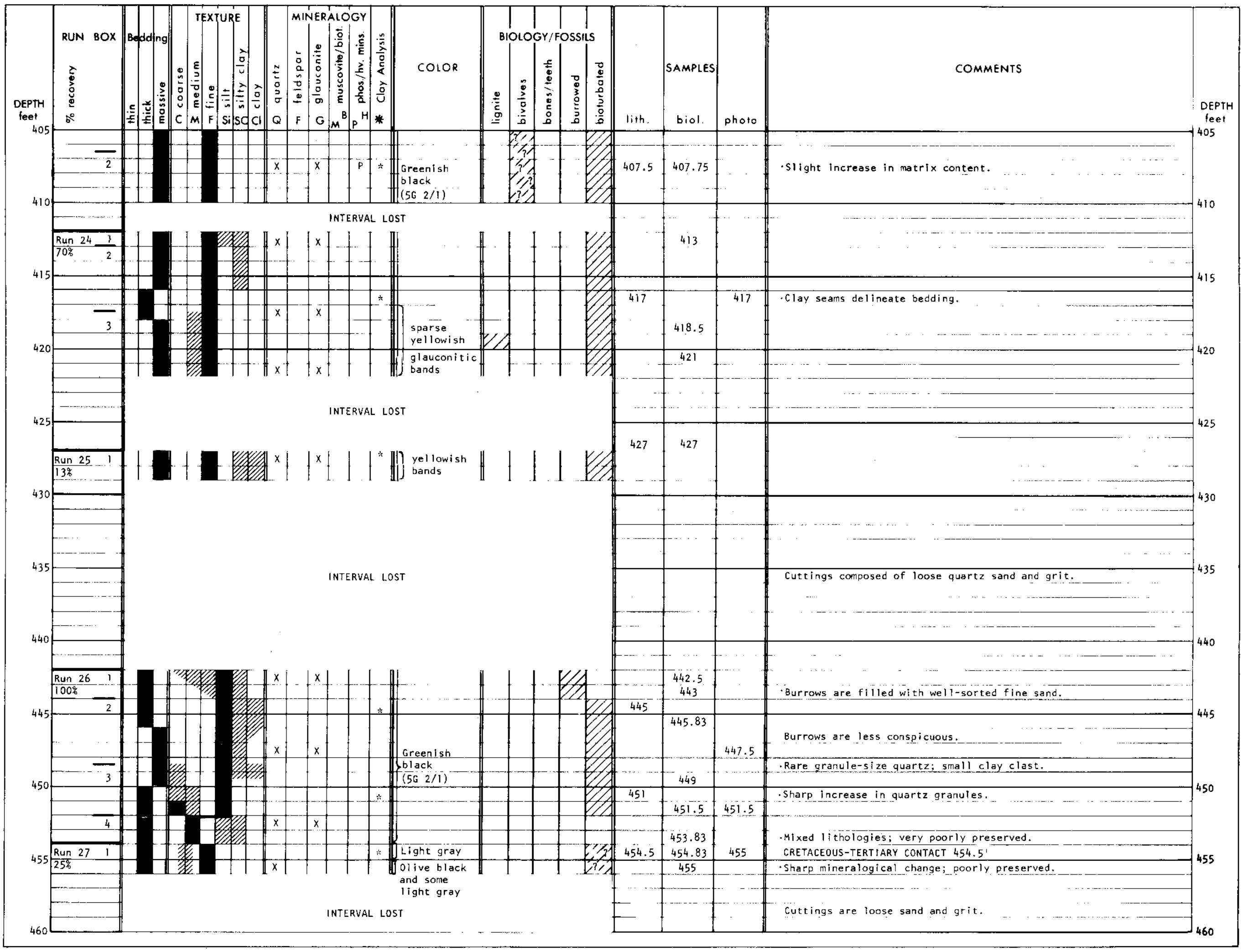

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
130
135
140
145
150
155
160
165
170
175
180
185
Run 5 1
100%
Run 6 1
100%
Run 7 1
100%
Run 8 1
100%
Grayish olive green
Mottled
133
143
160
182
144
146
149.83
155
159
162
168.33
171
131
132
136.5
150
150.5
160
164
166
179
181.5
·Very fine sand fills burrows in clay.
·Quartz sand is in pods.
·Note patches of laminated sediment.
·Bivalve shell fragments at 140'.
Quartz sand is concentrated in pods (burrows?).
Bedding is disrupted by burrows.
Laminae are millimeter scale organic clay or lignite chips in quartz sand pods.
·Phosphatic spines near 155'.
Abundant chips and clasts of clay and silty clay.
Swirled bedding; absence of primary sedimentary structures.
Mottled texture; wispy bedding?
Organic silt is interbedded with very fine sand.
Burrow diameter is up to 2 cm.
Notable increase in clay matrix.
·Fish scale and shark's tooth at 181'.
·Discrete sand-filled burrows.

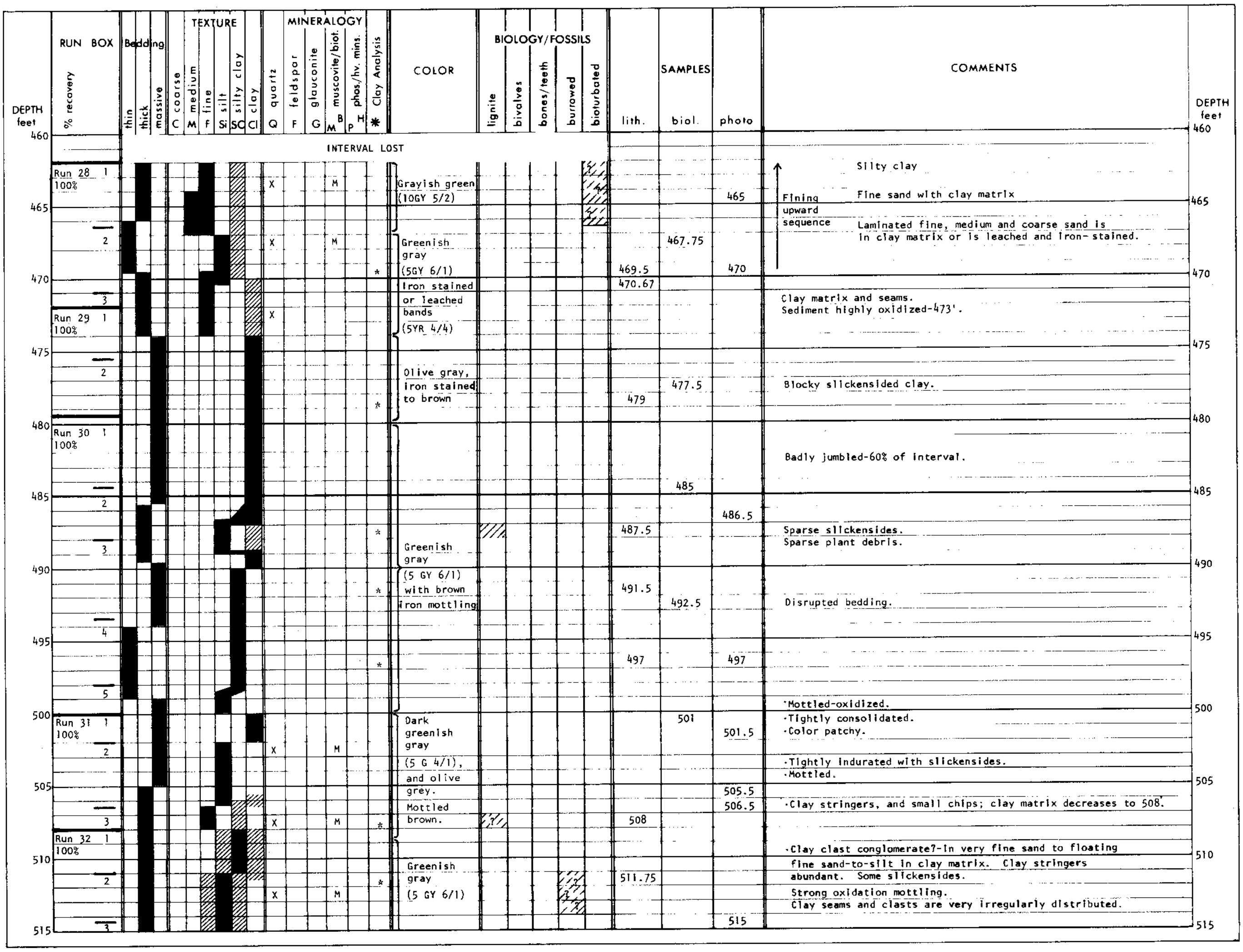

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
185
190
195
200
205
210
215
220
225
230
235
240
Run 9
100%
Run 10
100%
Run 11
100%
Grayish olive green
Dark greenish gray (5GY 4/1)
Mottled
Greenish black (5GY 2/1)
199.5
200
209
223
203.17
205.5
209
211
214
215
216.42
219.92
222
224.75
227
231
234
236
192.5
196.5
203
211
217
233
·Core badly broken.
Bivalves are in fragments.
·Note phosphate and quartz granules.
Fine sand is in pods and in burrow fillings.
·192' - Erosive contact? 6" Interval with abundant phosphatic shell overlies 19" interval of indurated silty clay.
·Indurated.
Abundant phosphatic shell fragments.
·Mottled. CALVERT/NANJEMOY CONTACT--199.5'
·Quartz grit.
Very micaceous.
Bivalve molds 201-206'. Burrow structures are discrete.
Bivalve shells 206-210'.
Abundant small muscovite flakes.
Very abundant small bivalves.
Rare coarse quartz granules.
Poorly bedded.
Slightly calcareous from randomly distributed shells.
·Clay clast layer - 220'.
Quartz is coarser than glauconite.
·Thin shell layer - 223'.
·Shell layer with coarse quartz sand - 228'.
·Disrupted silty clay to clay beds.
·Shell layer - 234'.
Spotty clay distribution.
Abundant angular clasts of clay and silty clay.
Interbedded sand and clay.
Clay clasts
·Large burrows - 239'; up to 1 cm.

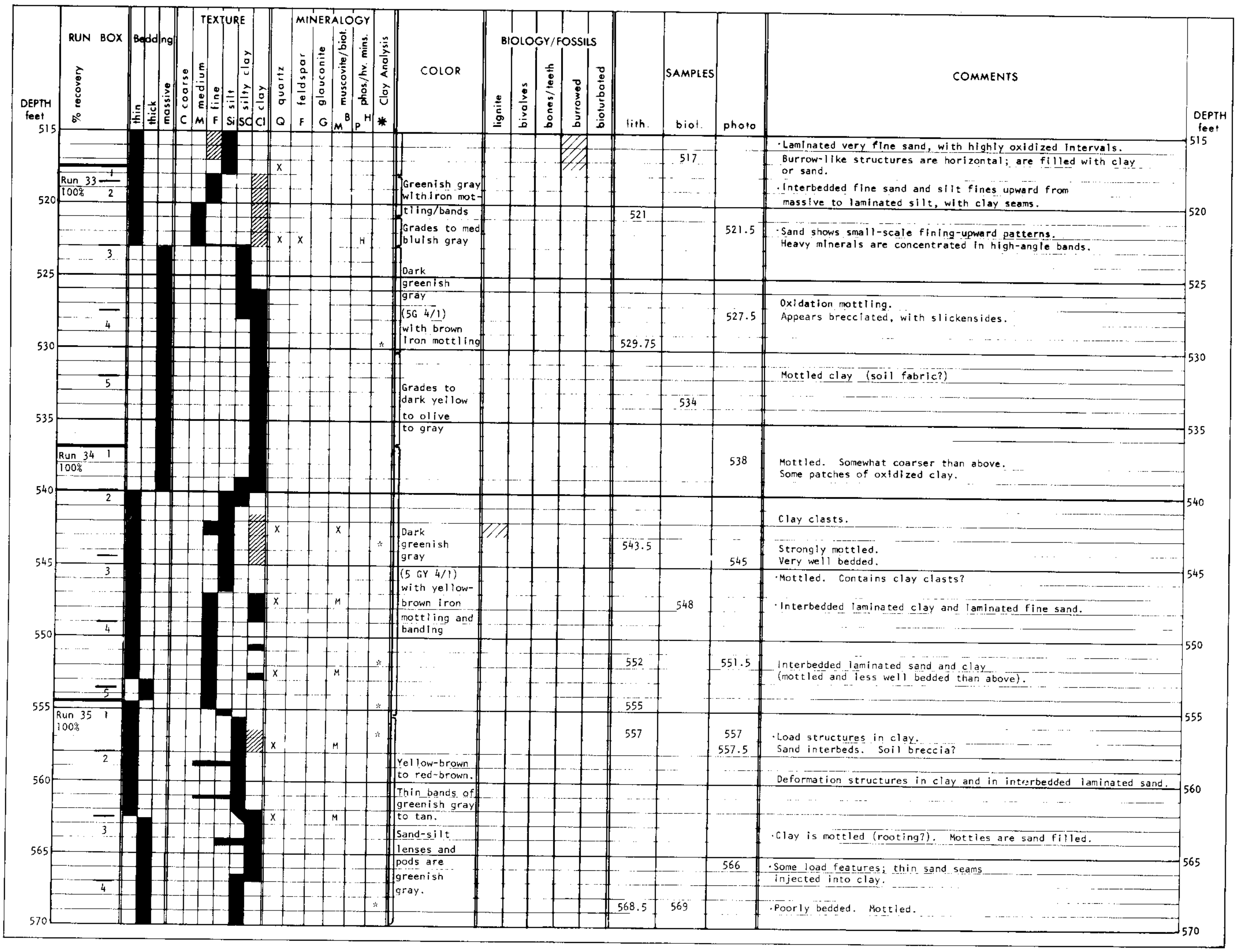

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G B M H P *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
240
245
250
255
260
265
270
275
280
285
290
295
Run 12 1
100%
Run 13 1
100%
Run 14 1
100%
Run 15 1
100%
Greenish black
Dark greenish gray
Olive black
Olive gray
Dark greenish gray (5GY 4/1)
242
254.5
258
267
276.5
277
282
293
241.17
242.34
243.34
245
248
252
254.25
256.83
257.5
261.08
263
265.17
267.5
269.5
272.25
275.5
276
277.34
279
284
285.5
287.75
291
292.5
241.5
250
257
262.5
277
279.5
291
293
Locally glauconite is more abundant than quartz.
·Shelly beds near 243'.
Weak bedding below 244'.
Large sand-filled burrows near 247'.
·Sand appears to fill burrows.
·Sand-filled burrows and some clay lined burrows.
Rare coarse angular quartz
Clay is burrow-bored? Is sand-filled.
Lignite seam and shell layer define beds.
·Large bivalves are dominant.

