MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 15

GEOLOGY AND MINERAL RESOURCES OF SOUTHERN MARYLAND

by

John D. Glaser

1971

MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 15

GEOLOGY AND MINERAL RESOURCES OF SOUTHERN MARYLAND

by

John D. Glaser

1971

COMMISSION OF MARYLAND GEOLOGICAL SURVEY

PREFACE

A reader interested in the economic geology of the Southern Maryland Coastal Plain has heretofore been obliged to consult a variety of references, many of them old and very much out of date. This report is intended to satisfy the present need for a comprehensive treatment of the mineral resources of this area. The existing data is summarized, and much new information is included, most of it generated by a test drilling program instituted by the Survey. The value of the report is further increased by the inclusion of test data on greensand, diatomite, and clay developed by the U.S. Bureau of Mines.

Mineral deposits in the Southern Maryland area are relatively few, and with the exception of sand, gravel, and clay, none have more than marginal economic potential. The most important single resource is undoubtedly sand and gravel. Large amounts of such aggregate underlie the upland areas of Southern Maryland and have the capability of supplying the needs of the local economy as well as the construction industry of the Washington metropolitan region. Urban development, chiefly housing, however, is spreading rapidly into southern Prince Georges, northern Charles, and northern Calvert Counties; consequently, the need is great for planned sequential use in those areas underlain by significant deposits of sand and gravel.

The report is comprised of two parts, the first a detailed treatment of the surface geology of Southern Maryland, which establishes the framework for the second part, a discussion of the mineral resources. Part one includes a description of each outcropping formation, its distribution within the survey area, and data on lithologic variation, paleontology, and probable genesis. Moreover, the mineralogy of each unit is considered in some detail. Part two is essentially a commodity by commodity discussion of the mineral resources of the region, including sand, gravel, clay, diatomite, greensand, and phosphate. Each of these is considered in terms of occurrence; distribution; quality; and past, present, and potential utilization.

The information presented in this report should be regarded mainly as a point of departure for comprehensive natural resource planning in Southern Maryland as well as for private exploration and development.

Kenneth N. Weaver, *Director*
Maryland Geological Survey

CONTENTS

ILLUSTRATIONS

TABLES

Table | Page

PLATES

Plate

ABSTRACT

Southern Maryland, defined here to include all of Charles, St. Marys, and Calvert as well as portions of southern Prince Georges and Anne Arundel Counties, takes in some 127 square miles of the Coastal Plain province of eastern Maryland. The area is bounded on the east by Chesapeake Bay and on the west and south by the Potomac River. Just to the north lies the burgeoning Baltimore-Washington metropolitan area.

Southern Maryland is wholly underlain by unconsolidated sediments ranging in age from Cretaceous to Pleistocene. The oldest rocks in the area are fine-grained sand, silt, and variegated clay of the Lower Cretaceous Patapsco Formation, which crops out in a narrow interrupted band in the extreme northwest. Overlying the Patapsco is the equally restricted Upper Cretaceous Monmouth Formation—mostly dark-gray muddy fossiliferous silt totaling about 30 feet of sediment. The Monmouth is succeeded unconformably by a relatively thick, tripartite Paleocene-Eocene section—the Aquia and Nanjemoy Formations separated by the Marlboro Clay—which outcrops over roughly the northwestern third of Southern Maryland. Both the Aquia and Nanjemoy are variably muddy, fossiliferous greensands in contrast to the Marlboro which is a thin but persistent pinkish to gray plastic clay. The Paleocene-Eocene section includes about 500 ft. of sediment. Miocene sediments belonging to the Chesapeake Group crop out over most of the remaining area of Southern Maryland. These include the Calvert, Choptank, and St. Marys Formations, comprising up to 400 ft. of fine dark muddy sand, silt, clay, and diatomite. Virtually all of the upland areas (greater than 100 ft. elev.) of Southern Maryland are thinly veneered with Plio-Pleistocene sand, gravel, and subordinate silt-clay, collectively termed the Upland Deposits. Finally, the youngest sediments in the survey area include the alluvium filling most stream valleys as well as sand with subordinate gravel and clay in the lowland terraces fringing the larger water bodies of Southern Maryland. All of these sediments are Pleistocene or younger in age.

The principal mineral resources of the area are constructional sand, gravel, and clay. Sand and gravel are abundant and widespread in the Upland Deposits and to a lesser extent in the lowland terraces bordering the Potomac and Patuxent Rivers. Thicknesses ranging from 15 to 25 feet of predominantly quartzose sandy gravel with little or no overburden are typical of the Upland Deposits over a large portion of the Southern Maryland area. Medium to coarse-grained quartz sand, and to a lesser extent small gravel, is locally distributed in the Lowland Deposits, but the fact that much of this material is near or below the water table diminishes its economic potential to some degree. Production of aggregate, currently the major mineral industry in Southern Maryland, is likely to remain so in the foreseeable future. Some clays in the St. Marys Formation have tested favorably for lightweight aggregate, and a ceramic clay suitable for face brick and structural tile is present in the Marlboro Clay. Deposits of diatomite, glauconite, and phosphorite also occur in the survey area but are not of economic value under present market conditions.

INTRODUCTION AND ACKNOWLEDGEMENTS

The field work for the Southern Maryland study was conducted during the summer months of 1966 and 1967, supplemented by additional outcrop investigations as required during the autumn and winter of 1967. I was ably assisted in the field throughout both years by J.F.C. Sanda, presently with the U.S. Corps of Engineers. The basic approach for the investigation was to gain familiarity with the stratigraphic succession in Southern Maryland as well as the lithologies represented chiefly by examining as many outcrops as time permitted. To this end, some 169 exposures were seen, mostly road cuts but also construction excavations, stream banks, bluffs bordering the Bay and major rivers, and sand, gravel, or clay pits. Moreover, a large number of sections were carefully measured; the most instructive of these are spotted in the text or in the locality register (Appendix A). An important adjunct of the outcrop study was a 27 hole test drilling program, carried out in 2 stages during the spring and autumn of 1967. The unconsolidated and largely clayey nature of the materials drilled permitted coring by means of 5 ft. thin-walled shelby tubes pressed hydraulically into the sediment (fig. 1) through hollow stem 8 in. augers. Core recovery was generally good, although recovery of medium or coarse clean sands was hardly ever complete. The cores were extruded at the site by means of a hydraulically driven piston assembly, logged more or less superficially, and wrapped in polyethylene film for transport to the laboratory. Footage cored totaled 1255 feet. In the laboratory, the cores were split in half and described in detail, while at the same time samples were taken for textural, mineralogic, and chemical analysis.

Although primarily the work of the author, others have supplied important data for this report without which its value would be materially less. Among these contributors are John W. Hosterman of the U.S. Geological Survey who developed the clay mineralogy of a number of samples, and the U.S. Bureau of Mines at Pittsburgh, responsible for the testing of the clays, greensands, and the diatomite. In addition, I should like to thank Harry J. Hansen and K. N. Weaver of the Maryland Survey staff for suggestions and constructive criticism which have doubtless improved the report to a considerable degree.

GEOGRAPHY

LOCATION AND SIZE

Southern Maryland (Pl. 1), as defined for this report, includes all of Calvert, Charles, and St. Marys Counties as well as the southern portions of Anne Arundel and Prince Georges Counties, a total land area of 1274 square miles. The area lies directly south of the Baltimore-Washington corridor and is wholly within the Coastal Plain. Southern Maryland is in the strict sense a peninsula bounded on the west and south by the Potomac River and on the east by Chesapeake Bay. The northern boundary was arbitrarily established as a straight line across the peninsula from the vicinity of Deale on the Bay shore of Anne Arundel County west to Fort Foote on the east bank of the Potomac in Prince Georges County. Thus the maximum north-south extent of the area is 52 miles and the east-west extent 49 miles.

CLIMATE

Southern Maryland lies within the humid temperate semi-continental climatic zone of the eastern United States, a zone marked by hot humid summers and relatively mild winters. Averaged climatological data for the 10-year period 1959 through 1968 is graphically depicted in figure 2. As can be readily surmised from the graphs, climatic conditions are essentially uniform throughout the Southern Maryland area. Yearly precipitation during the 10-year period ranged from 30.7 inches to 48.6 inches, averaging 38.4 inches. Fairly uniform distribution of precipitation throughout the year is the rule. The average snowfall for the region is about 16 inches per year. Late January through early February is the coldest portion of the winter; temperatures during this period may drop to as low as –12°F. but values

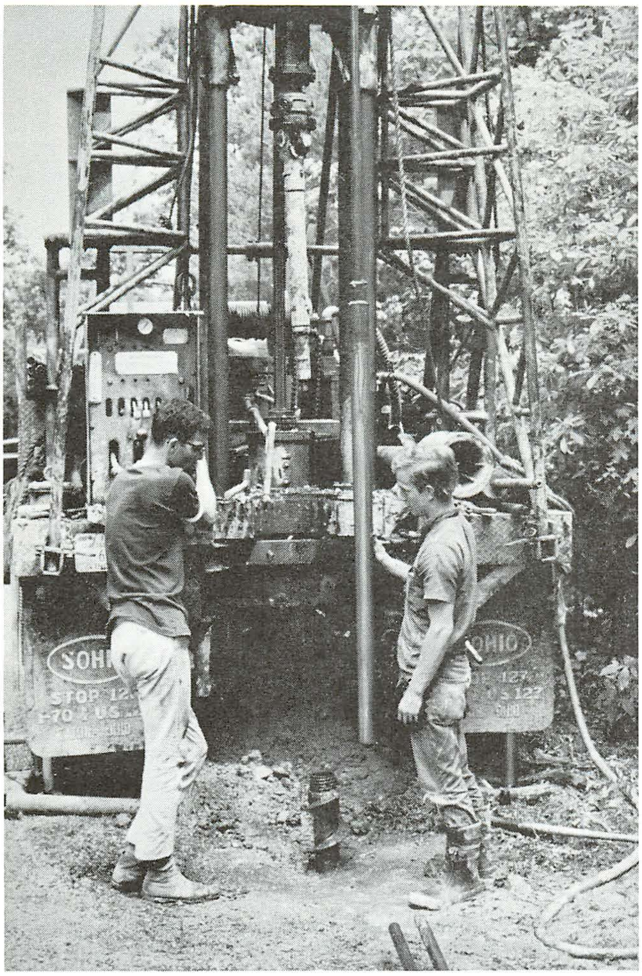

Figure 1. Core-loaded Shelby tube being withdrawn from auger string. This coring method was most successful in fine-grained clayey sediments.

that low are exceptional. In contrast, the hottest summer period is late July-early August when maximum afternoon temperatures average in the high eighties and occasionally exceed 100°F. Between May and October, about 60% of the daylight hours are sunlit as opposed to only 46% in December-January. The mean length of the growing season in Southern Maryland is about 190 days.

POPULATION

Since accurate population estimates are not feasible for those portions of Prince Georges and Anne Arundel Counties included in the survey area, the actual total population of Southern Maryland cannot be given. Population data is readily available, however, for Calvert, Charles, and St. Marys Counties which together comprise 82% of the survey area. These 3 counties in 1970 held 112,270 persons or 2% of the population of Maryland and would be considered sparsely settled by any yardstick. Population density varies from 71 persons per square mile in Charles County to 107 in St. Marys County. During the 10-year period 1960-1970, the tri-county area experienced a 28% increase in population, a growth rate which will doubtless rise substantially during the seventies in response to urban pressures from the Washington area to the north. The most rapid growth is occurring in northern Charles County, parts of northern Calvert County, and especially in southern Prince Georges County. The rest of Southern Maryland, however, remains essentially rural; in 1964, farms occupied 45% of the tri-county land area and most of the remaining land was forested. Table 1 lists the populations of all of the important towns in the survey area. The largest community in Southern Maryland—Lexington Park (pop. 9136 in 1970)—owes its size wholly to its proximity to the Patuxent Naval Air Training Station.

VEGETATION AND SOILS

The debarking colonists found Southern Maryland an unbroken expanse of mature hardwood forest dominated by oaks of several types, chestnut, hickory, beech, and sweet gum. Virtually none of this original forest remains. Most of the land has undergone a cycle of clearing for agriculture, abandonment, and natural reforestation at least once. The second or third growth forests which have sprung up on the cleared lands are quite different from the original cover. The long-continued practice of culling out the best timber trees without replanting is in part responsible for the present forest composition. The most conspicuous change has been the invasion of abandoned farmlands by fast-growing pines—mostly Virginia pine but also including shortleaf, pitch, and to the south, loblolly. Pines are now the most abundant trees in Southern Maryland woodlands. Given sufficient time, pines are generally succeeded by valuable hardwoods, but in practice, woodlots are seldom left undisturbed for the length of time necessary for the return of the climax vegetation.

At the present time, somewhat more than half of Southern Maryland is forested. The largest tracts of woodland are in Charles County where over 60% of the land is wooded. Upland slopes and flats throughout the survey area have suffered most from repeated clearing and are typically clothed with immature stands of hickory, pine, and black, scarlet, and red oak. Chestnut was formerly an important member of this association but epidemic chestnut blight has virtually eliminated this species from the forest scene. Lowlands in general and swampy flood plain areas in particular support a less-disturbed swamp hardwood forest in which sweet gum, red maple, river birch, sycamore, and both swamp and willow oak are prominent. The largest of such areas is Zekiah Swamp in eastern Charles County. Other lowland areas of limited extent, mostly fringing the Patuxent and some of the smaller streams, support a fresh-water marsh habitat grown up with coarse grasses and reeds of various kinds. Along the Bay shore and the lower Potomac River, analogous fringing flats are salt marsh (fig. 3) in which halophytic grasses such as *Spartina* are important elements.

An areally restricted but nonetheless notable occurrence in Southern Maryland is a mature stand of bald cypress on a 100 acre tract along Battle Creek in Calvert County. The Battle Creek cypresses are very near the northern extreme of their natural range.

Generally speaking, five factors—parent material, climate, vegetation, time, and topography—are recognized as collectively determining the type of soil which ultimately develops in a given area. Of these five, perhaps the most important are parent material and climate. In the case of a relatively small area such as Southern Maryland, climatic variation is slight and consequently unimportant as a soil differentiating factor. Thus parent material is the primary influence. Figure 4, a generalized soil map of Southern Maryland, points up this relationship. The map outlines the six major soil associations of the area, and the broad correspondence between soil groupings and geologic units is readily apparent.

The distribution of the Beltsville soils which form three associations in Southern Maryland approximates that of the Upland Deposits. These soils are characterized by a fragipan or "hardpan" 16 to 25 inches below the surface, essentially a dense compact subsoil which inhibits root penetration and water movement. Consequently, the Beltsville and associated soils are poorly adapted for agriculture. Westphalia soils are closely associated with outcropping Chesapeake Group sediments. As such, they blanket most of Calvert County as well as the eastern portions of Prince Georges, Charles, and St. Marys Counties—areas where the Upland Deposits are much dissected, thin, or absent, exposing the underlying Miocene rocks. Such soils are generally deep, well-drained, and admirably suited to agriculture, particularly tobacco farming.

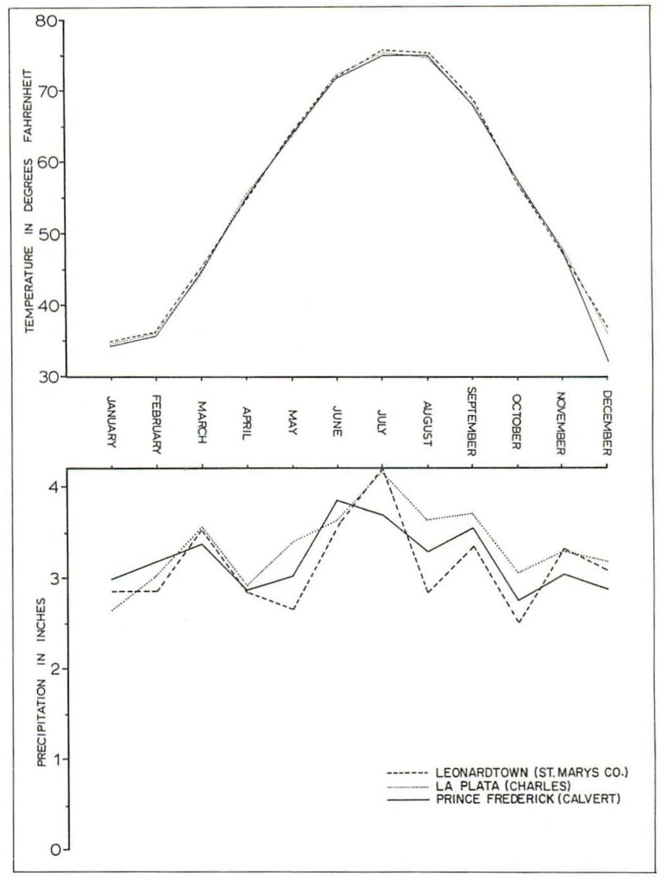

Figure 2. Average monthly temperatures and precipitation in Southern Maryland. Data compiled for three county seats.

Probably the best correspondence among geology, topography, and soils is the case of the Othello soil association which is essentially confined to the lowland flats bordering the Potomac and Patuxent Rivers. Othello soils have generally developed on the fine-grained upper member of the Lowland Deposits. Due to the lithology and low elevation, surface drainage is relatively slow and water tables are elevated during much of the year. With adequate artificial drainage, soils of the Othello association are agriculturally useful.

The final association in Southern Maryland, composed of the Pope and related soils, is represented solely by the Bibb series—light-colored, poorly-drained soils developed on the alluvium flooring the larger stream valleys.

Table 1. Populations of selected towns in Southern Maryland

	1970	1960	1950	1940
LaPlata	1439	1214	780	488
Leonardtown	1362	1281	1017	668
Indian Head	1347	780	491	1104
Upper Marlboro	646	673	702	565
Chesakeake Beach	934	731	504	326
North Beach	761	606	314	246

ACCESSIBILITY

Southern Maryland has an excellent highway net and is readily accessible from major urban centers, particularly those to the north. The area is nearly bisected by U.S. 301—one of the 2 major north-south routes along the Atlantic seaboard. Further, modern well-maintained highways extend the length of both the Calvert and St. Marys County peninsulas, affording ready access to the southern extremities of the survey area. Asphalt or concrete roads, both county and state, bring every portion of Southern Maryland within a few miles of a paved road.

Southern Maryland is uniquely situated as regards water transportation, having more than 300 miles of shoreline. In fact, the colonial prosperity of this region derived in large part from a number of excellent natural harbors on the Patuxent and Potomac Rivers as well as Chesapeake Bay. Whitney (1893) observed: "Numerous rivers and creeks make up into the land (Southern Maryland), providing cheap and easy communication with Baltimore by water, and in some of the lower counties there is no place over five miles from a good steamboat landing." Yet with the advent of a modern highway network, and the progressive shoaling of most Southern Maryland ports due to rapid siltation, commecial activities shifted to inland towns. The use of water transportation drastically declined. The potential, however, for inexpensive water transport to Atlantic Coast population centers nonetheless remains should a developing mineral industry call for it.

Southern Maryland is served by a branch line of the Penn Central Railroad which enters the survey area near Upper Marlboro and terminates at the Morgantown generating plant of the Potomac Electric Power Company. A subsidiary line leaves the main branch at Brandywine and extends southeast along the St. Marys County peninsula to Lexington Park.

PHYSIOGRAPHY

Topographic expression in Southern Maryland (fig. 5) is surprisingly varied and provides a welcome contrast to the low-lying undissected flats typical of the Eastern Shore of Chesapeake Bay. Elevations range from about 270 feet to sea level. The maximum heights are associated with erosional remnants of the Pliocene (?) upland surface along the northern margin of the survey area in southern Prince Georges County. The upland is the dominant topographic feature in Southern Maryland, spanning most of Charles County and extending southeastward along the spine of the St. Marys County peninsula. To the east in Calvert County, advanced dissection has reduced the upland to a series of digitate flat-topped ridge complexes. The largest intact area of upland in Southern Maryland straddles U.S. 301 between Mattawoman and White Plains in northern Charles County and is fairly typical of this topographic form throughout the region. It is notably flat, according at 200 to 220 feet elevation, and is poorly drained due to an extensive well-developed hardpan near the surface. The few streams of the region are scarcely incised and are fringed with patches of swampy ground. The thin soil cover is poorly suited for cultivation; consequently, most of the upland remains in forest. The upland forest, originally dominated by hardwoods, has doubtless been cut over many times and is now clothed by scrub oak and pine.

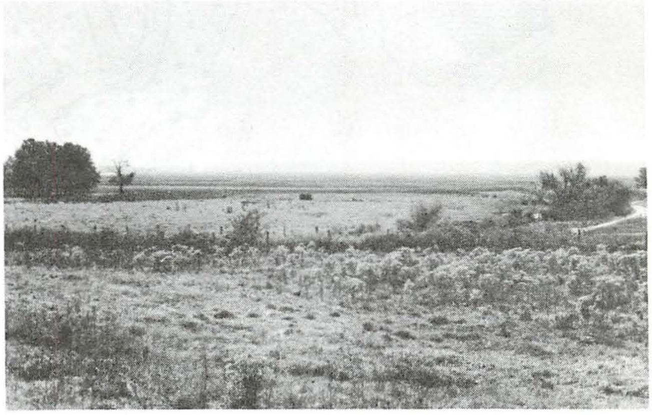

Figure 3. Salt marsh flats at the mouth of the Wicomico River, Charles County.

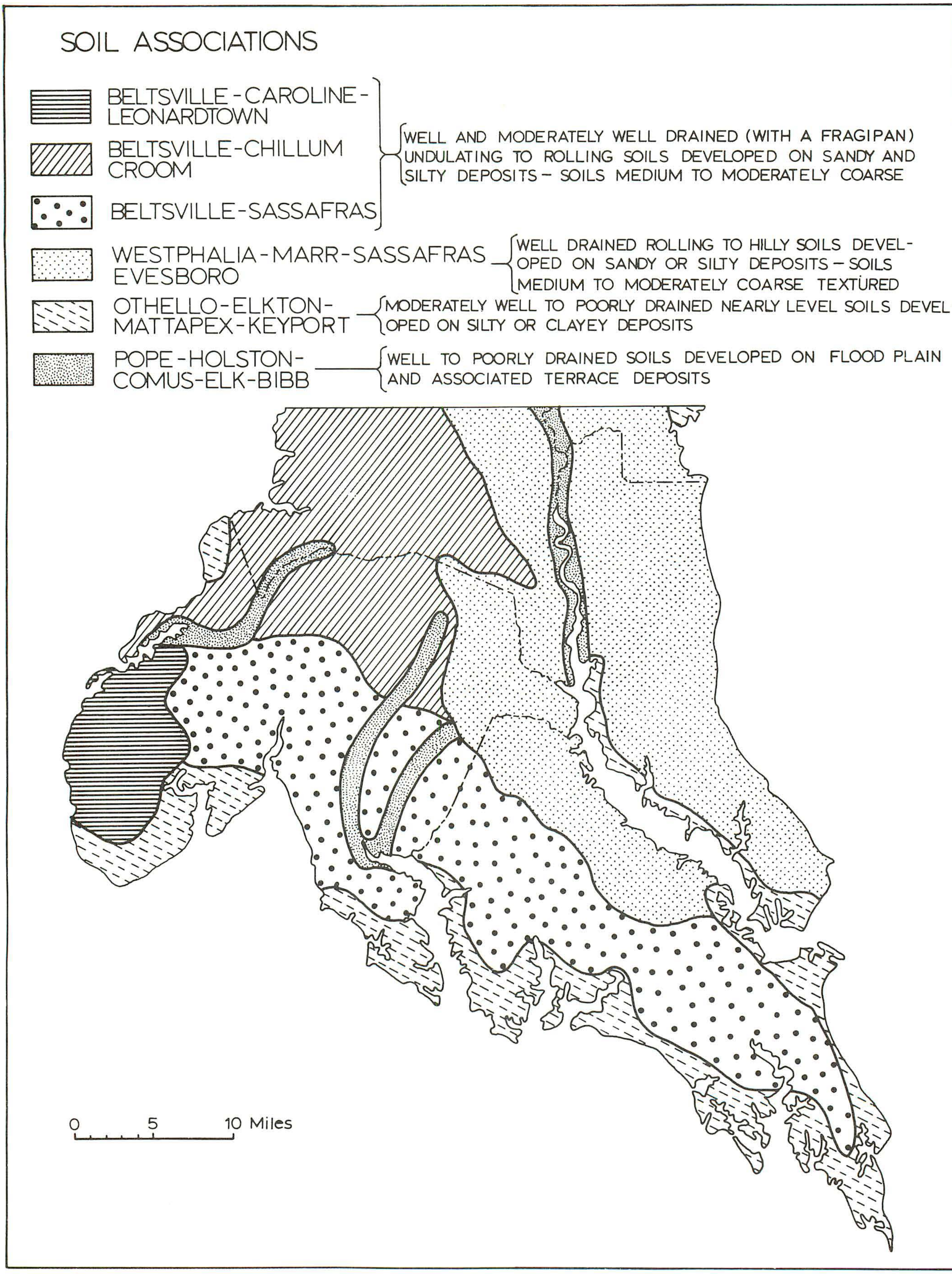

Figure 4. Generalized soil map of Southern Maryland.

The upland has undergone considerable dissection since elevation to its present height, and the process continues unabated today. Marginally, the surface is broken by numerous stream valleys tributary to the Potomac and Patuxent Rivers; these are commonly steep-walled and narrow headward but broad and flat in their lower reaches. Many such streams in their upper courses are cut in soft Tertiary sands in which headward erosion is rapid once the resistant gravel cap supporting the upland is breached. Downstream, the transition to broad alluvium-floored valleys is quickly accomplished. The lowermost reaches are invariably drowned.

The general slope of the upland surface is gently to the south-southeast at about 5 feet per mile, dropping from a high of 260-270 feet in southern Prince Georges County to about 100 feet near the tip of the St. Marys County peninsula. Moreover, the surface is also inclined toward the major drainage lines, i.e. the Potomac and Patuxent Rivers.

Drainage of the upland tends to be asymmetric. East to northeast flowing streams tributary to the Patuxent River are short and have relatively steep gradients; those flowing southwest into the Potomac are significantly longer and show lesser gradients. This phenomenon is most apparent in northern St. Marys County but exists in most of Charles County as well.

In southeastern Prince Georges, much of southernmost Anne Arundel, and northernmost Calvert Counties, the upland surface has been destroyed by dissection or perhaps was never really continuous. Erosion in this area has acted on soft readily-eroded Miocene sand to produce a rough knobby topography. Such topography is particularly in evidence along Md. 382 between Croom and Poplar Hill in Prince Georges County. Stream valleys are deep, narrow, and numerous. Remnants of the upland are preserved on some of the higher hills as small gravel caps. Soils of the area are rather deep and well-drained, and are excellent for farming. Most of the tobacco which is the principal cash crop of Southern Maryland is grown here.

The third major topographic division of Southern Maryland is the chain of lowland flats bordering the major watercourses. Such flats may reach a width of several miles and extend continuously for many times that distance parallel to the larger streams. A number of the lowland areas, e.g. Cobb, Cedar Point, and Medley's Necks, are remarkably flat and undissected. The inner edge of the lowland is commonly defined by a prominent escarpment which rises across Tertiary sediments to the upland surface. Good examples of such escarpments abut the inner edge of the flats on Cobb and Cedar Point Necks in Charles County. However, in other cases the lowland-upland juncture is not marked by an escarpment but rather a more or less gradational slope extends from the riverbank to the upland surface. The latter situation is typical over the whole of southwestern Charles County bordering the Potomac. In either case, the lowland flats owe their existence to fluvial planation and subsequent terrace deposition during the late Pleistocene.

Although most of the larger Southern Maryland watercourses are fringed by lowland, the exceptions are relatively spectacular. Nearly the whole of the Bay shoreline of Calvert County is lined with high precipitous bluffs—the famed Calvert Cliffs. The Cliffs vary from a few tens to over 100 feet in height and extend for some 30 miles from Chesapeake Beach to Drum Point. Erosion is very active along the bluffs; some segments have undergone as much as 800 feet of linear recession over the past 100 years. The continuity of Calvert Cliffs is broken only by small areas of salt marsh as at the mouths of Plum Point and Parker Creeks. High bluffs outside of the Calvert Cliffs area in Southern Maryland are confined to short stretches at Hollin Cliff on the Patuxent River in Calvert County and at Popes Creek fronting the Potomac River in Charles County.

GROUND-WATER RESOURCES

No report of this scope would be complete without some brief discussion of ground-water resources, especially in view of the fact that Southern Maryland relies almost wholly on wells for its water supply (Otton, 1955; Weigle, Webb, and Gardner, 1970).

Generally speaking, the deeply-buried Cretaceous units (Patuxent, Patapsco, and Magothy Formations) are potentially significant aquifers in Southern Maryland, but at the present time they are tapped only in western Charles County and along the northern fringe of the area. Although a prolific aquifer in the Baltimore-Washington area, the Patuxent Formation is essentially untested through most of Southern Maryland and remains somewhat of an unknown quantity. In the Indian Head area of western Charles County, Patapsco Formation sands exhibit transmissibility

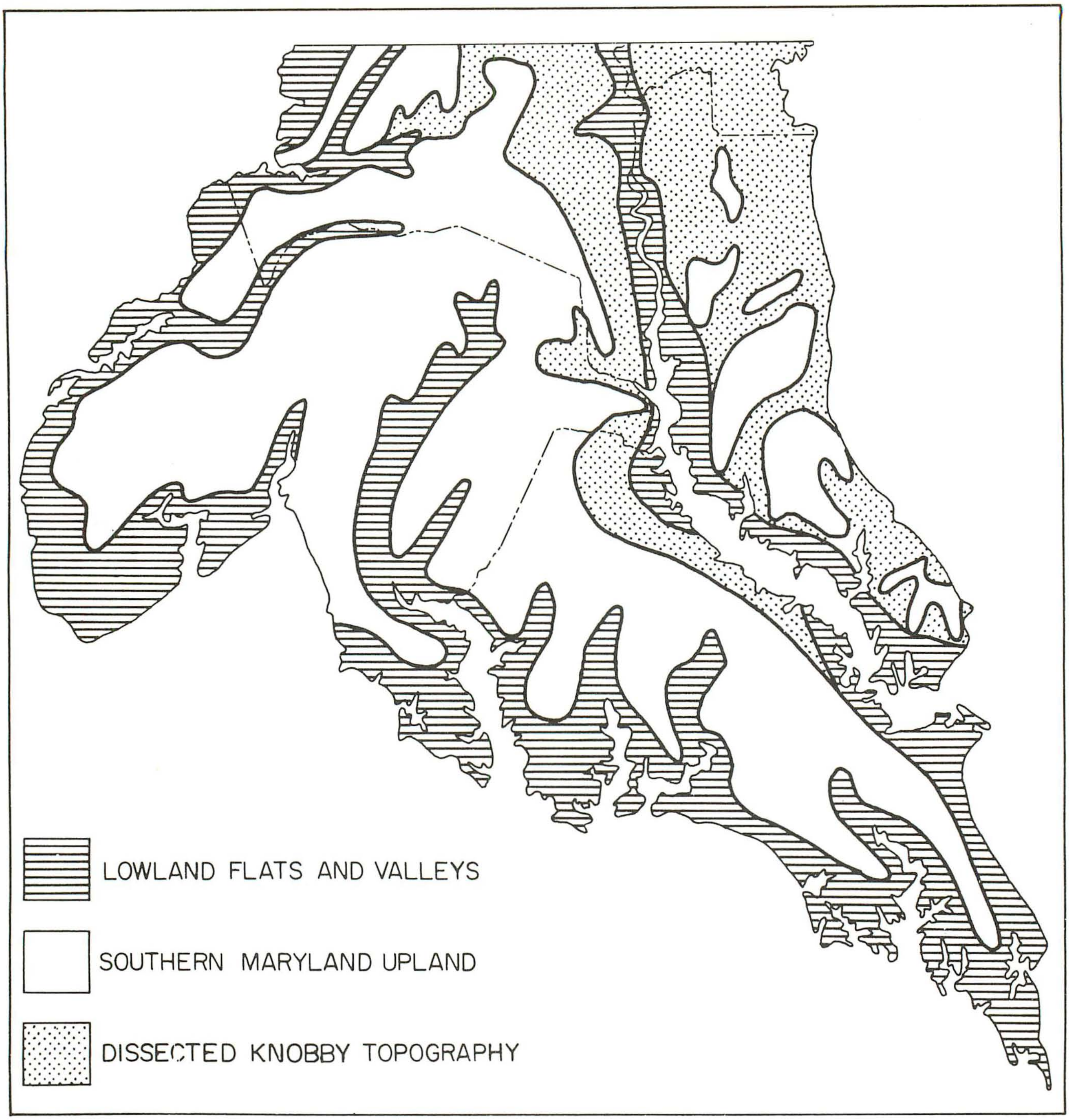

Figure 5. Major physiographic divisions of Southern Maryland.

values which are generally less than 10000 gpd/ft. The Magothy aquifer, heavily used in Anne Arundel County just north of the limits of the survey area, thins to the south and is believed to be absent over the southern half of the region. In northeastern Charles County, transmissibility values range between 2500 and 20000 gpd/ft.

Water from the Patapsco Formation in Charles County averages 110 ppm of dissolved solids, and tends to be soft and mildy alkaline. The iron content may exceed 0.8 ppm. Magothy water averages 131 ppm dissolved solids and is somewhat harder than that from the lower aquifers. The iron content is variable but may exceed 1.0 ppm.

The most widely used aquifers in Southern Maryland are the contiguous Eocene greensands—the Aquia, Nanjemoy, and Piney Point Formations. Some portion of this Eocene section underlies virtually every part of the survey area and supplies most of the domestic and municipal wells in the included region. The Piney Point and Nanjemoy Formations are hydraulically connected and show transmissibilities of 1000 to 10000 gallons per day per foot. The Aquia aquifer, more widely used than the overlying two units, shows similar transmissibility values. Water from the Aquia carries an average 189 ppm dissolved solids and can be characterized as a high bicarbonate, low sulfate-chloride, generally low iron supply. In general, water pumped from the Nanjemoy-Piney Point aquifer is somewhat harder and more mineralized than that taken from the Aquia.

Both the Calvert Formation, Upland Deposits, and Lowland Deposits yield limited amounts of water to shallow large-diameter wells.

GEOLOGY

GENERAL STATEMENT

Southern Maryland is composed wholly of typically unconsolidated sedimentary deposits ranging in age from Early Cretaceous to Late Pleistocene (table 2). Bedding strikes generally northeast-southwest and dips southeast at very low angles, mostly much less than 1°. The gross outcrop pattern is thus a succession of roughly arcuate bands which become younger to the southeast (pl. 1). The exceptions are the Plio-Pleistocene alluvial deposits, i.e. Upland and Lowland Deposits, which are nearly flat-lying and unconformably blanket all of the older rocks.

Structurally, Southern Maryland lies very nearly on the axis of the Chesapeake-Delaware Embayment—a shallow open-ended east-plunging basin in the basement surface. Most of the Embayment fill is Cretaceous sediment, several thousand feet in thickness. Beneath Southern Maryland, only about 25% of the sediment column is Tertiary-Quaternary. Broadly viewed, stratigraphic units within the Embayment are slightly-tilted planar sheets which thicken southeastward; in detail, however, minor structures in the form of broad shallow folds, expressed as strike rotations and local dip reversals, are not uncommon. An example of the latter is the Brandywine structure —an elongate domal warp centered in southern Prince Georges County which is thought to involve all of the Coastal Plain rocks, at least through the Lower Cretaceous.

The oldest rocks outcropping in the survey area (Cretaceous) are confined to the northwestern portion of the region. Two units, the Patapsco and Monmouth Formations, totaling about 50 feet of exposed section, are represented. The Early Cretaceous Patapsco Formation, of which only the uppermost few tens of feet are exposed in the survey area, is primarily a tough silty clay mottled in varying shades of red and gray. Minor amounts of yellowish argillaceous sand are interbedded with the clay. In contrast, the overlying Monmouth Formation consists of dark variably glauconitic fine sand and silt with a thin basal quartzose gravel. Immediately southeast of the Cretaceous rocks is a broad belt of Paleocene-Eocene sediments, mostly greensands, making up the Aquia and Nanjemoy Formations and the Marlboro Clay. These three units have an aggregate thickness of about 300 feet in outcrop. The Aquia and Nanjemoy Formations are similar dark greenish-gray glauconitic sands separated by 20 to 30 feet of pale-reddish to silvery Marlboro Clay. Overlying the Nanjemoy Formation and in fact making up the bedrock over most of the Southern Maryland peninsula is the Chesapeake Group—nearly 300 feet of Miocene fine-grained sand, silt, and clay. Of the component formations of the Group, the Calvert is the thickest at 150 to 200 feet, the St. Marys of intermediate thickness at about 80 feet, and the Choptank least thick at about 55 feet. Lithologically, the three units are somewhat similar, encompassing greenish to bluish-gray, fine argillaceous sand and silt; dark-gray clay; and highly-fossiliferous, fine to medium sand. The remaining sediments in Southern Maryland—Plio-Pleistocene sand, gravel, and subordinate silt-clay —constitute a thin veneer spread over the truncated edges of the older Tertiary and Cretaceous rocks.

CRETACEOUS ROCKS

Patapsco Formation

The oldest strata exposed in Southern Maryland are the uppermost beds of the Patapsco Formation. Outcrops of the Patapsco are confined to a narrow belt bordering the Potomac River from Fort Foote on the northern margin of the survey area southwest to Chicamuxen in Charles County. Actual exposures are few in number and rather poor in

Table 2. Essential characteristics of formations outcropping in Southern Maryland

System	Series	Group	Strati-graphic unit	Thickness (feet)	Lithologic character	Economic potential
Quaternary	Pleistocene		Lowland Deposits	0-150	Interbedded quartz gravel, medium to coarse sand, and silt-clay; grayish-white to dark greenish-gray; peat, and sparse molluscan fauna.	sand and gravel
	Pliocene (?)		Upland Deposits	0-70	Quartz gravel and medium to coarse sand overlain by massive silt; orange to reddish-brown where oxidized, otherwise pale-gray; rare plant fossils.	sand and gravel
			St. Marys Formation	0-80	Interbedded bluish-gray silt-clay and fine argillaceous sand, glauconitic in part; fossiliferous.	lightweight aggregate
	Miocene	Chesapeake	Choptank Formation	0-55	Interbedded bluish-gray to gray-green silt-clay and abundantly fossiliferous fine to medium sand.	
Tertiary			Calvert Formation	0-150	Olive-gray to olive-brown, fine argillaceous sand, silt and clay; diatomaceous silt near base; some beds abundantly fossiliferous.	diatomite
			Nanjemoy Formation	0-120	Dark greenish-gray, argillaceous, glauconitic sand and silt; minor dark-gray silty clay; fossiliferous.	glauconite
	Eocene	Pamunkey	Marlboro Clay	0-30	Pale-red to silvery-gray plastic clay with thin lenses of pale-gray silt; sparingly lignitic.	brick clay
	Paleocene		Aquia Formation	0-100	Dark greenish-gray, fine to medium glauconitic sand and silt; sporadic calcite-cemented sandstone; fossiliferous.	glauconite
			Monmouth Formation	0-40	Dark greenish-gray to black, fine micaceous clayey sand and silt; quartzose gravel at base; fossiliferous.	
Cretaceous		Potomac	Patapsco Formation	0-200	Red and gray mottled silty clay and fine to medium, gray to yellow sand; rare plant fossils.	

quality. The most accessible are in the bluffs overlooking Piscataway Creek on the south side of Fort Washington and in those facing the Potomac River between Potomac Heights and Indian Head. At Fort Washington, the Patapsco spans the lower 17 feet of the exposure, consisting wholly of tough red and brownish mottled silty clay. The Potomac Heights exposure is of similar thickness but is mostly fine yellowish clayey sand capped by a few feet of dirty grayish clay. Silt-clay is lithologically most typical of the Patapsco Formation in Southern Maryland. The latter is about 300 feet thick beneath Indian Head, and of this thickness, approximately 75% is silt-clay (Hansen, 1968, 1969).

Although the lower contact is not exposed in the survey area, the Patapsco presumably overlies unconformably the Patuxent Formation. These 2 formations, plus a third, the Arundel Clay, which has not yet been certainly identified in the Southern Maryland subsurface, comprise the Potomac Group. The Patuxent and Patapsco are much alike in lithology and are not readily separable either in the subsurface or in outcrop. The contact probably intersects the surface a few miles west of the Virginia shore of the Potomac River. The upper Patapsco contact, however, is exposed within the Southern Maryland area and is an unconformity. In the Fort Washington exposure, the overlying beds belong to the Monmouth Formation. The contact is sharp but the Patapsco surface is riddled with irregular burrows which are infilled with dark-gray clayey sand of the overlying unit. The Monmouth thins and pinches out along strike so that at Potomac Heights and southward, the Patapsco is directly overlain by the Paleocene Aquia Formation. A convenient exposure of this contact can be seen in the Md. 224 road cut immediately south of Reeder Run in Charles County. Grayish-brown oxidized glauconitic sand of the Aquia sharply overlies fine yellowish clayey sand typical of the Patapsco with greensand-filled burrows extending downward at least 2 feet into the Patapsco sand.

Mineralogically, Patapsco clays are essentially a kaolinite-illite assemblage. The sands are highly quartzose, compositionally mature residues with a stable heavy mineral suite dominated by zircon and tourmaline (Glaser, 1969). Patapsco sands are generally moderately well-sorted and are made up of chiefly subangular to angular grains. Considerable interstitial silt-clay matrix is characteristic.

Animal fossils are exceedingly rare in the Patapsco Formation but plant remains are relatively common, particularly in the sporadically distributed dark-gray clay lenses. These include impressions of leaves, needles, twigs etc. as well as lignitized stems and logs. Careful study of Patapsco pollen by Brenner (1963) and Doyle (1969) has fixed the age of this unit as late Early Cretaceous (Albian).

The Patapsco as the rest of the Potomac Group records alluvial sedimentation on a broad coastal plain, chiefly as overbank deposits and interbedded point bar sands (Glaser, 1969).

Monmouth Formation

The Monmouth Formation is restricted in Southern Maryland to the extreme northwestern portion. The outcrop belt enters the survey area along Henson Creek a few miles east of the Potomac River and stretches for 6 miles southeast to Fort Washington. The thin edge only of the Monmouth, totaling 20 to 30 feet of sediment, comes into Southern Maryland, and in fact it is absent to the west and south of Fort Washington. Like the underlying Patapsco, good outcrops of the Monmouth Formation are scarce. The bluff at Fort Washington affords the best exposure in the area. Here the Monmouth is represented by 17 feet of dark-gray fine clayey sand overlying the Patapsco Formation. As is the case throughout southern Prince Georges County, the basal bed of the Monmouth Formation in the bluff exposure is a 1 to 2 feet thick gravel bed containing vein quartz pebbles to 2 inches in diameter. Molds and casts of mollusks are common in the upper portion of the Monmouth. Further exposures, mostly very limited in vertical extent, can be seen in road cuts and in the beds of small streams near Friendly, a small community about 4 miles north of Fort Washington.

The lower contact with the Patapsco Formation in Prince Georges County is an unconformity marked by a sharp boundary between red and gray mottled clay below and the dark-gray basal gravel. Not represented are 30 to 40 million years of Cretaceous time, an interval occupied along strike to the northeast by an expanding section which includes in Anne Arundel County the Matawan and Magothy Formations. Still further northeast beyond Chesapeake Bay, the Raritan Formation is added to the top of the Potomac Group and the Matawan raised to group rank (Minard *et al.*, 1969). The age of the Monmouth in the survey area is not precisely known. In Cecil County (northeastern Maryland), the Monmouth Formation—represented by the Mt. Laurel Sand—is apparently Campanian in age. On the other hand, Monmouth strata along strike in Southern Maryland have yielded abundant specimens of the nautiloid *Sphenodiscus lobatus*, widely regarded as a Maestrichtian guide fossil. These latter sands, then, may be younger than the Mt. Laurel and perhaps correlative with the Red Bank Sand of northern New Jersey.

In the survey area, the Monmouth is succeeded in outcrop by the late Paleocene Aquia Formation. Early Paleocene strata (Brightseat Formation) are present a few miles further to the north (Seat Pleasant, Brightseat, and vicinity) in outcrop and extend as well through the subsurface of much of Southern Maryland. Updip in southern Prince Georges County, however, the earlier beds pinch out, and the Aquia-Monmouth contact is an unconformity. As seen in the upper part of the Fort Washington bluff, this contact is sharp but irregular due to burrowing and is marked by a line of small discoid siderite concretions.

Much of the Monmouth Formation in Southern Maryland is comprised of dark-gray silt and fine-grained sand with considerable interstitial clay. Sedimentary structures other than burrow-fillings are rare. The glauconite content varies widely, from nearly zero to as much as 35%. Upon exposure, Monmouth sediments generally pale to reddish-brown mottled with yellow; prolonged exposure, as at Fort Washington, commonly results in surficial casehardening with the growth of gypsum crystals. Interbedded with the typical dark-gray sands in some areas are thin even laminae of dusky blue-green sandy clay. Uncommon accessories in both lithologies are pyrite concretions, bone fragments, small black phosphatic clasts, and scattered granules or pebbles of quartz. The Monmouth heavy mineral assemblage in Prince Georges County is dominated by subangular to subrounded garnet and staurolite with lesser amounts of zircon, sillimanite, tourmaline, epidote, and chloritoid.

In spite of the relative richness of the Monmouth fauna in Southern Maryland, encompassing a number of fishes and crabs as well as 140 molluscan species, fossils are rare in most outcrops owing to the rapidity with which they are removed by ground-water leaching. However, the oysters *Exogyra costata* and *E. cancellata* are commonly found, and establish equivalence of the Monmouth with the Peedee Formation of North Carolina and the Ripley Formation of the Gulf Coastal Plain.

