COMMONWEALTH OF VIRGINIA

VIRGINIA CONSERVATION COMMISSION

VIRGINIA GEOLOGICAL SURVEY

ARTHUR BEVAN, *State Geologist*

BULLETIN 57

Eocene of Virginia

By

BENJAMIN GILDERSLEEVE

UNIVERSITY, VIRGINIA
1942

COMMONWEALTH OF VIRGINIA

VIRGINIA CONSERVATION COMMISSION

VIRGINIA GEOLOGICAL SURVEY

ARTHUR BEVAN, *State Geologist*

BULLETIN 57

Eocene of Virginia

By

BENJAMIN GILDERSLEEVE

UNIVERSITY, VIRGINIA

1942

RICHMOND:
Division of Purchase and Printing
1942

VIRGINIA CONSERVATION COMMISSION

WILLIAM A. WRIGHT, *Chairman,* Richmond

L. E. LICHFORD, *Vice Chairman,* Lynchburg

JAMES ASHBY, Stafford

C. S. CARTER, Bristol

EDWARD W. LAUCK, Luray

GEORGE PRINCE ARNOLD,
Assistant Commissioner, Richmond

RICHARD A. GILLIAM,
Executive Secretary and Treasurer, Richmond

LETTER OF TRANSMITTAL

COMMONWEALTH OF VIRGINIA

VIRGINIA GEOLOGICAL SURVEY

UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE, VA., September 1, 1942.

To the Virginia Conservation Commission:

GENTLEMEN:

I have the honor to transmit and to recommend for publication as Bulletin 57 of the Virginia Geological Survey series of reports a manuscript and illustrations on the *Eocene of Virginia,* by Dr. Benjamin Gildersleeve, now with the Tennessee Valley Authority. The field work on which this report is based was done at no cost to the Geological Survey except some aid for field expenses.

This report supplants part of Geological Survey Bulletin 4, *The Physiography and Geology of the Coastal Plain Province of Virginia,* which was published in 1912 and which is no longer available for distribution.

The distribution and characteristics of the Eocene formations in Virginia are concisely discussed in this report. Important constituents of these strata are greensand and greensand marl, which have been used as soil conditioners. They may have similar uses in the future on the soils of the western Coastal Plain and adjacent parts of the Piedmont region. The report is summarized in the "Abstract."

Respectfully submitted,

ARTHUR BEVAN,
State Geologist.

Approved for publication:
Virginia Conservation Commission,
Richmond, Virginia, September 15, 1942.
R. A. GILLIAM, *Executive Secretary and Treasurer.*

CONTENTS

ILLUSTRATIONS

TABLE

EOCENE OF VIRGINIA[1]

By Benjamin Gildersleeve

ABSTRACT

Eocene deposits in Virginia crop out only in the western part of the Coastal Plain, from the Fall Zone eastward for several miles and from northern Stafford County on the north to Petersburg on the south. The best exposures are in the Potomac drainage area. Bluffs along the south side of Aquia Creek and Potomac River contain the most complete exposed sections.

The Eocene consists of the Aquia and Nanjemoy formations. Both were deposited in marine environments, as indicated by their faunas. The sediments are lithologically similar, being mainly sand, clay, greensand, and greensand marl. The total thickness is about 225 feet. The beds dip gently seaward.

The fossils are chiefly marine pelecypods and gastropods, with scant remains of some other invertebrates and of a few vertebrates. More than thirty species of Foraminifera and ten species of Ostracoda have been identified.

[1]A dissertation submitted to the Board of University Studies of The Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy.

INTRODUCTION

SCOPE OF REPORT

The field investigations were made during May, June and July 1932, and in June and July 1933. Laboratory studies of the sediments and fossils were made later at The Johns Hopkins University. The report was submitted in 1939 for publication.

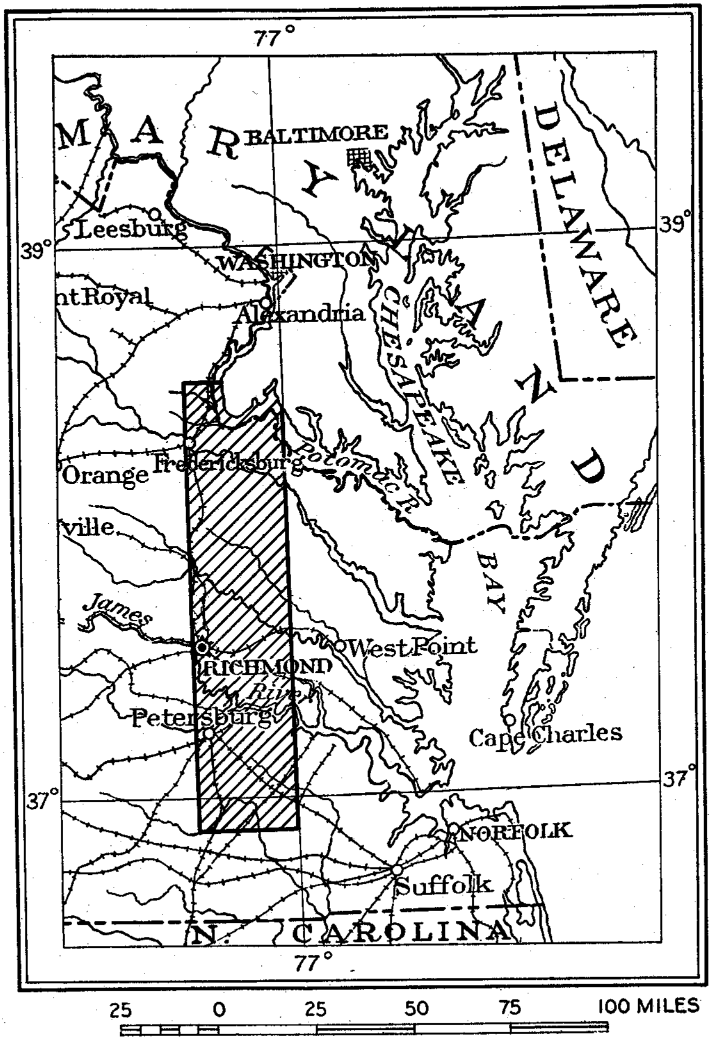


FIGURE 1—Index map of eastern Virginia showing location of the area in which Eocene deposits are exposed.

The area discussed in this report is in the western part of the Coastal Plain between Prince William County on the north and Nottoway River in Sussex County. It lies between the meridians of 77° and 77° 30′, and embraces parts of Stafford, King George, Spotsylvania, Caroline, King and Queen, King William, Hanover, Henrico, New Kent, Chesterfield, Charles City, Prince George, and Sussex counties. (See Fig. 1.) The area contains approximately 2,000 square miles.

ACKNOWLEDGMENTS

This investigation was suggested to the writer in 1928 by Dr. Joseph K. Roberts, Professor of Geology at the University of Virginia. A thesis on the Eocene deposits in the vicinity of Fredericksburg was prepared under his direction and presented in 1931 to the Academic Faculty of the University of Virginia in candidacy for the degree of Master of Science. The writer is indebted to Dr. Roberts for many valuable suggestions in the field and laboratory, for many of the illustrations, especially the photomicrographs, and for the use of a manuscript bibliography of Virginia geology.[2]

The Virginia Geological Survey assisted in financing the field studies. A grant of $50.00 from the Virginia Academy of Science for field studies is gratefully acknowledged.

Sincere thanks are due to Dr. J. E. Copenhaver, Department of Chemistry, University of South Carolina, for making analyses of the greensands. Dr. A. A. Pegau, School of Geology, University of Virginia, assisted in the studies of the sediments. Miss Margaret Hitchcock assisted in the study of the microfaunas. Dr. W. G. Lynn, The Johns Hopkins University, furnished additional collections of fossils from Belvedere Beach.

This opportunity is taken to express particular appreciation to Professor Edward W. Berry, under whose direction this report was written, for his constructive criticism and many helpful suggestions. The writer is also indebted to all the members of the Faculty of the Geological Department of The Johns Hopkins University for their interest and assistance.

[2]Roberts, J. K., Annotated geological bibliography of Virginia: Univ. of Virginia Bibl. Ser. No. 2, Charlottesville, The Alderman Library, 1942.

HISTORICAL SUMMARY

The earliest known reference to the geology of the Coastal Plain of Virginia is that of General Benjamin Lincoln.[3] As many later contributions to the geology of the region have been made, the literature is too voluminous to be outlined in this report. The earlier literature has been summarized by W. B. Clark.[4]

The first studies of the Atlantic Coastal Plain sediments were made on a lithologic basis and independent of the fossils. Finch[5] was the first to make a scientific correlation of the Coastal Plain deposits which he believed were "identical and contemporaneous with the newer Secondary and Tertiary formations" of parts of Europe and Asia. Prior to 1830 most investigations of the stratigraphy of the Tertiary were made without much study of the fossils. Generic identity was used in making correlations, but this was of service chiefly in determining the boundaries of the Tertiary and was not sufficient for making subdivisions.

Conrad[6] was the first to use fossils in interpreting the geology of the Coastal Plain. Although Say[7] had previously described several Tertiary species, he did not use them to make geological deductions. Conrad continued his investigations for a period of 40 years and added materially to the knowledge of the geology of the Coastal Plain.

Among the early writers on the Eocene deposits in Virginia was William B. Rogers who was State Geologist of Virginia from 1835 to 1841. In 1834 he[8] expressed the view that it was not improbable that greensands, similar to those in New Jersey, may occur in the marl beds of eastern Virginia, Carolina, and Maryland. The following year he published "Further observations on the greensands and calcareous marl of Virginia,"[9] in which he proved that Eocene deposits occur in Virginia. Rogers continued his study of the Tertiary geology of Virginia, and as State Geologist published the results of his observations in the annual reports of the Geological Survey from 1835 until 1841. These publications include descriptions of the Eocene deposits in Virginia,

[3]Lincoln, Benjamin, An account of several strata of earth and shells on the banks of York River in Virginia: Am. Acad. Arts and Sci., vol. 1, pt. 2, pp. 372-373, 1783.

[4]Clark, W. B., Correlation Papers—Eocene: U. S. Geol. Survey Bull. 83, pp. 17-37, 1891. See also Clark, W. B., and Martin, G. C., The Eocene deposits of Maryland: Maryland Geol. Survey, Eocene text, pp. 21-31, 1901.

[5]Finch, John, Geological essay on the Tertiary formations in America: Am. Jour. Sci., vol. 7, pp. 31-43, 1824.

[6]Conrad, T. A., On the geology and organic remains of a part of the Peninsula of Maryland: Phila. Acad. Nat. Sci. Jour., vol. 6, pp. 205-217, 1830.

[7]Say, Thomas, An account of some of the fossil shells of Maryland: Phila. Acad. Nat. Sci. Jour., vol. 4, pp. 124-155, 1824.

[8]Rogers, W. B., On the discovery of greensand in the calcareous deposit of eastern Virginia, and on the probable existence of this substance in extensive beds near the western limits of our ordinary marl: Farmers' Register, vol. 2, 1834. Reprinted in Geology of the Virginias, pp. 3-9, 1884.

[9]Farmers' Register for May, 1835.

and constitute an important source of information regarding their stratigraphy.

In 1884 Heilprin[10] published his "Contributions to the Tertiary Geology and Paleontology of the United States." This book was one of the most important treatises to that date. The author discussed fully the Eocene deposits of Delaware, Maryland and Virginia. He compared several species of the Eocene fossils of Maryland and Virginia with European forms and stated that this study "correlates the strata with the lower members of the English and French series."

W J McGee,[11] in his report on "Three Formations of the Middle Atlantic Slope," gives a full description of the stratigraphy of the Coastal Plain. Reference is made to the contact of the Eocene and Cretaceous in Virginia. In subsequent reports he also mentions the Eocene deposits of Virginia. In 1885 he published a small-scale map of the United States which showed the distribution of the Eocene deposits of the Middle Atlantic slope.

The Eocene deposits of Maryland and Virginia were described and given the name "Pamunkey formation" by Darton[12] in 1891. The Eocene of Virginia was more fully described by him in the Fredericksburg folio[13] which contains an areal map showing its distribution in that quadrangle.

One of the writers on the geology of the Coastal Plain was Clark. Most of his investigations were made in Delaware, Maryland and Virginia. He was joint author of an extensive report on the Eocene deposits of Virginia.[14] The description of the Eocene formations, together with correlations, sections, and tables showing the distribution of the fauna, make this report an important one. It is the latest detailed account that has been published on the Eocene deposits of Virginia. It is out of print.

The literature on the Virginia Coastal Plain has undergone an evolution, so to speak, which may be divided into three parts. The first period is that of the early days of Rogers, a hundred years ago, characterized by the reconnaissance type of study in which the stratigraphic value of fossils was not realized. Rogers' work formed the foundation for the detailed work of the succeeding years. The second period is marked by the use of fossils by Conrad, Fontaine, and others. During this time observations were made and deductions drawn which, to a very considerable degree, have determined the present knowledge of the Eocene

---

[10]Philadelphia, 117 pp. and map, 1884.
[11]Am. Jour. Sci., 3d ser., vol. 35, pp. 120-143, 328-330, 367-388, 448-466, 1888.
[12]Darton, N. H., Mesozoic and Cenozoic formations of eastern Virginia and Maryland: Geol. Soc. America Bull., vol. 2, pp. 431-450, 1891.
[13]U. S. Geol. Survey Geol. Atlas, Folio No. 13, 1894.
[14]Clark, W. B., and others, The physiography and geology of the Coastal Plain province of Virginia: Virginia Geol. Survey Bull. 4, 1912.

in the Atlantic Coastal Plain. The third period began about 1895 when Clark, returning from Zittel's laboratory at Munich, began to study the Eocene and other Tertiary deposits of the Atlantic Coastal Plain. He used the best methods of his time and developed the only reliable criteria to be used in correlation.

TOPOGRAPHY

GENERAL FEATURES

The Coastal Plain of Virginia is a part of the Atlantic Coastal Plain which extends from Long Island to Florida. The land, or emerged, part extends from the Atlantic Ocean westward to the Fall Zone which marks the contact between the weaker, poorly consolidated sediments of the Coastal Plain on the east and the resistant underlying crystalline rocks of the Piedmont province to the west. The Fall Zone extends through Washington, Fredericksburg, Richmond, Petersburg and Emporia.

