COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION
AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES

GEOLOGIC STUDIES, COASTAL PLAIN OF VIRGINIA

BULLETIN 83 (PARTS 1 AND 2)

VIRGINIA DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA
1973

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STRATIGRAPHIC UNITS OF THE LOWER CRETACEOUS THROUGH MIOCENE SERIES

By

ROBERT H. TEIFKE

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STRATIGRAPHIC UNITS OF THE LOWER CRETACEOUS THROUGH MIOCENE SERIES

By

Robert H. Teifke

ABSTRACT

The Coastal Plain of Virginia is divided into six rock-stratigraphic units of Cretaceous through Miocene age—the Patuxent, "transitional beds," Mattaponi, Nanjemoy, Calvert, and Yorktown formations. Each is a mappable unit whose stratigraphic boundaries can be determined from well cuttings using lithologic criteria. The subsurface configuration of the formations is shown in a series of five structure-contour and four isopach maps.

The petrologic characteristics and external form of the Patuxent Formation and "transitional beds" indicate a long period of active erosion and nonmarine sedimentation in which a thick sequence of terrigenous clastics was deposited, at first as a wedge of coarse feldspathic material (Patuxent Formation) and finally, with waning activity, as the finer sediments of the "transitional beds." Nonmarine sedimentation subdued the basement relief and set the stage for the marine transgressions that followed.

The net effect of the first two transgressions, represented by the Mattaponi and Nanjemoy formations, was to obscure most of the features on the surface of the nonmarine terranes. By the end of Calvert time the surface of deposition had begun to resemble the present surface. The Yorktown surface bears an even closer resemblance to the present topography.

INTRODUCTION

This report summarizes a geologic study of Cretaceous through Miocene rock-stratigraphic units in the Coastal Plain province of Virginia between the Virginia-North Carolina boundary on the south and the Potomac River on the north, and between the Fall Line on the west and Chesapeake Bay and the Atlantic Ocean on the east (Figure 1). From north to south, four major rivers flow southeastward to Chesapeake Bay: the Potomac, Rappahannock, York, and James, which divide the Coastal Plain into four areas commonly referred to as the Northern Neck peninsula, the Middle peninsula, the York-James peninsula, and Southside Virginia.

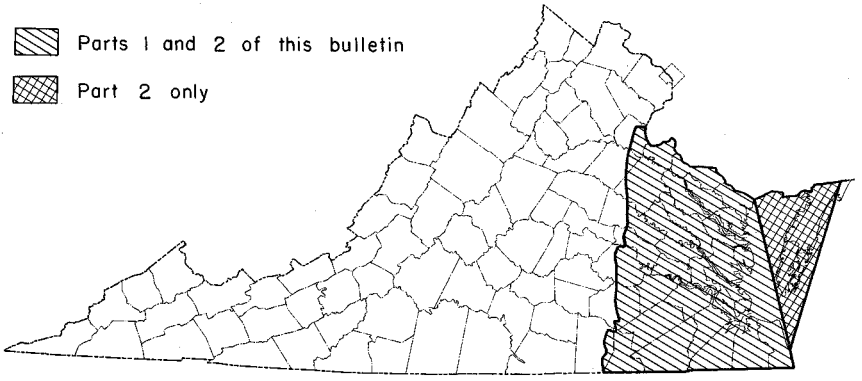


Figure 1. Index map showing location of area of study.

The purposes of this paper are:

(1) To describe and divide the sedimentary section in terms of easily determined and reproducible lithologic criteria applicable over wide areas.

(2) To map the distribution and form of the rock-strtigraphic units in such a way as to provide a sound basis for future studies relating to such problems as basin evolution.

(3) To construct a regional stratigraphic framework for projects of a more local nature.

The stratigraphic section reported upon includes all strata between the base of the Lower Cretaceous Patuxent Formation and the top of the upper Miocene Yorktown Formation. Rocks below

and above this interval are only briefly described in the text. Outcrop areas are shown on the maps for completeness, but all data that were utilized have been derived solely from boreholes. All drill cuttings that were examined are described in well logs on file at the Virginia Division of Mineral Resources. Numbers preceded by the letter "W" (W-2109) designate wells whose samples are on file in the Division's repository; the locations of the wells are shown on Plate 1. Detailed logs of representative wells, and summaries of all others which were used in preparing this report, are included in Appendices I and II.

METHODS OF INVESTIGATION

From the well cuttings and core repository, samples from 126 boreholes on file as of January 21, 1972 were chosen as the basis for this report. Selection was made on the following considerations: (1) maximum geographic distribution, (2) uniformity of coverage, (3) total depth of well and number of formations penetrated, (4) quality of samples, and (5) degree of precision with which well locations and elevations could be determined. The wells include 86 water wells, most of which were submitted by four drilling firms—Sydnor Hydrodynamics, Inc. of Richmond, Mitchell's Well and Pump Co. of Colonial Heights, Pittman's Wood & Metal Products Co. of Courtland, and Douglas and Dickinson, Inc. of Warsaw; 27 United States Geological Survey test holes; six Virginia Division of Mineral Resources test holes; and seven others.

The geographic locations and surface elevations of the wells were determined at the well sites using the latest 7.5-minute topographic maps. Sample descriptions were based mainly on examination of both washed and unwashed well cuttings with the binocular microscope. The petrographic microscope was used to verify the presence of diatoms, and to determine the amount and type of feldspar in a given sample. Sulfates, phosphates, iron oxides and hydroxides, and dolomite were identified in some instances by combinations of optical and X-ray diffraction techniques.

A base map (Plate 1) was drawn showing distribution of control, lines of section, the Piedmont-Coastal Plain boundary (the Fall Line), counties, and a few cities. Well locations initially were plotted on an overlay, and at each well, elevations of the following were posted: (1) ground level, (2) formation tops,

and (3) total depth. These data, summarized in Appendix I, were used to construct subsurface maps showing the areal distribution and three-dimensional configuration of the units.

Five structure-contour maps (Plates 2-6) were drawn, and four isopach maps (Plates 7-10) were constructed by overlaying appropriate structure-contour maps. Sample cuttings are normally recovered every 10 feet, so resolution of thinner intervals involves some interpretation. A 20-foot contour interval was chosen for the maps as the optimum interval to show desired detail consistent with this sampling frequency. Using the method described by LeRoy and Low (1954, p. 207-209) thickness values are determined not only at the wells but also at every point where contour lines on the structure maps intersect. This results in the generation of many secondary control points that permit thickness mapping in areas of little or no well control. Thickness variation, arrived at by this method, is interpretive only to the degree that the structure maps themselves are interpretive. Each structure contour and isopach map incorporates only those data points pertaining to that map.

DESCRIPTIVE STRATIGRAPHY

Six Cretaceous through Miocene formations are mappable rock-stratigraphic units in the subsurface of the Coastal Plain of Virginia. A generalized description of the formations and their age relationships are shown in Table 1. Comparison is made in Table 2 of the formations as used in this report with those of previous workers.

"BASEMENT" ROCKS

The Cretaceous-Tertiary sedimentary succession is underlain generally by granitic rocks, metamorphic rocks, and semi-consolidated "red beds." These lithologic types constitute the "basement" upon which the Lower Cretaceous Patuxent Formation was deposited nonconformably. At most places along the Fall Line, Patuxent strata are in contact with granitic rocks at elevations ranging from about 100 feet above to 100 feet below mean sea level. For the most part, the "basement" consists of biotite-microcline granite or its saprolite, that is correlated readily with the Petersburg granite exposed immediately to the west. Rela-

tively indurated "red beds" of Triassic (?) age that are tentatively assigned to the Newark Group underlie the Patuxent at several places in Henrico and Prince George counties (Plate 1, W-2071 and W-1921). Farther eastward, similar "red beds" occur beneath the Patuxent at West Point in King William County (W-515) and in the southern part of the City of Nansemond (W-3221 and W-3316). At Wakefield and Homeville in Sussex County (W-2253) and W-3220) the Patuxent rests upon biotitic schistose rocks.

CRETACEOUS SYSTEM

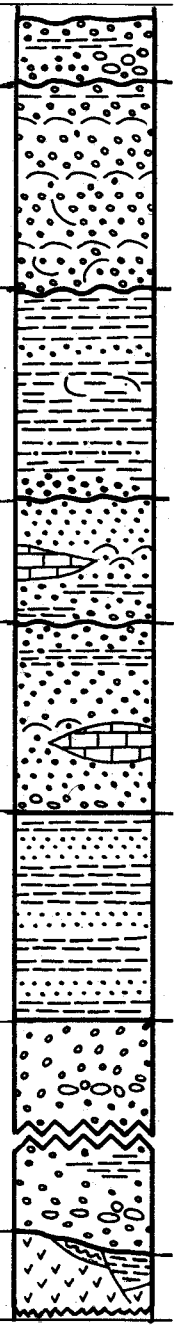
Patuxent Formation

The Patuxent Formation of Early Cretaceous age underlies most of the Coastal Plain of Virginia. It is exposed along the western margin (Plate 2) adjacent to the Nottoway, Appomattox, James, Pamunkey, and Rappahannock rivers. The formation ranges in thickness from a feather edge on the west to 310 feet in central Sussex County (W-3220), 530 feet in eastern Sussex County (W-2253), about 750 feet in the southwestern part of Nansemond (W-3221), 1210 feet in the southeastern part of Nansemond (W-3316) and more than 1785 feet at Norfolk (W-2154). Wells drilled in Dinwiddie, Prince George, Chesterfield, Henrico, and Hanover counties commonly intersect the base of the Patuxent anywhere from 100 feet above to 100 feet below sea level. In this area, Patuxent strata rest upon the Petersburg granite and, locally, upon "red beds" of Triassic (?) age. Westward toward the Fall Line, the "basement" surface becomes increasingly irregular and the thickness of the Patuxent less predictable. The "basement" surface has a steep downward inclination immediately east of the Fall Line but decreases to a regional slope of about 5 degrees eastward to the present coastline. The Patuxent is overlain mainly by Mattaponi strata; in a large part of the area south of the James River and just southeast of Fredericksburg it is overlain by the "transitional beds". In a few areas along the Fall Line the Calvert or Yorktown immediately overlies the Patuxent. In all cases, the contact is inferred to be a disconformity.

