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Geologic Map and Cross Sections of the Leonardtown 30 X 60-Minute Quadrangle, Maryland and Virginia

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GEOLOGIC MAP AND CROSS SECTIONS OF THE LEONARDTOWN 30 X 60 MINUTE QUADRANGLE, MARYLAND AND VIRGINIA

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INTRODUCTION

The Leonardtown 30x60-minute quadrangle includes the southeastern part of the Washington, D.C. metropolitan area, and is adjacent to the concurrently mapped Washington West (Lyttle and others, in press) and Fredericksburg (Mixon and others, in press) 30x60-minute quadrangles. Much of the geology of the Leonardtown quadrangle has been published at different scales with stratigraphic nomenclature suitable for tidewater Virginia, southern Maryland peninsulas, or the eastern shore of Chesapeake Bay. The present map draws together all the published and new information at a single regional scale and uses USGS stratigraphic nomenclature. For the first time, relationships among all the various units are described in detail (table 1). New information is presented for Calvert County, Maryland, and approximate locations are shown for contacts between pre-Quaternary units beneath Quaternary deposits in the waterways (discussed by Colman and Halka, 1989).

The Leonardtown quadrangle presents information useful to land use planners and those seeking large volumes of ground water for drinking and industrial and agricultural uses, and industrial mineral deposits of gravel, sand, and clay (tables 2 and 3). Because of increasing population in the area, the need for new sources of ground water, construction materials, and construction sites for various purposes is critically important. In addition, sources and characteristics of Quaternary deposits in the Potomac River estuary and Chesapeake Bay may be inferred from the Leonardtown geologic map (compare Nichols and others' (1991) report on sediment facies in the James River estuary). Information on geologic units both at the surface and in the subsurface, onshore and offshore, is required as a basis for planning optimal sequential land usage.

This map also gives a synoptic view of the evolution of a complex marine-nonmarine depositional system that cannot be fully appreciated on the ground because of low relief and generally poor exposures. The map is not only a source of geologic information of interest to other geologists, land use planners, and other users of geoscience information, but it also records the depositional and erosional effects of rising a falling of sea level. The sea level oscillations were induced by interaction between tectonic uplifting of land, particularly in the western part of the Leonardtown quadrangle, and several severe changes in climate during the last 40 million years.

MAP CONSTRUCTION

Although practical application of the geologic information contained in the map and cross sections was an important factor in selection of the study area, the philosophy underlying the construction of the map was based mainly on geologic factors and the distribution of published and new data.

This map is a compilation of data from field mapping done by the authors over the period 1976-1988 and previously published maps and reports. The formations were delineated on the basis of contacts seen in roadcuts and stream banks supplemented by drill hole information. Cores acquired during the various mapping projects provide nearly continuous subsurface lithostratigraphic and biostratigraphic control for well cuttings and geophysical logs. Cores also provide important control points for seismic profiles, both overland and in the larger waterways. Modern waterway channel axes were taken from preliminary bathymetry provided by the National Ocean Servercy. Quaternary channel axes were based on Colman and Halka (1989).

Relict geomorphic surfaces and scarps were helpful in locating some formational and facies boundaries. The surficial geology of Delmarva is slightly generalized from published maps by Owens and Denny (1984, 1986). The Virginia part of the mapping is mainly the work of Newell. It is a more detailed version of part of his contribution to the 1:250,000-scale map of Virginia (Mixon and others, 1989). The geology of Maryland west of Chesapeake Bay is based on modified versions of Charles and St. Marys County maps (McCartan, 1989a, 1989b) and new work by McCartan and Owens in Calvert County.

The new contributions of these maps and cross sections are the detailed delineation of late Cenozoic surficial units, general depiction of bedrock units beneath the major waterways, and documentation of apparent differential warping which may be associated with basement faulting throughout the area. In addition, correlation of provincial units, ground-water chemistry in Maryland, and some other characteristics of the stratigraphic units are presented in tables (tables 1-3).

Mapping paradigms.--Modern geologic mapping of the Leonardtown quadrangle is based on understanding the dynamics of transgressive-regressive sequences, surficial deposits, and the mineralogy and geochemistry of weathering profiles. Provenance of the deposits is also a key to interpreting the tectonic and erosional history of the preserved deposits. Successive marine transgressions and regressions are recorded in the Cretaceous and Cenozoic deposits, but stratigraphic sections vary from one part of the area to another. This pattern is characteristic of the entire Salisbury embayment, in which the Leonardtown map area is located, as well as other basins that compose the U.S. Atlantic margin (Prowell, 1988). Different stratigraphic sections reflect lateral changes in depositional lithofacies as well as interaction between eustatic sea level changes and differential uplift of basement blocks. Climatically controlled weathering, erosion, and colluviation overprint the results of other processes.

Time.--An essential part of this geologic map is the element of time. Without it, the map would be a texture and mineral map, with little sense of how the units are related, and little predictive capability. The Leonardtown map has a strong biostratigraphic component that permits us to decipher the geochronologic history. The Coastal Plain units portrayed in these maps and cross sections record about 55.5 of the last 110 m.y. of earth history; the other half of the record is represented by unconformities, including the effects of weathering. The longest hiatus is a period of about 16 m.y. during the Eocene and Oligocene; other major gaps occur in the Upper Cretaceous, the lower Paleocene, and the lower Miocene.

Periods of sediment accumulation were accompanied by uplift of the source area and downwarping of the depositional basin. Gaps in the sedimentary section are the result of periods of tectonic quiescence in the source area, and uplift and erosion, either subaerially or by geostrophic currents, of the inner edge of the depositional basin.

Depositional environments.--Five fluvial to marine depositional environments are represented by deposits in the map area: river, estuary, marginal marine (beach and bay), normal salinity shelf, and submarine delta. Some surficial deposits of subaerial processes such as colluviation are large enough to show at this scale.

The interbedded sand and clay of the Potomac Group (Lower Cretaceous; Brenner, 1963; Doyle and Hickey, 1976) reflects its origin in a fluvial system. Beds of foraminiferal, glauconitic, sand that are common in the Potomac Group indicate that the fluvial system extended seaward to form a shifting submarine delta (based on data in Hansen, 1969; Reinhardt and others, 1980; Trapp and others, 1984; and unpublished observations by McCartan).

The Pamunkey Group (lower Tertiary) and most of the Chesapeake Group (upper Tertiary) are composed of normal marine shelf deposits, generally fossiliferous, locally or pervasively glauconitic, fine- to medium-grained quartz sand and silt, clayey in places, and typically massive, due to bioturbation. Hiatuses are marked in many places by phosphatic lag sands and gravels that show up as sharp spikes on natural gamma radiation well logs. Marginal marine and fluvial facies are almost totally absent in the map area, presumably because they were uplifted and eroded or were deposited farther west.

Most units in the Pamunkey Group contain a higher proportion of quartz sand, fossils, and glauconite than do units in the Chesapeake Group that were deposited on the shelf. No marginal marine (beach sand or intertidal sand and mud) or nonmarine deposits in the Leonardtown quadrangle have been correlated with units in the Pamunkey Group.

The St. Marys and Eastover Formations in the Chesapeake Group contain marginal marine deposits as well as normal marine shelf deposits that are only locally glauconitic and fossiliferous. In Calvert County, the St. Marys is capped by as much as 50 ft (15 m) of beach sand and fine gravel that grades westward and upward into prograded stream gravel. The Yorktown Formation, which is the uppermost of the Chesapeake Group units, includes normal marine, estuarine, and fluvial deposits (fig. 1). The fluvial component forms a larger proportion of the unit northward and southwestward, toward the inner margin of the Coastal Plains in Maryland and Virginia.

PREVIOUS WORK

Maps and reports by Shattuck (1903, 1907), Dryden and Overbeck (1948), Hack (1955), Gibson (1971) and Gibson and others (1980), Hansen (1968, 1969, 1974, 1978) and Hansen and Wilson (1984), Glaser (1971, 1978, 1984), Owens and Denny (1979, 1984, and 1986), Ward (1984a, 1984b, 1985), and Ward and Blackwelder 1980), have been helpful in guiding the new mapping. The authors' specific contributions are acknowledged throughout the text.

GEOLOGIC OVERVIEW

The Leonardtown 30 x 60-minute quadrangle is wholly within the Atlantic Coastal Plain physiographic province. The Fall Zone, where Paleozoic rocks of the Piedmont are overlapped by what remains of Mesozoic and Tertiary Coastal Plain deposits, is about 25 mi (40 km) west of the map area. The Leonardtown quadrangle includes the confluence of the Potomac River estuary and Chesapeake Bay, and parts of Calvert, Charles, Dorchester, Somerset, and St. Marys Counties in southern Maryland, and Essex, Northumberland, Richmond, and Westmoreland Counties, Virginia. The area is just south of the southern edge of a belt of sedimentary structures attributed to permafrost that developed during full glacial cycles. Congelliturbate structures (ice-contorted bedding), frost-wedges, and closed depressions that were probably formed as a result of permafrost action are found northward across the Coastal Plain to the true glacial margin in New Jersey (Newell and Wyckoff, 1992).