The emerged portion of the Coastal Plain is a dissected lowland which, from an altitude of slightly more than 300 feet at its northwestern margin, slopes gradually eastward and southeastward to the coast. According to Wentworth,[15] the average slope to the east or southeast is less than 3 feet to the mile. Near the Fall Zone it may be as much as 10 to 15 feet to the mile.

The area in which Eocene strata crop out lies in the western part of the Coastal Plain, that is, the section adjacent to the Fall Zone. The surface has been dissected by the principal streams and their tributaries into sinuous and branching tabular divides. Near the Fall Zone the upland is gently rolling and more irregular than the portion to the east Most of the upland surface is relatively flat. Altitudes range from tide level to 150 feet or more in the southern part and to 250 feet or more in the northern part of the area.

DRAINAGE

The principal rivers which drain the western part of the Coastal Plain in Virginia are the Potomac, Rappahannock, Mattaponi, Pamunkey, Chickahominy, James, and Nottoway. The Mattaponi and Pamunkey unite to form the York River in the east-central part of the Virginia Coastal Plain. Near the Fall Zone some of the master streams, for example the James, flow south for some distance before turning southeastward across the Coastal Plain. This has been explained[16] as due to the relative ease with which the basal Coastal Plain deposits (Cretaceous) are eroded in comparison with the overlying Tertiary formations. Campbell[17] suggested that the deposition of alluvial fans may have affected the courses of some rivers.

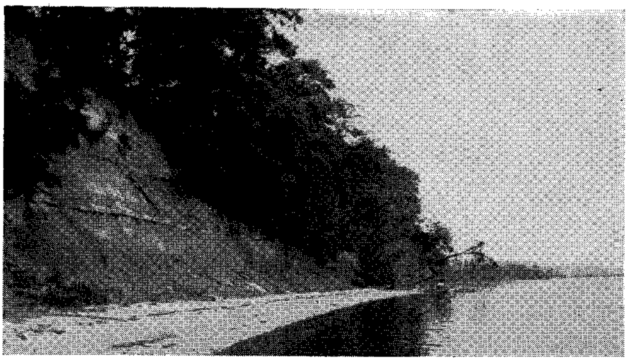
---

[15] Wentworth, C. K., Sand and gravel resources of the Coastal Plain of Virginia: Virginia Geol. Survey Bull. 32, p. 7, 1930.

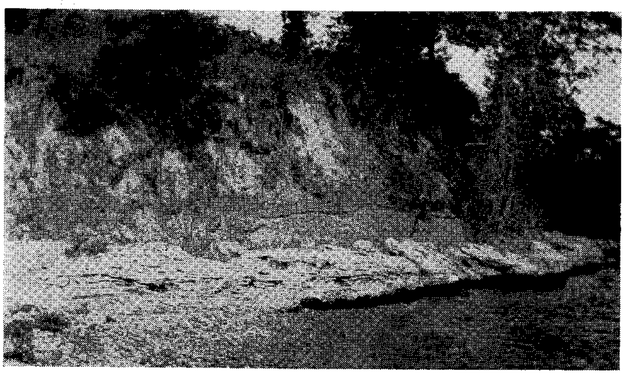
[16] Clark, W. B., and others, op. cit., p. 53, 1912.

[17] Campbell, M. R., Alluvial fan of Potomac River: Geol. Soc. America Bull., vol. 42, pp. 825-853, 1931.

A marked peculiarity of the drainage is the unsymmetrical location of the divides. The divide between the Potomac and the Rappahannock lies close to the Potomac and as a result the streams flowing into the Potomac are shorter, swifter and have steeper valleys than those flowing into the Rappahannock. Similar conditions prevail between the York and James rivers. The stream courses are characterized by meanders and flood plains which are bordered by marshes and swamps. In many places they have steep bluffs, in some of which the Eocene beds are exposed. The master streams have been drowned in their lower courses.

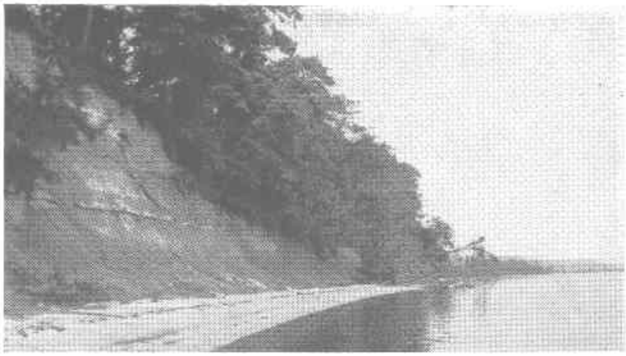


A. Aquia formation near the mouth of Aquia Creek, Stafford County, Virginia. Greensands with indurated beds are exposed.

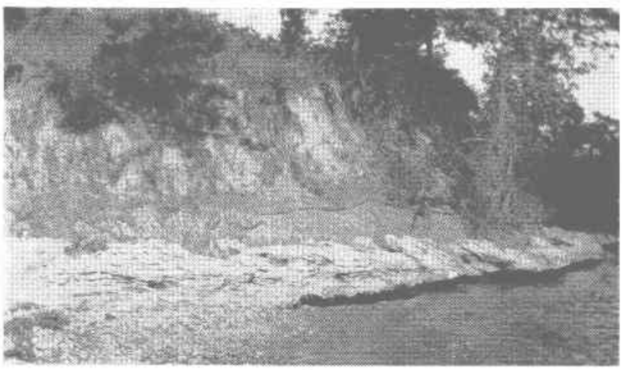


B. Indurated layer in Aquia formation near the mouth of Aquia Creek.

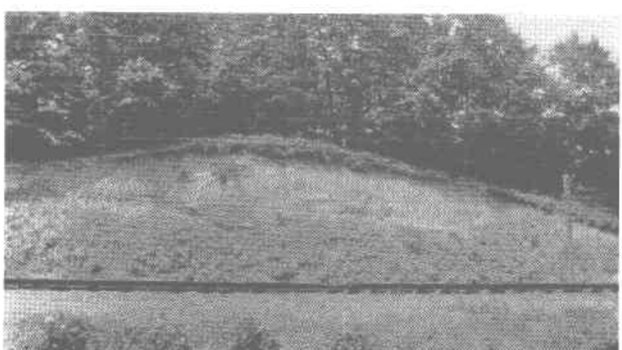
C. Aquia greensand in a cut along the R. F. & P. Railroad, 1½ miles south of Aquia Creek.



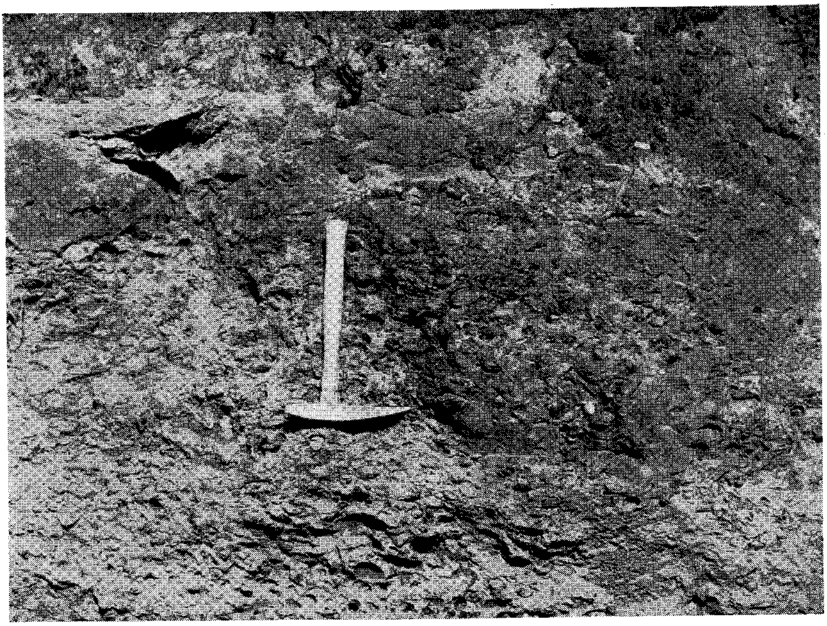
A. Aquia formation near the mouth of Aquia Creek, Stafford County, Virginia. Greensands with indurated beds are exposed.



B. Indurated layer in Aquia formation near the mouth of Aquia Creek.

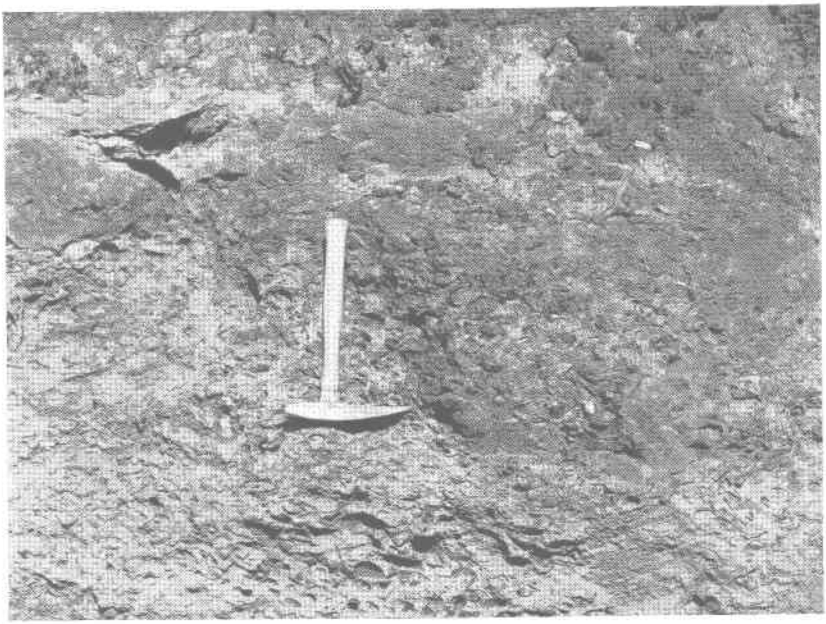


C. Aquia greensand in a cut along the R. F. & P. Railroad, 1½ miles south of Aquia Creek.

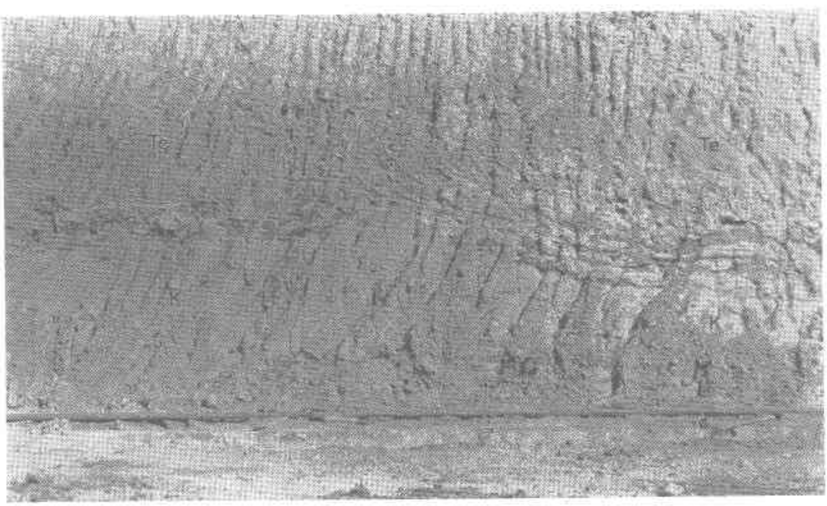


A. Silicified beds in the Aquia formation half a mile east of Stafford, Virginia.

B. Contact of the Cretaceous and Eocene beds along U. S. Highway 1, about 1½ miles south of Stafford, Virginia.



A. Silicified beds in the Aquia formation half a mile east of Stafford, Virginia.



B. Contact of the Cretaceous and Eocene beds along U. S. Highway 1, about 1½ miles south of Stafford, Virginia.

STRATIGRAPHY

The Tertiary of Virginia is represented by strata of Eocene and Miocene age and by some beds of sand and gravel regarded as of Pliocene age. These deposits form part of a series of formations extending from New Jersey southward to the Gulf of Mexico. They overlie unconformably the Cretaceous strata of the Coastal Plain. Deposits of Oligocene age have not been recognized in Virginia.

EOCENE FORMATIONS

The Eocene deposits of the Middle Atlantic slope were regarded by Darton as constituting a single unit, and were described by him as the Pamunkey formation, from the Pamunkey Valley in Virginia, where it is well exposed. Later investigators divided the Eocene into two well-defined formations, Aquia and Nanjemoy, both on stratigraphic and paleontological bases. The Aquia formation was named by Clark[18] from Aquia Creek, in Stafford County, Virginia. The Nanjemoy formation was named by Clark and Martin[19] from Nanjemoy Creek which flows from Maryland into Potomac River, and along the lower course of which beds of this age are well exposed.

The Eocene deposits consist chiefly of highly glauconitic marls and clays. (See Pls. 1 and 4B.) Coarse sands and gravels occur near the base of the Aquia which is more arenaceous and calcareous than the overlying Nanjemoy formation. The strata contain many shells and shell fragments which are locally so numerous as to form the chief constituent of certain beds. These beds are locally indurated into layers of impure limestone. (See Pl. 1A.) In the vicinity of Stafford and near Brooke, a local development of siliceous beds contains numerous casts and imprints of Eocene fossils. Unweathered Eocene deposits appear homogeneous but on weathering they become lighter in color and somewhat mottled. Where the shells and other calcareous materials have been removed by solution, the resulting material is a buff-colored sand containing various amounts of iron which has been redeposited in streaks and limonitic crusts.