The Patuxent is an alternating sequence of fine gravels, coarse sands, and silty to sandy clays. The ratio of sands and gravels to beds of finer clastic material is variable downdip and along

Table 1.—Geologic formations in the Coastal Plain of Virginia.

Age	Series	Name	Lithology
Quaternary	Pliocene-Holocene	Columbia Group	
	—?—?—?		
Tertiary	Miocene	Yorktown Formation	
		Calvert Formation	
	Eocene	Nanjemoy Formation	
	Paleocene	Mattaponi Formation	
—?—?—?	—?—?—?		
Cretaceous (?)	Upper (?)		
—?—?—?			
Cretaceous	Lower	"transitional beds"	
		Patuxent Formation	
Precambrian-Triassic		"basement"	



Character
Light-colored oxidized deposits; mainly clays, silts, sands, and gravels; some peat.
Gray to bluish-gray silts, sands, shell beds; clay beds uncommon. Bioclastic sands and quartz-glauconite sands in southeastern part.
Drab greenish-brown clays and silty clays, commonly consolidated. Plant fragments and mollusks common, locally abundant. Diatomaceous silty clays; *Siphogenerina* zone near base. Coarse basal sand—quartz-phosphorite, locally fossiliferous.
Quartz-glauconite sands; shell beds and cavernous shell limestone fairly common. Three basal lithologies: coarse sands in eastern part; pale-gray and pale-red clays in central part; fine, silty, glauconitic beds in northwestern part.
Drab green, gray, and brown glauconite-bearing clays; glauconite and quartz-glauconite sands; thin beds of shell and dense limestone. Glauconite mainly lobate, fissured, commonly sooty, commonly highly concentrated. Multicolored clay interbeds become increasingly common downward in eastern part; gravel marks base in western part.
Bright variegated fine-grained clastics; mainly nonfossiliferous. Finer and less feldspathic than Patuxent, less glauconitic than Mattaponi; feldspar and glauconite typically decomposed. Distinguishable only in south and northwest; bottom part is gray to maroon in extreme south.
Mainly medium- to very coarse-grained sands and fine-grained gravels; openwork deposits common. Mainly pale beds with tan, light-gray, and pale-green clay interbeds. Contains more coarse sand and gravel, and less silt and clay than "transitional beds". Potassic feldspar is diagnostic; blue quartz and pink garnet are very common.
Igneous and metomorphic rocks of Precambrian and Paleozoic age; partly consolidated sediments of Triassic(?) age.

Table 2.—Comparison of the stratigraphic units used in this report with those previously used in the Coastal Plain of Virginia.

Age		Richards (1967)	Present report
Quaternary	Pliocene-Holocene		Columbia Group
Tertiary	Miocene	Yorktown Formation	Yorktown Formation (possibly Pliocene in part)
		St. Marys Formation	
		Choptank Formation	
		Calvert Formation	Calvert Formation
	Eocene	Chickahominy and Piney Point fms.	
		Nanjemoy Formation	Nanjemoy Formation
		Aquia Formation	Mattaponi Formation
	Paleocene	Mattaponi Formation	
—?—	?—?		
Cretaceous	Upper (?)		
	Lower	Raritan Formation	"transitional beds"
		Patapsco Formation	
		Arundel Formation	
		Patuxent Formation	Patuxent Formation

strike, but in gross aspect the lithologic association is sufficiently distinctive to be identified in well cuttings. The distinction is difficult, however, where "transitional beds" are present because these beds are generally gradational in lithology with those of the Patuxent. Patuxent sands are variable in textural characteristics and tend to be coarse; the average grain size is 1.0 mm. The size distribution is skewed toward the coarser sizes and grades into a fine, well-sorted gravel fraction. The gravels comprise mostly granules (2-4 mm); pebbles larger than 10 mm are uncommon. The typical sand is well-winnowed to slightly clayey. The entire distribution, disregarding small amounts of clay, is

fairly even. Roundness increases with grain size; the gravel invariably is more rounded than the sand. Only in the fine fractions is there a marked degree of angularity.

Patuxent sands are mainly tan, gray, or white and are characteristically feldspathic. The percentage of feldspar is variable and commonly low, particularly near the top of the formation, but the essential absence of feldspar in the overlying units effectively defines this contact. The top of the Patuxent is routinely picked at the top of the highest feldspathic sandstone of a sand-rich interval. Feldspar is principally potassic, consisting mainly of microcline and microperthite; plagioclase is scarce. Grains range in state of preservation from fresh to intensely decomposed. Composition of the sands ranges from slightly feldspathic to arkosic (feldspar $>$ 25 percent); generally, the feldspar content increases with grain size from the silty fraction to the coarsest gravels. Clay units and clay within the coarse-grained units range from red, orange, and yellow through pale green and gray; they are seldom very dark. Where clay is present, it usually contains a fraction of angular coarse silt to fine sand. Clay units, especially the green and gray types, contain a few poorly preserved plant remains. Glauconite is relatively rare in the Patuxent but it becomes increasingly common upward through the formation. Glauconite is characteristically coarse grained and comparable in size with associated quartz, and is somewhat abraded. Large grains of pink garnet and large flakes of muscovite are typical accessories; zircon, tourmaline, and brown epidote are sporadic in occurrence, and kyanite is rare.

Regionally, the Patuxent is a wedge-shaped body of sediment. The western margin of the wedge is locally slightly lithic and reflects the nature of the adjacent Piedmont rock types. The sand-gravel units locally contain fragments of granitic rock, chert, schist, quartzite, or diabase that are most common in the coarsest grades. Clay pellets are another common constituent of the sand-gravel units. According to Glaser (1969, p. 29-32) clay clasts are a common feature of the Patuxent Formation, especially the gravels. However, some of the pelleted clay observed in cuttings from downdip wells may have been formed by the drilling process acting upon bedded clays. Discernible diagenetic changes in the Patuxent are restricted to isolated occurrences of spot-cementation by well-developed crystals of pyrite, and semi-consolidation of certain clayey sands by compaction. Generally, the coarse clastic units are quite unconsolidated.

"Transitional Beds"

Throughout the greater part of the mapped area, the Patuxent beds are overlain by the Mattaponi Formation. In the northern and southern parts of the Coastal Plain in Virginia, however, the Patuxent is immediately overlain by a succession of strata with few affinities to the Mattaponi as defined in this report. The beds in question are in gross aspect either intermediate in composition and texture to those of the Patuxent and Mattaponi or comprise alternations of lithotypes characteristic of the two units. In this report these intermediate strata of Early Cretaceous age, which have been observed only in well cuttings, are designated "transitional beds." They are underlain everywhere by Patuxent strata and the contact is presumably one of marked unconformity. Moreover, deposition of the "transitional beds" appears to have been greatly influenced by the configuration of the Patuxent surface. Greatest thicknesses of transitional strata in both the north and south correspond to low areas on the Patuxent surface whereas high areas on the Patuxent surface are overlain by markedly thinner sections of transitional strata (Plates 2, 7). The "transitional beds" are succeeded almost everywhere by the Mattaponi Formation.

The "transitional beds"-Patuxent Formation contact is picked at the top of the uppermost sequence of distinctly feldspathic coarse-grained sand in the Patuxent. Because feldspathic sands and brightly colored clay beds are common to both units in the vicinity of this contact, a sufficient thickness of Patuxent must be penetrated to make sure the borehole has not simply passed through a thin stringer of "transitional beds" sediment resembling the Patuxent. The top of the "transitional beds" is in most places immediately below the lowermost distinctly glauconitic interval or a fine basal gravel of the overlying Mattaponi Formation. Moreover, drab-colored clay beds and clay matrix in sand units of the Mattaponi contrast strongly with the clay in the "transitional beds," which usually is brightly colored and variegated.

The stratigraphic interval thus defined consists of beds of sand, silt, and clay; it has a lower sand-clay ratio, less gravel-size materials, and more fossils than the Patuxent. Sands may be as coarse-grained as those of the Patuxent, but are typically poorly sorted; most gravel is of granule size (2-4 mm). The average "transitional beds" sand contains more glauconite and less feld-

spar than the Patuxent, and less glauconite and more feldspar than the Mattaponi; the relative proportions of these essential constituents is highly variable, but quartz is normally the most abundant mineral. The "transitional beds," then, are texturally immature but are considerably more mature mineralogically than the Patuxent.

One important lithologic type is poorly sorted, very fine- to very coarse-grained quartz sand with an abundant clayey matrix. Glauconite is present and locally approaches quartz in abundance. Quartz tends to be angular and glauconite is somewhat rounded by transport. Glauconite in the "transitional beds" tends to be lighter in color— medium-, light-, and bluish-green—as opposed to the typically greenish-black to sooty appearance of the glauconite in the sands and clays of the Mattaponi Formation.

Clay occurs in the "transitional beds" as matrix in the sandy beds and as discrete beds of silt-, sand-, and gravel-bearing clay up to 50 feet in thickness. In either occurrence, the clays range in color from bright red, orange, and yellow to tan, brown, and gray; many of the drab-colored clays have a distinctive purplish cast and interlaminations of bright and drab clays are common. Marked variations in the percentages of silt and sand occur in the clays, and these variations appear to bear a relationship to the color of the clay at a given locality. The bright laminae are usually sandier where bright clays are interlaminated with, but subordinate to, dark clays. Glauconite of the clay beds is considered autochthonous because its shape precludes much transport; it occurs in various colors depending on the state of oxidation of the enclosing clay.

A limited number of genera of Foraminifera have been observed in the "transitional" interval; they occur in both sandy and clayey units and are mainly small forms, many of them pelagic. The darker gray clays are commonly quite carbonaceous. Abundant finely divided lignitic material, and a very few plant fragments, are most typical. Dark-brown to gray phosphorite is present as rounded to irregular fragments of multicycle origin. It is closely associated with glauconite, being most abundant where the beds are most glauconitic. Much of the phosphorite appears to be of organic origin. A small amount, however, comprises reworked fragments of bedded, sandy phosphorites.