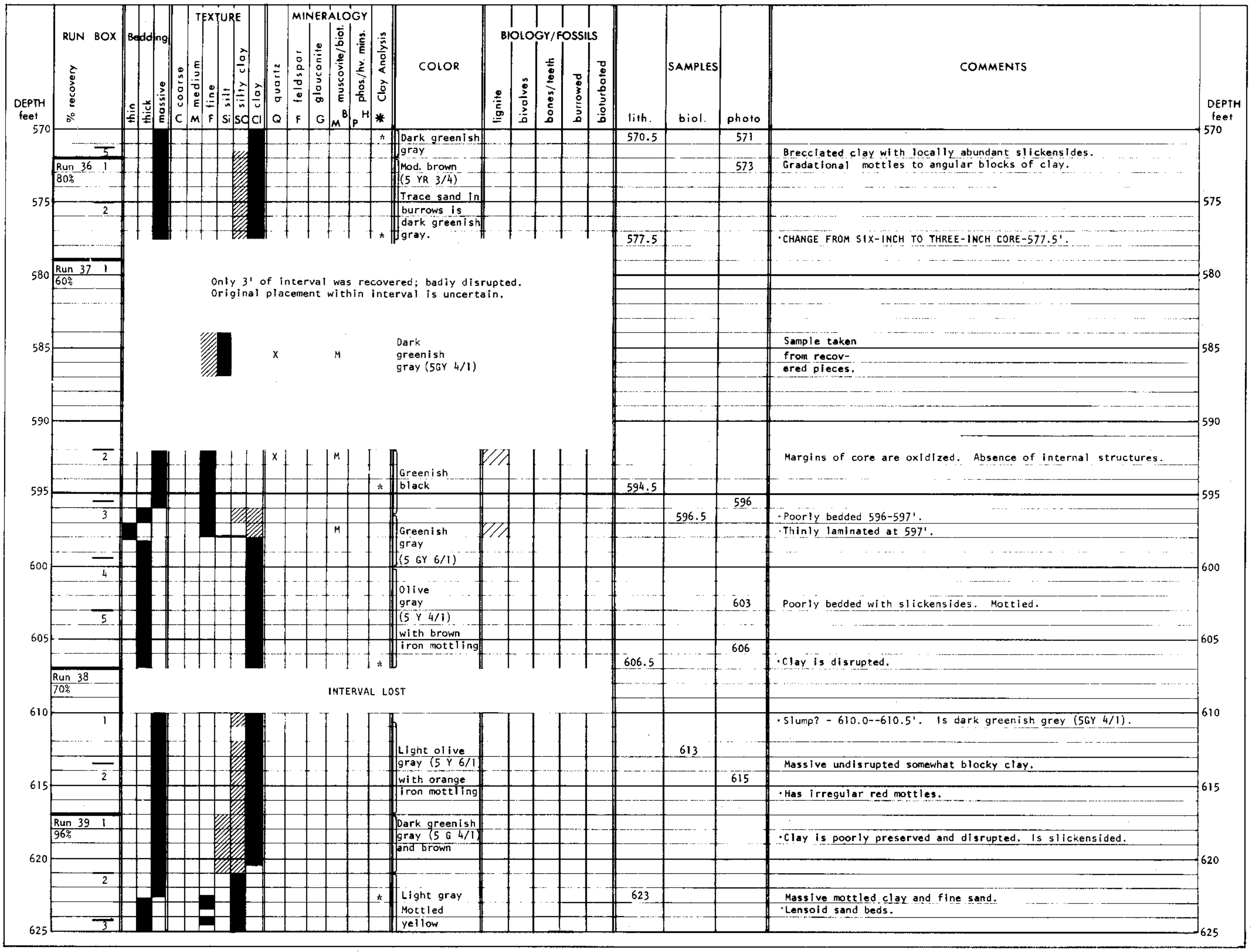

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Q F G M B P H
Clay Analysis
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
295
300
305
310
315
320
325
330
335
340
345
350
Run 16
100%
Run 17
100%
Run 18
100%
Dark greenish gray (5GY 4/1)
Light gray
Dark greenish gray
Medium light gray
Moderate brown
grades to brownish gray
Greenish black (5G 2/1)
296.42
296.67
298
300
299.5
301
302.5
305
304.17
308
309.83
310
310.5
312.17
314.5
317
319.34
319.5
322
322
323
323
323.25
324
323.5
325
325.5
327
328.5
330.5
333
335
339.5
340.5
340.83
340.5
343
345
346.67
Slickensided zone.
Laminated fine sand clast?
Fish scales 305-309'.
Abundant large shell associated with increased grain size. Shells are pyritized.
Carbonate-cemented nodule 311.5'-312'.
May be crudely laminated locally-core breaks along bedding.
Scattered pyritized fossils.
NANJEMOY/MARLBORO CONTACT--322'
Note color change.
Burrows with fine sand infill.
Sparse burrows with sand infill.
Mottles (reduction spots?)
MARLBORO/AQUIA CONTACT--340'; rather sharp but some gradation.
Friable greensand.

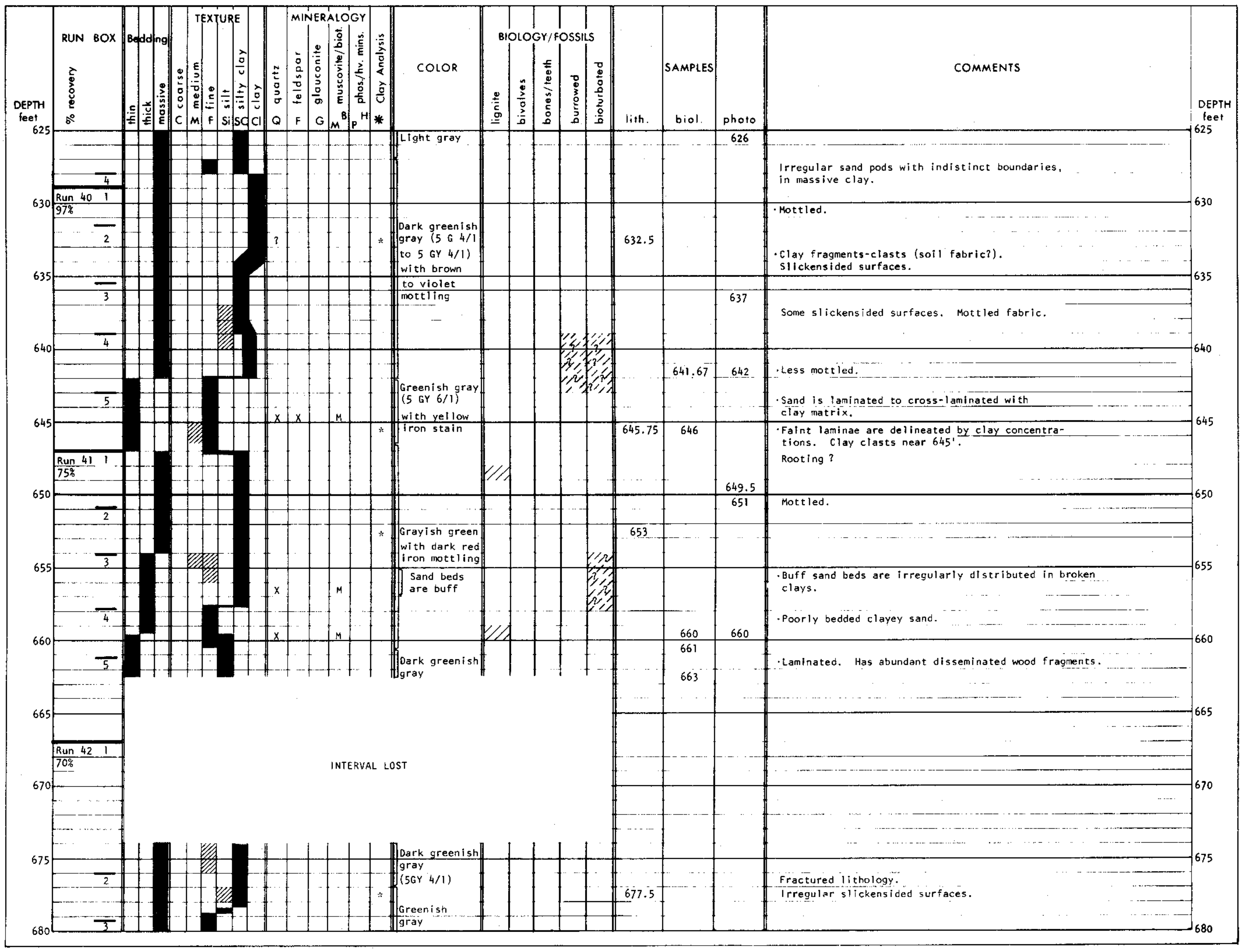

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse C
medium M
fine F
silt Si
silty clay SC
clay Cl
MINERALOGY
quartz Q
feldspar F
glauconite G
muscovite/biot. M B
phos./hv. mins. P H
Clay Analysis *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
350
355
360
365
370
375
380
385
390
395
400
405
Run 19 1
100%
Run 20 1
100%
Run 21 1
95%
Run 22 1
75%
Run 23 1
80%
Greenish black (5G 2/1)
slightly lighter
351
353
369
383.5
384.5
387.25
391.5
403.5
351
355
358
360
365.5
368.5
372.5
378.5
381
384.5
391.83
398
403
371.5
378
382
Patches of well-sorted quartz sand.
Badly weathered shell(s).
Increase in shell content 358-363'.
Decrease in shell 364-366'.
Less bioturbation than above.
Weathered shell concentration 370'.
Robust bivalves concentration 372-374'.
Increase in grain size; less matrix - 374-376'.
Very poor shell preservation.
Increase in matrix.
Poor core preservation.
Carbonate cemented intervals 6-8" thick from 382-384'.
Core poorly preserved - very friable.
CaCO3-cemented zone? - 390'.
Slightly indurated interval.
Abundant molds and weathered shell near 395'.
Shelly zone 398'
Locally indurated.

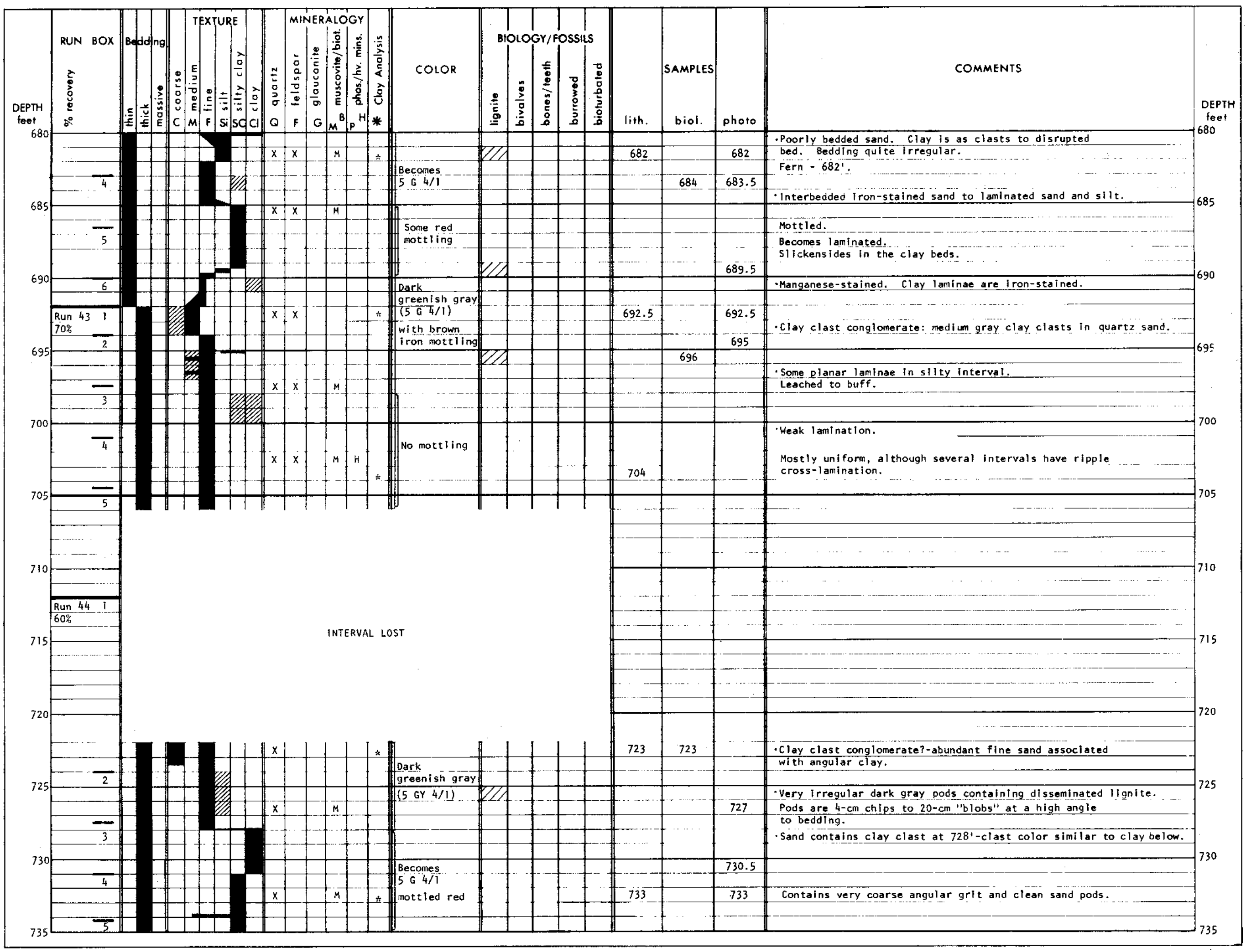

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G B M H P
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
Run 24 70%
Run 25 13%
Run 26 100%
Run 27 25%
Greenish black (5G 2/1)
INTERVAL LOST
sparse yellowish glauconitic bands
yellowish bands
Light gray
Olive black and some light gray
407.5
407.75
413
417
418.5
421
427
442.5
443
445
445.83
447.5
449
451
451.5
453.83
454.5
454.83
455
·Slight increase in matrix content.
·Clay seams delineate bedding.
Cuttings composed of loose quartz sand and grit.
·Burrows are filled with well-sorted fine sand.
Burrows are less conspicuous.
·Rare granule-size quartz; small clay clast.
·Sharp increase in quartz granules.
·Mixed lithologies; very poorly preserved.
CRETACEOUS-TERTIARY CONTACT 454.5'
·Sharp mineralogical change; poorly preserved.
Cuttings are loose sand and grit.