The Eocene strata are best exposed along the series of high bluffs near the mouth of Aquia Creek, and eastward along the south bank of Potomac River to Mathias Point, in eastern Stafford and northern King George counties. This is probably the most complete section of

[18]Clark, W. B., Description of the geological excursions made during the spring of 1895: Johns Hopkins Univ. Cir., vol. 15, p. 3, 1895.
[19]Clark, W. B., and Martin, G. C., The Eocene deposits of Maryland: Maryland Geol. Survey, Eocene text, p. 64, 1901.

beds of this age. Other important exposures of Eocene deposits occur along the banks of the Rappahannock, Pamunkey and James rivers. The peninsula between the Potomac and Rappahannock rivers in King George County is formed largely of greensands of Nanjemoy age.

The most southern exposure of the Eocene in Virginia has been recorded as being near Bolling's bridge on Nottoway River, where McGee[20] reported the presence of "three or four feet of greenish clay containing Eocene fossils." This material was referred to the Aquia formation by Clark and Miller[21]. At the river's edge, on the north side of Bolling's bridge, the writer found unmistakable Miocene fossils in a bed of blue, sandy clay overlying coarse-grained Cretaceous sands. Casts of *Pecten jeffersonius, Balanus concavus,* and *Glycymeris* sp., as well as bone fragments and a whale vertebra, were collected from the clay immediately overlying the Cretaceous sands. The banks along Nottoway River are very low for some distance northeast of Bolling's bridge and are mostly covered by vegetation. No Eocene exposures were found at any point along Nottoway River within the area which had been mapped as Aquia.

The Eocene strata are separated from the overlying and underlying formations by unconformities. (See Pl. 2B.) The contact between the Eocene (Aquia) and Lower Cretaceous has been found at altitudes ranging from about 50 feet to 200 feet. (See Fig. 2.) This may be due in part to the irregularly eroded surface of the Lower Cretaceous upon which the Aquia sediments were deposited and in part to the fact that the sediments deposited at the beginning of the westward transgression of the sea are older and lower than those formed at the maximum inundation of the Eocene sea. The writer is of the opinion that both the Aquia and Nanjemoy formations thin westward.

The Virginia Eocene may be regarded as forming the southern part of the northern belt of Eocene deposits of the Atlantic Coastal Plain, for the highly glauconitic sands which characterize the New Jersey-Virginia area are scarce in North Carolina and other southern states.

AQUIA FORMATION

Distribution.—The Aquia formation crops out in a narrow belt extending from Chopawamsic Creek in Stafford County southward to Petersburg. It is best exposed along the major streams and many of their tributaries. In the intervening divides it is generally concealed

[20]McGee, W J, Three formations of the Middle Atlantic slope: Am. Jour. Sci., 3d ser., vol. 35, p. 126, 1888.

[21]Clark, W. B., and others, The physiography and geology of the Coastal Plain province of Virginia: Virginia Geol. Survey Bull. 4, p. 103, 1912.

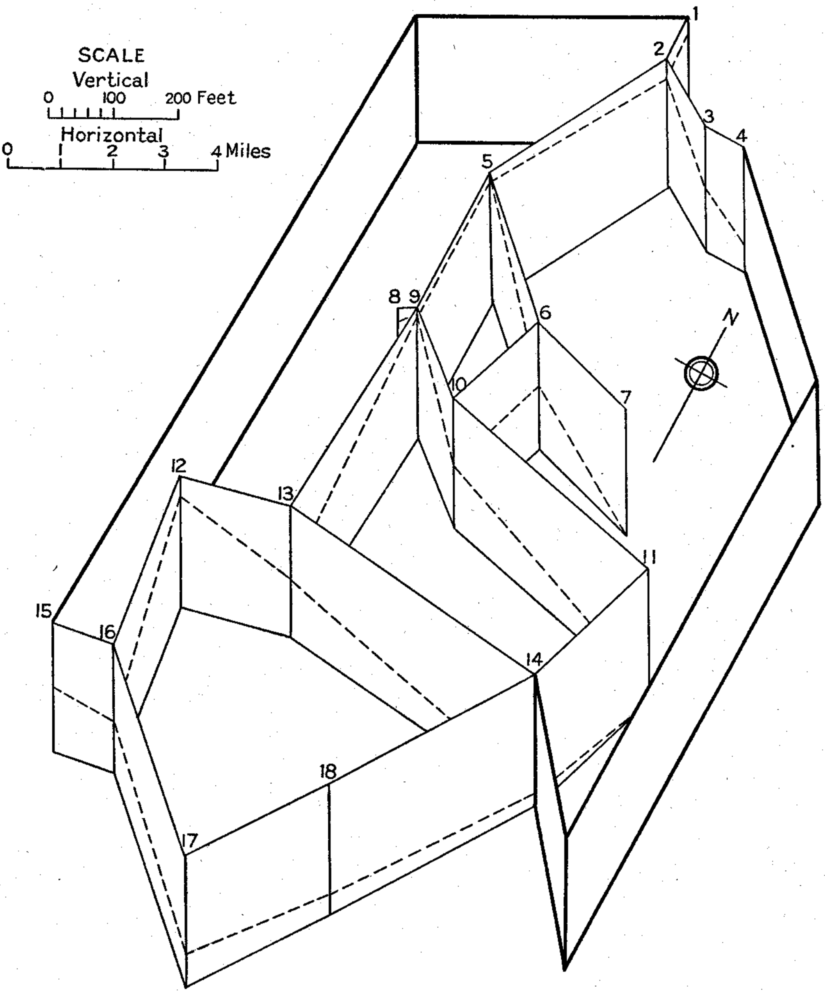


FIGURE 2—Postulated Cretaceous—Eocene contact in the Stafford, Virginia-Maryland, quadrangle. See p. 40 for locality descriptions.

by later deposits but is exposed in places as, for example, along the Richmond, Fredericksburg and Potomac Railroad in the vicinity of Brooke and Aquia Creek.

The Aquia is best exposed in the bluffs near the mouth of Aquia Creek and along the south bank of Potomac River between Bull Bluff and Fairview Beach. Excellent exposures are found along Rappahannock River at several points between Belvedere and the mouth of Jones Top Creek. Aquia greensands occur at intervals in the valley of the Mattaponi to a point a short distance east of Penola. Exposures of the Aquia along Pamunkey River are relatively scarce. Eocene deposits were not observed in the Chickahominy valley. If the Eocene is present, it is of limited extent and is largely covered by recent swamp deposits. The Aquia formation is poorly exposed in Richmond and Petersburg. Along James River it is best seen below the mouth of Bailey Creek and at Tar Bay.

Subdivisions.—The Aquia formation contains two members. The Piscataway member was named from Piscataway Creek, Maryland. It consists principally of greensands and greensand marls. The lower beds are argillaceous. The upper beds are characterized in places by persistent layers of indurated marl. The Paspotansa member was named from Paspotansa Creek, which enters Potomac River from Virginia, one mile below the mouth of Potomac Creek. It is characterized by beds of greensand marl. In the Potomac area the Piscataway member has been divided into seven zones and the Paspotansa member into two zones. Both members are lithologically similar. This twofold division and zoning of the Aquia formation was based by Clark and Martin, in their work on the Eocene deposits of Maryland, on paleontological differences. Clark and Miller also recognized these divisions in their work on the Virginia Eocene. Although these faunal zones are to be seen locally, the writer has experienced some difficulty in tracing their areal extent and in correlating them with those of other exposures throughout the region. As previously mentioned, the Aquia deposits are lithologically homogeneous, and where the greensands are weathered or fossils are lacking, zoning is more or less arbitrary and impracticable.

General character.—The Aqua formation is composed principally of greensand and greensand marl with some inter-bedded layers consisting almost entirely of shells. These shell beds are locally indurated, as near the mouth of Aquia Creek. (See Pl. 1B.) Two persistent layers, composed of indurated greensand and shell fragments, project from the bluff along the south bank of the creek. These layers are from 8 to 10 inches thick and are about 5 feet apart. They probably represent levels at which ground water was sufficiently charged with calcium carbonate to cement the greensand and shells. Near Stafford Court House and in the vicinity of Brooke, siliceous beds containing casts and imprints of shells are locally present. Argillaceous beds in the Aquia are commonly dark bluish-gray when wet and light-gray when dry. Near Stafford Court House and at Falmouth the clays are pink to light-red.

The Aquia formation locally contains calcareous concretions; those at Hop Yard[22] on Rappahannock River are as much as six feet long.

The Eocene deposits in northern Virginia consist almost entirely of greensand which is so much weathered that it is difficult to recognize. The sands are fine grained and light-yellow to brown and red. The Aquia greensands are sparsely glauconitic in the southern part of the area. In Richmond and Petersburg the Aquia consists largely of a light greenish-gray, fine-grained sand. Some glauconite is present but much less than at most places where the Aquia is exposed.

Greensand.—The greensands of the Aquia formation are uniformly medium to fine grained. They vary from light- to dark-green depending on the degree of weathering and the amount of water present. The more weathered sand is stained brown by iron oxide. The sands are characterized by the greenish mineral glauconite. (See Pls. 5B and 6A.) Quartz is the most abundant of the other minerals present. Small angular grains of muscovite give a glistening appearance to much of the greensand. The Aquia greensand also contains many fragments of shells.

Microscopically the greensand is composed largely of quartz. The larger grains of quartz are well rounded, but the smaller particles are angular. Glauconite occurs as rounded and mammillary grains less than 1 mm. in diameter, most of which are generally dull and have irregular surfaces. Muscovite is present as thin, angular plates. Irregular grains of magnetite are rare.

Indurated beds.—Beds half a mile east of Stafford on the road to Brooke are thoroughly silicified and represent replacement of greensand by silica. (See Pl. 2A.) Fossils are well preserved as siliceous casts, molds, and imprints.

The chert varies from white to black. Microscopically, it is composed of opaline or amorphous silica with some chalcedony and quartz. (See Pl. 5.) Chalcedony occurs as fibers in an opaline groundmass and also as spherulitic rims around opaline cores. The spherical particles of silica are about 0.1 mm. in diameter and have rims of radially oriented fibers which appear to be chalcedony.

Thickness.—The thickness of the Aquia formation in Stafford County, the type locality, where it is best exposed along Aquia Creek, was determined by Clark as being about 100 feet, representing about half of the total thickness of the Eocene in Virginia.[23]

[22]See Fredericksburg 30-minute sheet for location.
[23]Clark, W. B., and others, op. cit., p. 91.

Relations.—The Aquia formation overlies unconformably the Lower Cretaceous formations of the Potomac group. In the northern portion of Virginia it overlies the irregularly eroded surface of the Patapsco formation, as is shown in the first cut on the Richmond, Fredericksburg and Potomac Railroad south of Aquia Creek, and in road cuts along U. S. Highway 1, one and a half miles south of Stafford Court House. This unconformity is most marked in the James River basin where the Aquia rests upon the uneven surface of the Patuxent formation. In Richmond, along Shockoe and Gillie creeks, the Aquia is exposed as low as an altitude of about 60 feet, whereas along the strike of these exposures and to the east at Drewrys Bluff,[24] Howlett House,[24] and the bluffs above Dutch Gap canal,[24] on James River, the underlying Patuxent is exposed at altitudes as high as 80 feet. At Point of Rocks on the Appomattox River, the Patuxent occurs at an altitude of about 80 feet, whereas 1½ miles due west the Aquia deposits on Ashton Creek are found at an altitude of 50 feet. Faulting is not apparent. Since the general dip of the Patuxent near the Fall Zone is approximately 50 feet to the mile, and the average dip of the Eocene formations does not exceed 15 feet to the mile, the difference in altitude at the base of the Eocene is at least 100 feet.

The Aquia is overlain disconformably by the Nanjemoy formation, or by Pliocene and Pleistocene unconsolidated deposits. (See Pl. 4B.)

NANJEMOY FORMATION

Distribution.—The Nanjemoy formation crops out in a narrow belt east of the Aquia formation, between the Potomac and James rivers. It is best exposed along the Potomac River near Woodstock and in the valleys of the major streams. Like the Aquia formation, the exposures are discontinuous and in the southern part of the area are concealed in many places by later deposits. No exposures of the Nanjemoy formation were found in the Nottoway valley.

Subdivisions.—The Nanjemoy formation has also been divided into two members—the Potapaco clay and Woodstock greensand marl. The Potapaco varies in thickness from 60 to 65 feet and the Woodstock from 50 to 60 feet.[25]

The Potapaco member was named from Port Tobacco Creek, Maryland, a corruption of the word Potapaco on early maps. It is composed chiefly of greensand which is locally argillaceous and in places contains

[24]See Bermuda Hundred 30-minute sheet for location.

[25]Clark, W. B., and others, The physiography and geology of the Coastal Plain province of Virginia: Virginia. Geol. Survey Bull. 4, p. 104, 1912.

masses of crystalline gypsum. The Woodstock member was named from an old homestead, originally known as Woodstock but now called Mathias Point, on the south bank of Potomac River west of the real Mathias Point. It consists chiefly of greensand and greensand marl but is less argillaceous than the underlying Potapaco. In the Potomac area the Potapaco member has been divided into six zones and the Woodstock member into two zones.[26] The writer is of the opinion that only local zoning of these beds can be done, and that detailed correlation of zones throughout the outcrop area is impracticable if not impossible.

General character.—The Nanjemoy formation is composed chiefly of greensand and greensand marl. It differs lithologically from the Aquia formation in being less commonly calcareous. Indurated beds which are prominent in the underlying Aquia formation are not present in the Nanjemoy. Calcareous concretions are scarcer and smaller than those in the Aquia formation. At Morland they occur in a discontinuous horizontal zone a few feet above tide.

The base of the Nanjemoy, according to Clark and Miller,[27] is generally marked by a bed of compact white and pink clay resting directly upon the Aquia greensands. This bed of clay has been named Marlboro clay from Marlboro, Maryland, where it is well exposed. Such a clay bed was not found by the writer in Virginia.

Greensand.—The greensands of the Nanjemoy formation are uniformly fine grained. They are commonly dark-green but become light-gray to buff when weathered. They are discolored by iron oxides. Glauconite is the most prominent mineral. (See Pl. 6B.) Quartz and angular flakes of muscovite are present in variable amounts. The sands contain many fragments of shells.

The greensands of the Nanjemoy formation differ microscopically but slightly from those in the Aquia formation. Quartz is present in greater amount and consists of angular grains. Glauconite is present in smaller amounts but has all of the properties described above.