CRETACEOUS (?) AND TERTIARY SYSTEMS

Mattaponi Formation

The Mattaponi Formation lies directly upon either the Patuxent or "transitional beds" throughout the Coastal Plain of Virginia. It is overlain by the Nanjemoy Formation north of the James River and by either Calvert or Yorktown strata south of the James (Plate 12). Thus defined, the Mattaponi interval includes all rocks referred to the Aquia Formation in the outcrop belt (Virginia Division of Mineral Resources, 1963). It comprises beds of quartz-glauconite sand, drab-colored glauconite-bearing clay, shell beds, and an occasional bed or beds of indurated calcitic rock. Basal gravel and sandy dolomitic siltstone are subordinate lithologic types of relatively local occurrence. Abundant autochthonous glauconite is the principal lithologic criterion used to identify the unit. Although glauconite occurs in the Patuxent Formation, persists through the "transitional beds", and is a major constituent of the overlying Nanjemoy Formation, neither is it as consistently present nor concentrated as in the Mattaponi. More importantly, the autochthonous aspect of most Mattaponi glauconite is in marked contrast to its appearance in the other units. Typically, glauconite in the overlying Nanjemoy is abraded, especially near the base of the formation, and the glauconite in the "transitional beds" is slightly to intensely decomposed. Criteria for distinguishing autochthonous from allochthonous glauconite are grain morphology and grain-size characteristics. Firstly, grains classed as autochthonous show evidence of having been formed in place—polylobate form, deep fissures, and a sooty or low-luster appearance. Allochthonous glauconite is more-or-less abraded and commonly more lustrous. Secondly, variations in grain-size distributions of allochthonous glauconite and quartz, its most common accompanying mineral, are parallel with the grain size distribution of the glauconite tending toward coarser sizes than the quartz. In addition, the Mattaponi glauconite consists mainly of polylobate and globular forms, and very few flattened or squeezed grains. Glauconite morphology thus suggests that, in general, the Mattaponi "greensands" accumulated relatively slowly, with the glauconite passing the gelatinous stage before it was embedded.

Glauconite occurs in a wide range of colors interpreted as representing various stages and types of decomposition and alteration. Brown and red "glauconite" has been identified by

X-ray diffraction studies as goethite and hematite respectively, but other oxides and hydrous oxides of iron undoubtedly occur. Jarosite, a sulfate of iron and potassium, was identified locally by its color, habit, and association with glauconite, pyrite, calcitic material, and gypsum. Sulfate ions derived from pyrite commonly react with calcium carbonate to form gypsum, and with glauconite to generate jarosite (Carozzi, 1960, p. 56).

Glauconite ranges from dark green through bluish green, light green, yellowish green, and yellowish brown to brown, and locally to yellow and red. Of these, dark green, bluish green, and light green are typical of the glauconite in the Mattaponi beds. At the top and bottom of the unit in some areas, or immediately adjacent to calcitic beds, the mineral is more thoroughly decomposed. Sand-size glauconite in clayey sands closely approximates the color of the clay matrix, indicating the presence of abundant submicroscopic particles of glauconite in the clay. Submicroscopic glauconite similarly permeates much of the quartz and feldspar detritus as well as many microfossil fragments.

Brown to black phosphorite is common in the Mattaponi, tending to be concentrated in the coarsest sands and associated gravelly beds. It characteristically is associated with basal lithotypes, both those at the base of the Mattaponi and at intraformational diastems defined by textural (coarsening downward) and mineralogical (weathering) criteria.

Size and shape of phosphorite grains in the Mattaponi is very diverse, ranging from minute flakes in fine-grained glauconitic sands to polished nodules up to 15 mm in diameter in the pebbly zones. All but the smallest grains are well rounded. Nodules of various sizes and fragments showing some sign of organic origin are most common. These fragments include long bones of vertebrates, shark and ray teeth, vertebrae of various types, coprolites, internal molds of gastropods, pelecypod shell fragments, and occasional mammal bones and teeth. Tan pellets and fragments of sandy, glauconite-bearing phosphoritic rock also occur.

Although the Mattaponi in general is markedly more glauconitic than any other formation, individual beds within the Mattaponi contain as little as 5 percent of glauconite, with the complement of sand-size material consisting essentially of quartz. Speckled-appearing sands with comparable percentages of glauconite and quartz are common. Quartz ranges in shape from

angular to rounded with roundness increasing with grain size. Coarse, poorly-sorted units show this relationship. In the more distal and deeply buried beds, quartz exhibits a strong tendency towards finer grain sizes, good sorting, and angularity. This fine angular quartz component is markedly uniform throughout the area in being either clear or having a pale-green color undoubtedly imparted by submicroscopic particles of glauconite.

Clay beds intercalated with sands and clayey sands are characteristically dark in color—browns, grays, and greens; brightly variegated clays are common only north of the Rappahannock River. The drab-colored clays are sandy, but the sand-size sediment consists essentially of glauconite, sulfides, and sulfates generated in place; they contain little or no terriginous detritus. Relatively pure clays occur locally; these are pale orange to pale gray and contain only small percentages of fine quartz silt and sand-size grains of muscovite and autochthonous glauconite.

Fragments of calcitic rock are common in most cuttings from the Mattaponi interval. These are sporadically distributed both laterally and stratigraphically and in most cases are of little value as a basis for correlation. In most samples representing 10 feet of section, the fragments are diluted with various proportions of loose sand. Accordingly, the calcitic beds are inferred to have maximum thicknesses of 10 feet; probably they are much thinner. Recurrence of the fragments through many tens of feet of section may indicate successions of calcitic laminae intercalated with unconsolidated glauconitic sands. Lateral discontinuity and limited thickness suggest that these beds are lensoid or prismatic in shape.

The calcitic fragments are white to pale gray or pale yellow, are invariably sand-bearing and glauconitic, and range from sandy limestone to calcitic or dolomitic sandstone. Recognizable bioclasts usually are not present. The calcitic fragments are dense and noncavernous, and contain little secondarily precipitated sulfides and sulfates. *In situ* oxidation or replacement of glauconite by sulfides is not common in the calcitic beds of the Mattaponi. Zones of allochthonous, oxidized, and sorted glauconite and stained, polished quartz commonly occur adjacent to the calcitic zones. These sands are overlain within a few feet by the typical autochthonous "greensands."

Dolomitic beds are another distinct Mattaponi lithotype. They occur at or near the top of the formation in Southampton County

(W-2013, W-2049), in Isle of Wight County (W-1926), and in Nansemond (W-2012, W-2039, W-2050, W-2051). In the area of these wells, the Mattaponi ranges from 50 to 80 feet in thickness. Typically, the dolomite is restricted to the uppermost 20 feet of the section, but at Whaleyville (W-2050) the upper 40 feet is dolomitic. The dolomitic interval contains numerous lenses of sandy, green, glauconitic clay and calcitic, gray, glauconitic sandstone and grades downward successively into brown, dolomitic beds; green, glauconitic sands; and gray, calcitic sandstones.

The dolomitic lithotype comprises tan, brown, and brownish-green sands and sandy silts that locally are fairly well indurated. The sands consist mainly of glauconite and subordinately of quartz. Minor constituents include disseminated lignite, pyrite, nodular and bone phosphorite, and minute crystals and crystal aggregates of gypsum. The dolomite itself is restricted to the silt fraction and occurs abundantly as well-defined rhombic crystals of even grain size (0.02-0.05 mm).

The base of the Mattaponi where underlain by coarse-grained Patuxent lithotypes, as it is along and immediately east of the Fall Line, is a basal gravel of variable thickness. In Sussex and western Southampton counties (W-2207, W-2208, W-2210, W-2211, W-2212, W-2214), split spoon sampling recovered fine-grained gravel no more than a few inches thick immediately above coarse, feldspathic Patuxent sands. These basal Mattaponi gravels are infilled with, and grade upward into, the relatively fine-grained and better sorted glauconitic sands and clayey sands of the main body of the unit. A distinct basal gravel was not detected seaward of a northwestward-trending line through the southern tip of Isle of Wight County.

Thicker and coarser gravels of similar aspect and stratigraphic position have been observed along strike at Walthall (W-1908) in Chesterfield County, in southern Hanover County (W-1301, W-1662, W-1948, and W-2224), and in northern Hanover and western King William counties (W-1613 and W-2158). Downdip, basal gravels seldom are detected at this stratigraphic position.

The basal gravels consist mainly of rounded to well-rounded pebbles of quartz and quartzose sandstone, polished nodules and bone fragments of phosphorite, and rounded glauconite-stained cleavage fragments of potassic feldspar. Locally, phosphatized shark teeth and internal casts of gastropods are common. The

gravel ranges in size from granules to pebbles 15 mm and more in diameter. The matrix is much finer and well sorted.

Phophatized remains of vertebrates and invertebrates are very common in the Mattaponi, but make up only a small percentage of its faunal content. Of far more importance, volumetrically, is invertebrate debris consisting of fresh to intensely decomposed or comminuted carbonate shell materials. The original volume of shell material was much larger if the aggregate thicknesses of calcitic sandstone, sandy limestone and certain intervals of calcareous clay are considered to have been generated from precursor shell beds.

Pelecypods of several genera are dominant both in transported shell deposits and in shell accumulations that show no signs of having been transported. In the latter category, encrusting and ramose bryozoans in some places equal pelecypods in abundance. Gastropod tests, worm tubes, and the spines and plates of echinoderms are common; scaphopods and solitary corals are comparatively rare.

Foraminifers and ostracods are common in sands and clays alike. Many genera are noted, but three large forms—*Robulus*, *Dentalina*, and *Nodosaria*—are both conspicuous and consistently present. The first appearance of these genera downward through the section usually corresponds well with the first appearance of typical Mattaponi lithotypes. Moreover, these genera occur nearly everywhere in the Mattaponi making them especially useful for purposes of identifying the unit where other criteria might fail.