The low-lying Delmarva Peninsula occupies the area east of Chesapeake Bay. West of the bay are deeply-dissected, northwest-trending, interfluvial uplands that are dominated by nonmarine deposits north of the Potomac and marine deposits south of the Potomac. The highest altitude east of Chesapeake Bay in the map area is about 5 ft (1.5 m); north of the Potomac, the highest point is about 196 ft (59 m), and south of the Potomac the land surface reaches 174 ft (53 m). Discontinuous low terraces generally separate the highlands from the Potomac, Chesapeake Bay, and the other major waterways.

In the valleys of Chesapeake Bay, the Potomac River estuary, and their main tributaries are deposits from several late Quaternary depositional cycles. The map units and estimated ages for these deposits are (see Discussion of Selected Stratigraphic Units for further discussion and references): unit Q1, Holocene; unit Q2, probably 30 Ka; unit Q3, 70 Ka; unit Q4, 180 Ka; and unit Q5, 450 Ka. The axes of major Pleistocene channels, inferred from seismic profiles (Colman and Halka, 1989; J.T. Hack, USGS, written comm., 1980), are shown as long dashes on the geologic map; modern channel axes are shown as dotted lines. Contacts of pre-Quaternary units in the waterways are highly speculative. The positions of the contacts, which are shown as short dashed lines, were estimated from the intersection of formational surfaces with the deepest Pleistocene channel and the modern channel axis in each waterway. Modern channel bottoms are typically as much as 100 ft (30 m) shallower than the deepest Pleistocene channels. Chesapeake Bay at the southern edge of the map area has a maximum of 100 ft (30 m) of water today, but it had about 200 ft (60 m) one or more times during the Pleistocene.

The Eastover Formation (Miocene) and the Yorktown Formation (Pliocene) are found immediately below Quaternary fill in the southeast corner of the area, and the St. Marys (Miocene) is present in the northeastern channels. The Choptank Formation (Miocene) is present at or just below sea level most places west of Chesapeake Bay. The Calvert Formation (Miocene) probably floors much of the Potomac and Chesapeake Bay in the map area. The Nanjemoy Formation (Eocene), the Marlboro Clay (Paleocene), and the Aquia Formation (Paleocene) are present in the westernmost part of the Potomac channel.

Except in Calvert County, the highlands west of Chesapeake Bay are generally underlain by fluvial, estuarine, and marine deposits of late Pliocene age (fig. 1) that bevel Pliocene, Miocene, and Eocene marine units. Most of the upland surface of the Calvert County peninsula is underlain by fluvial and marginal marine gravel, sand, and mud of the Miocene St. Marys Formation. The lowland terraces are all underlain by varying proportions of Quaternary gravel, sand, mud, and peat. Mollusk shells are present in all but the oldest of the Quaternary deposits, and are more abundant downdip, especially in the southern and eastern parts of Delmarva Peninsula, which are outside the map area.

The part of the Delmarva Peninsula within Leonardtown quadrangle is a lowland covered mainly with Holocene and latest Pleistocene deposits. The lithologies are quartzose sand, mud, and peat, and minor gravel. The Quaternary surficial deposits of Delmarva bevel Miocene marine deposits; Pliocene deposits are present east of Chesapeake Bay within the Leonardtown quadrangle only in the subsurface south of South Marsh Island.

Structural and tectonic setting.--The basement in the map area consists of metamorphic rocks like those in the Piedmont geologic province (Daniels and Leo, 1985; Hansen and Edwards, 1986). The erosional surface at the base of Coastal Plain deposits dips southeastward more steeply than overlying units (Darton, 1951). Large, discontinuous, north-northeast-trending extensional basins within the basement contain Triassic and Jurassic sedimentary and igneous rocks. North- and northeast-trending high-angle reverse faults that are noted on seismic profiles (Jacobeen, 1972; Hansen, 1978) and suggested by magnetic and gravity anomalies (Zietz and others, 1978; Higgins and Zietz, 1983; Daniels and Leo, 1985), and northwest- to west-trending cross faults may be present in the area. The north-and northeast-trending faults are parallel to the Stafford and Brandywine high-angle reverse fault systems to the west (Mixon and Newell, 1977; Prowell, 1983 and 1988; Mixon and Powars, 1984; Newell, 1984; McCartan, 1989c).

During the early and middle Mesozoic, only the north- and north-northeast-trending faults were active; at that time the sense of motion was normal and extensional (Froelich and Robinson, 1988; Manspeizer and Cousminer, 1988). By the end of the Jurassic, compression replaced extension (Zoback and Zoback, 1980), and movement on the existing faults reversed (Battiau-Queney, 1989). With continuing compression, folds trending north and northwest may also have begun forming. These younger structures would account for kinks and discontinuities in the older, northeast-trending structures. Local warping, probably a response of unconsolidated sediments to basement faulting, controlled the locus of sedimentation (cross sections AA' and EE') (Newell and Rader, 1982).

The net motion of the basement surface has been downward, resulting in a post-Jurassic Coastal Plain section ranging from about 1650 ft (500 m) thick at the western edge of the map to about 2500 ft (760 m) thick at Lexington Park, Md. (Hansen and Wilson, 1984), and probably thicker in Somerset County. But differential uplift is evident several places in the map area. The Calvert County peninsula is covered by St. Marys Formation. Beach deposits of the St. Marys Formation in Calvert County are present at least to 100 ft (30 m) above sea level. In the St. Marys County peninsula, shelf deposits of the underlying Choptank Formation are present as high as 150 ft (45 m) above sea level, and the marginal marine facies of the overlying Eastover Formation is as high as 120 ft (36 m) in King George County, Va. Changes in unit thicknesses are due to multiple episodes of tectonism and sea level rise and fall, uneven deposition, and erosion (see cross sections).

The most striking physiographic change in the area is tectonically controlled. The cliffs and highlands fringed by lower terraces west of Chesapeake Bay have clearly been uplifted relative to the unbroken lowlands east of the bay. The structural nature of this transition is also borne out in the subsurface by the differences in the stratigraphic sections on either side of the bay (cross sections AA' and EE'). Similar subsurface changes were noted south of the map area (Powars and others, in press). The lack of deep drill cores immediately east of Chesapeake Bay precludes good control of the stratigraphic interpretations. However, in the vicinity of Chesapeake Bay on cross section A-A', the Nanjemoy Formation thins eastward to zero; the Old Church Formation thickens eastward from zero to over 200 ft (60 m) in a few miles (kilometers);

the Piney Point thickens eastward from less than 33 ft (10 m) to more than 116 ft (35 m); the Aquia thins eastward from 165 ft (50 m) to 66 ft (20 m); and Upper Cretaceous units thicken eastward from zero to 233 ft (70 m). Whether these changes occurred over 5 mi (8 km) or 10 mi (16 km), they require significant episodic tectonic movement.

The zone of flexure and rapid stratigraphic change shown on AA' beneath Patuxent River probably trends southeastward across the south-end of the Calvert peninsula. The eastern flexure and stratigraphic change zone trends southward beneath Chesapeake Bay. The two zones may become a single zone beneath the bay (as shown on cross section EE') or may continue separately. Flexures and rapid stratigraphic changes are shown beneath Chesapeake Bay for two reasons. First, the bay has a peculiar physiography. It is the largest estuary in the Eastern U.S. and it has a long, straight, shore-parallel trend that is difficult to explain without invoking structural control. The presence of the precursor north-trending Susquehanna River Valley is equally unusual on a coast where most rivers trend southeastward, down the regional topographic gradient. Second, the contrasting highlands west of the bay and lowlands east of the bay are most easily explained by differential uplift. The Pliocene Yorktown Formation is not present east of the bay north of Kedges Straits. Quaternary deposits indicate the extent of post-Yorktown marine transgressions. Where low-lying Miocene units are covered by neither Quaternary nor Yorktown deposits there must have been a highland during the Pliocene. Post-Yorktown uplift of areas west of the bay resulted in the present configuration. This interpretation, consistent with the map pattern and cross sections, requires significant differential vertical movement in the basement rocks during the Cenozoic. Such movement is recorded at many locations within or south of the map area (Newell and Rader, 1982; Jacobeen, 1972; Mixon and Newell, 1977; Mixon and Powars, 1984; Newell, 1984; McCartan, 1989a, b; Fleming and others, 1994; Wilson, 1986).