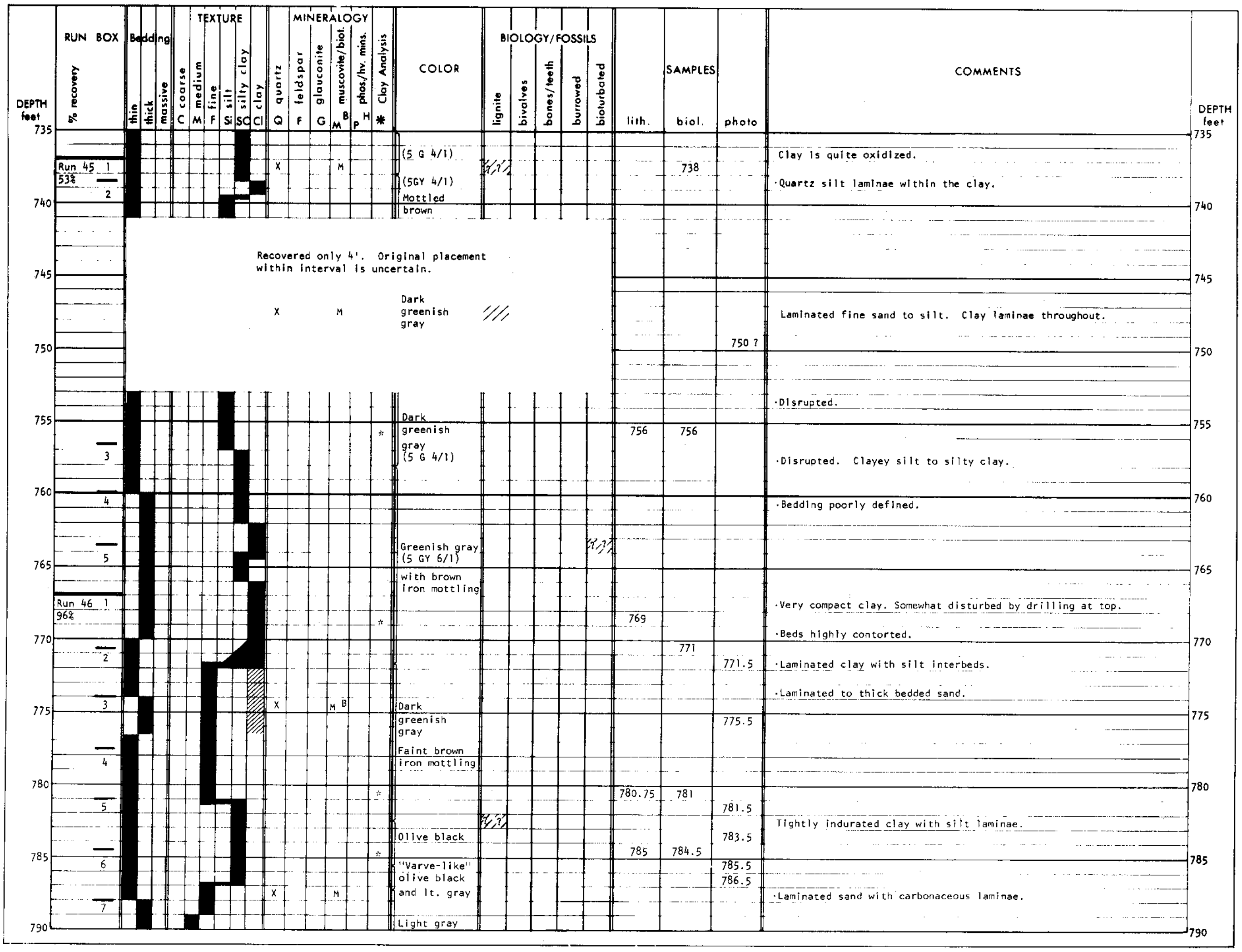

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos/hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
460
465
470
475
480
485
490
495
500
505
510
515
INTERVAL LOST
Run 28 1
100%
2
3
Run 29 1
100%
2
Run 30 1
100%
2
3
4
5
Run 31 1
100%
2
3
Run 32 1
100%
2
3
Grayish green (10GY 5/2)
Greenish gray (5GY 6/1)
Iron stained or leached bands (5YR 4/4)
Olive gray, iron stained to brown
Greenish gray (5 GY 6/1) with brown iron mottling
Dark greenish gray (5 G 4/1), and olive grey.
Mottled brown.
Greenish gray (5 GY 6/1)
469.5
470.67
479
487.5
491.5
497
508
511.75
467.75
477.5
485
492.5
501
465
470
486.5
497
501.5
505.5
506.5
515
Silty clay
Fining upward sequence
Fine sand with clay matrix
Laminated fine, medium and coarse sand is in clay matrix or is leached and iron-stained.
Clay matrix and seams.
Sediment highly oxidized-473'.
Blocky slickensided clay.
Badly jumbled-60% of interval.
Sparse slickensides.
Sparse plant debris.
Disrupted bedding.
·Mottled-oxidized.
·Tightly consolidated.
·Color patchy.
·Tightly indurated with slickensides.
·Mottled.
·Clay stringers, and small chips; clay matrix decreases to 508.
·Clay clast conglomerate?-In very fine sand to floating fine sand-to-silt in clay matrix. Clay stringers abundant. Some slickensides.
Strong oxidation mottling.
Clay seams and clasts are very irregularly distributed.

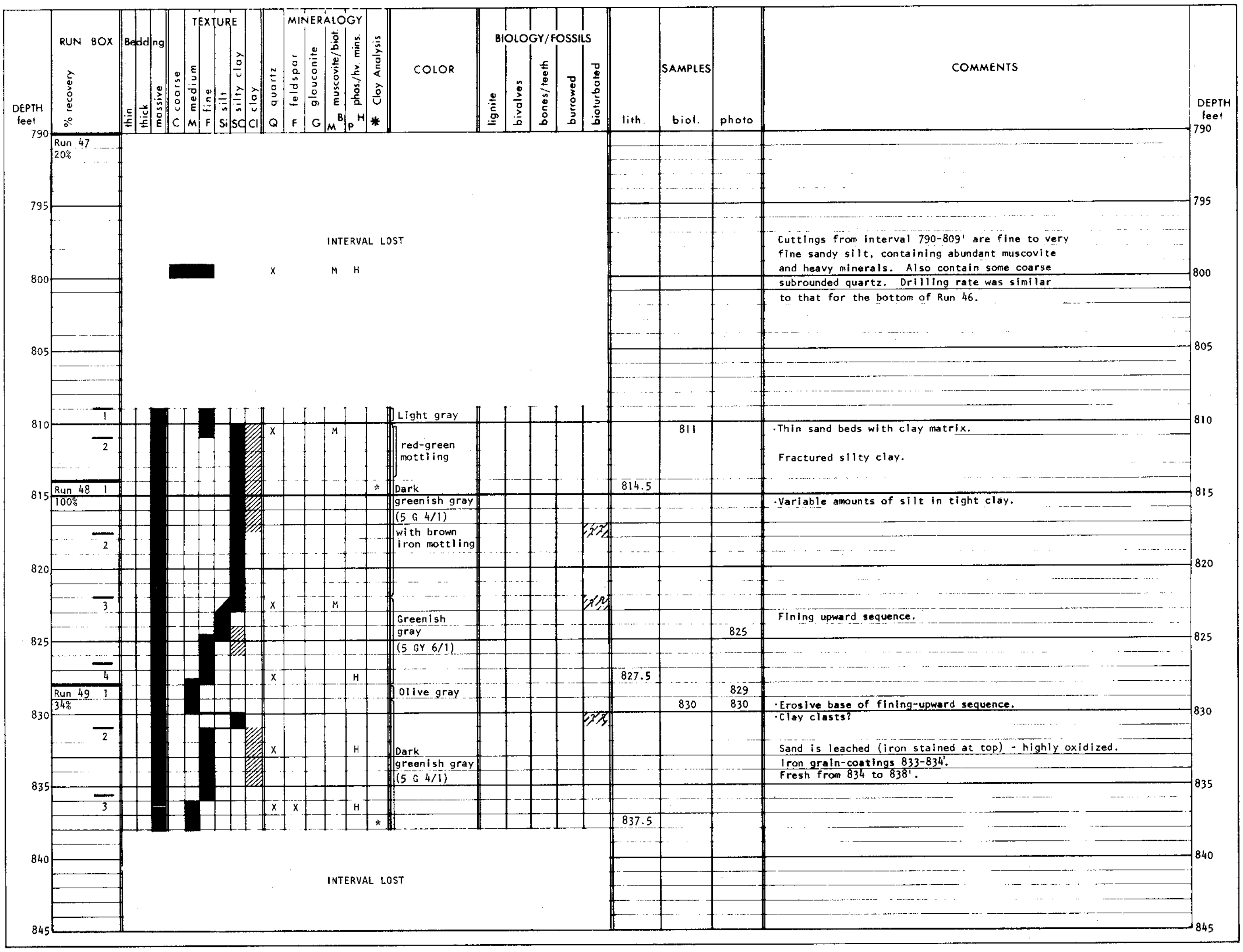

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
C coarse
M medium
F fine
Si silt
SC silty clay
Cl clay
MINERALOGY
Q quartz
F feldspar
G glauconite
M B muscovite/biot.
P H phos./hv. mins.
* Clay Analysis
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
515
520
525
530
535
540
545
550
555
560
565
570
Run 33
100%
Run 34
100%
Run 35
100%
Greenish gray with iron mottling/bands
Grades to med bluish gray
Dark greenish gray (5G 4/1) with brown iron mottling
Grades to dark yellow to olive to gray
Dark greenish gray (5 GY 4/1) with yellow-brown iron mottling and banding
Yellow-brown to red-brown. Thin bands of greenish gray to tan. Sand-silt lenses and pods are greenish gray.
517
521
521.5
527.5
529.75
534
538
543.5
545
548
552
551.5
555
557
557
557.5
566
568.5
569
·Laminated very fine sand, with highly oxidized intervals. Burrow-like structures are horizontal; are filled with clay or sand.
·Interbedded fine sand and silt fines upward from massive to laminated silt, with clay seams.
·Sand shows small-scale fining-upward patterns. Heavy minerals are concentrated in high-angle bands.
Oxidation mottling. Appears brecciated, with slickensides.
Mottled clay (soil fabric?)
Mottled. Somewhat coarser than above. Some patches of oxidized clay.
Clay clasts.
Strongly mottled. Very well bedded.
·Mottled. Contains clay clasts?
·Interbedded laminated clay and laminated fine sand.
Interbedded laminated sand and clay (mottled and less well bedded than above).
·Load structures in clay. Sand interbeds. Soil breccia?
Deformation structures in clay and in interbedded laminated sand.
·Clay is mottled (rooting?). Mottles are sand filled.
·Some load features; thin sand seams injected into clay.
·Poorly bedded. Mottled.