TERTIARY SYSTEM

Nanjemoy Formation

The Nanjemoy Formation comprises sediments generally considered to be of early to late Eocene age. The formation is an alternating succession of sands, clays, and calcitic units. The sands are mineralogically simple, consisting mainly of quartz and glauconite. However, they are highly variable in the relative proportions of these two minerals, ranging from brown clayey sands in which glauconite is a minor constituent to clean "greensands" in which glauconite may constitute as much as 90 percent of the grains. Sands of the second type, when examined out of sequence, are difficult to distinguish from "greensands" of the

Mattaponi. However, the dominant sand type in the Nanjemoy is more quartzose than glauconitic. Where they occur, glauconite-rich sands in the Nanjemoy are seldom more than 20 feet thick, whereas 50 consecutive feet of the same lithotype is common in the Mattaponi.

Generally, the Nanjemoy immediately overlies the Mattaponi Formation. Determination of the base of the Nanjemoy can be difficult because both units are glauconitic and contain semi-indurated to indurated calcitic strata, and because the Nanjemoy exhibits marked lateral variations in lithology.

Well cuttings show three distinct rock types that constitute the base of the Nanjemoy: (1) a "pink clay stratum"; (2) "brown speckled sands"; and (3) drab, clayey silts and fine sands. The first of these corresponds to the Marlboro clay member, which was described by Cederstrom (1957, p. 27) as forming the base of the Nanjemoy in parts of Henrico and Charles City counties. The "pink clay member" ranges in thickness from a few feet to as much as 30 feet of nonsandy clays. The textural uniformity of the clay, more than its color, is the main criterion for identifying this unit. Typically, the "clay" comprises interlaminations of (1) pink to pale-orange clay with traces of quartz silt and minor amounts of green glauconite, (2) light-gray clay with small percentages of quartz silt and fine-grained sand, and (3) dark-gray to black, clayey silt to very fine-grained sand. Either "pink" or light-gray clay is dominant and dark silty laminae are clearly subordinate.

Specific sequences identified as the "pink clay stratum" in areas other than the upper York-James Peninsula include (1) 20 to 30 feet of alternating pinkish-orange and dark-gray clay in King George County (W-1851), (2) approximately 20 feet of predominantly pink clay in central and eastern Essex County (W-1857), and (3) less than 10 feet of finely interlaminated orange-pink, light-gray, and yellow clays, with subordinate glauconitic silts at Jamestown (W-2102). The "pink clay stratum" thus appears to constitute the base of the Nanjemoy in a belt extending from northern Surry and Prince George counties to the northern limit of the study area.

To the east, the base of the Nanjemoy is marked by relatively coarse-grained and reworked glauconitic sands of basal lithotype 2. It consists of coarse sands which are locally either clayey

or contain abundant shell debris. Typically, however, they consist of slightly pebbly sands with very little clay matrix or shell material. Grain size ranges from medium to coarse and sorting is generally poor. Parallel variations in grain size distributions between the principal constituents, quartz and glauconite, are quite apparent.

The most distinctive characteristic of basal lithotype 2 is the nature of the glauconite. Whereas glauconite in the underlying Mattaponi strata is predominantly autochthonous, the glauconite in the basal Nanjemoy is interpreted to be allochthonous. Evidence of considerable transport is the scarcity of lobate forms of any type and the predominance of abraded grains, ranging from slightly abraded furrowed types to well-rounded oval grains. In addition to considerable abrasion, the glauconite of this lithotype has undergone slight to intense chemical decomposition. Colors range from pale green to yellow and brown with brown being most typical. X-ray diffraction patterns of the brown grains show a composition approximating that of goethite.

Quartz grains in basal lithotype 2 are rounded to extremely well rounded and polished. Fine well-rounded gravel, comprising quartz pebbles, and rounded shell fragments and phosphoritic nodules complete the average assemblage. The quartz component of the sand fraction, the gravel fraction, and the clay fraction, where present, are in most cases deeply stained by iron compounds of the same color as the accompanying sand-size glauconite; brown, yellow, and pale green are most common.

Basal lithotype 3 forms the base of the Nanjemoy in the northwestern part of the study area. Here, the basal Nanjemoy comprises well-sorted, fine- to very fine-grained silty sands and sandy silts with abundant matrix of drab green to brown clay. The sand and silt fractions consist of 70 to 90 percent, angular, clear to greenish quartz, and 10 to 30 percent dark-green glauconite. Muscovite is a minor but persistent component. Shell material, mainly gastropods and pelecypods, constitutes up to 10 percent of the unit; foraminifers and ostracods are present but not common. The unit is from 20 to 50 feet thick and exhibits a subtle coarsening downward to its contact with the texturally similar but more glauconitic beds of the underlying Mattaponi. Basal lithotype 3 in all of its occurrences constitutes all or most of the Nanjemoy as far westward as the zero isopach contour of the Nanjemoy.

The distribution of the three basal lithotypes is incompletely known. Present information does seem sufficient, however, to indicate that additional lithotypes do not occur.

The lithologic character of the Nanjemoy above its basal lithotypes is generally similar to that of the underlying Mattaponi Formation. Strata overlying the coarse-grained basal unit of the Nanjemoy (basal lithotype 2) under the eastern part of the Coastal Plain consist of variously clayey, quartzo-glauconitic sands; gray to white, sandy and glauconitic limestones; and subordinate intervals of greenish-gray to pale-gray clay. Westward toward the Fall Line, it becomes increasingly difficult to distinguish the Nanjemoy from the underlying Mattaponi and even from the overlying Calvert.

Where both sands and calcitic sandstones are fairly thick, a dominantly calcitic interval, in some places several tens of feet in thickness, immediately overlies basal lithotypes 2 (W-1859, W-1909, W-1922). This calcitic section is overlain in turn by medium- to coarse-grained glauconitic sands that are somewhat finer and considerably less oxidized and abraded than those of the basal lithotype.

Calcitic intervals in the Nanjemoy are relatively indurated and abundantly fossiliferous. In places, they grade upward into unindurated shell accumulations which they resemble in every respect but degree of cementation. Regardless of degree of cementation, most shell-limestone units consist of the following types of shell fragments, in order of decreasing abundance: pelecypods, bryozoans, gastropods, corals, echinoderm spines and plates, and worm tubes. Foraminifers and ostracods usually are present in large numbers but are volumetrically important in only a few wells.

The most indurated calcitic units invariably contain some quartzo-glauconitic sand, but are less sandy than the calcitic units in the underlying Mattaponi. A typical characteristic of the Nanjemoy limestones is their cavernous structure and relatively high percentage of pyrite. Pyrite occurs as drusy coatings in the interstices among shell fragments, as replacements of shell materials, and as replacements of glauconite pellets. It commonly is altered to white, powdery, microcolliform sulfates. Cavernous shell limestone in the Nanjemoy in James City County (W-1909) is exceptionally pyritic and grades downward into lime-

stone and basal sands stained with hematite. Whatever the nature of the alteration, it appears that the pyritic zone was the source of the hematite stain.

In Northumberland, Lancaster, Mathews, and eastern Westmoreland counties, basal lithotype 2 is overlain by a sequence of quartzo-glauconitic sands, calcitic standstones to sandy limestones, and greenish-gray to light-gray clays. Sands are medium- to coarse-grained, as they are farther south. Typically, however, they have a very abundant matrix of light-gray calcareous clay-size particles which appears to be a "paste" of comminuted shell material. In most places, shell beds, sands with abundant shell debris, and fossiliferous limestone occur in the middle of the Nanjemoy.

Calvert Formation

The Calvert Formation includes all strata between the top of the Eocene Nanjemoy Formation and the base of the Miocene Yorktown Formation or, where the Yorktown is absent, the base of the Pliocene-Holocene Columbia Group (Table 1). South of Petersburg the Calvert is absent beneath most of Prince George, Sussex, and Southampton counties where Yorktown strata rest directly upon the Mattaponi Formation. North of Petersburg the Calvert is the most widespread unit in the Coastal Plain of Virginia. It overlaps progressively older strata westward and rests upon rocks of the Piedmont province at many places along the Fall Line. Within its "outcrop" area (Plate 6) the Calvert is mostly covered by thin post-Miocene deposits. Eastward it passes beneath sediments of the Yorktown Formation. In turn, Calvert strata may immediately overlie any of the older Cretaceous or Tertiary units except the "transitional beds", which are directly overlain only by the Mattaponi Formation. Mainly, the Calvert overlies the Nanjemoy north of the James River and the Mattaponi south of the river.

Maximum observed thicknesses of the total Calvert section include 345 feet at the mouth of Chesapeake Bay (W-979) and 332 feet in Northumberland County (W-1184). Where the Calvert is thick, it generally is possible to define two internal lithologic boundaries with a fair degree of confidence and thereby divide the formation into three parts: the basal sand member, diatomaceous member, and upper member.

Basal sand member: This unit rests upon either Nanjemoy or Mattaponi strata and is overlain in most places by younger Calvert beds. It has a maximum observed thickness of about 80 feet. Mainly, the basal sands are subordinate in thickness to the rest of the Calvert section, but south of the James River, they form a much greater proportion of the total thickness. This sand member seems to form the base of the Calvert at most places east of 77° west longitude. It is mainly absent west of that line but does extend to the western limit of the Calvert south of the James River.

The basal sand member consists predominantly of sands with minor intercalated clay beds or lenses. The sands are distinctive in that they contain only traces of glauconite, which invariably is very fine grained. The principal constituents are clear, inclusionless, subrounded to rounded, polished quartz and 5 to 25 percent reworked phosphorite—bone, nodular, pelletal, and fragments of sandy phosphate rock. This is the most highly phosphoritic zone in the Coastal Plain section and causes a marked inflection on gamma-ray logs.

Texturally, the sand fraction of the basal member is well sorted and tends to be coarse grained, but ranges in grain size from medium to very coarse grained. Although commonly developed as a sequence of "clean" sands, the basal member in many places contains a matrix of brown to grayish-brown clay that constitutes up to 40 percent by volume of specific beds within the interval. Some of the clayey beds are highly foraminiferal, whereas others consist partly of sand-size shell fragments in which the clay matrix generally is light gray and calcareous. Locally, these calcareous beds directly overlie calcareous Nanjemoy strata and cause the Calvert-Nanjemoy contact to be somewhat indistinct.