The regional sense of motion is "up on the west". Rising blocks on the western sides of the basement fault zones (Stafford, Brandywine, and the unnamed fault zones farther east, including those inferred beneath the Chesapeake Bay and Patuxent River), were subject to subaerial erosion and dissection but were not as likely to incur the beveling action of a marine transgression as were the lower-lying eastern blocks. Subaerial and submarine erosion and deposition, controlled by tectonic movements, which were most intense along widely-spaced, northwest- to northeast-trending compressional, high-angle faults, can explain much of the significant stratigraphic changes portrayed in the cross sections. The remainder of the stratigraphic changes can be attributed to deposition and erosion related to eustatic sea level oscillations (Newell, 1984).

GROUND-WATER CHEMISTRY

Ground-water chemistry has been studied in Maryland (Otton, 1955; Slaughter and Laughlin, 1966; Weigle and others, 1970; Woll, 1978; and Wilson, 1986) but comparable studies are not available from Virginia. The highest concentration of Ca, Mg, and Fe in water from aquifers in sediment of mainly Cretaceous and Paleocene age is north of Leonardtown Quadrangle; within the Eocene aquifer system, hard, iron-rich water is present in northeastern Calvert County and in central St. Marys County adjacent to the Patuxent River (Otton, 1955; Weigle and others, 1970). Other ground-water chemistry trends in the Leonardtown Quadrangle can be seen in the representative data in Table 2 (Woll, 1978). Sodium, bicarbonate, and total dissolved solids are highest in water from the downdip parts of the Piney Point, Nanjemoy, and Aquia Formations, and the Potomac Group. Water in the Eastover Formation in Dorchester County is also enriched in sodium and chloride. Dissolved silica is over 50 mg/L in water from the Eastover Formation east of Chesapeake Bay, in the updip parts of the Piney Point Formation in St. Marys County, and the Nanjemoy Formation in Calvert County. Fluoride is generally more concentrated in water from older deposits, and lithium is notable in water from the Aquia in Calvert County and the Aquia and Nanjemoy Formations of St. Marys County. Water from surficial units (Pliocene and Quaternary) tends to be more acidic than water from mainly subsurface units. This may be a function of depth from which the water sample was taken. Samples taken from shallower depths contain water with relatively high SiO_2 concentrations, which is more representative of typically acidic meteoric water than it is of the mineralogy of the unit containing the water.

DISCUSSION OF SELECTED STRATIGRAPHIC UNITS

Unit QTc (colluvium of late Cenozoic age, undifferentiated)--Larger clasts, which are matrix supported, were derived from topographically higher colluvium or waterlaid deposits of Miocene to Pleistocene age. Erosional remnants of Tertiary colluvium have persisted longer than the waterlaid beds which supplied the coarse-grained clasts to the colluvium. The matrix is fine-grained sand, silt, and clay that may have been derived from any deposit. Colluvium forms by slow creep or mass movement downhill. Accumulation of colluvium occurs intermittently on intermediate slopes, probably during extended periods of moderate rainfall. Colluvium is typically 3-10 ft (1-3 m) thick. The thickest, most extensive colluvium is found in aprons at toes of scarps bounding Quaternary terraces. Similar accumulations along scarps between Pliocene deposits are deeply weathered and dissected. Colluvium is not shown along the contacts between Pliocene units because it is difficult to distinguish from the residuum which in most places constitutes the upper part of the Pliocene units.

In Calvert County, gravel of the St. Marys Formation is found in sparse patches at many elevations. Some of these gravel beds are poorly sorted and have bedding parallel to the slope, and are considered colluvial. In St. Marys and Charles Counties, colluvium consisting of clasts derived from the edge of the upland gravel plain and silty, fine-grained sand from the underlying Choptank Formation is present in many places in the Potomac and Patuxent River drainage areas. The distribution of this colluvium is very irregular and is not shown on the map. The low relief east of Chesapeake Bay is not conducive to the formation of colluvium in mappable thicknesses.

Pleistocene deposits

Four lithostratigraphic units of Pleistocene age have been mapped in the Leonardtown quadrangle. Units Q2-Q5 are correlated across the Potomac River, and Q2-Q4 are correlated across Chesapeake Bay, on the basis of the distribution of lithofacies, fossil content, stratigraphic position, and elevation. The units occupy remnants of terraces along the modern waterways. The predominant minerals in the Pleistocene units include quartz, ilmenite, leucoxene, staurolite, sillimanite, rutile, tourmaline, zircon, kaolinite, vermiculite, goethite and gibbsite. This suite of minerals is chemically mature. That is, easily oxidized minerals such as hornblende and epidote that are found in the source area rocks are generally absent in the Pleistocene units within the Leonardtown quadrangle. The mature suite reflects recycling of weathered sediment. The main source of sediment in the Pleistocene units was, therefore, the highlands adjacent to the terraces, rather than the Piedmont or terranes farther west.

Lowland Unit Q2--The broad extent and fine-grained sediment of Q2 suggests that it was deposited mainly in an estuary environment. East of Chesapeake Bay, freshwater to brackish peat from the Kent Island Formation (equivalent to unit Q2 in this report) and brackish to salt marsh peat from the age-equivalent Sinepuxent Formation east of the map area have yielded ^{14}C dates in the 24,000-36,000 YBP range (Owens and Denny, 1978). In the type area, the Kent Island Formation originally included two estuarine units (Owens and Denny, 1979) which should probably be separated. The upper one, which contains the dated peat samples, belongs to the Kent Island (unit Q2), and the lower unit is probably part of the Ironshire Formation (unit Q3).

Over most of the map area, the lower contact is an erosional unconformity resting directly on units that are Pleistocene to Miocene in age. East of Chesapeake Bay, low sand dunes that are conformable over the Kent Island Formation are mapped separately as Q2d (Parsonburg Sand of Owens and Denny, 1979).

Lowland Unit Q3--The unit correlates with beach and shallow marine facies east of the map area (Ironshire Formation, Owens and Denny, 1979; Nassawadox Formation, Occohannock Member, Mixon, 1985; Mixon, Berquist and others, 1989). Corals in the part of the Tabb Formation (Mixon and others, 1989; supersedes the Norfolk Formation of Oaks and others, 1974) that is correlative with unit Q3 typically have a uranium-disequilibrium-series age of about 70 Ka (Szabo, 1985). The lower contact of unit Q3 is an erosional unconformity, where unit Q4 and older formations are beveled by unit Q3.

Lowland Unit Q4--Unit Q4 contains deposits that record a complete depositional cycle.

The lower part (transgressive phase) is present in St. Marys, Charles, and Calvert Counties, and in Virginia. The transgressive phase is inferred from peat at the base of the Virginia sequence, which grades upward into muddy sand. The unit grades northwestward from sandy clay and clayey sand along Chesapeake Bay to mud over clean fine sand with traces of marsh grass roots along the Patuxent and Potomac Rivers.

The regressive phase lies conformably above the uppermost beds of the transgressive phase in the western part of the map area, where it consists of gravel and coarse-grained sand. In eastern and southeastern St. Marys County, unit Q4 grades upward from muddy sand containing Arca, Mercenaria, Mya, Crepidula, and Polinices, to sandy mud containing Ostrea, Mulinia, and Cyrtopleura (list modified from Shattuck, 1907, by L.W. Ward, oral communication, 1985). The oyster zone gives upward to muddy sand with plant fragments. The depositional environments are open bay at the base, restricted bay in the middle, and marsh and swamp at the top. Pollen from the upper part of the sequence includes pine, oak, and cattails, and suggest warm temperate forest and wetlands (L.A. Sirkin, USGS and Adelphi University, written communication, 1982).

Unit Q4 sediment derived from surrounding highlands contains minerals such as quartz, ilmenite, kaolinite, illite, vermiculite, goethite, and gibbsite.

Unit Q4 below 20-30 ft (6-9 m) is unconformably overlain by units Q3, Q2, and Q1. The upper depositional surface of unit Q4 is at about 50 ft (15 m) elevation. The lower contact is an erosional unconformity on unit Q5 and older units. A coral from a bluff near the mouth of the Rappahannock River gave a uranium disequilibrium-series age of 180 Ka (Mixon, Berquist and others, 1982).

Lowland Unit Q5--Reworked ironstone and flat pebbles of quartz and quartzite are common. Other important minerals derived from the adjacent highlands are ilmenite, kaolinite, vermiculite, gibbsite, and goethite. The unit accumulated in a river and estuary system. A channel east of St. Marys River beneath units Q4 deposits contains 40 ft (12 m) of silt and clay with abundant plant fragments probably assignable to unit Q5. Pollen in the clay are dominantly oak, pine, and hickory, indicating warm temperate conditions (L.A. Sirkin, USGS and Adelphi University, written communication, 1983).

Unit Q5 probably includes the Charles City Formation (Mixon, Berquist and others, 1989). In North and South Carolina, a formation in this stratigraphic position has yielded several coral uranium-disequilibrium-series dates of about 450 Ka years (Szabo, 1985), and has normal magnetic polarity (Liddicoat and others, 1979, 1981), indicating an age for the unit less than about 730 Ka. Unit Q5 is unconformable on unit T1 and older units.