Concretions.—Concretions at Woodstock and Morland on the south bank of Potomac River, consist of a light greenish-gray, calcareous sandstone, composed chiefly of fine quartz grains and glauconite. (See Pl. 4A.) The rock is uniformly fine grained, with a few flakes of mica.

[26]Clark, W. B., and Martin, G. C., The Eocene deposits of Maryland: Maryland Geol. Survey, Eocene text, pp. 65-67, 1901.
Clark, W. B., and others, The physiography and geology of the Coastal Plain province of Virginia: Virginia Geol. Survey Bull. 4, p. 104, 1912.
[27]Clark, W. B., and others, *op. cit.*

The glauconite and quartz grains are evenly distributed, thus giving a "salt and pepper" effect. Casts, imprints, and fragments of shells are numerous.

The rock shows in thin section a matrix of calcite, slightly iron stained, which forms a rather dense groundmass that is studded with angular to rounded grains of quartz, glauconite, magnetite, muscovite, and feldspar, which are not in contact with each other but are separated by the calcite matrix. (See Pl. 6B.) Glauconite is the most prominent constituent. It occurs as light-green rounded grains and masses, many of which are broken and filled with iron oxide. A few of the glauconite grains have a shredded appearance.

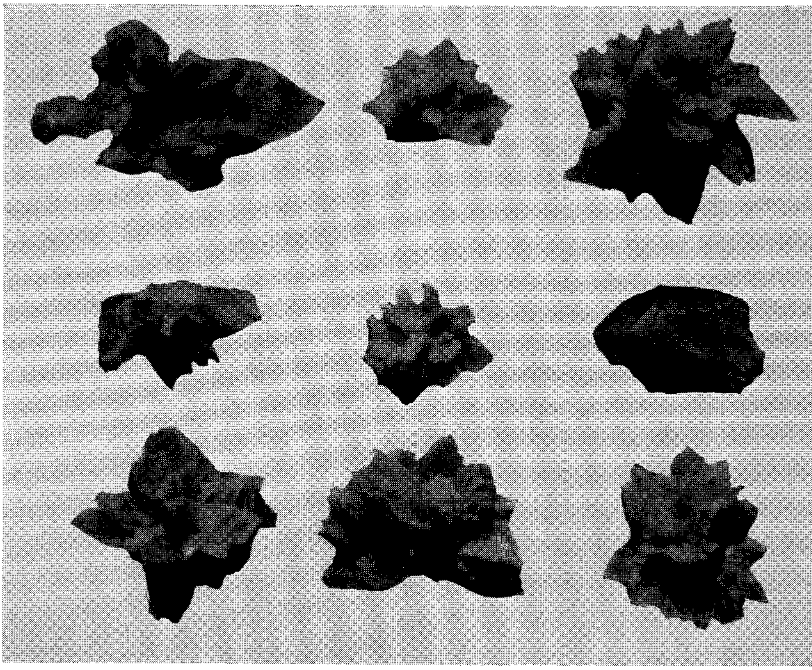
Gypsum.—Crystals of gypsum (selenite) occur in the Nanjemoy greensands and argillaceous beds but are more plentiful and better developed in the latter. The earliest reference to such an occurrence in Virginia is that of W. B. Rogers.[28]

At River Tie Wharf (Rock Stop) northwest of Port Royal, on the south bank of the Rappahannock, crystalline masses of gypsum are exceptionally well developed in a lens of Eocene clay. (See Pl. 3.) The clay is dark gray, highly weathered, and stained brownish yellow by iron oxides. The crystals of gypsum are best developed in fissures in the clay. They occur commonly in the form of rosettes. The crystals range from less than an inch to as much as 4 inches in length. The clusters are commonly equidimensional with from five to twenty-five crystals. The crystals vary from one-tenth of an inch to an inch in diameter. Small crystals which line vuglike cavities represent a later crystallization. The weathered surface of the clay is coated with mammillary growths of gypsum. Many tree roots above this clay are also covered with gypsum. These coatings under magnification show typically developed gypsum crystals.

Small crystals and crystalline aggregates of gypsum are found in many exposures of the Nanjemoy formation along Rappahannock River and in places along James River as at Coggins Point.

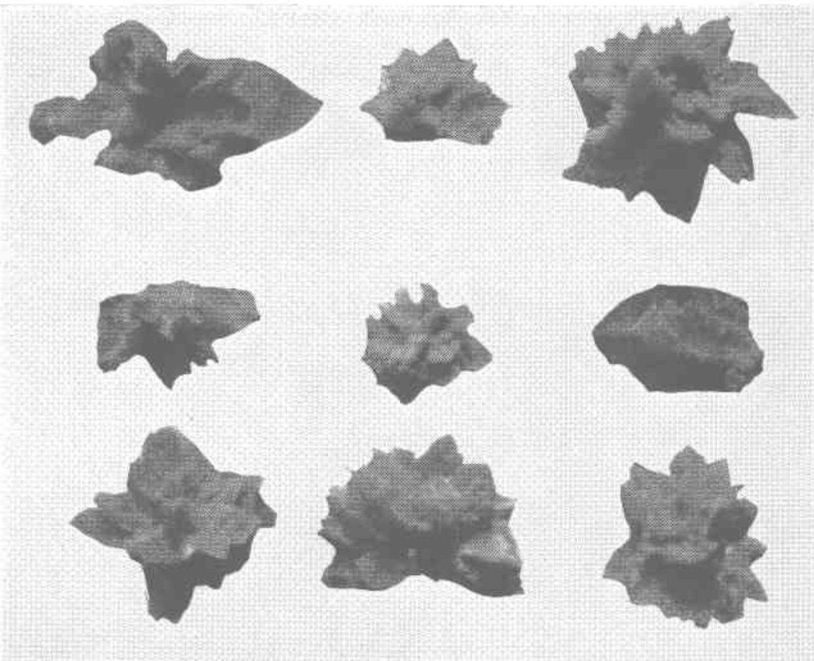
Upon observing similar crystals in the Miocene of Virginia, Rogers attributed their origin to permeating waters carrying sulphuric acid which resulted from the disintegration of sulphate of iron. These acid waters reacted with the calcium carbonate in the sediments to form sulphate of lime or gypsum.

[28]Rogers, W. B., A reprint of annual reports and other papers on the geology of the Virginias: New York, D. Appleton & Co., 1884.

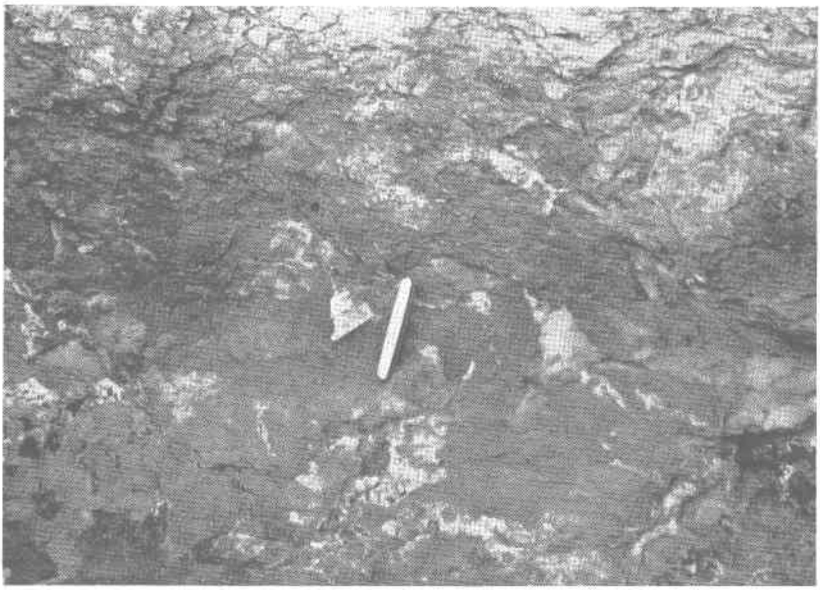


A. Clusters of gypsum crystals from Nanjemoy clay at River Tie Wharf, along Rappahannock River northwest of Port Royal, Virginia.

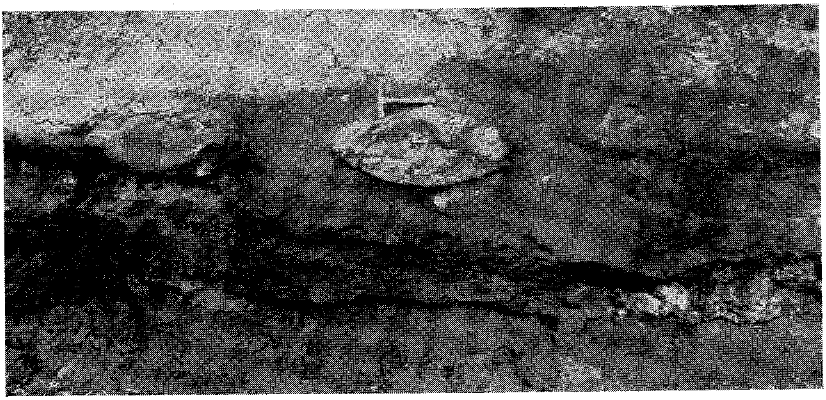
B. Gypsum crystals and aggregates in weathered Nanjemoy clay at River Tie Wharf, northwest of Port Royal, Virginia.



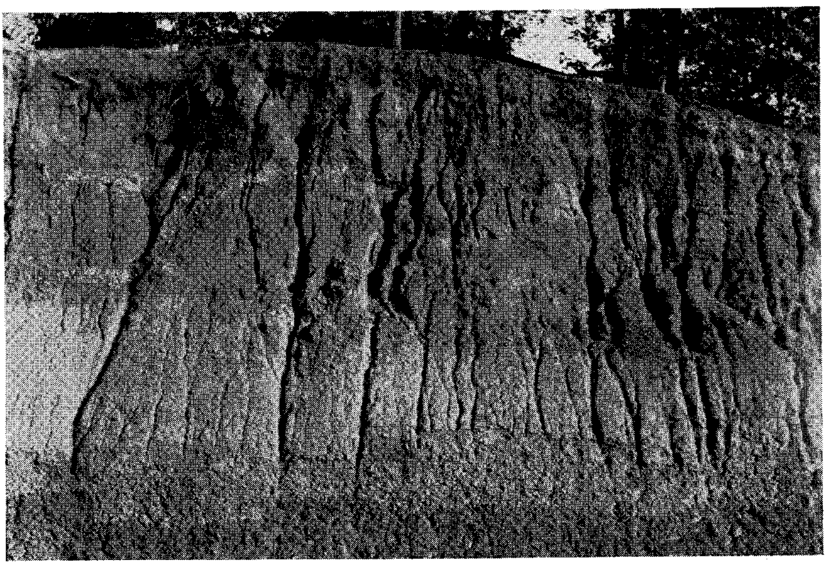
A. Clusters of gypsum crystals from Nanjemoy clay at River Tie Wharf, along Rappahannock River northwest of Port Royal, Virginia.



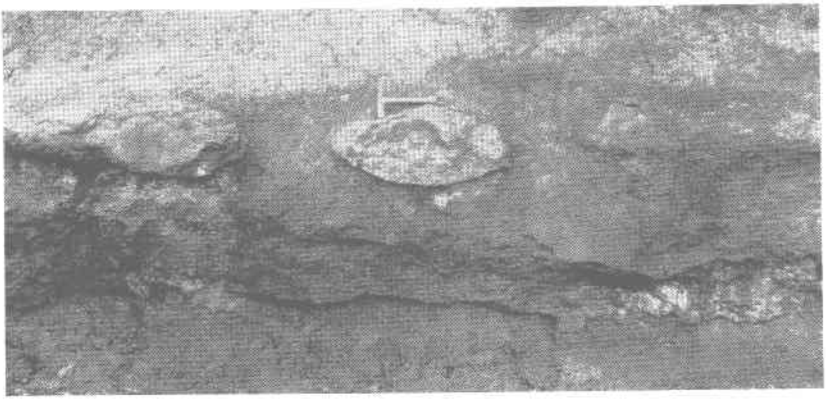
B. Gypsum crystals and aggregates in weathered Nanjemoy clay at River Tie Wharf, northwest of Port Royal, Virginia.



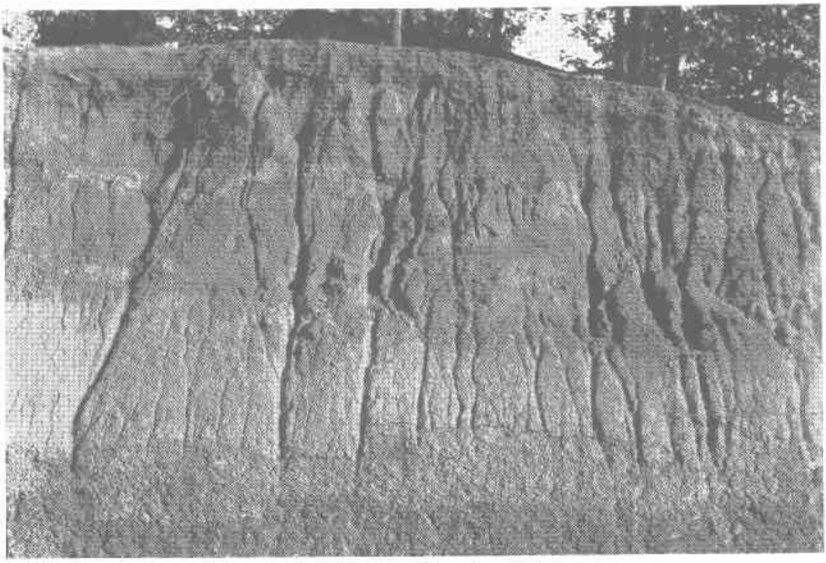
A. Calcareous concretions in the Nanjemoy formation at Morland, on the south side of Potomac River.



B. Aquia clays overlain by Pliocene (?) sand and gravel, along U. S. Highway 1, half a mile south of Stafford, Virginia.



A. Calcareous concretions in the Nanjemoy formation at Morland, on the south side of Potomac River.



B. Aquia clays overlain by Pliocene (?) sand and gravel, along U. S. Highway 1, half a mile south of Stafford, Virginia.

Relations.—The Nanjemoy formation is unconformably overlain by the Calvert (Miocene) formation or by Pleistocene unconsolidated deposits. It has a thickness of about 125 feet.