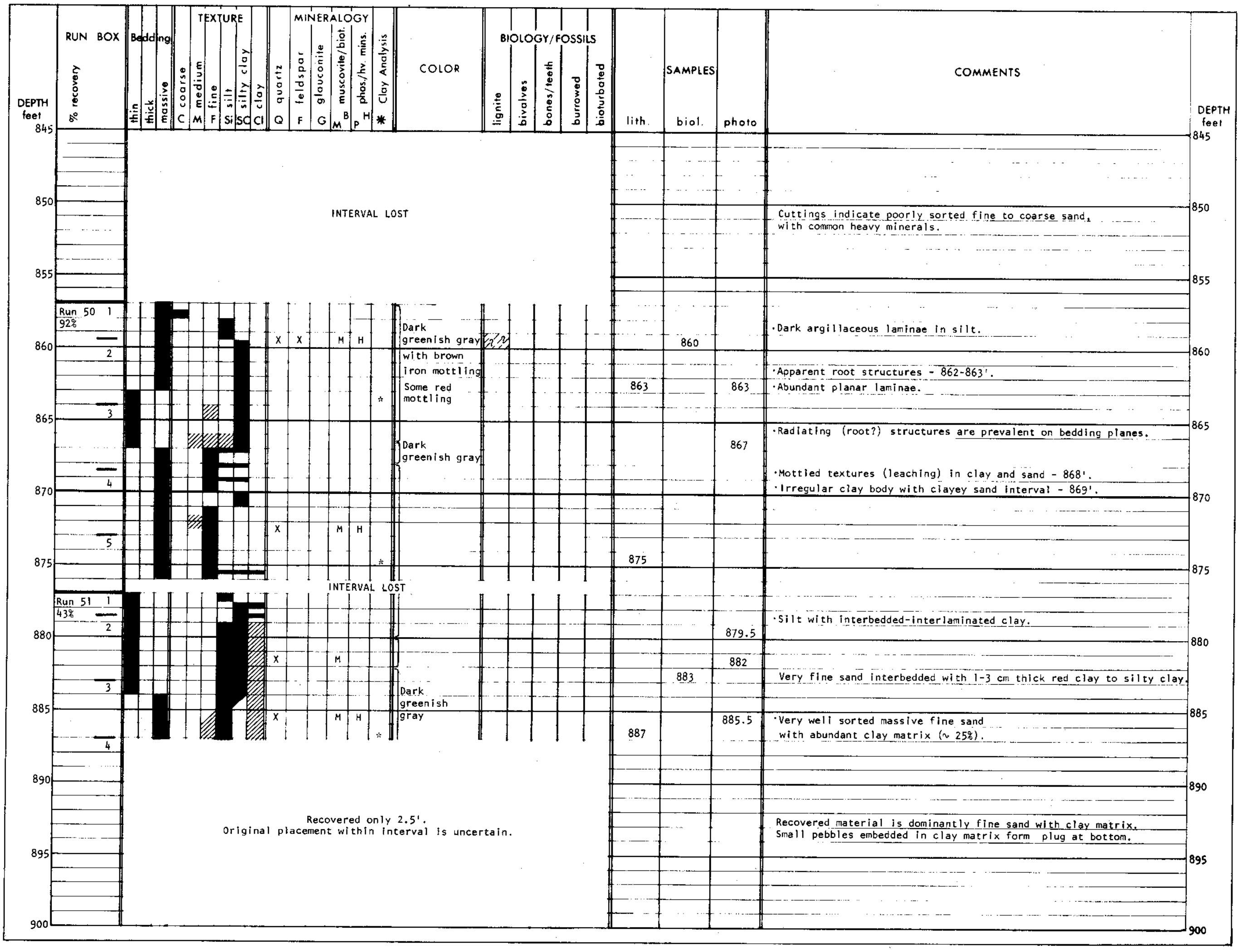

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
lith.
SAMPLES
biol.
photo
COMMENTS
570
575
580
585
590
595
600
605
610
615
620
625
Run 36 1
80%
Run 37 1
60%
Run 38
70%
Run 39 1
96%
Dark greenish gray
Mod. brown (5 YR 3/4)
Trace sand in burrows is dark greenish gray.
Only 3' of interval was recovered; badly disrupted.
Original placement within interval is uncertain.
Dark greenish gray (5GY 4/1)
Greenish black
Greenish gray (5 GY 6/1)
Olive gray (5 Y 4/1) with brown iron mottling
INTERVAL LOST
Light olive gray (5 Y 6/1) with orange iron mottling
Dark greenish gray (5 G 4/1) and brown
Light gray Mottled yellow
570.5
577.5
594.5
596.5
606.5
613
623
571
573
596
603
606
615
Brecciated clay with locally abundant slickensides.
Gradational mottles to angular blocks of clay.
·CHANGE FROM SIX-INCH TO THREE-INCH CORE-577.5'.
Sample taken from recovered pieces.
Margins of core are oxidized. Absence of internal structures.
·Poorly bedded 596-597'.
·Thinly laminated at 597'.
Poorly bedded with slickensides. Mottled.
·Clay is disrupted.
·Slump? - 610.0--610.5'. Is dark greenish grey (5GY 4/1).
Massive undisrupted somewhat blocky clay.
·Has irregular red mottles.
·Clay is poorly preserved and disrupted. Is slickensided.
Massive mottled clay and fine sand.
·Lensoid sand beds.

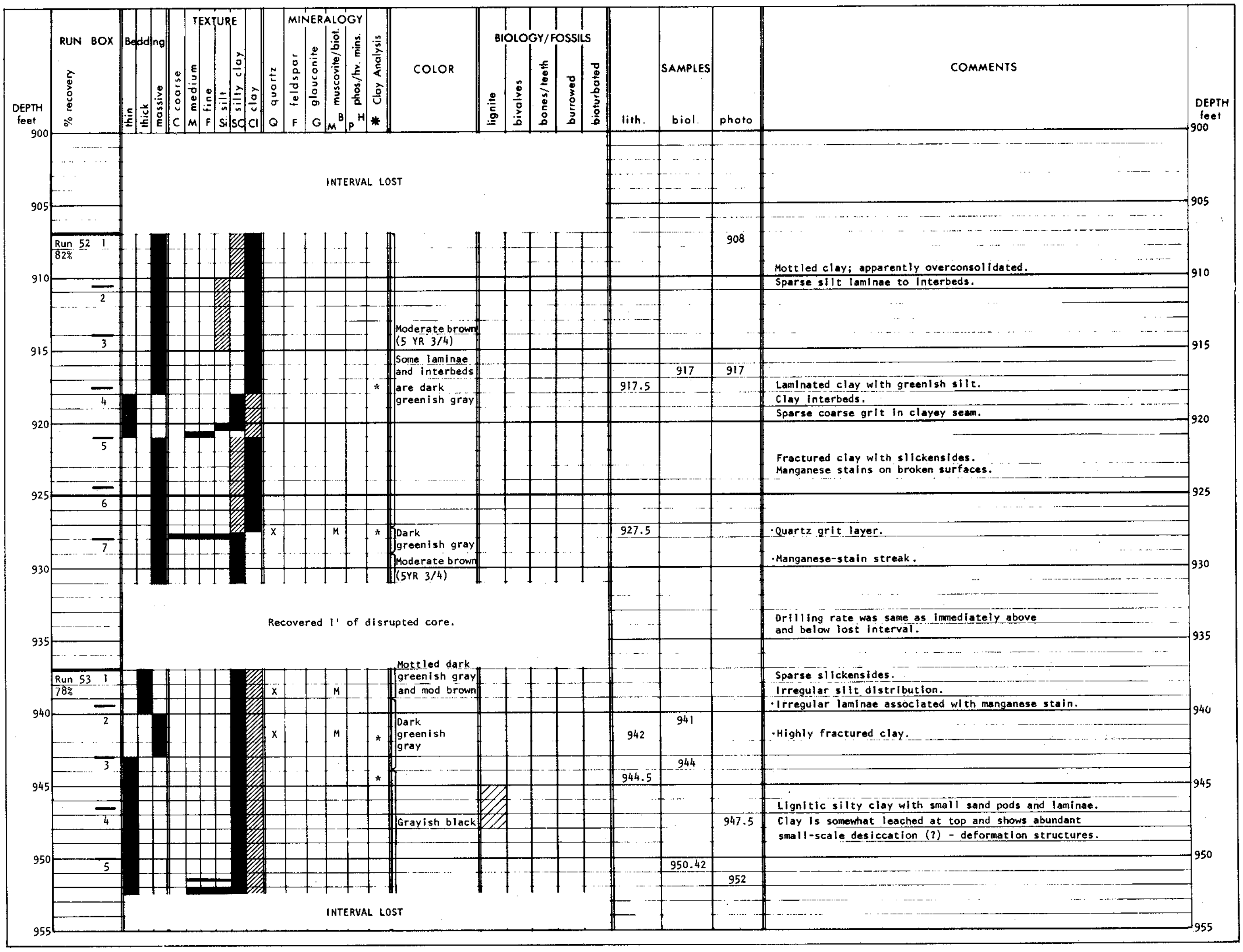

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
625
630
635
640
645
650
655
660
665
670
675
680
Run 40 1
97%
Run 41 1
75%
Run 42 1
70%
Light gray
Dark greenish gray (5 G 4/1 to 5 GY 4/1) with brown to violet mottling
Greenish gray (5 GY 6/1) with yellow iron stain
Grayish green with dark red iron mottling
Sand beds are buff
Dark greenish gray
INTERVAL LOST
Dark greenish gray (5GY 4/1)
Greenish gray
626
632.5
637
641.67
642
645.75
646
649.5
651
653
660
660
661
663
677.5
Irregular sand pods with indistinct boundaries, in massive clay.
·Mottled.
·Clay fragments-clasts (soil fabric?). Slickensided surfaces.
Some slickensided surfaces. Mottled fabric.
·Less mottled.
·Sand is laminated to cross-laminated with clay matrix.
·Faint laminae are delineated by clay concentrations. Clay clasts near 645'.
Rooting ?
Mottled.
·Buff sand beds are irregularly distributed in broken clays.
·Poorly bedded clayey sand.
·Laminated. Has abundant disseminated wood fragments.
Fractured lithology.
Irregular slickensided surfaces.


DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H ✱
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
680
685
690
695
700
705
710
715
720
725
730
735
Run 43 70%
Run 44 60%
Becomes 5 G 4/1
Some red mottling
Dark greenish gray (5 G 4/1) with brown iron mottling
No mottling
INTERVAL LOST
Dark greenish gray (5 GY 4/1)
Becomes 5 G 4/1 mottled red
682
684
683.5
689.5
692.5
695
696
704
723
727
730.5
733
·Poorly bedded sand. Clay is as clasts to disrupted bed. Bedding quite irregular.
Fern - 682'.
·Interbedded iron-stained sand to laminated sand and silt.
Mottled.
Becomes laminated.
Slickensides in the clay beds.
·Manganese-stained. Clay laminae are iron-stained.
·Clay clast conglomerate: medium gray clay clasts in quartz sand.
·Some planar laminae in silty interval.
Leached to buff.
·Weak lamination.
Mostly uniform, although several intervals have ripple cross-lamination.
·Clay clast conglomerate?-abundant fine sand associated with angular clay.
·Very irregular dark gray pods containing disseminated lignite. Pods are 4-cm chips to 20-cm "blobs" at a high angle to bedding.
·Sand contains clay clast at 728'-clast color similar to clay below.
Contains very coarse angular grit and clean sand pods.

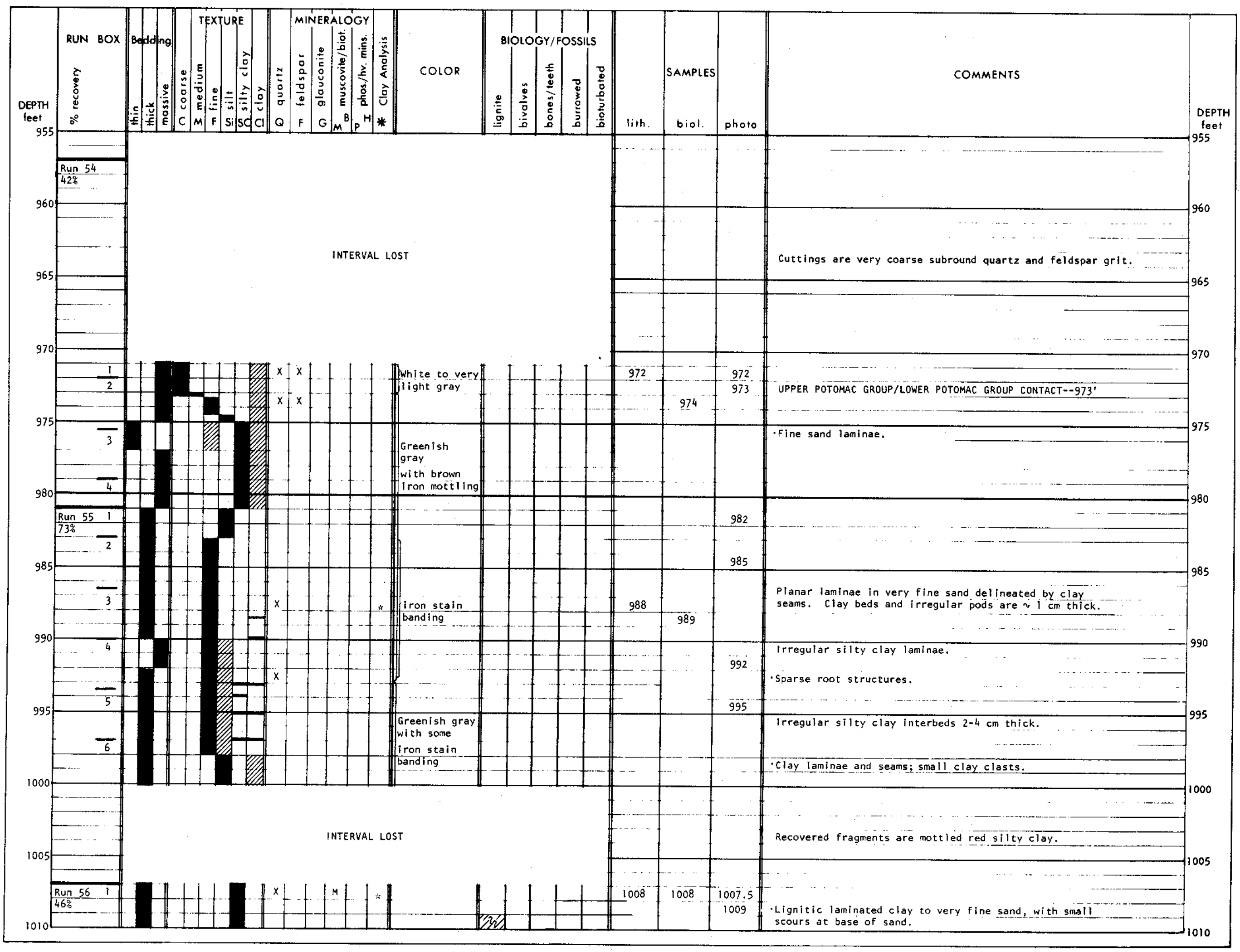

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
Run 45
53%
Run 46
96%
(5 G 4/1)
(5GY 4/1)
Mottled brown
Recovered only 4'. Original placement within interval is uncertain.
Dark greenish gray
Dark greenish gray (5 G 4/1)
Greenish gray (5 GY 6/1) with brown iron mottling
Dark greenish gray
Faint brown iron mottling
Olive black
"Varve-like" olive black and lt. gray
Light gray
738
750 ?
756
756
769
771
771.5
775.5
780.75
781
781.5
783.5
785
784.5
785.5
786.5
Clay is quite oxidized.
·Quartz silt laminae within the clay.
Laminated fine sand to silt. Clay laminae throughout.
·Disrupted.
·Disrupted. Clayey silt to silty clay.
·Bedding poorly defined.
·Very compact clay. Somewhat disturbed by drilling at top.
·Beds highly contorted.
·Laminated clay with silt interbeds.
·Laminated to thick bedded sand.
Tightly indurated clay with silt laminae.
·Laminated sand with carbonaceous laminae.
735
740
745
750
755
760
765
770
775
780
785
790