Pliocene deposits

The uplands west of Chesapeake Bay are covered with gravelly deposits that are the major sources of commercial sand and gravel in the area. The gravel deposits are assigned to the fluvial and estuarine facies of two units on this map. The younger unit, T1, is beveled into the older unit, which is the Yorktown Formation. Dark-green glauconitic sand that is the shelf facies of the Yorktown Formation is present below estuarine and fluvial gravel. The highest glauconitic sand in Pliocene deposits in Virginia is at or below 110 ft (33 m) elevation. In Maryland, the shelf facies of the Yorktown is present only in the southeastern part of St. Marys County, below the gravel of unit T1, and in the subsurface east of Chesapeake Bay south of South Marsh Island.

The Yorktown Formation and unit T1 are considered upper Pliocene on the basis of marine fossils in the Yorktown and plant fossils in both units. Unit T1 has an upper depositional surface that is flatter and lower than that of the Yorktown Formation. The two units are separated by a scarp that is distinct in some places but more typically is obscured by dissection or colluvium.

Residuum has developed at the top of the Pliocene units and is present except where the units have been stripped by erosion. The residuum is poorly sorted pebbly silt and clay or muddy, fine- to medium-gravel. Larger clasts are matrix supported, as in colluvium. Reddish orange, brown, and tan are typical colors; medium- to pale-gray occurs along cracks and root casts. Residuum is gradational with the underlying waterlaid material, and it becomes part of the colluvium (QTc) as it moves down shallow to intermediate slopes adjacent to the gravel sheets. The residuum forms by ground-water processes that alter minerals in the upper part of the gravel deposits, and by long-term downward infiltration of airborne clay and silt from the surface. Soil vermiculite, one of the alteration products, tends to filter out and concentrate certain agricultural compounds that may have harmful effects on human beings if the chemicals reach the aquifers. The actual and potential extent of these reactions is not known. Vermiculite is commonly found at greater depths in older deposits. It may be derived along with other minerals from adjacent weathered highlands, but it also forms in place by alteration of illite-smectite and illite, which are detrital clays associated with the gravel. The Pliocene units west of Chesapeake Bay are correlated on the same basis as Pleistocene units: by distribution of lithofacies, fossil content, stratigraphic position, and elevation.

Upland Unit T1--Unlike younger units, unit T1 contains a large component of sediment derived directly from the Piedmont, Triassic basin, and Appalachian Mountains, as well as locally derived clasts.

Sparse pollen is present in thin, dark clay beds at a few localities in Maryland. Oak, pine, hickory, sweet gum, and black gum indicate a warm, temperate climate. The presence of a few specimens of exotics such as Pterocarya and Ulmus (Zelkova) indicate a Pliocene age (L.A. Sirkin, USGS and Adelphi University, written communication, 1980). A similar pollen assemblage is present in the Beaverdam Sand of the Delmarva Peninsula (Owens and Denny, 1979). Although fosssils have not been found in unit T1 in the Virginia part of the Leonardtown quadrangle, farther south the Bacons Castle Formation contains sparse exotics (L.A. Sirkin, USGS and Adelphi University, written communication, 1984.

The estuarine and fluvial beds composing unit T1 are also correlated with the Walston Silt of the Delmarva Peninsula (Owens and Denny, 1979), and with marine shelly sand deposits on the Chowan River in North Carolina (Blackwelder, 1981; we include the overlying sand in this unit although Blackwelder did not). In southern St. Marys County, the lower contact is an erosional unconformity on marine beds of the Yorktown and older formations. Upland unit T1 is unconformably overlain by lowland unit Q5 and in a few places by Holocene deposits (unit Q1).

Yorktown Formation--In Maryland, the updip facies of the Yorktown Formation is fluvial gravel. The medium- to coarse-grained gravel grades abruptly southeastward across a discontinuous, low scarp into coarse-grained sand and fine-grained gravel, presumably an estuary shoreline deposit. The fine sand of the marine facies is present farther southeast. The Yorktown Formation lies unconformably on all the Miocene units and is beveled by unit T1, unit Q5, and by Holocene erosion.

In Virginia, the Yorktown is composed of the same facies as those in Maryland, but the marine and estuarine facies extends farther westward, beneath the fluvial facies. The shelf facies of the Yorktown Formation is a thin, dark-green to black, sparsely fossiliferous, fine-grained, glauconitic quartz sand that weathers to a medium yellowish orange. It is present between elevations of 40-60 ft (12-18 m) in southern St. Marys County, and up to 110 ft (33 m) in Westmoreland County.

Although originally described as Miocene (Stephenson and MacNeil, 1954), the Yorktown Formation is now considered Pliocene (Ward and Blackwelder, 1980). It is a subsurface unit in the southeastern part of the map area (Owens and Denny, 1984). Original detrital mineralogy of unit T3 is best preserved in the more clayey beds. The presence of feldspar, epidote, garnet, and illite in addition to more resistant minerals, such as quartz and kaolinite, reflects a source from the Piedmont province west of the Fall Zone. Gibbsite, soil vermiculite, and the red color reflect the long history of weathering.

Miocene deposits

Eastover Formation--The dark green and gray colors and immature mineral suite at the top of the formation (feldspar, hornblende, epidote, sulfides, illite-smectite, and illite), suggest stripping of the upper (weathered) part of the unit prior to deposition of younger units. In the map area, the Eastover contains plant fragments and, near the base, rare shells. Farther south, the Eastover contains abundant shells in some places (Mixon, Berquist and others, 1989).

The top of the Eastover contains glauconitic-sand-filled burrows where it lies beneath the shelf facies of the Yorktown Formation. Burrows and ubiquitous, small, discoidal quartz pebbles typically mark the contact with the underlying St. Marys Formation. The Eastover Formation is the youngest of the subsurface units in St. Marys County and unconformably overlies the St. Marys Formation. It occurs discontinuously between Leonardtown and Lexington Park, and southeastward it is overlain unconformably by units T1 and the shelf facies of the Yorktown.

The Eastover Formation was first recognized by Ward and Blackwelder (1980). It has been mapped in Virginia (Newell and Rader, 1982; Mixon and others, 1989), and it is correlated with the Pensauken Formation northeast of the map area (Owens and Denny, 1979). The age is late Miocene on the basis of mollusks and pollen. The Eastover within the map area was deposited in estuarine to nearshore marine environments. Just north of the Leonardtown quadrangle, at Brandywine, late Miocene pollen and plant macrofossils in a black clay lens within a gravel deposit have been correlated with either the Eastover Formation or the St. Marys Formation. This deposit appears to record the regressive phase of one of the late Miocene units.

St. Marys Formation--Detrital nonresistant minerals such as illite-smectite, illite, feldspar, hornblende, and epidote are abundant. Pollen from an outcrop southeast of Leonardtown, Md., and from a cliff on Chesapeake Bay at Little Cove Point, Md., includes Tertiary forms such as Pterocarya, Ulmus (Zelkova), and Momipites that are no longer represented in eastern North America (L.A. Sirkin, USGS and Adelphi University, 1984, written communication). The upper half of the formation, consisting of crossbedded sand and dissoidal to pea gravel exposed in cliffs facing Chesapeake Bay in Calvert County (McCartan and others, 1985) and present over much of the southern part of Calvert County, is replaced in St. Marys County mainly by beds of the Eastover and Yorktown formations. An unpublished report by Britt McMillan (Old Dominion University Geological Science Technical Report Contribution GSTR #85-2, 1985) shows significant statistical similarity among fossils of Little Cove Point and St. Marys River outcrops in Maryland, and fossils of the St. Marys Formation in Virginia. Fossils from the Eastover Formation in Virginia are signficantly dissimilar. Common mollusks include *Mercenaria*, *Anadara*, and *Turritella.* The St. Marys Formation is late middle Miocene to early late Miocene on the basis of mollusks (McCartan and others, 1985). It was deposited in estuarine to nearshore marine environment. The formation was named by Shattuck (1902; see also Shattuck, 1903, and Shattuck and Miller, 1906; Blackwelder and Ward, 1976; Ward, 1985) from fossiliferous exposures along the St. Marys River, Md.

Choptank Formation--The Choptank contains abundant nonresistant detrital minerals such as illite-smectite, illite, feldspar, hornblende, epidote, and authigenic sulfide. The

Choptank is unconformably overlain by the St. Marys and younger units. It unconformably overlies the Calvert Formation, but that contact is difficult to determine in a few places. Choptank and Calvert formations are also difficult to distinguish in some places in both outcrop and in subsurface samples without referring to diatoms or mollusks, because both formations consist of alternating fine sand and clayey silt subunits. In St. Marys County, however, the top of the Choptank and the base of the Calvert are usually distinguishable from younger and older units, and the combined "Choptank-Calvert" unit is useful in structural interpretation.