The bottom of the basal sand member is marked by a distinct change in mineralogy from quartz-phosphorite above the Nanjemoy-Calvert contact to quartz-glauconite or glauconite-bearing clays below it. The top of the basal member is picked where the coarse-grained sands contact distinctly finer grained, younger Calvert sediments.

Diatomaceous member: The first Calvert beds above the basal sand member are typically highly diatomaceous, especially in the northeastern counties of Westmoreland, Northumberland, Lan-

caster, Richmond, and Middlesex. The 100 to 180 feet of moderately diatomaceous to very diatomaceous strata that occur in this area constitute the diatomaceous member of the Calvert. In other areas this interval is thinner, less diatomaceous, and less easily defined. The diatomaceous beds are pale brown to buff, very pulverulent, and extremely uniform in texture; they contain little sand or coarse silt. In addition to its diatom content, this member of the Calvert commonly contains numerous plant fragments and lignitic masses. Near its base, it is characterized by "floods" of well-preserved foraminifers dominated by the genera *Siphogenerina* and *Uvigerina*. In most places this faunal assemblage does not persist downward into the underlying basal sand unit. Strata referred to here as the diatomaceous member most likely constitute the Fairhaven member of the Calvert as defined by Dryden and Overbeck (1948).

Upper member: This unit comprises that part of the Calvert Formation between the diatomaceous member and the base of the Yorktown Formation. It consists mainly of greenish-gray to brownish-gray silty clay and interbedded accumulations of mollusk shells. Additional lithologies include light-gray, bluish-gray, and purplish-gray clays; dark-gray, presumably carbonaceous clay; clayey and sandy, relatively well-indurated, calcareous strata; and thin laminae of gray, fine-grained sand. Commonly, the clay beds are compact and in some cases slightly fissile. Plant fragments are common and authigenic gypsum and vivianite are locally prominent. The upper part of the Calvert Formation has been called the Plum Point marl (Dryden and Overbeck, 1948).

In the northern part of the map area where the Calvert is thickest, the base of the upper member is placed at the top of the diatomaceous beds. The transition, ideally, is from buff or tan, pulverulent clays of the diatomaceous member to relatively dense, greenish-gray, silty clays of the upper member. Commonly, samples from the contact zone beneath the diatomaceous and upper members contain yellow- or orange-mottled clay or sand, and weathered, iron-stained shell fragments, suggesting subaerial exposure. To the south and west, the diatomaceous member is not defined as easily, and the upper member must be determined on the basis of the more subtle characteristics listed for each member. Commonly, these criteria fail and the section cannot be subdivided. North of Petersburg, strata referred to the

upper two members (undifferentiated) constitute the entire Calvert section, and fine-grained, well-sorted beds persist to the western limit of the formation where they rest upon Patuxent sediments or igneous and metamorphic rocks.

The top of the Calvert is defined by its contact with one of several basal Yorktown lithotypes—medium- to coarse- grained quartz or quartzo-glauconitic sands, shell beds, or sandy and highly fossiliferous bluish-gray clays. Commonly, the top of the upper member of the Calvert is a greenish-gray clay that is mottled orange to brownish orange. This clay is probably a zone of decomposition, presumably a few feet in thickness, at the top of the formation; its extent has not been mapped. Criteria used to define the Calvert-Yorktown contact relate to either an unconformity or an influx of relatively coarse-grained terrigenous material. Where these criteria cannot be used, as where clays common to the upper Calvert and the Yorktown are in immediate superposition, the Miocene remains undifferentiated.

Yorktown Formation

Sediments between the top of the Calvert Formation and the base of the Columbia Group are referred to as the Yorktown Formation. They are distinguished from the Calvert by their more abundant and markedly coarser sand-gravel units; by more abundant and thicker shell beds; and, to a lesser extent, by the prevalence of gray, light-gray, and bluish-gray colors of the Yorktown strata. In summary, the Yorktown is coarser, more fossiliferous, and lighter in color than the upper member of the Calvert which is a drab greenish-gray, predominantly clayey unit containing fewer and thinner shell beds. Compared to the upper member of the Calvert, the sediments at the base of the Yorktown mark a pronounced change in the conditions of sedimentation, which are interpreted as involving shoaling and a sudden influx of coarse-grained terrigenous detritus.

The Yorktown constitutes the present land surface over wide areas of the Coastal Plain of Virginia. Yorktown strata extend farthest inland south of the James River and are recognized as far west as western Prince George, Sussex, and Southampton counties (W-1804, W-1937, W-2240, W-2211, W-2212, and W-2214). The western limit of the formation north of Petersburg corresponds with the Calvert-St. Marys boundary shown

on the geologic map of Virginia (Virginia Division of Mineral Resources, 1963). The Yorktown is thickest near the mouth of the James River where it ranges from 250 to 350 feet (Plate 11, E-E′).

The petrography of the Yorktown is significantly different north and south of the James River. To the north, the formation is a relatively uniform succession of interbedded gray sands, shell beds, clays, and thin, fine-grained gravels. These occur both as discrete lithologic units and as various admixtures, such as clayey and pebbly sands. At present, the Yorktown in the north is not lithologically divisible.

The sandy units to the north consist almost entirely of quartz, and most contain a few percent reworked phosphorite. Glauconite, while ubiquitous in trace amounts, is rarely prominent. The sands range from very fine to very coarse grained and commonly occur with fine-grained and well-sorted quartz gravel. Roundness of the sands is variable, even within a given sample. Most samples contain numerous well-rounded, nearly spherical quartz grains interpreted to be of dune origin because of their frosted appearance.

Shell beds, or intervals of sand and shell containing a small amount of clay, are as much as 50 feet in thickness. Generally, the fossil assemblage is predominantly molluscan, comprising pelecypods, gastropods, and a few scaphopods. Other common invertebrates are bryozoans, echinoderms, corals, and worm tubes. A variety of ostracods and distinctly Yorktownian assemblages of porcelaneous and agglutinated foraminifers are common to abundant. The original condition of much of the shell material, especially of the more fragile forms, indicates that at least some of these materials are in-place accumulations. Vertebrate remains consist mainly of teeth, vertebrae, fish scales, and earbones.

Clay beds in the northern Yorktown are gray to bluish-gray and locally dark-gray. Typically, they are quite silty and sandy, and seem completely gradational with clayey sands and gravels. Plant fragments are common, and locally abundant (W-1841). The clay beds themselves contain only small amounts of shells or shell fragments.

South of the James River, in Norfolk, Portsmouth, the northern parts of Nansemond and Chesapeake, and the northern half

of Isle of Wight County, the Yorktown is about 100 feet thick and includes 20 to 90 feet of quartzo-bioclastic to bioclastic sand. The bioclastic element of these sands consists mainly of sand-size fragments of larger mollusc shells; locally, however, it consists largely of foraminifers and ostracods. Bioclastic sands are well developed in West Norfolk (W-2084, W-2085, W-2168), South Norfolk (W-2111), eastern Isle of Wight County (W-1924 and W-2109), and western Nansemond (W-1565). At Suffolk and northward, and as far eastward as Virginia Beach, the bioclastic sands appear to be interbedded with numerous beds of distinctly coarser shell material (2 to 20 mm). Southward and westward, the Yorktown is less sandy, and clay beds and beds of coarse shell are more abundant.

In the area south of the James River where the bioclastic beds are well developed they are underlain conformably by a series of quartzo-glauconitic sands and sandy clays. The transition downward is an interbedding relationship occurring over an interval of less than ten feet (W-1786) to several tens of feet, in which the quartzo-glauconitic sands become more numerous and the bioclastic sands less numerous; it is not a gradual replacement of bioclasts by glauconite within successive sand beds. Sands with both bioclasts and glauconite as major constituents were not observed.

The clayey strata interbedded with the quartzo-glauconitic sands are greenish-gray and are probably somewhat glauconitic. The sand fractions are fine- to medium- grained, well-sorted, clear to greenish quartz with an average of 15 percent, and a maximum of 50 percent, dark-green glauconite. These glauconitic strata—sands and sandy clays—resemble many intervals in the Nanpemoy Formation, but are unlike any Yorktown strata north of the James River.

The areal distribution and thickness of the Yorktown glauconitic beds are difficult to define. Generally, they grade downward into a sequence of gray fossiliferous clayey sands and sandy clays much like those in the Yorktown section north of the James River. The thickness of this lowest Yorktown sequence south of the river ranges from 0 to 100 feet and varies inversely with the combined thickness of the overlying glauconitic and bioclastic strata. The northern Yorktown possibly is related to the southern Yorktown as shown in Figure 2. According to this interpretation, the glauconitic-bioclastic sequence is younger than any

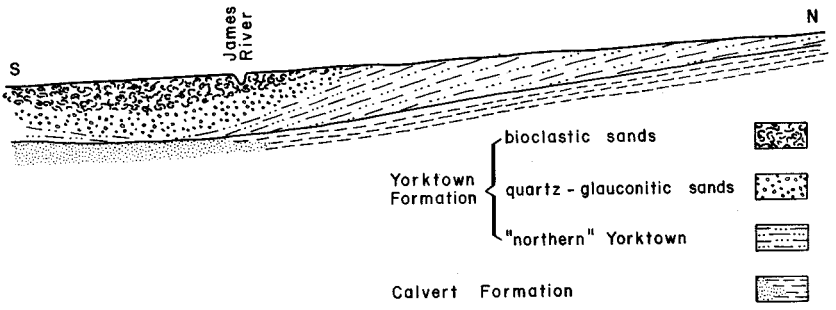


Figure 2. Schematic north-south section showing inferred stratigraphic relationships among Yorktown lithologic types at end of Yorktown time.

Yorktown north of the James, and was deposited at a site of maximum deposition that had shifted progressively southward throughout Yorktown time. The southeast corner of the study area probably was the last place from which the Yorktown sea withdrew as indicated by the comparatively great thickness of the Yorktown and its upward change in lithology, which are characteristic of gradual basin shoaling.