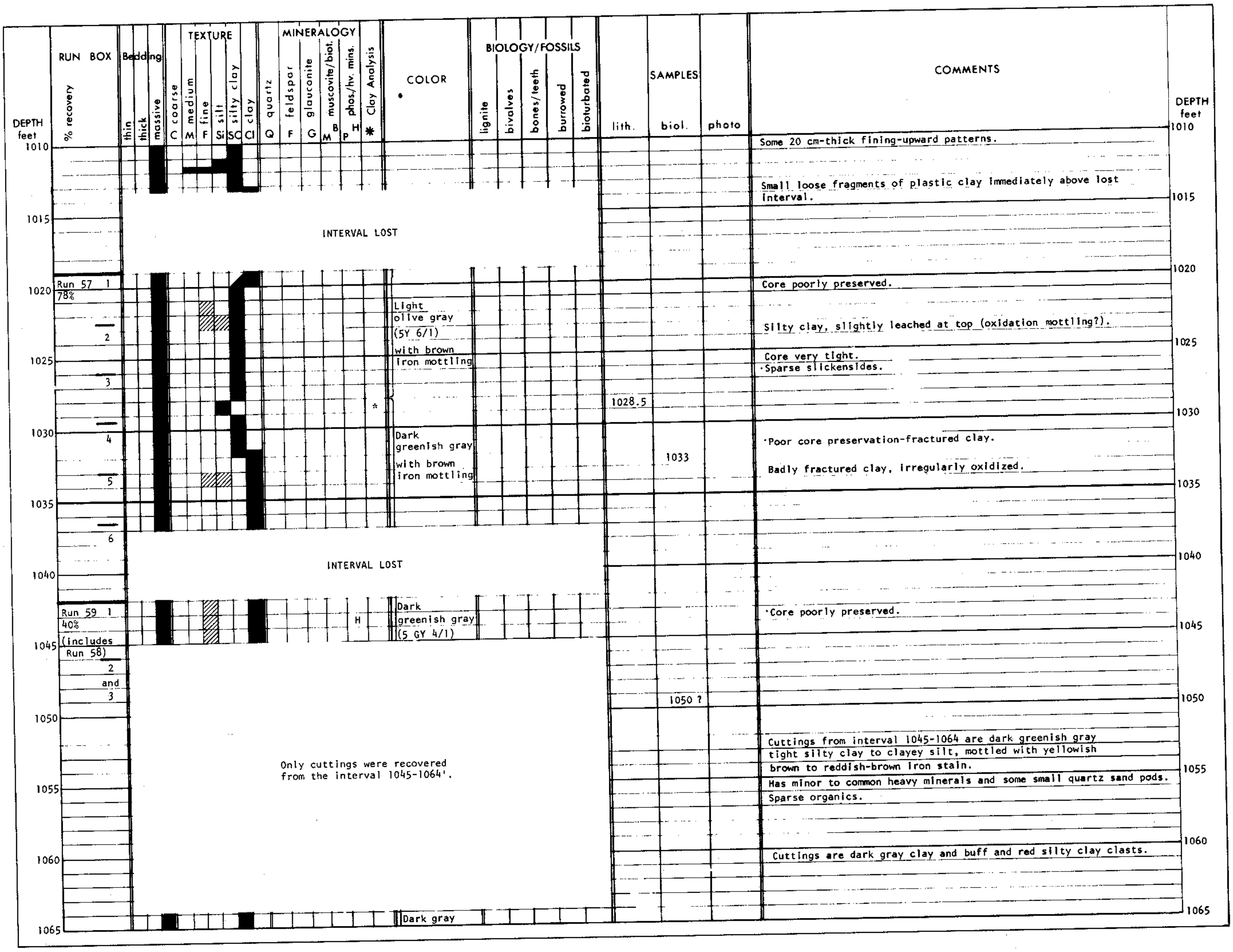

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
790
795
800
805
810
815
820
825
830
835
840
845
Run 47
20%
INTERVAL LOST
Cuttings from interval 790-809' are fine to very fine sandy silt, containing abundant muscovite and heavy minerals. Also contain some coarse subrounded quartz. Drilling rate was similar to that for the bottom of Run 46.
Light gray
red-green mottling
Dark greenish gray (5 G 4/1) with brown iron mottling
811
·Thin sand beds with clay matrix.
Fractured silty clay.
Run 48
100%
814.5
·Variable amounts of silt in tight clay.
Greenish gray (5 GY 6/1)
825
Fining upward sequence.
827.5
Run 49
34%
Olive gray
829
830
830
·Erosive base of fining-upward sequence.
·Clay clasts?
Dark greenish gray (5 G 4/1)
Sand is leached (iron stained at top) - highly oxidized.
Iron grain-coatings 833-834'.
Fresh from 834 to 838'.
837.5
INTERVAL LOST

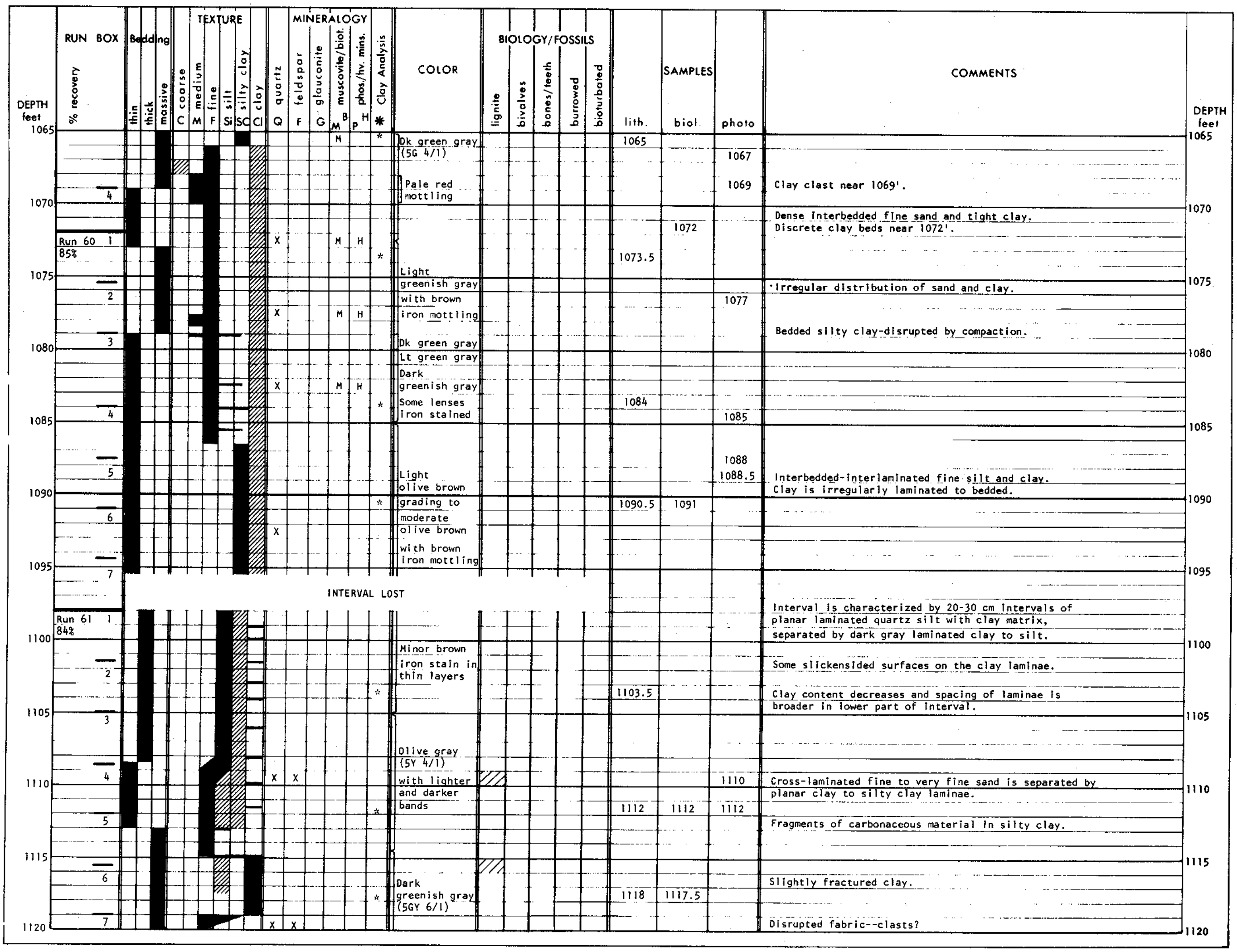

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
C coarse
M medium
F fine
Si silt
SC silty clay
Cl clay
MINERALOGY
Q quartz
F feldspar
G glauconite
M B muscovite/biot.
P H phos./hv. mins.
✱ Clay Analysis
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
845
850
855
860
865
870
875
880
885
890
895
900
INTERVAL LOST
Run 50 92%
Dark greenish gray with brown iron mottling
Some red mottling
Dark greenish gray
INTERVAL LOST
Run 51 43%
Dark greenish gray
Recovered only 2.5'.
Original placement within interval is uncertain.
860
863
867
875
879.5
882
883
885.5
887
Cuttings indicate poorly sorted fine to coarse sand, with common heavy minerals.
·Dark argillaceous laminae in silt.
·Apparent root structures - 862-863'.
·Abundant planar laminae.
·Radiating (root?) structures are prevalent on bedding planes.
·Mottled textures (leaching) in clay and sand - 868'.
·Irregular clay body with clayey sand interval - 869'.
·Silt with interbedded-interlaminated clay.
Very fine sand interbedded with 1-3 cm thick red clay to silty clay.
·Very well sorted massive fine sand with abundant clay matrix (~ 25%).
Recovered material is dominantly fine sand with clay matrix. Small pebbles embedded in clay matrix form plug at bottom.