Common genera in the Choptank are the mollusks Mercenaria, Macrocallista, Turritella, and Glossus, and the barnacle Balanus (L.W. Ward, written communication, 1987). Three taxa found in the Oaks core in northwest St. Marys County are Cardium, Turritella, and fragments of an amber colored, phosphatic-shelled brachiopod, Discinisca (L.W. Ward, USGS, oral communication, 1987). The age of the Choptank Formation is the middle part of the middle Miocene (Andrews, 1978; Ward, 1984a). It was deposited in an open shelf under less than 200 ft (60 m) of water (Gibson, 1971).

Calvert Formation--The Calvert Formation is composed predominantly of quartz, but non-resistant detrital minerals such as illite-smectite, feldspar, hornblende, and epidote, are also relatively abundant. Diatoms, sponge spicules, and foraminifers are abundant in much of the formation; chalky calcareous and thin phosphatic mollusk shells are common in some beds. Phosphatic zones in the Calvert have a brownish cast. Bedding in the Calvert is generally indistinct due to bioturbation, and small burrows filled with fine-grained sand are common. There are sparse hard zones, 0.5 to 2.5 in (1 to 4 cm) thick. In some areas, thin alternating beds of silt and silty clay or silt and fine-grained sand are preserved.

The Calvert in most of the map area is unconformably overlain by the Choptank or Yorktown Formations. It unconformably overlies the Piney Point and Nanjemoy Formations. On the basis of diatoms, the Calvert is early to middle Miocene age (Andrews, 1978). The Calvert was deposited in shallow shelf to open bay environments.

PRE-MIOCENE UNITS, NOT SHOWN ON MAP

The Nanjemoy Formation, Marlboro Clay, and Aquia Formation are discussed below because they are well known stratigraphic units that were reached in several shallow drill holes. The Marlboro Clay and Aquia Formation do not occur above sea level in the map area. The Nanjemoy Formation is above sea level in the Popes Creek area but is not shown beneath the Calvert because its map width along the cliff exposures is too narrow. Four other pre-Miocene units are described briefly in Table 4.

Nanjemoy Formation--Muddy, poorly sorted, medium-grained quartz sand with abundant glauconite and mica is the typical lithology of the Nanjemoy Formation. The Nanjemoy is distinct from the muddy fine- to medium-grained quartz sand and abundant phosphate grains of the Calvert Formation. The Nanjemoy is overlain by the Calvert Formation throughout most of the map area. Both the upper and lower contacts of the Nanjemoy are burrowed. The lower contact is marked by an abrupt change to the Marlboro Clay, or, in a few places, by the more subtle change to the sand of the Aquia Formation. Both contacts are unconformities, and the upper at least represents a significant loss of time, as the age of the Nanjemoy is early Eocene (calcareous nannoplankton zones NP10-12, L.M. Bybell, USGS, written communication, 1985, and Gibson and others, 1980).

The Nanjemoy Formation was divided into two members, the lower or Potapaco, and the upper or Woodstock, by Clark and Martin (1901). The main lithologic distinction is that the lower part of the Nanjemoy is much clayey than the upper part. In the subsurface, the distinction between the members is less evident than in outcrops, especially in Maryland, so the formation has been left undivided. In the outcrops along the Potomac River near Popes Creek, the contact between the Woodstock and Potapaco at about 10 ft (3 m) above the water level (Ward, 1984a).

The depositional environment of the Nanjemoy Formation is shallow shelf (Ward, 1984a). The more clayey beds suggest an area or time of quiet water, not affected by waves, tides, or current activity; intercalated sandier zones may reflect the higher energy of waves or currents during episodic storms. Its regional dip is eastward at 15-20 ft per mile (3-3.5 m/km).

Marlboro Clay (subsurface only)--The Marlboro is described with units that reach the surface because it is the most distinctive and stratigraphically useful marker unit in the Tertiary section. It is a thin but widespread clay unit between two dark, glauconitic, micaceous, sand units, the Nanjemoy and Aquia Formations. It is found in outcrops roughly 1-6 miles (1.6-10 km) east of the Potomac River estuary, and in the subsurface farther east. Both upper and lower contacts are sharp and burrowed in some places (Glaser, 1971; Ward, 1984a). Elsewhere, material from the Aquia appears to have been reworked into the lowest part of the Marlboro, and the top of the Marlboro appears to have been reworked into the base of the overlying Nanjemoy Formation in some places.

Macrofossils have not been found in the Marlboro in the map area, but microfossils here and elsewhere suggest that the Paleocene-Eocene boundary is contained in the Marlboro (calcareous nannoplankton zone NP9 and NP10, L.M. Bybell, USGS, written communication, 1985, and oral communication, 1987). Also, pollen (Frederiksen, 1979; see also Frederiksen and others, 1982) and dinoflagellates (Gibson and others, 1980) support this interpretation. The texture and microfossil assemblage suggests that the Marlboro was deposited in a shallow, nearshore, marine environment such as a tidal flat (Glaser, 1971) or estuary (Gibson and others, 1980). The regional dip is southeastward at 15-20 ft per mile (3-3.5 m/km).

Aquia Formation--The Aquia Formation is typically fine-grained, moderately-sorted, glauconitic, quartz sand. Rounded grains of glauconite and goethite, both probably authigenic within fecal pellets, are abundant in most samples of the Aquia (Hansen, 1974). Zones of light-gray concretions and hard beds up to several inches (centimeters) thick are common. In most cases, the hard beds are fine- to medium-grained sand cemented by either calcite or dolomite.

The Aquia is coarser-grained and thicker toward the northwest (Hansen, 1974). Most of the coarse clasts, other than fossils and sand-sized glauconite and goethite, are well-rounded, quartz sand grains and pebbles, that were probably derived from the underlying Potomac Group during transgression of the Aquia sea.

Burrowing has disrupted the primary bedding in most cores and outcrops, and organic activity probably contributed to the poor sorting. Chalky shell fragments occur in beds up to 1.5 ft (0.5 m) thick with a fine-grained sand and silt matrix. Turritella and Ostrea are two of the most abundant mollusks in the Aquia in the map area.

Throughout most of the quadrangle, the Aquia is overlain by the Marlboro Clay, and the contact is a sharp lithologic boundary. Burrows are sparse and pebbles are absent; this evidence suggests that little time is missing between the two formations. Where the Eocene Nanjemoy Formation directly overlies the Aquia, the contact may be indistinct and quantitative mineralogy or fossils may be required to delineate it. In most places, however, the Aquia is better sorted than the Nanjemoy. The lower boundary of the Aquia is sharp where it overlies the Potomac Group (Lower Cretaceous) or Magothy Formation (Upper Cretaceous) but is less distinct where the Aquia overlies the Brightseat Formation (lower Paleocene, Hazel, 1968 and 1969) or Severn Formation (Upper Cretaceous). Concentrations of phosphatic clasts occur near the base of the Aquia in most places.

The benthic foraminiferal assemblage suggests that the Aquia in Virginia was deposited under middle- to shallow-shelf conditions (Nogan, 1964; Gibson and others, 1980). Ubiquitous glauconite suggests similar regional conditions for the Aquia, even where large, shore-derived pebbles are abundant.

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DESCRIPTION OF MAP UNITS

QTc CENOZOIC COLLUVIUM UNDIVIDE Marys County, and south of Mattox Creek, near Oak Grove, Virginia; it is absent east of Chesapeake Bay. Thickness ranges from 30 to 50 ft (9 to 15 m), and the top of the unit is generally between 60 and 80 ft (10 to 24 m) elevation.

T1 Upland UNIT T1 (UPPER PLIOCENE)--Silty, fine-grained sand, and fine- to medium-grained sand and clay, interbedded with medium- to coarse-grained sand with pebbles, cobbles, and boulders. Coarser material is common at the base. Typical colors of finer-grained and poorly-sorted material are pink, pale-brown, or medium-yellow-orange. Unit T1, includes the Ravens Crest Formation in Maryland (McCartan, 1989c; the Park Hall Formation of McCartan, 1989a and 1989b is hereby abandoned) and some of the deposits assigned to the Windsor and Bacons Castle Formation in Virginia (Mixon, Berquist and others, 1989). The top of the unit is typically about 105-110 ft (32 to 33 m) elevation; the base is in most cases between 60 ft and 70 ft (18 and 21 m) elevation.