The Monmouth Formation is the oldest outcropping formation deposited under marine conditions

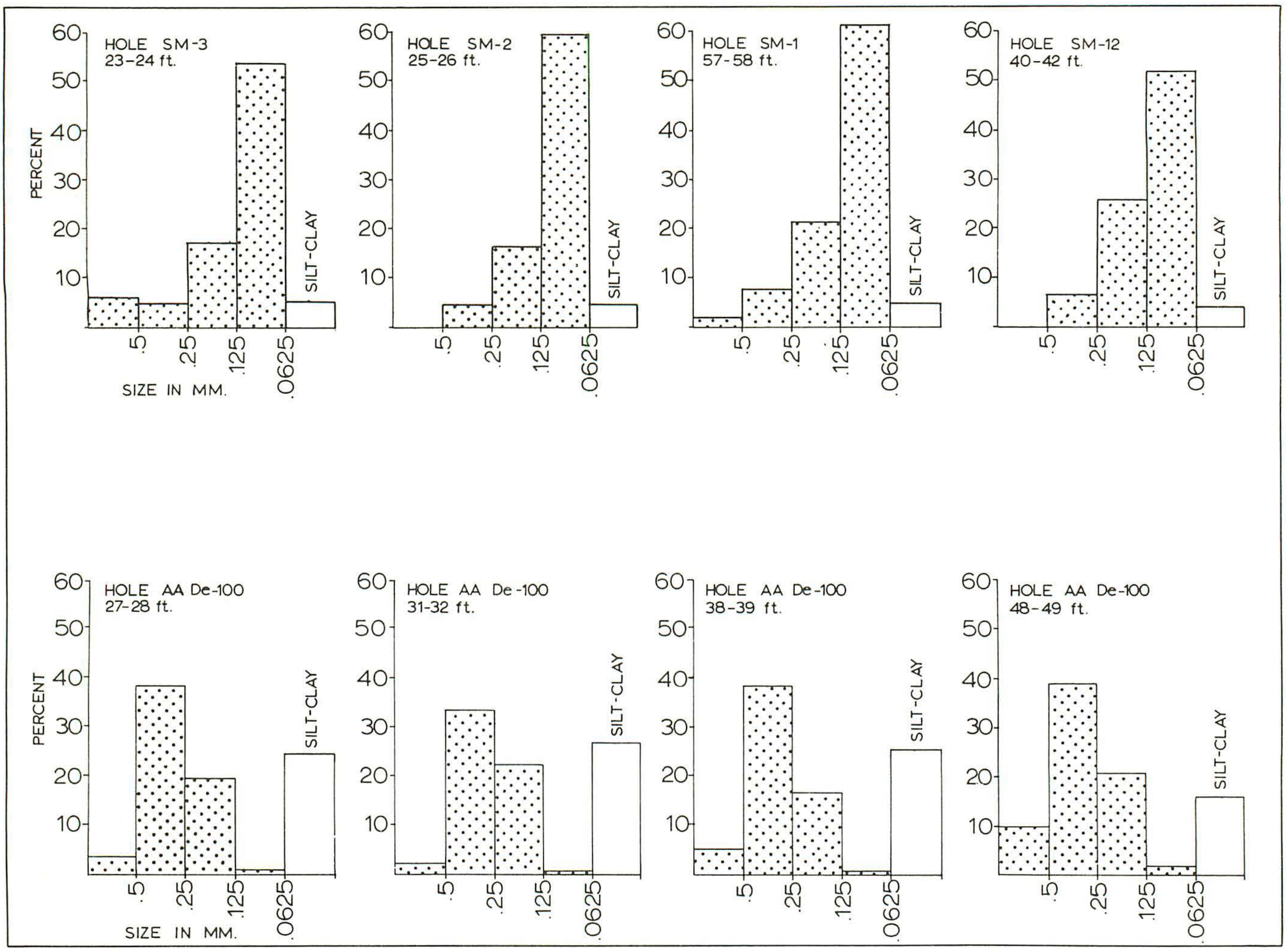

Figure 6. Size distribution histograms of Aquia sands in Anne Arundel (lower row) and Charles Counties (upper row).

in Southern Maryland. Both lithologically and faunally, the resemblance between the Monmouth and the Carolina Peedee Formation is striking. The Peedee records open shelf sedimentation (Stephenson, 1923) and so probably does the Monmouth. Gradational bed to bed contacts, abundant burrow-mottling, and the predominant muddy sand lithology of both units point to deposition beyond the surf zone where wave and current winnowing was minimal and burrowing animals abundant.

PAMUNKEY GROUP

Aquia Formation

The outcrop belt of the Aquia Formation, although somewhat more extensive than that of the foregoing Cretaceous rocks, nonetheless occupies a very small portion of the Southern Maryland area. Aquia sands are at the surface within a narrow sinuous band immediately east of the Patapsco or Monmouth Formation and roughly parallel to the Potomac River. Outcrops are considerably more numerous than in the underlying rocks and further, are commonly abundantly fossiliferous. Readily accessible exposures of the Aquia can be seen in the bluff at Fort Washington, in the north bank of Piscataway Creek at Md. 210, in the bluffs overlooking the Potomac River at Potomac Heights, in the cuts of the Government Railway to Indian Head just west of Knotts Crossing, and in the large roadcut one-half mile southwest of Mason Springs on Md. 224. The thickest of the exposed sections in Southern Maryland is in the upper portion of the Potomac Heights bluff where the lower 50 feet of the Aquia Formation—here variably fossiliferous dark greenish glauconitic sand—is preserved. This is just about half of the total thickness of the Formation in the outcrop belt.

Most of the Aquia consists of well-sorted fine to medium silty sand, typically dark greenish-gray and variably glauconitic. The sand tends to coarsen upward in the section, and similarly, northeastward along the strike (Drobnyk, 1965). The latter trend is exemplified by the size distribution histograms of figure 6. The upper four histograms, analyses of Aquia sand from Charles County, are conspicuously finer distributions than the lower four, Aquia sand from an Annapolis (Anne Arundel County) drillhole some 40 miles northeast along strike. In detail, much of the Aquia sand is interlaminated with more clayey sediment—thin even beds of pale olive sandy clay. Whitish chalky calcite as irregular patches through much of the greensand is the probable consequence of solution and redeposition of shell carbonate. Well-cemented calcareous sandstone beds up to 2 feet thick distributed at various stratigraphic levels are typical and diagnostic of the Aquia Formation in Southern Maryland. Good examples of such sandstones can be seen in outcrop in the Piscataway Creek-Md. 210 exposure and in the Md. 224 roadcut at Mason Springs.

The Mason Springs example is a discontinuously-cemented bed appearing as large sandstone blocks scattered along the base of the exposure; the blocks are doubly conspicuous for the large numbers of *Turritella mortoni* which lend a coquinoid character to the rock. A similar *Turritella*-packed sandstone crops out nearly at river level along the east shore of the Potomac between Liverpool and Smith Points in Charles County where it can be followed in outcrop for several thousand feet.

Weathered Aquia sediments are generally reddish-brown in contrast to the typically grayish-green to olive-green color of the fresh material. Most of the Aquia Formation in the Fort Washington bluff is so colored, and as is the case in virtually all of the weathered exposures, devoid of carbonate. The depth of oxidation increases along strike to the northeast such that in the Annapolis area of Anne Arundel County, this unit is reddish-brown and permeated with limonite as well as leached of carbonate to depths of 70 feet or more.

As previously noted, the Aquia unconformably overlies the Patapsco Formation in western Charles County, but northeastward along the strike, the basal contact is with the Monmouth and ultimately with the Brightseat Formation. The lowermost few inches of the Aquia are prevailingly coarse, usually bearing pebbles of quartz, chert, and phosphate as well as bone fragments, fish teeth, and small siderite concretions. Moreover, the surface of the underlying unit is invariably bored, the burrows in some cases extending several feet downward. The Aquia is succeeded in Southern Maryland by the Marlboro Clay. This contact in updip exposures probably records a minor hiatus since the uppermost few inches of Aquia sand are limonite-cemented and contain gypsum casts. Downdip, however, the same contact is marked by a transition zone, several inches thick, of interlaminated glauconitic sand and silvery-gray Marlboro Clay.

All of the Aquia sands are basically quartz sands with a variable glauconite content ranging form 5 to about 70%. Feldspar, mica, and chert are minor components. Among the heavy minerals, staurolite is the most abundant species, followed closely by garnet in the lower portion of the Formation. The upper Aquia Formation contains considerably less garnet, presumably due to removal during the weathering process. The rest of the assemblage is made up of kyanite, sillimanite, tourmaline, zircon, chloritoid, and epidote.

Fossils are common in the Aquia Formation and can be seen in nearly every exposure in which relatively unweathered materials are preserved. The total fauna includes over 100 species of mollusks as well as crocodiles, turtles, and fishes (Clark *et al.,* 1901). Moreover, a large foraminiferal fauna in the lower Aquia has been studied by a number of workers, including Shifflett (1948), Loeblich and Tappan (1957), Page (1959), and most recently Nogan (1964). Among the macrofossils, some of the mollusks are particularly abundant as well as diagnostic of the Aquia, as for example *Ostrea compressirostra* and *Turritella mortoni.* Shells of the latter species make up nearly pure accumulations in some beds.

Drillhole data indicate the Aquia Formation is restricted to an elongate basin reaching from mid-Virginia northeast into the upper Delmarva peninsula (Shifflet, 1948). The maximum known thickness of the Aquia lies along the basin axis. In Southern Maryland, this unit reaches 200 feet thick along a line extending through central Charles, southern Prince Georges, and southern Anne Arundel Counties (Otton, 1955).

Aquia sedimentation was essentially regressive. Based on the foraminiferal assemblage, Nogan (1964) suggested that the basal Aquia was deposited in somewhat less than 300 feet of water. On the other hand, successively higher beds point to progressive shoaling such that the uppermost Aquia probably accumulated in very shallow water (Drobnyk, 1965).

Although long regarded as wholly Eocene in age, the Aquia is now known to straddle the Paleocene-Eocene boundary (Nogan, 1964). Most of the lower portion of the unit is late Paleocene (Thanetian) whereas the upper portion is early Eocene.

Marlboro Clay

The Marlboro Clay, named by Darton (1948) for exposures near the Prince Georges County seat of Upper Marlboro, has long been regarded as the lower member of the Nanjemoy Formation. However, it is a continuous stratum throughout nearly the whole of Southern Maryland as well as abundantly distinct from the overlying glauconitic sand of the Nanjemoy. Further, the Marlboro is of considerable value as a marker bed in the area subsurface. Consequently, my feeling is that it fulfills the requirements for formational rank, and it is employed as such in this report.

The Marlboro is poorly exposed in the survey area, mostly because it is thin and readily covered by slumping of the overlying sediments. The outcrop belt is a narrow sinuous line (Pl. 2) which enters the area near Palmers Corner in Prince Georges County and trends southwest for some 20 miles to the vicinity of Rison in Charles County. In the broad valleys of Piscataway and Mattawoman Creeks, the clay is effectively buried beneath Holocene alluvium. Similarly, it disappears southwest of Rison beneath a thick mantle of Pleistocene Potomac River terrace deposits. Exposures in this, the main outcrop belt, are few. Scattered patches of typically pale-red Marlboro clay can be seen in the much-overgrown cuts along Md. 210 just south of Hunters Mill Branch and just north of Piscataway Creek, both in Prince Georges County. An excellent exposure, perhaps the finest in Southern Maryland, is in a high cut bank a few yards southeast of Md. 224 just .6 mile southwest of Mason Springs in Charles County. The entire thickness of the Clay, in this case 14 feet, is exposed here as well as 10 feet of the underlying Aquia and several feet of the overlying Nanjemoy sand.

Beyond the main belt in southwestern Charles County, the Marlboro is present in the lower valley walls of Wards Run beneath a thin cover of alluvium. To the northeast in Prince Georges County, a similar situation prevails along Charles Banch between U.S. Route 301 and the Patuxent River flats. Upstream, however, in the vicinity of the Route 301 bridge, the Clay is covered only by slope wash.

The Marlboro Clay is essentially a silvery-gray to pale-red plastic clay interbedded with much subordinate yellowish-gray to reddish silt. In most instances where the unit is relatively thick, the gray hues are characteristic of the uppermost and lowermost several feet of clay whereas the pale-red to reddish-brown colors are typically developed in the middle portion. Much of the clay is finely-laminated on a one millimeter or less scale, the laminations being defined by slight color contrasts or by varying silt content. Laminations are best developed in the reddish clays, yet some of these are apparently massive as are most of the gray beds. Smooth even bedding is much less common than irregularly lenticular, hummocky bedding. Volumetrically, silt composes only a very small portion of the Marlboro, but it is distributed throughout the unit. The silt layers range in thickness from paper-thin partings to 24 inch beds. The latter are much the exception. Much of the silt is pale-gray in color, micaceous, and in some instances finely lignitic. Those beds associated with pale-red clays take on a distinctly pinkish hue in contrast to the yellow-gray to greenish-gray silt interbedded with the gray Marlboro. Fine lamination, or less commonly ripple cross-lamination is characteristic of the thicker silts. Moreover, a large proportion are graded, having sharp erosive bases and gradational tops. Proximal to the upper and lower contacts of the Marlboro, silts tend to coarsen and to contain glauconite.

The lower contact of the Marlboro Clay with the Aquia Formation is in updip exposures sharp and probably records a brief hiatus. The uppermost few inches of the Aquia are limonite-cemented, very argillaceous sand exhibiting crude gypsum casts in some places. In contrast, cores of the same contact in downdip sections show a transition zone, several inches thick, marked by interbedded gray-green glauconitic sand and silvery-gray clay. The top of the Marlboro Clay, although sharp, is so disrupted by burrowing invertebrates as to give the impression of a jumble of angular clay blocks isolated in glauconitic sand. Many burrows extend downward for several feet into the clay.

Fauna in the Marlboro Clay is exceedingly scarce. The shells of very small mollusks are occasionally encountered, particularly in the upper and lower gray portions, and Nogan (1964) recorded several species of arenaceous foraminifera in the lowermost few feet of sediment. Bits of lignite, mostly sand-sized, are quite common in the silts; larger fragments are rare although pieces of wood up to several inches in length have been noted.

Although no direct evidence bearing on the age of the Marlboro Clay is available, its insertion between the early Eocene portion of the Aquia Formation and the middle Eocene Nanjemoy Formation effectively brackets its age.

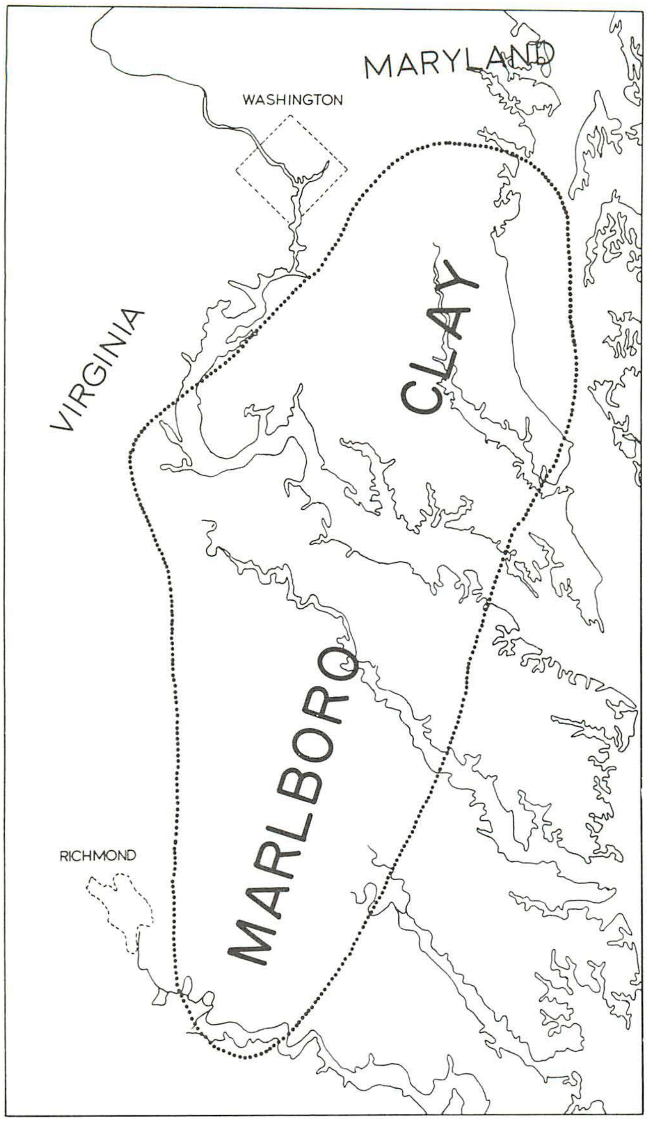

Figure 7. Geographic limits of the Marlboro Clay.

In the subsurface, the Marlboro is a distinctive marker bed, useful in dividing the thick Eocene greensand section into Aquia and Nanjemoy portions. The available drillhole data is sufficient to establish the approximate limits of the Clay downdip as well as along strike (figure 7). Thus delimited, the Marlboro Clay is a thin sheet with an approximate 120 mile extent along the strike from the James River in Virginia to the Chesapeake Bay shore of Maryland near Annapolis. The sheet has a maximum dip extent of about 45 miles and is nearly bisected by the Potomac River. Whether the Clay feathers out at its margin or simply grades into more sandy sediments cannot be ascertained from the present data.

The precise depositional environment of the Marlboro Clay is moot. Nogan (1964) suggested a brackish-water regime on the basis of the few arenaceous forams found at the base of the unit, and indeed, the extremely sparse fauna, interbedded silt-clay lithology, abundant laminations, partly oxidized character, and position immediately above the upward-shoaling Aquia all point to very shallow water, perhaps a tidal flat environment.

Nanjemoy Formation

The Nanjemoy Formation, so-named from Nanjemoy Creek in southwestern Charles County, is well exposed in Southern Maryland, cropping out in the walls of nearly all of the deeper stream valleys between Lyons Creek at the Calvert-Anne Arundel County boundary and Nanjemoy Creek, 40 miles to the southwest. Outcrops of the Nanjemoy, although numerous, rarely expose more than a few feet of section which is in most cases badly-weathered. The greatest thickness in any single exposure in the survey area is the nearly 40 feet in the bluff north of Popes Creek on the Potomac River. Numerous smaller outcrops can be seen along Lyons Creek and its tributaries in northern Calvert County and in the east bank of the Patuxent River from Lyons Creek south to Hall Creek. Other exposures occur across the Patuxent on Mattaponi, Old House, and Swan Point Creeks in Prince Georges County as well as in the valley of Charles Branch west to the vicinity of U.S. Route 301. Between this latter point and Tinkers Creek, 9 miles further to the west, the Nanjemoy Formation is wholly overlapped by the Calvert Formation and hidden from view. Within the broad area making up the western third of Southern Maryland, exposures of the Nanjemoy are fairly numerous. Typical Nanjemoy greensands come to the surface in the lower valleys of Piscataway and Tinkers Creeks in Prince Georges County, and in both walls of the broad lower valley of Mattawoman Creek in Charles County. Further south in Charles County, exposures can be found flanking Port Tobacco Creek, Mill Run, and Wards Run in addition to the north bank of Nanjemoy Creek, the type locality, near its mouth. The southernmost, and doubtless the best outcrops in Charles County, are in a 4 mile stretch of bluffs facing the Potomac River in the vicinity of Popes Creek. Here 20 to 40 feet of the upper Nanjemoy are nearly continuously exposed, much of it fossiliferous.

Basal Nanjemoy sands are in sharp contact with the Marlboro Clay, but viewed in detail the contact is decidedly irregular due to the intensely burrowed surface of the clay. Exposures of this contact are scarce in the survey area. The mostly readily accessible one is in a cut bank a few yards southeast of Md. 224 at a point .6 mile southwest of Mason Springs in Charles County. The contact, near the top of the bank, is between unctuous silvery-gray clay and reddish mottled fine micaceous sand. The clay surface is riddled with winding burrows filled with sand, the latter with shell impressions common, all attesting to an influx of bottom-dwelling organisms accompanying the beginning of sand deposition.

The predominant Nanjemoy lithology is variably-glauconitic muddy sand. Sands in the lower part of the unit tend to be finer-grained, very muddy, and only slightly glauconitic (see, for example, samples SM-1 40-42 ft, CO-9 59-62 ft, and SM-4 79-81 ft in figure 8). In southwestern Charles County, the basal Nanjemoy sand is typically very fine-grained, pale-gray to greenish-gray muddy sand containing much lignite and scattered small pelecypods. Glauconite is sparse or absent. Grain size increases upward in the section (figure 9) so that medium to coarse sands are common in the upper Nanjemoy as are increasingly glauconitic sediments. Moreover, the mud content of the sands declines markedly. Thus, clean medium to coarse greensands are wholly typical of the uppermost beds. Interbedded with the greensands in the upper Nanjemoy are thin lenses of pale-brown clay as well as extensive zones containing small chips of such clay. The clays and greensands alike are riddled with burrows of several types (figure 10). Most, however, are irregular in form with sand fillings characterized by a succession of concentric curved laminae. Near the contact of the Nanjemoy Formation with the overlying Calvert Formation, burrows of the cylindrical branching type and u-shaped tubes (*Rhizocorallium*) are quite common and often show preferentially cemented fillings which weather out and accumulate on the outcrop.

The top of the Nanjemoy, although a significant unconformity, is markedly planar. In the Popes Creek bluffs where the contact is continuously visible for several hundred yards, scarcely any major irregularities can be seen. In detail, however, the Nanjemoy surface is perforated with numerous borings infilled with coarse muddy Calvert sand, giving the false impression of a mixed or transitional zone of a foot or so thickness. In a few areas, the topmost Nanjemoy sand is limonite-cemented to a depth of an inch or less.

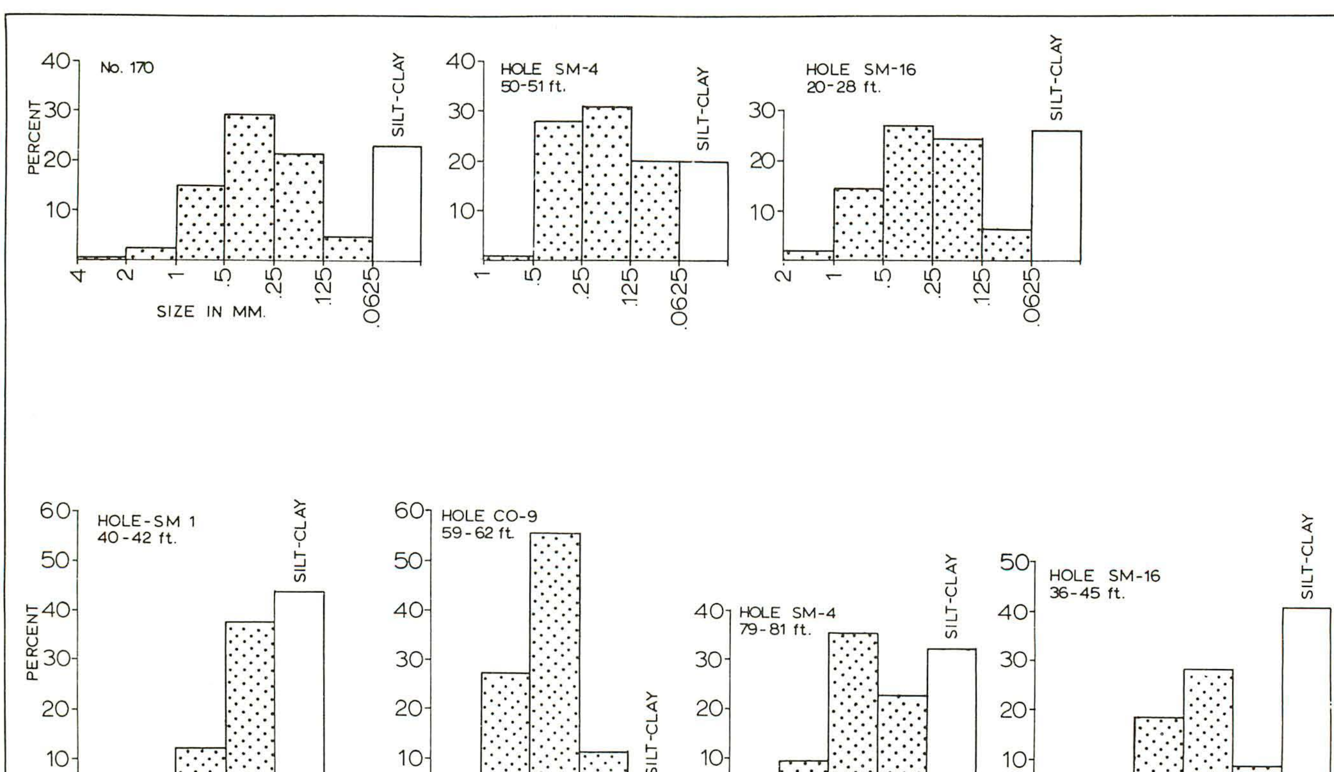

Figure 8. Size distribution histograms of Nanjemoy sands.

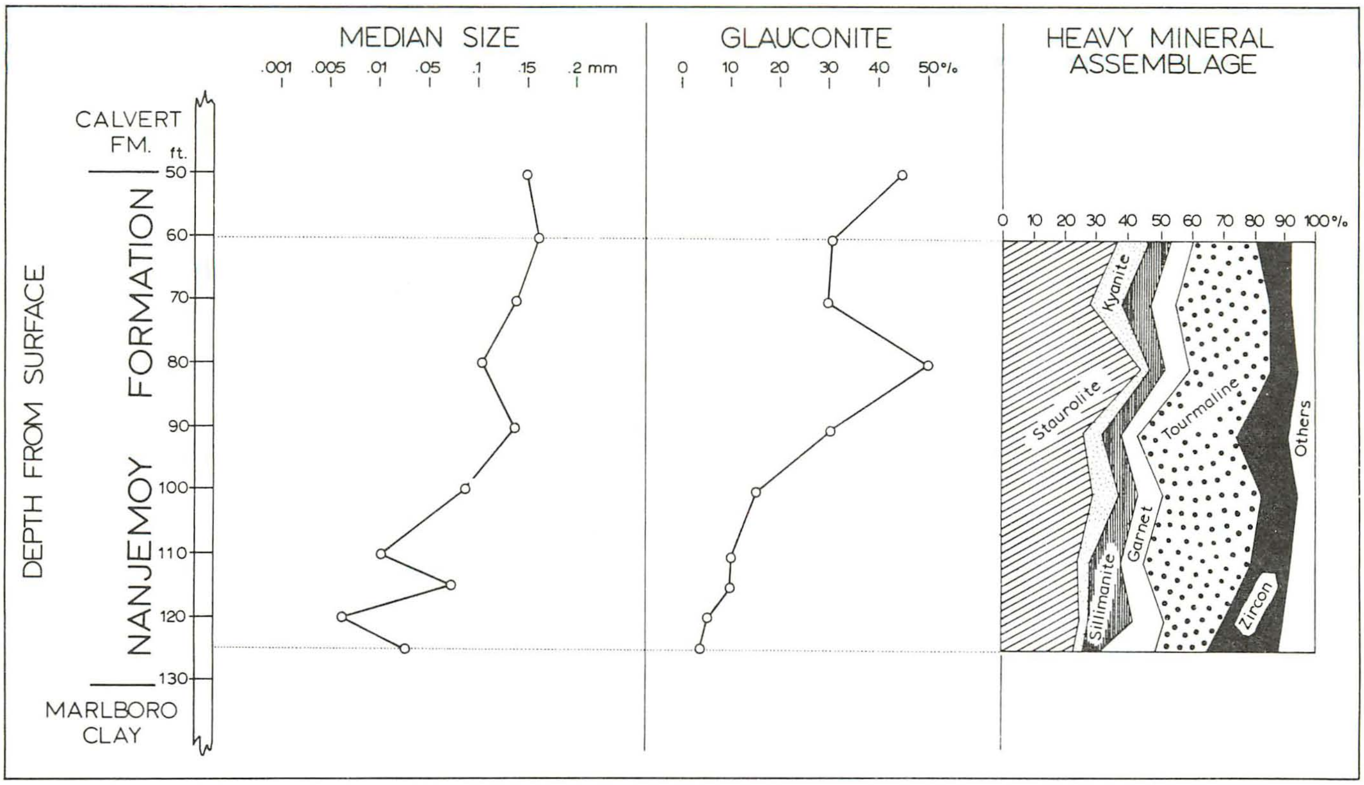

Figure 9. Vertical variation in texture and mineralogy within the Nanjemoy Formation of Corehole SM-4

The contact is exposed at a number of points in northwestern Calvert County and the adjacent portion of Prince Georges County, and in a few isolated outcrops in Charles County.

Sedimentary structures in the Nanjemoy are relatively few. Most of the sand beds show a pervasive mottling as a result of the feeding activities of various invertebrate burrowers. The mottling derives from a network of burrow fillings of clean pale-gray sand cutting gray-green muddy sand, and in most cases little if any primary stratification remains. Where the bottom fauna was sparse or absent, however, laminations are preserved and generally consist of alternations of sand, muddy sand, and mud on an inch or less scale. The laminations are defined not only by texture but by color as well; the greater the proportion of fines, the greener the sediment.

Nanjemoy sands are essentially quartzose with a variable amount of glauconite. Most of the quartz is glassy transparent and in the coarser grades subrounded to rounded. The associated glauconite ranges from pale to deep green in color. Polylobate grains with smooth polished surfaces are most common by far but always present in small proportions are accordian-type grains. The non-opaque heavy mineral assemblage of the Nanjemoy Formation is dominated by staurolite, tourmaline, and zircon, but small proportions of kyanite, sillimanite, and garnet are invariable associates. Little significant vertical variation can be detected in the relative composition of the suite (see fig. 9). The majority of the grains are subangular or subrounded although a few percent of well-rounded grains are always present. The clay mineralogy of the Nanjemoy is typically a montmorillonite-illite-kaolinite assemblage with montmorillonite far and away the dominant species. Illite generally makes up about one-third of the assemblage and kaolinite a tenth or less.

The maximum thickness of the Nanjemoy Formation within the outcrop belt is about 100 feet; downdip, in the southern portion of Calvert and St. Marys Counties, this increases to as much as 250 feet. The Nanjemoy is middle Eocene and probably correlative with the late Wilcox-early Claiborne rocks of the Gulf section (Shifflett, 1948; Cooke, 1952). To the southeast, however, these strata are rapidly replaced by younger Eocene rocks in the lower Delmarva Peninsula, and there is considerable doubt as to the presence of any but upper Eocene beds in Delmarva (Otton, 1955; Rasmussen and Slaughter, 1955).

Fossils are relatively common components of the Nanjemoy clastics, and hardly any portion of the unit is devoid of some fauna. Mollusks are the most abundant fossils with about 50 species, mostly pelecypods. The sole Nanjemoy cephalopod, the large nautiloid *Hercoglossa tuomeyi,* is rather common in concretions in the upper part of the formation at Popes Creek. Several kinds of fishes and a few fragmentary crustaceans complete the known Nanjemoy faunal list. Vertebrate or arthropod remains other than shark teeth are rare, although the jaw of a large scombroid (mackeral) was found in the Popes Creek exposure during the course of this investigation. Most common by far of the Nanjemoy fossils is a thick-shelled, moderately-large clam, *Venericardia potapacoensis.* This species is abundant throughout the formation and in places forms thick shell beds in which 90 percent or more of the shells are *V. potapacoensis.* Such a shell bed (fig. 11) is excellently exposed on the south side of Md. 4 about half a mile east of Osborne Road in Prince Georges County.

Lithology, texture, and fauna indicate that most of the Nanjemoy Formation was deposited on the marginal shelf in relatively-shallow waters. The abrupt transition from the restricted-marine environment of the Marlboro Clay to the basal Nanjemoy fine muddy lignitic sand suggests a rapid transgression during which any record of a high-energy beach-nearshore sand complex, if deposited, was destroyed. Lower Nanjemoy clastics resemble to a large degree modern sediments of the inner shelf. The upper portion of the unit is essentially regressive; the progressive increase upward in median size (fig. 9) reflects the growing availability of medium to coarse sand and an approaching higher energy regimen. The parallel increase in the proportions of glauconite is not so readily explained but is doubtless due in part to greater concentration in the coarser sand grades. Relatively coarse, occasionally pebbly clean sands at the top of the Nanjemoy and the associated sharply-bounded chocolate clay lenses, abundant burrows, and zones of intraformational clay chips collectively suggest high energy littoral sands, perhaps close to the foreshore. This facies is truncated by the overlying Calvert Formation.

Figure 10. Burrow-riddled clay lense in the upper Nanjemoy Formation.

CHESAPEAKE GROUP

Calvert Formation

The basal unit of the Miocene Chesapeake Group in Maryland is the Calvert Formation, named for the extensive and spectacular exposures in the Bay cliffs of Calvert County. The Calvert with the overlying Choptank and St. Marys Formations has held the interest of geologists, professional and amateur alike, for nearly 200 years, chiefly because of its classic Middle Miocene fauna. In both abundance and quality of preservation, the fossil mollusks of the Chesapeake Group make up perhaps the finest assemblage in North America. Moreover, the Calvert Formation with its low dip (10-15 feet per mile) and relatively great thickness is the surface unit over a very large area of Southern Maryland, an area second only in size to that occupied by the Upland Deposits. Exposures are numerous and widely distributed over the southern portions of Anne Arundel and Prince Georges Counties as well as northern Calvert and the eastern two-thirds of Charles County. The best of these by far are in the northern half of the Calvert Cliffs where nearly continuous vertical bluffs up to 100 feet in height stretch for 11 miles from Chesapeake Beach to Parker Creek.

The Calvert Formation is bipartite, consisting of the Fairhaven Member overlain by the Plum Point Marls. The Fairhaven Member received its name from a small bayside community in southern Anne Arundel County where the basal portion is conspicuous in a series of low bluffs. Most of the Fairhaven is a monotonous sequence of olive-gray to olive-green, fine muddy sand and silt divided over most of the outcrop belt into two portions by a distinct stratum of diatomaceous silt or clay (fig. 12). The lower Fairhaven sand, 4 to 26 feet thick, is crudely graded coarse to fine. Typical of the basal few feet is fine to medium-grained muddy olive-brown sand laced with anastomosing cylindrical burrows filled with clean pale-gray sand. Coarse sand grains and small pebbles, concentrated for the most part in the burrow fillings, become increasingly conspicuous as the contact is approached and are most abundant immediately above the surface of the Nanjemoy. In some areas, this surface bears a thin pavement of coarse debris including sandstone and vein quartz pebbles

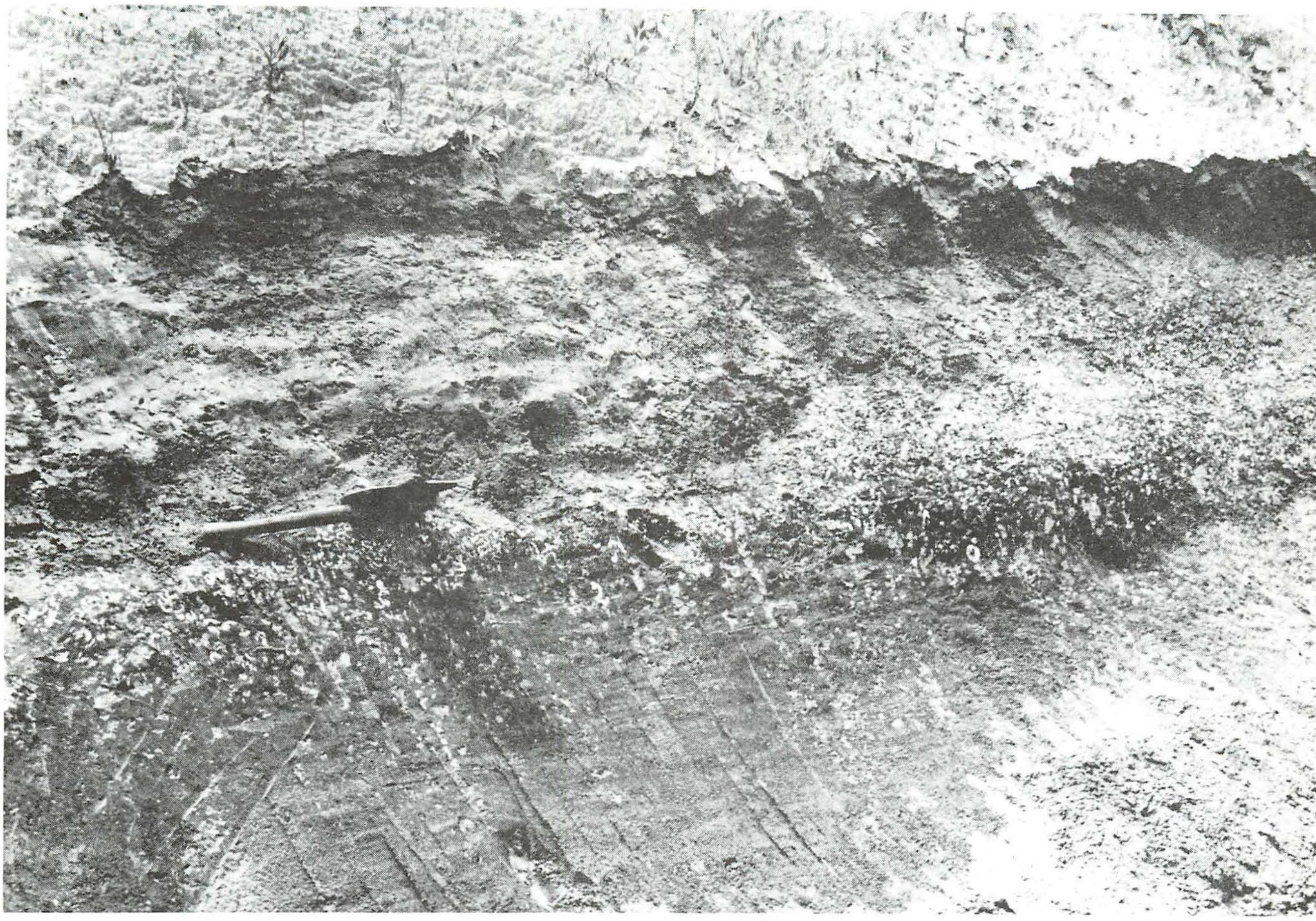

Figure 11. Shell bed in upper Nanjemoy Formation near Upper Marlboro (shells virtually all *Venericardia potapacoensis*). Note each line which transects bed

to 2 inches in diameter, mineralized bone fragments and fish teeth, phosphatized molluscan shells and internal molds, phosphatized echinoid plates, and a variety of dark phosphatic pebbles of indeterminate origin. Phosphate pebbles, mostly in the coarse sand to fine gravel size range, are variably abundant through much of the lower Fairhaven sand, extending up in a few of the sections examined to the base of the diatomaceous bed. The lower Fairhaven sand is similar throughout Southern Maryland. Good exposures may be examined, for example, in the bluffs at Popes Creek where the sand is 19 feet thick, in the banks of a small tributary to Lyons Creek near the Calvert-Anne Arundel County boundary, and in the Kaylor greensand pit near Dunkirk in Calvert County. The Lyons Creek outcrop, located a few hundred feet northwest of Md. 4 just over a mile southwest of the County boundary, shows 8 feet of sand between the top of the Nanjemoy Formation and the bottom of the diatomaceous bed with a well-developed zone of coarse detritus at the base. In the Kaylor pit, the section is atypical in that the sand is abnormally thin—3 feet—and wholly fine-grained; in fact the basal portion is clayey silt.

The overlying diatomaceous bed ranges in thickness from 4 to 17 feet, averaging 8 feet in some 15 test borings and outcrops. The color of the fresh sediment is olive-green varying to olive-gray cut by paler-gray burrow mottling; primary structures other than burrowing are limited to infrequent thin sandier beds set off by paler color. Although small amounts of diatom tests are distributed throughout the Fairhaven, this particular bed is distinct by virtue of an abundance of diatoms (fig. 13), reaching as high as 65% of the sediment in some cases but generally within the range 20 to 45%. The highly diatomaceous sediment tends to be dry and brittle, chipping readily, and functions in the subsurface as an aquiclude. Silt and fine sand are distributed unevenly within the diatomaceous bed as a whole but are most evident in burrow fillings. Although one can usually see on fresh surfaces of the diatom-rich sediment scattered large tests with the aid of a lens, the great bulk are microscopic in size. Both upper and lower boundaries of the bed are gradational over several inches.

Overlying the diatomaceous stratum is a considerable thickness of fine to very fine-grained olive-gray to olive-green muddy sand and silt. Most of this upper Fairhaven sand is devoid of primary structures exclusive of burrow-mottling and sporadic shell impressions; further, bedding is poorly indicated except for slight vertical variations in the mud content of the sand. Although normally fairly thick—40 to 50 feet—the upper Fairhaven varies notably in this respect. In test boring SM-7 in which the top of the Fairhaven can be drawn with some confidence, the upper sand is only 17 feet thick. In contrast, it is at least 49 feet thick in boring SM-6.

The contact between the Fairhaven Member and the overlying Plum Point Marls is an unconformity, but this is doubtless of relatively small magnitude since both members of the Calvert Formation are Middle Miocene in age. It is marked by a densely burrowed surface on bluish-gray brittle sandy clay, sharply overlain by olive-green fine to medium sand. The latter basal Plum Point sand contains a scattering of coarse grains, particularly in the sand filling the burrows in the underlying bluish clay. In some places, the fillings are broken shell hash. Further evidence of unconformity is provided by a degree of angular dis-

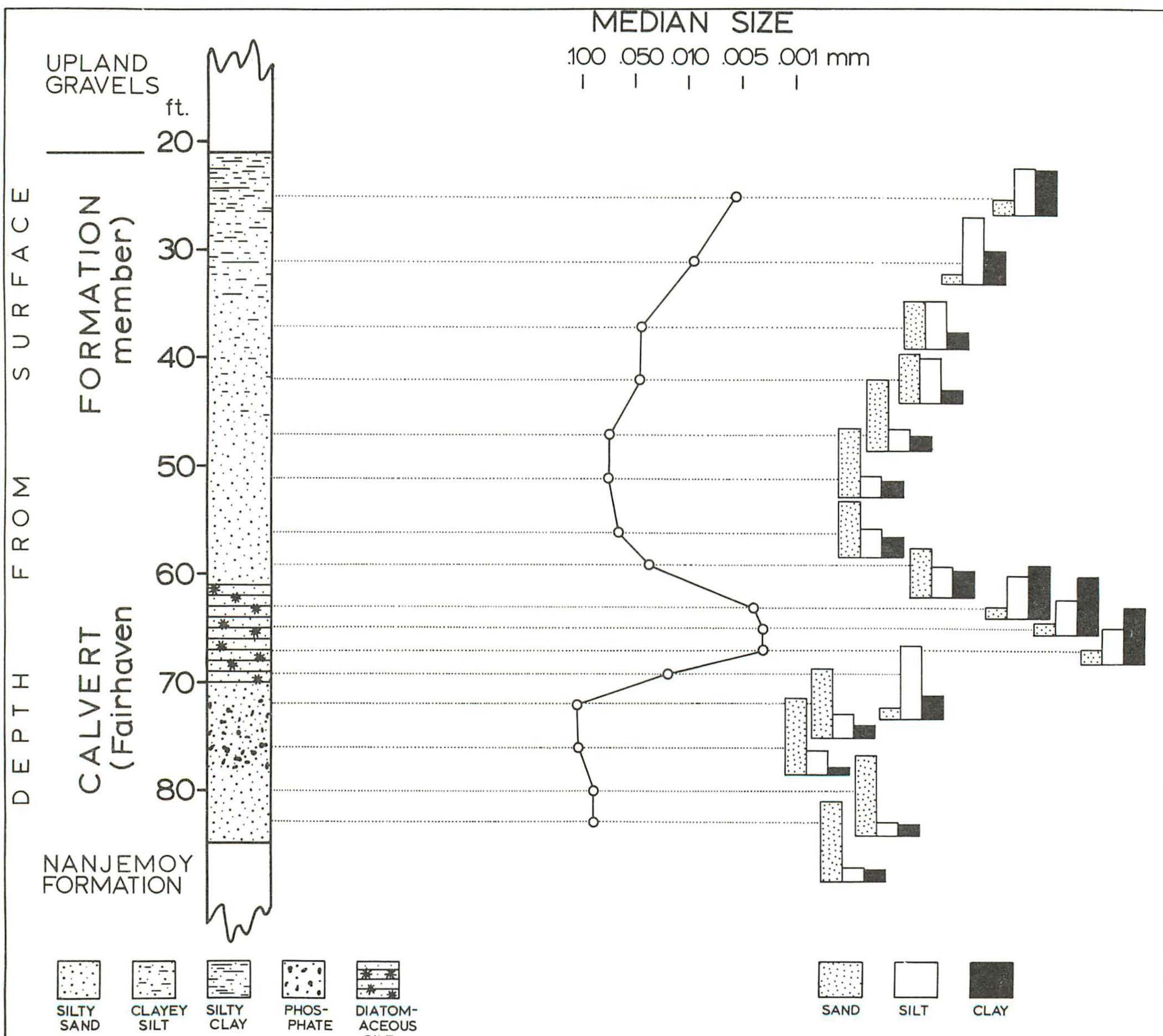

Figure 12. Vertical variation in texture within the Fairhaven Member of the Calvert Formation.

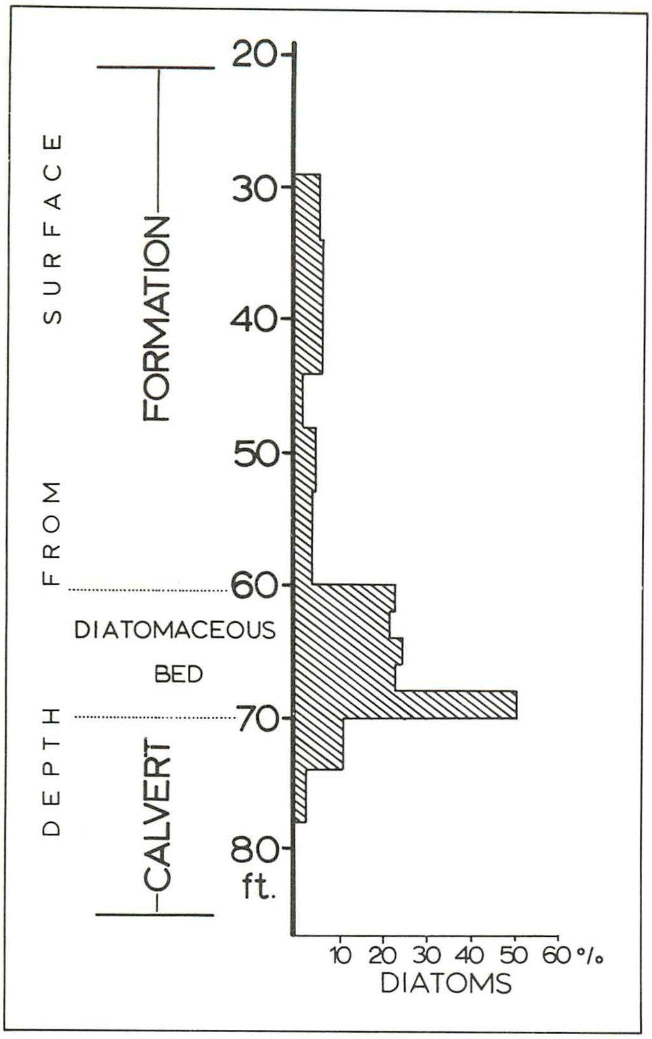

Figure 13. Vertical variation in diatom proportions within the Fairhaven Member of the Calvert Formation in Corehole SM-8.

cordance between the two members, best observed in the northern part of the Calvert Cliffs where the top of the Fairhaven rises against the regional dip of the Plum Point Marls. The contact is also exposed at several points inland from the Cliffs, for example in the road cuts for Md. 4 immediately south of Hall Creek in Calvert County, and at Hollin Cliff on the Patuxent River. In the Cliffs and for several miles inland, the lower few inches of Plum Point sand carries a thin *Pyncnodonte percrassa* biostrome which further points up the contact. Between the top of the Fairhaven and the base of the prominent shell bed ("Zone 10") which has provided most of the prolific Calvert fauna is a variable thickness of more or less uniform olive-green fine muddy sand. The sand totals a maximum 35 feet in the northern Calvert Cliffs but reduces to a few inches only at Hollin Cliff. Twenty to 30 feet is, however, the average thickness in most of the exposures and test borings in which the boundaries of this unit can be delineated. The lithology is typically very fine to fine-grained, poorly-sorted sand with a vertically variable mud content producing a succession of rather ill-defined sandy clays and clayey sands. Bioturbation is the most prominent structure aside from scattered thin shell bands of largely *Corbula elevata*.