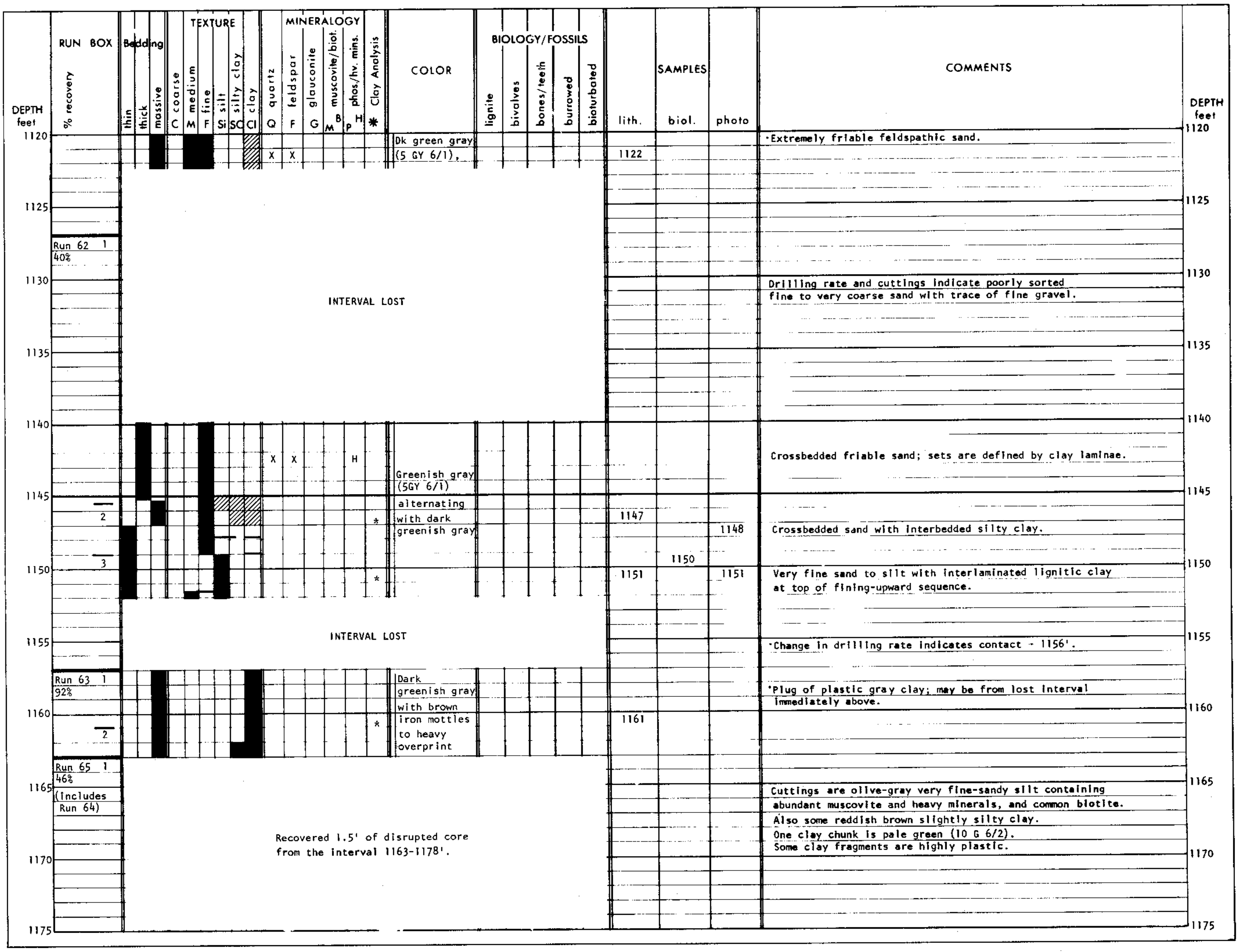


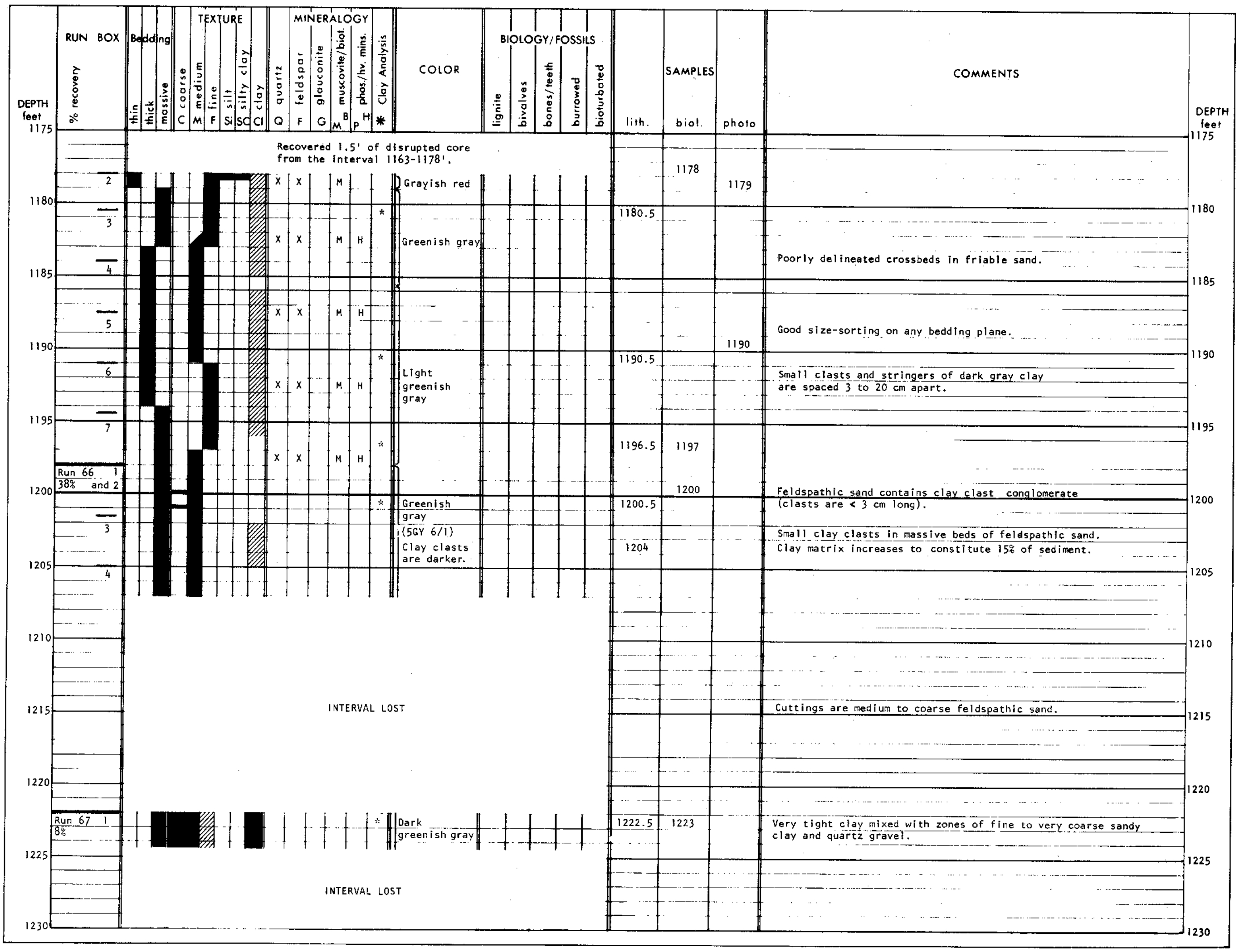
DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos/hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
900
905
910
915
920
925
930
935
940
945
950
955
INTERVAL LOST
Run 52 1
82%
2
3
4
5
6
7
Moderate brown (5 YR 3/4)
Some laminae and interbeds are dark greenish gray
Dark greenish gray
Moderate brown (5YR 3/4)
X
M
908
917
917
917.5
927.5
Mottled clay; apparently overconsolidated.
Sparse silt laminae to interbeds.
Laminated clay with greenish silt.
Clay interbeds.
Sparse coarse grit in clayey seam.
Fractured clay with slickensides.
Manganese stains on broken surfaces.
·Quartz grit layer.
·Manganese-stain streak.
Recovered 1' of disrupted core.
Drilling rate was same as immediately above and below lost interval.
Run 53 1
78%
Mottled dark greenish gray and mod brown
Dark greenish gray
Grayish black
941
942
944
944.5
947.5
950.42
952
Sparse slickensides.
Irregular silt distribution.
·Irregular laminae associated with manganese stain.
·Highly fractured clay.
Lignitic silty clay with small sand pods and laminae.
Clay is somewhat leached at top and shows abundant small-scale desiccation (?) - deformation structures.
INTERVAL LOST

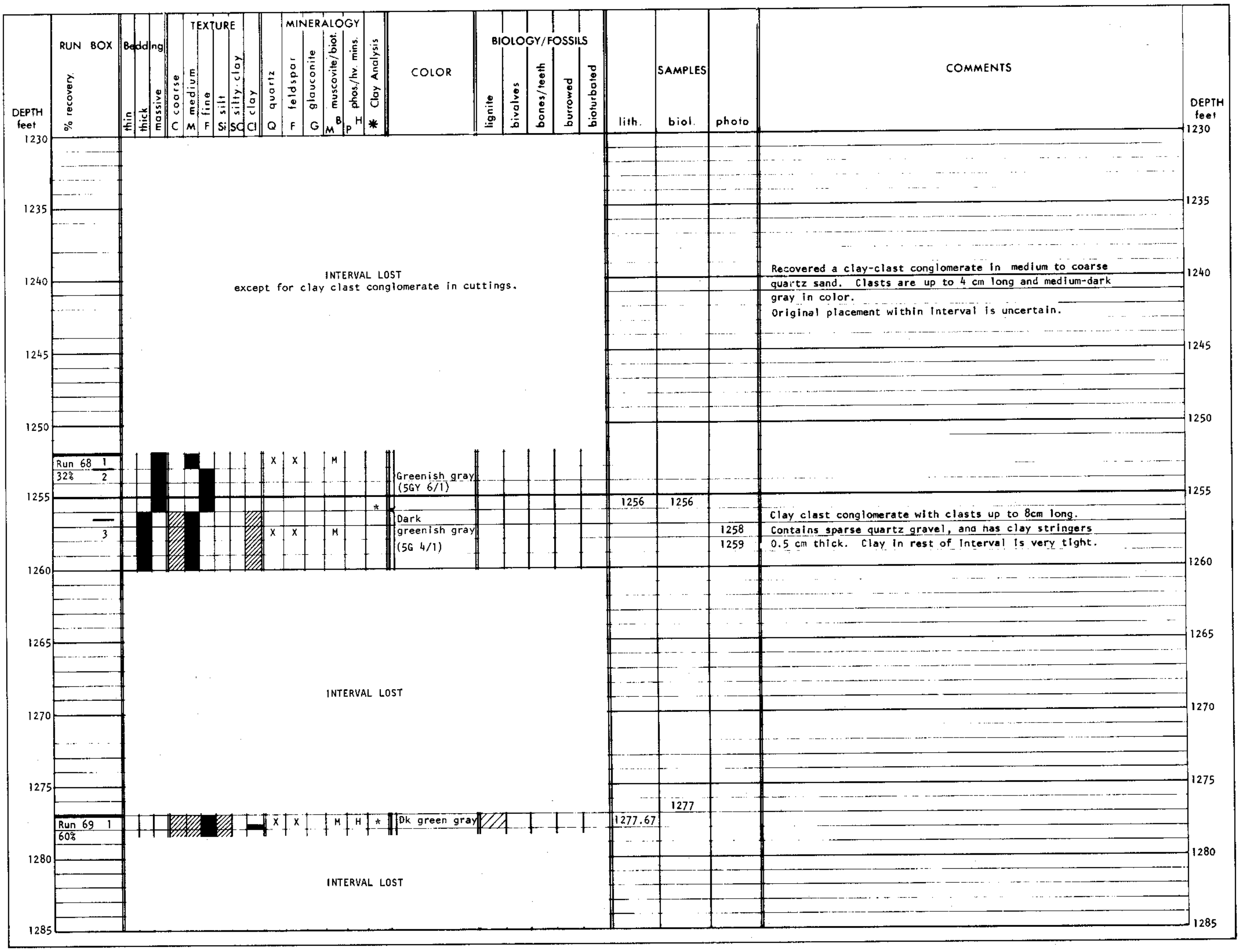

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
955
960
965
970
975
980
985
990
995
1000
1005
1010
Run 54
42%
INTERVAL LOST
Cuttings are very coarse subround quartz and feldspar grit.
1
2
White to very light gray
972
972
973
974
UPPER POTOMAC GROUP/LOWER POTOMAC GROUP CONTACT--973'
3
·Fine sand laminae.
Greenish gray with brown iron mottling
4
Run 55 1
73%
982
2
985
3
Planar laminae in very fine sand delineated by clay seams. Clay beds and irregular pods are ~ 1 cm thick.
Iron stain banding
988
989
4
Irregular silty clay laminae.
992
·Sparse root structures.
5
995
Irregular silty clay interbeds 2-4 cm thick.
Greenish gray with some iron stain banding
6
·Clay laminae and seams; small clay clasts.
INTERVAL LOST
Recovered fragments are mottled red silty clay.
Run 56 1
46%
1008
1008
1007.5
1009
·Lignitic laminated clay to very fine sand, with small scours at base of sand.

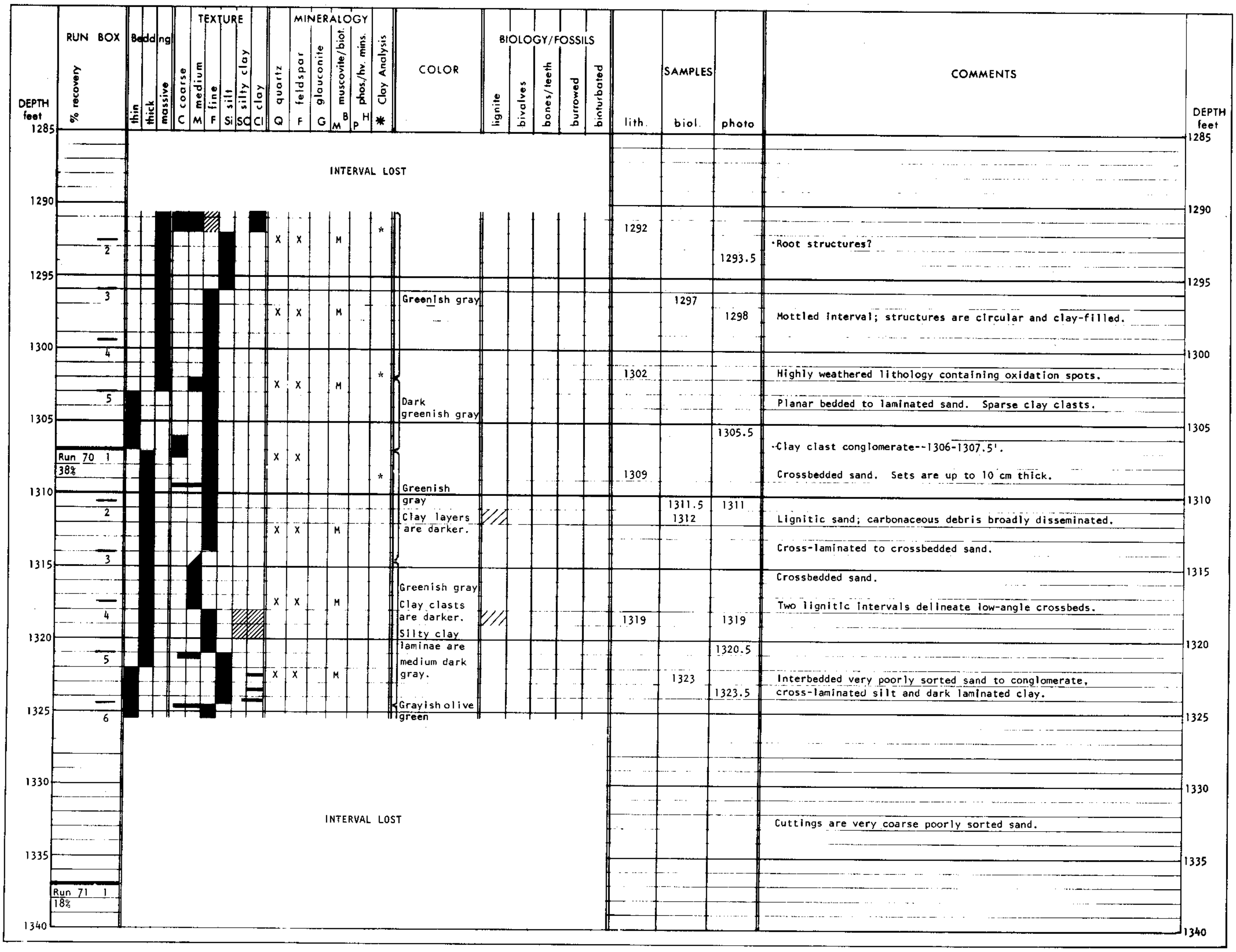

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
DEPTH feet
1010
1015
1020
1025
1030
1035
1040
1045
1050
1055
1060
1065
INTERVAL LOST
Run 57 1
78%
2
3
4
5
6
Light olive gray (5Y 6/1) with brown iron mottling
Dark greenish gray with brown iron mottling
1028.5
1033
INTERVAL LOST
Run 59 1
40%
(includes Run 58)
2 and 3
H
Dark greenish gray (5 GY 4/1)
1050 ?
Only cuttings were recovered from the interval 1045-1064'.
Dark gray
Some 20 cm-thick fining-upward patterns.
Small loose fragments of plastic clay immediately above lost interval.
Core poorly preserved.
Silty clay, slightly leached at top (oxidation mottling?).
Core very tight.
Sparse slickensides.
Poor core preservation-fractured clay.
Badly fractured clay, irregularly oxidized.
Core poorly preserved.
Cuttings from interval 1045-1064 are dark greenish gray tight silty clay to clayey silt, mottled with yellowish brown to reddish-brown iron stain.
Has minor to common heavy minerals and some small quartz sand pods.
Sparse organics.
Cuttings are dark gray clay and buff and red silty clay clasts.