Ty Yorktown Formation (UPPER AND MIDDLE PLIOCENE) --Three depositional lithofacies compose the Yorktown Formation. The fluvial facies is made up of coarse, pinkish-gray to dark-red-orange gravel, typically 25 ft (7.5 m) thick, overlain by gray-brown, sandy, silt with scattered pebbles. The fluvial to estuarine facies, typically 6 to 10 ft (2 to 3 m) thick, is made up of fine, well sorted gravel and coarse-grained sand, tan to bright-yellow, typically 15 to 20 ft (5 to 6.5 m) thick; interbedded fine- to medium-sand and silty clay, gray, 3-6 ft (1-2 m) thick; muddy sand, gray, pink, or yellow-orange, which grades laterally or upward into medium- to coarse-grained gravel, yellow to tan, 10 to 20 ft (3 to 6.5 m) thick. The fluvial to estuarine facies altogether is typically 33-50 ft (10-15 m) thick, but varies due to erosion and an irregular lower contact; this facies is the main surficial unit in parts of St. Marys, Charles, and Westmoreland Counties. It includes the Upland Gravel 4 in Maryland (McCartan, 1989a and 1989b), and possibly some of the Bacons Castle Formation in Virginia (Mixon, Berquist and others, 1989). Within the map area, the maximum elevation of the fluvial facies in Virginia is about 195 ft (60 m); in Maryland the maximum elevation is about 180 ft (55 m).

The shelf facies is fine-grained, dark-green, glauconitic sand with shelly beds, that weathers to a medium-yellow-orange. It is 10 to 30 ft (3 to 9 m) thick in Maryland, where it occurs southeast of the remainder of the Yorktown Formation, but is as much as 50 ft (15 m) thick in swales in Westmoreland County, Va., where it is overlain by the fluvial and estuarine facies of the Yorktown.

Te **EASTOVER FORMATION (UPPER MIOCENE)**--Clayey silt with thin laminae of silt, clay, or sand; greenish-gray to greenish-black where fresh, olive-gray where weathered. The basal 3-10 ft (1-3 m) contains coarse quartz sand grains and small, rounded phosphate and quartz pebbles, and flat, quartz pebbles up to 2.5 inches (3 cm) long. In Leondardtown quadrangle, the Eastover crops out only west of Chesapeake Bay but it is present in the subsurface east of the map area (Powars and others, 1992). Thickness ranges from 0.5 to 40 ft (0.2-12 m); the upper contact reaches a maximum elevation of 72 ft (22 m) just southeast of Leonardtown and about 130 ft (40 m) in Westmoreland County.

Ts **ST. MARYS FORMATION (UPPER MIOCENE)**--Muddy, fine-grained sand, fine sandy silt, or silt and clay, dark-greenish-gray; locally contains iron sulfide and glauconite; chalky mollusk shells abundant in some beds. Maximum thickness is about 40 ft (12 m), and the maximum elevation (near Leondardtown) is about 65 ft (20 m).

Tch **CHOPTANK FORMATION (MIDDLE MIOCENE)**--Fine- to medium-grained sand; some beds are silty to clayey, and most are bioturbated. Dark- to medium- olive-gray, weathers golden-yellow with green streaks. Locally abundant chalky shells, diatoms, thin lenses of phosphatic sand, and small pebbles. The formation reaches its maximum thickness (150 ft, 38 m) near Hollywood in the middle of St. Marys County (see cross section A-A'). The maximum elevation of the upper contact is about 180 ft (55 m) in the northwest corner of the map.

Tc **CALVERT FORMATION (LOWER AND MIDDLE MIOCENE)**--Clayey silt, silty clay, and muddy sand, medium- to dark-olive-brown to olive-gray, weathers to golden- or pale-greenish-yellow; and thin beds of well-sorted, fine-grained, gray sand. Thin (less than 1 inch, 2.5 cm) beds of silty clay and clayey silt in places and hard zones 0.5-2.5 in (1-4 cm) thick. Thickness ranges from about 65 ft (20 m) in the northwest corner of the map to about 780 ft (240 m) in the southeast corner; maximum elevation is about 145 ft (45 m), in the northwest.

Tn **NANJEMOY FORMATION (LOWER EOCENE)**--Dark-greenish-gray to olive-black (tan to orange where weathered), fine- to medium-grained, glauconitic, quartz sand and dark greenish-gray, silty clay. In places the sand is very muddy or contains many small quartz pebbles, and the clay is silty or sandy. Both lithologies contain very fossiliferous beds including abundant Venericardia. Its maximum thickness is about 230 ft (70 m) in the eastern part of Charles County (Dryden and Overbeck, 1948), and it is below sea level in the map area except along the Maryland side of the Potomac River near Popes Creek.

UNITS FOUND ONLY BELOW LAND SURFACE (SEE CROSS SECTIONS AND TEXT)

Unit	Age	Lithology	Depositional environment	References
Old Church Formation (To)	Late Oligocene	Calcareous, clayey quartz sand	Shallow shelf	Ward, 1985
Piney Point Formation (Tp)	Middle Eocene	Glauconitic quartz sand and clayey sand	Shallow shelf	Otton, 1955; Ward, 1985
Marlboro Clay (Tm)	Early Eocene and late Paleocene	Clay and silty clay; dominantly kaolinite	Shallow to deep shelf	Glaser, 1871; Ward, 1984a
Brightseat Formation (Tb)	Early Paleocene	Phosphatic quartz sand	Shallow shelf	Bennett and Collins, 1952; Nogan, 1964; Hazel, 1968, 1969; Whitney, 1984
Cretaceous, undifferentiated (K)	Late and Early Cretaceous	Well-consolidated quartz sand (feldspathic in places) and clay of variable composition	Fluvial to shallow shelf	Brenner, 1963; Brenner in Hansen, 1968; Doyle and Hickey, 1976; Wilson, 1986

Table 1. Regional correlation of stratigraphic units.

Stratigraphic age	This map and cross sections (symbol)	Charles and St. Marys Counties McCartan, 1989 a, b	Eastern Shore of Maryland and Virginia [1]Owens and Denny, 1979,1984, 1986; [2] Mixon, 1985; [3]this map	Virginia Coastal Plain west of Chesapeake Bay Mixon, Berquist and others, 1989 Mixon, Powars, and others, 1989
	QTc	Cenozoic colluvium		
Holocene	Q1	Holocene deposits	Qal[1], Qtm[1]	Qh and some Qu
Pleistocene	Q2, Q2d	Kent Island Formation	Kent Island Formation[1] Parsonburg Sand[1]	Poquoson and Lynnhaven Members of the Tabb Formation
	Q3	Maryland Point Formation[2]	Nassawadox Formation[2] Ironshire Formation[1]	Sedgefield Member of the Tabb Formation
	Q4	Omar Formation	Omar Formation[1, 2]	Shirley Formation
	Q5	Chicamuxen Church Formation	(not present)	Chuckatuck and Charles City Formations
Pliocene	T1	Ravens Crest Formation[4] Upland Gravel[4]	Walston Silt[1] Beaverdam Sand[1]	Windsor and Bacons Castle Formations
	Ty	Upland Gravel[3]	(not present)	Yorktown Formation
Miocene	Te	Eastover Formation	Pocomoke and Manokin units[5]	Eastover Formation
	Ts	St. Marys Formation	St. Marys Formation[3]	St. Marys Formation
	Tch	Choptank Formation	Choptank Formation[1]	Choptank Formation
	Tc	Calvert Formation	Calvert Formation[1]	Calvert Formation
Oligocene	To	Old Church Formation	Old Church Formation[3, 6] undivided	Old Church Formation
Eocene	Tp	Piney Point Formation	Piney Point Formation[3, 6]	Piney Point Formation
	Tn	Nanjemoy Formation	Nanjemoy Formation[3, 6]	Nanjemoy Formation
Paleocene	Tm	Marlboro Clay	(not present)	Marlboro Clay
	Ta	Aquia Formation	Aquia Formation[3, 6]	Aquia Formation
	Tb	Brightseat Formation	(not recognized)	(not recognized)
Lower Cretaceous	Kp	Potomac Group undivided	Potomac Group undivided[6]	Potomac Formation undivided

[3]Formations now identified on the Eastern Shore

[4]McCartan, 1989c; "Park Hall Formation" is hereby abandoned

[5]Owens and Denny, 1979, Manokin is equivalent to the Eastover Formation, which includes the "St. Marys of Virginia"

[6]Trapp and others, 1984

Table 2. Ground-water chemistry of selected formations in the Maryland part of Leonardtown 30x60-minute quadrangle (from Woll, 1978)