Succeeding these strata over at least the eastern half of Southern Maryland is a well-defined bed of mottled brown and brownish-green, very clean fine sand packed with molluscan shells. This shell bed is unique within the Calvert Formation and serves as a distinct marker bed for the unit and the Plum Point Marls in particular. In terms of Shattuck's (1904) zonation of the Calvert Formation, this is "Zone 10", probably the only one of the 15 such zones erected by Shattuck with any real validity as a paleontologic entity. As pointed out by Dryden (1936) and subsequently by others, many of the Calvert zones are defined on the basis of lithology or by lack of fauna and are thus not faunal zones in the strict sense. Moreover, with the important exception of Zone 10 and perhaps the 3 overlying beds, none of Shattuck's zones are traceable beyond the general vicinity of the Calvert Cliffs. It would seem than that the chief modern utility of the zonal classification is to provide convenient handles for the component beds of the various Chesapeake Group formations. The numbered zones have the additional advantage of consistency with past useage albeit technically incorrect. Zone 10 in the area of the Cliffs maintains a rather constant thickness of about 10 feet, and similarly is 7 to 10 feet thick over a broad area spanning northern Calvert, southeastern Prince Georges, and eastern Charles County. The concentration of shells varies vertically and laterally; where densely packed, they form a self-supporting framework with sand-filled interstices. The Zone 10 fauna comprises some 65 species of mollusks, of which a half dozen are unique to that bed and are therefore diagnostic. Both upper and lower contacts are gradational over several inches in most exposures but exceptionally are knife-sharp. Zone 10 is best exposed in the Cliffs between Chesapeake Beach and Plum Point, but inland exposures are not rare. Good examples are at Hollin Cliff and at Burch in the east bank of the Patuxent in Calvert County, and in a deep ravine a few hundred feet east of Md. 381 just north of Swanson Creek in Prince Georges County.

Succeeding Zone 10 in the Calvert Cliffs is a 4 to 17 feet thick bed of blue-gray dense silty clay ("Zone 11") overlain by a thin (1-2 ft.) brownish muddy sand bed ("Zone 12"). This latter sand is notable for its prolific vertebrate fauna; pieces of bone are present in nearly every sample. Silty clay

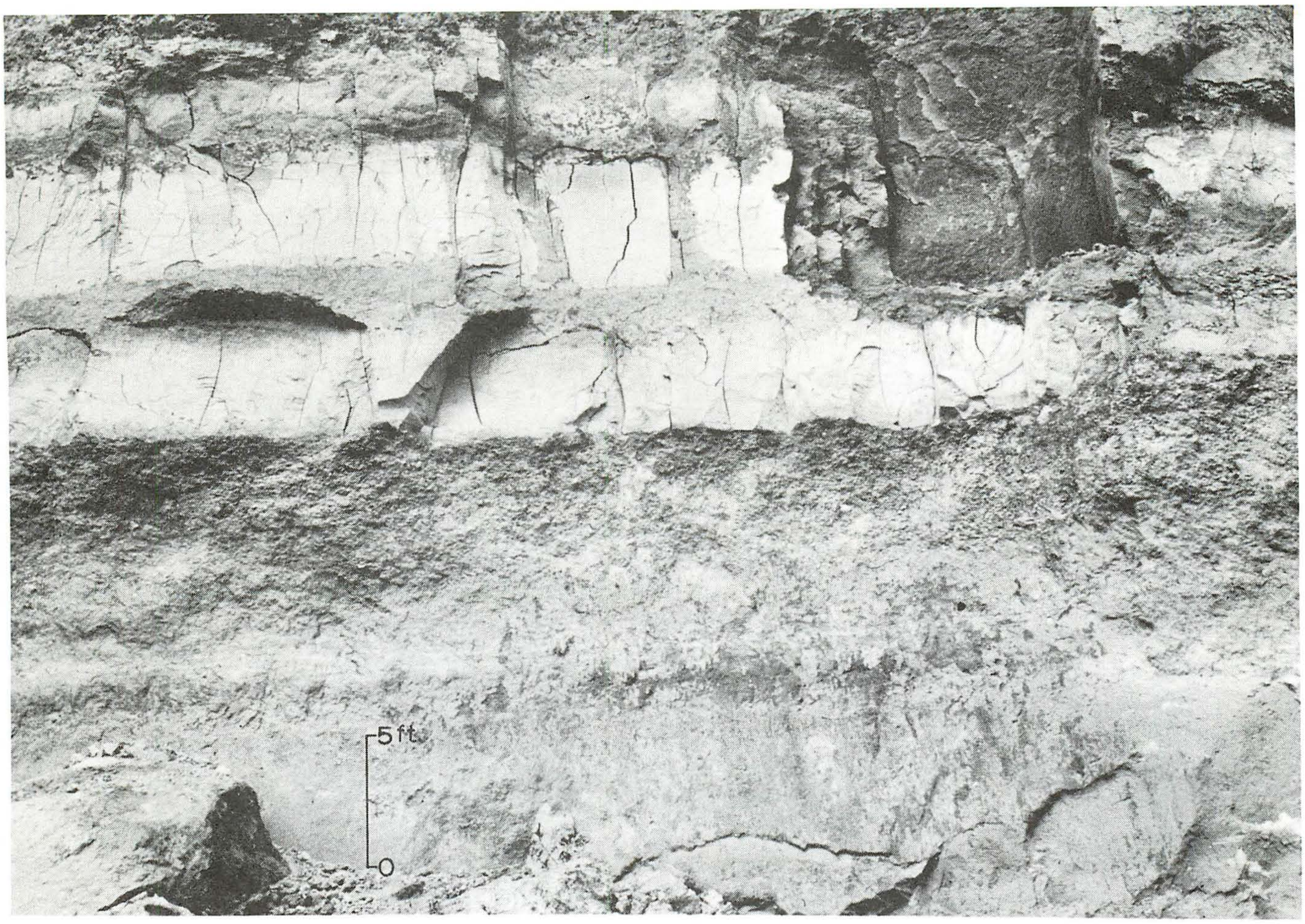

Figure 14. Exposure of Plum Point Marls in the Calvert Cliffs near Randle Cliff. Conspicuous in the bluff is the Zone 10 shell bed overlain by two pale dense clay beds.

identical to that of "Zone 11" composes "Zone 13", the next higher bed which range in thickness from 6 to 10 feet. Both clay beds are typically massive and somewhat brittle, practically barren of fossils, and tend to spall off in vertical sheets (fig. 14). All 3 beds are traceable for a considerable length of the Calvert Cliffs—about 10 miles —but have not yet been identified inland with any degree of certainty. In most of the inland exposures where Zone 10 affords a marker bed, the sediment above the shell bed is fine-grained, variably muddy sand, generally deeply weathered.

The uppermost Calvert strata, assigned by Shattuck to "Zones 14 and 15", total only about 15 feet of section which in the northern part of the Cliffs is deeply weathered as well as largely inaccessible due to height above the beach, and to the south truncated by the overlying Choptank Formation. Generally speaking, these strata consist of several feet of greenish-brown, sparsely fossiliferous sandy clay, succeeded by a massive bluish to bluish-gray, dense silty clay.

Fossils, consisting mostly of mollusks but including a considerable vertebrate fauna as well as a few bryozoans, echinoderms, coelenterates, and a single brachiopod, are abundant in the Calvert Formation but are by no means uniformly distributed. Macrofossils are uncommon in the Fairhaven Member, and moreover shell carbonate is only rarely preserved as such; molds and casts are the usual case. Calcium carbonate in any form is in fact nearly absent from the Fairhaven. Such shells as are ocassionally seen are invariably rotten and partially dissolved. These observations suggest that the Fairhaven was subjected to leaching at some point in its history, probably prior to deposition of the Plum Point Marls since shells are excellently preserved in the upper member.

In the lower Fairhaven sand, the most common bivalves are *Pecten humphreysii, Dosinia acetabulum,* and *Lucinoma contracta* in addition to *Chlamys madisonius* and the barnacle *Balanus concavus,* both nearly ubiquitous in the Calvert Formation. Macrofossils in the overlying diatomaceous bed are not at all common; *L. contracta* is most persistent. This observation is equally valid for the upper Fairhaven sand. Dorsal valves of the small phosphatic brachiopod *Discinisca lugubris* are relatively abundant throughout the Fairhaven Member and doubtless owe their preservation to a relatively insoluble shell mineralogy. In contrast, molluscan shells are common and conspicuous in fresh exposures of the Plum Point Marls. Concentrations of shells occur in at least 3 beds in this member: (1) a 6 in. bed immediately above the base which is crowded with *Pyncnodonte percrassa,* (2) Zone 10, and (3) a thin sandy bed several feet above the "Zone 13" clay containing numerous thick-shelled clams (*Isocardia fraterna*). Further, thin bands of the small bivalve, *Corbula elevata,* which occasionally expand into broadly lenticular concentrations, are characteristic of the section between the *Pyncnodonte percrassa* bed and the base of Zone 10.

Calvert sands are essentially quartz sands with variable proportions of silt-clay matrix. The quartz grains in the coarser sand grades tend to be subangular to subrounded in contrast to the finer sizes which are predominantly angular. Most of the sands contain a few percent of muscovite and alkali feldspar. Moreover, many include as minnor accessories small shell fragments, foraminifera, sponge spicules, and broken echinoid spines. Other components are one or two percent of glauconite in the basal few inches of Fairhaven sand, doubtless reworked from the underlying Nanjemoy greensand, and a highly variable percentage of sand-sized to pebble-sized phosphate distributed through the lower Fairhaven Member. Although the Calvert heavy mineral assemblage (fig. 15) is relatively varied, containing some 9 species and trace amounts of several others, it does not differ greatly from the Nanjemoy suite. Both are "full suite" assemblages (Dryden and Dryden, 1956), that is they contain significant proportions of unstable species such as garnet, epidote, and chloritoid. High-grade schist accessories—staurolite, tourmaline, garnet, kyanite, and sillimanite—dominate the Calvert suite. Both epidote and chloritoid are a bit more abundant in the Calvert than in the Nanjemoy but the difference in proportions is small and may not be significant. The major clay minerals in the Calvert are montmorillonite, illite, and kaolinite; trace amounts of phosphate, allophane, goethite, and clinoptilolite are also present in the clay fraction of some samples. The latter mineral is virtually confined to the lower Fairhaven sand. Although vertical variation in the major clay species is not pronounced (fig. 16), a small upward increase in the proportion of kaolinite is evident.

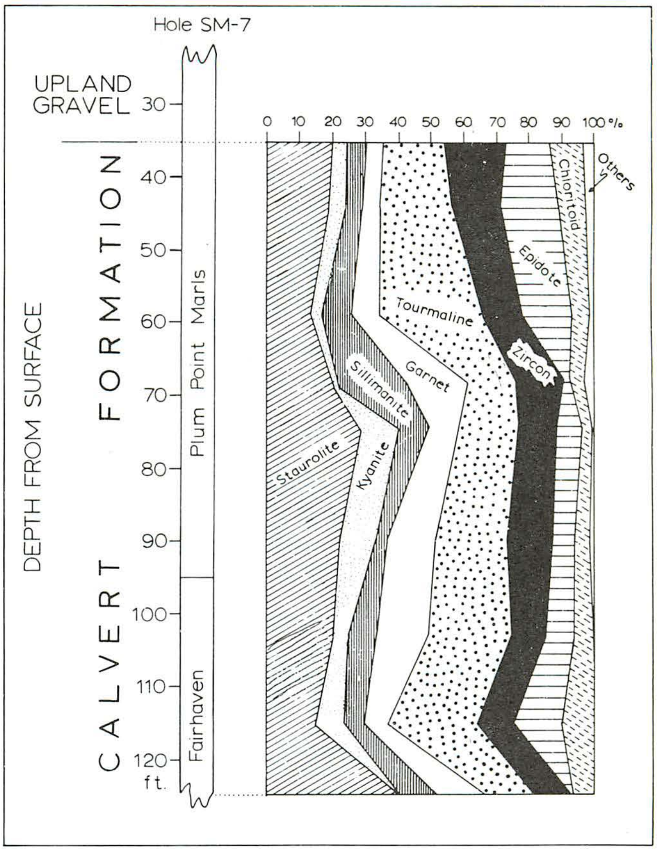

Figure 15. Vertical variation in heavy mineral composition of the Calvert Formation.

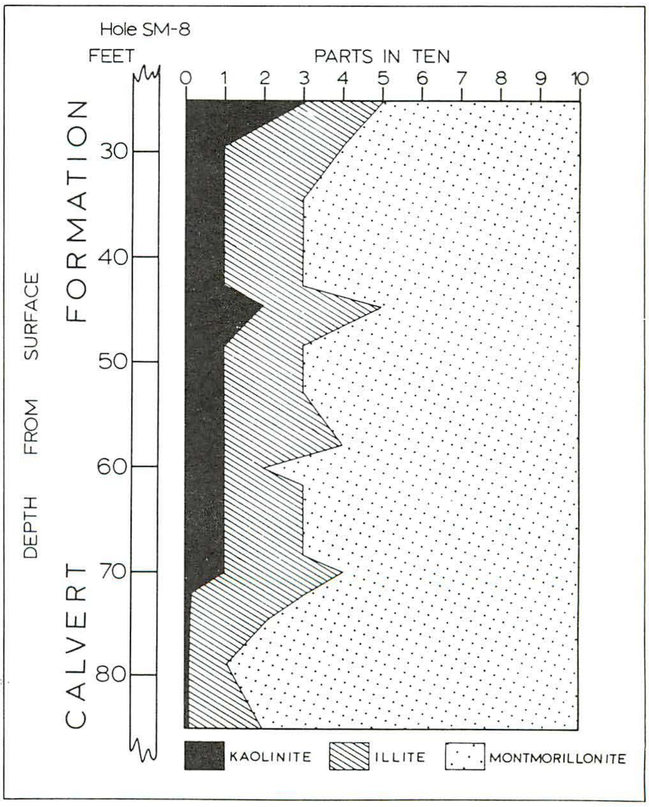

Figure 16. Vertical variation in clay mineralogy within the Calvert Formation.

Most of the exposed Calvert Formation in Southern Maryland is weathered to some degree and differs substantially in appearance from the unaltered sediment. The latter is nearly always dark in color—olive-green, olive-brown, or bluish-gray—and very firm in consistency, giving the impression of a high clay content even when quite sandy. Exposure to weathering rapidly bleaches the color to progressively lighter shades of brown and softens the sediment considerably. Shell carbonate is concurrently leached from the fossiliferous parts of the Formation. The consequences of such weathering are clearly evident in all but the most recently excavated outcrops. In much of the Calvert Cliffs, the weathered zone encompasses the uppermost 15 to 25 feet of section and contacts the unweathered sediment below along a knife-sharp line. The diatomaceous bed is particularly affected by weathering alteration. In contrast to the deep olive-green, firm and brittle fresh sediment, the weathered equivalent is pale-brown, soft and chalky in texture. Dry exposures of the diatomaceous sediment may be nearly white in color.

Generally speaking, depth of weathering in the Calvert Formation is inversely correlated with the thickness of its cover and is probably a function of the level of the permanent water table. A considerable area of Calvert Formation is overlain by the predominantly coarse Upland Deposits ranging in thickness from a feather-edge to 70 feet or more. Where the Upland Deposits are thick and relatively undissected, as in north-central and southeastern Charles County, the Calvert Formation is essentially unweathered (see logs of test borings SM-4, SM-6, SM-7, and SM-11). Conversely, the upper part of the Calvert generally exhibits some degree of weathering where the cover is thin, patchy, or absent (see logs of borings SM-15, SM-10, and SM-9). Perhaps the best example of the latter situation is the northeastern portion of the survey area, i.e. northern Calvert and eastern Prince Georges Counties. A glance at the geologic map (Pl. 1) shows that over a substantial portion of this area, Upland Deposits are absent or at best represented by small isolated outliers. Over most of this region the Calvert Formation is deeply weathered; the surficial material is pale-gray, variably-clayey fine and very fine silty sand sporadically mottled with orange or yellow. Deep road cuts reveal that this oxidized sand may reach as much as 50 feet in thickness, but 20 to 30 feet is nearer the average. Hack (1955), working chiefly in southeastern Prince Georges and northern Calvert Counties, erected the North Keys Sand to include the greater portion of this material. His belief that the North Keys constituted a valid rock-stratigraphic unit was founded on stratigraphic position and lithologic contrast with the underlying Calvert Formation. As described by Hack, the North Keys comprises 20 to 60 feet of fine yellowish-orange sand conformable on the underlying Calvert and overlain unconformably by gravel of the Upland Deposits. He proposed that the sand is a time-transgressive littoral or shore dune facies of the Middle to Late Miocene, equivalent in age to the upper Choptank Formation in the Brandywine area of southern Prince Georges County but younging to the south. Previous workers such as Clark et al. (1904) and Miller and Bibbins (1911) did not recognize these sandy sediments as distinct but rather included them in the Upland Deposits or in the Calvert or Choptank Formations.

The foregoing are the essentials of Hack's thesis. Unfortunately, however, the "North Keys Sand" does not seem to be a valid stratigraphic unit. All of the observed facts are more easily accounted for by a residual origin for this sand blanket. These facts can be summarized as follows. Throughout much of northern Calvert and southeastern Prince Georges Counties, unweathered Miocene sediments (Calvert and Choptank Formations) grade upward into progressively more weathered materials and ultimately into a well-oxidized and leached sand mantle. The sand is thickest where the Upland Deposits are thin or absent. It is clear from stratigraphic considerations and from scattered faunal evidence that the unweathered Miocene sediments immediately beneath the "North Keys Sand" are the Plum Point Marls, or in a few instances belong to the Choptank Formation. Comparison of texture and mineralogy between these Miocene units and the overlying sand shows no important differences. In fact, grain-size distributions of sands in the Plum Point Marls and the "North Keys Sand" (fig. 17) differ significantly only in silt-clay proportions; i.e. the Calvert sands are predominantly muddier sediments. Eluviation of the fine fraction from these muddy sands through prolonged weathering in the absence of a continuous Upland Deposit protective shield could easily have produced the cleaner "North Keys Sand" of the upper residuum. This process has been amply documented in the Pliocene of central Florida (Altschuler and others, 1963, 1964). There, clays in the upper Bone Valley Formation, which in unweathered condition is a muddy greenish sand similar to the Calvert Formation, have been decomposed and eluviated, creating an apparently unconformable

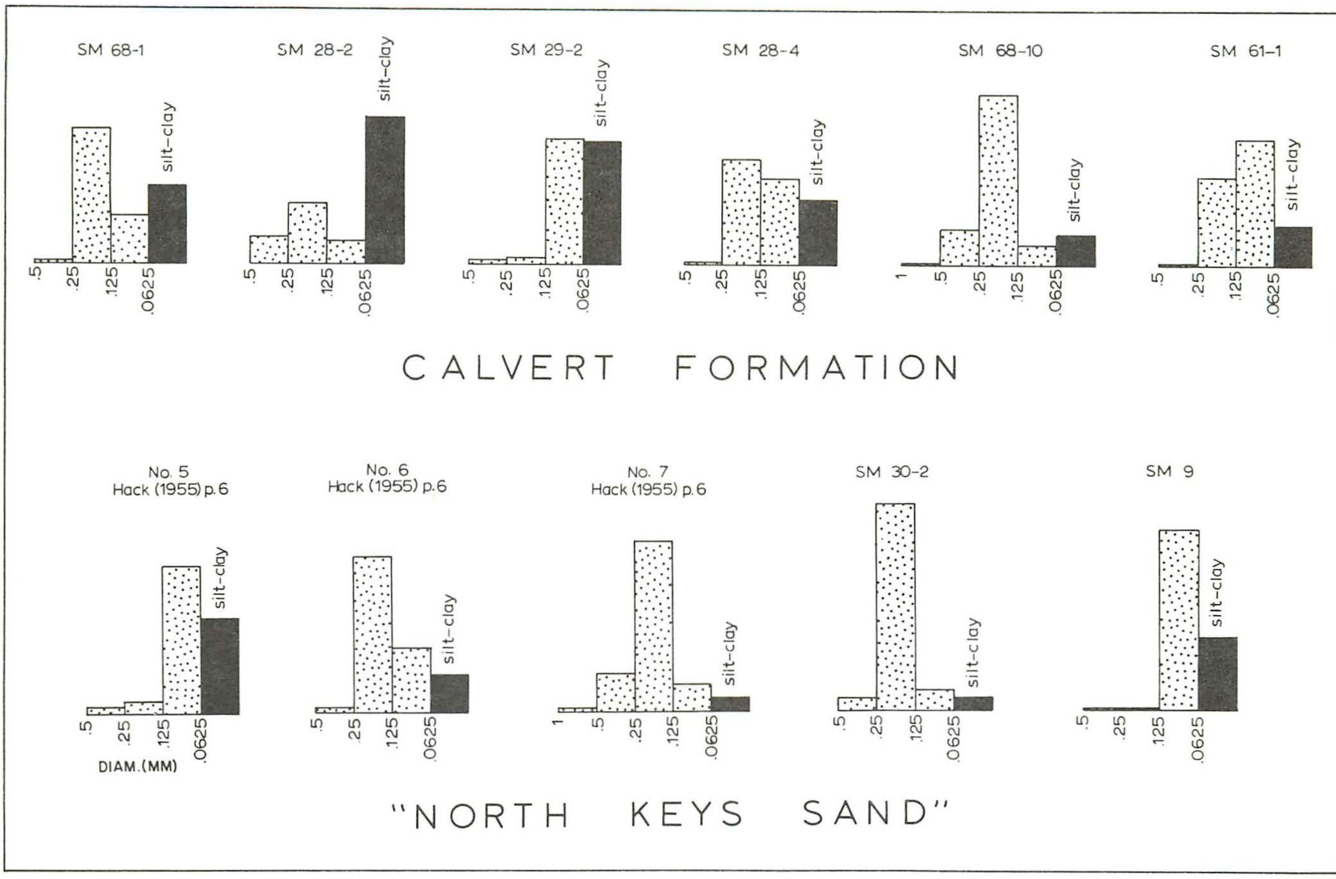

Figure 17. Size distribution histograms of sands in the Plum Point Marls and Hack's "North Keys Sand".

mantle of residual quartz sand. Key to this weathering transformation is the degradation of montmorillonite, the chief clay mineral in unaltered Bone Valley sediments, to kaolinite and goethite. Silica is freed in the process and commonly forms chert, in this case silicifying fossils. Although such a clay transformation has not been investigated in the case of the Calvert-"North Keys" sequence, one can point to a number of features shared by the Maryland and Florida sediments. Chief among these are widespread limonitic mottling, the reduction in clay content downward into the residuum, and the release of silica. The latter is exemplified by selectively-cemented shell beds in which the cementing agent is opal or chert and the shells dissolved or opalized. Such quartzite beds occur at scattered points in the lower portion of the weathered Calvert mantle.

Further evidence of the essential identity of the Calvert Formation and the "North Keys Sand" is similarity in the non-opaque heavy mineral assemblage (table 3). Proportions of the major species are nearly the same in the upper Calvert (Plum Point Marls) and the overlying sandy residuum. Although garnet and epidote decline in abundance upward into the "North Keys", this might be expected as a consequence of weathering intensity in the residuum.

Hack's assessment of a Choptank age for the "North Keys" in the northern Calvert-southeastern Prince Georges County area is based largely on the occurrence near Paris in Calvert County of a shell bed enclosed in the sand. Since the shell bed fauna was a "Zone 19" assemblage, Hack reasoned that his "North Keys" must correlate with the upper Choptank Formation. According to Gernant (1970, p. 24), however, the shell bed in question is in fact an updip outlier of the Boston Cliffs Member (= "Zone 19") as are the enclosing sands. Summing up then, there is no persuasive evidence to suggest that Hack's "North Keys Sand" is anything more than weathered Calvert residuum, or in limited areas weathered Choptank.

The Calvert Formation accumulated in shallow, cool marine waters (Dall, 1904; Gibson, 1962). Most of the paleoenvironmental study to date has focused on the Plum Point Marls because these sediments hold the bulk of the fauna. Gibson's work, based on the foraminifera, postulates deposition of the basal Plum Point Marls in very

Table 3. Comparison of average heavy mineral composition of the Miocene and Pliocene units in Southern Maryland

AVERAGE HEAVY MINERAL COMPOSITION	ZIRCON	TOURMALINE	STAUROLITE	KYANITE	SILLIMANITE	GARNET	CHLORITOID	EPIDOTE	RUTILE	HORNBLENDE
Upland Deposits	53	12	17	6	5	tr	tr	tr	3	tr
St Marys Fm.	30	12	12	4	6	5	5	9	tr	17
Choptank Fm.	35	8	14	3	17	12	1	4	1	3
Calvert Fm. (Plum Pt. Marls)	17	20	18	6	10	11	6	8	2	tr
"North Keys Sand"	12	30	19	3	17	2	8	1	6	-

shallow water with a deepening trend through the mid-portion of the member. The upper beds, however, exhibit evidence of shoaling waters as well as somewhat warmer temperatures. Gernant (unpublished rept.), working with the total fauna, advances a more detailed analysis of the upper Calvert paleoenvironment. He thinks that the *Pyncnodonte* oyster bioherm on the eroded top of the Fairhaven was established in relatively shallow water, yet probably not shallower than 15 meters. Succeeding strata up through the Zone 10 shell bed suggest deposition in 50-75 meters of open ocean water. The higher beds of the Plum Point appear to record progressively more shallow marine waters.

The paleoenvironment of the Fairhaven is not so readily reconstructed. The Fairhaven is characterized by paucity of fauna, fine grain size, essential homogeneity, and a marked accumulation of diatoms—features which suggest a quiet-water clastically-starved marine environment poorly-suited for bottom fauna. The sparse fauna is dominated by deep-burrowing lucinid pelecypods, mostly species adapted for relatively inhospitable, poorly-oxygenated environments. Gernant's tentative assessment of a restricted basin may be valid.

Choptank Formation

The Calvert is succeeded in Southern Maryland by the Choptank Formation, a thin sheet of variably muddy, fine-grained fossiliferous sand which is poorly-exposed inland from tidewater. The Choptank contains little of any real economic potential and thus was studied only superficially; the following discussion is based mostly on Gernant's (1970) work.

By far the best Choptank exposures are in the Calvert Cliffs, mainly between Parker Creek and Cove Point, with the result that the internal stratigraphy has historically been based on what can be seen there. Shattuck (1904) subdivided the Choptank into 5 zones (16 through 20)—two abundantly fossiliferous sands interbedded with 3 finer muddier sands with notably fewer fossils. As earlier noted, these zones are basically rock stratigraphic units rather than paleontologic ones, and as such have been assigned member rank by Gernant. The basal member is the Calvert Beach —twelve to 16 feet of dusky bluish-green, very muddy fine to very fine sand with scarce macrofossils. Good outcrops of the Calvert Beach Member can be seen at the type locality (Calvert Beach) and at other points in the Cliffs such as Kenwood Beach and Governor Run. Inland from the Cliffs, the only good exposure is at Sandgates in the west bank of the Patuxent River. The Calvert Beach Member is an open shelf accumulation in perhaps 45 to 60 meters of water initially but shallowing to 15 to 25 meters in the upper portion. Although Shattuck's original assessment had the Calvert Beach Member resting unconformably on the underlying Calvert Formation, recent work by Gernant (unpubl. rept.) indicates a conformable relationship.

Succeeding the Calvert Beach is the Drumcliff Member of the Choptank, the lower of the 2 major shell beds. The Drumcliff varies substantially in thickness from a maximum 8 feet in the Calvert Cliffs between Parker Creek and Point of Rocks to 30 ft. at Drumcliff on the Patuxent. The typical lithology is pale yellowish-brown to pale orange, well-sorted fine sand crowded with well-preserved shells. Among the latter are about 60 species of molluscan macrofossils which can be considered common. The basal Drumcliff Member, which is nearly everywhere gradational into the underlying Calvert Beach Member, commonly holds heavy accumulations of the large nacreous oyster, *Isognomon maxillata.* Above this, layers in which shells are concentrated alternate with sparsely shelly intervals. Virtually all of the bivalves, excepting deep burrowers such as *Panope,* are flat-lying and disarticulated. This phenomenon is key to Gernant's explanation of the origin of the Drumcliff Member which involves the periodic passage through the area of marine swell. According to this hypothesis, "a pressure gradient was established . . . causing flow into the bottom sediments. As the swell passed by, release of pressure allowed flow out of the sediments accompanied by effusion of the substrate. This effusion caused vertical sorting within the sediments establishing two separate zones. The upper zone, or the zone of traction, has better sorted sediments with smaller grain size, more abundant microfauna, and less abundant macrofauna. The lower zone, or zone of accumulation, contains poorer sorted sediments with larger grain size, less abundant microfauna, and more abundant macrofauna." The Drumcliff Member presumably accumulated in some 8 to 25 meters of open ocean water.

Sharply overlying the Drumcliff is the St. Leonard Member. The contact is fixed at the upper limit of the shells, and is succeeded by a thin dark-brown fine to medium-grained basal sand. Above this, however, the St. Leonard is much like the Calvert Beach Member and consists of dusky-blue, fine muddy sand and silt with a few fossils. The St. Leonard Member is maximally thick—18 to 22 feet—in the Calvert Cliffs near the type section and thins to the southwest; in St. Marys County, only 4 to 8 feet of sediments can be assigned to this member. Accompanying the thinning is a facies change to light-brown sand. Despite the superficial lithologic similarity between this member and the Calvert Beach, the St. Leonard fauna indicates a marginal-marine environment and probably the shallowest water extant during Choptank deposition.

The Boston Cliffs Member (Zone 19), named for Boston Cliffs on the Choptank River in Talbot County, succeeds the St. Leonard gradationally—the base is marked by the first influx of shells. This is the higher of the 2 Choptank shell beds and much resembles the Drumcliff Member in consisting of brown to reddish, variably muddy fine sand containing an abundance of shells. The latter, like those in the Drumcliff, are distributed in alternating bands of heavy and sparse concentration having a similar mode of origin. The fauna is prolific and is dominated by oysters and scallops with notably fewer snails than in the lower bed. Gernant's assessment of the Boston Cliffs paleoenvironment is accumulation in less than 30-35 meters of ocean water in the survey area but shoaling eastward toward the type locality. The top of the unit is oxidized and indurated, suggesting subaerial exposure prior to deposition of the overlying Conoy Member. In the Calvert Cliffs, where Boston Cliffs strata are well-exposed from Parker Creek nearly to Cove Point, this member is 14-15 feet thick. To the southwest in St. Marys County, the thickness is reduced to 5-10 feet.

The uppermost member of the Choptank—the Conoy—is comprised of 9 to 15 feet of dusky green to greenish-blue, very muddy, very fine sand and silt. The Conoy-Boston Cliffs contact is sharply-defined by the abrupt passage from reddish-brown, indurated sandstone to the over-lying dark fine-grained sediments. Within the Conoy, sedimentary structures other than occasional laminations are scarce as are macrofossils. Exposures in Southern Maryland are limited to the Calvert Cliffs and a short stretch along the Patuxent in the vicinity of Helen and Hungerford Creeks. The Conoy sediments are the most consistently fine-grained of any of the Choptank subdivisions and were apparently laid down in relatively deep water—35 to 50 meters of open ocean.

To sum up, the Choptank Formation consists in outcrop of about 75 feet of variably muddy, fine sand and silt, mostly dark-greenish or bluish in color but lightening to yellowish or brownish in the 2 shelly members. The macrofauna includes some 200 species of mollusks and a few echinoderms, bryozoans, and a coral, as well as a number of vertebrates. Among the latter are several whales, turtles, and rays, plus one species each of porpoise, crocodile, drumfish, sailfish, and mastodon. The heavy mineral assemblage (see table 3) is much like that of the Calvert with the difference that hornblende makes its first appearance in significant quantities. Clay mineralogy in the Choptank was not investigated.

St. Marys Formation

The St. Marys Formation, so-called for the Maryland County of that name, is the uppermost[1] unit of the Chesapeake Group in Southern Maryland. The outcrop belt is confined to the lower portions of the Calvert and St. Marys County peninsulas, and although the belt is relatively broad, actual outcrops are few and virtually limited to the shoreline. Chief among these are the Calvert Cliffs between Point of Rocks and Drum Point, and the banks of the St. Marys River above Windmill Point. Perhaps the best exposure in the area is at Little Cove Point where nearly 50 feet of the lower St. Marys can be seen in the Bay bluff.

Like the Choptank, the St. Marys is relatively thin—about 80 feet maximum. Shattuck (1904) subdivided it into 4 "zones" which have no more validity than the lower ones as real biostratigraphic entities yet may have some utility as rock units. According to Shattuck, and enlarged upon by Gernant (in litt.), the lower St. Marys ("Zone" 21) is a drab clay with very few macrofossils. Gernant further points out that the Choptank-St. Marys contact is an erosional unconformity along

[1] In the Maryland Eastern Shore, the St. Marys is succeeded by the Yorktown—the highest formation in the Chesapeake.

which the Conoy clays have been truncated, bored, and the borings filled with St. Marys sand. Moreover, a thin discontinuous basal sand (Gernant, 1970) immediately succeeds the unconformity. Four of the borings put down during this investigation were drilled through the St. Marys Formation and bottomed in the Boston Cliffs Member of the Choptank. With the Boston Cliffs as a convenient datum, the overlying section in the borings can be compared with Gernant's subdivision of the St. Marys. A thin (1 to 2 ft.) gray or grayish-green sand packed with shell fragments, interposed in the section within a foot or so of the top of the Boston Cliffs Member in two of the borings, is probably Gernant's "basal sand" marking the bottom of the St. Marys. If so, then the Conoy Member of the Choptank is absent (SM-26) or represented only by a foot or so of clay (SM-25). The sand is succeeded by 4 to 13 feet of barren dark-gray clay probably referable to "Zone 21". In the case of the other two borings, relationships are considerably less clear; the basal sand is not distinct, and thus the mostly clay section above the Boston Cliffs Member is not readily divisable into Choptank (Conoy) and St. Marys ("Zone" 21) portions. Where identifiable as such, "Zone" 21 is a variable thickness (maximum 15 ft.) of dark-gray plastic clay or sandy clay, generally with few macrofossils and containing common pods or thin lenses of tan laminated silt. Gernant has found a very shallow water ostracode assemblage in this bed and speculates, probably correctly, that it accumulated in a restricted marine environment.

The overlying beds ("Zone" 22) are a sequence of interbedded, very shelly sands and much less fossiliferous clays totaling about 14 to 17 feet of section. These strata are excellently exposed in the bluff at Little Cove Point in southern Calvert County. Gernant points out that the shelly sands, sharply bounded and containing mostly broken and worn specimens, are probably allochthonous and represent extremely shallow water deposition. The highly fossiliferous sands encountered in the St. Marys Formation in borings SM-19 and SM-22 belong in all likelihood to this stratigraphic subdivision. As can be seen from the faunal lists, snails are the dominant element in these assemblages. The associated clays contain few fossils—chiefly *Turritella* and *Mercenaria*.

The upper portion of the St. Marys Formation in the test holes is medium-gray, variably muddy, fine to very fine sand interbedded with subordinate dark-gray clay. Much of the clay contains thin pods or lenticles of light-colored finely-laminated silt. Fossils are scarce throughout this portion of the section; the few present are practically all *Turritella*. In the zonal scheme, the upper St. Marys is comprised of "Zones" 23 and 24, but I was not able to relate the test hole sections to this framework. "Zone" 23 is described by Gernant as "sparsely fossiliferous, muddy, fine to very fine sand" with *Turritella* the sole macrofossil. Shattuck (1904) gives the thickness of this unit as 30 feet. "Zone" 24, apparently confined in outcrop to southern St. Marys County, includes two lithofacies. The first, a brownish sand with abundant fossils—predominantly gastropods as is the case throughout the St. Marys, is presumably an extremely shallow water accumulation. A similar environmental interpretation applies to the second lithofacies—a bluish gypsiferous clay with numerous articulated bivalves in living position.

The sands in the St. Marys Formation are with few exceptions fine to very fine grained quartz sands (fig. 18), generally more or less muddy but occasionally clean and well-sorted. The latter are generally pale gray or pale grayish-green, but with increasing mud content, the color darkens to medium or dark gray. Silt-clay beds in the St. Marys are most commonly homogeneous dark-gray and seemingly massive. Exceptionally, fine

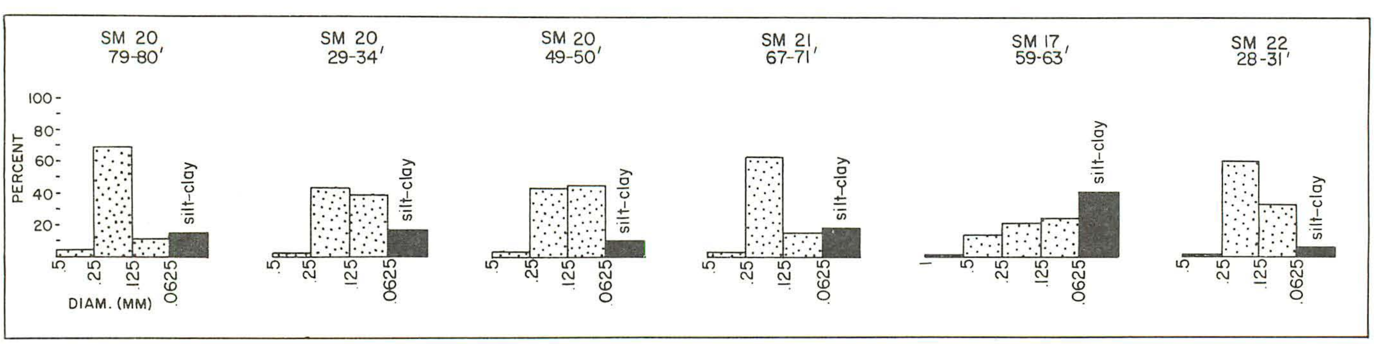

Figure 18. Size distribution histograms of St. Marys Formation sands.

Figure 19. Clay bed in St. Marys Formation the upper portion of which has been severely disrupted by burrowing organisms.

laminations are developed. Aside from laminations, nearly all of the sedimentary structures in the St. Marys Formation are biogenic. Burrows of various types are abundant throughout the unit, and in many sands are responsible for a pervasive mottling of the sediment. In the clays, burrowing is less common but more conspicuous as a result of the sharp contrast between the clay and the sand fillings in the burrows. The intensity of burrowing in some instances has reduced clay strata to isolated lumps seemingly floating in the sand (fig. 19).

Sands in the St. Marys Formation are mostly quartz sands with very small amounts of feldspar, and in some cases, an abundance of abraded shell fragments. The upper portion of the formation in southern St. Marys County is moderately glauconitic; in fact, some of the sands encountered in test borings south of the St. Marys River contain more than 50% glauconite. The glauconite grains are olive green to blackish green, polylobate, abraded, and average somewhat larger than the associated quartz grains. The St. Marys heavy mineral assemblage (table 3) is similar to that of the other Chesapeake Group Formations with one important difference—blue-green hornblende is an abundant component of the suite and in some instances the dominant species. Thus the importance of amphibolites in the Chesapeake Group source area apparently increased steadily through Middle Miocene time.

Clays in the St. Marys Formation were investigated by Hosterman (*in* Knechtel et al., 1966) who found the mineralogy to be kaolinite, illite, and montmorillonite in approximately a 1:1:1 ratio. This is in contrast to the clay mineralogy of the underlying Choptank and Calvert Formations in which montmorillonite fairly consistently comprises better than half of the suite.

UPLAND DEPOSITS

Nearly all of the upland area of Southern Maryland is capped by a relatively thin veneer of coarse clastics, collectively designated the Upland Deposits. These consist mostly of sand but also include considerable gravel as well as much subordinate silt-clay.

The term Upland Deposits, now in use by the Maryland Geological Survey, was first employed by Bennett and Meyer (1952) for all of the Pleistocene sediments in the Baltimore area lying at a "relatively high altitude". Otton (1955) extended the name to include "sediments of Pliocene (?) and/or Pleistocene age lying higher than 40 feet above sea level" in Southern Maryland. Hack (1955), on the other hand, reporting on essentially the same area, employed Upland Deposits for the Brandywine Formation of Clark (1915) plus portions of the Sunderland and Wicomico Formations of Shattuck (1906). His map shows the base of the unit everywhere above 100 feet elevation. It is probably clear at this point that Upland Deposits is a rather vague and in many ways unsatisfactory term, and some explanation should be offered as to why it is so widely employed. Shattuck (1906), one of the earliest students of these sediments, held that all of the Plio-Pleistocene sediments accumulated as gently sloping marine terrace sheets bounded at their inner edges by wave-cut scarps. Shattuck's terraces, named Lafayette, Sunderland, Wicomico, and Talbot from oldest to youngest, were presumed to have been deposited at successively lower altitudes with each recording an erosion-deposition cycle during a sea stand. The Lafayette, later renamed the Brandywine Formation by Clark (1915), was assigned to the Pliocene on the basis of its unconformable stratigraphic position between the Chesapeake Group and the oldest known Pleistocene. All of the remaining terrace deposits were placed in the Pleistocene. Shattuck's geologic maps of Calvert (1903) and St. Marys (1903) Counties reflect the terrace hypothesis as does Dryden's (1939) Charles County map and the geologic map of Prince Georges County by Cooke (1952). However, most of the recent workers dealing with these sediments have abandoned the concept of marine terraces. It has become increasingly clear that all of the exposed Plio-Pleistocene sediments of Southern Maryland excepting some low-level fine sands and clays in southern St. Marys County are fluvial in origin; moreover, well-defined laterally traceable scarps are poorly developed within the fluvial deposits. The nonmarine character of these sediments was first suspected by Chamberlain and Salisbury (1906), and expanded upon by Wentworth (1930) and Campbell (1931). Wentworth's conclusions, based on petrologic study, interpreted the Brandywine, Sunderland, and Wicomico Formations as stream deposits but retained Shattuck's nomenclature and age assignments. Campbell, on the other hand, affirmed the fluvial origin of these deposits but further concluded that the sediments above an altitude of about 100 feet were not separable into formations bounded by scarps. Similar views have been expressed by a number of modern workers, e.g. Dryden (1949), Hack (1955), and Schlee (1957), and there is now virtually no disagreement on the fluvial character of the Upland Deposits.

Current problems center around the stratigraphy of these sediments. In the Brandywine and Lower Marlboro quadrangles where detailed mapping has been done, Hack (1955) recognized in addition to the Upland Deposits (greater than 160 feet) four terraces stepping down to the Patuxent River, each a collection of flat surfaces underlain by coarse clastics similar to those on the Upland. The highest of these terraces is cut at elevations of from 80 to 140 feet with the others at successively lower altitudes down to 12 feet above river level. It is probable that similarly detailed mapping elsewhere along the Potomac and Patuxent Rivers will reveal analogous terraces. Dryden (1948) was able to trace a well-defined scarp toeing at 40 to 60 feet for a considerable distance paralleling the Potomac River in Charles County, but he could recognize none higher. My own observations confirm the presence of this scarp, not only bordering the Potomac but also at numerous points along the Patuxent. Higher scarps and associated terrace deposits are less continuously developed but are nonetheless apparent at scattered points. An excellent example of such a terrace, in this case a broad flat surface at 100 to 110 feet underlain by sandy gravel capped by sandy loam, is transected by Md. 381 in southernmost Prince Georges County where the highway descends to Swanson Creek (fig. 20). In other cases, however, intermediate terraces between the Upland and the lowland flats bordering the rivers are absent; rather a single high scarp separates the two surfaces. Instances of this relationship are numerous—the Upland margin on Cobb Neck and Cedar Point Neck, both in Charles County, may be cited as examples. The broad westernmost peninsula of Charles County, around which the great bend of the Potomac is described, exemplifies one of the many stratigraphic problems posed in delimiting the base of the Upland Deposits. The Upland over a large part of this area appears to decline without stratigraphic break to the level of the terrace adjoining the Potomac River. What probably occurs here is the descent of the Upland Deposits toward the River through a series of

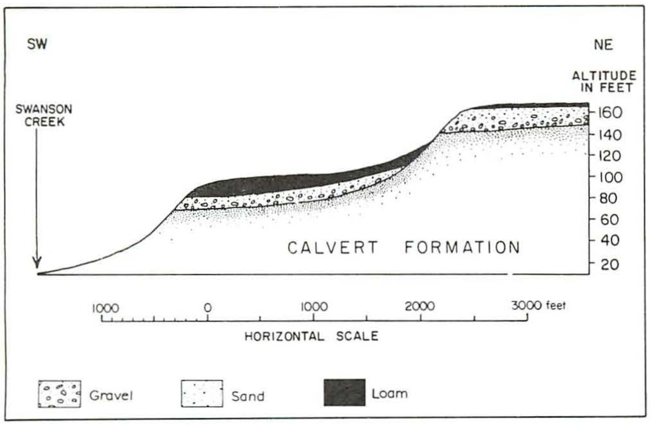

Figure 20. Diagramatic cross-sectional view of well-defined intermediate terrace below the Upland near Aquasco in southern Prince Georges County.

broad shallow steps separated by minor stratigraphic breaks, much as Hack (1955) has demonstrated for the Brandywine area. If this is indeed the case, it will be documented only by careful and very detailed large-scale mapping. An interim solution, albeit arbitrary, is a modification of Hack's (1955) definition of the base of the Upland Deposits. So viewed, the Upland Deposits comprise a roughly planar sediment sheet whose base slopes southeastward from approximately 240 feet elevation at the northern boundary of the survey area to about 80 feet near Ridge in southern St. Marys County. Moreover, the sheet appears to slope toward the Potomac and Patuxent Rivers, probably by virtue of the terrace step mechanism discussed earlier. Where a simple clearly-defined scarp separates the Upland and its sediment mantle from near sea-level lowland deposits, no difficulty is encountered with delimitation of the Upland Deposits. Difficulties are met, however, when intermediate terraces are present, and here the base of the Upland Deposits is placed arbitrarily at about 100 feet.

Through most of Southern Maryland the Upland Deposits are bipartite, consisting of a basal sand-gravel portion and an upper sandy loam. Hack (1955) considered these divisions to be members and mapped them separately in the Brandywine area. The lower member includes interbedded medium to coarse sand, pebbly sand, and sandy gravel, but as can be seen from the logs of the test borings, the greater part is sand. The sand is nearly everywhere oxidized to some degree, but generally speaking the color intensifies upward in the section from pale-yellowish or grayish near the base to deep reddish-brown at the top. Thin beds of mottled red, gray, or purple silt-clay are sporadically interbedded with the sand (fig. 21). Much of the sand in the lower member is relatively clean, but mud matrix generally increases in abundance vertically. The gravel fraction is mostly fine to medium in texture. However coarse gravel (fig. 22) is not uncommon basally or proximal to the Potomac River. Occasional boulders (fig. 23) are met, also at the base of the gravel.

The loam member of the Upland Deposits is composed primarily of yellowish to reddish brown, poorly-bedded sandy or silty loam with scattered coarse sand grains and small pebbles. Most of the loam is massive or mottled with pockets or nests of lighter colored sand; beyond this, little internal structure can be seen. The loam is in most cases transitional into the underlying sand-gravel. Advanced dissection has removed much of this member in Southern Maryland, particularly near the margins of the sediment sheet, and consequently it is thin, averaging about 15 feet in thickness. It is best preserved along the spine of the Upland, as for example in central Charles County where good exposures can be seen in most of the road cuts along U.S. 301 between Waldorf and LaPlata (fig. 24).