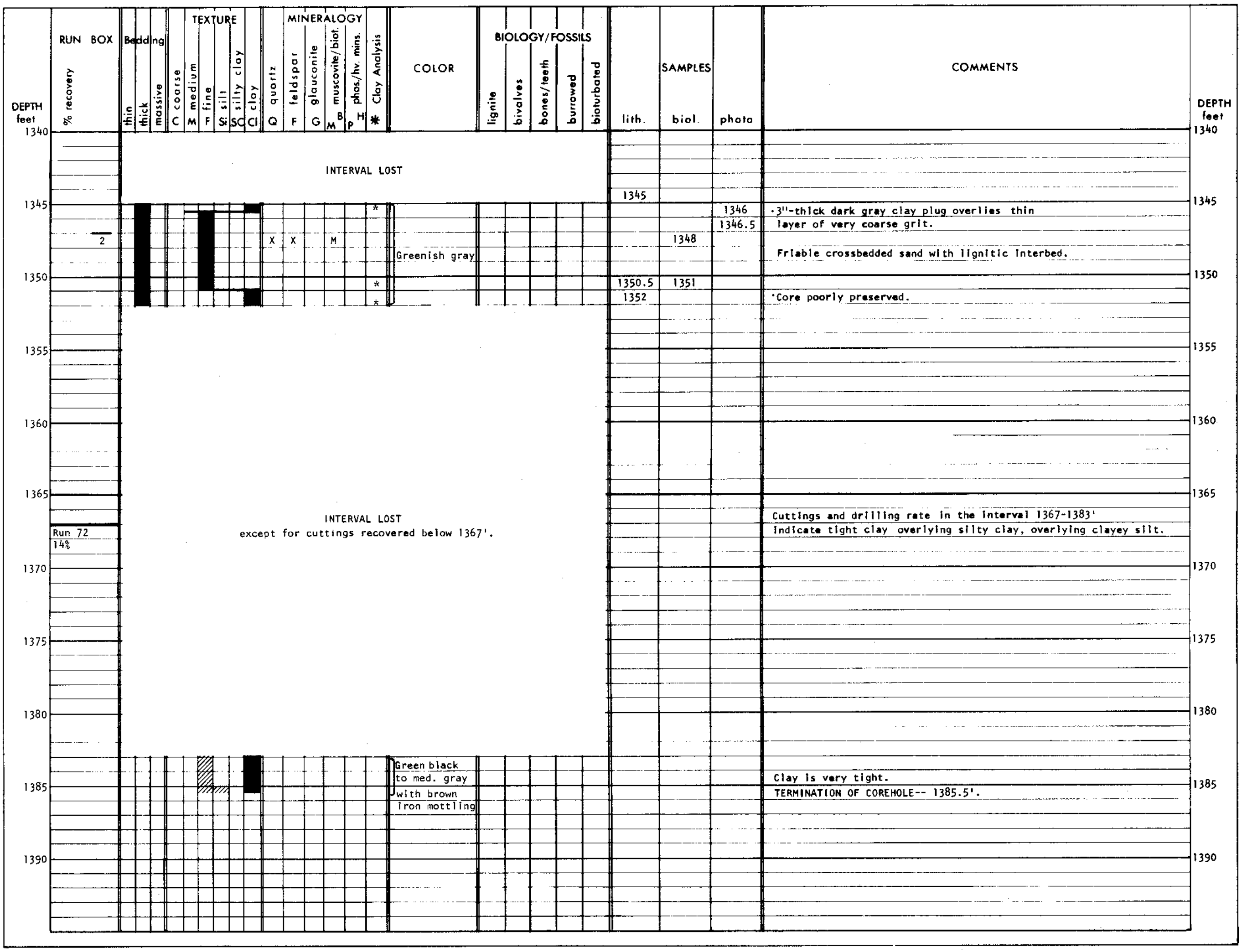

DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
1065
1070
1075
1080
1085
1090
1095
1100
1105
1110
1115
1120
Run 60
85%
Run 61
84%
INTERVAL LOST
Dk green gray (5G 4/1)
Pale red mottling
Light greenish gray with brown iron mottling
Dk green gray
Lt green gray
Dark greenish gray
Some lenses iron stained
Light olive brown grading to moderate olive brown with brown iron mottling
Minor brown iron stain in thin layers
Olive gray (5Y 4/1) with lighter and darker bands
Dark greenish gray (5GY 6/1)
1065
1067
1069
1072
1073.5
1077
1084
1085
1088
1088.5
1090.5
1091
1103.5
1110
1112
1112
1112
1118
1117.5
Clay clast near 1069'.
Dense interbedded fine sand and tight clay.
Discrete clay beds near 1072'.
Irregular distribution of sand and clay.
Bedded silty clay-disrupted by compaction.
Interbedded-interlaminated fine silt and clay.
Clay is irregularly laminated to bedded.
Interval is characterized by 20-30 cm intervals of planar laminated quartz silt with clay matrix, separated by dark gray laminated clay to silt.
Some slickensided surfaces on the clay laminae.
Clay content decreases and spacing of laminae is broader in lower part of interval.
Cross-laminated fine to very fine sand is separated by planar clay to silty clay laminae.
Fragments of carbonaceous material in silty clay.
Slightly fractured clay.
Disrupted fabric--clasts?


DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
lith.
SAMPLES
biol.
photo
COMMENTS
1120
1125
1130
1135
1140
1145
1150
1155
1160
1165
1170
1175
X X
Dk green gray (5 GY 6/1)
1122
·Extremely friable feldspathic sand.
Run 62 1
40%
INTERVAL LOST
Drilling rate and cuttings indicate poorly sorted fine to very coarse sand with trace of fine gravel.
X X H
Greenish gray (5GY 6/1)
Crossbedded friable sand; sets are defined by clay laminae.
2
alternating with dark greenish gray
*
1147
1148
Crossbedded sand with interbedded silty clay.
3
1150
*
1151
1151
Very fine sand to silt with interlaminated lignitic clay at top of fining-upward sequence.
INTERVAL LOST
·Change in drilling rate indicates contact - 1156'.
Run 63 1
92%
Dark greenish gray with brown iron mottles to heavy overprint
·Plug of plastic gray clay; may be from lost interval immediately above.
2
*
1161
Run 65 1
46%
(Includes Run 64)
Recovered 1.5' of disrupted core from the interval 1163-1178'.
Cuttings are olive-gray very fine-sandy silt containing abundant muscovite and heavy minerals, and common biotite.
Also some reddish brown slightly silty clay.
One clay chunk is pale green (10 G 6/2).
Some clay fragments are highly plastic.


DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
DEPTH feet
1175
1180
1185
1190
1195
1200
1205
1210
1215
1220
1225
1230
Recovered 1.5' of disrupted core from the interval 1163-1178'.
2
3
4
5
6
7
Run 66 1
38% and 2
3
4
Run 67 1
8%
X X M
X X M H
X X M H
X X M H
X X M H
Grayish red
Greenish gray
Light greenish gray
Greenish gray (5GY 6/1) Clay clasts are darker.
Dark greenish gray
1178
1179
1180.5
Poorly delineated crossbeds in friable sand.
Good size-sorting on any bedding plane.
1190
1190.5
Small clasts and stringers of dark gray clay are spaced 3 to 20 cm apart.
1196.5
1197
1200
Feldspathic sand contains clay clast conglomerate (clasts are < 3 cm long).
1200.5
Small clay clasts in massive beds of feldspathic sand.
1204
Clay matrix increases to constitute 15% of sediment.
INTERVAL LOST
Cuttings are medium to coarse feldspathic sand.
1222.5
1223
Very tight clay mixed with zones of fine to very coarse sandy clay and quartz gravel.
INTERVAL LOST


DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
coarse
medium
fine
silt
silty clay
clay
C M F Si SC Cl
MINERALOGY
quartz
feldspar
glauconite
muscovite/biot.
phos./hv. mins.
Clay Analysis
Q F G M B P H *
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
DEPTH feet
1230
1235
1240
1245
1250
1255
1260
1265
1270
1275
1280
1285
INTERVAL LOST
except for clay clast conglomerate in cuttings.
Recovered a clay-clast conglomerate in medium to coarse
quartz sand. Clasts are up to 4 cm long and medium-dark
gray in color.
Original placement within interval is uncertain.
Run 68 1
32% 2
3
X X M
Greenish gray
(5GY 6/1)
*
Dark
greenish gray
(5G 4/1)
X X M
1256
1256
1258
1259
Clay clast conglomerate with clasts up to 8cm long.
Contains sparse quartz gravel, and has clay stringers
0.5 cm thick. Clay in rest of interval is very tight.
INTERVAL LOST
1277
Run 69 1
60%
X X M H *
Dk green gray
1277.67
INTERVAL LOST


DEPTH feet
RUN BOX
% recovery
Bedding
thin
thick
massive
TEXTURE
C coarse
M medium
F fine
Si silt
SC silty clay
Cl clay
MINERALOGY
Q quartz
F feldspar
G glauconite
M B muscovite/biot.
P H phos./hv. mins.
* Clay Analysis
COLOR
BIOLOGY/FOSSILS
lignite
bivalves
bones/teeth
burrowed
bioturbated
SAMPLES
lith.
biol.
photo
COMMENTS
1285
1290
1295
1300
1305
1310
1315
1320
1325
1330
1335
1340
INTERVAL LOST
Run 70
38%
Run 71
18%
Greenish gray
Dark greenish gray
Greenish gray
Clay layers are darker.
Greenish gray
Clay clasts are darker.
Silty clay laminae are medium dark gray.
Grayish olive green
1292
1293.5
1297
1298
1302
1305.5
1309
1311.5
1312
1311
1319
1319
1320.5
1323
1323.5
·Root structures?
Mottled interval; structures are circular and clay-filled.
Highly weathered lithology containing oxidation spots.
Planar bedded to laminated sand. Sparse clay clasts.
·Clay clast conglomerate--1306-1307.5'.
Crossbedded sand. Sets are up to 10 cm thick.
Lignitic sand; carbonaceous debris broadly disseminated.
Cross-laminated to crossbedded sand.
Crossbedded sand.
Two lignitic intervals delineate low-angle crossbeds.
Interbedded very poorly sorted sand to conglomerate, cross-laminated silt and dark laminated clay.
Cuttings are very coarse poorly sorted sand.



REFERENCES

Andrews, G.W., and others, 1977, Mesozoic and Cenozoic biostratigraphy of the Oak Grove core, Northeastern Virginia (abs.): Am. Assoc. Petroleum Geologists Bull., vol. 61, no. 5, p. 761.

Johns, W.D., Grim, R.E., and Bradley, W.F., 1954, Quantitative estimations of clay minerals by diffraction methods: Jour. Sed. Petrology, vol. 24, no. 4, p. 242-251.

Perry, E.A., and Hower, John, 1970, Burial diagenesis of Gulf Coast pelitic sediments: Clays and Clay Minerals, v. 18, no. 3, p. 165-177.

Reinhardt, Juergen, Newell, W.L., and Mixon, R.B., 1977, Tertiary lithostratigraphy of the Oak Grove core, Northeastern Virginia (abs.): Am. Assoc. Petroleum Geologists Bull., vol. 61, no. 5, p. 822.

Reynolds, R.C., and Hower, John, 1970, The nature of interlayering in mixed-layer illite-montmorillonites: Clays and Clay Minerals, vol. 18, no. 1, p. 25-36.

APPENDIX 1
SIZE ANALYSIS

Samples were selected to best represent a relatively thick core interval. A subsample for clay analysis was taken where sufficient clay was present.

All lithologic samples listed were wet sieved. A system of six standard brass and stainless steel sieves (8-inch diameter) was arranged by size of sieve opening. The sieved splits were allowed to dry in watch glasses at room temperature, then were weighed. Fine silt and clay percentages were calculated by weight lost. The sieves were cleaned ultrasonically between sample runs.

The majority of sampled core intervals were massive, quite uniformly textured, and poorly sorted. Their pre-sieved dry weight was typically between 50 and 85 grams. More than 85 grams was sieved if samples appeared to be: 1) mostly silt or clay; 2) thinly bedded, with a wide range of grain sizes apparent; or 3) mostly very coarse. This was done to provide maximum grain size variability in the sampled interval.

Weight percent

Sample depth (feet)	very coarse * >18	coarse >35	medium >60	fine >120	very fine >230	coarse silt >325	finer silt and clay < 325	Dry weight of sample before sieving (grams)
86.5	—	—	0.02	0.62	1.49	2.52	95.35	81.48
111.5	—	—	0.02	9.36	60.63	3.48	26.51	64.60
125.5	—	0.09	0.21	3.07	59.16	7.53	29.93	42.63
133	—	0.04	0.10	0.98	59.58	4.02	35.28	50.00
143	—	0.05	0.05	10.76	40.91	5.20	43.03	39.97
160	0.01	—	0.11	5.69	64.16	6.80	23.22	89.66
182	0.05	0.03	0.03	0.12	1.39	2.04	96.35	41.15
199.5	5.14	7.33	16.31	17.26	30.39	5.46	18.11	81.12
200	3.04	1.39	6.12	14.63	47.48	4.22	23.13	78.63
209	1.17	1.64	7.59	23.43	44.96	6.72	14.49	54.92
223	0.50	1.49	9.16	56.69	13.24	3.81	15.11	97.20
242	0.48	1.87	12.35	38.81	23.91	5.74	16.84	64.85
254.5	0.15	2.45	29.71	13.66	18.62	5.91	29.50	103.10
258	—	1.69	31.23	21.63	15.85	6.83	22.77	84.22
267	0.14	4.43	41.01	11.34	5.85	4.39	32.85	57.60
276.5	0.36	2.61	27.24	17.15	14.57	7.13	30.93	60.46
277	0.37	4.19	41.68	20.80	10.18	3.48	19.29	81.21
282	0.03	1.93	14.38	10.16	9.30	8.89	55.32	74.22
293	0.13	2.30	17.43	26.72	13.98	3.17	36.27	75.11
298	0.03	0.42	3.39	13.02	24.83	5.81	52.50	74.13
305	0.04	0.04	0.38	2.28	9.79	9.92	77.55	74.26
310.5	0.07	0.63	4.52	17.47	30.28	5.29	41.74	90.72
314.5	—	0.33	2.07	7.89	9.96	7.19	72.55	56.91
322	0.49	0.27	2.55	14.82	36.36	11.44	34.06	76.99
323.25	—	0.03	0.04	0.13	2.17	2.26	95.34	67.60
325.5	—	—	0.02	0.02	0.07	0.40	99.49	57.15
339.5	—	0.04	0.24	0.46	0.58	0.14	98.54	84.69
340.5	0.02	0.42	26.96	41.84	11.10	4.27	15.39	61.64
351	—	0.03	14.46	69.44	3.33	1.00	11.75	112.12
353	—	0.18	8.68	75.33	3.89	1.71	10.20	68.30
369	1.59	0.70	13.54	55.46	15.80	3.70	9.21	76.81
383.5	2.94	11.37	37.10	24.50	6.28	2.90	14.93	73.89
384.5	0.09	6.43	46.55	31.64	4.33	1.42	9.54	91.72