The glauconitic Yorktown, as developed in Chesapeake and Nansemond, and in Isle of Wight County, is not present north of the James River. Westward and southwestward, these beds become less glauconitic and increasingly difficult to identify as a discrete unit. The absence of Calvert strata in Prince George, Sussex, and Southampton counties, where the Yorktown Formation immediately overlies typically glauconitic beds of the Nanjemoy and Mattaponi formations, adds to the difficulty in identification of the unit.

On the eastern edge of the map area, the Yorktown is in places an indurated, calcitic to dolomitic unit. For example, the formation contains bioclastic limestones and bryozoan buildups in eastern Mathews County (W-2149) and Gloucester County (W-2160), and dense, greenish-gray, sandy limestones or tan, dolomitic sandstones in the eastern part of Chesapeake (W-2354 and W-2154).

Although the Yorktown has been considered by most workers to be late Miocene in age as based on its macrofauna, it may be Pliocene in age in its uppermost part as based on microfauna and vertebrate fossils (McLean, 1966, p. 28; Oaks and Coch, 1973, p. 51; U. S. Geological Survey, 1965, p. A71).

TERTIARY AND QUARTERNARY SYSTEMS

Columbia Group

All sediments overlying recognizable Yorktown strata are referred to the Columbia Group (Tables 1 and 2). These younger deposits, Pliocene through Holocene in age, cover most of the Yorktown and older rocks in the map area and are at least as much as 122 feet thick. Mainly they are oxidized clays, silts, sands, and gravels; locally, and particularly near the present coastline, carbonaceous and peaty sediments are present. In most places, the sediments of the Columbia Group contrast sharply with any marine formation which they overlie.

THREE-DIMENSIONAL DISTRIBUTION OF SEDIMENTS

The Lower Cretaceous through Miocene sedimentary rocks beneath the Coastal Plain of Virginia are platform deposits upon the buried seaward extension of the Piedmont province. Borehole data indicate that the pre-Cretaceous "basement" is equally as diverse lithologically as the exposed part of the Piedmont province, and that "red beds" of the Newark type are at least as common beneath the Cretaceous-Tertiary sediments as they are west of the Fall Line. These "red beds" are referred to the "basement" because of their relatively high degree of induration and their position in the sequence of tectonic events, as inferred from the mode of occurrence of the Newark Group in the exposed Piedmont.

Data from deep wells on the periphery of the study area—Esso No. 1 Maryland at Ocean City, Maryland, and Esso No. 1 Hatteras Light in northeastern North Carolina—show depths to "basement" far in excess of any determined on the Virginia mainland including the depth of about 2600 feet reported at Norfolk. Contours representing the "basement" surface (U. S. Geological Survey and American Association of Petroleum Geologists, 1961) depict Virginia as the site of a major positive element roughly perpendicular to the present shoreline and flanked

by major reentrants on the "basement"—the Salisbury embayment in Maryland and the Hatteras "low" in North Carolina. The thick Cretaceous strata at these locations and the fact that the embayments are not reflected in the structure of shallower horizons have been interpreted by most geologists as indicating these reentrants in the "basement" predate Cretaceous deposition.

The Patuxent Formation is the landward part of a massive clastic wedge deposited in these "basement" reentrants. The configuration of the top of the Patuxent (Plate 2) shows a break in slope, from gentle to steep, on the seaward periphery of the map area. The break is interpreted to be a subdued reflection of the gross configuration of the "basement" surface. Most minor irregularities on the Patuxent surface probably reflect minor features on the surface of the "basement." A series of east-west lineations, however, is more probably related to the fluvial regime in which the Patuxent was deposited. Continuation of fluvial processes during post-Patuxent time undoubtedly further modified the Patuxent surface and resulted in the formation of the "transitional beds."

The "transitional beds" occur as two lensoid bodies of mainly nonmarine clastics on the northern and southern flanks of a central Patuxent "high" (Plate 3). In the center, the Patuxent is overlain by still younger strata and the "transitional beds" are missing (Plate 18). Evidence for a transverse "basement" high in the center of the study area, the flank positions of the "transitional beds," and the lithologic similarity of the "transitional beds" to the Patuxent indicate that the basement high existed at least as early as the beginning of "transitional beds" time and that the Patuxent was a local source of "transitional beds" sediments. The isopach contours of the "transitional beds" parallel the zero lines in both the northern and southern areas (Plate 7), implying that these are depositional limits. This is true for the most part, but that part of the zero line in the Westmoreland-Richmond counties area defines the eastern limit of the area in which the criteria defined in this report can be applied, rather than the eastern limit of the "transitional beds" themselves.

Deposition of the "transitional beds" further subdued the relief inherited from the "basement," marked the end of nonmarine sedimentation in Virginia, and set the stage for a series of marine transgressions and regressions that lasted through late

Miocene time (or possibly into early Pliocene time). The first of these transgressions was widespread and resulted in deposition of the Mattaponi Formation over most of the Coastal Plain of Virginia.

The Mattaponi surface (Plate 4) continued to reflect the major break in slope in the southeast corner of the map area, but the keyhole-shaped reentrant in the underlying surface was largely obscured. The prominent linear, northeastward-trending "high" across the center of the area probably is related to the less pronounced compound "high" at the same position on the underlying Patuxent surface. With the exception of these features, the Mattaponi surface slopes coastward quite regularly, and most irregularities on the pre-Mattaponi surface are no longer apparent.

In general, thickness variation of the Mattaponi (Plate 8) complements the configuration of the underlying surface: it is thickest over "lows" and thinnest over "highs". For the most part, the zero isopach line marks the limit of deposition of the Mattaponi, but locally the isopach contours abut the zero line, indicating areas in which the unit subsequently was eroded.

The present surface of the Nanjemoy Formation (Plate 5) is broadly undulating with a constant seaward slope; it has less relief than any of the underlying units. The absence of Nanjemoy strata in the southern quarter of the map area has been interpreted as evidence for a fault parallel to the James River (Cederstrom, 1945, p. 85).

Thickness variation of the Nanjemoy (Plate 9) complements the configuration of the underlying surface. The principal features are the two areas of maximum development of the Nanjemoy, defined by the 100-foot isopach contour, which flank the central linear "high" on the Mattaponi surface. Apparently this "high" greatly influenced the distribution of Nanjemoy strata while remaining an area of restricted or no deposition.

During the following marine transgression the Calvert Formation was deposited on a relatively featureless, gently sloping surface. The surface expression of the Calvert (Plate 6), therefore, almost certainly is related to processes operating during and after Calvert time. In general, this surface resembles the present topography, and many of its elements, both major and minor, are apparently reflected by the present drainage. This

suggests that the modern drainage pattern began to develop sometime in the Miocene.

Similarly, thickness variation in the Calvert (Plate 10) must be attributed to factors other than the configuration of the underlying surface. The thickness, too, bears a perceptible relationship to the present river system. Examples are the elongate thin areas along the axis Hampton Roads-Nansemond River and the more subtle, but similar, features along the axes of the York River and middle James River. The zero-line of the Calvert is a depositional limit in the south where the unit is overlapped by younger strata, and mainly erosional in the north where Calvert strata have been and presently are being removed from the underlying Precambrian-Paleozoic igneous and metamorphic rocks.

The last marine transgression resulted in deposition of the Yorktown Formation over most of the Coastal Plain of Virginia. The distribution of the units by which it is underlain are shown in Plate 21. No subsurface maps were prepared for the Yorktown, but where the formation is present its surface may be considered to approximate the present topography. There is some bevelling seaward where post-Miocene marine deposits are well developed along the present coastline and considerable dissection farther inland; in many places along major streams the Yorktown has been completely removed by fluvial processes.

Fluvial and littoral processes have been dominant throughout the area since the recession of the Yorktown sea, and the form and stratigraphy of the exposed Coastal Plain are the products of these and allied processes.

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APPENDIX I

GEOLOGIC SUMMARIES

(Only wells used in mapping)

EXPLANATION

W-194 Numbers preceded by the letter "W" refer to those wells whose samples are on file in the Division's repository.

post-Ty, post-Tc, post-Tn, post-Tm, post-trans, and post-LK refer to the top of rocks of younger formations than the Yorktown, Calvert, Nanjemoy, Mattaponi, "transitional beds", and Patuxent respectively.

Ty Top of Yorktown Formation

Tc Top of Calvert Formation

Tn Top of Nanjemoy Formation

Tm Top of Mattaponi Formation

trans Top of "transitional beds"

LK Top of Patuxent Formation

base Top of "basement"

nd Formation top not determined

TD Total depth of well in feet

All elevations are relative to a sea level datum.