Compositionally, the Upland Deposits are mature siliceous residues. The sand fraction is comprised of an average 93% quartz, 5% chert, and 2% feldspar plus micas (Schlee, 1957). Most of the quartz grains are subangular to subrounded and exhibit overgrowths, pointing to a polycyclic origin. Similarly, vein quartz, sandstone-quartzite, and chert make up all but a few percent of the pebbles in the gravel fraction. The abundance of chert, which reaches as much as a third of the total pebbles, is particularly significant because it requires an Appalachian source. Minor rock types in the gravels include red to purple siltstone, gray and greenish phyllites, and weathered gneiss and schist. The latter are virtually confined to that portion of the sediment sheet adjacent to the Potomac River, presumably the youngest part of the Upland Deposits (Schlee, 1957). In contrast to the underlying older Tertiary, the heavy mineral assemblage of these sediments is essentially one of stable species (fig. 25). Zircon, tourmaline, and staurolite make up the bulk of the suite, accompanied by lesser quantities of kyanite, sillimanite, and rutile, and only trace amounts of garnet, epidote, chloritoid, and hornblende. The zircon-tourmaline-staurolite assemblage is more or less typical of all of the fluvial facies in the Maryland Coastal Plain with the exception of low-lying Pleistocene. The Upland Deposit profile examined in fig. 25 suggests that zircon and tourmaline increase in abundance vertically at the expense of

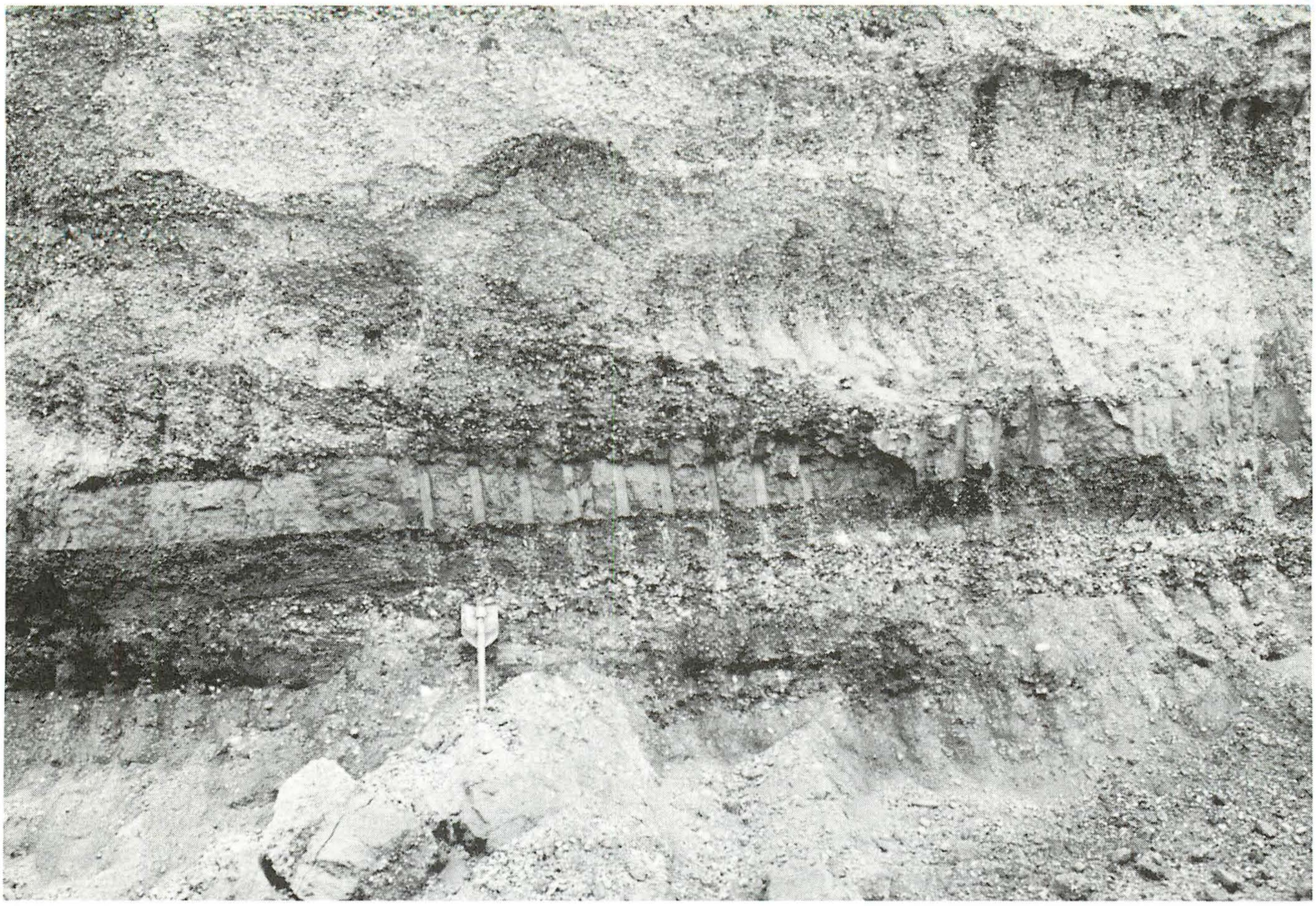

Figure 21. Thin sharply-bounded silt-clay in gravel of the Upland Deposits near Leonardtown in St. Mary's County.

staurolite, kyanite, and sillimanite, a trend probably attributable to weathering either in place or during transport to the basin. The clay mineral suite was investigated in several silt-clay samples from these sediments and proved to be a kaolinite-illite-mixed layer suite.

Systematic geographic variations can be demonstrated within the Upland Deposits of the Southern Maryland area. Schlee (1957) has pointed out several such trends, namely a decline southeastward in the maximum size grade, a parallel decrease in modal gravel size, and a southeasterly decline in the proportions of weathered chert. Cross-bedding in the Upland Deposits indicates fairly consistent easterly to southeasterly sediment transport; thus, the emergent pattern is that of a fluvial sediment sheet fining in the direction of transport and becoming younger to the southeast. Consistent with this picture, the sediments on the Upland in Calvert County and in southern St. Marys County are predominantly sandy with very much subordinate gravel, most of it fine. Minor rock types and anomalously large boulders are virtually limited to the margins of the sheet proximal to the Potomac River. Some of these boulders are quartzite clasts as much as 3 feet across. This portion of the Upland Deposits is doubtless younger than that inland, but age alone is not sufficient to account for the boulders and unstable rock types. Schlee's suggestion of a colder climate initiated with the advent of Pleistocene glaciation to explain these features is probably well-founded. In that event, rafting by river ice is a plausible mechanism for the transport of large boulders.

Many features typical of fluvial sediments are well-developed in the Upland Deposits. Trough cross-bedding, cut and fill, clay clast conglomerates, fining upward cycles, and openwork gravels are some of these. Viewed broadly, the Upland Deposits in their entirety can be regarded as a fining upward cycle (fig. 25); in most cases, the coarsest gravels lie at the base of the unit whereas the fine-grained sediments are concentrated in the uppermost portion. Hack's (1955) assessment, amplified by Schlee (1957), of the Upland Deposits as a degradational channel gravel-floodplain silt couplet laid down by the ancestral Potomac River is probably accurate. Schlee found no spatial variations across the sediment sheet or more importantly in the current pattern to suggest that the Patuxent River was extant during the deposition of the Upland Deposits. It is clear, however, that those deposits proximal to the modern Patuxent were terraced or otherwise modified by that river during the late Pleistocene or Holocene.

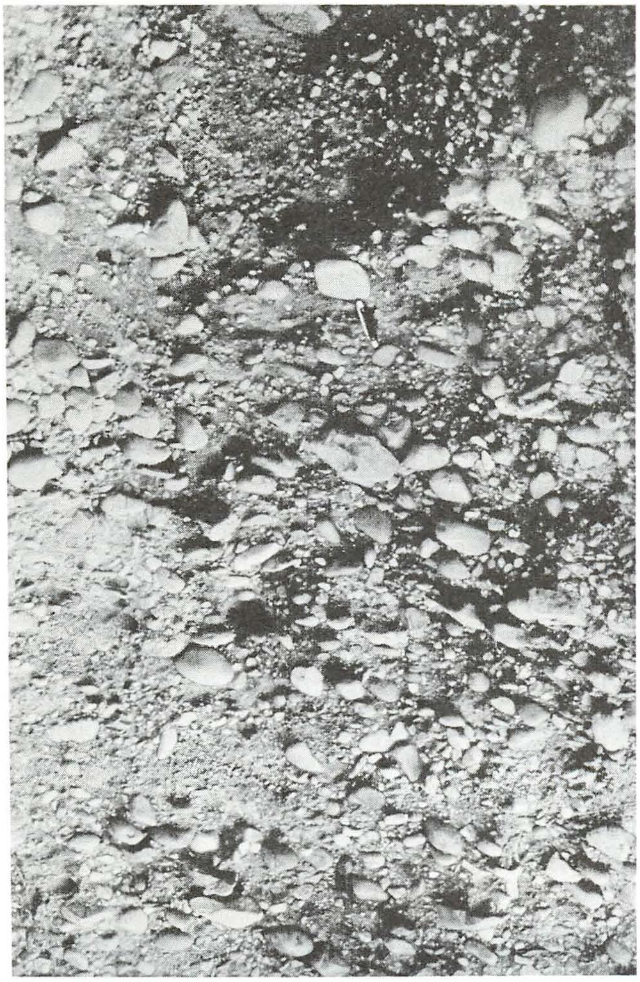

Figure 22. Coarse gravel in the Upland Deposits near Accokeep, Prince George's County.

The time of initiation of Upland Deposit sedimentation is a matter for conjecture. The youngest materials beneath these sediments are late Middle Miocene (St. Marys) so deposition could have begun at any time from late Miocene through Pliocene. Hack (1955) favors a late Miocene age but others, including Wentworth (1930) and Cooke (1952), regard the Upland Deposits as wholly Pliocene. Unfortunately, fossils are exceedingly scarce in these sediments, and the few finds include non-diagnositc vertebrate remains and plants, the latter not different in any important respect from the modern flora.

Since the top of the Upland Deposits is everywhere an erosion surface undergoing active dissection, the thickness of these sediments varies considerably. In some cases, as little as 10 feet is preserved, in others as much as 85 feet. There is a tendency for the sheet to increase in thickness from northwest to southeast, paralleling the decline in gravel content. The Upland Deposits overlie with angular unconformity a number of stratigraphic units ranging from the Eocene Aquia Formation up through the Miocene St. Marys Formation. The basal contact is usually quite sharp and readily drawn, particularly when the initial Upland sediments consist of gravel. Sand on sand contacts, prevalent in much of Calvert County (fig. 26), are less obvious but nonetheless distinct. To the southeast, the Upland Deposits include increasingly greater proportions of fine-grained sediments and tend to exhibit a more complex internal stratigraphy. The section following, measured in a road cut near Leonardtown in southern St. Marys County, illustrates the point.

Section in road cut, west side of Md. 5, 1.4 miles southeast of Leonardtown, St. Marys County (upper 18 feet of section measured in gravel pit nearly opposite cut).

	Thickness (ft.)
Upland Deposits:	
Silt and sand, very fine grained, muddy, brownish-red, massive	5
Gravel, brownish to tan, medium grading to coarse at base, cobbles to 6 in. diameter at base; and sand, medium to coarse grained; cross-bedded to flat-bedded; scattered thin bands of reddish clayey silt	14
Sand, orange fading to medium-gray at base, fine grained, muddy	5
Clay, medium gray, plastic; interbedded with grayish silt and fine grained sand	3
Clay, mottled pale gray and orange, sandy; scattered burrows	1
Peat, dark-gray, coarse	½
Sand, orange-brown, fine grained	5
Gravel, brownish, sandy, medium	½
St. Marys Formation:	
Clay, medium gray, brittle	2
Total section	36

The inclusion of interbedded fine muddy sand, drab silt-clay, and peat suggests the introduction of quiet water, floodplain or fluviomarine environments which are absent upcurrent to the northwest.

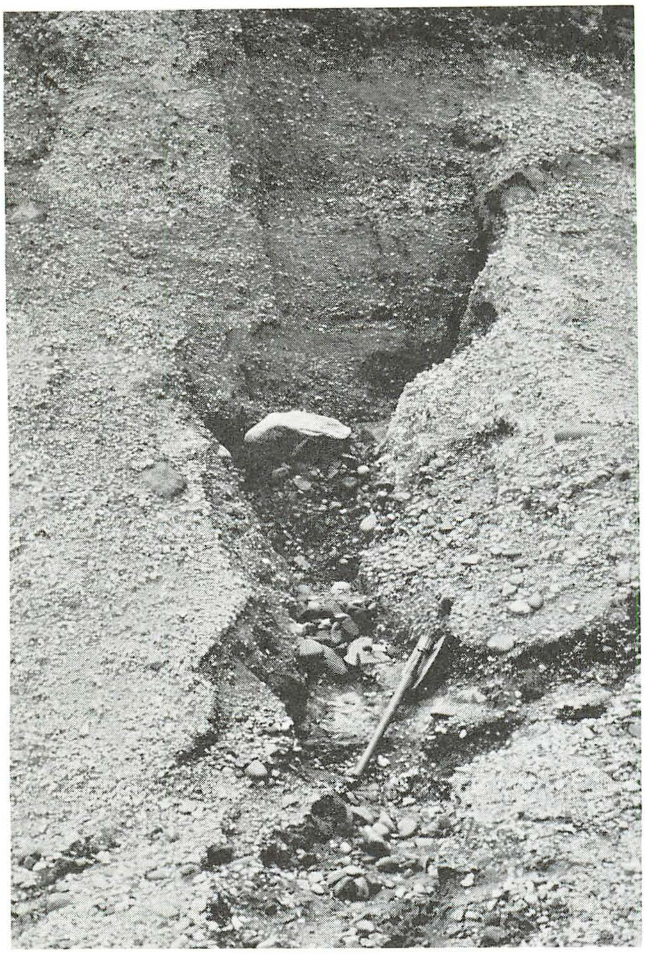

Figure 23. Boulder and large cobbles in gravel of the Upland Deposits near Dynard, St. Mary's County.

LOWLAND DEPOSITS

The designation Lowland Deposits, a companion grouping to Upland Deposits, covers a rather heterogeneous assemblage of sediments, all of which, however, are Quaternary in age. Included are sand, mud, and subordinate gravel blanketing the lower reaches of the stream valleys in Southern Maryland as well as all of the terrace sediments flanking the Potomac and Patuxent Rivers which lie below 100 feet of elevation. The rationale for using the term Lowland Deposits follows along much the same lines as that given for replacing the existing stratigraphic confusion with the designation Upland Deposits. Meaningful mapping of Shattuck's Talbot (45 ft. shoreline) and Wicomico (45 to 130 ft. shorelines) terraces or Cooke's Pamlico (25 ft. shoreline) Formation has not proved possible. Like the Upland Deposits, all of these sediments are fluvial excepting some drab clays fringing the southern tip of St. Marys County. Continuously traceable scarps or lithologic breaks within the Lowland sequence have not been seen during field study with the possible exception of Dryden's 40 to 60 ft. scarp facing the Potomac in Charles County. The latter, although well-defined at several points in that County, is not sufficiently developed elsewhere in Southern Maryland to be mapped.

Alluvium, encountered in most of the stream valleys in the survey area, varies from a few inches to as much as 25 feet in thickness although the average is closer to 10 feet. The lithology is diverse, reflecting the local source rocks, but in general the basal beds are gravelly or pebbly sand grading up to fine sand or mud. The pebbles are nearly always vein quartz. Most of the alluvium is poorly-sorted with an abundance of mud matrix accompanying all grain sizes. Moreover, glauconite is usually a component of the sediment where the local drainage basin contains glauconitic sediments at the surface (Aquia, Nanjemoy Fms.). The glauconitic materials tend to be greenish or drab in color as do nearly all of the fine-grained beds in the alluvium. Bits of wood and disseminated organic matter are common in the muds.

The bulk of the Lowland Deposits is contained in terraces bordering the Potomac and Patuxent Rivers. In the larger view, however, the Lowland Deposits extend as well to the sediments beneath the river channels (see fig. 27) ; consequently, the thickness range is enormous—from a feather edge to about 150 feet. Accumulations of over 100 feet, however, are confined to the distal portions of St. Marys and Calvert Counties, as for example 150 feet at Scotland Beach and 125 feet at Solomons Island (Otton, 1955). Twenty to 30 feet is more nearly the average thickness. The bulk of the Lowland Deposits is medium to coarse-grained

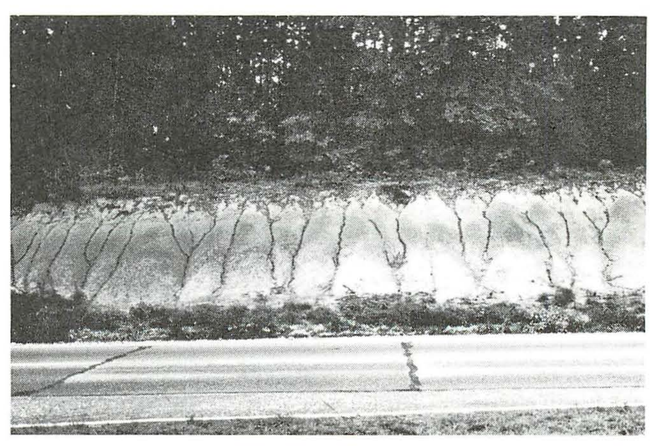

Figure 24. Loam Member of the Upland Deposits along U.S. 301 near La Plata, Charles County.

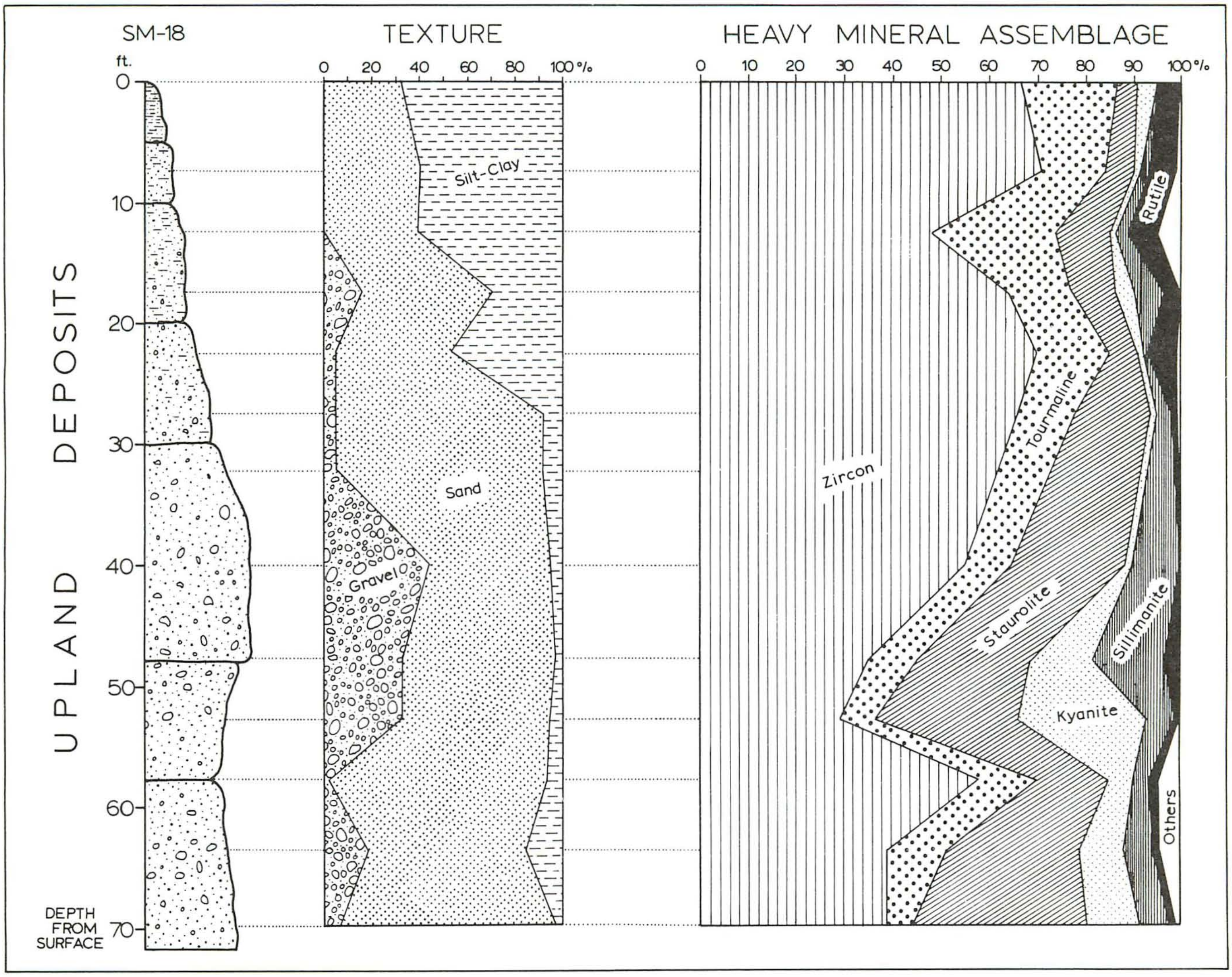

Figure 25. Vertical variation in texture and mineralogy within the Upland Deposits.

sand or pebbly sand (fig. 28), and in this respect these sediments do not differ greatly from the Upland Deposits. Most of these Lowland sands, however, do tend to be much less weathered as well as cleaner and paler in hue. The telltale reds or browns of oxidation are seldom noted. Moreover, these younger sands are loosely compacted and cave readily. Gravel as such is much subordinate in the Lowland terraces; pebbly sand containing fine to medium diameter quartz pebbles generally makes up the coarsest portion of any given section. The sands contain small amounts of feldspar but otherwise are wholly quartzose. In contrast to the Upland Deposits, the heavy mineral assemblage of the Lowland terrace sands contains large amounts of epidote (fig. 28)—a mineral virtually absent in the Upland sediments. Since the source areas of both Upland Deposits and Lowland terraces were essentially the same, some explanation other than provenance must be offered to explain the presence of abundant epidote in the younger rocks. Perhaps the answer lies in the progressive exhumation of fresher mafic rock in the Piedmont.

Broadly viewed, the Lowland Deposits are tripartite in character, at least in southern St. Marys County where they are thickest. The lower as well as thickest unit is sand and gravelly sand, coarsest at the base and fining upward. Otton (1955) reports very coarse gravel in places with cobbles to 6 inches in diameter. Overlying this lower sandy unit is a variable thickness of tough bluish-gray to dark brown clay, commonly plastic but becoming silty or sandy in some areas. This clay ranges in thickness from as little as 10 feet to as much as 90 feet beneath some segments of the present Potomac shoreline. It is fossiliferous in part and unique within the Maryland Pleistocene in being marine in origin. Although outcrops of the clay

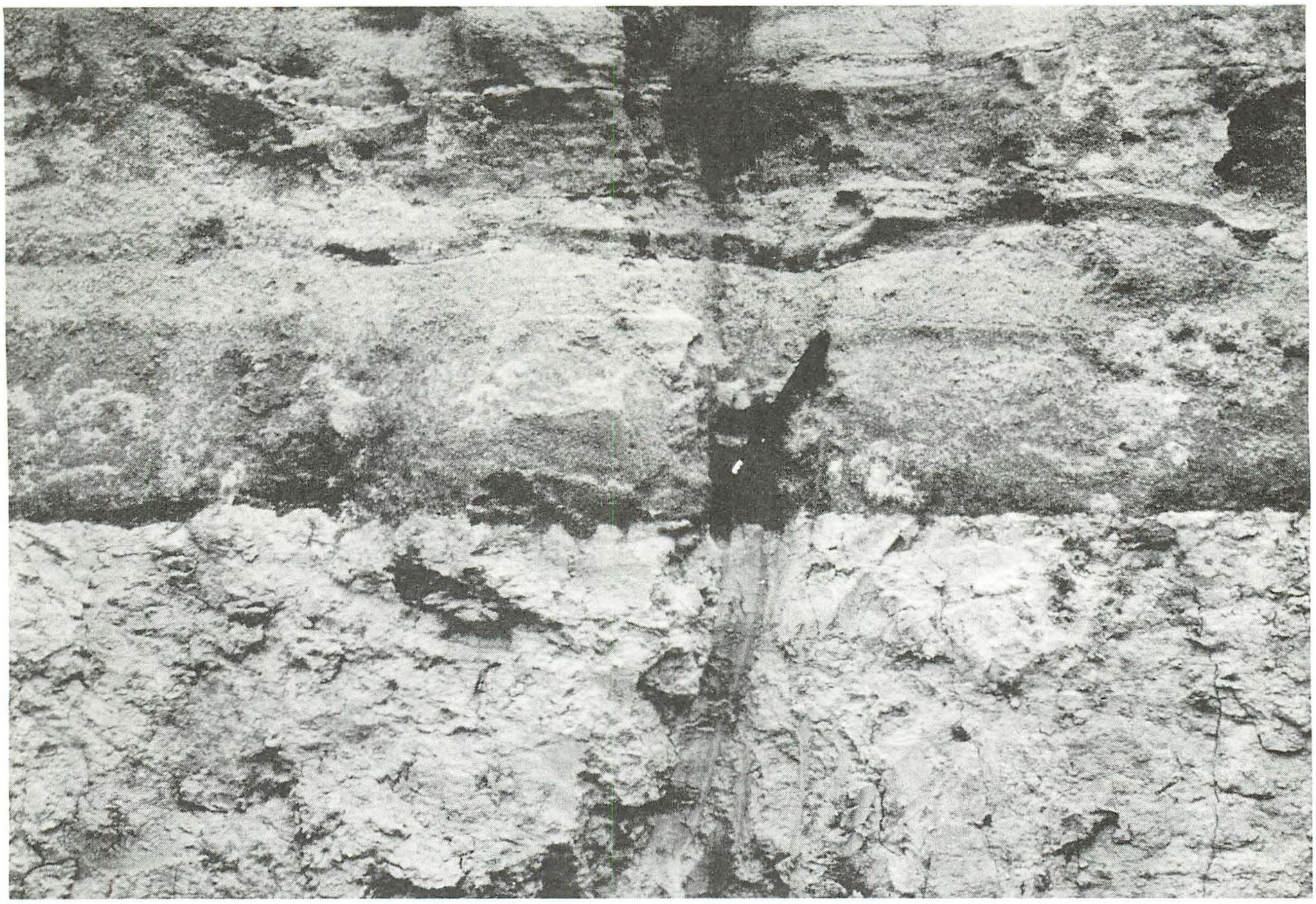

Figure 26. Sharp erosive contact between the Upland Deposits (coarse sand) and the Calvert Formation (weathered fine muddy sand) in northern Calvert County.

are scarce, a good exposure was seen during relocation of Md. 5 about 1 mile north of St. Inigoes in St. Marys County. The new cut exposed 5 feet of sticky dark-gray clay grading laterally to greenish silty clay with fossils conspicuous in the upper portion of the darker clay. Particularly common were the bivalves *Crassostrea virginica* and *Mytilus clava,* and the snail *Ilyanassa obsoleta.* The fossiliferous bed is truncated along a moderately channeled contact and overlain by several feet of coarse white sand. The clay bed in the road cut is in all probability the same as that exposed at Wailes and Langleys Bluffs, both notable Pleistocene fossil sites in Southern Maryland. At both Langleys Bluff on the Bay some 7 miles north of St. Inigoes, and Wailes Bluff on the Potomac about the same distance south of that community, the exposure includes several feet of greenish-blue sandy clay which carries a large and varied assemblage of mollusks as well as echinoderms, crustaceans, and bryozoans. The clay apparently thickens from north to south; at Langleys, the underlying St. Marys Formation is exposed beneath the clay whereas a test boring at Wailes Bluff penetrated 21 feet of Pleistocene clay without reaching the Miocene (Blake, 1953).

The upper unit of the Lowland Deposits in Southern Maryland consists of pale gray, fairly clean, medium to coarse-grained sand much like the basal unit but considerably less pebbly and much thinner. Seven to 12 feet of such sand was measured in the several outcrops seen during the course of this study.

The threefold division of the Lowland Pleistocene holds up only for the terraces fringing the southern tip of St. Marys County and portions of southernmost Calvert County. To the north and northwest, the central clay unit pinches out, the entire section is reduced in thickness, and the whole becomes essentially a sandy section. These sands and pebbly sands are marked by cross-bedding, fining upward cycles, lenticular bedding and channeling, all suggestive of fluvial deposition (fig. 29). Only the fossiliferous clay to the south is shallow marine or estuarine.

All of the available evidence points to a Pleistocene age for the Lowland Deposits but precisely how much of the Pleistocene is represented has been the subject of continuing investigation. Cooke (*in* Blake, 1953), basing his conclusion on geomorphologic considerations, thought the fossiliferous clay Aftonian or early Pleistocene, whereas Mansfield (1927) proposed a late Pleistocene age on the basis of the geologic time range and modern distribution of the enclosed fauna. The age problem has also been approached through the fossil flora. Seeds, fruits, leaf remains, and wood fragments are widely distributed in the Lowland Deposits and afford some clues as to the character of the Pleistocene flora in this region. Important accumulations of plant fossils occur in drab clay and peat near Drum Point and at Sollers in Calvert County; the latter occurrence includes a number of large *in situ* stumps. A third plant bearing bed crops out at Cedar Point on the Bay in St. Marys County. The fossil flora at most of these localities contains such familiar modern genera as *Quercus* (oak), *Ulmus* (elm), *Fagus* (beech), *Carya* (hickory), and *Alnus* (alder) and doubtless records integlacial conditions. Knox (1966), however, in his investigation of Lowland terraces in Washington, D.C., found an interbedding of zones dominated by spruce-fir pollen on the one hand, and by that of broad-leaved deciduous trees on the other, reflecting sedimentation spanning the Illinoan glacial, Sangamon interglacial, and Wisconsin glacial. It is probable then that a similar time span will ultimately be found in the Lowland Deposits of Southern Maryland.

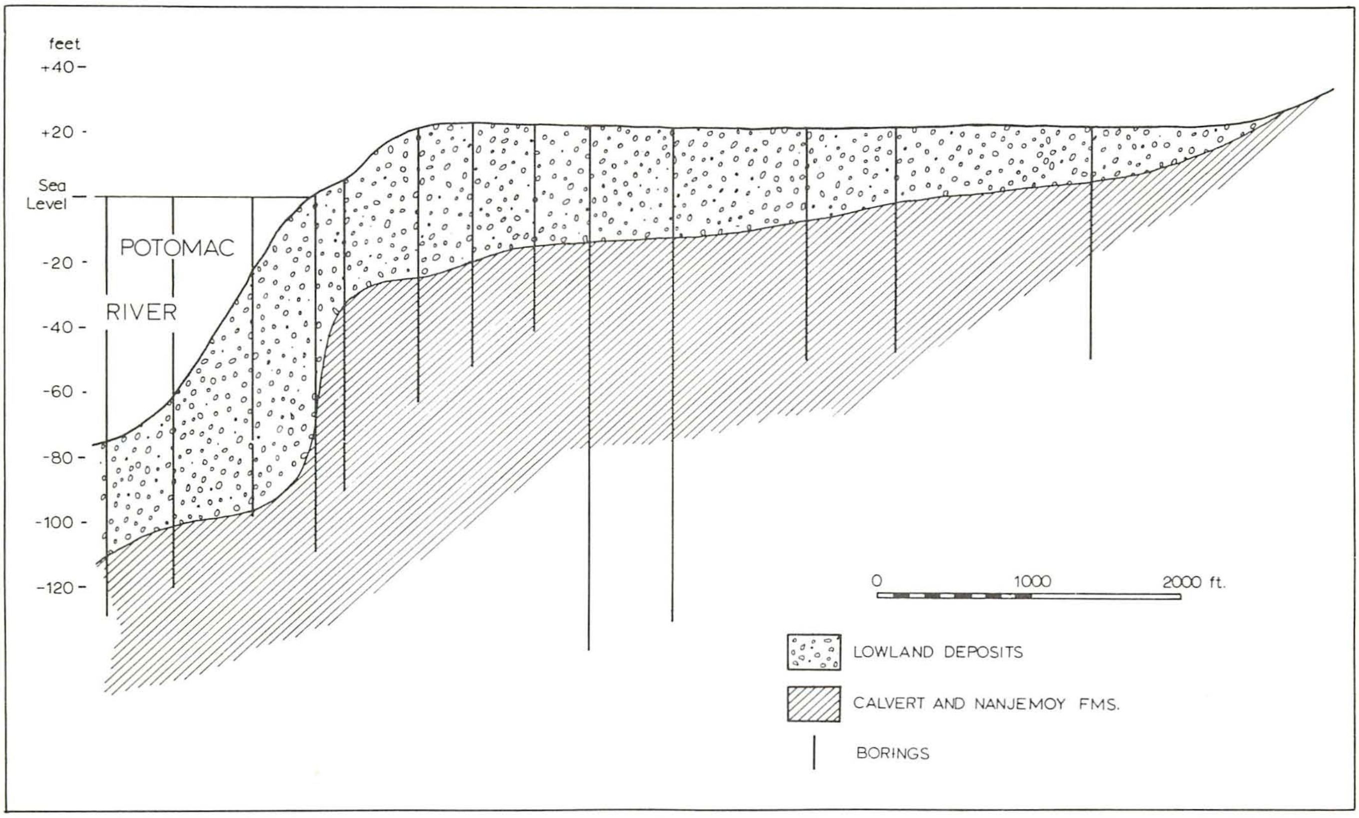

Figure 27. Profile of the Lowland Deposits underlying the site of the Potomac Electic Power Co. plant at Morgantown, Charles County.

INTRODUCTION

The underlying purpose of this investigation has been the location, description, and evaluation of the mineral resources of the Southern Maryland area. The bulk of the data collection was carried out with this end in mind, including all of the test borings which were designed specifically to aid in this evaluation. Mineral deposits of economic significance are relatively few in the area surveyed, and further, none of these, with the exception of sand and gravel, can be considered to be real potential value. In former years, small quantities of diatomite, greensand, and shell marl were produced locally, but of these commodities only greensand is exploited at the present time.

Urbanization has begun in the northern portion of the area, and is likely to make substantial inroads into Southern Maryland through the next decade and beyond. New construction will require quantities of bricks, mortar, structural tiles, and other building materials, needs that will perhaps provide the necessary climate for expansion of the existing aggregate industry as well as the development of new deposits in Southern Maryland. A major segment of the growing market for mineral aggregate lies immediately to the north of Southern Maryland in the rapidly expanding population centers of the metropolitan Washington area. New sources of raw materials for this area will clearly be needed to replace those in the Baltimore-Washington corridor which are being depleted or covered by urbanization.

DIATOMITE

Diatomite is usually defined as a siliceous rock consisting mainly of the remains of diatoms or diatom *tests* as they are properly termed. Very little of the diatomaceous sediment in the Calvert Formation qualifies as such. In fact, the Fairhaven diatomaceous bed rarely contains more than 50% diatoms and generally less—25 to 50% of the sediment in most instances (fig. 30). Nonetheless, this material does have economic potential and for convenience will be called diatomite.

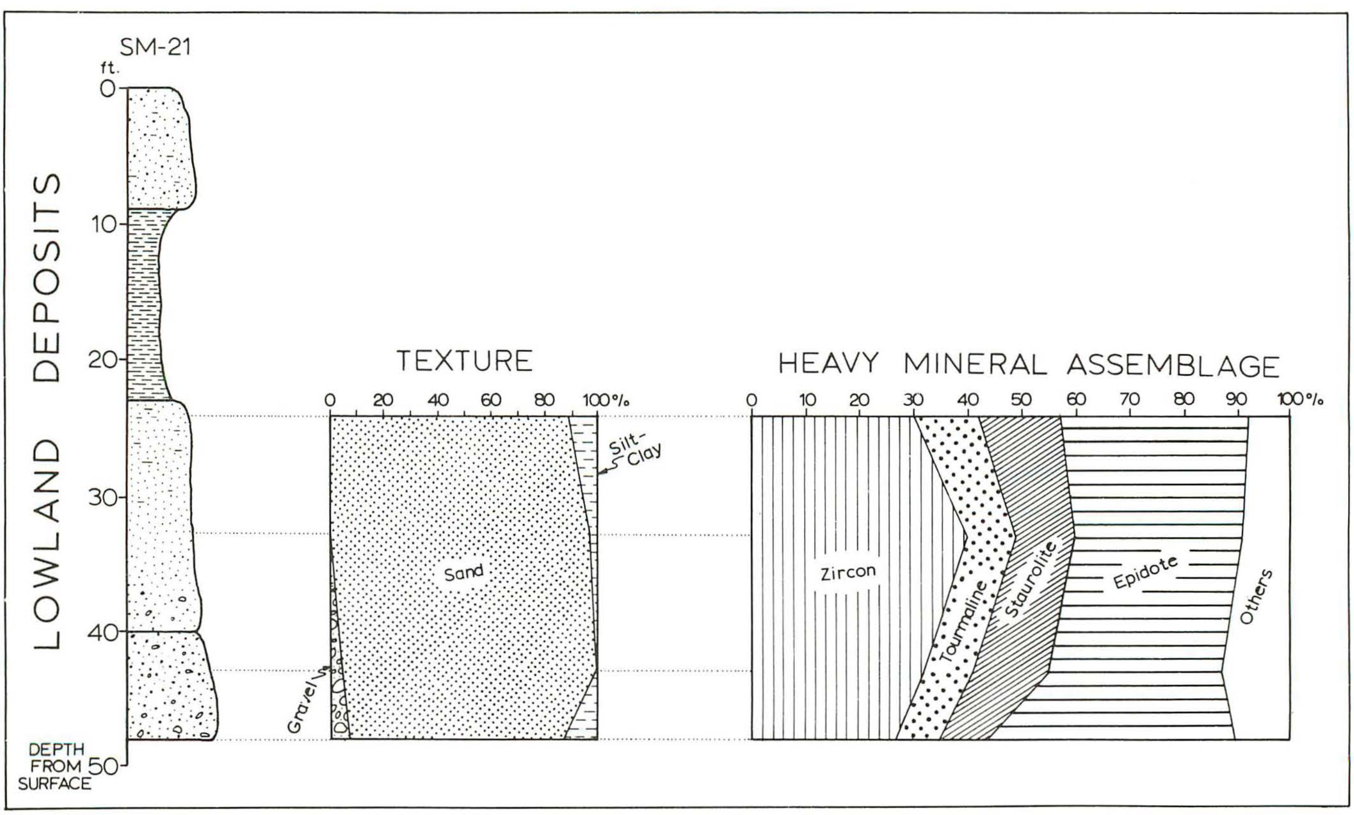

Figure 28. Vertical profile of texture and mineralogy in the Lowland Deposits.

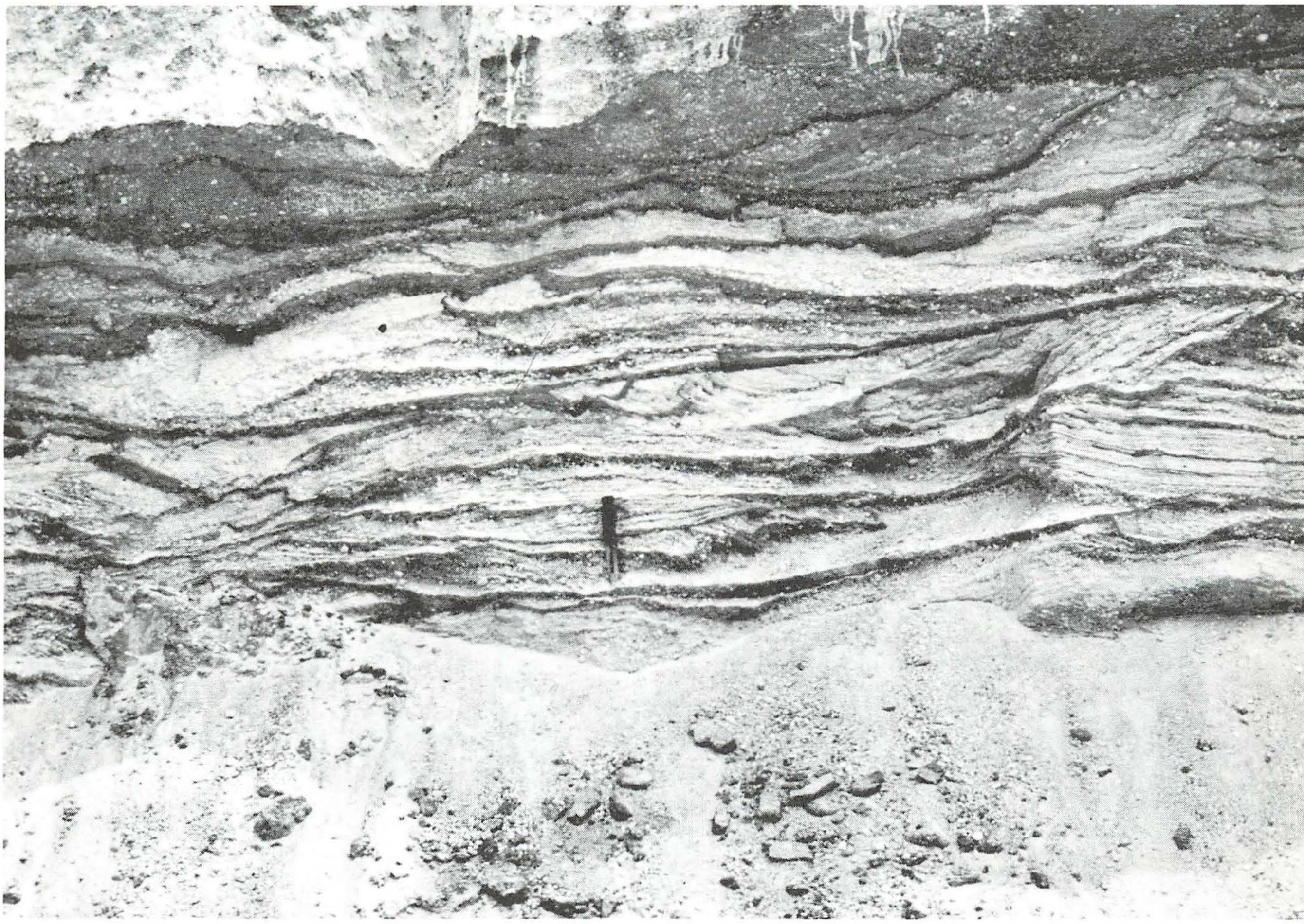

Figure 29. Lenticular bedding in sand and fine gravel of the Lowland Deposits near Appeal, Calvert County.

The presence of diatomite in the Calvert Formation has been known for some 125 years. Emphasis was given this feature by Shattuck (1904) in his choice of the name Fairhaven diatomaceous earth for the lower member of the Calvert although he did recognize that diatomite made up only a portion of the unit. Over much of Southern Maryland, the diatomite is restricted to a single bed or zone within the Fairhaven (see fig. 13). The zone varies considerably in thickness—4 to 17 ft.—and shows gradational boundaries with the adjacent muddy sands. In other cases, however, the diatomaceous zone is rather poorly defined, spanning as much as 40 feet of sediment and exhibiting numerous peaks and valleys of diatom concentration. The stratigraphic position of the diatomite is roughly constant with the initial large influx of diatoms entering the section between 8 and 25 feet above the base of the Calvert Formation. This latter horizon (Calvert-Nanjemoy contact) has proven a convenient datum in outlining the areal distribution of the diatomite in Southern Maryland. The abrupt downward change to greensand at this contact is easily detected in most drillers' logs whereas the diatomite *per se* is rarely noted; thus a large amount of data could be effectively utilized in constructing a structure contour map of the Calvert-Nanjemoy interface (pl. 3). Bearing in mind the more or less constant position of the diatomite with respect to this contact, the map shows indirectly then the position of the diatomite bed at any given point in Southern Maryland. Included on the map are the locations of the 10 core holes drilled during the course of this investigation which encountered the diatomite. Diagrammatic logs of the holes are also shown.

Unweathered diatomite, seen mostly in cores but also in some outcrops, is olive-green in color, brittle in tenacity, and appears drier than the host Calvert sands. It is not homogeneous but rather shows irregularly distributed anastomosing sandy burrow fillings which probably account for much

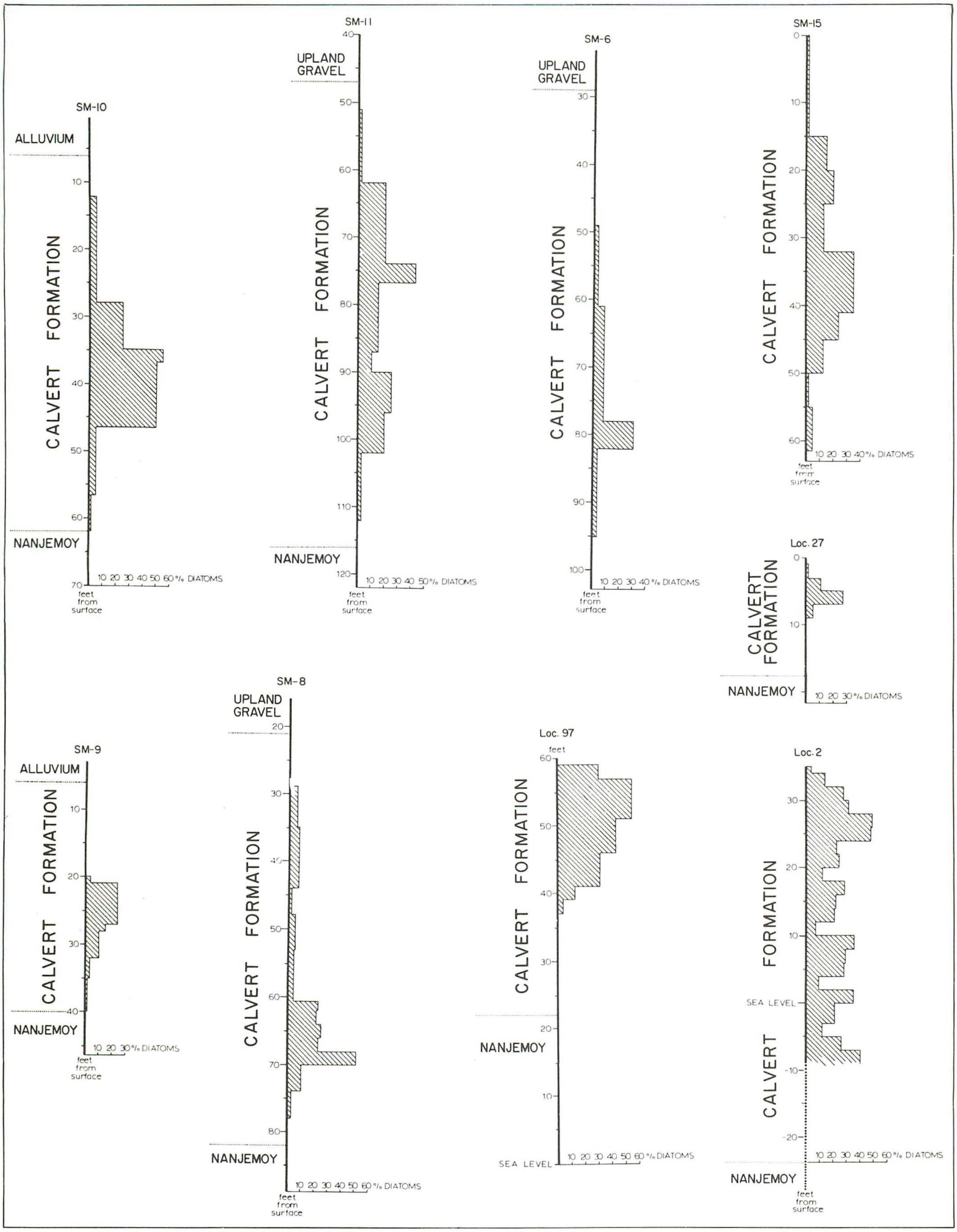

Figure 30. Diatom content of Calvert Formation sediments encountered in test borings (see Appendix B for logs). Proportions determined by point count of serial samples in each core.

of the observed variability in diatom proportions in the samples analyzed. Fossils are scarce in the diatomite, and with the exception of the nearly ubiquitous phosphatic brachiopod *Discinisca lugubris,* shell carbonate is leached even in seemingly fresh sediment. Aside from *Discinisca,* the most common fossil in the diatomite is the deep burrowing bivalve *Lucinoma contracta.* Stratification is only rarely apparent in this material. Occasional sandy beds, usually a few inches thick, can be seen in places as can sets of fine laminations, but the bulk of the diatomite is massive or at most burrow-mottled. It is likely that bedding was initially well-developed throughout but was disrupted and the sediment homogenized by burrowing organisms soon after deposition. Small irregular pellets and grains of dark gray phosphate are in some places abundant in the lower portion of the diatomite where they tend to be concentrated in burrow fillings.