Geologic unit*	Data site	Year of sample	Elev. of land surface above MSL (ft)	Depth to bottom of sample interval (ft)	Dissolved silica (SiO_2) (mg/L)	Total aluminum (Al) (um/L)	Total iron (Fe) (um/L)	Total manganese (Mn) (um/L)	Dissolved calcium (Ca) (mg/L)
Ccu	SM Db-24	1950	50	10	8.8	–	2300	0	34
Q2	SM Df-31	1952	15	19	13	–	220	0	2.5
T1	SM Eg-14	1952	105	31	9.5	–	60	0	6.8
Ty (shelf)	SM Gh-9	1952	125	26	12	–	80	0	3.8
Ty (fluvial and beach)	SM Bb-1	1947	170	13	4.7	–	450	—	14
Te	DO Dg-4	1965	3.0	290	62	–	40	10	11
Te	DO Dh-7	1952	10	305	55	–	3000	0	9.0
Tp	CA Fd-3	1947	109	345	18	–	20	—	8.6
Tp	CA Gd-4	1947	15	250	19	–	3800	—	10
Tp	SM Df-53	1967	110	350	57	–	30	0	28
Tp	DO Dd-8	1965	6	443	17	–	80	10	5.1
Tp	DO Fe-14	1954	2	504	25	–	60	0	7.8
Tn	CA Eb-9	1967	140	389	54	–	180	20	32
Tn	CA Fd-38	1967	85	355	43	–	70	0	15
Tn	SM Bb-13	1967	170	350	43	–	430	0	28
Tn	SM De-33	1967	120	380	36	–	990	0	26
Tn	SM Gh-7	1967	10	415	14	–	20	0	3
Ta	CA Ed-1	1952	62	540	15	–	30	0	9.8
Ta	CA Fd-1	1956	21	500	13	–	70	0	2.3
Ta	CA Gd-1	1956	16	505	21	<50	530	<5	14
Ta	SM Bc-16	1967	160	482	13	–	420	0	21
Ta	SM Df-10	1962	46	534	18	–	70	0	16
Ta	SM Ff-36	1975	7	618	12	–	180	0	3.9
Ta	DO Db-4	1965	5	543	12	–	20	0	4.1
K	CA Gg-14	1966	3	681	12	–	130	<5	0.8
K	SO Dc-3	1970	4	1135	12	200	360	10	0.8

*Unit designations conform to map and cross sections.
Approximate locations of most data sites are shown on map. DO Dg-4, DO Dh-7, and SO Dc-3 are east of map.

Table 2 (cont.)

Geologic unit*	Data site	Dissolved magnesium (Mg) (mg/L)	Dissolved sodium (Na) (mg/L)	Dissolved potassium (K) (mg/L)	Bicarbonate (HCO_3) (mg/L)	Dissolved Sulfate (SO_4) (mg/L)	Dissolved chloride (Cl) (mg/L)	Dissolved fluoride (F) (mg/L)
Ccu	SM Db-24	6.1	14	8.1	121	2.7	16	0
Q2	SM Df-31	5.1	18	1.4	19	9.5	28	0
T1	SM Eg-14	1.4	2.8	1.7	27	4.8	4.5	0.1
Ty (shelf)	SM Gh-9	3.3	19	2.2	28	8.0	22	0.1
Ty (fluvial and beach)	SM Bb-1	1.5	33	4.4	15	22	55	0.1
Te	DO Dg-4	7.2	312	13	622	60	102	0.8
Te	DO Dh-7	6.2	438	14	804	163	170	1.0
Tp	CA Fd-3	4.2	59	12	177	27	1.5	0.4
Tp	CA Gd-4	4.8	50	13	187	12	3.1	0.3
Tp	SM Df-53	13	7.9	11	165	6.4	2.3	0.2
Tp	DO Dd-8	3.3	186	8.8	471	19	24	1.6
Tp	DO Fe-14	5.2	300	16	528	22	195	1.4
Tn	CA Eb-9	11	2.8	9	145	8.4	2.5	0.3
Tn	CA Fd-38	9.1	46	13	218	12	1.2	0.5
Tn	SM Bb-13	13	4.7	13	160	11	1.4	0.2
Tn	SM De-33	13	63	17	164	6.0	3.1	0.2
Tn	SM Gh-7	1.7	185	8.3	460	4.2	5.1	2.0
Ta	CA Ed-1	2.8	30	13	133	4.5	2.1	0.3
Ta	CA Fd-1	1.4	51	5.8	120	7.4	4.0	0.4
Ta	CA Gd-1	6.2	28	15	163	7.5	4.0	0.4
Ta	SM Bc-16	11	11	16	162	11	0.6	0.1
Ta	SM Df-10	6.4	39	12	182	7.4	3.0	0.8
Ta	SM Ff-36	0.2	120	4.3	305	14	2.5	0.8
Ta	DO Db-4	0.7	42	8.3	124	6.8	2.4	0.4
K	CA Gg-14	0.3	131	3.6	318	20	2.3	0.9
K	SO Dc-3	0.5	244	5.0	508	43	41	0.4

*Unit designations conform to map and cross sections.
Approximate locations of most data sites are shown on map. DO Dg-4, DO Dh-7, and SO Dc-3 are east of map.

Table 2 (cont.)

Geologic unit*	Data site	Dissolved nitrate (NO_3) (mg/L)	Phosphate (PO_4) (mg/L)	Dissolved solids residue at 180°C (mg/L)	Dissolved solids sum of constituents (mg/L)	Hardness (Ca, Mg) (mg/L)	Noncarbonate hardness (mg/L)	Specific conductance (micro-mhos)
Ccu	SM Db-24	2.5	—	176	—	111	12	307
Q2	SM Df-31	3.8	—	99	91	27	12	164
T1	SM Eg-14	9.0	—	102	94	23	0	163
Ty (shelf)	SM Gh-9	0.7	—	47	—	23	1	69
Ty (fluvial and beach)	SM Bb-1	9.0	—	102	94	23	0	163
Te	DO Dg-4	0.1	—	914	898	57	0	1390
Te	DO Dh-7	0.5	—	1270	1260	48	0	2030
Tp	CA Fd-3	0.2	—	221	222	39	0	350
Tp	CA Gd-4	0.1	—	204	205	95	0	327
Tp	SM Df-53	0	—	211	214	124	0	281
Tp	DO Dd-8	0.1	—	502	497	26	0	803
Tp	DO Fe-14	0.9	—	864	—	41	—	1450
Tn	CA Eb-9	0.2	—	189	195	125	0	256
Tn	CA Fd-38	0.2	—	240	247	75	0	342
Tn	SM Bb-13	0.1	—	194	197	124	0	275
Tn	SM De-33	0.1	—	190	193	119	0	270
Tn	SM Gh-7	0.4	—	469	468	15	0	748
Ta	CA Ed-1	0.2	—	137	143	36	0	322
Ta	CA Fd-1	7.2	—	165	—	12	0	234
Ta	CA Gd-1	0.4	0.1	184	177	60	0	276
Ta	SM Bc-16	0.2	—	165	164	98	0	270
Ta	SM Df-10	0	—	194	191	65	0	305
Ta	SM Ff-36	—	—	—	308	11	0	—
Ta	DO Db-4	0.2	—	136	138	13	0	207
K	CA Gg-14	0.6	0.92	325	328	3	0	528
K	SO Dc-3	—	624	611	611	4	0	982

*Unit designations conform to map and cross sections.
Approximate locations of most data sites are shown on map. DO Dg-4, DO Dh-7, and SO Dc-3 are east of map.

Table 2 (cont.)

Geologic unit*	Data site	pH	Temperature (deg. C)	Color (platinum cobalt units)	Total copper (Cu) (ug/L)	Total zinc (Zn) (ug/L)	Total lithium (Li) (ug/L)	Data site	County
Ccu	SM Db-24	6.7	11.1	10	—	—	—	SM Db-24	St. Marys
Q2	SM Df-31	6.3	—	3	—	—	—	SM Df-31	St. Marys
T1	SM Eg-14	6.3	—	5	—	—	—	SM Eg-14	St. Marys
Ty (shelf)	SM Gh-9	6.6	—	5	—	—	—	SM Gh-9	St. Marys
Ty (fluvial and beach)	SM Bb-1	6.3	—	5	—	—	—	SM Bb-1	St. Marys
Te	DO Dg-4	8.2	17.2	—	—	—	—	DO Dg-4	Dorchester
Te	DO Dh-7	8.5	—	38	—	—	—	DO Dh-7	Dorchester
Tp	CA Fd-3	8.2	13.5	2	—	—	—	CA Fd-3	Calvert
Tp	CA Gd-4	8.0	15	5	—	—	—	CA Gd-4	St. Marys
Tp	SM Df-53	8.3	16.6	1	—	—	—	SM Df-53	St. Marys
Tp	DO Dd-8	8.1	18.3	—	—	—	—	DO Dd-8	Dorchester
Tp	DO Fe-14	8.5	14.4	8	—	—	—	DO Fe-14	Dorchester
Tn	CA Eb-9	8.3	16.1	0	—	—	—	CA Eb-9	Calvert
Tn	CA Fd-38	8.2	16.6	0	—	—	—	CA Fd-38	Calvert
Tn	SM Bb-13	8.3	15.5	3	—	—	—	SM Bb-13	St. Marys
Tn	SM De-33	8.4	15.5	2	—	—	—	SM De-33	St. Marys
Tn	SM Gh-7	8.7	17.2	1	—	—	—	SM Ch-7	St. Marys
Ta	CA Ed-1	7.9	17.7	1	—	—	—	CA Ed-1	Calvert
Ta	CA Fd-1	9.0	—	10	—	—	—	CA Fd-1	Calvert
Ta	CA Gd-1	7.8	10	6	10	<5	1500	CA Gd-1	Calvert
Ta	SM Bc-16	8.0	17.7	3	—	—	—	SM Bc-16	St. Marys
Ta	SM Df-10	7.8	—	5	—	—	—	SM Df-10	St. Marys
Ta	SM Ff-36	8.7	21.0	1	—	—	—	SM Ff-36	St. Marys
Ta	DO Db-4	7.7	18.3	—	—	—	—	DO Db-4	Dorchester
K	CA Gg-14	7.7	20	5	—	—	—	CA Gg-14	St. Marys
K	SO Dc-3	8.5	27.5	17	—	—	—	SO Dc-3	Somerset

*Unit designations conform to map and cross sections.
Approximate locations of most data sites are shown on map. DO Dg-4, DO Dh-7, and SO Dc-3 are east of map.