	Elevation of top (in feet)	Thickness (in feet)
W-194		
post-Ty and Ty	128	53
Tc	75	83
Tn	—8	68
Tm	—76	129
LK	—205	4 drilled
TD 337		
W-228		
Tc	5	87
Tn	—82	113
Tm	—195	75
LK	—270	67 drilled
TD 342		
W-515		
post-Ty and Ty	30	110—
Tc	nd	50+
Tn	—130	40
Tm	—170	125
LK	—295	995
base	—1290	312 drilled
TD 1632		

	Elevation of top (in feet)	Thickness (in feet)
W-979		
post-Ty	0	120—
Ty	nd	395+
Tc	—515	345
Tm	—860	125
trans	—985	135
LK	—1120	380 drilled
TD 1500		
W-1135		
post-Ty	10	75
Ty	—65	70
Tc	—135	300
Tn	—435	20
Tm	—455	170
LK	—625	157 drilled
TD 792		
W-1177		
post-Tc	162	20
Tc	142	60
Tn	82	
Tm	nd	
LK	—28	136 drilled
TD 326		
W-1182		
post-Ty	5	21
Ty	—16	21
Tc	—37	275
Tn	—312	85
Tm	—397	163
LK	—560	55 drilled
TD 620		
W-1184		
post-Ty	3	40
Ty	—37	41
Tc	—78	332
Tn	—410	47
Tm	—457	130
LK	—587	50 drilled
TD 640		
W-1194		
post-Ty	173	10
Ty	163	
Tc	nd	
base	78	80
TD 175		

	Elevation of top (in feet)	Thickness (in feet)
W-1232		
post-Ty	30	20
Ty	10	160
Tc	—150	65
Tn	—215	5
Tm	—220	110
LK	—330	27 drilled
TD 387		
W-1247		
post-Tc	135	20
Tc	115	50
Tn	65	30
Tm	35	20
LK	16	176 drilled
TD 296		
W-1291		
post-Tc	155	10
Tc	145	60
Tn	85	42
Tm	43	51
LK	—8	177 drilled
TD 340		
W-1301		
post-Tc	175	50
Tc	125	
Tn	nd	
Tm	nd	
LK	—78	67 drilled
TD 320		
W-1306		
post-Tm	23	240—
Tm	nd	60+
trans	—277	
LK	nd	
TD 1050		
W-1312		
post-Tm	225	14
Tm	211	6
LK	205	34 drilled
TD 54		
W-1342		
post-Tc	26	29
Tc	—3	59

	Elevation of top (in feet)	Thickness (in feet)
Tn	—62	153
Tm	—215	119
trans	—334	40
LK	—374	267 drilled
TD 667		
W-1343		
post-Ty	100	50
Ty	50	150
Tc	—100	70
Tn	—170	30
Tm	—200	130 drilled
TD 430		
W-1362		
post-LK	75	23
LK	52	109 drilled
TD 132		
W-1368		
Tc	180	80
Tn	100	40
Tm	60	75
trans	—15	215
LK	—230	96 drilled
TD 506		
W-1389		
post-Tc	205	25
Tc	180	105
Tn	75	17
Tm	58	169
trans	—111	70
LK	—181	30 drilled
TD 416		
W-1419		
post-Tm	145	40
Tm	105	60
LK	45	320 drilled
TD 420		
W-1421		
post-Ty	80	40
Ty	40	
Tc	nd	
Tn	—150	50
Tm	—200	70
LK	—270	75 drilled
TD 425		

	Elevation of top (in feet)	Thickness (in feet)
W-1506		
post-Tm	15	20
Tm	—5	10
LK	—15	141 drilled
TD 171		
W-1508		
post-LK	92	10
LK	82	120
base	—38	263 drilled
TD 393		
W-1548		
post-Ty	140	30
Ty	110	137
Tc	—27	111
Tn	—138	
Tm	nd	
LK	—470	207 drilled
TD 817		
W-1565		
post-Ty	63	30
Ty	33	186
Tc	—153	108
Tn	—261	42
Tm	—303	62
LK	—365	755 drilled
TD 1183		
W-1612		
post-Tc	155	30
Tc	125	40
Tn	85	60
Tm	25	20
LK	5	152 drilled
TD 302		
W-1613		
post-Tc	97	10
Tc	87	50
Tm	37	72
LK	—35	102 drilled
TD 234		
W-1635		
post-Ty	12	15
Ty	—3	65
Tc	—68	74

	Elevation of top (in feet)	Thickness (in feet)
Tn	—142	48
Tm	—190	123
LK	—313	213 drilled
TD 538		
W-1662		
post-Tc	180	40
Tc	140	60
Tn	80	72
Tm	8	36
LK	—28	90 drilled
TD 298		
W-1694		
post-Tc	200	50
Tc	150	95
Tn	55	45
Tm	10	80
LK	—70	203 drilled
TD 473		
W-1699		
post-Tc	195	31
Tc	164	29
Tm	135	70
LK	65	120 drilled
TD 250		
W-1739		
post-Ty	83	30
Ty	53	120
Tc	—67	160
Tn	—227	30
Tm	—257	120
LK	—377	30 drilled
TD 490		
W-1771		
Ty	0	33
Tc	—33	242
Tn	—275	56 drilled
TD 331		
W-1804		
post-Ty	140	10
Ty	130	
Tc	nd	
LK	40	145 drilled
TD 245		

	Elevation of top (in feet)	Thickness (in feet)
W-1836		
post-Ty	65	20
Ty	45	
Tc	nd	
Tn	—195	90
Tm	—285	35
LK	—320	115 drilled
TD 500		
W-1841		
post-Ty	8	42
Ty	—34	94
Tc	—128	263
Tn	—391	51
Tm	—442	223
LK	—665	126 drilled
TD 799		
W-1849		
post-Tm	95	10
Tm	85	80
trans	5	30
LK	—25	105 drilled
TD 225		
W-1851		
post-Tc	205	31
Tc	174	136
Tn	38	103
Tm	—65	45
trans	—110	189
LK	—299	167 drilled
TD 671		
W-1852		
post-Tc	180	30
Tc	150	82
Tn	68	87
Tm	—19	74
trans	—93	137
LK	—230	210 drilled
TD 620		
W-1853		
Ty	45	84
Tc	—39	31
Tn	—70	157
Tm	—227	85
LK	—312	104 drilled
TD 461		

	Elevation of top (in feet)	Thickness (in feet)
W-1855		
post-Ty	125	41
Ty	84	64
Tc	20	273
Tn	—253	105
Tm	—358	148
LK	—506	159 drilled
TD 790		
W-1856		
post-Ty	8	42
Ty	—34	45
Tc	—79	264
Tn	—343	126
Tm	—469	164
LK	—633	151 drilled
TD 792		
W-1857		
Ty	30	84
Tc	—54	26
Tn	—80	160
Tm	—240	87
LK	—327	101 drilled
TD 458		
W-1859		
post-Ty	80	84
Ty	—4	52
Tc	—56	210
Tn	—266	117
Tm	—383	162
LK	—545	112 drilled
TD 737		
W-1860		
post-Tc	140	42
Tc	98	95
Tn	3	62
Tm	—59	85
trans	—144	254
LK	—398	58 drilled
TD 596		
W-1861		
post-Ty	10	31
Ty	—21	44
Tc	—65	260
Tn	—325	65

	Elevation of top (in feet)	Thickness (in feet)
Tm	—390	95
LK	—485	186 drilled
TD 681		
W-1862		
post-Ty	75	42
Ty	33	84
Tc	—51	262
Tn	—313	95
Tm	—408	189
LK	—597	42 drilled
TD 714		
W-1871		
post-Ty	110	30
Ty	80	112
Tm	—32	30
trans	—62	30
LK	—92	150 drilled
TD 352		
W-1873		
post-Ty	105	20
Ty	85	70
Tm	15	30
LK	—15	48 drilled
TD 168		
W-1878		
post-Tc	185	50
Tc	135	10
Tm	125	60
LK	65	50
base	15	470 drilled
TD 640		
W-1908		
post-Tm	85	40
Tm	45	20
LK	25	60
base	—35	20 drilled
TD 140		
W-1909		
post-Ty	110	40
Ty	70	168
Tc	—98	60
Tn	—158	42
Tm	—200	20 drilled
TD 330		

	Elevation of top (in feet)	Thickness (in feet)
W-1914		
post-Ty	145	30
Ty	115	136
Tc	—21	97
Tn	—118	160
Tm	—278	165
trans	—443	21
LK	—464	32 drilled
TD 641		
W-1921		
post-Tm	140	60
Tm	80	5
LK	75	25
base	50	350 drilled
TD 440		
W-1922		
post-Ty	35	100
Ty	—65	20
Tc	—85	80
Tn	—165	80
Tm	—245	80
LK	—325	40 drilled
TD 400		
W-1924		
post-Ty	80	30
Ty	50	180
Tc	—130	30
Tm	—160	50 drilled
TD 290		
W-1925		
post-Ty	64	40
Ty	24	189
Tc	—165	41
Tm	—206	20 drilled
TD 290		
W-1926		
post-Ty	60	10
Ty	50	150
Tc	—100	21
Tm	—121	62 drilled
TD 243		
W-1927		
post-Ty	62	20
Ty	42	120

	Elevation of top (in feet)	Thickness (in feet)
Tc	—78	10
Tm	—88	40 drilled
TD 190		
W-1937		
post-Ty	125	20
Ty	105	
Tc	nd	
Tm	35	20
LK	15	58 drilled
TD 168		
W-1948		
post-Tc	175	50
Tc	125	60
Tn	65	91
Tm	—26	24
LK	—50	81 drilled
TD 306		
W-1952		
post-Ty	85	30
Ty	55	
Tm	nd	
trans	—89	131
LK	—220	455 drilled
TD 760		
W-2000		
post-Ty	20	42
Ty	—22	23
Tc	—45	293
Tn	—338	63
Tm	—401	219
LK	—620	33 drilled
TD 673		
W-2012		
post-Ty	55	10
Ty	45	230
Tc	—185	36
Tm	—221	2 drilled
TD 278		
W-2013		
post-Ty	80	30
Ty	50	140
Tm	—90	50
trans	—140	10 drilled
TD 230		

	Elevation of top (in feet)	Thickness (in feet)
W-2014		
post-Ty	120	20
Ty	100	80
Tm	20	30
LK	—10	10 drilled
TD 140		
W-2019		
post-Ty	115	30
Ty	85	100
Tm	—15	20 drilled
TD 150		
W-2020		
post-Ty	110	20
Ty	90	32
Tm	58	56
LK	2	2 drilled
TD 110		
W-2021		
post-Ty	152	20
Ty	132	46
Tm	86	19
LK	67	5 drilled
TD 90		
W-2022		
post-Tm	92	20
Tm	72	30
LK	42	15 drilled
TD 65		
W-2023		
post-trans	45	30
trans	15	135
LK	—120	145 drilled
TD 310		
W-2024		
post-Ty	50	20
Ty	30	40
trans	—10	110
LK	—120	150 drilled
TD 320		
W-2038		
post-Ty	90	30
Ty	60	90
trans	—30	110
LK	—140	145 drilled
TD 375		