The diatomite rapidly pales upon exposure, often within a matter of days, to progressively lighter shades of brown or gray. Weathered outcrops tend toward pale gray and ultimately to nearly white when dry (fig. 31). The weathered sediment is light and chalky in texture with the development of reddish-brown Leisegang banding proximal to the soil zone. Most of these features are well shown in the type section of the Fairhaven, i.e. the low bluffs bordering the Bay just south of the community of Fairhaven in southern Anne Arundel County. The section here comprises 35 to 40 feet of the lower Calvert, most of it diatomaceous to some degree and richly diatomaceous in part. At Bay level, the sediment is olive green (essentially unweathered), compact, and relatively hard, with conspicuous pods and lenses of phosphate pellets. Fine horizontal laminations are visible in places. Within a couple of feet of the waterline, the color has faded to gray and the sediment is noticeably softer. Within 10 feet, the diatomite is nearly white. This material is separated from 10 to 15 feet of deeply weathered, reddish-mottled hackly diatomite above by a sharp undulatory contact which crosscuts the stratigraphy. In the Fairhaven bluffs, zones of high diatom concentration are spread over a greater stratigraphic interval (about 40 feet) than elsewhere in Southern Maryland; southwest along the strike, diatomite is generally confined to a single bed or zone which seldom exceeds 10 feet in thickness.

Microscopic examination of a large number of samples has shown 3 major components in the diatomite—diatom tests, quartz sand and silt, and clays. Diatoms make up as much as 65% of the material by volume, and this fraction is best described as a hash of largely broken tests. The size span of the fragments ranges well down into the clay fraction; most, however, are sufficiently large to be identified. Figure 32 is a typical field in a highly diatomaceous sample. Indicated are the most common diatom types—in this case, *Melosira, Coscinodiscus, Raphoneis,* and *Cestodiscus,* all typical Calvert genera. Tests which are round in cross-section are the prevalent type in the Calvert Formation, much as is the case in the famous Lompoc, California deposits. Lohman (1948) has identified some 90 forms in the Calvert but only a small number of these can be considered common. Silt and very fine quartz sand is the second significant component of the diatomite, in some cases comprising nearly half the sediment (see table 4). The sand is concentrated in burrow fillings and irregularly distributed sandy zones, and is thus very unevenly distributed within the diatomaceous bed.

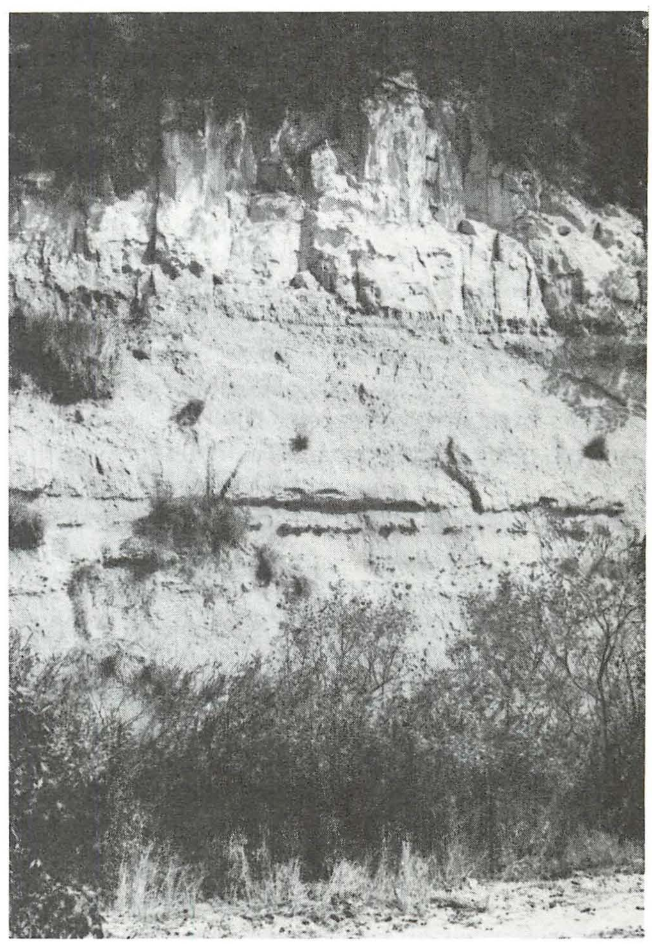

Figure 31. Diatomite bed (whitish blocky material at top) in Popes Creek bluff. The overhanging ledge midway in the section marks the Calvert-Nanjemoy contact.

The proportions of clay, the third component of the diatomite, vary widely, and in addition, present difficulties in accurate assessment. In the samples studied, the amounts of clay-size material range from 10 to 60%, but both microscopic examination and x-ray diffraction analyses suggest that much of this fine fraction is made up of finely fragmented diatoms. Clay minerals *per se* may actually comprise only 5 to 30% of the diatomite. Estimates made by other workers range from 15 to 35% clays in individual samples. The available data indicate that the clay content of the diatomite is highest in the northeastern third of the outcrop belt and declines to the southwest. Montmorillonite, illite, and kaolinite in an average 7:2:1 ratio make up the clay suite in all of the samples examined. Accessories include quartz, dolomite, and the zeolite clinoptilolite, a product of the devitrification of volcanic glasses.

Minor constituents of the diatomite include occasional volcanic glass shards, rodlike siliceous sponge spicules, skeletal radiolarians and silicoflagellates, and various heavy minerals dominated by garnet, zircon, and tourmaline. In addition, several of the samples from the Fairhaven bluffs contain numerous tiny euhedral rhombs of dolomite.

The physical properties of a commercial natural diatomite might be summarized as follows. The material is pale gray to nearly white in color, and chalky and friable in texture. Apparent dry density is in the range 20 to 45 lbs. per cubic foot, lowering to 5 to 16 lbs. per cubic foot in powdered processed diatomite. The specific gravity varies from 1.9 to 2.4. Although the fusion temperature of pure diatomite is approximately 1600°C., sintering generally commences in an average quality, more clayey material at about 800°C. and is sufficiently advanced at about 1000°C. to bond a pressed brick. The thermal conductance of diatomite is quite low—hence its usefulness as an insulating material. In abrasive applications, the hardness of diatomite is 4.5 to 6.0 on the Mohs scale. The average particle diameter of a typical commercial diatomite is .025 mm, but the complete range is large, from .001 to .100 mm. Chemical composition of natural diatomites does not vary greatly; representative analyses of 4 commercially exploited deposits are tabulated in Table 5.

In comparison, the Fairhaven diatomite is olive-green in color, drying to gray-brown, with a bulk dry density of 40 to 52 lbs. per cubic foot varying to 25 lbs. per cubic foot for weathered material. Properties such as specific gravity, thermal conductance, hardness, and particle size do not vary greatly in natural diatomites, and although not investigated in the Fairhaven, are doubtless close to those enumerated above for commercial grade diatomite. Chemically, the Maryland diatomite (see table 6) averages less silica, more alumina, and is somewhat higher in iron oxide than the western U.S. and Mexican deposits (table 5). The results of tests conducted by the U.S. Bureau of Mines at Pittsburgh on 5 bulk samples of Fairhaven diatomite are summarized in table 7 and fig. 33. Oil decolorization tests (fig. 33) indicate that the diatomite is not an efficient bleaching agent, a result not unexpected view of the variable but generally low clay content of the samples. The samples do show, however, high absorbency (table 7) but it is doubtful that the unprocessed material could be economically used as a granular absorbent in view of its high crushing loss.

Figure 32. Typical diatomite containing in addition to fragmental and entire diatoms, sponge spicules, silicoflagellates and much angular quartz silt. Diatom genera indicated are: A. *Melosira*, B. *Conscinodiscus*, C. *Raphoneis*, and D. *Cestodiscus*.

The Calvert Formation furnished the initial production of diatomite in the U.S., and for a numbers of years, Maryland led the list of producing states. Diatomite was supplied from a pit at Lyons Creek Wharf on the east bank of the Patuxent River in Calvert County by the Maryland Silicate Company. The Lyons Creek pit was opened in 1884 and a second one 4 years later at the mouth of Popes Creek in Charles County; the combined production from both pits in 1888 was about 1500

Table 4. Particle size distribution in diatomite samples from Southern Maryland. Tabulated are proportions of sand, silt, and clay-size particles irrespective of particle lithology

Test boring or Locality No.	Diatomite intervals	Sand (>.063 mm) %	Silt (>.004 mm) %	Clay (<.004 mm) %
SM-8	60-62 ft.	22	34	44
	62-64	11	40	49
	64-66	12	34	54
	66-68	14	33	53
	68-70	10	68	22
27	5-7	19	55	26
	7-9	8	58	34
70	0-2	31	57	12
	2-4	29	52	19
	4-6	41	48	11
	6-8	18	33	49
	8-10	21	42	37
	10-11	13	25	62
SM-15	20-25	65	n.d.	n.d.
	35-40	42		
	40-43	54		
	43-45	53		
SM-11	74-77	34	n.d.	n.d.
	90-96	45		
SM-5	16-19	30	n.d.	n.d.
	19-21	15		
	21-25	36		
	25-27	48		
97	19-24	44	n.d.	n.d.
	24-29	35		
	29-35	19		
	35-39	34		

Table 5. Chemical analyses of commercially exploited diatomites from various localities [1]

	Lompoc Calif.	Idaho	Jalisco Mexico	Nevada
Silica (SiO_2)	88.60	89.82	91.20	86.00
Alumina (Al_2O_3)	3.72	1.82	3.20	5.27
Iron oxide (Fe_2O_3)	1.50	.44	.70	2.12
Lime (CaO)	.60	1.26	.19	.34
Magnesia (MgO)	.60	.54	.42	.39
Potash (K_2O)	.50	.22	.24	.29
Soda (Na_2O)	.50	1.03	.13	.24
Titanium (TiO_2)	.20	.07	.16	.21
Ignition loss	3.75	4.02	3.60	4.90
Total	99.97	99.22	99.24	99.76

[1] Data from Cummins (1960).

Table 6. Chemical analyses of diatomite samples from Southern Maryland

	1	2	3	4	5	6
Silica (SiO_2)	80.30	84.10	81.20	76.60	82.70	79.30
Alumina (Al_2O_3)	5.80	4.40	3.70	5.60	4.90	4.30
Iron oxide (Fe_2O_3)	2.40	2.60	2.50	2.00	2.40	2.00
Lime (CaO)	nil	1.10	.90	1.30	1.40	.70
Magnesia (MgO)	1.90	.40	.40	.90	.60	.60
Potash (K_2O)	.04	1.00	.90	1.00	.90	.90
Soda (Na_2O)	.24	.90	.20	.80	.20	.30
Titanium (TiO_2)	.48	.90	.70	.50	.70	.60
Ignition loss	8.92	4.50	6.40	10.40	6.20	7.80
Totel	100.08	100.90	96.90	99.10	100.10	96.50

(1) Kaylor pit, near Dunkirk, Calvert Co.
(2) Fairhaven bluffs, Anne Arundel Co.
(3) Three miles southwest of Upper Marlboro, Prince Georges Co.
(4) Two miles north of Dunkirk, Calvert Co.
(5) Two miles northeast of Bel Alton, Charles Co.
(6) Popes Creek bluff, Charles Co.

Table 7. Results of absorbency tests conducted on diatomites from Southern Maryland (see table 6 for sample identifications)

Sample No.	Particle size: retained on 30 mesh, %	Particle size: retained on 40 mesh, %	Particle size: retained on 60 mesh, %	Absorbency (ml/gm): oil	Absorbency (ml/gm): water
2	21.5	26.5	33.2	1.54	1.54
3	35.0	41.7	50.7	1.26	1.42
4	25.9	32.1	39.6	1.22	1.56
5	19.7	27.6	38.2	1.10	1.48
6	23.3	28.5	35.4	1.50	1.72

short tons valued at $7500 (Knechtel and Hosterman, 1965). The diatomite was shipped by water to New York for marketing as insulating material, filter aid, and cleansing-polishing compound. Intermittent production of small amounts of this material continued through 1930 when all commercial activity ceased. The discovery and subsequent development of the extensive California deposits doubtless contributed to this decline. An additional factor, perhaps equally important, is the relatively high admixtures of sand, silt, and clay in the Maryland diatomite. An efficient and inexpensive method of removing these contaminants must be considered essential to any further development of the Southern Maryland deposits. Experimental work with this end in view was initiated by the U.S. Bureau of Mines in 1937 at their College Park laboratories (Norman and Ralston, 1940). Diatomites from California, Oregon, and Kansas as well as Maryland were treated, and after considerable testing, a pilot plant was established at the site of the old Maryland Silicate Company pit on the Patuxent at Lyons Creek wharf. The plant, using material from the adjacent Fairhaven, produced 12 to 15 tons of diatom concentrate while in operation. Beneficiation involved a 4 step process: (1) blunging of an aqueous slurry of raw material followed by settling to remove sand, (2) breakdown of clay by attrition milling, (3) settling of diatoms from the slurry, and (4) froth flotation to effect removal of the remaining clay. Although no estimate of cost factors for a large scale operation of this type was given, it is reasonable to assume that such costs would be high and perhaps uneconomical. On the other hand, diatomite is a bulky commodity with a high shipping cost between West Coast producers and Midwestern and Eastern markets. The Maryland deposits, if developed, would not incur this cost disadvantage, and higher beneficiation costs might then be economically feasible.

Sporadic interest has been shown in the Fairhaven diatomite over the past decade by a number of companies but none of these inquiries has been followed by more than superficial investigation. Recently, however, a major Eastern energy corporation has prospected the Southern Maryland area and completed an extensive test drilling program in the diatomite. No further steps toward development have thus far been taken.

PHOSPHATE

Phosphorite is the name given to sedimentary phosphate rock which consists largely of carbonate fluorapatite. All United States phosphate production is from such phosphorites, coming mostly from Florida but also from Tennessee, North Carolina, and several western states. Ore quality is expressed as percentage P_2O_5 (phosphorus pentoxide) or alternatively as $Ca_3(PO_4)_2$ (tricalcium phosphate or bone phosphate of lime). The bulk of this phosphorite—about 70% of United States production—goes into the fertilizer industry for beneficiation to superphosphate; from the remaining production are extracted elemental phosphorus, phosphoric acid, and sundry phosphorus compounds. Natural phosphorites range in color from white through brown to black, have a specific gravity of 2 to 3, and contain varying amounts of impurities including iron, alumina, silica, and carbonate. The P_2O_5 content may be as high as 40% but is generally less.

The occurrence of phosphorite in the survey area is restricted to a thin but persistent zone in the basal Calvert Formation. The zone varies in thickness from a few inches to as much as 20 feet, and in phosphorite content from trace amounts to fully 75-85% of the sediment in places. In all of the exposures and cores examined, the occurrence of phosphate is confined to the lower Fairhaven sand, i.e. to the beds between the top of the Nanjemoy and the base of the diatomite. The largest phosphate clasts, usually fragments of phosphatized bone or bivalve molds, are nearly always found in the thin pavement of coarse material immediately on top of the Nanjemoy. Some of these clasts are an inch or more in diameter. The distribution of phosphorite in the lower Fairhaven, both laterally and vertically, is anything but uniform. Thin lenses and irregular pods packed with phosphorite are the dominant mode of occurrence. These may be concentrated in a thin zone a few inches thick or spread unevenly over the entire interval of sand between the base of the Fairhaven and the diatomite bed. For example, in a streambank exposure (loc. 27) in northern Calvert

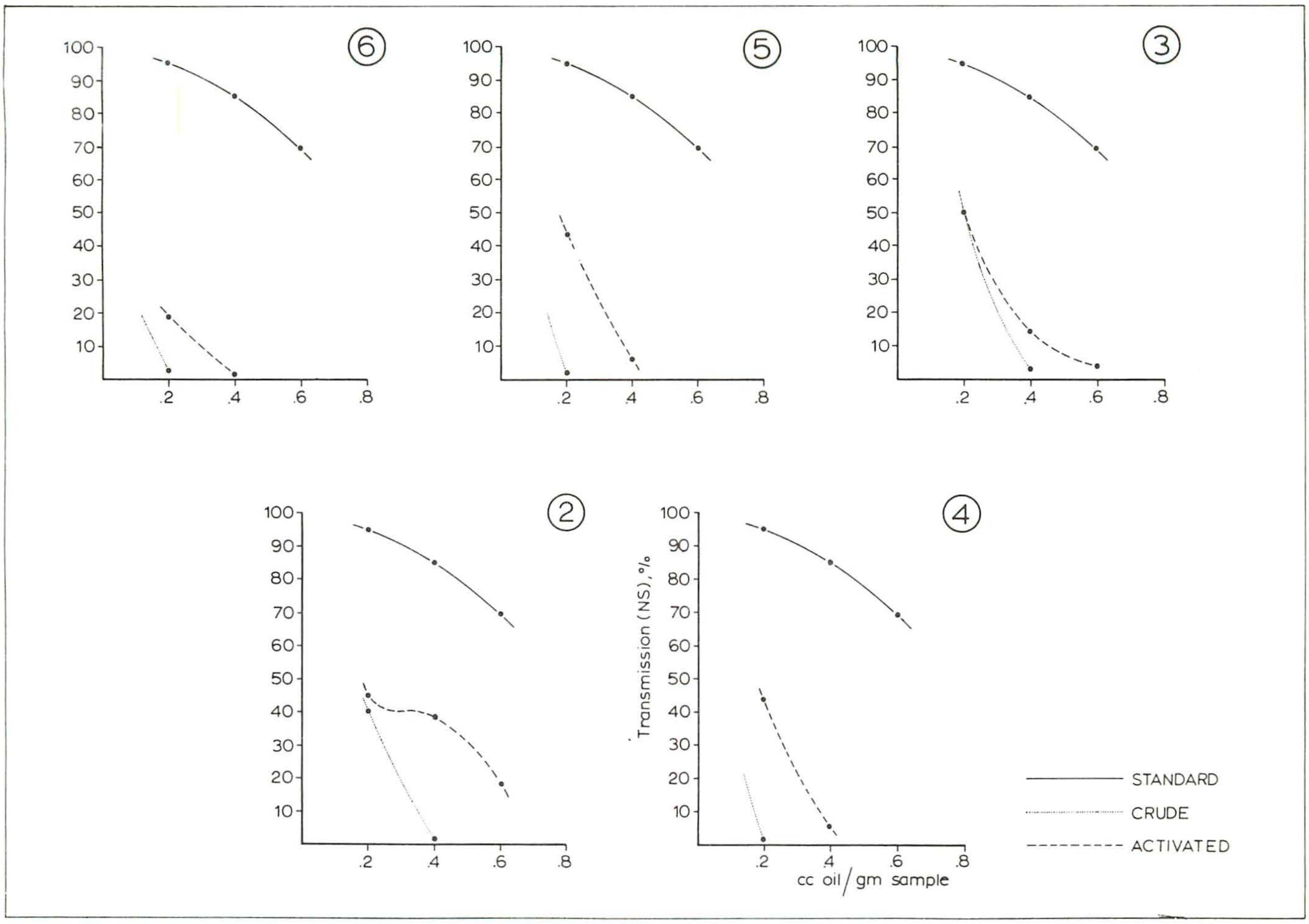

Figure 33. Results of oil decolorization tests on diatomite samples (see table 6 for sample identifications).

County which shows an abnormally thin lower Fairhaven sand, phosphorite is restricted to a basal pavement of a couple of inches thickness. The opposing extreme is illustrated by the section in core hole SM-15 where phosphorite is spread over at least 23 feet of sand interval.

The physical composition of Fairhaven phosphorite is varied; identifiable clasts include the internal molds of bivalves and snails (mostly *Turritella*), fish teeth, bone fragments, phosphatized echinoid spines, and fragmented valves of the brachiopod *Discinisca*. Most of the phosphorite, however, consists of rounded dark-gray pebbles and granules of indeterminate origin. The composition of a representative sample is shown diagramatically in fig. 34. Nearly all of this phosphorite falls into the size range of coarse sand (> 18 mesh) to fine pebbles (< 8 mm diam.). Very little occurs in the finer sand grades.

Also subject to variation is the P_2O_5 content of the phosphorite. Several analyses of representative samples indicate a range of 15 to 25%—low by most economic yardsticks. There is common agreement that phosphorite should contain at least 30% P_2O_5 to be exploitable (Sever *et al.*, 1967).

The Fairhaven phosphorite is not of economic value at the present time and is unlikely to be of any real value in the future due to poor quality as well as generally low concentration. Broadly speaking, a phosphorite desposit must be able to supply at least 400 tons per acre foot to be economically feasible. Moreover, the thickness of minable material should be at least 3 feet for the profitable use of heavy equipment. None of these criteria are consistently met by the Southern Maryland phosphorites.

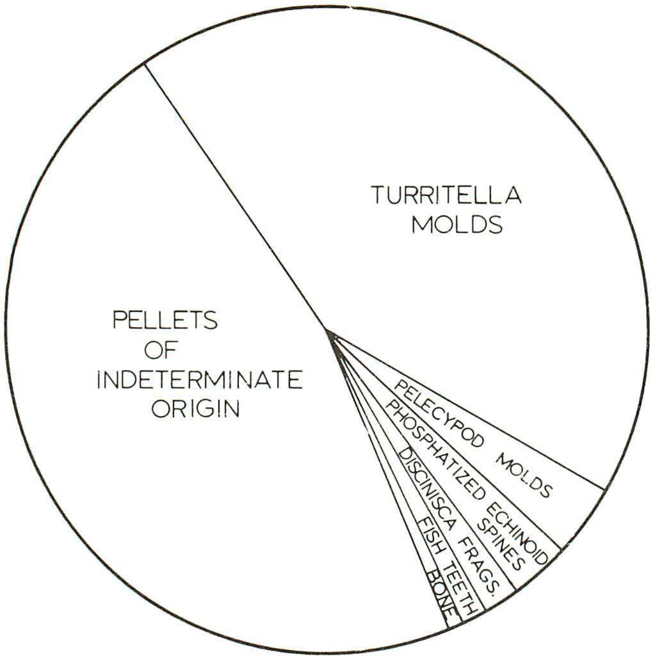

Figure 34. Genetic composition of a typical phosphorite concentrate from the basal Calvert Formation of Southern Maryland (SM-15, 41-50 feet).

GLAUCONITE

The mineral glauconite, a complex hydrous silicate of iron, aluminum, magnesium, and photassium, is the essential constituent of the greensands which comprise most of the Eocene section in Southern Maryland. Glauconite occurs most commonly as sand-sized, olive to dark-green polished grains exhibiting lobate, botryoidal, or accordian shape. Maryland glauconites are invariably accompanied by quartz sand or silt as well as clay in many cases. The Aquia and Nanjemoy Formations are the chief sources of glauconite in the survey area; amounts range from less than 5% to about 60% of the sediment. Within the Nanjemoy Formation, which of the two units has by far the greater area of outcrop in Southern Maryland, the distribution of glauconite varies from bed to bed but nonetheless conforms to a broad trend. Amounts increase steadily from the bottom of the formation to the top, from 2 or 3% to about 50% in the uppermost beds. The Aquia Formation crops out over a relatively small portion of Southern Maryland, and moreover is relatively low in glauconite in this area—less than 25% in the samples examined. A third but minor source of glauconite is the St. Marys Formation, but here the amounts are small and confined to a few thin sandy beds in southern St. Marys County.

Glauconite is of value primarily as a soil conditioner and secondarily as a water softener. The value of this material as a soil additive is probably due in part to its potash content (2 to 7%) and in part to a significant number of trace elements beneficial to plant life. The success of glauconite, or greensand for that matter, as a soil conditioner, however, can be attributed in many instances to its sandy texture which doubtless improves the structure of heavy soils. A significant drawback, however, is that the potash in glauconite is only very slowly soluble; consequently, chemical fertilizers are far more efficient and economical for general agricultural use. Although glauconite is a fairly efficient water softener due to relatively high base exchange capacity and was successfully marketed for that purpose for a number of years, it has been largely replaced by synthetic sulfonated polystyrenes with much greater exchange capacity.

The current United States production of glauconite or greensand is limited to 2 relatively small operations—the Iversand Co. which produces water softener from the Hornerstown Formation (Paleocene) in Gloucester County, New Jersey, and the Kaylorite Corp. at Dunkirk, Calvert County, Maryland. Kaylorite markets 2 products, one a finely ground greensand and the other a minus 30 mesh granular greensand, both designed for use as a soil conditioner. Production is from the uppermost 20 feet of the Nanjemoy Formation exposed in shallow pit on the east bank of the Patuxent River about 2 miles west of the town of Dunkirk.

Chemical analyses of representative greensands and glauconite separates from Southern Maryland are tabulated in table 8. Predictably, there is essential similarity in composition among all of the glauconites. Maryland glauconites tend to be higher in potash (6-7%) than New Jersey glauconites (5%).

In summary, it is very unlikely that glauconite production in Southern Maryland will undergo any significant expansion in the future due to a declining market, falling prices, and the widening production of synthetic substitutes.

SAND AND GRAVEL

Sand and gravel, as discussed here, consists of continuously graded, naturally fragmented, unconsolidated aggregates of rock and mineral particles with a size range of 230 mesh to about 3½ inches. These materials are used primarily for

Table 8. Chemical analyses of natural greensands and glauconite separates from Southern Maryland

	Greensands		Glauconite separates		
	Nanjemoy (Loc. 170)	Aquia (SM-12)	Aquia (Loc. 169)	Nanjemoy (Loc. 170)	St. Marys (Loc. 126)
Silica (SiO_2)	63.55	77.93	50.79	50.50	50.01
Alumina (Al_2O_3)	4.41	7.48	9.43	4.12	3.41
Iron oxide (Fe_2O_3)	15.74	3.54	22.04	25.95	28.34
Lime (CaO)	.48	2.39	.21	.36	.17
Magnesia (MgO)	2.35	1.01	3.25	3.38	3.04
Potash (K_2O)	6.24	2.30	6.22	7.63	6.63
Soda (Na_2O)	.03	.12	.04	.04	.04
Phosphorus (P_2O_5)	.19	.22	.18	.21	.45
Ignition loss	6.91	4.83	7.73	7.68	7.72
Total	99.90	99.82	99.89	99.87	99.81

construction and constitute the most important mineral resource currently exploited in Southern Maryland.

The value of sand and gravel depends largely upon the physical and chemical properties of the aggregate. For example, sand destined for use in concrete should ideally be graded such that at least 20% is retained on the 16 mesh screen, and 90 to 98% on the 100 mesh screen (Lenhart, 1960). Similarly, gravel is well-graded if 95% passes the maximum diameter screen (generally 2½ inches), 30 to 70% is less than half that diameter, and not more than 10% passes the 4 mesh sieve. As for quality, both coarse and fine aggregate should be free from deleterious materials such as vegetable or other organic matter, clay lumps, weathered fragments, and mica-coated grains. An additional potentially objectionable material is chert. Chert, flint, opal, and the like can be undesirable because such forms of silica may react readily with free alkali in cement to form water soluble sodium or potassium silicate. The end result is badly cracked concrete with numerous "pop-outs". The chemically reactive substance in such cases is apparently opaline or amorphous silica, a mineral characteristic of young cherts and organically-secreted siliceous materials. Although gravel in the Southern Maryland Upland Deposits averages 21% chert in the fraction passing the 1¼ inch sieve, most if not all of this chert is derived from the Appalachian Paleozoic limestones and has crystallized to the extent that it is no longer chemically reactive.

Considerably more than half of the sand and gravel dug in Southern Maryland comes out of the Upland Deposits. The sands, gravel, and overlying silty loam which comprise this unit constitute a more or less continuous veneer over most of the survey area (see pl. 4). Such materials are as much as 85 feet thick in some places but the average thickness is considerably less—about 30 to 35 feet (pl. 4) of which two-thirds is generally sand and gravel. Based on these averages, a rough estimate of the amount of aggregate in the Upland Deposits is in the neighborhood of 4 billion tons. The salient geologic characteristics of the Upland Deposits, most specifically those affecting the economic potential, can be summaried as follows: (1) The bulk of the coarser gravel (greater than 1¼ inch) is in the northwestern portion of the survey area—southwestern Prince Georges and northwestern Charles Counties. Similarly, the proportions of gravel of all sizes in the total section are greatest in the same region. Thus a greater number of aggregate grades are available, and this fact combined with the proximity of the Washington area market doubtless accounts for the fact that 4 of the 8 producers operating fixed plants in Southern Maryland are located here. (2) Amounts of sand in the Upland Deposits increase eastward and southeastward such that in southern St. Marys and most of Calvert Counties, the sediment is largely sand with thin interbeds of find to medium gravel or simply pebble bands. (3) Paralleling the textural changes is a weak tendency for the amount of chert to increase southeastward along with average thickness values. These spatial variations, particularly as regards texture, can best be illustrated by comparison of several measured sections—two in Calvert County where gravel is relatively scarce, and 2 in northwestern Charles County where gravel is more plentiful and generally coarser.

Section in road cut, Md. 4 at Sunderland, Calvert Co., Md.

Upland Deposits:	Feet
Coarse sand interbedded with subordinate fine gravel, pale gray mottled with reddish-brown	16
Clay, silty, brick red	2
Clay, sandy, mottled pale gray and brown	4
Coarse pebbly sand interbedded with fine sand, orange brown	12
Fine sand interbedded with medium to coarse sand and granule gravel, pale gray	6
Calvert Formation	
Total	40

Corehole SM-7, Piney Church Rd., 1.1 miles north of junction Md. 488, Charles Co., Md.

Upland Deposits:	Feet
Medium to coarse sand and medium gravel, pale orange	10
Coarse sand and coarse gravel, cobbles to 4 in. diam., pale orange	5
Coarse to very coarse sand and fine to medium gravel, pale gray	19
Calvert Formation	
Total	34

Corehole SM-11, Mill Hill Rd., 1.0 mile south of Md. 228, Charles Co., Md.

Upland Deposits:	Feet
Sandy yellowish-gray loam	5
Pebbly reddish-brown muddy sand	18
Coarse gravel and muddy sand, yellowish-brown	12
Fine to medium gravel and muddy sand, brown	12
Calvert Formation	
Total	47

Corehole SM-24, junction Md. 4 and Md. 497, Calvert Co., Md.

Upland Deposits:	Feet
Fine to medium, muddy orange brown sand	15
Medium to coarse, clean pale orange sand	40
Medium to coarse, muddy reddish sand	10
Medium to coarse, clean pale orange sand	13
Calvert Formation	
Total	78

Included in table 9 are some 58 screen analyses of sand-gravel samples from the Upland Deposits, most of them taken from Schlee (1957). A glance at the locality map (fig. 35) is sufficient to show that the exposures sampled are fairly well distributed over the sediment sheet, particularly in the area where gravel proportions are greatest. In all cases, the samples are channel samples taken through the total exposed thickness of the deposits. The bulk of the samples have an abundance of sizes and are well-graded from an economic point of view. As can be seen from the pebble counts (table 10), virtually all of the coarse aggregate is silica in some form. Very minor amounts of other rock types—chiefly clayey siltstone, phyllite, and weathered schist or gneiss—do sporadically occur, particularly adjacent to the Potomac River. Unwanted components such as clay lumps, organic matter, and soft pebbles are not generally a problem in the Upland Deposits, but thin silt or silty clay beds are in some instances interspersed in the sand-gravel section. It is common to find the upper 5 to 10 feet of the unit reddened by limonite as well as semi-consolidated by clay infiltration. Below the oxidized zone, however, the sand and gravel is pale gray to yellowish in color and relatively clean with 5% or less of interstitial silt-clay.

Considerable sand and to a lesser extent gravel is contained in the Lowland Deposits, particularly those comprising the terraces bordering the Potomac River. The lowest and most extensive of these terraces, immediately adjacent to the River, is topped by a flat surface lying at 5 to about 15 feet above river level and varying in width from a few hundred feet to as much as 2 to 3 miles on Cobb Neck and along the southern tip of St. Marys County. Unfortunately, much of this lower terrace material is very fine grained as well as excessively clayey in the upper portion and consequently of little economic value. Moreover, any exploitation of such near river level sediments must of necessity require a dredging operation. Flanking the lowland flats and reaching up to the base of the Upland Deposits are several intermediate terrace levels which through most of Southern Maryland occupy a relatively narrow band. In places where the terraces are broad, as for example on Maryland Neck and a number of disjunct areas along either bank of the Patuxent (see pl. 4), the section contains much sand and limited amounts of gravel. The sand varies from fine to very coarse in texture, is generally quite clean and very loosely consolidated, and is largely free of deleterious materials. On the debit side, however, sand in the Lowland Deposits is commonly interbedded with clay, silt, or very fine muddy sand which must be eliminated during processing. Furthermore, gravel as such is not common in the Lowland Deposits; pebbly sand or thin beds of granules or fine gravel are usually the coarsest aggregate available. Typical sections of these materials are exposed in several small sand pits in southern Calvert County:

Sand pit, Newtown, Calvert Co., Md.

Lowland Deposits:	Feet
White pebbly sand, medium to coarse, cross-bedded; thin beds of fine gravel at base	15

Sand pit, Coster Rd., .5 mile west of Appeal, Calvert Co., Md.

Lowland Deposits:	Feet
White sand and interbedded fine gravel; sand medium to coarse, cross-bedded; oxidized to reddish-brown in upper portion	28

The sand and gravel industry is a relatively important one in Southern Maryland and is likely to become increasingly so in the future as the Cretaceous deposits in the Baltimore-Washington corridor are exhausted or disappear beneath subdivisions. In 1968, the latest year for which complete data is available, production in the survey area totaled some 2,445,000 tons valued at $4,045,000. Most of the larger operators are working in the Upland Deposits, although the single largest producer is the Potomac Sand and Gravel Co. which dredges aggregate from the bed of the Potomac River near Marshall Hall in Charles County. Table 11 lists the major sand and gravel

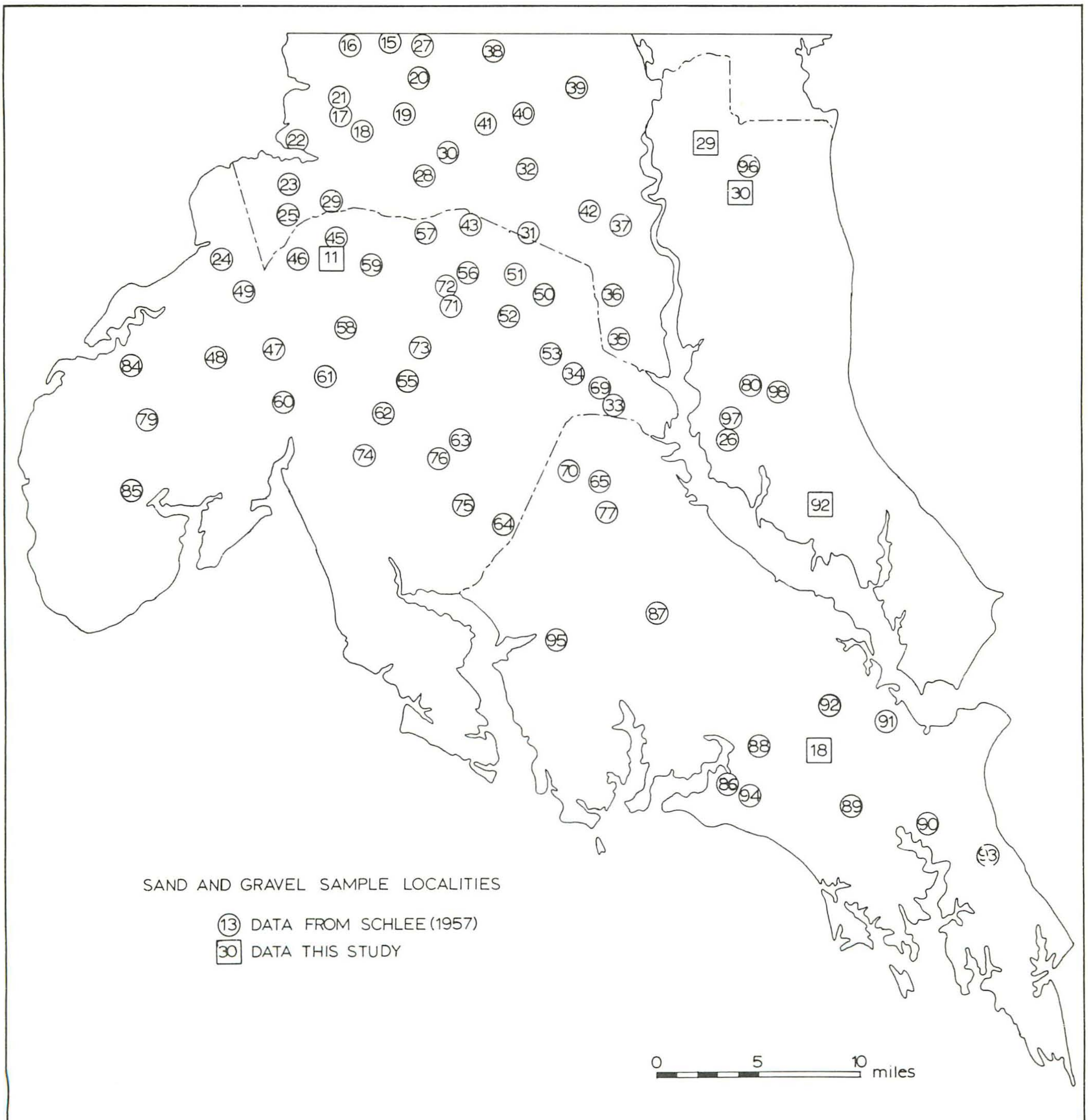

Figure 35. Locations of sand and gravel samples analyzed.

Table 9. Screen analyses of sand and gravel samples

Sample number	2½ inch	1¼ inch	⅝ inch	5/16 inch	5 mesh	10 mesh	18 mesh	35 mesh	60 mesh	120 mesh	230 mesh	pan
S 15[1]	.8	8.4	18.7	17.6	9.6	5.9	5.8	15.0	11.6	4.3	1.2	1.1
S 16	5.7	16.6	14.3	10.7	7.2	5.8	7.9	12.0	10.0	5.2	2.1	2.4
S 17	15.4	24.4	16.7	11.4	6.4	3.9	4.1	6.5	5.8	2.1	1.0	2.3
S 18	5.1	18.0	20.4	17.6	10.5	6.6	3.2	4.6	5.8	2.9	1.5	3.7
S 19	4.4	15.0	16.9	15.5	10.4	6.3	5.3	11.2	11.5	2.1	.9	.7
S 20	—	7.5	24.7	20.1	11.9	7.5	4.8	9.7	9.1	2.7	.8	1.1
S 21	5.3	19.9	18.8	15.0	7.1	3.9	2.6	8.6	9.7	5.4	2.0	2.2
S 22	13.0	20.0	15.9	11.3	6.7	3.9	3.2	7.0	11.7	3.9	1.3	1.4
S 23	9.3	19.6	13.3	9.0	5.5	3.7	4.1	10.9	15.5	4.1	1.8	3.0
S 24	14.8	18.6	16.4	13.1	7.1	3.8	3.6	7.4	9.1	3.2	1.1	1.8
S 25	4.1	10.5	19.3	11.7	8.0	6.0	3.3	8.2	12.2	9.0	4.1	3.6
S 26	—	.5	2.0	15.8	20.8	14.6	8.4	15.1	17.7	4.2	1.0	.8
S 27	1.2	5.4	18.2	27.2	15.3	9.3	6.3	8.5	4.8	2.3	.6	.8
S 28	—	7.6	28.4	19.1	10.9	6.6	3.8	8.2	10.6	3.0	.8	.9
S 29	8.6	25.2	22.4	11.0	8.0	4.8	2.9	7.3	6.4	1.8	.8	.9
S 30	2.5	5.5	16.9	19.4	13.3	8.9	4.9	12.0	13.4	1.9	.6	.8
S 31	—	.8	22.4	26.9	12.4	6.9	3.8	8.5	13.8	3.8	.4	.3
S 32	—	.4	7.3	16.0	13.2	9.9	6.4	13.9	26.8	4.5	.7	.8
S 33	—	—	.3	13.2	14.4	12.5	7.2	14.3	23.3	7.5	3.3	3.9
S 34	—	—	1.9	15.2	19.6	17.9	14.4	17.0	7.3	3.8	1.4	1.5
S 35	—	—	1.8	31.4	18.0	10.3	5.6	9.6	16.1	5.0	1.2	1.0
S 36	—	.8	1.2	11.9	5.7	4.2	8.3	14.4	23.8	18.7	5.6	5.4
S 37	—	—	2.7	15.2	17.0	16.1	11.8	18.4	12.9	2.6	1.0	2.2
S 38	1.7	3.2	6.2	12.0	16.5	14.6	9.0	13.2	10.6	8.6	2.7	1.7
S 39	—	1.6	7.7	15.5	14.9	12.0	11.6	11.9	12.3	6.1	2.7	3.8
S 40	—	.3	7.8	21.3	21.0	15.7	9.1	11.5	7.3	3.3	1.0	1.6
S 41	1.6	3.7	25.7	27.1	11.7	5.8	4.2	6.8	7.8	3.5	1.2	1.1
S 42	—	—	2.2	17.8	19.3	11.7	12.3	13.9	14.4	5.7	1.1	1.6
S 43	1.2	6.3	28.0	20.3	6.6	4.3	3.3	8.5	14.7	4.3	1.1	1.5
S 45	4.8	16.7	27.7	13.1	7.0	3.8	4.7	8.0	8.8	3.8	1.0	1.0
S 46	5.9	33.7	16.2	9.7	5.9	5.3	5.2	7.6	5.2	2.5	1.1	2.0
S 47	1.4	8.5	19.9	16.9	8.2	4.1	3.3	8.6	21.6	4.7	1.2	1.7
S 48	—	2.2	14.7	21.2	13.2	9.9	6.4	9.2	10.9	5.0	2.6	4.7
S 49	—	—	.4	5.0	4.4	3.7	3.2	15.7	51.8	9.4	2.3	4.1
S 50	—	—	10.7	25.6	13.4	8.4	3.6	11.2	21.9	3.7	.8	.7
S 51	—	2.2	24.2	28.5	13.3	6.6	4.9	6.9	6.7	4.3	1.3	1.2
S 52	—	7.9	23.2	20.1	11.3	6.6	3.2	7.0	10.9	5.3	2.0	2.4
S 53	—	—	4.5	16.0	16.5	11.4	8.9	16.5	14.2	6.8	2.6	2.7
S 54	1.3	2.4	8.2	13.5	10.8	9.3	10.3	21.0	19.9	2.8	.8	.8
S 55	—	.3	5.3	9.0	6.3	4.3	7.8	15.3	30.1	13.4	4.1	4.3
S 56	—	1.0	6.7	29.2	17.6	6.5	3.3	5.7	16.3	10.2	2.3	1.0
S 57	—	4.8	19.4	19.1	12.9	7.4	5.5	14.9	10.6	3.0	1.1	1.4
S 58	1.1	5.8	17.7	18.9	11.2	7.4	6.7	13.3	12.4	3.0	1.1	1.4
S 59	—	6.3	18.8	20.8	14.7	13.5	12.0	7.1	3.7	1.2	.5	1.5
S 60	—	6.9	19.3	20.3	12.8	8.0	4.0	11.5	13.1	2.5	.9	.8
S 61	—	7.8	26.8	19.1	10.6	5.4	3.0	7.7	14.6	3.2	.9	.9
S 62	1.7	17.6	24.4	12.3	9.4	5.3	4.4	9.1	11.4	2.4	1.0	1.1
S 63	—	.3	5.9	27.7	18.5	6.6	5.0	8.2	20.2	6.1	.8	.6
S 64	—	.5	4.1	17.0	12.7	9.7	8.0	22.2	18.1	4.5	1.8	1.5
S 65	—	—	4.3	20.4	16.4	11.2	8.7	14.4	17.6	5.3	.8	.9
S 75	—	1.3	7.9	27.6	14.0	6.7	3.0	7.2	28.7	2.4	.6	.6
S 77	—	—	1.0	7.1	8.7	7.7	7.2	22.7	38.2	4.7	1.4	1.4
S 79	—	12.3	13.3	16.8	12.8	10.9	8.3	15.4	6.8	2.1	.8	.9
SM-11	—	—	—	—	.5	5.9	5.3	14.7	24.8	34.9	12.7	1.2
SM-18	—	—	—	5.6	12.2	7.2	5.6	12.1	32.1	10.3	3.1	11.3
30	—	—	—	—	—	18.4	34.3	27.0	7.9	2.3	.8	9.3
29	—	—	—	—	—	14.1	8.0	3.8	12.1	41.2	19.8	1.0
92	—	—	—	—	2.6	3.8	4.1	11.4	37.4	33.0	7.2	.5

[1] Data from Schlee, 1957. (S15-S79)

Table 10. Pebble lithologies in gravel samples (data from Schlee, 1957)

Sample number	Lithology	Size class (% retained)		
		5/16 inch	5/8 inch	1¼ inch
S 15	Quartz	70	48	36
	Quartzite and sandstone	12	33	38
	Chert	18	19	26
S 16	Quartz	86	58	30
	Quartzite and sandstone	9	38	65
	Chert	5	4	5
S 17	Quartz	61	50	26
	Quartzite and sandstone	20	32	66
	Chert	19	18	8
S 18	Quartz	69	69	36
	Quartzite and sandstone	14	18	48
	Chert	18	13	16
S 19	Quartz	72	53	38
	Quartzite and sandstone	11	21	50
	Chert	17	26	12
S 22	Quartz	51	45	29
	Quartzite and sandstone	21	34	59
	Chert	28	21	12
S 23	Quartz	49	47	28
	Quartzite and sandstone	12	34	57
	Chert	39	19	15
S 26	Quartz	61	52	—
	Quartzite and sandstone	15	12	—
	Chert	24	36	—
S 31	Quartz	77	57	—
	Quartzite and sandstone	9	15	—
	Chert	14	28	—
S 32	Quartz	67	60	—
	Quartzite and sandstone	11	15	—
	Chert	22	25	—
S 35	Quartz	44	68	—
	Quartzite and sandstone	16	9	—
	Chert	40	23	—
S 39	Quartz	52	72	—
	Quartzite and sandstone	12	12	—
	Chert	36	16	—
S 41	Quartz	79	51	34
	Quartzite and sandstone	9	20	32
	Chert	12	29	34
S 42	Quartz	76	47	—
	Quartzite and sandstone	7	17	—
	Chert	17	36	—
S 43	Quartz	66	59	35
	Quartzite and sandstone	10	14	50
	Chert	24	27	15
S 45	Quartz	74	57	31
	Quartzite and sandstone	7	23	43
	Chert	19	20	26
S 47	Quartz	60	56	—
	Quartzite and sandstone	17	29	—
	Chert	23	15	—
S 48	Quartz	63	51	—
	Quartzite and sandstone	8	23	—
	Chert	29	26	—
S 49	Quartz	62	—	—
	Quartzite and sandstone	22	—	—
	Chert	16	—	—
S 50	Quartz	73	47	—
	Quartzite and sandstone	8	12	—
	Chert	19	41	—
S 52	Quartz	74	62	23
	Quartzite and sandstone	8	15	50
	Chert	18	23	17
S 53	Quartz	53	53	—
	Quartzite and sandstone	5	17	—
	Chert	42	30	—
S 54	Quartz	69	59	—
	Quartzite and sandstone	9	15	—
	Chert	22	26	—
S 58	Quartz	73	71	—
	Quartzite and sandstone	12	17	—
	Chert	15	12	—
S 60	Quartz	64	57	—
	Quartzite and sandstone	19	21	—
	Chert	17	12	—
S 62	Quartz	55	45	33
	Quartzite and sandstone	25	27	54
	Chert	20	28	—
S 63	Quartz	60	55	—
	Quartzite and sandstone	13	9	—
	Chert	27	36	—
S 64	Quartz	69	55	—
	Quartzite and sandstone	6	11	—
	Chert	25	34	—
S 65	Quartz	66	49	—
	Quartzite and sandstone	13	11	—
	Chert	21	40	—
S 75	Quartz	66	49	—
	Quartzite and sandstone	14	20	—
	Chert	20	31	—
S 77	Quartz	69	—	—
	Quartzite and sandstone	9	—	—
	Chert	23	—	—
S 79	Quartz	40	66	—
	Quartzite and sandstone	32	15	—
	Chert	28	19	—
S 82	Quartz	65	49	19
	Quartzite and sandstone	21	37	66
	Chert	—	—	—
S 83	Quartz	12	—	—
	Quartzite and sandstone	78	—	—
	Chert	9	—	—
S 84	Quartz	43	25	12
	Quartzite and sandstone	33	43	62
	Chert	24	32	26
S 85	Quartz	50	56	22
	Quartzite and sandstone	20	25	63
	Chert	30	19	15
S 86	Quartz	64	55	29
	Quartzite and sandstone	10	23	45
	Chert	26	22	26
S 87	Quartz	72	58	—
	Quartzite and sandstone	7	22	—
	Chert	21	20	—
S 89	Quartz	68	50	—
	Quartzite and sandstone	13	14	—
	Chert	19	36	—
S 90	Quartz	66	56	—
	Quartzite and sandstone	12	26	—
	Chert	22	18	—
S 91	Quartz	68	55	—
	Quartzite and sandstone	10	24	—
	Chert	22	21	—
S 92	Quartz	67	54	—
	Quartzite and sandstone	5	14	—
	Chert	28	32	—
S 93	Quartz	66	—	—
	Quartzite and sandstone	9	—	—
	Chert	25	—	—
S 94	Quartz	65	—	—
	Quartzite and sandstone	17	—	—
	Chert	18	—	—
S 95	Quartz	65	47	—
	Quartzite and sandstone	8	34	—
	Chert	27	19	—

producers in Southern Maryland. A number of smaller pits, however, are dotted through the area; many of these are abandoned but others are operated on a demand basis. Plotted on plate 4 are the locations of all of the known pits, both active and abandoned.