CORRELATION

The Eocene formations of Virginia are closely related to those occurring in Maryland. The strata are practically continuous and in the main are similar.

Clark[29] recognized the Eocene strata of Maryland and Virginia as equivalent to the Claibornian in part, as well as to the underlying Chickasawan. He also agreed with Harris[30] that the Aquia Creek beds could be correlated with the Bells Landing, or Tuscahoma, group of Wilcox age in Alabama. He later recognized the intermediate position of the Pamunkey group between the younger Castle Hayne formation delineated by Miller in North Carolina and the older Shark River beds in New Jersey.[31]

Vaughan[32] regarded the Aquia formation as of about the same age as the Tuscahoma formation (middle Wilcox) in Alabama and the Nanjemoy formation as equivalent to the upper Wilcox and lower Claiborne in Alabama.

Cooke and Stephenson[33] grouped the Vincentown sand, Hornerstown marl (Rancocas group), and Manasquan marl, formerly considered Cretaceous in age, with the Shark River beds as constituting the New Jersey Eocene and correlated the four formations with the Pamunkey group of Maryland and Virginia. The Pamunkey group has also been regarded[34] as including representatives of the Wilcox and Claiborne groups of Alabama. Cooke,[35] however, more recently correlates the Aquia formation with the middle Wilcox group and the Nanjemoy formation with the lower Claiborne group, as previously done by Woodring and Gazin.[36]

[29] Clark, W. B., The Eocene deposits of the middle Atlantic slope in Delaware, Maryland, and Virginia: U. S. Geol. Survey Bull. 141, 1896.

[30] Harris, G. D., On the geological position of the Eocene deposits of Maryland and Virginia: Am. Jour. Sci., 3d ser., vol. 47, pp. 301-304, 1894.

[31] Clark, W. B., Results of a recent investigation of the Coastal Plain formation of the area between Massachusetts and North Carolina: Geol. Soc. America Bull., vol. 20, pp. 646-654, 1910.

[32] Vaughan, T. W., Criteria and status of correlation and classification of Tertiary deposits: Geol. Soc. America Bull., vol. 35, pp. 677-742, 1924.

[33] Cooke, C. W., and Stephenson, L. W., The Eocene age of the supposed late Upper Cretaceous greensand marls of New Jersey: Jour. Geology, vol. 36, no. 2, pp. 139-148, 1928.

[34] Stephenson, L. W., Cooke, C. W., and Mansfield, W. C., Chesapeake Bay region: XVI Internat. Geol. Congr., Washington, Guidebook 5, 1933.

[35] Cooke, C. W., Geology of the Coastal Plain of South Carolina: U. S. Geol. Survey Bull. 867, p. 40, 1936.

[36] Woodring, W. P., and Gazin, C. L., Tentative correlation of the Tertiary and Pleistocene formations: XVI Internat. Geol. Congr., Washington, Guidebook 29, pl. 9, 1933.

DETAILED SECTIONS

Measured sections given below show the lithologic and faunal character of the exposed Eocene beds throughout the Coastal Plain in Virginia. Geologic sections 1-10 are in the Potomac Valley, 11-18 are in Rappahannock Valley, 19-22 are in Mattaponi Valley, 23-26 are in Pamunkey Valley, and 27-28 are in the James Valley.

Geologic Section 1.—In Richmond, Fredericksburg and Potomac Railroad cut, half a mile south of Aquia Creek

	Feet
Pleistocene	
Gravel and loam	3
Eocene	
Aquia formation (14 feet)	
Weathered greensand with limonitic crusts	2
Greensand, sparingly fossiliferous	12
Lower Cretaceous	
Patapsco formation (61 feet)	
White coarse-grained, cross-bedded sands	6
White sandy clay and coarse-grained sand	10
Greenish and purplish clay and coarse-grained sand	20
Coarse-grained sandstone	2
Gravel and coarse-grained sand	8
Coarse-grained sand	15
	78

Geologic Section 2.—On the west side of Potomac River, S. 10° E. of Brents Point

	Ft.	In.
Pleistocene		
Partly concealed; mainly fine-grained white sand	20	
Eocene		
Aquia formation (51½ feet)		
Indurated layers with traces of *Turritella* and *Ostrea*.	4	6
Light-colored greensand; *Turritella mortoni, Crassatellites alaeformis, Meretrix* sp., *Ostrea compressirostra, Nucula* sp.	18	
Dark-colored greensand; fossils very poorly preserved	14	
Indurated layer; *Turritella mortoni*	1	

	Ft.	In.
Zone of broken shells	3	
Indurated layer		6
Greensand with broken shells		6
Indurated layer	1	
Dark-colored greensand with broken shells	9	
	71	6

Material collected from the beach at this locality yielded the following fossils: *Turritella mortoni, Ostrea* sp., *Ostrea compressirostra, Crassatellites aquiana, Meretrix ovata, Myliobatis copeanus, Myliobatis magister, Trionyx* sp., *Tudicla* sp., *Cucullaea gigantea, Odontaspis elegans, Odontaspis macrota,* and *Odontaspis obliquus,* and *Trochocyathus clarkeanus.*

Geologic Section 3.—On the west side of Potomac River, S. 20° E. of Brents Point

	Ft.	In.
Pleistocene		
Concealed	30	
Fine-grained white sand	5	
Eocene		
Aquia formation (26½ feet)		
Weathered greensand; *Turritella mortoni*	4	
Greensand with traces of fossils	6	
Indurated layer filled with *Crassatellites alaeformis, Venericardia planicosta, Ostrea, Panopea elongata, Turritella mortoni* and other species	2	6
Zone of broken shells, mainly *Turritella* and *Crassatellites,* with a few *Ostrea*	4	6
Indurated layer, same fossils as in above indurated layer		6
Zone of broken shells		6
Indurated layer; *Turritella mortoni, Crassatellites,* and *Ostrea*		6
Zone of broken shells	2	
Indurated layer		6
Greensand with a few shells	2	6
Greensand, very fossiliferous; *Meretrix ovata, Dosiniopsis lenticularis, Ostrea compressirostra,* and *Crassatellites alaeformis*	3	
	61	6

Geologic Section 4.—*On the west side of Potomac River near Marlboro Point*

	Feet
Pleistocene	
Coarse-grained sand and gravel	3
Eocene	
Aquia formation (17 feet)	
Greensand, weathered with shark teeth and traces of fossils	6
Greensand, weathered, very fossiliferous; *Turritella mortoni, Turritella mortoni* var. *postmortoni, Ostrea compressirostra, Trochocyathus clarkeanus, Dosiniopsis lenticularis?, Myliobatis* sp., *Crassatellites alaeformis, Venericardia* sp., *Meretrix ovata, Lunatia marylandica?, Tornatellaea* sp., *Corbula aldrichi, Corbula* sp., *Turritella humerosa,* and *Crassatellites aquiana*	5
Indurated layer with *Turritella mortoni, Turritella humerosa, Panopea elongata, Crassatellites aquiana, Odontaspis* sp., *Ostrea compressirostra.* and other species	4
Greensand, dark-green, fossiliferous; *Ostrea compressirostra, Crassatellites alaeformis*	2
	20

Material collected from the beach at this locality yielded the following species: *Ostrea compressirostra, Crassatellites alaeformis, Scala sessilis?, Turritella mortoni, Trionyx* sp., *Meretrix ovata, Dosiniopsis* sp., *Panopea elongata, Odontaspis* sp., *Lunatia* sp., *Myliobatis* sp., *Thecachampsa* sp., *Eupsammia elaborata, Trochocyathus* sp.

Geologic Section 5.—*On the south side of Potomac River near Belvedere Beach*

	Feet
Pleistocene	
Coarse-grained light-colored sand	3
Eocene	
Aquia formation	
Greensand, very fossiliferous, weathered and light-colored near top; *Ostrea compressirostra, Tri-*	

	Feet
onyx virginiana, Fulguroficus argutus, Tudicla marylandica, Turritella mortoni var. *post-mortoni, Turritella mortoni, Turritella humerosa, Cucullaea gigantea, Venericardia planicosta, Meretrix ovata, Crassatellites alaeformis, Protocardia lenis, Myliobatis magister, Myliobatis copeanus, Thecachampsa sericodon?, Pecten johnsoni, Odontaspis elegans, Otodus obliquus, Phyllodus medius?, Phyllodus toliapicus, Phyllodus marginalis,* and *Phyllodus speciosus;* reptilian coprolites, crocodile bones?; detached vertebral centrum of a teleost fish	14
	17

Geologic Section 6.—On the south side of Potomac River, S. 70° *E. of Maryland Point*

	Feet
Pleistocene	
Coarse-grained sand and gravel	15
White sandy clay	6
Coarse-grained white sand and layers of white clay	4
White, coarse gravels	3
Eocene	
Nanjemoy formation	
Greensand, fossiliferous; *Venericardia potapacoensis,* and *Turritella potomacensis*	10
	38

Geologic Section 7.—On the south side of Potomac River, S. 40° *W. of Maryland Point, near Grymes Cove*

	Ft.	In.
Pleistocene		
Sand and gravel, partly concealed	17	
Eocene		
Nanjemoy formation (15 feet)		
Greensand, bluish		6
Greensand, mottled, a few imprints of pelecypods, iron-streaked		6
Greensand, dark-colored; *Venericardia potapacoensis*	4	

	Feet
Greensand, dark-colored; *Venericardia potapacoensis, Dentalium minutistriatum, Corbula aldrichi, Pecten dalli, Nucula potomacensis, Dentalium mississippiensis, Cadulus abruptus?, Meretrix ovata, Leda potomacensis, Corbula* sp., *Tellina* sp.	1
Greensand, dark-colored, argillaceous	9
	32

Geologic Section 8.—*On the south side of Potomac River, N.* 80° *E. of Metomkin Point*

	Feet
Pleistocene	
Gravel, partly concealed	3
Fine-grained white sand	20
Eocene	
Nanjemoy formation (40 feet)	
Greensand, iron-streaked; a few fossils, mainly *Venericardia potapacoensis*	10
Greensand, dark-colored, very fossiliferous; *Meretrix subimpressa, Venericardia marylandica, Meretrix ovata, Corbula aldrichi, Lucina uhleri, Tellina virginiana?,* and *Turritella* sp.	20
Greensand, iron-streaked and gray on weathered surfaces	10
	63

Geologic Section 9.—*On the south side of Potomac River near Woodstock, above Mathias Point*

	Feet
Pleistocene	
Gravel and coarse-grained sand	25
Eocene	
Nanjemoy formation (28 feet)	
Greensand, argillaceous; *Turritella potomacensis, Ostrea sellaeformis, Corbula* sp., and *Leda* sp.	20
Greensand, less argillaceous, weathered gray; *Meretrix ovata, Leda parva, Corbula aldrichi, Venericardia potapacoensis, Nucula ovula,*	

Ostrea sellaeformis, Leda cultelliformis, Turritella potomacensis, and *Litiopa marylandica*	8
	53

Microfaunas were identified from greensands near the base of this section. The Foraminifera consists of *Cibicides fletcheri, Cibicides conoides, Cibicides lobatulus, Cibicides* sp., *Planularia* sp., *Bulimina gracilis, Globigerina bulloides, Globigerina* sp., *Lagena sulcata, Nonion pizarrensis, Polymorphina austriaca, Globulina gibba, Pyrulina albatrossi, Rotalia beccarii, Valvulineria floridans,* and *Discorbis* sp. The Ostrocoda comprise *Cytheridea perarcuata, Cytheridea mulleri, Cythere marylandica, Cythere oliveri, Cythere* sp., and *Bairdiidae subdeltoidea.*

Geologic Section 10.—*About* 3 *miles northeast of Edge Hill along Machodoc Creek*

	Feet
Recent	
Soil	4
Pleistocene	
Argillaceous sand	10
Fine-grained white sand	25
Eocene	
Nanjemoy formation	
Greensand, dark-colored, weathered at top; fragments of lignitized wood, *Carpolithus marylandicus*	15
	54

Geologic Section 11.—*On the south side of Rappahannock River, half a mile southeast of mouth of Massaponax Creek*

	Feet
Pleistocene	
Sand and gravel, largely concealed	20
Eocene	
Aquia formation	
Greensand, weathered; traces of *Turritella* and a few pelecypods	8
Lower Cretaceous	
Cross-bedded sand and gravel with stringers of clay	12
	40

Geologic Section 12.—*On the south side of Rappahannock River, 2 miles above the mouth of Muddy Creek*

	Feet
Concealed	10
Eocene	
Aquia formation (20 feet)	
Greensand, weathered, iron-streaked	12
Greensand, dark-colored, argillaceous; *Meretrix ovata, Ostrea compressirostra, Crassatellites alaeformis, Turritella humerosa, Corbula aldrichi, Modiolus alabamensis,* and *Lucina uhleri*	8
	30

Geologic Section 13.—*On the south side of Rappahannock River at Moss Neck*

	Feet
Recent	
Soil	3
Eocene	
Nanjemoy formation (?)	
Greensand, argillaceous, weathered gray in places and iron-streaked; gypsum crystals abundant	30
Aquia formation	
Greensand, weathered, limonitic crusts and gypsum crystals; *Turritella mortoni*	4
Greensand, less weathered, with many casts of *Turritella mortoni* and *Turritella humerosa*	3
	40

Geologic Section 14.—*On the north side of Rappahannock River at Ratcliff Wharf*

	Feet
Recent	
Soil	2
Pleistocene	
Sand and gravel	10
Eocene	
Aquia formation (14 feet)	
Greensand, weathered, traces of shells	7

Greensand, very fossiliferous; *Turritella mortoni, Meretrix ovata, Crassatellites alaeformis, Cucullaea gigantea, Modiolus alabamensis,* and *Lunatia* sp.	7
	26

Geologic Section 15.—*On the north side of Rappahannock River near Hop Yard, southwest of King George*

	Feet
Pleistocene	
Sand and gravel	10
Eocene	
Aquia formation (20 feet)	
Weathered sandy clay and greensand; *Ostrea compressirostra, Turritella mortoni,* and *Meretrix ovata*	17
Dark, greenish-blue, fine-grained greensand	3
	30

The following microfossils were identified from the greensand at this locality. The Foraminifera include *Anomalina bilateralis, Dentalina baggi, Dentalina* sp., *Nodosaria consorbrina, Polymorphina gibba, Robulus americanus, Nonion pizarrensis, Nonion* sp., *Rotalia advena, Discorbis isabelleana,* and *Epistomina elegans.* The Ostrocoda include *Cytherella submarginata, Cytheridea mülleri, Cytheridea* sp., *Cythere plebeia, Bairdia subdeltoidea,* and *Bairdia* sp.