Table 3. Some typical physical characteristics of stratigraphic units in Leonardtown 30x60-minute quadrangle.

Formation -depositional lithofacies	Dominant mineralogy[1]	Fragipan[2]	Depth to weathering front (m)[3]	Permeability	Resource: Gravel	Sand	Clay	Glauconite	Diatomite	Ground water[4] Low	Ground water[4] High
Q1 - beach, dune	Quartz	None	None	Very high	X					N	N
-bay, tidal marsh	Quartz	None	None	High to low	X					N	N
-small stream bottom	Quartz	None	None	High to low	X	X				N	N
Q2-river, estuary	Quartz	None	None	High to low	X	X				X	
-dune	Quartz	None	1-2 m	Very high		X				X	
Q3	Quartz	None	3 m	High to low	X	X				X	
Q4	Quartz	Rare	4 m	High to low	X	X				X	
Q5	Quartz	Yes	4.5 m	Medium	X	X				X	
T1	Quartz	Yes	5 m	High to med	X	X				X	
Ty-river	Quartz	Yes	5 m	High to low	X	X				X	
-estuary	Quartz	Yes	5 m	High to med	X	X				X	
-marine	Quartz	Yes	?	High		X	X	X		X	
Te	Qtz, glauc	I	5.5 m	Medium		X				X	
Ts	Qtz, I/S	I	6 m	High to low	X	X	X			X	
Tch	Quartz	I	N	High to low		X				X	
Tc	Qtz, I/S	I	N	High to low				X	X		
To	Quartz	None	N	High to med.							
Tp	Quartz	None	N	High							X
Tn	Qtz, glauc	I	N	High to med				X			X
Tm	Kaol, illite	I	N	Low							
Ta	Qtz, glauc	I	N	High to med.						X	
Tb	Qtz, phos, glauc	I	N	High to med.							
Kp	Qtz, kaol, illite, I/S	I	N	High to low							X

[1]Qtz, quartz; glauc, glauconite; I/S, illite/smectite mixed layer clay; kaol, kaolinite; phos, phosphate;

[2]Hard, clay-rich zone at depths of less than 1 meter to several meters below the surface; iron oxide layers (I) common between Tertiary marine units and overlying surficial units. None, no fragipan encountered; rare, rarely encountered; yes, commonly encountered.

[3]Approximate, based on presence of soil (dioctahedral) vermiculite and loss of epidote, hornblende, garnet, actinolite, tremolite, and feldspar. 1 m = 3.28 ft. None, no noticeable weathering; N, weathering zone not recorded, typically absent in subsurface.

[4]Low=low volume, mainly residential use and farm ponds; high=high volume, possible public usage. N, generally not used.

EXPLANATION OF MAP UNITS

Q1	Lowland unit 1		Holocene		
unconformity					
Q2, Q2d	Lowland unit 2				
unconformity		Upper			
Q3	Lowland unit 3		Pleistocene	Quaternary	
unconformity					
Q4	Lowland unit 4				
unconformity		Middle			
Q5	Lowland unit 5				QTc
unconformity					Quaternary
T1	Upland unit 1	Upper			and
unconformity			Pliocene		Tertiary
Ty	Yorktown Formation	Middle			colluvium
unconformity					
Te	Eastover Formation	Upper			
unconformity					
Ts	St. Marys Formation	Upper		Tertiary	
unconformity		Middle	Miocene		
Tch	Choptank Formation				
unconformity		Middle +			
Tc	Calvert Formation	Lower			
unconformity					
Tn	Nanjemoy Formation	Lower	Eocene		

MAP SYMBOLS

Contact on land -- approximately located

Contact in major waterways beneath Quaternary deposits; highly speculative

Axis of deepest Quaternary channel in major waterways

A A' Line of cross section; extended to control points outside the map area

Drill hole; SM = Maryland Geological Survey; others, USGS

- Auger hole
- Core or cuttings with gamma log
- Core or cuttings without gamma log
- Gamma log only

O Water well (Woll, 1978)

CROSS SECTIONS

Vertical exaggeration 25X

Trace of borehole on or projected to section line

Intersection of cross section lines

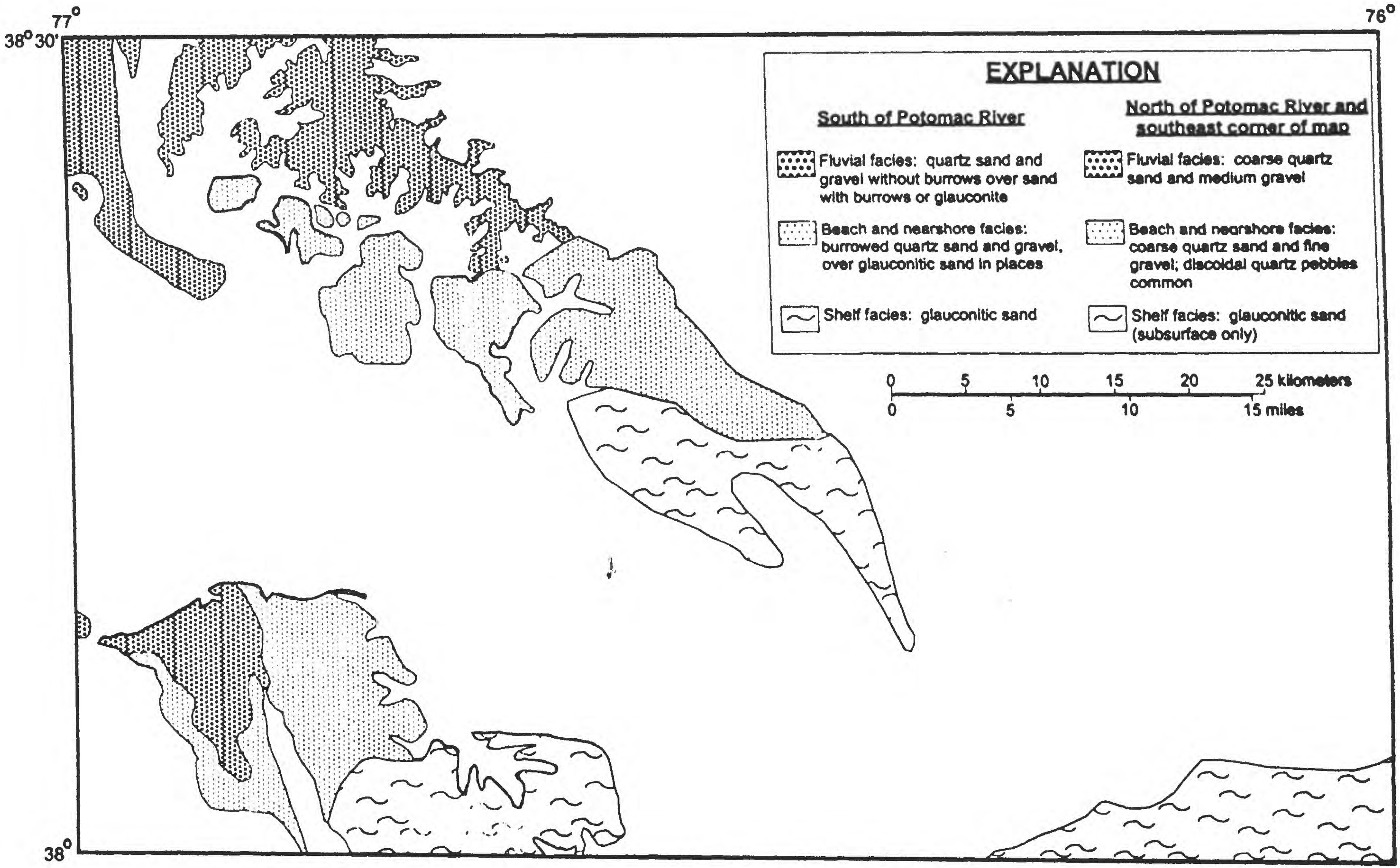

Figure 1. Map showing distribution of depositional lithofacies of the Yorktown Formation. Generalized from the geologic map.