The future of the aggregate business in Southern Maryland is relatively bright. Rapid urbanization in the greater Washington area will demand increasing amounts of sand and gravel, materials which are currently supplied from Tertiary or Quaternary deposits adjacent to the District or from Cretaceous deposits in the Baltimore-Washington corridor. These sources, however, will ultimately be exhausted or enveloped by urban growth. The growing demands of the construction industry will necessitate the development of more distant sources, among which Southern Maryland is a logical choice.

Multiple Land Use

Geologists and natural resource planners alike are viewing with increasing alarm the disappearance of potentially valuable mineral deposits beneath urban development as well as the imposition of increasingly restrictive local zoning regulations upon both existing mineral producers seeking expansion and would-be producers in metropolitan areas. Such restrictive zoning is in large part a reflection of growing public concern with environmental quality, and in fact, some of this concern is certainly justified by past abuse. In other cases, however, local governments have been guilty of overreaction to the extent that extractive mineral industries have been wholly prohibited from sizable jurisdictions without due consideration of the present and future resource needs of the community. Such extreme positions are to be avoided.

There is a clear need for comprehensive advance planning for multiple or sequential use of land underlain by valuable mineral deposits. Planners, and indeed the public, should be made to appreciate this need through education and emphasis by the geologic community. In Southern Maryland, multiple use planning is particularly important in the case of the sand and gravel industry for two reasons—not only is it the largest by far of the mineral industries in the area but it is these deposits which are in the greatest danger of preemption by urban expansion. A suggested use sequence, modified from that of Hackett and McComas (1969), might be the following:

(1) preservation of land underlain by sand and gravel by placing it in a rural or open space zoning category, or perhaps better yet, a "conservation zone"
(2) planned and orderly removal of the sand and gravel in such fashion so as to facilitate reclamation of the site
(3) reclamation of the mined area and transfer to a final use category, such as recreation, residential, or perhaps sanitary land fill

Such a scheme insures the optimum use of both the sand and gravel deposit, and the land. The application of the multiple use concept is probably most urgent in the case of the Upland tract which straddles U.S. Route 301 in northern Charles County and southern Prince Georges County, since residential development is spreading rapidly into this region from the north. There is every indication that a substantial quantity of aggregate in this area is being pre-empted by such development.

Table 11. Sand and gravel producers with fixed equipment in Southern Maryland in 1970

Company name	Address	Pit location	Stratigraphic unit
Potomac Sand and Gravel Co.	3020 K St., N.W. Washington, D.C. 20007	Potomac River at Marshall Hall, Charles Co.	Lowland Deposits
Charles Co. Sand and Gravel Co.	P.O. Box 322 Waldorf, Md. 20601	Waldorf	Upland Deposits
Buffalo Sand and Gravel Co.	Auth Rd., Camp Springs, Washington, D.C. 20023	La Plata, Charles Co.	Upland Deposits
A. H. Smith Co.	Branchville, Md. 20721	Cheltenham, Prince Georges Co.	Upland Deposits
Inland Materials Inc.	5101 Kirby Rd Clinton, Md. 20735	Clinton	Upland Deposits
Davis Sand and Gravel Co.	Box L.M. Clinton, Md. 20735	Clinton	Upland Deposits
Leonardtown Sand and Gravel Co.	P.O. Box 117 Leonardtown, Md. 20650	Leonardtown	Upland Deposits
Charlotte Hall Sand and Gravel Co.	Charlotte Hall, Md. 20622	Charlotte Hall, Md.	Upland Deposits

Ceramic Clay

Clay is employed as both a textural term and as a rock term. Textural clay indicates the smallest size grade of any sediment, usually those particles less than 4 microns in diameter. Used as a rock term, clay generally refers to natural fine-grained materials, composed largely of clay minerals, which tend toward plasticity when wet. Such sediments rarely consist of clays alone; variable amounts of silt or even sand are intermixed, giving a continuous gradation from relatively pure clay through silty or sandy clay to clayey silt or sand. From an economic point of view, the proportions of silt or sand are important, since excessive amounts of these materials adversely affect the usefulness of natural clay mixtures by contributing to lowered plasticity and consequently reduced strength.

Clays have varied uses, some quite specialized as drilling muds, pigments, fillers, and bleaching agents, but the broadest use by far is in the ceramic industry as structural products including brick, drain tile, sewer pipe, glazed tile, and terra cotta. The most important properties to be considered in evaluating the economic potential of ceramic clays are plasticity, green strength, dry strength, drying and firing shrinkage, vitrification range, and fired color, although no rigorous specifications have been established. The first—plasticity—depends not only upon particle size and shape, and the proportions of non-clay minerals, but also on amounts of organic matter, soluble salts, and adsorbed ions. In addition, plasticity has an important bearing on green strength. Dry strength, on the other hand, is determined by the proportions and shape of the fine particles comprising the clay, the degree of hydration of the colloidal fraction prior to sample preparation, and the extent to which the sample is dryed prior to testing. Shrinkage, both drying and firing, is correlated with the water content of the material and the clay mineralogy. Both very plastic or "fat" clays and sandy or "lean" clays yield poor shrinkage properties, the fat ones tending to crack and warp whereas lean clays dry to a weak porous product. The temperature range of vitrification is significant because it can be extremely short for some materials, demanding close monitoring of kiln temperature. The final but very important property of color is primarily determined by the amount of iron oxide in the clay and the firing temperature. White to buff burning clays generally have less than 5% of Fe_2O_3 in contrast to red burning clays in which iron exceeds 5%. The reader interested in additional detail with respect to clay properties and uses should consult Murray (1960) or Cooper (1965).

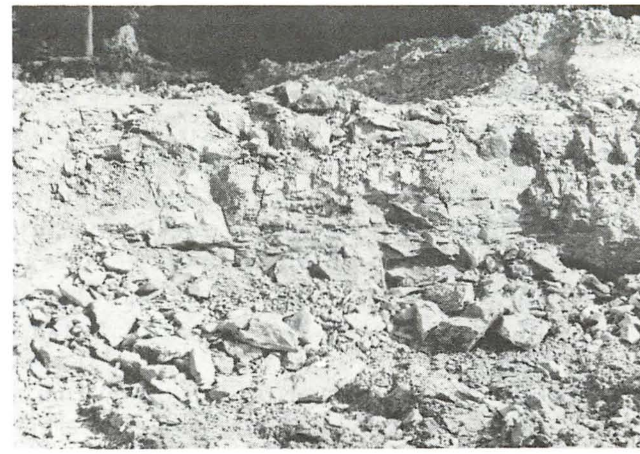

Figure 36. Excavation in typical Malboro Clay near Collinson Corner, Anne Arundel County.

Clay makes up only a minor portion of the stratigraphic column in Southern Maryland, and much of it is either too sandy or too restricted vertically and laterally to be of any real economic value. Included in this category are sporadically distributed thin sandy clays in the Upland Deposits and in the Nanjemoy Formation. Considerable moderately-pure clay is contained in the middle member of the Lowland Deposits in lower St. Marys County, but this material is affected by at least two serious drawbacks. This clay lies everywhere very near or below sea level; consequently, any pit opened in this material would probably involve a dewatering problem. A more serious objection may be to the common occurrence of shell material in Lowland Deposit clays since calcium carbonate is quite detrimental in ceramic applications.

The Marlboro Clay is the only Southern Maryland unit with substantial economic potential for ceramic useage. It has the obvious advantages of lateral continuity, fixed stratigraphic position, and relative homogeneity of composition in addition to favorable qualities for use in face brick and structural tile. The map of plate 2 defines the Marlboro outcrop belt, the distribution of the Clay in the shallow subsurface, and the configuration of the top of the unit. Essentially, the Marlboro is a thin irregularly-warped sheet draped across the surface of the Aquia greensand over most of Southern Maryland. Structure contours on the sheet indicate the presence of a northeast-southwest oriented zone of linear warp parallel to the strike between Cheltenham and LaPlata. The sharpest deformation has occurred in the northern half of the zone where a significant domal structure is centered in the Clinton Acres area. The sheet has a regional dip to the southeast as do nearly all of the Tertiary units. The truncated edge of the Marlboro is a narrow sinuous band which enters Southern Maryland in southwestern Prince Georges County and terminates in outcrop just below Indian Head in Charles County 20 miles to the southwest. Beyond that point, the Clay is effectively buried beneath a thick cover of Lowland Deposits.

The Marlboro Clay ranges in thickness from a feather edge to as much as 30 feet with an average of about 20 feet. Generally speaking, the unit increases in thickness from southwest to northeast along the outcrop belt such that most of the measured thicknesses exceeding 20 feet occur in Prince Georges County. The typical Marlboro lithology consists of pale-red to pale-brown, moderately plastic clay laced with grayish silt partings (fig. 36). Much of the Clay in western Charles County as well as a variably thick middle portion of the Marlboro elsewhere is pale-gray to silvery gray in color. Contaminants other than fine organic matter and silt in partings and sporadic thin lenticles are generally absent. The principal clay mineral in the Marlboro is kaolinite with lesser amounts of illite and montmorillonite (fig. 37). Variation in clay mineral composition is small.

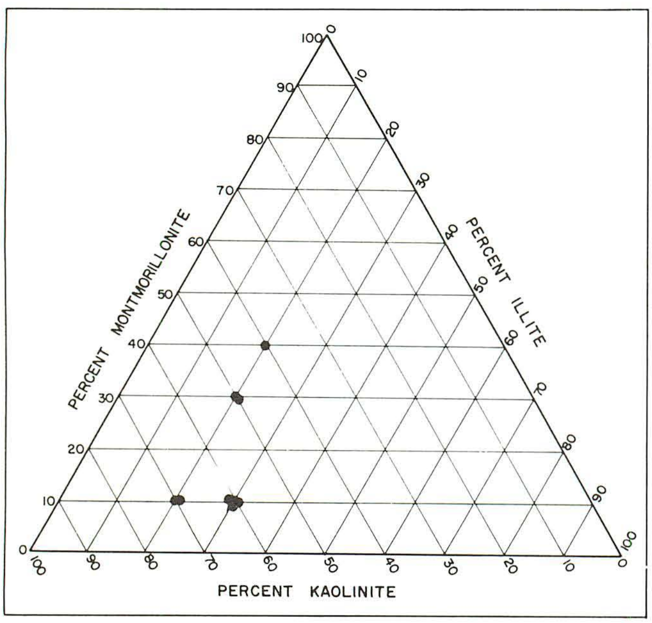

Figure 37. Clay mineralogy of the Malboro Clay.

The chemical composition of the Marlboro (table 12) is typical of kaotinitic clays; it is perhaps worth noting that the red Marlboro is relatively high in iron whereas the gray phase contains less.

Tables 13 and 14 summarize the physical and chemical properties of several typical samples of the Marlboro Clay. All of the samples tested show firing properties well within desirable limits for use as face brick or structural tile.

Clays in the St. Marys Formation have ceramic potential but at the same time suffer several distinct disadvantages. Not least of these is the location of these clays in the extreme south of the survey area relatively distant from Washington and Baltimore area markets. Moreover, slow firing tests (table 15) conducted by the U.S. Bureau of Mines on several St. Marys clay samples resulted in bricks with poor color, although other properties were satisfactory. A further drawback is the lack of firm stratigraphic control on St. Marys clay beds. This means that the lateral continuity of such clays, variations in thickness, and homogeneity of composition are not predictable with the available data. An exception may be the lowest clay bed in the Formation ("Zone 21") which was encountered at or near the base of the St. Marys in all 4 coreholes which passed through that unit into the Choptank. The stratigraphy and composition of these clays is discussed more fully in the section dealing with lightweight aggregate.

Table 12. Chemical analyses of the Marlboro Clay

	Red Marlboro	Gray Marlboro
Silica (SiO_2)	59.36	61.84
Alumina (Al_2O_3)	23.05	21.77
Iron oxide (Fe_2O_3)	5.15	3.15
Lime (CaO)	.77	1.12
Magnesia (MgO)	.95	.98
Potash (K_2O)	1.79	2.12
Soda (Na_2O)	.06	.06
Phosphorus (P_2O_5)	.18	.17
Ignition loss	8.52	8.64
Total	99.83	99.85

Table 13. Physical and chemical properties of Marlboro Clay samples

Sample identification	Color	Water of plasticity (%)	Working properties	Drying defects	Drying shrinkage (%)	Dry strength	pH	Potential use	Remarks
Loc. 6	tan	32.5	moderate plasticity	none	5.0	good	4.6	face brick	should fire to "SW" face brick specifications at about 2100°F.
Loc. 80	tan	27.2	moderate plasticity	none	2.5	good	3.8	face brick, glazed structural tile	should fire to "MW" face brick specifications at about 2100°F.
Loc. 169	tan	29.1	moderate plasticity	none	5.0	good	4.2	face brick, structural tile	should fire to "MW" face brick specifications at about 2100°F.
SM-3	tan	27.6	moderate plasticity	none	5.0	good	5.7	face brick	should fire to "MW" face brick specifications at about 2000°F.
SM-12	tan	25.8	moderate plasticity	none	5.0	good	6.4	face brick	should fire to "MW" face brick specifications at about 2000°F.

Lightweight Aggregate

The production of lightweight aggregate for use in low density concrete is a rapidly growing mineral industry in the United States; in 1968, some 67 plants were in operation in 31 states, and were current data available, this figure would doubtless be substantially higher. The raw materials for such aggregate are basically of 2 types. Relatively lightweight materials such as pumice, slag, and cinders can be used in concrete without modification, producing a material denser than that incorporating expanded aggregate but still less dense than concrete containing gravel. The second type of lightweight aggregate is expanded perlite, clay, shale, or slate. Perlite is strictly a western or southwestern industry in this country and will not be considered here. Aggregate in the form of expanded clay or shale however is produced widely in the east, making an extremely lightweight material of high structural strength. In most instances, the process involves rapid firing in a rotary kiln at temperatures of 1600° to 2400°F. If the material is expandable, the result is a bloated pyroplastic mass full of gas bubbles and weighing from 40 to 60 lbs. per cubic foot. The bulk density of concrete incorporating such aggregate is about 90 to 100 lbs. per cubic foot in contrast to 150 lbs. per cubic foot for conventional concrete prepared with gravel or crushed stone.

At present, lightweight aggregate is marketed in Maryland by 4 companies, but only one of these is producing from local materials—Lehigh Portland Cement Company at Woodsboro in Frederick County. Lehigh's product is expanded shale from the basal portion of the Frederick Limestone.

The essential steps in the production of expanded aggregate entail first breaking up the clay or shale to about 2 inch size, feeding the product through a kiln for about 45 minutes, and finally sizing the crushed aggregate after cooling, commonly in a water bath. The bloating characteristics of a clay or shale depend largely on its total mineralogy. Mixtures of kaolinite, illite, and montmorillonite provide the majority of the successful bloaters. Fisher and Garner (1965) report that the most consistent of these contain less than 30% kaolinite, more than 10% illite, and from 20 to 90% of mortmorillonite. Free silica, mostly as quartz silt, is also necessary for success. Moreover, a potential bloating clay or shale must contain some iron oxide, carbon, alkalis, or alkaline earths to act as fluxing agents during heating.

Clays in the St. Marys Formation in southern Calvert and St. Marys Counties have proved to some degree expandable and have at least the potential of providing a convenient source of lightweight aggregate for the Washington metropolitan area. Expandable clay was first reported in the St. Marys by Knechtel and others (1966) who examined samples from some 16 outcrop localities and 8 augerholes in Southern Maryland. In fact, all 3 Chesapeake Group Formations were investigated but only the St. Marys was found to contain suitable clays. Contrasts in clay mineralogy are probably the causes for the differing bloating character for the Calvert and Choptank as opposed to the St. Marys. The St. Marys clay suite is an approximately equal mixture of kaolinite, illite, and montmorillonite whereas both the Calvert and Choptank Formations contain much less kaolinite —about 10% of the assemblage.

Bloating clays in the St. Marys are typically dark, moderately plastic, variably silty, and generally massive in bedding character. Silt occurs both in discrete lenticles or laminae and dispersed through the clay. Shells are usually sparse but occasionally are concentrated in thin beds of sev-

Table 14. Slow firing tests of Marlboro Clay samples

Loc. 6

Temp. °F	Color	Moh's Hard-ness	Per-cent Total shk.	Per-cent Abs.	Per-cent App. Por.	Bulk Dens. gm/cc
1800	Tan	3	5.0	25.6	39.2	1.53
1900	Tan	3	7.5	22.7	38.1	1.68
2000	Tan	3	10.0	18.0	31.0	1.72
2100	Light brown	4	12.5	10.4	20.0	1.92
2200	Brown	5	15.0	4.1	8.8	2.15
2300	Gray	6	15.0	1.5	3.2	2.14

Loc. 80

Temp. °F	Color	Moh's Hard-ness	Per-cent Total shk.	Per-cent Abs.	Per-cent App. Por.	Bulk Dens. gm/cc
1800	Tan	3	5.0	21.5	35.0	1.63
1900	Tan	3	5.0	20.3	34.5	1.70
2000	Tan	4	5.0	18.7	31.8	1.70
2100	Buff	4	7.5	14.0	26.2	1.87
2200	Gray	5	10.0	5.6	11.5	2.06
2300	Gray	6	12.5	2.9	6.2	2.14

Loc. 169

Temp. °F	Color	Moh's Hard-ness	Per-cent Total shk.	Per-cent Abs.	Per-cent App. Por.	Bulk Dens. gm/cc
1800	Light tan	2	7.5	29.5	43.7	1.48
1900	Light tan	2	10.0	27.5	41.3	1.50
2000	Med. tan	3	12.5	21.6	35.2	1.63
2100	Dark tan	4	15.0	13.2	24.4	1.85
2200	Gray brown	5	17.5	3.7	7.8	2.12
2300	Dark brown	6	17.5	2.1	4.5	2.14

SM-3

Temp. °F	Color	Moh's Hard-ness	Per-cent Total shk.	Per-cent Abs.	Per-cent App. Por.	Bulk Dens. gm/cc
1800	Tan	2	5.0	20.6	33.0	1.59
1900	Tan	3	5.0	19.2	32.8	1.72
2000	Light brown	4	10.0	11.4	22.2	1.95
2100	Med. brown	5	12.5	4.5	9.9	2.20
2200	Dark brown	6	15.0	1.2	2.7	2.28
2300	———	—	Expanded	—	—	—

SM-12

Temp. °F	Color	Moh's Hard-ness	Per-cent Total shk.	Per-cent Abs.	Per-cent App. Por.	Bulk Dens. gm/cc
1800	Tan	2	5.0	19.4	33.0	1.70
1900	Tan	3	7.5	17.7	31.1	1.76
2000	Light brown	4	10.0	11.1	21.7	1.96
2100	Med. brown	5	12.5	4.7	10.2	2.17
2200	Dark brown	6	15.0	1.5	3.3	2.23
2300	———	—	Expanded	—	—	—

eral inches thickness; such beds are in many cases packed with the high-spired snail *Turritella.* Clay beds in the St. Marys vary widely in thickness—from a foot or so to as much as 20 feet, but most fall into the range 5 to 15 feet. The internal stratigraphy of the St. Marys is not adequately known at present to permit categorical statements concerning the number of clay beds, their thicknesses, or their positions in the unit. In all probability, the St. Marys like the Calvert and Choptank Formations can be subdivided into a number of beds with more or less constant lithologic character and stratigraphic position. Shattuck's attempt at such subdivision ("Zones" 21 through 24), although far from satisfactory, suggests that this is the case. On the basis of present data, the most stratigraphically persistent clay bed in the St. Marys lies at the base of the unit. This lowest bed, encountered in all of the coreholes reaching the uppermost Choptank shell marl, is typically dark gray, tough unfossiliferous clay with sporadic silt lenticles. As much as 15 to 20 feet of such clay may be present. Respecting thickness, however, it should be pointed out that measurements in excess of 15 ft. may encompass part of the uppermost Choptank clay (Conoy Member), particularly in those instances where the thin basal St. Marys sand is absent (for example, see log of SM-19). At least one and in many cases 2 thinner clay beds are present at higher levels of the St. Marys but a fixed stratigraphic position for either has not been established. The physical characteristics of these clays are essentially the same as those of the basal clay bed.

Shown in figure 38 is the generalized outcrop of the St. Marys Fm. and a plot of Knechtel's sample locations as well as the current corehole series. All but 2 of Knechtel's samples were unweathered clays obtained from the power-augerholes or from outcrops; the 2 samples affected by weathering did not behave during testing in any appreciably different manner from fresh materials. The core samples were wholly unweathered, in each case channel samples of the indicated interval. The intervals tested ranged in thickness from 5 to 25 feet.

The results of muffle-kiln tests conducted on a total of 22 St. Marys samples are tabulated in table 16. Most of these samples were reported upon earlier by Knechtel *et al.* (1966) but are included here for completeness. All except one of the clays bloated to some degree, but as indicated in the table, preliminary evaluations by the U.S. Bureau of Mines range from marginal to excellent. In fact, all of the tested samples obtained during the present program were adjudged marginal raw materials for lightweight aggregate. The indicated bulk densities of the expanded products at the optimum bloating temperature (2100°-2200°F.) are somewhat greater than those given for Knechtel's samples. The reason for this

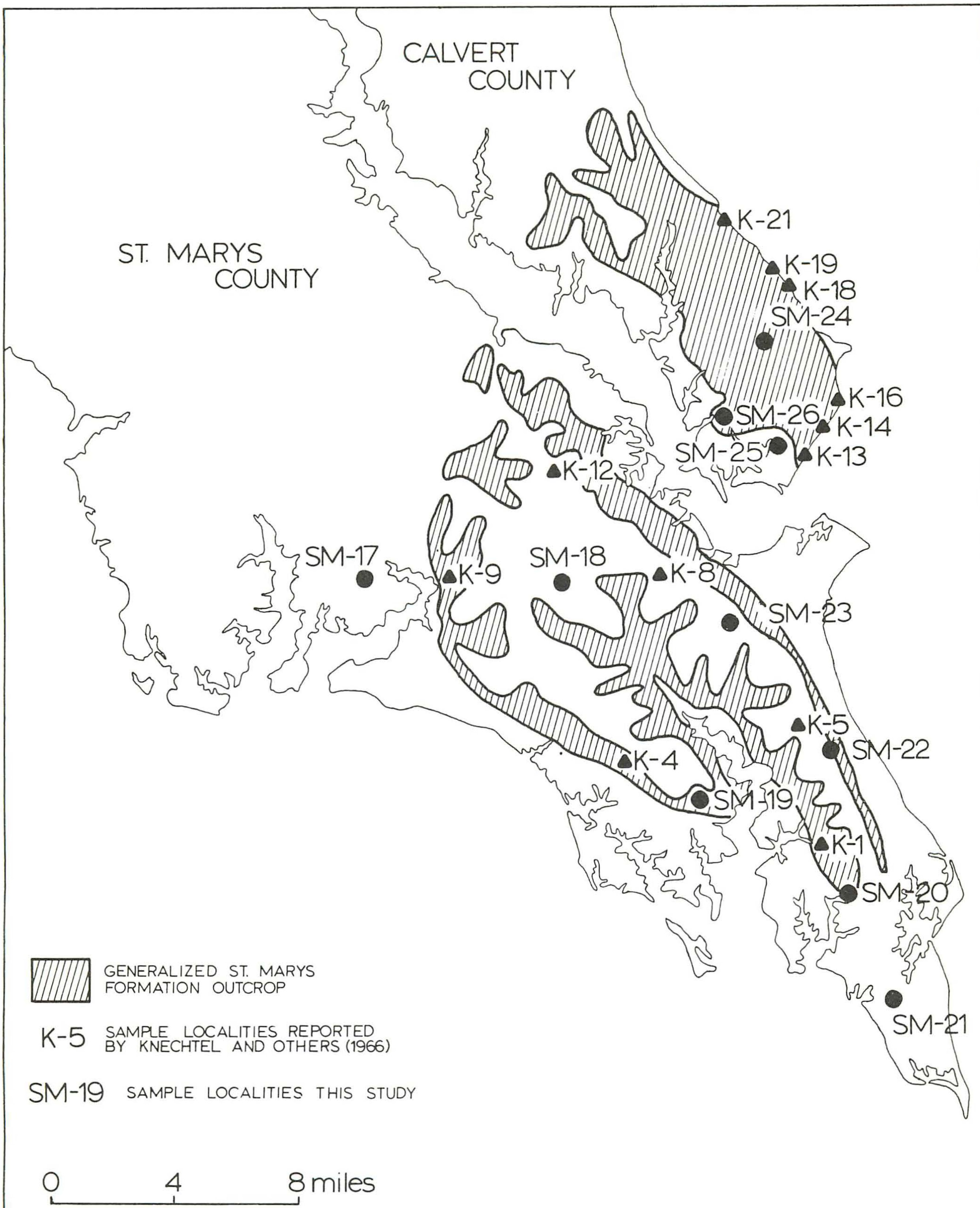

Figure 38. Sample localities for St. Mary's Formation bloating clays.

Table 15. Slow firing tests of St. Marys Formation clay samples

Sample identification	Before firing: Color	Water of plasticity (%)	Working properties	Drying defects	Drying shrinkage (%)	Dry strength	pH	After heating to indicated temperatures: Temperature	Color	Hardness	Shrinkage (%)	Water absorption (%)	Apparent porosity (%)	Specific gravity	Remarks
Road cut, Md. 5, 1500 yds. SE of Leonardtown, St. Mary's Co.*	olive gray	40.0	good	—	7.5	—	—	1800	orange red	fairly hard	10.5	19.1	—	2.68	
								2000	dark red	very hard	13.5	8.6	—	2.55	
								2100	reddish brown	fairly hard	11.0	11.2	—	2.08	
								2200	brown	—	expanded	—	—	1.46	
								2300	—	—	melted	—	—	—	
Bay bluff, 1.5 m. NE of Drum Pt. lighthouse, Calvert Co.*	weak olive	36.0	good	—	8.0	—	—	1800	light red	soft, crumbly	10.5	21.1	—	2.64	
								2000	medium red	very hard	13.5	31.1	—	2.64	
								2100	brownish red	steel hard	15.0	8.1	—	2.40	
								2200	medium brown	steel hard	expanded	—	—	2.19	
								2300	dark brown	steel hard	expanded	—	—	—	
								2400	—	—	melted	—	—	—	
Bay bluff, 1.4 m. S of Cove Point lighthouse, Calvert Co.*	olive gray	33.0	good	—	7.5	—	—	1800	light red	fairly hard	6.5	21.3	—	2.65	
								2000	medium red	very hard	12.0	12.4	—	2.64	
								2100	dark brown	steel hard	14.0	6.9	—	2.54	
								2200	dark brown	—	expanded	7.3	—	2.34	
								2300	nearly black	—	expanded	—	—	—	
Corehole SM-19, 47-69 ft.	olive gray	23.2	moderately plastic	none	5.0	good	4.2	1800	light brown	3	7.5	15.9	28.9	1.82	should fire to "MW" face brick specifications at about 1950°F. but color poor
								1900	light brown	4	10.0	14.7	27.4	1.87	
								2000	medium brown	5	12.5	10.5	20.9	1.99	
								2100	dark brown	6	15.0	6.1	11.7	1.91	
								2200	—	—	expanded	—	—	—	
								2300	—	—	—	—	—	—	
Corehole SM-20, 43-59 ft.	dark gray	23.8	moderately plastic	none	5.0	good	5.7	1800	tan	3	7.5	15.6	29.0	1.86	ditto
								1900	light brown	4	10.0	12.1	23.5	1.94	
								2000	medium brown	5	12.5	6.6	13.9	2.11	
								2100	dark brown	6	12.5	4.9	9.6	1.96	
								2200	—	—	expanded	—	—	—	
								2300	—	—	—	—	—	—	
Corehole SM-26, 33-46 ft.	dark gray	28.2	moderately plastic	none	5.0	good	4.2	1800	dark tan	3	7.5	17.5	31.0	1.77	ditto
								1900	light brown	4	10.0	15.5	28.4	1.83	
								2000	medium brown	5	12.5	9.5	19.1	2.01	
								2100	dark brown	6	15.0	5.8	11.3	1.95	
								2200	—	—	expanded	—	—	—	
								2300	—	—	—	—	—	—	
Corehole SM-22, 70-80 ft.	dark gray	27.5	moderately plastic	none	5.0	good	5.5	1800	dark tan	3	7.5	15.8	28.8	1.82	ditto
								1900	light brown	4	10.0	14.1	26.2	1.86	
								2000	medium brown	5	12.5	9.1	18.1	1.99	
								2100	—	—	expanded	—	—	—	
								2200	—	—	—	—	—	—	
								2300	—	—	—	—	—	—	

* Data from Knechtel, Hamlin, and Hosterman (1966).

Table 16. Results of bloating tests on clay samples from the St. Mary's Formation

Sample identification	After firing 15 minutes in muffle kiln at indicated temperatures																Comments
	1900°F			2000°F			2100°F			2200°F			2300°F				
	Bulk density (lb/ft³)	Water absorption (%)	Expansion	Bulk density (lb/ft³)	Water absorption (%)	Expansion	Bulk density (lb/ft³)	Water absorption (%)	Expansion	Bulk density (lb/ft³)	Water absorption (%)	Expansion	Bulk density (lb/ft³)	Water absorption (%)	Expansion	Evaluation	
*Augerhole K-1 20-40 ft.	89.7	15.8	none	68.5	18.1	slight	50.5	20.8	ample	28.7	32.4	excessive	24.9	36.0	excessive	good	
Augerhole K-1 50-55 ft.	105.3	13.0	none	62.3	18.1	ample	53.0	16.0	ample	43.6	22.6	excessive	48.6	17.0	excessive	excellent	
Augerhole K-1 55-80 ft.	113.3	10.0	none	103.4	8.7	none	86.0	9.9	slight	62.3	12.2	adequate	54.8	12.2	excessive	fair	
Outcrop K-4	—	—	—	84.7	17.6	none	77.9	14.6	slight	57.3	16.3	adequate	48.0	15.0	excessive	fair	
Augerhole K-5 45-67 ft.	82.2	15.3	none	76.6	13.4	none	55.4	15.9	ample	38.0	18.9	excessive	24.9	27.9	excessive	good	product at 2100° strong, absorption low
Augerhole K-5 67-85 ft.	95.9	14.2	none	85.4	13.4	none	64.8	15.7	adequate	46.7	17.3	excessive	39.9	17.2	excessive	good	product at 2100° fragile, bloating range short
Augerhole K-8 30-42 ft.	90.3	17.1	none	90.3	14.8	none	65.4	28.2	moderate	41.7	19.6	adequate	26.8	35.4	excessive	good	
Outcrop K-9	100.9	13.3	none	79.1	20.8	moderate	52.3	30.3	adequate	53.6	22.8	adequate	34.3	20.3	excessive	good	
Augerhole K-12 55-75 ft.	—	—	—	101.5	10.7	none	77.9	12.4	slight	63.5	12.3	moderate	45.5	12.8	good	fair	product at 2200° strong, absorption low
Outcrop K-13	83.5	11.2	none	67.3	10.8	adequate	54.8	9.2	ample	44.9	10.3	ample	31.8	13.3	excessive	excellent	
Outcrop K-13	85.4	13.9	none	72.3	12.9	moderate	49.2	12.8	excellent	—	—	excessive	—	—	—	excellent	
Outcrop K-14	88.5	10.8	none	77.9	9.2	moderate	48.6	8.2	ample	47.3	10.6	ample	36.1	20.0	excessive	excellent	
Outcrop K-16	89.7	15.0	none	81.0	16.0	none	66.6	16.6	moderate	53.6	17.3	adequate	33.0	24.9	excessive	excellent	
Outcrop K-16	90.3	13.8	none	81.6	13.9	moderate	44.9	20.4	excellent	—	—	excessive	—	—	—	excellent	
Outcrop K-18	92.8	22.0	none	92.8	22.0	none	89.1	22.5	none	87.2	22.6	slight	72.3	16.0	slight	unsuitable	
Outcrop K-19	86.0	17.1	none	87.2	14.7	none	56.1	24.1	excellent	38.6	26.0	adequate	33.6	27.6	excessive	good	product at 2100° strong
Outcrop K-21	96.6	13.7	none	84.7	16.8	none	59.8	20.4	excellent	38.0	33.5	excellent	26.8	26.7	excessive	excellent	expansion uniform, products at 2100° and 2200° strong
Outcrop K-21	84.7	27.8	none	80.4	26.0	slight	53.0	21.8	adequate	55.4	35.0	excessive	66.7	—	excessive	very good	
Corehole SM-19 47-69 ft.	102.0	13.9	none	91.0	12.8	none	70.0	15.2	slight	68.0	15.9	ample	45.0	25.2	excessive	marginal	
Corehole SM-22 70-80 ft.	109.0	14.1	none	94.0	13.5	none	77.0	13.4	moderate	43.0	17.1	adequate	47.0	20.6	excessive	marginal	
Corehole SM-26 33-46 ft.	106.0	13.0	none	89.0	14.8	slight	76.0	14.4	adequate	39.0	27.7	moderate	37.0	37.0	moderate	marginal	
Corehole SM-20 43-59 ft.	112.0	11.8	none	90.0	11.4	slight	74.0	11.7	adequate	67.0	14.6	ample	47.0	15.9	excessive	marginal	

* All samples prefixed by K from Knechtel, Hamlin, and Hosterman (1966).

Table 17. Physical properties chemical analyses and results of rotary-kiln firing tests of bulk samples of St. Mary's clay (from Knechtel *et al.*, 1966)

Localities	K-13	K-16	K-21
USBM Lab. Nos.	1277-B	1277-A	1277-C
Raw materials:			
Weight (lb/ft^3)	70.0	70.0	68.2
Strength	Above average	Above average	Average
Crushing characteristics	Excellent	Good	Fair Fairly
Workability	Plastic, smooth	Plastic, smooth	plastic, smooth
H_2O needed for plasticity (percent)	36	33	41
Drying shrinkage (percent)	8.0	7.5	6.0
Drying defects	None	None	None
Screen analysis (sizes):			
−¾ ½	14.55	10.00	6.1
−½ ¼	48.00	38.00	40.2
−¼ 8M	12.50	14.50	14.3
−8M	25.00	37.30	39.4
TOTAL	100.05	100.00	100.0
Chemical analysis:			
SiO_2	65.77	69.51	76.38
Al_2O_3	15.70	14.66	9.09
Fe_2O_3	0.76	0.64	0.78
FeO	1.93	1.67	0.88
TiO_2	0.95	1.00	0.80
CaO	0.63	0.04	1.00
MgO	0.85	0.98	0.82
Na_2O	0.32	0.28	0.28
K_2O	2.04	2.00	1.40
P_2O_5	0.05	0.07	0.08
S*	(1.97)	(1.31)	(1.15)
SO_3	0.95	0.44	0.34
C*	(0.18)	(0.36)	(0.60)
CO_2*	(Trace)	(0.50)	(0.62)
H_2O loss:			
−140°C*	(2.79)	(2.37)	(2.87)
1100°C	8.94	7.72	6.43
S[1]	1.59	1.13	1.01
C[2]	---	(0.22)	(0.43)
TOTAL	100.48	100.14	99.29
Fired products:			
Weight (lb/ft^3, ASTM method)	50.0	53.0	50.0
Weight (lb/ft^3)	61.7	59.2	63.0
Water absorption (percent)	7.2	7.3	9.4
Effect of quenching	Deleterious	Deleterious	Deleterious
Screening analysis, ⅜" crush:			
½	4.6	3.0	1.3
−½ ⅜	29.3	23.3	21.3
−⅜ ¼	48.4	44.2	56.3
−¼ 8M	12.4	20.6	15.7
−8M 65M	3.5	6.7	3.2
−65 (Pressing)	1.7	2.2	2.3
	99.9	100.0	100.1
Kiln temperatures (°F)			
Maximum	2070	2085	2090
Minimum	2020	2000	2020
Optimum	2050	2060	2070

* Not in total
[1] S not soluble
[2] C not CO_2

disparity is not apparent, and further testing is clearly needed to properly evaluate the material. Bulk densities for much of the expanded material are at the high end of the ideal range (40 to 60 lbs. per cubic ft.). Concrete prepared with St. Marys aggregate weighs 86 lbs. per cubic ft. and exhibits a compression strength of about 3500 lbs. per sq. in. according to Knechtel. These values are entirely comparable with most standard lightweight aggregate concretes.

Bulk samples of clays showing good bloating characteristics in preliminary tests were fired in a rotary-kiln for final evaluation and the results reported by Knechtel. Table 17 lists the physical and chemical properties of these samples as well as the firing test data. The expanded aggregate was judged highly satisfactory. Pore structure was generally uniform, and more importantly, the water absorption capacity of the aggregate at 7.2 to 9.4% of weight was significantly lower than the relatively high values noted in the muffe kiln tests.

Although clays in the St. Marys Formation have the capability of providing a reasonably good raw material for lightweight aggregate, several factors will probably work against the development of this resource at the present time. Firstly, the bloating characteristics of apparently similar clays are not uniform; rather they range from unsuitable to excellent. Secondly, the area of accessibility and acceptable overburden thickness is relatively small; large areas of potential St. Marys Formation outcrop, including most of the region inland from the waterways, are blanketed with 50 ft. or more of Upland Deposits clastics. A third factor likely to inhibit development is location at least 50 miles from the nearest substantial market in the greater Washington region. Although not a prohibitive distance in itself, it becomes important when faced with the competition of relatively abundant sand and gravel aggregate immediately adjacent to Washington. At present, then, lightweight aggregate in Southern Maryland must probably be viewed as a potential industry for the future rather than the present.

SUMMARY

Southern Maryland contains no mineral deposits of great value; rather the area should be regarded as possessing sufficient constructional raw materials for its own present and future needs, but nothing with real potential of reaching broad markets beyond the limits of the greater Washington metropolitan region. Although a limited amount of industrial development is likely to take place in Southern Maryland, much of the area, particularly the northern half, seems destined to become a suburbia for the growing Washington metropolitan area. Ample supplies of constructional sand and gravel as well as structural clay are present in Southern Maryland for development needs. The Upland Deposits, distributed over most of the survey area, contain abundant sand and gravel of good quality, perhaps as much as 4 billion tons. Supplementary amounts are to be found in the Lowland terraces bordering the Patuxent and portions of the Potomac River, although most of this material is sand. Ceramic clay suitable for face brick or structural tile is available in the Marlboro Clay, a relatively thin but persistent and homogeneous unit outcropping in the northwestern portion of the area. A further clay resource having a potential for lightweight aggregate occurs in the St. Marys Formation in southern Calvert and southernmost St. Marys Counties. Samples of drab clay in this unit have proved expandable in kiln tests, and this material could ultimately compete with sand and gravel as concrete aggregate.

Resources other than these conventional constructional materials are relatively unimportant in Southern Maryland. Small amounts of phosphorite and fairly substantial quantities of glauconite are present but neither is economic at the present time. Impure diatomite occurs in the lower Calvert Formation of southeastern Charles and Prince Georges Counties as well as in northern Calvert County, but without the development of a cheap method of beneficiating this material, utilization of the diatomite as a mineral product is unlikely.

REFERENCES

ALTSCHULER, Z. S., DWORNIK, E. J., and KRAMER, H., *1963, Transformation of mortmorillonite to kaolinite during weathering: Science, Vol. 141, p. 148-251.*

———, CATHCART, J. B., and YOUNG, E. J., *1964, Geology and geochemistry of the Bone Valley Formation and its phosphate deposits, West Central Florida: Geol. Soc. America, Guidebook No. 6, Miami Beach Ann. Meeting (1964).*

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

BLAKE, S. F., *1953, The Pleistocene fauna of Wailes Bluff and Langleys Bluff, Md.: Smithsonian Misc. Coll., Vol. 121, No. 12, 32 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.*

CAMPBELL, M. R., *1931, Alluvial fan of the Potomac River: Geol. Soc. America Bull., Vol. 42, p. 825-852.*

CHAMBERLIN, T. C., and SALISBURY, R. D., *1906, Geology, Vol. 3, Earth history, 624 p., Holt and Co., New York.*

CLARK, W. B., *1915, The Brandywine Formation of the Middle Atlantic Coastal Plain: Amer. Jour. Sci., 4th ser., Vol. 40, p. 499-650.*

———, *1916, Geological map of Anne Arundel County, Md.: Maryland Geol. Survey.*

———, and others, *1901, Eocene volume: Maryland Geol. Survey, 331 p.*

———, ———, *1904, Miocene volume: Maryland Geol. Survey, 543 p.*

COOKE, C. W., *1952, Sedimentary deposits of Prince Georges County and the District of Columbia, in Prince Georges County Geology and Water Resources: Maryland Dept. Geology, Mines, and Water Resources Bull. 10, p. 1-53.*

COOPER, J. D., *1965, Clays, in Mineral Facts and Problems, 1965 ed.: U.S. Bureau of Mines Bull. 630, p. 227-240.*

DALL, W. H., *1904, The relations of the Miocene of Maryland to that of other regions and to the*

Recent fauna: Maryland Geol. Survey, Miocene Volume, p. 129-155.

DARTON, N. H., *1948, The Marlboro Clay: Econ. Geol., Vol. 43, p. 154-155.*

DOYLE, J. A., *1969, Cretaceous angiosperm pollen of the Atlantic Coastal Plain and its evolutionary significance: Jour. Arnold Arboretum, Vol. 50, p. 1-35.*

DROBNYK, J. W., *1965, Petrology of the Paleocene-Eocene Aquia Formation of Virginia, Maryland and Delaware: Jour. Sed. Petrology, Vol. 35, p. 626-642.*

DRYDEN, L., *1936, The Calvert Formation in Southern Maryland: Pennsylvania Acad. of Sci. Proc., Vol. 10, p. 42-51.*

———, *1939, Geological map of Charles County, Md.: Maryland Geol. Survey.*

———, and OVERBECK, R. M., *1948, The physical features of Charles County, Md.: Maryland Dept. of Geology, Mines, and Water Resources, 267 p.*

———, and DRYDEN, C., *1956, Atlantic Coastal Plain heavy minerals: a speculative summary: preprint of paper presented before Int. Geol. Congress, Mexico.*

FISHER, W. L., and GARNER, L. E., *1965, Clay and clay materials, in Rock and Mineral resources of East Texas: Bureau of Econ. Geology, Univ. of Texas, Rept. of Investigations No. 54, p. 79-179.*

GERNANT, R. E., *1970, Paleoecology of the Choptank Formation (Miocene) of Maryland and Virginia: Maryland Geol. Survey Rept. of Investigations No. 12, 90 p.*

GIBSON, T. G., *1962, Benthonic foraminifera and paleoecology of the Miocene deposits of the Middle Atlantic Coastal Plain: unpubl. PhD Dissertation, Princeton University, 194 p.*

GLASER, J. D., *1968, Coastal Plain geology of Southern Maryland: Maryland Geol. Survey Guidebook No. 1, 56 p.*

———, *1969, Petrology and origin of Potomac and Magothy (Cretaceous) sediments, Middle Atlantic Coastal Plain: Maryland Geol. Survey Rept. of Investigations No. 11, 101 p.*

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, 43 p.*

HANSEN, H. J., *1968, Geophysical log cross-section network of the Cretaceous sediments of Southern Maryland: Maryland Geol. Survey Rept. Investigations No. 7, 32 p.*

———, *1969, Depositional environments of subsurface Potomac Group in Southern Maryland: Amer. Assoc. Petroleum Geologists Bull., Vol. 53, p. 1923-1937.*

KNECHTEL, M. M., and HOSTERMAN, J. W., *1965, Outlook for resumption of diatomite mining in southern Maryland and eastern Virginia: U.S. Geol. Survey Prof. Paper 252-D, p. 151-155.*

———, et al., *1966, Expandable clay in the St. Marys Formation of Southern Maryland: Maryland Geol. Survey Rept. of Investigations No. 4, 17 p.*

KNOX, A. S., *1966, Washington Interglacial Swamp, Washington, D.C.: Wash. Acad. Sci. Jour., Vol. 56, p. 1-8.*

LENHART, W. B., *1960, Sand and gravel,* in *Industrial Minerals and Rocks, Amer. Inst. Mining, Metallurgical, and Petrol. Engineers, N.Y., p. 733-758.*

LOHMAN, K. E., *1948, Middle Miocene diatoms, Hammond Well,* in *Cretaceous and Tertiary subsurface geology: Maryland Dept. Geology, Mines, and Water Resources Bull. 2, p. 151-186.*

LOEBLICH, A. R., and TAPPAN, H. N., *1957, Planktonic foraminifera of Paleocene and early Eocene age from the Gulf and Atlantic Coastal Plains: U.S. National Museum Bull. 215, p. 173-198.*

MANSFIELD, W. C., *1927, Miocene stratigraphy of Virginia, based upon a study of the faunas: PhD Dissertation, George Washington University, 156 p.*

MINARD, J. P., et al., *1969, Cretaceous-Tertiary Boundary in New Jersey, Delaware, and Eastern Maryland: U.S. Geol. Surv. Bull. 1274-H, 33 p.*

MILLER, B. L., and BIBBINS, A. B., *1911, Geological map of Prince Georges County: Maryland Geol. Survey.*

MURRAY, H. H., *1960, Clay,* in *Industrial Minerals and Rocks: Amer. Inst. of Mining, Metallurgical, and Petroleum Engineers, Inc., Maple Press, York, Pa., p. 259-284.*

NOGAN, D. S., *1964, Foraminifera, stratigraphy, and paleoecology of the Aquia Formation of Maryland and Virginia: Cushman Foundation for foraminiferal research Spec. Publ. No. 7, 50 p.*

NORMAN, J., and RALSTON, O. C., *1940, Purification of diatomite by froth flatation: Amer. Inst. Mining Metall. Engineers Tech. Publ. 1198, 11 p.*

OTTON, E. G., *1955, Ground water resources of the Southern Maryland Coastal Plain: Maryland Dept. of Geol. Mines and Water Resources Bull. 15, 347 p.*

PAGE, R. A., *1959, Micropaleontology and stratigraphy of the Brightseat Formation: unpubl. PhD Dissertation, Rutgers University, 186 p.*

RASMUSSEN, W. C., and SLAUGHTER, T. G., *1957, Ground water resources of Caroline, Dorchester, and Talbot Counties: Maryland Dept. Geology, Mines, and Water Resources Bull. 18, 371 p.*

SCHLEE, J. S., *1957, Upland gravels of Southern Maryland: Geol. Soc. America Bull., Vol. 68, p. 1371-1409.*

SEVER, C. W., CATHCART, J. B., and PATTERSON, S. W., *1967, Phosphate deposits of south-central Georgia and north-central peninsular Florida: Georgia State Div. Conservation, Dept. of Mines, Mining, and Geol. Project Report No. 7, 62 p.*

SHATTUCK, G. B., *1903, Geologic map of Calvert Co., Md.: Maryland Geol. Survey.*

———, *1903, Geologic map of St. Marys Co., Md.: Maryland Geol. Survey.*

———, *1904, Geological and paleontological relations, with a review of earlier investigations: in Miocene Vol., Maryland Geol. Survey, p. xxxiii-cxxxvii.*

———, *1906, The Pliocene and Pleistocene deposits of Maryland: Maryland Geol. Survey, 291 p.*

SHIFFLETT, E., *1948, Eocene stratigraphy and foraminifera of the Aquia Formation: Maryland Dept. Geology, Mines, and Water Resources Bull. 3, 93 p.*

STEPHENSON, L. W., *1923, The Cretaceous Formations of North Carolina: North Carolina Geological and Economic Survey Vol. 5, 604 p.*

UNIVERSITY OF MD., DEPT. OF CIVIL ENGIN., *1965, Engineering Soil Map of Maryland.*

WEAVER, K. N., CLEAVES, E. T., EDWARDS, J., and GLASER, J. D., *1968 Geologic map of Maryland: Maryland Geol. Survey.*

WENTWORTH, C. K., *1930, Sand and gravel resources of the Coastal Plain of Virginia: Virginia Geol. Survey Bull. 32, 146 p.*

APPENDICES

APPENDIX A

LOCALITY REGISTER

The list following contains the essential data describing the 169 localities examined during the course of this study. Measured sections are included where instructive. Locality numbers are preceded by the pertinent county name, and are the numbers referred to in the text and tables.