Geologic Section 16.—*On the north side of Rappahannock River, 2 miles above Port Conway*

	Feet
Pleistocene	
Sand and gravel	15
Eocene	
Nanjemoy formation	
Greensand, light-colored, with iron crusts, fine needles and rosettes of gypsum. A few indistinct imprints of *Turritella* and *Meretrix*	13
Aquia formation	
Greensand, indurated; *Turritella mortoni* abundant	1
Greensand, mostly concealed	6
	35

Geologic Section 17.—On the south side of Rappahannock River at Port Royal

	Feet
Recent	
Soil and sand, largely concealed	3
Eocene	
Nanjemoy formation (22 feet)	
Greensand, weathered; traces of fossils	4
Greensand, rather fossiliferous; mainly *Venericardia potapacoensis*	8
Greensand, very fossiliferous; *Venericardia potapacoensis, Lucina dartoni, Cadulus abruptus, Meretrix ovata, Leda parva, Corbula aldrichi, Nucula potomacensis,* and *Lunatia* sp.	10
	25

Geologic Section 18.—On Mill Creek, half a mile northwest of Pin Hook, near U. S. Highway 17

	Feet
Recent	
Soil	2
Eocene	
Nanjemoy formation	
Greensand, very fossiliferous; *Lucina uhleri, Venericardia potapacoensis, Cadulus abruptus, Meretrix subimpressa, Meretrix ovata, Tellina virginiana, Leda parva, Leda* sp., *Leda improcera, Nucula potomacensis, Corbula aldrichi, Pecten dalli, Turritella potomacensis, Hercoglossa* sp., and *Ostrea sellaeformis*	12
	14

Geologic Section 19.—On the south side of Mattaponi River, 3 miles north of Penola

	Feet
Concealed	5
Eocene	
Aquia formation (11 feet)	
Greensand, weathered; partly concealed, *Turritella mortoni*	3

	Feet
Greensand, dark-colored; *Turritella mortoni, Cucullaea gigantea,* and *Ostrea compressirostra*....	8
	16

Geologic Section 20.—*On the south side of Mattaponi River,* 0.3 *mile west of State Highway* 2

	Feet
Concealed..	8
Eocene	
Aquia formation	
Greensand, dark-colored; numerous moulds and imprints of *Meretrix ovata, Dosiniopsis* sp., *Turritella mortoni,* and *Modiolus* sp............	5
	13

Geologic Section 21.—*On the west side of Mattaponi River at Reedy Mill (Doswell quadrangle)*

	Feet
Recent	
Soil..	2
Eocene	
Nanjemoy formation	
Greensand, argillaceous, light-colored at top, darker at base, very fossiliferous; *Meretrix ovata, Tellina papyria?, Leda parva, Leda improcera, Leda tysoni, Leda cutelliformis, Corbula aldrichi, Tellina virginiana, Meretrix subimpressa, Venericardia potapacoensis, Venericardia* sp., and *Lucina uhleri*.........................	12
	14

Geologic Section 22.—*On the south side of Mattaponi River near the mouth of Cobbin Swamp*

	Ft.	In.
Pleistocene		
Sand and gravel, mostly concealed....................	20	
Eocene		
Nanjemoy formation (6 feet)		
Greensand, weathered, a few *Venericardia potapacoensis*..................................		6

Greensand, argillaceous, iron-streaked, with crystals of gypsum; a few imprints of *Venericardia potapacoensis*	5	6
	26	

Geologic Section 23.—On the north side of Pamunkey River, half a mile above the Tram Bridge

	Feet
Pleistocene	
Concealed	3
Coarse-grained sand and gravel	5
Eocene	
Aquia formation (19 feet)	
Greensand, weathered	3
Clay, gray	2
Greensand, weathered, with fossil imprints	6
Greensand, dark-colored, very fossiliferous; *Ostrea compressirostra, Turritella mortoni, Meretrix ovata, Cucullaea gigantea, and Modiolus* sp.	8
	27

Geologic Section 24.—On the south side of Pamunkey River at the Tram Bridge

	Feet
Pleistocene	
Sand and gravel, largely concealed	8
Eocene	
Aquia formation	
Greensand, very fossiliferous; *Turritella mortoni, Cucullaea gigantea, Meretrix ovata, Crassatellites alaeformis,* and *Modiolus* sp.	3
	11

Geologic Section 25.—On the north side of Pamunkey River, half a mile west of Dabney Mill

	Feet
Pleistocene	
Concealed	3
Sand and gravel	5

Eocene

Nanjemoy formation (25 feet)

Greensand, weathered; few fossil imprints; *Carpolithus marylandicus*	6
Greensand, mostly concealed	15
Greensand, dark-colored, very fossiliferous; *Hercoglossa* sp., *Ostrea sellaeformis, Venericardia potapacoensis, Meretrix ovata,* and *Cadulus* sp.	4
	33

Geologic Section 26.—In the old marl pit 2½ miles northeast of Old Church, near south side of Pamunkey River

	Feet
Recent	
Soil, mostly concealed	4
Eocene	
Nanjemoy formation (8 feet)	
Greensand, weathered; with *Ostrea sellaeformis,* and a few shark teeth	5
Greensand, dark-colored; *Venericardia potapacoensis,* and *Ostrea* sp.	3
	12

Geologic Section 27.—On the south side of James River, half a mile east of City Point

	Feet
Pleistocene	
Concealed sand and gravel.	
Miocene	
Concealed: *Venus mercenaria, Chama, Teredo, Plicatula, Arca,* and *Ecphora* are present on the beach below this section.	
Eocene	
Nanjemoy formation	
Greensand, largely concealed.	
White blocky clay, gypsum crystals	5
Aquia formation (15 feet)	
Greensand, weathered; fossils poorly preserved, *Turritella mortoni, Cucullaea gigantea, Crassatellites alaeformis, Modiolus* sp., and *Natica* sp.	3

Greensand, weathered in places; a few fragments of shells and pieces of gypsum................	12
	20

Geologic Section 28.—On the south side of James River, half a mile below Indian Point

	Feet
Pleistocene	
Sands and gravel, mostly concealed	
Miocene	
Mostly concealed	
Eocene	
Nanjemoy formation	
Greensand, weathered; *Venericardia potapacoensis,* and *Ostrea sellaeformis*....................	15

On the south bank of James River at Coggins Point, talus and vegetation cover the slopes of the bluff to such an extent that it is impossible to measure the exact thickness of the formations. At a point where the bluff is about 60 feet high, Nanjemoy greensands are exposed to a height of 15 feet above river level. This is probably the easternmost exposure of the Nanjemoy formation in the James Valley.

SOURCE OF SEDIMENTS

The chief constituents of the Aquia and Nanjemoy formations may be classified in regard to origin as terrigenous arenaceous and argillaceaus materials; calcareous materials of organic origin; and glauconite, a secondary deposit of marine origin. The arenaceous and argillaceous materials were originally derived from the weathering and disintegration of crystalline rocks in the Piedmont province to the west. Possibly some sediment was derived from the Paleozoic rocks still farther west. The organic remains consist chiefly of shells of mollusks which were buried in the sediments in which they are now found. They have been subjected to considerable solution since they were deposited. This calcareous material now forms the cement of the indurated layers and the calcareous concretions.

ORIGIN OF GREENSAND

Greensand is an important component of the Eocene formations. (See Pls. 5 and 6.) Its mode of occurrence and origin have been discussed by several writers.[37] Glauconite is a characteristic constituent.

Greensand was recognized at an early date. Alexander von Humboldt in 1823 reported its occurrence in the Carboniferous of Hungary, the Trias and Cretaceous of Germany, and the Eocene of France. An analysis of the Eocene greensand made by Berthier in 1821 was accepted by later students of the problem. In 1855, Ehrenberg first showed the relationship between greensand and foraminifera, based on material from various Cretaceous and Tertiary marls of the United States. J. W. Bailey in 1856 made further studies of American Cretaceous and Tertiary greensands. He was the first to show that greensands are forming in present seas, probably under conditions similar to those existing in earlier geologic ages. He thought it likely that all greensands were formed as a result of the decay of organisms and that changes during the decay formed glauconite.

One of the most satisfactory explanations of the formation and origin of glauconite is that given by Murray and Renard in their report on the deep-sea deposits of material obtained by the Challenger expedition of 1872-76. They believed that glauconite is principally developed in the interior of calcareous structures, more particularly the shells of foraminifers. A perfect transition was observed from chambers filled with a green opaline mass to grains which showed indistinct imprints of the organisms in which they were formed. It was thought that organic matter caused the precipitation of certain mineral substances. Murray and Renard postulated that a chemical reaction takes place in the organic matter enclosed in the shell and in the mud itself whereby the iron in the mud is transformed into sulphide which may be oxidized into hydrate with the liberation of sulphur at the same time. Sulphur oxidized into sulphuric acid would decompose the fine clay and set free colloidal silica, with aluminum being removed in solution. Thus, colloidal silica and hydrated oxide of iron are available for combination. They thought that the potash in the glauconite was derived from the terrigenous minerals, particularly orthoclase and muscovite, with which glauconite is associated.

Cayeux[38] suggests that some glauconite was formed after the consolidation of its rocky matrix, and that it can be formed without the intervention of Foraminifera. He also states that ferric hydroxide and pyrite are produced by the decomposition of glauconite.

[37]Clark, W. B., A preliminary report on the Cretaceous and Tertiary formations of New Jersey: New Jersey Geol. Survey Ann. Rept., pp. 167-245, 1893.

Clark, W. B., Origin and classification of the greensands of New Jersey: Jour. Geology, vol. 2, pp. 161-177, 1894.

Clark, W. B., and Martin, G. C., The Eocene deposits of Maryland: Maryland Geol. Survey, Eocene text, pp. 55-57, 1901.

Clarke, F. W., The data of geochemistry (fifth edition): U. S. Geol. Survey Bull. 770, p. 523, 1924.

Murray, J., and Renard, A. F., Deep sea deposits, Challenger Rept., pp. 519-523, 1891.

[38]Cayeux, L., Contributions à l'étude micrographique des terrains sédimentaires: Mém. Soc. géol. du Nord, vol. 4, pt. 2, pp. 163-184, 1897.

It has recently been suggested that certain glauconite in littoral deposits near Japan is in part fossil coprolites that have become glauconized.[39] Such grains, called "coproglauconite," have been identified with glauconite of other areas.

One of the most recent contributions to the origin of greensand and glauconite is that of Hadding.[40] He shows that the relationship of glauconite to Foraminifera is coincidental, and that its formation is not dependent on, although favored by, the presence of organic matter. He thinks that it forms at relatively low temperatures and not in a highly oxidizing environment. He concludes that much glauconite forms in relatively shallow marine waters and is most abundantly deposited following periods of scant sedimentation.

It has been estimated that approximately 1,000,000 square miles of sea floor are now covered with deposits of glauconite. The depth at which it occurs is commonly 100 to 200 fathoms although it has been found at depths as great as 900 fathoms.

Goldman[41] advanced the idea that some glauconite deposits occur at breaks in a sedimentary series. He thinks that the significant breaks, or pronounced changes in lithology of a sedimentary series, are likely to be marked by glauconite that was formed contemporaneously. He recognized the fact that not all glauconite deposits are associated with unconformities.

It has been generally recognized that glauconite commonly is associated with phosphate and that both are related to the occurrence of organic matter. Cayeux[42] was of the opinion that the glauconite associated with phosphate was formed during periods of disturbance of ocean levels, in which a general destruction of life resulted. Goldman does not subscribe to this view but regards such a condition as being too local to account for such a destruction.

In view of the studies of Goldman and other workers cited above, it seems reasonable to assume that the association of glauconite and phosphate with stratigraphic breaks is significant in many localities. It cannot be used, however, as an unqualified criterion in recognizing unconformities.

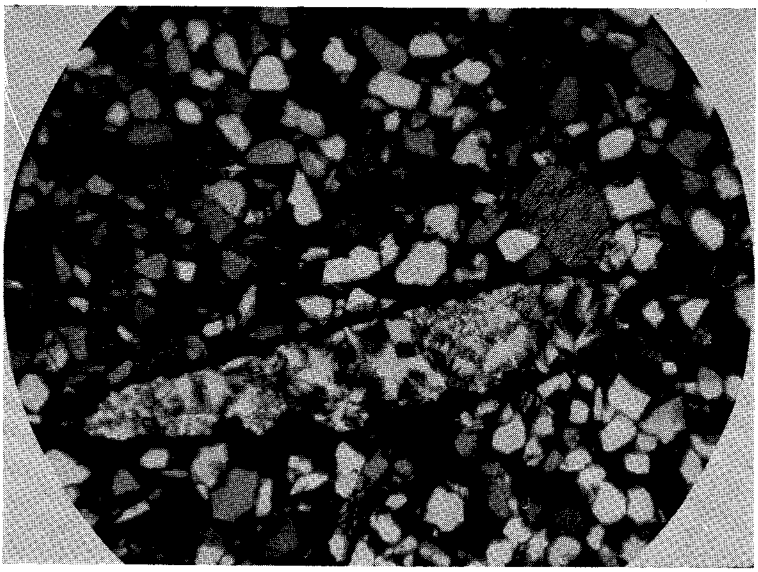
---

[39]Takahashi, Jun-Ichi, and Yagi, Tsugio, Peculiar mud-grains and their relation to the origin of glauconite: Econ. Geology, vol. 24, pp. 838-852, 1929.