*U.S. Standard sieve mesh

Weight percent

Sample depth (feet)	very coarse * >18	coarse >35	medium > 60	fine >120	very fine >230	coarse silt >325	finer silt and clay <325	Dry weight of sample before sieving (grams)
391.5	0.22	6.97	39.12	36.90	4.41	2.14	10.24	76.59
403.5	–	0.62	26.23	63.99	1.70	0.49	6.97	73.61
407.5	0.54	0.96	22.36	68.03	1.69	0.69	5.72	75.66
417	0.24	3.13	41.62	41.39	3.41	0.64	9.57	74.82
427	0.01	1.42	41.59	46.58	2.80	0.71	6.90	82.21
445	0.14	1.04	7.23	65.91	10.42	2.57	12.68	56.71
451	6.34	14.08	15.19	44.59	8.28	2.39	9.14	83.62
454.5	12.24	27.84	27.67	18.04	5.69	0.85	7.66	84.41
469.5	0.02	0.03	0.61	6.50	14.84	8.73	69.27	68.51
470.67	0.40	21.67	37.36	4.32	4.01	3.07	29.16	55.32
487.5	–	0.02	0.15	7.29	15.19	7.07	70.29	59.00
491.5	–	–	0.02	2.55	12.39	9.67	75.37	63.98
497	–	–	0.05	0.82	9.22	6.91	83.00	62.23
508	–	0.07	1.28	9.37	23.92	13.91	51.45	58.60
511.75	–	–	0.03	1.56	20.63	11.95	65.82	57.72
521	0.30	14.86	45.16	9.45	4.90	3.14	22.20	67.30
543.5	–	–	0.25	8.02	15.56	10.32	65.85	55.64
552	–	0.02	4.15	24.26	15.35	7.18	49.04	55.69
555	–	0.06	16.56	34.40	13.55	4.48	30.95	64.30
557	–	–	–	0.11	1.69	7.93	90.27	56.75
568.5	–	–	–	2.92	14.27	10.87	71.94	64.97
594.5	–	0.09	2.36	15.40	12.35	5.09	64.71	57.55
623	–	–	1.09	11.05	13.41	6.42	68.03	56.84
645.75	–	0.53	48.36	11.05	6.13	2.88	31.06	56.93
653	–	–	–	0.21	5.70	5.56	88.53	56.84
677.5	–	–	0.29	3.73	9.02	8.03	78.92	57.88
682	–	0.17	11.69	19.53	13.48	7.79	47.34	53.40
692.5	0.88	11.79	18.38	7.27	7.00	4.95	49.72	57.74
704	–	0.03	53.05	32.40	5.54	1.92	7.06	57.78
723	–	0.03	3.38	10.04	20.72	8.21	57.62	64.54
733	–	–	0.02	3.04	16.95	10.70	69.29	62.52
756	0.09	0.14	0.63	25.89	24.70	11.24	37.31	56.85
769	–	–	0.03	0.78	17.62	6.13	75.43	57.39
780.75	–	0.85	55.14	28.70	5.33	1.95	8.03	57.42
790-809 (cuttings)	10.01	60.32	15.18	4.57	3.03	1.11	5.79	73.11
814.5	–	0.17	0.38	1.31	3.69	1.69	92.76	52.60
827.5	0.25	5.17	40.08	38.79	6.76	2.56	6.38	62.87
837.5	–	5.65	66.90	10.50	5.20	2.05	9.70	57.52
875	–	–	4.59	70.31	13.23	2.20	9.66	54.43
887	–	0.19	29.25	47.75	9.59	2.20	11.02	54.01
917.5	–	0.05	0.18	0.46	6.18	2.81	90.33	54.89
927.5	0.40	0.83	8.33	10.42	11.12	7.76	61.15	53.07

*U.S. Standard sieve mesh

Weight percent

Sample depth (feet)	very coarse * >18	coarse >35	medium >60	fine >120	very fine >230	coarse silt >325	finer silt and clay <325	Dry weight of sample before sieving (grams)
972	18.48	46.68	18.59	5.19	1.23	0.72	9.11	56.86
988	—	0.08	1.66	10.07	19.53	8.35	60.32	51.26
1008	—	—	—	1.96	19.28	12.23	66.53	57.06
1028.5	—	0.02	0.69	30.37	13.94	5.40	49.59	55.03
1065	—	0.05	0.17	1.38	8.45	4.51	85.42	57.15
1073.5	—	0.50	19.97	28.38	10.58	3.03	37.54	55.49
1084	—	0.49	4.89	11.42	11.80	6.71	64.69	58.91
1090.5	—	—	—	0.05	2.70	3.50	93.74	55.14
1103.5	—	0.07	0.02	1.32	11.54	9.48	77.56	56.83
1112	—	0.38	46.22	30.67	7.48	2.41	12.84	57.72
1118	0.20	0.42	0.14	0.40	1.69	2.37	94.78	49.77
1122	6.62	40.66	32.03	5.99	2.61	1.37	10.72	80.18
1147	—	0.73	24.88	40.77	9.18	4.15	20.30	57.60
1151	—	—	0.15	1.11	2.91	3.93	91.90	40.49
1180.5	—	1.07	44.11	23.80	7.46	3.59	19.96	56.00
1190.5	0.40	15.64	41.84	14.13	7.02	2.83	18.13	55.42
1196.5	—	—	0.06	0.35	5.33	5.31	88.94	50.83
1200.5	54.13	17.74	12.06	3.77	1.63	0.70	9.97	88.69
1204	1.21	25.65	41.90	8.67	4.64	1.95	15.97	98.97
1222.5	5.93	8.48	4.09	1.47	1.35	1.45	77.24	89.18
1256	52.52	6.98	23.74	4.66	2.93	1.34	7.83	96.75
1277.58 (cuttings)	0.08	2.94	21.58	43.37	11.84	2.73	17.46	71.37
1292	—	—	0.27	11.40	38.24	11.27	38.82	55.70
1302	1.19	18.35	52.01	13.82	5.03	1.67	7.93	49.70
1309	9.77	13.73	57.14	8.10	3.99	1.35	5.91	59.87
1319	—	0.16	21.83	42.23	15.69	3.61	16.47	70.54
1350.5	0.88	29.75	36.39	9.56	5.80	2.54	15.09	50.02

*U.S. Standard sieve mesh

APPENDIX 2
CLAY ANALYSIS

All samples were dispersed in distilled water using ultrasonics, and a 2 micron fraction was separated by centrifugal sedimentation.

The suspension of 2 micron material was pipetted onto a glass slide and allowed to dry at room temperature, producing an oriented clay film. A diffraction pattern was run from 0 to 32° on a Picker diffractometer at 2°-2 theta/min. using Cu alpha radiation. The sample was then solvated with ethylene glycol and re-scanned over the same range. Qualitative clay mineral identifications were made using both diffraction patterns; semi-quantitative determinations of abundance of each species were made using the pattern of the ethylene glycol solvated sample.

The proportion of smectite (expandable) layers in illite/smectite was determined by using calculated diffraction profiles (Reynolds and Hower, 1970). The "low angle saddle" in the 17 angstroms peak was used as a measure of this composition. This measure yields a weighted mean proportion of smectite layers of a sample containing a heterogeneous mixture of illite/smectite.

Estimates of the relative intensities of specific (00*l*) reflections were used in determining quantities of the nonmixed-layered components, (Johns, Grim, and Bradley, 1954; Perry and Hower, 1970). Abbreviations used in the table follow.

APPENDIX 2 (continued)

1) Major clay minerals:

K	Kaolinite	I/S	illite/ smectite
I	illite		

2) Other minerals:

calc	calcite	glauc	glauconite
clino	clinoptilolite	goeth	goethite
cristo	cristobalite	gyp	gypsum
feld	feldspar	qtz	quartz
gibb	gibbsite	verm	vermiculite

3) Other symbols:

tr	trace	hi	high
exp	expandable	lo	low

*Chlorite contribution to total clay mineral percentage

Sample Depth (feet)	Approx % of Major Clay Minerals K	I	I/S	% Expandable Layers	Other minerals
86.5	20	44	36	65	verm, tr feld, tr qtz, bayerite?
111.5	6	81	13	66	
125.5	11	67	22	64	verm, tr qtz
143	31	53	16	59	clino, verm, tr feld, calc?, qtz?
160	6	65	29	60	clino, gyp, verm, tr feld
182	11	69	20	56	verm, tr feld, tr gyp, clino?
199.5	5	84	11	54	clino, gyp, qtz, tr feld
200	11	64	25	56	clino, glauc (20-30% exp.), verm, tr feld, cristo (lo)?
209	54	15	31	56	clino, feld, glau (10-20% exp.), verm, cristo (lo)?
223	20	50	30	66	gyp, tr clino, tr feld, tr verm, cristo (lo)?
242	12	52	36	64	glauc, gyp, tr clino, tr feld, cristo (lo)?
258	0	61	39	62	tr feld, calc?
267	6	74	20	62	calc, clino, gyp, tr feld, tr qtz
277	4	57	39	70	tr calc, tr clino, tr feld
282	32	48	20	69	clino, tr calc, tr feld, tr gyp, tr qtz
298	21	66	13	65	gyp, tr calc, tr feld, tr qtz
305	38	40	22	70	gyp, tr feld, tr qtz
314.5	40	31	29	61	tr calc, tr clino, tr feld, tr gyp, tr qtz, bayerite?
322	42	47	11	54	calc, gyp, tr feld
323.25	50	41	9	59*	tr qtz, *tr chlorite layers
325.5	53	39	8	53	bayerite?, cristo (hi)?, qtz?
339.5	50	31	19	63*	tr bayerite, tr feld, *tr chlorite layers
340.5	44	46	10	50	verm, tr calc, tr feld, tr gibb, tr gyp, tr qtz, bayerite?
351	15*	77	8	53	tr calc, tr feld, tr gyp, cristo (lo)? *also chlorite
369	14	67	19	63	tr feld, tr verm
384.5	5	87	8	40	calc, gyp, tr bayerite, tr clino, tr feld, tr gibb, boehmite?
391.5	9	84	7	49	calc, gyp, tr bayerite, tr clino, tr feld, gibb? verm?
407.5	8	77	15	64	calc, gyp, tr bayerite, tr clino, tr feld
417		?	tr	40	glauc
427	5	59	36	69	gyp, tr clino, calc?, feld?

APPENDIX 2 (continued)

Sample Depth (feet)	Approx % of Major Clay Minerals K	I	I/S	% Expandable Layers	Other Minerals
445	20	60	20	63	gyp, tr feld, cristo (lo)?
451	21	57	22	69	gyp, verm, tr bayerite, tr feld, tr gibb
454.5	41	48	11	74	calc, clino, tr feld, tr qtz
469.5	32	3	65	89	
479	41	4	55	99	cristo (hi), feld
487.5	57	9	34	76	feld
491.5	52	19	29	71	cristo (lo), goeth, tr feld
497	67	3	30	72	cristo (lo), feld
508	51	12	37	72	cristo (lo), tr feld
511.75	50	17	33	61	cristo(hi), tr feld
529.75	32	22	46	71	cristo(hi), feld
543.5	27	21	52	67	opal claystone
552	25	33	42	73	cristo(hi)
555	29	24	47	70	goeth, tr feld
557	29	11	60	78	cristo(hi), clino?
568.5	33	16	51	81	goeth, tr feld
570.5	30	15	55	75	tr cristo (hi)
577.5	28	14	58	73*	cristo(hi), feld *includes chlorite
594.5	29	7	64	73	feld
606.5	68	8	24	68	cristo(hi)
623	67	16	17	66	tr clino
632.5	35	15	50	70	cristo(hi)
645.75	27	16	57	73	feld, opal claystone
653	18	44	38	67	goeth, tr feld
677.5	27	11	62	87	feld
682	36	6	58	87	
692.5	23	15	62	83	feld
704	24	12	64	83	tr feld
723	18	27	55	80	tr feld
733	26	17	57	72	feld, clino?
756	55	25	20	70	cristo(lo), feld
769	23	17	60	87	feld
780.75	12	6	82	100	feld
785	41	7	52	76	tr feld
814.5	24	20	56	90	feld, tr goeth
837.5	35	27	38	76	feld, opal claystone
863.5	10	11	79	96	feld
875	8	16	76	100	feld, opal claystone
887	83	13	4	90	feld, goeth
917.5	11	25	64	77	feld, tr clino
927.5	17	22	61	91	feld, tr clino
942	19	32	49	87	feld

APPENDIX 2 (continued)

Sample Depth (feet)	Approx % of Major Clay Minerals K	I	I/S	% Expandable Layers	Other Minerals
944.5	35	19	46	84	feld, opal claystone
988	47	6	47	92	clino, feld, cristo(lo)?, gyp?
1008	24	24	52	82	cristo(lo), feld
1028.5	40	8	52	79	cristo(lo), feld
1065	14	43	43	83	tr feld
1073.5	68	10	22	94	clino, tr feld
1084	18	18	64	82	
1090.5	8	46	46	87	
1103.5	13	7	80	100	feld, goeth?
1112	23	27	50	93	feld
1118	6	31	63	83	feld
1147	52	24	24	92	feld, verm
1151	31	21	48	100	feld
1161	12	34	54	81	feld
1180.5	69	3	28	100	tr cristo (lo), tr feld
1190.5	22	3	75	100	feld
1196.5	16	39	45	85	feld
1200.5	24	15	61	100	feld, tr clino
1222.5	15	25	60	82	feld
1256	30	25	45	97	feld, clino?
1277.67	42	21	37	100	feld
1292	17	79	4	91	feld
1302	36	39	25	100	feld, gyp, tr verm
1309	37	13	50	83	feld, gyp, verm
1345	27	11	62	98	feld, tr calc
1350.5	36	9	55	95	feld, verm
1352	26	22	52	80	feld

INDEX

VIRGINIA DIVISION OF MINERAL RESOURCES – PUBLICATION 20 –
GEOLOGY OF THE OAK GROVE CORE