Calvert 1. Cut bank facing Patuxent River a few hundred feet south of the mouth of Lyons Creek. Exposed is the uppermost Nanjemoy Fm. and the lower part of the Calvert Fm. Section badly weathered.

Anne Arundel 2. Bay bluff, 1700 ft. south of Fairhaven. Exposed is about 30 ft. of the lower Calvert Fm., most of which is diatomite.

Prince Georges 3. Abandoned sand pit, southeast corner of intersection U.S. 301 and Md. 408. Exposed is about 25 ft. of the lower Calvert Fm., largely pale-gray fine muddy sand.

Prince Georges 4. Road cut, northeast side of Ritchie-Marlboro Rd., .7 mile northwest of Brooks Rd. Exposed is 6 ft. of very weathered lower Calvert Fm., mostly badly weathered fine whitish sand.

Prince Georges 5. Road cut, northeast side of Osborne Rd., 1.4 miles northwest of U.S. 301. Exposed is about 20 ft. of the lower Calvert Fm. including 5 ft. of diatomite.

Prince Georges 6. Cut bank, east side of U.S. 301, 2100 ft. south of junction Md. 408. Exposed are portions of the Marlboro Clay, Nanjemoy Fm., and lower Calvert Fm. Section badly weathered and slumped in part.

Prince Georges 7. Road cut, west side of U.S. 301, 1.5 miles south of junction Md. 408. Exposed is the upper Marlboro Clay and lower Nanjemoy Fm.

Prince Georges 8. Road cut, west side of U.S. 301, .35 mile north of junction Old Crain Highway. Exposed is about 6 ft. of very weathered lower Calvert Fm.

Prince Georges 9. Road cut, north side of Brandywine-North Keys Rd., 4800 ft. west of junction North Keys-Naylor Rd. Exposed is a partly slumped section of very weathered lower Calvert Fm.

Prince Georges 10. Road cut, east side of Rock Branch Rd., 1.1 miles south of junction Martin Rd. Section of lower Calvert Fm. as follows:

Diatomaceous silt, yellowish white	4 ft.
Sandy clay, pale-gray, much burrowed	4
Clayey sand, brown	1

Prince Georges 11. Road cut, east side of Md. 223, .25 mile south of Old Md. 4. Exposed is a few feet of lower Calvert fine sand, very weathered.

Prince Georges 12. Road cut, north side of Old Crain Highway a few hundred feet east of the entrance ramp to westbound Md. 4. Section of upper Nanjemoy and lower Calvert Formations as follows:

Calvert:	
Sand, pale-gray to whitish, moderately clayey, very fine to fine grained, massive	21 ft.
Sand, pale-brown, very clayey, grading from coarse at base to fine near top of interval; hard, compact	5
Nanjemoy:	
Sand, greenish-brown to dark green, clayey, variably glauconitic, medium-grained; contains small pale-brown clay clasts near top	16
Clay, dark-gray, sandy, micaceous; hard, compact	5

Prince Georges 13. Drainage ditch, south side of Md. 4 service road, .25 mile northwest of Old Crain Highway. Exposed is a few feet of the lower Calvert Formation.

Prince Georges 14. Drainage ditch, south side of Md. 4 service road, 1.3 miles northwest of Old Crain Highway. Exposed is the Nanjemoy Fm.-Marlboro Clay contact.

Prince Georges 15. Deep gully between Md. 4 and its service road to the south, 2.3 miles northwest of Old Crain Highway. Exposed is an excellent section encompassing the upper Nanjemoy Fm. and the lower few feet of the Calvert Fm.

Calvert Fm.:	
Sand, whitish, fine grained, slightly clayey, loosely consolidated	17 ft.
Sand, pale-brown, clayey, medium to coarse grained	2
Nanjemoy:	
Sand, pale gray to reddish brown, very clayey, fine to medium grained, variably glauconitic, coarsens upward, scattered pale brown clay chips and thin laminae	15
Shell marl (greensand packed with shells of *Venericardia potapacoensis*), both top and bottom of bed transitional; leach line passes through this bed such that all shells above the line have been dissolved	3
Sand, dark-gray, moderately glauconitic, fine grained, clayey	2

Prince Georges 16. Road cut, Croom Rd., .5 mile south of St. Thomas Rd. Low exposure of very weathered Calvert sand.

Prince Georges 17. Road cuts, both sides of Croon Station Rd., .5 mile south of junction U.S. 301. Exposed is a few feet of the upper Nanjemoy Fm. and about 10 ft. of the lower Calvert Fm.

Prince Georges 18. Road cut, north side of Queen Anne Bridge Rd., 100 ft. east of U.S. 301. The same section is exposed along the east side of U.S. 301 immediately south of the intersection but is largely overgrown. Upper few feet of the Aquia Fm. and lower portion of the Marlboro Clay exposed.

Anne Arundel 19. Stream bank, 200 ft. southwest of Md. 4, 1.5 miles northwest of Md. 258. Exposed is approximately 15 ft. of Nanjemoy greensand.

Calvert 20. Abandoned excavation, south side of Md. 260, 1.0 mile east of Paris. Exposed is a 19 ft. section of the Plum Point Marls Member of the Calvert Fm. Section weathered and leached.

Calvert 21-22. Road cuts, north side of Fifth St. Extended at about 1.5 miles west of Md. 261 in North Beach. Exposed is about 17 ft. of very weathered Calvert sand.

Calvert 23. Road cut, north side of Fifth St. Extended at 2.1 miles west of Md. 261 in North Beach. Section as follows:

Upland Gravel:	
Hard clayey orange sand with considerable gravel, cobbles to 5 in. diam.	5 ft.

Calvert Fm.:
Fine sand, orange and pale gray mottled, loose, massive 12

Calvert 24. Road cut, east side of Md. 613 immediately north of junction Fifth St. Extended. Exposed is a few feet of sparsely pebbly sand belonging to the Upland Gravel.

Calvert 25. Road cut, east side of Md. 2, .9 mile north of Owings. Exposed is about 5 ft. of pebbly sand belonging to the Upland Gravel.

Calvert 26. Road cut, east side of Md. 2, .7 mile north of junction Dalyrymple Bridge Rd. Section is about 30 ft. of Calvert olive-green sandy clay.

Calvert 27. Banks of tributary to Lyons Creek about 200 ft. west of Md. 4, 1.0 mile south of junction Md. 260. Section as follows:

Calvert Fm.:
Pale gray diatomite .... 4 ft.
Sandstone, reddish brown, hard, silica-cemented 1
Sand, clayey, olive-green to dark brown, abundant shell impressions; small pebbles and phosphate clasts concentrated at base 7

Nanjemoy Fm.:
Sand, clayey, variably glauconitic, dark green to nearly black 4

Calvert 28. Calvert Cliffs, 2000 ft. north of Randle Cliff. Exposed is a nearly complete section of the Plum Pt. Marls Member of the Calvert Fm. Approximately 80 ft. of section can be examined.

Calvert 29. Road cuts, east side of Md. 4 extending from Fowlers Mill Branch south to the crest of the first hill (about 1500 ft.). Exposed is a much weathered section of the Plum Point Marls overlying a few feet of the Fairhaven Member of the Calvert:

Upland Gravel:
Gray sandy clay .... 5 ft.
Sand, pale gray, medium grained, with several pebble bands 6
Gravel, pale gray, sandy 1

Calvert Fm. (Plum Pt. Marls):
Sand, fine grained, mottled red and whitish 2
Sandstone, silica-cemented, abundantly fossiliferous, pale gray ("Zone 10") 1
Sand, whitish, clayey, fine grained 51

Calvert Fm. (Fairhaven):
Clay, silty, hard, bluish-green 6

Calvert 30. Road cut, west side of Md. 4, .9 mile north of junction Md. 262. Exposed is about 20 ft. of very weathered Calvert sand overlain by several feet of Upland Gravel.

Calvert 31. Road cut, west side of Md. 4, .5 mile north of junction Md. 262. Exposed is about 17 ft. of very weathered and oxidized Calvert sand.

Calvert 32. Road cuts, west side of Md. 4 immediately south of junction Md. 262. A good section of the Upland Gravel is exposed in these cuts:

Sand, coarse, interbedded with fine gravel, cross-bedded .... 16 ft.
Clay, brick-red, silty 2
Sand, very clayey, mottled brown and pale gray 4
Clay, medium gray, sandy 3
Sand, orange, coarse, interbedded with fine gravel 10
Thinly interbedded medium to coarse clayey sand, fine gravel, and sandy clay, mottled orange and pale gray 8

Calvert 33. Road cut, Dalyrymple Bridge Rd. at Fishing Creek. Exposed is a few feet of oxidized Calvert sand bearing cemented lumps with abundant shell impressions.

Calvert 34. Road cut, west side of Dares-Wilson Rd., 1.5 miles north of junction Emmanual Church Rd. Exposed is about 15 ft. of very much weathered Choptank Fm. with clustered shell impressions in upper portion.

Calvert 35. Road cut, Parran Post Office Rd., 1.4 miles southeast of junction Plum Pt. Rd. Exposed is 12 ft. of coarse sand with thin gravel lenses belonging to the Upland Gravel.

Calvert 36. Road cut, Parran Post Office Rd. at Plum Pt. Rd. Exposed is about 7 ft. of coarse gray sand and subordinate gravel (Upland Gravel).

Calvert 37. Stream bank, Friday Creek at Lower Marlboro Rd. Exposed is several feet of pebbly bluish silty clay (Alluvium).

Calvert 38. Road cut, east side of Lower Marlboro Rd. immediately north of Friday Creek. Exposed is about 8 ft. of interbedded gray clay and whitish sand (Lowland Deposits).

Calvert 39. Road cut, Lower Marlboro Rd. immediately west of Chew Creek. Poor exposure of much weathered and oxidized Calvert Fm.; cut littered with fossiliferous sandstone blocks.

Calvert 40. Road cuts, Md. 510 immediately north of Cocktown Creek. Exposed is gravelly alluvium and possibly some weathered Miocene sand.

Calvert 41. Road cut, north side of Breezy Pt. Rd. immediately east of Md. 4. Exposed is 14 ft. of coarse sand and subordinate gravel (Upland Deposits).

Calvert 42. Road cut, Guy Hardesty Rd., .7 mile southeast of Fishing Creek. Exposed is about 10 ft. of orange loamy sand with shell impressions (Choptank Fm.).

Calvert 43. Road cut, Guy Hardesty Rd., immediately southeast of Fishing Creek. Poor exposure of sandy alluvium.

Calvert 44. Road cut, Md. 260, 1.1 miles west of junction Grovers Turn Rd. Low exposure of oxidized Calvert sand.

Calvert 45. Road cut, Md. 260, .35 mile west of junction Grovers Turn Rd. Small exposure of brownish sand with gravel bands (Upland Deposits).

Calvert 46. Road cut, Md. 260 at Grovers Turn Rd. Exposed is orange fine sand with pebble bands (Upland Deposits).

Calvert 47. Drainage ditch, north side of Paris-Mt. Harmony Rd., .7 mile west of Mt. Harmony. Exposed at intervals in the ditch walls is medium to coarse reddish-brown sand with numerous thin pebble bands; scattered shell impressions, mostly large *Lyropecten* (Choptank Fm.?).

Calvert 48. Road cut, Fowlers Rd., .9 mile east of Md. 4. Exposed is about 20 ft. of fine orange sand (Calvert Fm.).

Calvert 49. Road cut, Hunting Creek Rd., 3.5 miles northwest of junction Lowery Rd. Exposed is a few feet of Upland Deposits—coarse reddish brown sand with thin gravel bands.

Calvert 50. Road cut, Hunting Creek Rd., 2.5 miles northeast of junction Lowery Rd. Exposed is about 20 ft. of coarse sand with 2 gravel beds (Upland Deposits).

Calvert 51. Abandoned sand and gravel pit, Lowery Rd., 1.0 mile east of Hunting Creek Rd. Exposed is about 16 ft. of Upland Deposits, mostly hard reddish-brown pebbly sand and subordinate gravel.

Calvert 52. Road cut, south side of Plum Pt Rd., 1.7 miles west of junction Emmanual Church Rd. Exposed is hard reddish brown coarse sand and grayish sandy clay (Upland Deposits?).

Charles 53. Road cuts, junction Md. 232 and Grosstown Rd. Exposed is about 15 ft. of reddish brown mottled clayey sand (Upland Deposits).

Charles 54. Stream bank, 50 ft. north of Md. 558, 1.9 miles east of junction U.S. 301. Exposed is about 15 ft. of fine Calvert sand overlying several ft. of diatomaceous silt.

Charles 55. Abandoned pit, immediately east of Md. 227, .9 mile southeast of junction Md. 224. Exposed is a much weathered section comprising the uppermost Nanjemoy Fm. and lower-most Calvert Fm. Contact exhibits significant undulations approaching overturning.

Anne Arundel 56. Road cut, junction Hawkins and Crownsville Rds. Exposed is a few feet of fine Calvert sand.

Calvert 57. Bluff on east bank of Patuxent River at Holland Cliff. Exposure is partly slumped and overgrown but encompasses about 40 ft. of the Fairhaven Member of the Calvert Fm. including at least 10 ft. of diatomite, the whole overlain by a much reduced Plum Pt. Marls section. Prominent in the upper portion of the cliff is a shell bed ("Zone 10" of Shattuck).

Calvert 58. Road cut, Holland Cliff Rd., .5 mile west of junction Md. 4. Exposed is a few feet of Upland Deposits.

Calvert 59. East bank of Patuxent River at Gods Grace Point. Exposed is 15 ft. of Lowland Deposits, chiefly loose clean sand with thin gravel bands.

Calvert 60. Road cut, Md. 507, 700 ft. northeast of Mill Creek. Exposed is fine to medium orange sand with scattered pebbles (Lowland Deposits).

Calvert 61. East bank of Patuxent River, immediately north of the Burch-Benedict Bridge. Section as follows:

Lowland Deposits:	
Pale-gray, loosely-bedded, medium-grained sand with a few pebble bands	5 ft.
Medium gravel	4 in.
Calvert Fm.:	
Pale-gray hard sandy clay	2 ft.
Pale-gray fine clayey sand	4
Brown clayey sand with abundant burrows	7
Dark-brown coarser sand with abundant shell impressions; cemented in part, forms beach and river bed	2

Calvert 62. Road cut, Md. 506, 1.45 miles southwest of Md. 4. Exposed is about 20 ft. of Upland Deposits sand and subordinate pebbly beds.

Calvert 63. Road cut, northeast side of Md. 4, immediately northwest of junction Md. 765. Exposed is about 30 ft. of reddish orange sand with scattered gravel bands (Uplands Deposits) overlying 16 ft. of fine clayey yellowish sand (Calvert Fm.).

Calvert 64. Cut bank, 300 ft. southwest of Calvert 20. Exposed is about 20 ft. of pale gray to reddish brown fine-grained loose sand with 2 concentrations of shells; lower is a 4 ft. shell bed packed with bivalve shells (Choptank Fm.).

Calvert 65. Road cut, gravel road 200 ft. north of junction Md. 263. Gravel road leaves Md. 263 1000 ft. west of Plum Pt. Creek. Exposed is about 20 ft. of grayish fossiliferous sandy clay (Calvert Fm.).

Calvert 66. Calvert Cliffs, 3500 ft. south of Md. 263 terminus. Exposed is about 60 ft. of the Plum Pt. Marls Member of the Calvert Fm.

Calvert 67. Road cuts, Emmanuael Church Rd. immediately south of junction Md. 555. Exposed is interbedded sand, gravel, reddish mottled clay, and thin ironstone beds (Upland Deposits).

Prince Georges 68. Cut bank and gullies, southeast side of Md. 381, 1100 ft. north of Swanson Creek. Bank exposes about 12 ft. of Upland Deposits; deep gullies reveal an additional 35 ft. of section below the Upland Deposits. This latter is a much weathered Plum Pt. Marls section including the "Zone 10" shell bed.

Prince Georges 69. Road cut, 2.1 miles east of Md. 381 on Eagle Harbor Rd. Exposed is a few feet of much weatherer Calvert Fm.

Prince Georges 70. Ditch and road cut, west side of Md. 382 a few hundred feet north of Black Swamp Creek. Exposed is about 30 ft. of weathered lower Calvert Fm. including at least 10 ft. of diatomite.

Prince Georges 71. Road cut, north side of Croom Md., .4 mile west of Penn Central RR tracks. Exposed is about 6 ft. of loosely-bedded white pebbly sand belonging to the Lowland Deposits.

Prince Georges 72. Road cuts, southwest side of Croom Rd. extending from 800 ft. east of the Penn Central tracks to about 1900 ft. east of the tracks. Exposed is 40 ft. of weathered Calvert Fm., mostly grayish fine-grained clayey sand with scattered shell impressions.

Prince Georges 73. Road cut, junction Croom Rd. and Mt. Calvert Rd. Exposed is about 15 ft. of Upland Deposits consisting of interbedded gravel and coarse sand; large cobbles at base.

Prince Georges 74. Road cut, Croom Rd., .85 mile north of Airport Rd. Exposed is 30 to 40 ft. of much weathered yellowish fine sand belonging to the Calvert Fm.

Calvert 75. Bank of Patuxent River, .6 mile south of Sandy Point. Exposed is 8 ft. of bluish-gray clayey sand (Choptank Fm.) overlain by about 12 ft. of medium to coarse-grained pebbly sand (Lowland Deposits). Uppermost 1 ft. of section crowded with oyster shells (midden).

Cavert 76. Road cut, Grays Mutual Rd., 1.1 miles west of Md. 265. Low exposure of Upland Deposits consisting of interbedded sand and fine gravel.

Calvert 77. Road cuts, Ross Rd., both sides of Island Creek. Exposed is about 20 ft. of weathered impressions overlain by Upland Deposits.

Charles 78. RR cut, Indian Head Railway, 900 ft. west of Md. 225. Exposed is about 6 ft. of indurated shelly greensand (Aquia Fm.).

Charles 79. Road cut, south side Md. 225, 2.1 miles southeast of junction Md. 224. Exposed is several feet of Nanjemoy Fm. greensand including a prominent shell bed.

Charles 80. Road cut, south side Md. 224, .6 mile southwest of junction Md. 225. Section as follows:

Nanjemoy (?) Fm.:	
Gray micaceous fine sand, little glauconite; few shell impressions	10 ft.
Marlboro Clay:	
Gray to pinkish plastic clay interbedded with minor silt	14
Aquia Fm.:	
Gray-green sand glauconitic sand	10
Sandstone, medium-gray, crowded with *Turritella* shells	1

Charles 81. Road cut, Md. 224 immediately west of Reeder Run. Exposed is about 10 ft. of fine gray pebbly sand (Potomac Gr.) unconformably overlain by 15 ft. of weathered brownish greensand (Aquia Fm.).

Charles 82. Road cut, Md. 224, 1.0 mile north of Smith Pt. Rd. Exposed is a graded sequence of cross-bedded pale-gray sand, gravel, and reddish mottled clay; large cobbles in basal portion (Lowland Deposits).

Charles 83. Road cut, Durham Church Rd., .2 mile north of Md. 425. Exposed is about 10 ft. of very much weathered greensand with many brown clay blebs. Resting on the greensand is a few feet of medium to coarse reddish-brown sand and interbedded gravel (Upland Deposits).

Charles 84. Road cut, Md. 6, .3 mile east of Wards Run. Cut largely grown over but partial exposures reveal about 10 ft. of Nanjemoy greensand overlain by a few feet of Calvert olive-green sandy clay.

Charles 85. Road cut, Md. 6, 1.5 miles each of Valley Rd. Exposed is about 12 ft. of rusty brown greensand (Nanjemoy Fm.).

Charles 86. Road cut, Cedar Point Rd., .75 mile north of Brentland Rd. Exposure shows at least 20 ft. of weathered Calvert Fm. succeeded by a few feet of Upland Deposits.

Charles 87. Road cut, junction Cedar Point Rd. and Mill Swamp Rd. Exposed is a few feet of Lowland Deposits, chiefly dark-brown pebbly sand.

Charles 88. Road cut, Md. 6, 1200 ft. east of Mill Swamp. Largely covered but shows a Nanjemoy-Calvert section very similar to Charles 84.

Prince Georges 89. Bluff facing Piscataway Creek at the Md. 210 bridge. Exposed is a good but much weathered 35 ft. section of the upper Aquia Fm. Fossils are numerous in the upper portion. A calcite cemented sandstone bed is prominent in the middle of the section.

Calvert 90. Road cut for west lane of Md. 4 at Briscoes Turn Rd. Good exposure of the Calvert-Upland Deposits contact. Interbedded coarse brownish pebbly sand and gravel sharply overlying pale-gray very fine-grained clayey sand.

Calvert 91. Road cuts, Tom Parran Rd., 500 ft. northeast of St. Leonard Creek. Exposed is loosely-bedded medium-grained pebbly sand and subordinate gray clay (Lowland Deposits).

Calvert 92. Road cut, north side of Ross Rd., 1100 ft. west of junction Md. 265. Exposed is interbedded sand and gravel belonging to the Upland Deposits. Cobbles to 6 in. diameter are present.

Calvert 93. Road cut, north side of Governor Run Rd., .3 mile west of junction Kenwood Beach Rd. Exposed is the Drumcliff Member of the Choptank Fm.

Calvert 94. River bank, terminus of Md. 265 at St. Leonard Creek. Exposed is a well-indurated sandstone at river level (Choptank Fm.). Shell impressions are numerous.

Calvert 95. Road cut, Md. 265, .25 mile from terminus. Exposed is about 20 ft. of coarse white pebbly sand (Lowland Deposits).

Prince Georges 96. Excavation, east side of U.S. 301, 2.1 miles south of Clagett Landing Rd. Exposed is about 15 ft. of weathered clayey fine-grained sand (Calvert Formation).

Charles 97. Popes Creek Bluff. Classic exposure of almost the full thickness of the Fairhaven Member of the Calvert Fm. resting on 20 ft. of Nanjemoy greensand. The Fairhave diatomite is prominent midway in the bluff.

Charles 98. Road cut, Popes Creek Rd., 200 ft. north of Penn Central RR tracks. Exposed is some 12 ft. of Lowland Deposits comprising well stratified, white, sparsely pebbly sand.

Charles 99. Stream bank, immediately east of Popes Creek Rd. at .15 miles north of the Penn Central RR tracks. Exposed is about 30 ft. of very weathered Calvert Fm.

Calvert 100. Sand pit, immediately west of Md. 4 at junction Md. 263. Good exposure of pale-gray, loosely-bedded, cross-stratified sand in the Lowland Deposits.

Charles 101. Road cut, Riverview Village Rd., 500 ft. north of Indian Head Highway. Section as follows:

Lowland Deposits:	
Reddish-brown clayey sand, medium grading up to fine, upper portion glauconitic; uppermost 2 ft. contains much gravel and cobbles to 12 in. diameter	20 ft.
Interbedded reddish sand and pale-gray clay	1
Reddish-brown sand, coarse at base grading up to medium, limonite-stained, contains much blue qtz. and chalky feldspar	13
Hard pale-gray and reddish mottled clay, sandy and limonite-stained	7

Charles 102. Road cut, Sweden Point Rd., .25 mile west of Md. 224. Exposed is pale clayey sand of the Lowland Deposits.

Charles 103. Road cut, Md. 224, .5 mile north of Rison. Exposed is about 20 ft. of gravelly Upland Deposits.

Charles 104. Road cut, Md. 224, .3 mile southwest of Rison. Exposed is hard mottled reddish and gray clayey sand in Upland Deposits.

Charles 105. Road cut, Md. 224, immediately west of Chicamuxen Church. Exposed is brick-red loamy sand in Upland Deposits.

Charles 106. Abandoned sand and gravel pit, northeast side of secondary road leading northwest from Marbury, 1400 ft. from Md. 224. Exposed is about 15 ft. of coarse cobble and boulder gravel belonging to the Upland Deposits. Large clasts include quartzite, green siltstone, and schist.

Charles 107. Road cuts, southeast side of abandoned roadway (old Md. 224), about 100 ft. east of new road, 1300 ft. north of Rison. Section as follows:

Upland Deposits:	
Coarse gravel succeeded by loamy reddish sand	6 ft.
Nanjemoy (?) Fm.:	
Pale-gray fine-grained clayey sand, reddish-brown in upper part, impressions of small bivalves throughout	7
Sand as above, very clayey, transitional into clay below; shell impressions, burrows, and lignite fragments abundant	2
Marlboro Clay:	
Steel-gray plastic clay	4
Aquia Fm.:	
Fine-grained greenish-brown sand, sparsely glauconitic	42

Charles 108. Abandoned sand and gravel pit, junction Md. 210 and Md. 225. Exposed is about 15 ft. of Lowland Deposits consisting of reddish-brown loamy sand and interbedded gravel containing clasts to 24 in. diameter.

Charles 109. Road cuts, Md. 224, from .1 to .3 mile east of Chicamuxen Church. Intermittent exposures of medium to coarse clayey sand, orange and gray mottled, pebbly in basal portion (boulders to 3 ft. in diameter).

Charles 110. Road cut, Md. 234, 1.0 mile east of Allens Fresh Run. Poor exposure of weathered Calvert Fm.

Charles 111. Road cut, Md. 234, .6 mile east of Charles 110. Exposed is a few feet of fine clayey Calvert sand.

Charles 112. Road cut, Md. 382, 1300 ft. east of Zekiah Swamp. Exposed is a few feet of Upland Deposits consisting of coarse orange pebbly sand.

Prince Georges 113. Road cuts, Md. 233, .25 mile east of Swanson Creek. Exposed is yellowish pebbly sand (Upland Deposits).

Prince Georges 114. Road cut, Md. 381, .6 mile south of junction Eagle Harbor Rd. Poorly exposed orange sandy clay (Calvert Fm.).

Prince Georges 115. Road cut, Md. 381, .4 mile south of Prince Georges 114. Complete section of Upland Deposits in cuts. Orange pebbly sand and gravel grading up into mottled sandy loam.

Charles 116. Road cut, Md. 231, 2.35 miles southeast of junction Md. 381. Exposed is about 15 ft. of very weathered Calvert Fm.

Charles 117. Road cut, Md. 231, 2.75 miles east of junction Md. 381. Poor exposure of about 15 ft. of Calvert Fm. overlain by a few feet of Upland Deposits.

Charles 118. Road cut, Md. 231, .55 mile east of Charles 117. Exposure much the same as the last.

Charles 119. Road cut, Md. 231, .2 mile east of Charles 118. Poor exposure of weathered Calvert Fm.

Charles 120. Road cut, Md. 6, 900 ft. west of Wheatley Run. Exposed is about 25 ft. of fine fluffy sand grading down into more compact clayey sediment (Calvert Fm.).

Charles 121. Hand-auger boring, 200 ft. southwest of Acton Lane, 700 ft. southeast of Mattawoman Creek. Boring revealed 6 ft. of pebbly sand alluvium overlying weathered Calvert Fm.

Charles 122. Road cut, Sharperville Rd., .5 mile south of Mattawoman Creek. Exposure of weathered Calvert Fm.

Charles 123. Stream banks, 600 ft. northwest of the terminus of Brooks Haven Rd. (Brooks Haven Rd. joins Md. 228 .7 mile east of Cat Pond Rd.). Exposed is the Calvert Fm., at this point bluish sandy clay grading up to gray clayey sand.

Prince Georges 124. Road cut, Md. 214 at junction Church Rd. Exposed is the Calvert Fm., consisting of pale-gray sandy clay with scattered shell impressions.

St. Marys 125. Road cut, Md. 5, 1.1 miles north of St. Inigoes. Exposed is a 4 ft. lense of dark-gray plastic clay containing abundant *Ostrea* and other fossils, overlain by 6 ft. of coarse grayish sand (Lowland Deposits).

St. Marys 126. Road cut, Md. 5, .2 mile south of St. Inigoes. Section as follows:

Upland Deposits:	
Medium to coarse-grained reddish-brown sand	11 ft.
Interbedded sand as above and gravel, cobbles at base to 5 in. diameter	5
St. Marys Fm.:	
Fine yellow and white mottled sand, interbedded with gray clay near top of interval	8
Weathered greensand, orange and yellow mottled; sharp contact with unweathered sediment below	6
Greenish-black greensand, abundant burrows, fossiliferous	7
Gray plastic clay, abundantly burrowed in upper portion with burrows greensand filled	9

St. Marys 127. Road cut, Md. 5, .8 mile south of St. Inigoes. Exposed is greenish pebbly sand and reddish-brown sandy clay (Upland Deposits).

Charles 128. Railway cut, Penn Central, immediately north of Md. 234, .2 mile east of U.S. 301. Exposed is about 25 ft. of Calvert Fm.

Charles 129. Road cut, Mill Hill Rd., 600 ft. south of Md. 228. Exposed is about 14 ft. of very weathered Calvert Fm. overlain by a few feet of Upland Deposits.

Charles 130. Gully, 50 ft. northeast of Md. 230, 1.6 miles north of junction Md. 3. Exposed is grayish fine clayey sand with scattered shell impressions (Calvert Fm.).

Charles 131. Abandoned pit, west side of U.S. 301, .25 mile south junction Md. 3. Exposed is interbedded fine yellow sand and red and white mottled clay (Upland Deposits).

Calvert 132. Sand and gravel pit, Coster Rd., 1.1 miles east of Appeal. Exposes interbedded coarse sand, granule gravel, and subordinate medium gravel (Lowland Deposits).

Calvert 133. Sand and gravel pit, Coster Rd., .5 mile east of Appeal. Exposed is about 30 ft. of cross-bedded medium to coarse white sand and fine gravel, limonite stained in part (Lowland Deposits).

Calvert 134. Sand and gravel pit, northeast corner intersection Md. 4 and Dowell Rd. Pit face shows about 15 ft. of cross-bedded white pebbly sand (Lowland Deposits).

Calvert 135. Abandoned sand and gravel pit, west side of Md. 760, .3 mile south of Brown Creek. Exposed is 15 to 20 ft. of interbedded reddish-brown sand and medium gravel (Upland Deposits).

Calvert 136. Cut bank, northeast side of Md. 760, .35 mile east of junction Olivet Rd. Poor exposure of dark-gray fine-grained clayey sand (St. Marys Fm.).

Calvert 137. Calvert Cliffs at Rocky Pt. Excellent exposure of upper Choptank Fm. and lower St. Marys Fm. overlain by Upland Deposits.

St. Marys 138. Road cut, Md. 242 a few hundred feet south of Dynard Run. Exposed is about 15 ft. of Upland Deposits consisting here of fine to medium-grained orange sand and subordinate silty clay.

St. Marys 139. Sand and gravel pit, north side of Bull Rd., .7 mile southeast of junction Society Hill Rd. Pit shows a 15 ft. face exposing coarse gravel fining upward to medium pebbly sand. Boulders to 20 in. in diameter in basal portion.

St. Marys 140. Road cut, west side of Md. 5, 1.4 miles southeast of Leonardtown. Upland Deposits and St. Marys Fm. Measured section in text (p. 33).

St. Marys 141. Sand and gravel pit, east side of Md. 5 opposite St. Marys 140. Measured section in text (p. 33).

St. Marys 142. Road cut, Md. 249, 1.0 mile north of junction Md. 251. Exposed is about 6 ft. of reddish-orange pebbly sand (Upland Deposits).

St. Marys 143. Road cut, Md. 249, 1.2 miles south of Md. 5. Exposed is 12 ft. of reddish-orange coarse sand (Upland Deposits).

St. Marys 144. Abandoned sand and gravel pit, southwest side of Md. 5, 1.8 miles west of Willows Rd. Pit has 15 ft. face in reddish-brown sand and pebbly sand. Large boulders to 24 in. diameter at base.

St. Marys 145. Road cut. Willows Rd., 1.15 miles south of junction Great Mills Rd. Exposed is fine yellowish sand and gray sandy clay of the Upland Deposits.

St. Marys 146. Railway cut, U.S. Government Railway to P.A.T.C., 1.0 mile southeast of Md. 574. Exposed is about 20 ft. of reddish-brown clayey sand and subordinate brown and gray mottled clay (Upland Deposits).

Prince Georges 147. Road cut, north side U.S. 50, 2.45 miles west of Freeway Airport. Exposure of Patapsco-Monmouth Fm. unconformity.

Prince Georges 148. Road cut, Kirby Rd., 100 yds. north of Temple Hills Rd. Exposure of Calvert Fm. overlain by Upland Deposits.

Prince Georges 149. Abandoned sand and gravel pit, southwest side of Md. 5, .6 mile north of Surrats Rd. Poor exposure of Upland Deposits.

St. Marys 150. Road cut, Md. 236, 3.5 miles north of Budds Creek. Exposed is about 6 ft. of Upland Deposits.

St. Marys 151. Road cut, Md. 234, .85 mile west of Chaptico Run. Exposure of Upland Deposits.

Charles 152. Road cut, Mill Run Rd., 1.0 mile west of Mt. Victoria Rd. Exposure of Upland Deposits.

Prince Georges 153. Abandoned excavation, North Keys Rd., .75 mile northeast of junction Md. 381. Exposed is the Upland Deposits.

Prince Georges 154. Road cut, Bryans Pt. Rd., 1.5 miles northwest of junction Farmington Rd. Upland Deposits exposure.

Prince Georges 155. Cut bank, rear of shopping plaza on northwest side of Indian Head Highway at Silesia. Good exposure of cobble gravel in Upland Deposits.

Calvert 156. Road cut, Stoakley Rd., .85 mile northeast of intersection Barstow Rd. Exposed is about 8 ft. of orange sand and gravel (Upland Deposits).

Calvert 157. Road cut, Md. 231, .3 mile west of junction Md. 508. Upland Deposits exposure.

Calvert 158. Road cut, west side of Parker Creek Rd., .4 mile north of junction Md. 4. Exposed is about 15 ft. of interbedded white coarse sand and fine gravel (Upland Deposits).

Calvert 159. Road cut, Md. 4, .8 mile north of Calvert Beach Rd. Exposed is about 15 ft. of Upland Deposits.

Calvert 160. Road cut, Mackalls Rd., .55 mile south of Parran Rd. Poor exposure of Upland Deposits.

Calvert 161. Road cut, Md. 4, 1.2 miles north of Lusby. Low exposure of coarse orange sand in the Upland Deposits.

Charles 162. Road cut, northeast side of Md. 5, 1.1 miles north of Hughesville. Exposed is about 10 ft. of coarse yellow pebbly sand (Upland Deposits).

St. Marys 163. Sand and gravel pit, northeast side of Md. 5, .3 mile southeast of Md. 242. Exposed is about 15 ft. of reddish-orange fine to medium sandy gravel (Upland Deposits).

St. Marys 164. Road cut, Md. 5, 1.3 miles northwest of Park Hall. Exposed is about 10 ft. of gray clay (St. Marys Fm.) overlain by a few feet of Upland Deposits. About 20 ft. of the latter are exposed in an old gravel pit approximately 700 ft. east of the cut.

St. Marys 165. Abandoned sand and gravel pit, north side of Md. 5, 1.0 mile north of St. Marys 123. Exposed is some 15 ft. of Upland Deposits sand and coarse gravel overlying much weathered St. Marys Fm.

St. Marys 166. Road cut, Md. 5, .25 mile northwest of St. Marys 123. Exposed is about 20 ft. of coarse grayish sand belonging to the Lowland Deposits.

St. Marys 167. Road cut, Md. 235, .35 mile south of Bay Forest Rd. Poor exposure of the Upland Deposits.

St. Marys 168. Road cut, Evergreen Park Rd., 400 ft. east of junction Md. 235. Exposed is a graded section of the Upland Deposits consisting of medium gravel with a few cobbles passing upward into sand and ultimately fine clayey sand.

Anne Arundel 169. Clay pit, north side of Md. 214, 1.1 miles east of Muddy Creek Rd. Exposed is about 10 ft. of Marlboro Clay overlain by a similar thickness of Nanjemoy Fm. greensand.

APPENDIX B

TEST BORING LOGS

Hole SM-1

Location: Rison-Ironsides Road, 20 ft. southwest of pavement edge, .93 mile southeast of junction Md. 224 at Rison.

Elevation: 120 feet

Description from cuttings on auger flights 0-25 feet; from cores 20-57.5 feet.

Thickness	Depth	Description
		Upland Gravel
6	6	Sand, yellowish-brown, fine-grained, very clayey.
4	10	Sand, yellowish-brown, fine-grained, less clayey.
10	20	Sand, dark yellowish-orange, medium-grained; scattered small pebbles; interbedded with clay, red and tan, plastic.
2	22	Clay, light-brown to pale yellow, laminated, soft, plastic.
6	28	Sand, dark yellowish-orange, medium to coarse-grained, pebbly, pebbles increase in abundance downward.
		Nanjemoy Formation
4	32	Clay, grayish-black, sandy, sparsely glauconitic; much burrowed with fillings of fine-grained, pale gray sand.
5	37	Sand, greenish-black, fine to medium-grained, scattered coarse grains, clayey, sparsely glauconitic; phosphate granules rare; burrows common.
10	47	Sand, brownish-black to olive, fine to medium-grained, less clayey; molluscan fragments and lignite chips rare to abundant; burrows common.

Thickness	Depth	Description
7	52	Sand, greenish-black, fine-grained, very clayey; in part burrowed, in part undisturbed interlaminated sandy clay and sand, laminations .5 in. or less in thickness.
		Marlboro Clay
5	57	Clay, pale silvery-gray to medium-gray, plastic, with thin laminae of silt, very light-gray to pale green, micaceous, sporadically glauconitic; burrowed in part; finely-divided lignite rare to abundant, pyrite rare; lower contact sharp.
		Aquia Formation
1	58	Sand, dark greenish-gray to dark gray mottled, fine-grained, sparsely glauconitic, pyritic.

Hole SM-2

Location: Rison-Ironsides Road, 3 ft. northeast of pavement edge, 1.05 miles northwest of junction Md. 425 at Ironsides.

Elevation: 70 feet

Description from cuttings on auger flights 0-15 feet; from cores 15-26 feet.

Thickness	Depth	Description
		Alluvium
5	5	Sand, greenish-tan, medium-grained, very clayey; wood fragments common.
10	15	Sand, medium to coarse-grained, greenish-tan, clayey, pebbly, pebbles increase in abundance and size downward, glauconitic.
		Marlboro Clay
2	17	Clay, medium light-gray to light brownish-gray, plastic; in part faintly laminated, in part burrowed, burrows filled with greenish-gray micaceous silt; pelecypod fragments rare.
3	20	Clay, pale red to pale reddish-brown, plastic, with thin laminae of silt, pinkish-gray, micaceous, lignitic, pyritic.
5	25	Clay, light olive-gray to medium dark-gray, plastic irregular laminae of silt, yellowish-gray to greenish-gray, micaceous, variably glauconitic and lignitic, silt increases in abuandance downward as do shell fragments.
		Aquia Formation
1	26	Sand, mottled greenish-gray and dark greenish-gray, fine-grained, glauconitic; few molluscan fragments; few thin irregular lenses of dark-gray clay; upper contact transitional.

Hole SM-3

Location: Durham Church Road, 7 ft. east of pavement edge, 100 feet south of junction Md. 6.

Elevation: 40 feet

Description from cuttings on auger flights 0-11 feet; from cores 11-24 feet.

Thickness	Depth	Description
		Alluvium
5	5	Sand, greenish-tan, fine to medium-grained, very clayey.
6	11	Sand, greenish-tan to brown, medium-grained, pebbly near base, less clayey.
		Marlboro Clay
8	19	Clay, pale red to grayish-red, plastic, interlaminated with grayish-orange silt, micaceous, sparingly lignitic.
4	23	Clay, light olive-gray to olive-gray, silty, interlaminated with micaceous silt, silt yellowish-gray darkening to greenish-gray near base, glauconitic near base.
		Aquia Formation
1	24	Sand, dark greenish-gray, fine to medium-grained, glauconitic, burrowed.

Hole SM-4

Location: Ripley Road, 4 feet southeast of pavement edge, .88 mile northeast of Poor House Rd. (6.5 miles west of La Plata).

Elevation: 148 feet

Description from cuttings on auger flights 0-24 feet; from cores 24-145 feet.

Thickness	Depth	Description
		Upland Gravel
6	6	Clay, pebbly, mottled reddish-brown and pale-gray.
4	10	Sand, grayish-brown, fine to medium-grained, with quartz and chert pebbles.
14	24	Sand, orange-brown, medium to coarse-grained, and quartz-chert gravel.
		Calvert Formation (Fairhaven Member)
4	28	Clay, silty, olive-green, homogeneous.
7	35	Sand, olive-green, very fine to fine-grained, clayey.
7	42	Clay, silty, olive-green, diatomaceous.
8	50	Sand, mottled olive-brown and gray, fine-grained, abundantly burrowed; phosphatic granules common.
		Nanjemoy Formation
41	91	Sand, dark greenish-gray, fine-grained, poorly-sorted, clayey, medium to coarse grains sporadically distributed through sediment; abundantly glauconitic; blebs and irregular patches of olive-gray clay; burrows common; fossiliferous throughout, shells mostly broken, friable, disarticulated, *Venericardia potapacoensis* dominant (cored at 50-51, 60-61, 69-71, 79-81, 89-91 feet).
25	116	Sand, medium to very dark-gray, fine-grained, silty, glauconitic, very clayey; interbedded with dark-gray silty clay, beds .5 in. or less in thickness; burrows rare; sand beds abundantly fossiliferous, *Venericardia potapacoensis* dominant (cored at 99-111, 114-116).
15	131	Sand, dark greenish-gray, very fine to fine-grained, silty, glauconitic with thin laminations of medium-gray clay; few burrows, fossils very rare (cored at 119-121, 124-126, 129-131).
		Marlboro Clay
2	133	Clay, silvery-gray to medium-light-gray, plastic, with thin lenticles of greenish-gray, glauconitic silt; upper contact sharp with 3 in. zone of intensive burrowing, burrows filled with fine-grained glauconitic sand; interbedded silts grade to yellowish-gray at base of interval; small shell fragments confined to silts.
12	145	Clay, grayish-red to pale reddish-brown, plastic, faintly-laminated in part, interbedded with silt, pale-red, micaceous, laminated, silt beds to 2 in. in thickness; sporadic tubular burrows filled with gray-green, fine-grained, glauconitic sand; lignite chips common; pyritic and calcareous concretions rare.

Hole SM-5

Location: Oak Ave., 3 ft. east of pavement edge, 400 feet north of junction Spring Hill Ave. (2 miles southwest of La Plata).

Elevation: 100 feet

Description from cuttings on auger flights 0-14 feet; from cores 14-47 feet.

Thickness	Depth	Description
		Alluvium
7	7	Sand, light-brown, medium to coarse-grained, with quartzose gravel to cobble size.
4	11	Sand, tan, fine-grained, clayey, with small pebbles.
3	14	Sand, tan, medium to coarse-grained, with quartzose gravel.
		Calvert Formation (Fairhaven Member)
4	18	Sand, mottled olive-brown and pale-gray, very fine to fine-grained, silty.
7	25	Clay, olive-gray, silty, diatomaceous, sparsely mottled with filled burrows containing very-fine whitish sand.
8	33	Sand, olive-gray to olive-brown, very fine to fine-grained, silty, burrows abundant; dark phosphatic granules evident.

Thickness	Depth	Description
4	37	Sand, olive-brown, fine-grained, silty, abundantly burrowed; phosphatic granules and rounded quartz granules common.
6	43	Sand, mottled olive-brown and pale-gray, fine-grained, silty, abundantly burrowed; phosphate less evident.
4	47	Sand, mottled olive-brown, pale-gray, and olive-green, fine to medium-grained, abundantly burrowed; few phosphatic granules, shark teeth.
		Nanjemoy Formation
1	48	Sand, dark-gray, medium-grained, glauconitic.

Hole SM-6

Location: Turkey Hill Road, 6 ft. south of pavement edge, .42 mile northwest of junction U.S. 301 at Lyons Corner.

Elevation: 190 feet

Description from cuttings of auger flights 0-29 feet; from cores 29-95 feet.