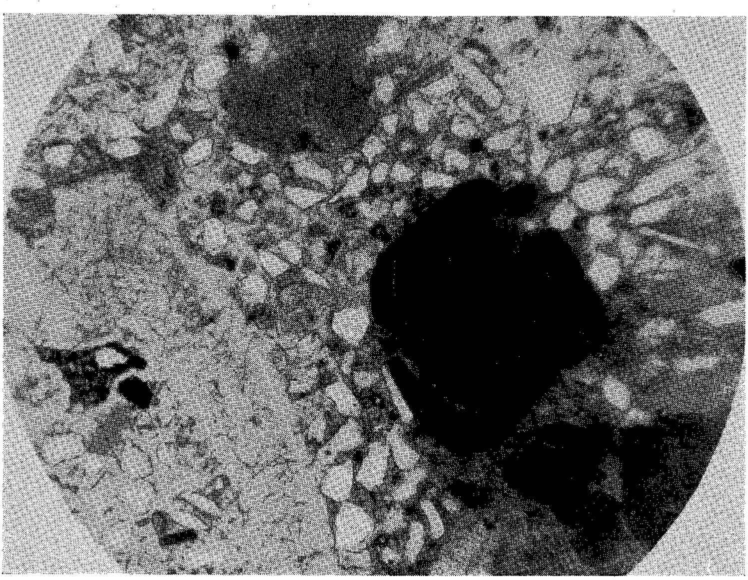
[40]Hadding, Assar, The pre-Quarternary sedimentary rocks of Sweden, Part IV: Med. fran Lunds Geologisk-Mineralogiska Inst., No. 51, 1932.

[41]Goldman, M. I., Lithologic subsurface correlation in the "Bend Series" of north-central Texas: U. S. Geol. Survey Prof. Paper 129, pp. 1-22, 1921; Association of glauconite with unconformities (abstract); Geol. Soc. America Bull., vol. 32, p. 25, 1921; Basal glauconite and phosphate beds: Science, new ser., vol. 56, pp. 171-173, 1922.

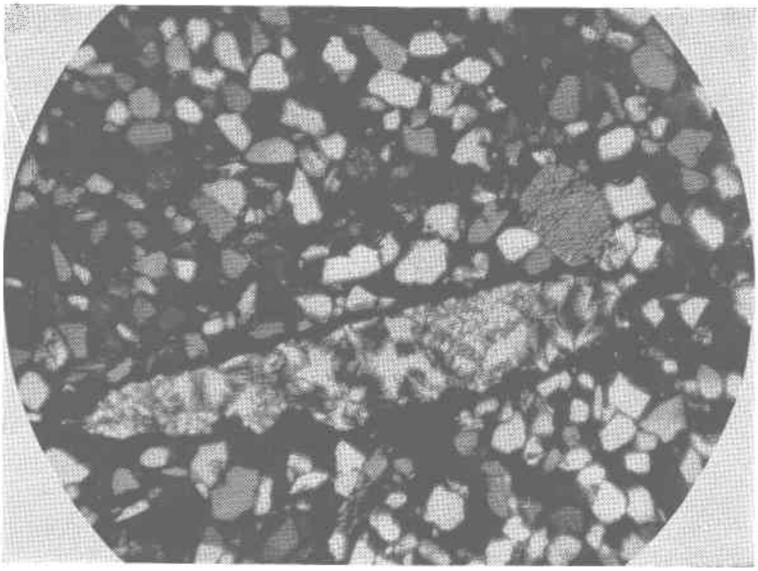
[42]Cayeux, L., Contributions à l'étude micrographique des terrains sédimentaires: Mém. Soc. géol. du Nord, vol. 4, pt. 2, pp. 163-184, 427-432, 1897; Genèse des gisements de phosphates de chaux sédimentaires: Bull. Soc. géol. de France, 4e ser., vol. 5, pp. 750-753, 1905.



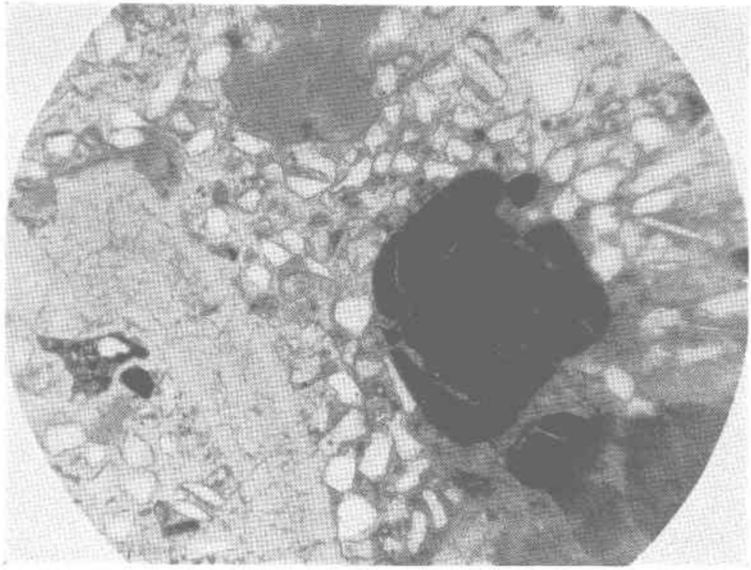
A. Photomicrograph of silicified bed in the Aquia formation, half a mile east of Stafford, Virginia. Grains of quartz, with some grains of other minerals, stud the groundmass of quartz. X 35.



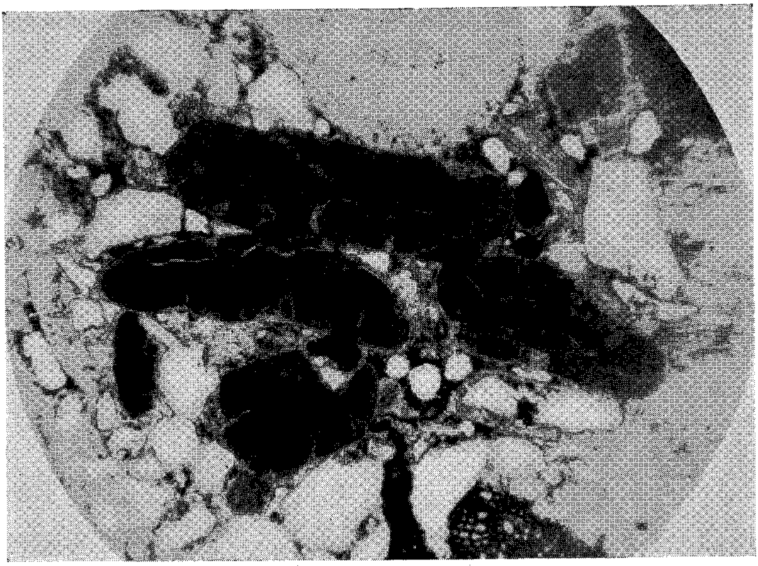
B. Photomicrograph of silicified bed in the Aquia formation, showing large grains of glauconite. The angular grains are quartz. The arcuate section is part of a shell. X 35.



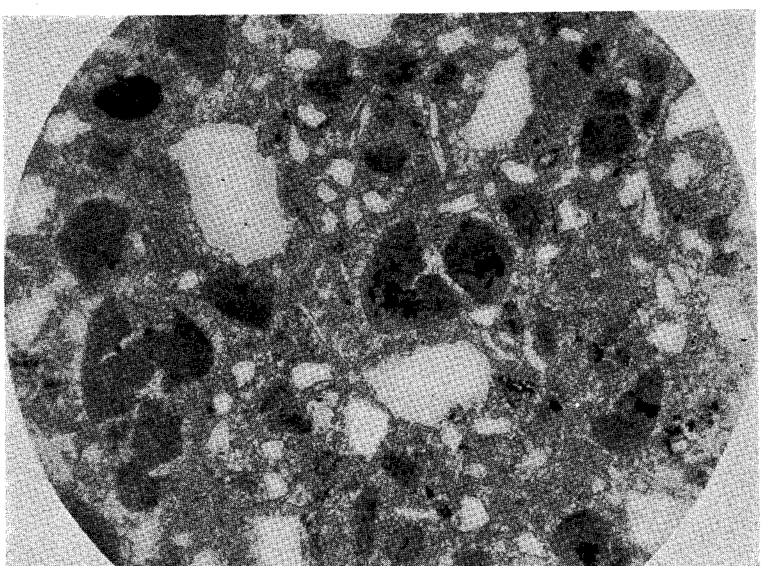
A. Photomicrograph of silicified bed in the Aquia formation, half a mile east of Stafford, Virginia. Grains of quartz, with some grains of other minerals, stud the groundmass of quartz. X 35.



B. Photomicrograph of silicified bed in the Aquia formation, showing large grains of glauconite. The angular grains are quartz. The arcuate section is part of a shell. X 35.

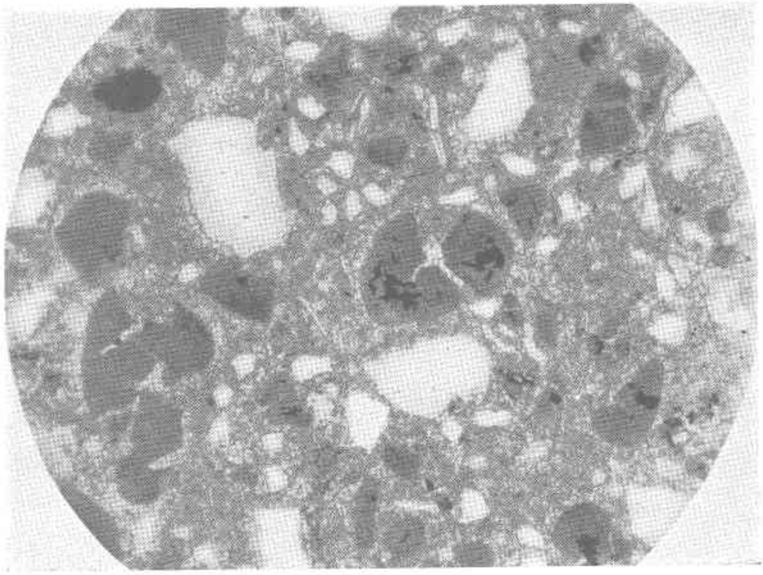


A. Photomicrograph of silicified bed in the Aquia formation, showing large grains of glauconite spotted with secondary iron oxide. X 35.



B. Photomicrograph of calcareous concretion in the Nanjemoy formation at Woodstock, along Potomac River. Fresh and weathered grains of glauconite are in a groundmass of calcite. The white grains are quartz. X 35.

A. Photomicrograph of silicified bed in the Aquia formation, showing large grains of glauconite spotted with secondary iron oxide. X 35.



B. Photomicrograph of calcareous concretion in the Nanjemoy formation at Woodstock, along Potomac River. Fresh and weathered grains of glauconite are in a groundmass of calcite. The white grains are quartz. X 35.

STRUCTURE

The Eocene beds have been only slightly deformed. Folds and faults were not observed. The strike of the formations is almost due north. The beds have an eastward dip of 12 to 15 feet to the mile.

According to McGee,[43] a monoclinal displacement at the mouth of Aquia Creek amounts to 25 feet. The writer has been unable to recognize this displacement. It is thought that any post-Eocene movement in this area has been one of slight uplift rather than sinking and warping. It is possible that changes may have been caused by sedimentation in old estuaries.

GEOLOGIC HISTORY

CRETACEOUS PERIOD

In Early Cretaceous time the Coastal Plain was the site of extensive continental sedimentation. The sediments consist mainly of clastic material derived from lands farther west. Lignitic sediments indicate local swamps. In Late Cretaceous time the sea apparently transgressed the eastern part of the Virginia Coastal Plain, but all sediments of this age are concealed by the Tertiary deposits.

TERTIARY PERIOD

During Early Tertiary time (Wilcox epoch) the Coastal Plain was again submerged and the Eocene sediments were deposited. They represent the advance of the Atlantic Ocean across an old land surface of low relief, as is shown by the almost horizontal contact between the Cretaceous and Eocene formations. The writer is of the opinion that the Virginia Coastal Plain of Eocene times was indented, similar to the Virginia coast today. This would account in part for the difference in altitude of the contact between the Eocene and Cretaceous strata, mentioned above. The maximum extent of the submergence and the original extent and thickness of the Eocene formations are unknown. The adjacent land was relatively low and flat. The fauna and sediments indicate that the seas were of moderate depth. The abundance of oysters (*Ostrea compressirostra* and *O. sellaeformis*) is indicative of shallow depths as the food supply of these forms is obtained in waters rarely exceeding 15 fathoms deep. Furthermore, Bagg has pointed out that

[43]McGee, W J, The geology of the head of the Chesapeake Bay: U. S. Geol. Survey 7th Ann. Rept., pp. 545-646, 1888.

the Foraminifera are mainly shallow water types. The coarser materials at the base of the Aquia formation are suggestive of shallower depths than the overlying finer-grained and more glauconitic beds. The glauconite is indicative of relatively shallow water.

Absence of Oligocene sediments in the Coastal Plain of Virginia can best be explained by assuming continental conditions. It hardly seems possible that either contemporaneous or subsequent erosion could have removed all sediments of Oliogocene time.

The Coastal Plain was elevated and eroded before Miocene (Chesapeake) deposition took place. The extent of the uplift, the amount of tilting, and the thickness of sediments removed are not known. The emergence was followed by submergence and deposition. The Miocene formations are separated by unconformities, which indicate that there were repeated emergences and submergences during Miocence time, with accompanying changes in the character of the faunas.

Sand, gravel, and clay were deposited over the western part of the Coastal Plain during Late Tertiary (Pliocene) time. No Pliocene fossils, however, have been found in these deposits. Most of the material was evidently deposited by streams that had extended drainage basins to the west. The character of the sand and gravel, as well as fossiliferous pebbles, shows that the material was derived from rocks of the Piedmont and Appalachian Valley provinces.

PLEISTOCENE AND RECENT TIME

Deposits of sand and gravel were made over the Coastal Plain during Pleistocene time. In general the deposits along the seaward margin of the Coastal Plain are regarded as of marine origin, whereas many of the inland deposits are of fluviatile origin.[44] Scattered through the deposits are beds of clay and lignite, and ice-borne striated boulders. According to Wentworth, the boulders were probably carried downstream by floating ice.