Thickness	Depth	Description
		Upland Gravel
3	3	Loam, sandy, pale-brown.
9	12	Sand, mottled reddish-brown and pale gray, fine to medium-grained, very clayey.
9	21	Sand, pale-orange, medium to coarse-grained, scattered quartz pebbles near base.
8	29	Sand, pale-orange, medium to coarse-grained, with quartz gravel.
		Calvert Formation (Fairhaven Member)
6	35	Sand, olive-green, very fine to fine-grained, clayey, scattered burrows.
11	46	Silt, olive-green, clayey, homogeneous, scattered *Discinisca* fragments.
5	51	Sand, mottled olive-green and grayish-brown, fine-grained, much burrowed, phosphatic grains common; *Discinisca* fragments.
22	73	Sand, olive-green to olive-brown, very fine to fine-grained, sporadically burrowed, clayey.
5	78	Sand, olive-green, very fine-grained, clayey, sporadic burrows.
4	82	Silt, clayey, mottled olive-brown and gray, diatomaceous, abundantly burrowed, burrows filled with very fine sand.
5	87	No recovery.
8	95	Sand, mottled olive-brown and pale-gray, fine to medium-grained, clayey, abundantly burrowed, phosphatic grains and granules conspicuous.

Hole SM-7

Location: Piney Church Road, 8 feet east of pavement edge, 1.1 miles north of junction Md. 488 (5 miles northeast of La Plata).

Elevation: 190 feet

Description from cuttings of auger flights 0-34 feet; from cores 34-126 feet.

Thickness	Depth	Description
		Upland Gravel
10	10	Sand, pale-orange, medium to coarse-grained, with medium quartz gravel.
5	15	Sand, pale-orange, coarse-grained, with coarse quartz gravel; cobbles to 4 in. diam.
19	34	Sand, coarse to very-coarse-grained, pale grayish-orange, with fine to medium quartz gravel.
		Calvert Formation (Plum Point Marls)
12	46	Clay, pale bluish-gray, silty, homogeneous.
9	55	Sand, mottled bluish-gray and pale gray, very fine to fine-grained, clayey, burrowed, upper contact sharp.
9	64	Silt, clayey, olive-green with patches of bluish-gray.
10	74	Sand, grayish-brown, fine to medium-grained, little interstitial clay; very fossiliferous, shells friable, mostly fragmentary; *Chlamys*, *Astarte*, *Corbula*, *Mercenaria* identified.
21	95	Sand, mottled dark-gray and greenish-gray, uniformly fine-grained, little interstitial clay; lower 11 feet fossiliferous, shells almost wholly fragmentary, very few fragments exceeding .5 in. diam.

		Calvert Formation (Fairhaven Member)
17	112	Sand, olive-green and pale-gray mottled, very fine to fine-grained, clayey, much burrowed; upper contact sharp with burrows filled with medium-grained, clean shelly sand.
8	120	Silt, clayey, olive-green, diatomaceous; sand-filled burrows becoming increasingly prevalent downward in interval.
6	126	Sand, mottled olive-brown and pale-gray, fine to medium-grained, clayey, much burrowed; phosphatic grains evident.

Hole SM-8

Location: Old Stage Coach Road, 4 feet south of pavement edge, 1.60 miles west of U.S. 301 (3 miles southwest of LaPlata).

Elevation. 170 feet

Description from cuttings on auger flights 0-24 feet; from cores 24-86 feet.

Thickness	Depth	Description
		Upland Gravel
5	5	Sand, dark yellowish-orange, medium-grained, clayey.
7	12	Sand, brown, medium-grained, with thin laminae of pale-gray sandy clay.
3	15	Sand, brown, medium to coarse-grained, with medium quartz gravel.
6	21	Sand, yellowish-gray, medium to coarse-grained, little clay, with coarse quartz gravel, cobbles to 3 in. diam.
		Calvert Formation (Fairhaven Member)
8	29	Silt, clayey, yellowish-brown, faintly mottled.
5	34	Silt, clayey, grayish-olive, burrowed, scattered pelecypod molds.
13	47	Sand, mottled olive-gray and light olive-gray, very fine to fine-grained, abundantly burrowed, scattered pelecypod molds, *Discinisca* fragments.
2	49	Sand, very fine to fine-grained, silty, patchy laminations of pale-gray and olive-green silt.
12	61	Sand, mottled light olive-gray and dark olive-green, very fine to fine-grained, silty, *Discinisca* fragments, scattered phosphate granules; intensive burrowing throughout interval.
10	71	Clay, silty, diatomaceous, mottled yellowish-gray and olive-gray, burrowed.
14	85	Sand, mottled olive-gray and pale-gray, fine to medium-grained, coarse quartz grains and small pebbles sporadic, dark phosphatic granules throughout.
		Nanjemoy Formation
1	86	Sand, dark-gray, medium-grained, silty, glauconitic, burrowed.

Hole SM-9

Location: Billingsley Road, 4 feet south of pavement edge, .30 mile east of Md. 228 at Bennsville.

Elevation: 145 feet

Description from cuttings on auger flights 0-20 feet; from cores 20-42 feet.

Thickness	Depth	Description
		Alluvium
6	6	Sand, tan, medium to coarse-grained, very clayey, pebbly.
		Calvert Formation (Fairhaven Member)
13	19	Silt, very clayey, pale-gray to pale-brown with orange mottling.
2	21	Sand, mottled olive-brown and pale-brown, very fine to fine-grained, burrowed.
6	27	Silt, clayey, olive-brown, diatomaceous.
8	35	Sand, mottled olive-brown and pale-gray, fine-grained, clayey, burrowed; *Discinisca* fragments common, scattered friable shell frags.
5	40	Sand, mottled dark-brown and pale-brown, fine to medium-grained, clayey, abundantly burrowed; phosphate grains and small pebbles evident.
		Nanjemoy Formation
2	42	Sand, gray-green irregularly mottled with yellow, fine to medium-grained, glauconitic, clayey.

Hole SM-10

Location: Hamilton Road, 3 feet southeast of pavement edge, .10 mile southwest of junction Acton Lane (1.7 miles northwest of Waldorf).

Elevation: 160 feet

Description from cuttings on auger flights 0-9 feet; from cores 9-64 feet.

Thickness	Depth	Description
		Alluvium
6	6	Sand, reddish-orange, medium to coarse-grained, with coarse quartz gravel.
		Calvert Formation (Fairhaven Member)
7	13	Sand, mottled pale-brown and whitish, very fine to fine-grained.
15	28	Sand, mottled olive-green and pale-gray, very fine to fine-grained, clayey, burrowed.
8	36	Silt, clayey, diatomaceous, olive-brown.
11	47	Sand, mottled olive-green and pale-brown, very fine to fine-grained, clayey, abundantly burrowed.
5	52	Sand, mottled olive-green and pale-brown, fine-grained, clayey, scattered coarse quartz grains and phosphate granules, burrowed.
10	62	Sand, mottled olive-green and pale-gray, fine-grained, clayey, much burrowed.
		Nanjemoy Formation
2	64	Sand, mottled gray-green and dark gray, fine to medium-grained, clayey, burrowed, glauconitic.

Hole SM-11

Location: Mill Hill Road, 3 feet west of pavement edge, 1.0 miles south of Md. 228. (4 miles west of Waldorf.)

Elevation: 220 feet

Description from cuttings on auger flights 0-47 feet; from cores 47-117.

Thickness	Depth	Description
		Upland Gravel
5	5	Loam, sandy, yellowish-gray.
5	10	Sand, moderate reddish-brown, fine to coarse-grained, very clayey, poorly-sorted, with few quartz pebbles.
13	23	Sand, dark reddish-brown, fine to medium-grained, clayey, with quartz gravel.
7	30	Gravel, quartz, yellowish-brown, coarse, with sand, fine to medium-grained, clayey.
5	35	Gravel, quartz, yellowish-brown, very coarse, cobbles to 5 in. diam., with sand, medium-grained, clayey.
12	47	Sand, moderate-brown, fine to coarse-grained, very clayey, very poorly-sorted, with fine quartz gravel.
		Calvert Formation (Plum Point Marls)
4	51	Silt, sandy, dark bluish-gray, somewhat plastic.
2	53	Sand, dark bluish-gray, very fine-grained, silty; scattered burrows.
2	55	Sand, dark bluish-gray, very fine to fine-grained, clayey; abundantly burrowed; shell fragments abundant (*Lucinoma, Chlamys, Turritella*); wood chips common.
2	57	Sand, olive-gray, very fine-grained, clayey.
1	58	Sand, olive-gray, very fine to fine-grained, silty, burrowed; molds and casts of mollusks abundant, *Chione* prominent.
3	61	Sand, olive-gray, very fine to fine-grained, silty; irregular patches of olive-green, more clayey sediment; small shell fragments very abundant (*Chione*, many *Turritella*).
2	63	Sand, olive-brown, fine-grained, abundantly burrowed.
3	66	Sand, mottled olive-brown and pale gray, fine-grained, silty; shell fragments common throughout (*Chione, Lucinoma, Astarte*).
6	72	Sand, olive-brown, fine-grained, silty, burrowed.
		Calvert Formation (Fairhaven Member)
2	74	Sand, olive-green, very fine to fine-grained, clayey, burrowed.
3	77	Clay, silty, olive-green, diatomaceous.

13	90	Sand, mottled olive-brown and olive-green, fine-grained, silty, scattered burrows and pelecypod molds.
7	97	Silt, sandy, light olive-gray, diatomaceous, burrowed.
4	101	Sand, mottled olive-brown and olive-gray, very fine-grained, clayey, burrowed.
15	116	Sand, mottled olive-brown and pale-gray, fine to medium-grained, clayey, abundantly burrowed; quartz, phosphatic granules and small pebbles conspicuous throughout; *Discinisca* abundant; scattered impressions of mollusks (*Chlamys, Turritella*).
		Nanjemoy Formation
2	118	Sand, dark gray-green, fine to medium-grained, clayey, glauconitic, burrowed.

Hole SM-12

Location: Billingsley Road, 3 feet south of pavement edge, 2.25 miles west of Md. 228 at Bennsville.

Elevation: 57 feet

Description from cuttings on auger flights 0-14 feet; from cores 14-42 feet.

Thickness	Depth	Description
		Alluvium
5	5	Loam, mottled gray and brownish, clayey, with quartz pebbles.
5	10	Quartz gravel, grayish-tan, with sand, fine to medium-grained.
		Marlboro Clay
4	14	Clay, silty, plastic, grayish-red.
26	40	Clay, plastic, silty in part, grayish-red, pale brown to brownish-gray (brown-gray predominates in lower half of interval), irregularly interlaminated with silt, pale red to grayish-orange, laminated in part, scattered small pelecypod valves, buroows, finely-divided lignite.
		Aquia Formation
2	42	Sand, olive-gray to grayish-olive, fine to medium-grained, clayey, glauconitic; thin laminae of medium-gray, silty, plastic clay; scattered friable pelecypod valves; small pyritic concretions.

Hole SM-13

Location: Md. 381, 30 feet northwest of pavement edge, northeast bank of Swanson Creek.

Elevation: 20 feet

Description from cuttings on auger flights 0-24 feet; from cores 24-49 feet.

Thickness	Depth	Description
		Alluvium
5	5	Sand, greenish-gray, fine to medium-grained, clayey; clay clasts near base.
4	9	Sand, greenish-gray, very fine to fine-grained, silty.
3	12	Sand, medium-gray, medium-grained.
9	21	Sand, medium-gray, medium to coarse-grained, with quartz gravel.
		Calvert Formation (Fairhaven Member)
3	24	Sand, olive-green, very fine-grained, silty.
7	31	Silt, clayey, olive-gray, diatomaceous.
4	35	Sand, mottled olive-brown and pale-gray, fine-grained, clayey, phosphatic grains and granules apparent.
8	43	Sand, interlaminated olive-brown and pale-gray, bedding well-defined, fine-grained, phosphate less abundant.
4	47	Sand, pale-gray, fine to medium-grained, phosphatic, closely interbedded with clay, dark gray; clay-sand contacts sharp.
2	49	Clay, silty, olive-gray; abuandantly burrowed, burrows filled with pale-gray, fine to medium-grained, clean sand.

Hole SM-14

Location: Md. 382, 4 feet southeast of pavement edge, 300 feet northeast of Swanson Creek.

Elevation: 120 feet

Description from cuttings on auger flights 0-20 feet; from cores 20-34 feet.

Thickness	Depth	Description
		Alluvium
11	11	Sand, pale-brown, fine to medium-grained, with quartz gravel.
8	19	Sand, dark gray-green, fine to medium-grained, very clayey, with scattered quartz pebbles.
		Calvert Formation (Plum Point Marls)
4	23	Clay, silty, pale olive-gray, scattered friable pelecypods (*Isocardia* prominent).
6	29	Clay, sandy, olive-green, few shell fragments, lignite chips.
3	32	Sand, olive-gray and pale-gray mottled, fine-grained, grading to medium-grained at base of interval, burrowed.
2	34	Sand, olive-brown, fine to medium-grained, clean; upper contact sharp; abundantly fossiliferous, shells friable, mostly fragmentary (*Corbula elevata, Eucrassitella melina, Chlamys madisonius, Mercenaria campechiensis, Ecphora* sp., *Turritella* sp.).
		Sandstone at 34 feet; no further penetration possible.

Hole SM-15

Location: Naylor-North Keys Road, 5 feet south of pavement edge, .25 mile east of Rock Branch Road at North Keys (5 miles east of Brandywine).

Elevation: 130 feet

Description from cuttings on auger flights 0-10 feet; from cores 10-63 feet.

Thickness	Depth	Description
		Calvert Formation (Plum Point Marls)
10	10	Sand, mottled grayish-orange and light-brown, fine-grained, clayey; limonitic lumps and crusts scattered through interval.
6	16	Sand, mottled dark yellowish-brown and dark-brown, fine-grained, clayey; small ovoid limonite concretions common.
4	20	Sand, mottled dark greenish-gray and olive-gray, fine-grained, clayey, much burrowed, burrows filled with clean, whitish sand; contact with yellow-brown weathered sediment above sharp.
		Calvert Formation (Fairhaven Member)
2	22	Sand, olive-green, very fine to fine-grained, very clayey; laced with anastomosing burrows filled with fine brownish sand and shell fragments.
9	31	Sand, olive-green, very fine to fine-grained, clayey; several *Discinisca* and lignite fragments.
1	32	Sand, olive-brown, fine-grained, abundantly burrowed.
9	41	Silt, clayey, olive-green, diatomaceous, relatively homogeneous; few *Discinisca*.
8	49	Sand, mottled olive-brown and olive-green, fine-grained; medium to coarse grains, granules, and small pebbles scattered in sediment; *Discinisca* common; phosphatic granules and small pebbles common.
6	55	Sand, mottled olive-green and brownish, fine-grained, silty; molds and casts of mollusks throughout (*Chlamys, Ecphora*); scattered bone fragments; burrows abundant.
5	60	Sand, mottled olive-green and brownish, fine-grained, silty.
3	63	Sand, mottled olive-green and brownish, fine-grained, silty; interval with three thin fossil bands, shell material absent, of small pelecypods (*Chione* sp., *Corbula* sp. determinate).

Hole SM-16

Location: Mt. Calvert Road, 8 feet south of pavement edge, 1.60 miles east of Md. 392 (3 miles southeast of Upper Marlboro).

Elevation: 90 feet

Description from cuttings on auger flights 0-20 feet; from cores 20-45 feet.

Thickness	Depth	Description
		Nanjemoy Formation
5	5	Sand, mottled gray and brownish, fine to medium-grained, very clayey, glauconitic.
5	10	Sand, pale grayish-green, fine to medium-grained, very clayey, glauconitic.
10	20	Sand, dark gray-green, fine to medium-grained, clayey, glauconitic.
5	25	Clay, silty, medium-gray, abundantly burrowed, burrows filled with sand, gray-green, medium to coarse-grained, glauconitic, poorly-sorted; scattered sub-horizontal lenticles of sand define bedding.
3	28	Sand, pale gray-green, loose, medium to coarse-grained; with thin laminae of gray clay; thin (2 in.) bed of bright-green, glauconitic silty clay at 27 feet.
3	31	Clay, sandy, medium-gray; moderately burrowed, burrows filled with fine to medium-grained glauconitic sand; sand fines downward, glauconite content decreases.
3	34	Clay, sandy, medium-gray; few burrows; few pale-gray silt partings.
5	39	Clay, silty, medium to dark-gray, plastic; scattered small pyritic concretions; interval becomes sandy toward base.
6	45	Clay, sandy, medium-gray; burrows increase in abundance downward, filled with poorly-sorted glauconitic sand, medium to coarse.

Hole SM-17

Location: Bull Road, 5 ft. southwest of pavement edge, .55 mile southeast of junction Md. 243, St. Marys Co.

Elevation: 125 feet

Description from cuttings on auger flights 0-48 feet; from cores 48-96 feet.

Thickness	Depth	Description
		Upland Gravel
7	7	Silt, tan, clayey.
1	8	Clay, mottled dark red and pale gray, silty.
9	17	Sand, orange-tan, fine-grained, muddy, some medium grains mixed.
3	20	Sand, reddish-brown, fine-grained, silty; pebbly, pebbles fine to medium, vein quartz and chert.
10	30	Gravel, reddish-brown, fine to medium-grained, a few larger pebbles to 2 in. diameter; sand matrix fine to medium-grained.
13	43	Sand, dark reddish-brown, medium to coarse-grained; pebbly, mostly fine to medium pebbles but a few to 2 in. diameter.
		St. Marys Formation
5	48	Sand, dark-gray, fine-grained, clean, interbedded with subordinate silt-clay of similar color.
10	58	Silt-clay, dark-gray, variably lignitic (fragments to 10 mm), variably plastic, with irregular lenses, pods, and mottles of medium to pale-gray silt, laminated in part; many burrows filled with fine clean sand.
30	88	Sand, mottled dark and pale-gray, fine to medium-grained, variably muddy, burrowed; barren.
8	96	Sand, similar to above but coarser, mostly medium-grained; abundantly shelly, shells fragmentary and rotten.

Hole SM-18

Location: Md. 471 (Indian Bridge Rd.), 10 ft. southwest of pavement edge, .35 mile southeast of junction Church Rd., St. Marys Co.

Elevation: 134 feet

Description from cuttings on auger flights 0-73 ft.; from cores 73-98 ft.

Thickness	Depth	Description
		Upland Gravel
5	5	Silt-clay, orange brown.
5	10	Sand, reddish-brown, fine-grained, muddy; medium grains admixed.
10	20	Sand, mottled reddish-brown and pale-gray, fine to medium-grained, very muddy, sticky.
10	30	Sand, reddish-brown, medium to coarse-grained, few small pebbles, sand much cleaner.
18	48	Sand and fine gravel, light-tan, sand medium to coarse-grained, coarses downward in interval.
10	58	Sand, bright-orange, uniformly medium-grained, clean.
14	72	Sand, pale-orange to tan, medium to coarse-grained, clean, few small pebbles.
		St. Marys Formation
3	75	Sand, mottled pale and dark-gray, very fine-grained, muddy, few shell fragments in thin band.
6	81	Clay, dark-gray, plastic; abundantly burrowed, burrows filled with clean fine olive-gray sand; scattered shells and a 5 in. band of concentrated *Turritella.*
6	87	Sand, dark-gray, very fine-grained, and silt, very muddy, burrowed as above; pockets of *Turritella* fragments throughout.
11	98	Clay, dark-gray, plastic, with pods and small irregular lenses of pale-gray silt, laminated in part, lignitic.

Hole SM-19

Location: Beauvue Rd., 5 ft. north of pavement edge, 1.4 miles east of junction Clark Rd., St. Marys Co.

Elevation: 50 feet

Description from cuttings on auger flights 0-23 ft., from cores 23-78 ft.

Thickness	Depth	Description
		Lowland Deposits
7	7	Sand, brown, medium-grained, very muddy.
3	10	Sand, pale-brown, medium-grained, clean.
5	15	Sand, pale-brown, coarse-grained, and gravel, coarse.
6	21	Sand, medium-gray, pebbly, very muddy, sticky, interbedded with bluish-gray clay.
		St. Marys Formation
7	28	Clay, dark-gray, plastic, with lenses and pods of gray very-fine sand or silt, laminated in part.
5	33	Sand, dark-gray, very fine-grained, mottled with pale-gray cleaner sand; interval contains a 5 in. band of concentrated shells, mostly gastropods, including: *Lunatia heros*, *Nassarius peralta*, *Mitrella communis*, *Hemipleurotoma communis*, *Turritella plebia*, *Turritella variabilis*, *Dosinia acetabulum*, *Saxolucina anodonta*, *Anadara idonea*
10	43	Sand, dark-gray, very fine-grained, and silt, very muddy.
4	47	Sand as above, but moderately shelly.
22	69	Clay, dark-gray, plastic, lignitic, with lenses and mottles of gray silt, laminated in part; silt contains clay chips in places; abundantly burrowed in part; shell fragments rare.
		Choptank Formation
9	78	Sand, bluish-gray, fine to medium-grained, variably clayey; abundantly fossiliferous, mostly fragmentary large pelecypod shells including: (Zone 19) *Anadara staminea*, *Eucrassatella marylandica*

Hole SM-20

Location: Md. 5 (abandoned segment), at pavement edge, .5 mile southeast of St. Inigoes, St. Marys County.

Elevation: 15 feet

Description from cuttings on auger flights 0-19 ft.; from cores 19-80 ft.

Thickness	Depth	Description
		Alluvium
3	3	Silt-clay, medium-brown, pebbly, very sticky.
2	5	Silt-clay, medium-brown, sticky.
2	7	Sand, dark-gray, fine-grained, very muddy, and gravel.
5	12	Clay, tan, pebbly.
3	15	Gravel (no feed).
		St. Marys Formation
14	29	Sand, dark gray-green, very fine to fine-grained, clean.
3	32	Sand, similar to above, but moderately glauconitic and fossiliferous (lower 12 in. abundantly shelly, mostly gastropods including: *Turritella plebia* *Turritella variabilis* (typical form) *Dentalium attenuatum* *Busycon tuberculatum* *Nassarius peralta* *Lunatia heros* *Chione alveata* *Semele carinata*
11	43	Sand, mottled dark-gray and pale-gray, very fine to fine-grained, variably muddy, interbedded with much subordinate silt-clay; sparsely fossiliferous.
6	49	Clay, dark-gray, plastic.
2	51	Sand, dark-green, fine-grained, clean, moderately glauconitic.
8	59	Clay, dark-gray, plastic, sparsely fossiliferous.
10	69	Sand, mottled dark-green and pale-gray, fine-grained, muddy; moderately fossiliferous (shells mostly broken, rotten), many *Turritella.*
9	78	Sand, similar to above but coarser and cleaner.
2	80	Sand, as above but very clean and sugary.

Hole SM-21

Location: Md. 5, 8 ft. east of pavement edge, 2.1 miles south junction Md. 235, St. Marys Co.

Elevation: 18 feet

Description from cuttings on auger flights 0-13 feet; from cores 13-98 feet.

Thickness	Depth	Description
		Lowland Deposits
9	9	Sand, pale-gray, medium to coarse-grained, clean.
14	23	Clay, dark bluish-gray, plastic, sticky.
17	40	Sand, medium-gray, medium-grained, clean.
8	48	Sand, coarse-grained, clean, slightly pebbly.
		St. Marys Formation
30	78	Sand, dark gray-green, uniformly fine-grained, variably muddy; sparsely fossiliferous.
5	83	Sand as above but finer grained and very muddy; abundantly fossiliferous, shell mostly fragmentary, include: *Corbula inaequalis* *Anadara idonea*
5	88	Sand as above but barren.
5	93	Clay, dark-gray, silty, barren.
5	98	Sand, dark-gray, very fine to fine-grained, muddy; abundantly fossiliferous, pelecypods include: *Astarte perplana.*

Hole SM-22

Location: Evergreen Park Rd., 5 ft. north of pavement edge, .35 mile east of junction Md. 235, St. Marys Co.

Elevation: 75 feet

Description from cuttings on auger flights 0-28 ft.; from cores 28-95 ft.

Thickness	Depth	Description
		Upland Gravel
6	6	Clay, mottled brown and pale-gray, sandy.
14	20	Sand, tan, medium to coarse-grained, and fine gravel.
		St. Marys Formation
11	31	Sand, medium-gray, uniformly fine-grained, clean, barren.
15	46	Clay, dark-gray, plastic, interbedded with pods and lenses of very fine sand and silt, laminated in part; many well-defined tubular burrows; interval barren.
24	70	Sand, dark-gray to dark gray-green, fine-grained, variably muddy, interbedded with much subordinate sticky clay; most of interval abundantly fossiliferous, mostly broken shells; species include: *Dosinia acetabulum*, *Mactra clathrodon*, *Corbula inaequalis*, *Hemipleurotoma communis*, *Bulliopsis integra*, *Epitonium sayanum*, *Actaeon shilohensis*, *Lunatia heros*, *Turritella plebia*, *Turritella variabilis* (typical form), *Cymatosyrinx limatula*, *Terebra simplex*, *Coralliophila cumberlandiana*, *Nassarius peralta*, *Dentalium attenuatum*
10	80	Clay, dark-gray, plastic, silty, sparsely fossiliferous.
2	82	Sand, mottled light and dark-gray, very fine grained, silty, muddy.
10	92	Clay as 70-80 ft.
		Choptank Formation
3	95	Sand, olive-brown, fine-grained, clean; abundantly fossiliferous, many large *Chlamys* and *Isognomon* (Zone 19).

Hole SM-23

Location: Shangri-la Drive, 11 ft. southeast of pavement edge, .25 mile southwest of junction Md. 246, St. Marys Co. (Lexington Park).

Elevation: 100 feet

Description from cuttings on auger flights 0-38 ft.; from cores 38-103 ft.

Thickness	Depth	Description
		Upland Gravel
7	7	Clay, sandy, mottled pale-gray and brown.
3	10	Sand, tan, medium to coarse-grained, muddy, and medium gravel.
9	19	Sand, pale-yellow, medium-grained, loose and clean.
24	43	Sand, pale-red, medium-grained, very muddy.
24	68	Same but pale-gray in color.
		St. Marys Formation
30	98	Sand, fine-grained, dark-gray, muddy, barren.
5	103	Clay, dark-green, plastic, barren.

Hole SM-24

Location: Southeast corner of junction Md. 4 and Md. 497, 25 feet from pavement edge, Calvert Co.

Elevation: 128 feet

Description from cuttings on auger flights 0-83 ft.; from cores 83-99 ft.

Thickness	Depth	Description
		Upland Gravel
15	15	Sand, orange-brown to reddish-brown, fine to medium-grained, very muddy, mud content decreases downward in the interval.
15	30	Sand, pale-orange, medium to coarse-grained, loose and clean.
25	55	Sand, pale-yellow to whitish, coarse-grained, loose and clean.
10	65	Sand, mottled reddish and yellow, medium to coarse-grained, hard, moderately muddy.
13	78	Sand, pale-orange, medium to coarse-grained, clean.
		St. Marys Formation
5	83	Sand, mottled orange and gray, very fine-grained, muddy.
16	99	Sand, dark-gray to dark gray-green, very fine to fine-grained, muddy with mud content increasing downward through interval; barren.

Hole SM-25

Location: Md. 760, 5 ft. west of pavement edge, 1.3 miles south of Cherry Hill, Calvert Co.

Elevation: 50 feet

Description from cuttings on auger flights 0-13 ft.; from cores 13-79 ft.

Thickness	Depth	Description
		St. Marys Formation
20	20	Sand, mottled pale-orange and pale-gray, fine-grained, clean at top but mud content increases downward; color becomes progressively grayer and darker downward; interval barren.
1	21	Sand, medium-gray, fine-grained, clean and loose; abundantly shelly, mostly gastropods with *Turritella* predominant.
22	43	Clay, dark-gray, hard; pods and thin lenses of laminated tan silt; interval has 5 thin bands of packed *Turritella*, mostly broken.
4	47	Sand, mottled olive-green and pale gray-green, fine-grained, variably muddy; barren.
4	51	Clay, dark-gray, sandy; barren.
2	53	Sand, medium-gray, fine to medium-grained, loose and clean; upper 1 ft. crowded with small shell fragments.
1	54	Silty clay, dark-gray, barren.
		Choptank Formation
25	79	Sand, fine-grained, pale-gray to medium-gray, variably muddy; pods of cemented sand; fossiliferous, many large shells including *Isognomon maxillata*, *Lyropecten madisonius*, *Saxolucina anodonta*, *Mercenaria* sp. (Zone 19).

Hole SM-26

Location: Md. 4, 15 ft. east of pavement edge, 100 ft. north of junction Dowell Rd., Calvert Co.

Elevation: 60 feet

Description from cuttings on auger flights 0-33 ft.; from cores 33-76 ft.

Thickness	Depth	Description
		Lowland Deposits
5	5	Sand, reddish-brown, medium to coarse-grained, clean.
		St. Marys County
20	25	Sand, pale-orange and pale-gray mottled, fine-grained, very muddy.
8	33	Sand, medium to dark-gray, very fine-grained, very muddy; barren.
13	46	Clay, dark-gray, plastic; few pods of laminated tan silt.
2	48	Sand, dark gray-green, very fine-grained, very muddy; packed with small shell fragments.

		Choptank Formation
28	76	Sand, pale to medium-gray, fine to medium-grained, mostly clean; fossiliferous, many large shells including *Isognomon maxillata, Balanus concavus, Lyropecten madisonius.* (Zone 19)

Hole SM-27

Location: Md. 760, 6 ft. north of pavement edge, 1.6 miles southwest of SM-25, Calvert Co.

Elevation: 10 feet

Description from cuttings on auger flights 0-28 ft.; from cores 28-49 ft.

Thickness	Depth	Description
		Lowland Deposits
23	23	Sand, mottled brownish and pale-gray, fine-grained, very muddy; becomes progressively more sandy downward in interval, at base very sandy and sparsely pebbly.
		Choptank Formation
26	49	Sand, pale grayish-green, medium-grained, variably clayey; many large shells; cemented to quartzite in part. (Zone 19)

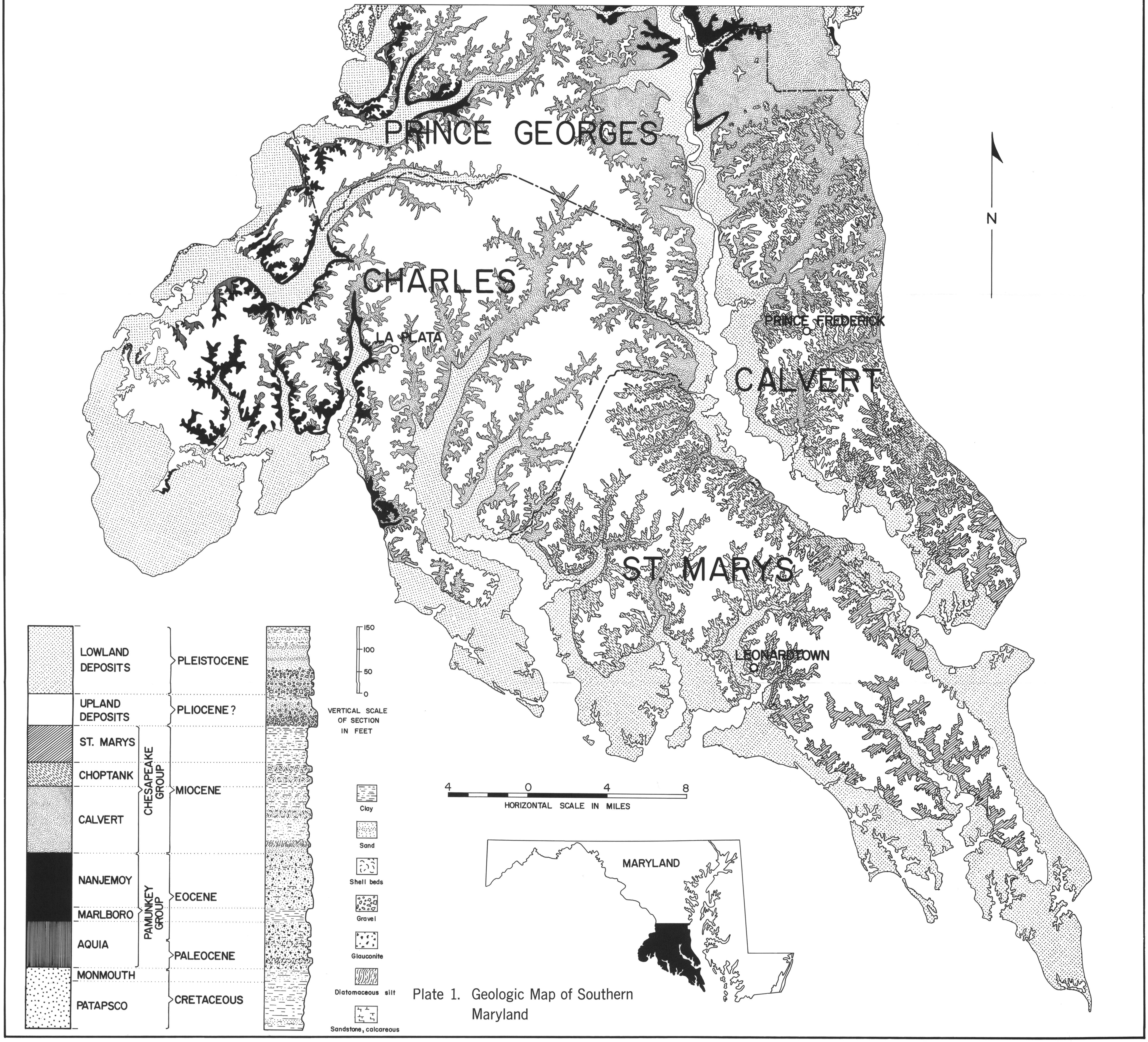

Plate 1. Geologic Map of Southern Maryland

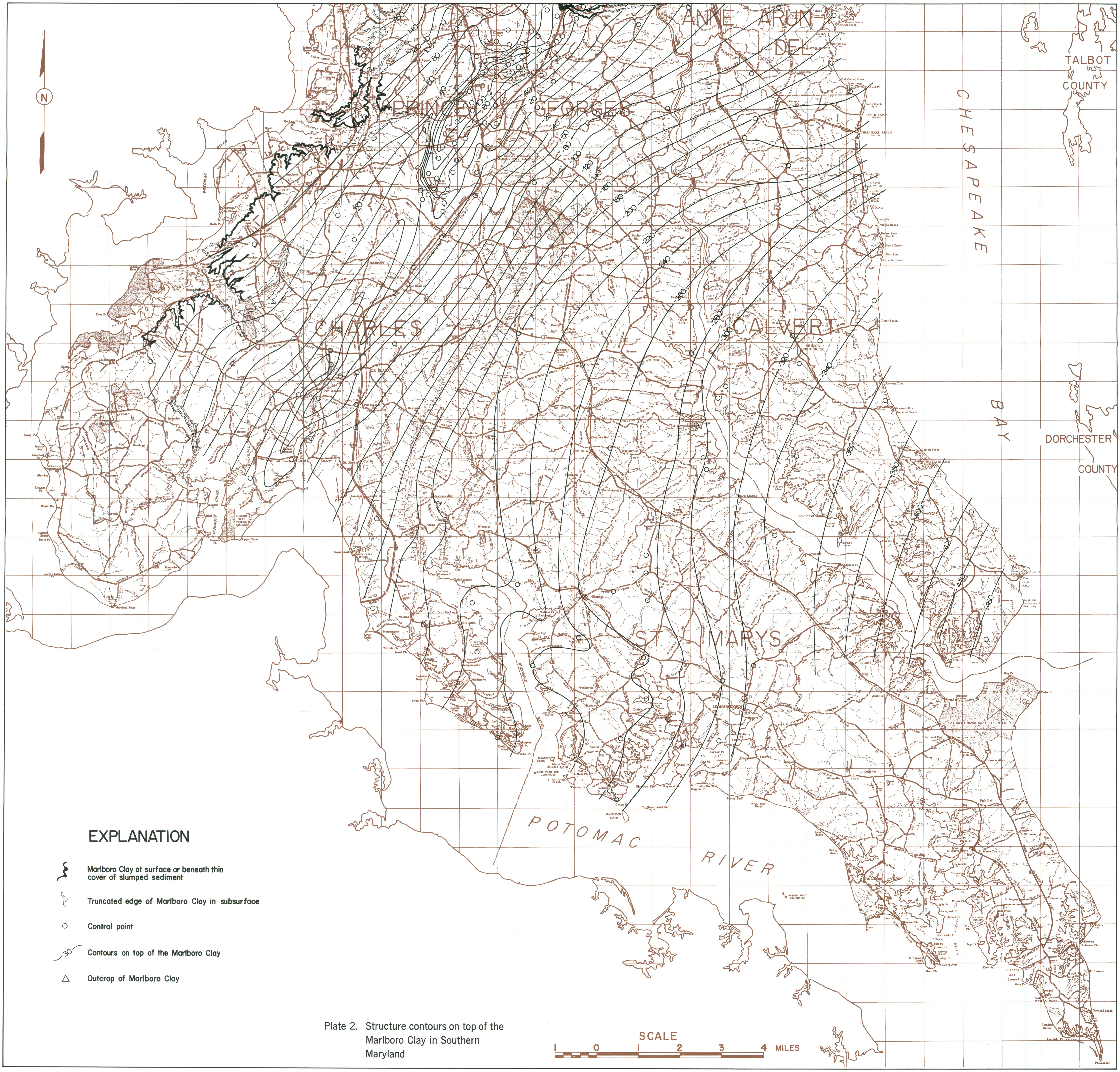

Plate 2. Structure contours on top of the Marlboro Clay in Southern Maryland

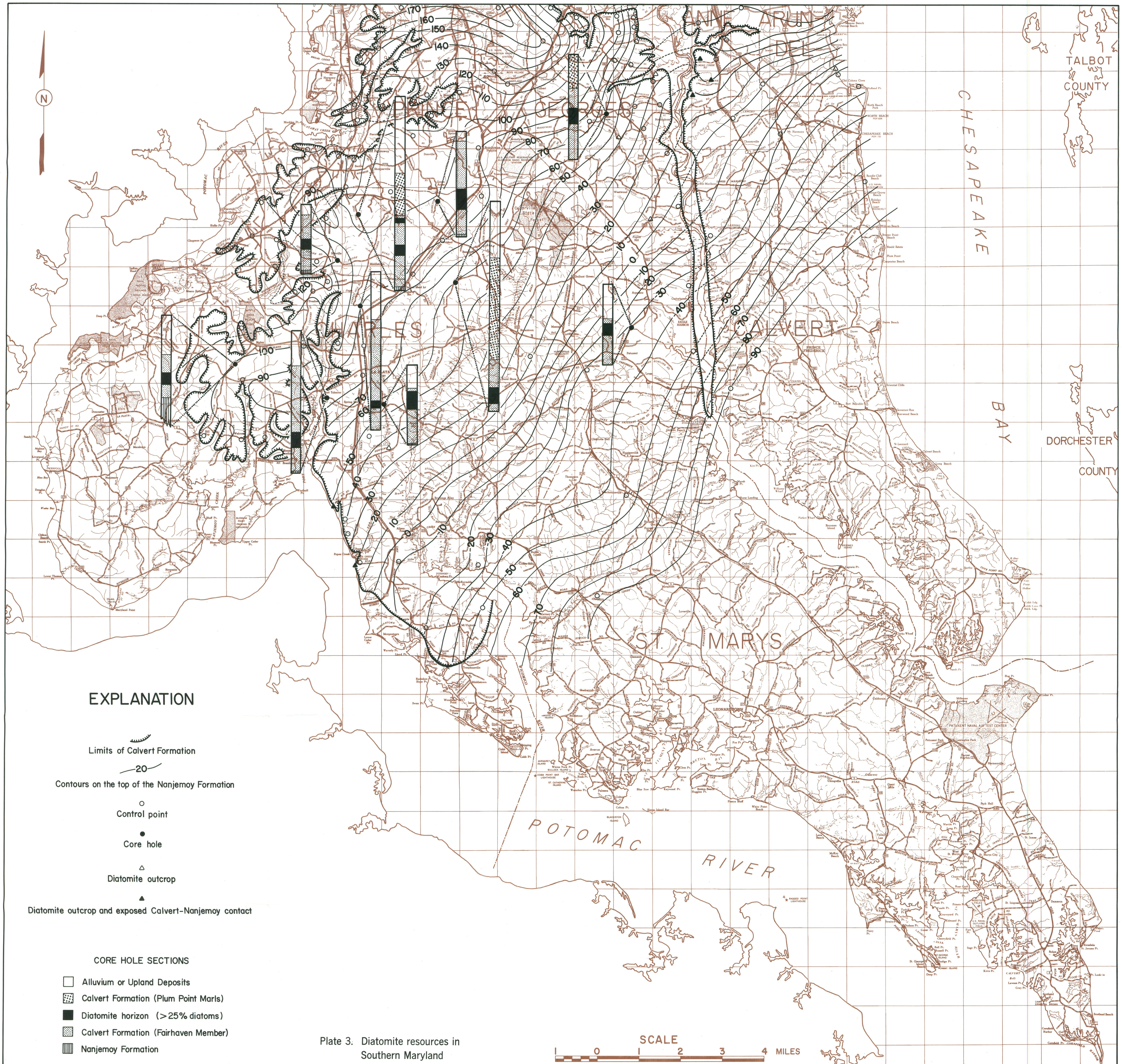

Plate 3. Diatomite resources in Southern Maryland

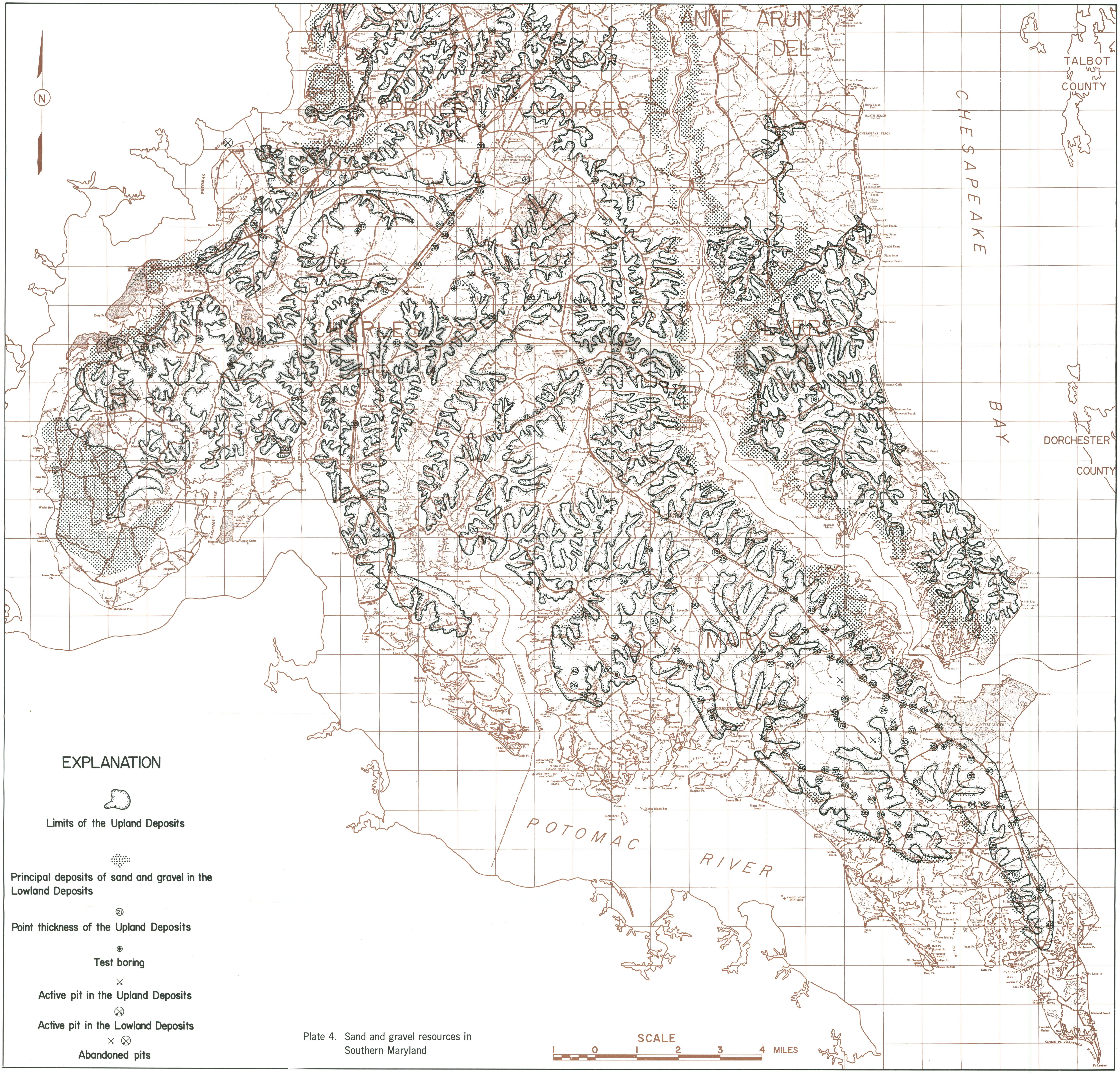

Plate 4. Sand and gravel resources in Southern Maryland

MARYLAND GEOLOGICAL SURVEY
Latrobe Hall
The Johns Hopkins University
Baltimore, Maryland 21218

Reports of Investigation:

1. Chemical quality of water and trace elements in the Patuxent River Basin, by S. G. Heidel and W. W. Frenier, 1965, 52 p. --- $1.00
2. Pleistocene stratigraphy of the Salisbury area, Maryland and its relationship to the lower Eastern Shore: a subsurface approach, by H. J Hansen, 1966, 56 p. ---------------------------------- 2.25
3. Water resources of the Salisbury area, Maryland, by D. H. Boggess, and S. G. Heidel, 1968, 69 p. ---------------------- 3.00
4. Expandable clay in the St. Marys Formation of Southern Maryland, by M. M. Knechtel, H. P. Hamlin, and J. W. Hosterman, 1968, 19 p. -- 1.00
5. Chemical quality reconnaissance of water of Maryland streams, by J. D. Thomas, 1966, 61 p. ------------------------------ 2.00
6. Revision of stratigraphic nomenclature—Glenarm Series of the Appalachian Piedmont, by D. L. Southwick and G. W. Fisher, 1968, 19 p. -- 1.50
7. Geophysical log cross-section network of the Cretaceous sediments of Southern Maryland, by H. J. Hansen, 1968, 56 p. ---- 4.00
8. Piedmont and Coastal Plain geology along the Susquehanna Aqueduct: Baltimore to Aberdeen, Maryland, by E. T. Cleaves, 1968, 45 p. -- 2.00
9. Chemical and physical character of municipal water supplies in Maryland, by J. D. Thomas and S. G. Heidel, 1969, 52 p. ------ 1.00
10. Ground-water occurrence in the Maryland Piedmont, by L. J. Nutter and E. G. Otton, 1969, 56 p. ------------------------- 2.50
11. Petrology and origin of Potomac and Magothy (Cretaceous) sediments, Middle Atlantic Coastal Plain, by J. D. Glaser, 1969, 101 p. -- 3.50
12. Paleoecology of the Choptank Formation (Miocene) of Maryland and Virginia, by R. E. Gernant, 1970, 90 p. ------------------ 4.50
13. Extent of brackish water in the tidal rivers of Maryland, by W. E. Webb and S. G. Heidel, 1970, 46 p. ------------------- 1.50
14. Geologic and hydrologic factors bearing on subsurface storage of liquid wastes in Maryland, by E. G. Otton, 1970, 39 p. ------ 2.75
15. Geology and mineral resources of Southern Maryland, by J. D. Glaser, 1971, 84 p. ------------------------------------- 4.75

Maryland Residents Add 4% Sales Tax