During Recent geologic time the old valleys of the Coastal Plain were submerged by the sea, thus forming Chesapeake Bay and the drowned valleys of the major streams and many of the small tributaries. The land surface is now being eroded and sediments are accumulating, chiefly along the rivers, in lakes and swamps, and in the sea.

EOCENE FAUNAS

Aquia formation.—The majority of fossils in the Aquia formation are mollusks. Other groups of invertebrates as well as some vertebrate

[44]Wentworth, C. K., Sand and gravel resources of the Coastal Plain of Virginia: Virginia Geol. Survey Bull. 32, p. 100, 1930.

remains occur. All the mollusca are marine forms, represented by a large variety of pelecypods and gastropods. The most representative forms are: *Turritella mortoni, Lunatia marylandica, Meretrix ovata, Cucullaea gigantea, Ostrea compressirostra, Crassatellites alaeformis,* and *Dosiniopsis lenticularis.*

Corals are represented by a few Hexacoralla forms which are nowhere abundant. Vaughan,[45] in 1900, described the coral species *Eupsammia conradi,* from a locality along Pamunkey River, Kent (New Kent) County, Virginia. He did not state the age of the containing bed, but it is probably Eocene (Aquia). Bryozoa are represented by a single species of limited occurrence. Fragmentary spines of echinoderms have been found.

Fish teeth and dental plates constitute the greater part of the vertebrate remains. Detached vertebral centrums, costal plates of turtles, crocodile teeth, fragmentary reptilian bones and vertebrae, and questionable reptilian coprolites are rare. All of these vertebrate remains have been found in the Aquia formation at Belvedere Beach.

The microscopic faunas of the Aquia formation consist of two main groups, Foraminifera and Ostrocoda. Foraminifera constitute the principal microfaunas, of which six families, twelve genera, and sixteen species have been determined. One family, four genera, and six species of Ostrocoda have been identified.

The Aquia beds have been so leached by ground waters in many places that the original shells have either disappeared or have been so weakened as not to be collectible. Molds, casts, and imprints of Mollusca are abundant throughout the formation. They are particularly well preserved in the indurated layers near the mouth of Aquia Creek, at Fairview Beach, and in the large calcareous concretions at Hop Yard on Rappahannock River. The same association of forms has been preserved in the silicified beds near Stafford Court House and in the vicinity of Brooke. One specimen of a pyritized internal mold of *Meretrix ovata* was collected on the south bank of Rappahannock River, 15 miles southeast of Fredericksburg.

The extreme scarcity of microfaunas may be due in part to leaching by ground water. The majority of the forms are well preserved and have not lost their original markings. The larger species which were collected at Hop Yard appear to be more worn than those identified from the locality 15 miles southeast of Fredericksburg on the south bank of Rappahannock River, or from Woodstock.

[45] Vaughan, T. W., The Eocene and lower Oligocene coral faunas of the United States: U. S. Geol. Survey Mon. 39, p. 183, pl. 21, figs. 10-10b, 1900.

Nanjemoy formation.—The large forms of the Nanjemoy formation are not as plentiful as in the Aquia. The same classes are present but they are not as well represented either in numbers or varieties. Foraminifera compose the principal microfaunas, of which seven families, twelve genera, and sixteen species have been determined. One family, three genera, and six species of Ostrocoda have been identified.

The large forms in the Nanjemoy formation have not been preserved as well as those in the Aquia formation. The original shells of a few forms such as *Ostrea, Meretrix* and *Venericardia* are preserved in the greensand, but commonly only as moulds and casts. The microfaunas are very scarce but are well preserved.

Comparison of faunas.—The Eocene faunas in Virginia are about the same as those in Maryland. Although the number of distinctive species which are common to other Atlantic states and the Gulf Coast is sufficient to permit approximate correlations of the formations, sufficient data are not yet available for a detailed comparison of faunas of widely separated areas. Previous investigations indicate that many of the Virginia species are not represented in other Middle Atlantic states or the Gulf region. In addition, many of the identical species appear to have a wide geological range.

Climatic implications.—The climate, as indicated by the faunas of the Virginia Eocene, was slightly warmer than at present. It was probably more like that of eastern South Carolina and Florida. The predominant mollusks suggest a rather uniform and equable climate.

Post-Eocene hiatus.—The faunal break at the top of the Eocene in Virginia is rather marked. The next youngest Tertiary (Oligocene) deposits are absent. Toward the close of Eocene time, marine waters withdrew from the Coastal Plain region of Virginia. Hence, the Eocene faunas and those of the next youngest beds which overlie them, the Calvert beds of lower Miocene age, are somewhat dissimilar.

EOCENE FLORAS

The fossil record of plants in the Virginia Eocene is meager. The remains consist chiefly of small lignitic nuts and fragments of lignitized wood. Ruffin[46] described a fossil nut from the Eocene marl of Marlboro, Virginia. The writer has collected small lignitized fossil fruits,

[46]Ruffin, Edmund, Description of a nut found in Eocene marl: Am. Jour. Sci., 2d ser., vol. 9, pp. 127-129, 1850.

Carpolithus marylandicus, and wood from the Nanjemoy formation, 3 miles northeast of Edge Hill, King George County, and half a mile west of Dabney Mill on Pamunkey River in King William County. More recently a new species of lignified pine cone, *Pinus lynni,* and a new species of fig, *Ficus aquiana,* have been found at Belvedere Beach, both of which have been described by Berry.[47]

MINERAL RESOURCES

Mineral resources are not abundant in the Eocene deposits of the Virginia Coastal Plain. Greensand marl and clay are the most important ones. Sand and gravel are found locally. Ground water is also an important resource. Some of the mineral resources discussed below occur in other formations in the area shown in Figure 1.

GREENSAND MARL

Greensand marl is characterized by greensand in which glauconite is the most important constituent. Chemical analyses show variable percentages of potash, lime, and phosphate of lime. (See Table I.) Thus the material is a natural fertilizer, a fact which was early recognized by Edmund Ruffin of Virginia.[48] The potash content varies according to the amount of glauconite present. It ranges from about 1 per cent in the very impure greensand to 10 per cent in the purer greensand.[49] Greensand is also used as a filler in the manufacture of fertilizer. It has been used elsewhere as a water softener. Cretaceous greensand has been worked in New Jersey for a long time and sold for fertilizer. Similar greensands have been worked to a less extent in Maryland and Virginia.

The Eocene formations in Virginia contain much greensand and greensand marl. Pits have been dug throughout the area underlain by the Aquia and Nanjemoy formations. The most extensive workings were along the Potomac, Rappahannock, Pamunkey and James rivers. The marl was usually obtained by digging pits, but along Pamunkey River it was also mined by horizontal drifts driven from the river's edge into the banks. Presumably this was done to avoid removal of the overburden. The marl has been used locally as a fertilizer with satisfactory results. Much of the marl was also dried and shipped to fertilizer factories. Little greensand is now being used for fertilizer and there has been no commercial development for 25 years or more.

---

[47] Berry, E. W., A pine from the Potomac Eocene: Wash. Acad. Sci. Jour., vol. 24, pp. 182-183, 1934; A fig from the Eocene of Virginia: Wash. Acad. Sci. Jour., vol. 26, pp. 108-111, 1936.

[48] See Fippin, E. O., More than lime benefits in Ruffin's results: Am. Soc. Agronomy Jour., vol. 33, no. 9, pp. 841-848, 1941.

[49] Clark, W. B., and others. The physiography and geology of the Coastal Plain province of Virginia: Virginia Geol. Survey Bull. 4, p. 239, 1912.

TABLE I.—CHEMICAL ANALYSES OF EOCENE GREENSAND FROM THE COASTAL PLAIN OF VIRGINIA

(J. E. Copenhaver, Analyst)

	1	2	3	4	5
Silica (SiO_2)	77.80	80.20	80.20	73.00	74.68
Alumina (Al_2O_3)	7.86	7.24	6.49	9.60	9.16
Iron oxide (Fe_2O_3)	5.42	5.11	4.75	7.20	8.08
Lime (CaO)	2.12	1.04	2.10	2.88	1.00
Magnesia (MgO)	0.82	0.70	0.58	1.55	1.29
Potash and soda ($K_2O + Na_2O$)	3.60	3.50	3.47	3.30	3.40
Loss on ignition	2.26	2.10	2.35	2.40	2.57
	99.88	99.89	99.94	99.93	100.18

1. Aquia formation, Hop Yard on Rappahannock River. (Spec. G-17.)
2. Aquia formation, near mouth of Aquia Creek. (Spec. G-34.)
3. Aquia formation, near mouth of Aquia Creek. (Spec. G-68.)
4. Nanjemoy formation at Woodstock. (Spec. G-49.)
5. Nanjemoy formation at Woodstock. (Spec. G-72.)

CLAY

Clay is found throughout the area. (See Pl. 4B.) It has been used for making bricks. Some of the clays might also be used for making tile and low-grade pottery. The clays are sandy and vary in color and plasticity. Near Fredericksburg and Stafford are pink clays which are said to have been used by the Indians for paint clay, which it is still called. These clays are not used at present although they were used by the early settlers in making bricks. A somewhat detailed account of the Virginia Coastal Plain clays was published by Watson.[50]

SAND

Fine- to coarse-grained sands are found in all the Tertiary formations of the area. They commonly consist of quartz grains, more or less mixed with clay or gravel. Glauconite, muscovite, feldspar, magnetite, and other minerals may be present in variable amounts. The best grades of sand have been used locally for roads and general construction. Some of the sands may be pure enough to be used as glass sands. Molding sand from the Aquia formation was formerly obtained from several pits along Gillie Creek in the vicinity of Richmond.[51]

[50]Watson, T. L., Clays, *in* Economic products of the Virginia Coastal Plain: Virginia Geol. Survey Bull. 4, pp. 223-239, 1912.
[51]Clark, W. B., and others, *op. cit.*, p. 239.

Deposits of Pleistocene sand and gravel have been extensively worked near Fredericksburg. The pit and gravel works of the Massaponax Sand and Gravel Company are located near Massaponax Creek, about 5 miles southeast of Fredericksburg.

GRAVEL

Gravel of commercial importance is widely distributed throughout the area. It is found chiefly in Pliocene and Pleistocene terrace deposits. It has been used for road metal, railroad ballast, and construction work. The gravel is composed largely of rounded quartz pebbles. In places it occurs in a clay or ferruginous matrix; elsewhere it is found with unconsolidated sands. The occurrence of sand and gravel in this area has been discussed by Wentworth.[52]

OCHER

Ocher was extensively mined in the eastern part of Chesterfield County by the American Ocher Company from 1872 until about 1890. The mine and tunnels are located on the north bank of Appomattox River, about 4 miles west of City Point. There has been no later production.

GROUND WATER

Ground water in the area has been described by Sanford.[53] No later investigations have been made until recent years. Detailed studies are now being made of the ground water resources of the Virginia Coastal Plain, in cooperation with the Federal Geological Survey.

All of the Coastal Plain formations contain water-bearing strata. Deep wells drawing water from Eocene beds are usually far enough inland to be free of salt water. Sanford[54] discusses the Eocene water-bearing sands as follows:

"Of the two Pamunkey formations the Aquia is more important as an artesian reservoir than the Nanjemoy. The former underlies a wider area, and has been more developed along the Potomac and Rappahannock rivers.

"The Nanjemoy formation is, however, an important water-bearer and near its base contains sandy beds that have been tapped by many wells between Potomac and James rivers. . . ."

According to Sanford, flowing wells at Colonial Beach obtain a large supply of water from Eocene sands at a depth of 250 feet; at Loretta at

[52]Wentworth, C. K., Sand and gravel resources of the Coastal Plain of Virginia: Virginia Geol. Survey Bull. 32, 1930.

[53]Sanford, Samuel, The underground water resources of the Coastal Plain province of Virginia: Virginia Geol. Survey, Bull. 5, 1913.

[54]Sanford, Samuel, op. cit., pp. 56-57.

a depth of 150 feet; at Tappahannock at depths of 250 and 275 feet; at White House at a depth of about 160 feet; and at West Point at a depth of about 325 feet.

Ground-water conditions in the Eocene southeast of Petersburg have been discussed by Cederstrom.[55] He is preparing a detailed report on the geology and ground-water resources south of James River.[56]

[55]Cederstrom, D. J., Geology and artesian-water resources of a part of the southern Virginia Coastal Plain: Virginia Geol. Survey Bull. 51E, pp. 119-136, 1939.

[56]To be published by the Virginia Geological Survey.

DESCRIPTION OF LOCALITIES SHOWN IN FIG. 2 (p. 11)

1. Half a mile south of Chopawamsic Creek; Eocene at altitude of 200 feet.
2. At 3½ miles northwest of Widewater; Eocene at altitude of 180 feet.
3. At 1.1 miles northwest of Widewater; Cretaceous-Eocene contact at altitude of 90 feet.
4. One-fourth of a mile northwest of Widewater; Cretaceous at altitude of 20 feet.
5. At Holly; Cretaceous at altitude of 180 feet.
6. First railroad cut south of Aquia Creek; contact at altitude of 100 feet.
7. North bank of Aquia Creek, half a mile west of Brents Point; Eocene at altitude of 20 feet.
8. Half a mile west of Stafford; contact at altitude of 180 feet.
9. Three-tenths of a mile east of Stafford; Eocene at altitude of 200 feet.
10. At Brooke; contact at altitude of 100 feet.
11. At Belvedere Beach; Eocene at altitude of 20 feet.
12. At 3 miles north of Falmouth; Cretaceous at altitude of 160 feet.
13. At Daffen; contact at altitude of 90 feet.
14. At 1.1 miles east of Passapatanzy; Eocene at altitude of 80 feet.
15. About 800 feet west of Falmouth; contact at altitude of 100 feet.
16. At 1 mile northeast of Fredericksburg; contact at altitude of 80 feet.
17. At Belvedere; contact at altitude of 50 feet.
18. At Muddy Creek 0.6 mile northwest of Sealston; Eocene at altitude of 40 feet.

INDEX

PAGE