	Elevation of top (in feet)	Thickness (in feet)
W-2039		
post-Ty	65	50
Ty	15	190
Tc	—175	40
Tm	—215	60
trans	—275	30 drilled
TD 370		
W-2049		
post-Ty	30	20
Ty	10	60
Tm	—50	50
trans	—100	90 drilled
TD 220		
W-2050		
post-Ty	50	30
Ty	20	160
Tc	—140	75
Tm	—215	55
trans	—270	30 drilled
TD 350		
W-2051		
post-Ty	50	10
Ty	40	100
Tc	—60	55
Tm	—115	65
trans	—180	10 drilled
TD 240		
W-2055		
post-Ty	10	30
Ty	—20	52
Tc	—72	297
Tn	—369	61
Tm	—430	82
LK	—512	34 drilled
TD 556		
W-2056		
Ty	8	61
Tc	—53	195
Tn	—248	92
Tm	—340	113
LK	—453	81 drilled
TD 542		

	Elevation of top (in feet)	Thickness (in feet)
W-2071		
post-Ty	140	60
Ty	80	10
Tc	70	20
Tn	50	53
Tm	—3	87
LK	—90	410
base	—500	12 drilled
TD 652		
W-2088		
post-Ty	80	30
Ty	50	168
Tc	—118	22
Tm	—140	50
trans	—190	105 drilled
TD 375		
W-2092		
post-Ty	20	20
Ty	0	240
Tc	—240	50
Tm	—290	50
trans	—340	80
LK	—420	167 drilled
TD 607		
W-2093		
post-Ty	23	30
Ty	—7	260
Tc	—267	30
Tm	—297	35
trans	—332	20 drilled
TD 375		
W-2097		
Ty	25	330
Tc	—305	45
Tm	—350	5 drilled
TD 380		
W-2098		
Tn	75	68
Tm	7	82
LK	—75	10 drilled
TD 160		
W-2100		
post-Tc	140	30
Tc	110	138

	Elevation of top (in feet)	Thickness (in feet)
Tn	—28	18 drilled
TD 186		
W-2102		
post-Ty	10	40
Ty	—30	43
Tc	—73	99
Tn	—172	68
Tm	—240	35
LK	—275	85 drilled
TD 370		
W-2103		
post-Ty	7	25
Ty	—18	172
Tc	—190	82
Tn	—272	82
Tm	—354	41
LK	—395	22 drilled
TD 424		
W-2105		
Ty	15	380
Tc	—365	55
Tm	—420	75
trans	—495	70 drilled
TD 580		
W-2106		
Ty	20	200
Tc	—180	100
Tm	—280	
trans	nd	
LK	—480	160 drilled
TD 660		
W-2107		
Ty	20	260
Tc	—240	175
Tm	—415	55
trans	—470	50 drilled
TD 540		
W-2108		
Ty	10	188
Tc	—178	82
Tm	—260	118
LK	—378	92 drilled
TD 480		

	Elevation of top (in feet)	Thickness (in feet)
W-2109		
post-Ty	82	60
Ty	22	152
Tc	—130	48
Tm	—178	50
trans	—228	105
LK	—333	45 drilled
TD 460		
W-2110		
post-Ty	7	20
Ty	—13	280
Tc	—293	80
Tm	—373	130
trans	—503	95
LK	—598	35 drilled
TD 640		
W-2111		
post-Ty	5	40
Ty	—35	320
Tc	—355	170
Tm	—525	89
trans	—614	125
LK	—739	56 drilled
TD 800		
W-2154		
post-Ty	10	100—
Ty	nd	310+
Tc	—400	210
Tm	—610	67
trans	—677	105
LK	—782	1796 drilled
TD 2588		
W-2158		
post-Tc	190	50
Tc	140	80
Tn	60	40
Tm	20	70
LK	—50	80 drilled
TD 320		
W-2168		
post-Ty	10	40
Ty	—30	290
Tc	—320	120
Tm	—440	70

	Elevation of top (in feet)	Thickness (in feet)
trans	—510	120
LK	—630	375 drilled
TD 1015		
W-2169		
post-Ty	30	10
Ty	20	60
Tm	—40	30
trans	—70	135
LK	—205	137 drilled
TD 372		
W-2193		
Ty	35	90
Tc	—55	220
Tn	—275	75
Tm	—350	75
LK	—425	194 drilled
TD 654		
W-2197		
post-Tc	185	30
Tc	155	90
Tn	65	70
Tm	—5	60
LK	—65	70 drilled
TD 320		
W-2207		
post-Ty	42	18
Ty	24	7
Tm	17	12
trans	5	2
LK	3	11 drilled
TD 50		
W-2208		
post-Tm	73	23
Tm	50	40
LK	10	3 drilled
TD 66		
W-2211		
post-Ty	80	19
Ty	61	9
Tm	52	45
LK	7	7 drilled
TD 80		

	Elevation of top (in feet)	Thickness (in feet)
W-2212		
post-Ty	129	26
Ty	103	67
Tm	36	10
LK	26	12 drilled
TD 115		
W-2213		
post-LK	35	19
LK	16	26 drilled
TD 45		
W-2214		
post-Ty	50	13
Ty	37	7
Tm	30	23
LK	7	7 drilled
TD 50		
W-2218		
post-Ty	65	10
Ty	55	160
Tc	—105	110
Tn	—215	20
Tm	—235	70
LK	—305	42 drilled
TD 412		
W-2223		
post-Tn	50	50
Tn	0	20
Tm	—20	60
LK	—80	85 drilled
TD 215		
W-2224		
post-Tc	175	50
Tc	125	80
Tn	45	60
Tm	—15	30
LK	—45	192 drilled
TD 412		
W-2238		
post-Tc	200	50
Tc	150	70
Tn	80	30
Tm	50	50
trans	0	150
LK	—150	25 drilled
TD 375		

	Elevation of top (in feet)	Thickness (in feet)
W-2240		
post-Ty	156	30
Ty	126	50
Tc	76	40
Tm	36	10
LK	26	26 drilled
TD 156		
W-2247		
post-Ty	40	122
Ty	—82	85
Tc	—167	84
Tn	—251	119
Tm	—370	50
LK	—420	1100 drilled
TD 1560		
W-2253		
post-Ty	105	50
Ty	55	110
Tm	—55	50
trans	—105	30
LK	—135	530
base	—665	113 drilled
TD 883		
W-2329		
post-Tc	50	20
Tc	30	40
Tn	—10	80
Tm	—90	60
LK	—150	106 drilled
TD 306		
W-2349		
post-Tc	140	40
Tc	100	70
Tm	30	70
LK	—40	86 drilled
TD 266		
W-3095		
post-Ty	20	20
Ty	0	290
Tc	—290	115
Tm	—405	265
trans	—670	110
LK	—780	100 drilled
TD 900		

	Elevation of top (in feet)	Thickness (in feet)
W-3118		
post-Ty	90	50
Ty	40	120
Tc	—80	178
Tn	—258	42
Tm	—300	100
LK	—400	218 drilled
TD 708		
W-3220		
post-Ty	95	20
Ty	75	60
Tm	15	80
trans	—65	30
LK	—95	310
base	—405	54 drilled
TD 554		
W-3221		
post-Ty	35	20
Ty	15	70
Tc	—55	40
Tm	—95	50
trans	—145	220
LK	—365	750 drilled
TD 1150		
W-3316		
post-Ty	50	80
Ty	—30	145
Tc	—175	90
Tm	—265	65
trans	—330	330
LK	—660	1210
base	—1870	100 drilled
TD 2020		

APPENDIX II

SELECTED GEOLOGIC LOGS

The following descriptions of samples from selected wells are included in order that the reader might better visualize the rocks in the Coastal Plain of Virginia. The wells, as identified by the Division's repository number, are W-2000, W-2051, W-2056, W-2071, W-2103, W-2168, W-2218, and W-2238. Geologic summaries of these wells are in Appendix I. The initials "G. L." after the surface elevation indicate that the datum is ground level.

REPOSITORY NUMBER: W-2000 COUNTY: Northumberland
OWNER: Fred W. Haislip ELEVATION: 20 feet G.L.
DRILLER: Douglas & Dickinson, Inc. TOTAL DEPTH: 673 feet
LOCATION: 0.75 mile NE of intersection of State Roads 604 and 740, 3.5 miles north of Burgess Post Office.

Depth (in feet)

COLUMBIA GROUP (0-42′)

0-42 Sand, slightly clayey, orangish-brown, fine- to medium-grained, very well-sorted, subangular to subrounded; trace of feldspar.

YORKTOWN FORMATION (42-65′)

42-65 Sand, clean, light-gray, medium- to coarse-grained, fairly well-sorted, subangular to subrounded; 15 percent rounded gravel (2-10 mm); clear quartz with accessory magnetite and feldspar; traces of epidote, weathered glauconite, carbonaceous material, and shell; few ostracods; interval 52-65 is slightly feldspathic.

CALVERT FORMATION (65-358′)

65-84 Clay, uniformly silty, dark-gray with greenish cast; trace of glauconite, trace of shell.

84-105 Silt and clay; silt (60 percent), very clayey, greenish-gray, coarse-grained, well-sorted, slightly glauconitic; clay (40 percent), pure, dull pink; scattered plant and shell fragments; interval 94-105 is 75 percent silt and 25 percent clay.

105-115 Silt and clay; silt (60 percent), very clayey, greenish-gray, coarse-grained, well-sorted, slightly glauconitic; clay (40 percent), pure, dull pink; abundant plant fragments and a few shell fragments; very few foraminifers.

115-126 Clay, dark- to light-gray, diatomaceous; very little silt or sand; few shell and plant fragments; dark clay contains a few foraminifers.

126-178 Silt and clay; silt, clayey, dark greenish-gray; clay, sand- and silt-free, light- to pinkish-gray; few plant and shell fragments, trace of phosphatic bone fragments, trace of glauconite.

178-220 Clay, locally very slightly sandy, dull-pink; a few pelecypod and gastropod shell fragments; interval 189-199 contains 15 percent clayey, greenish-gray silt.

Depth (in feet)

220-231 Silt, clayey, greenish-gray; plant fragments common; few shell fragments.

231-242 Clay, variably silty and sandy, quartzose, light to dark greenish-gray; few plant and shell fragments.

242-263 Clay, typically silt- and sand-free, light-gray with greenish cast; small amounts carbonaceous material and plant debris; a few fragments of shell and phosphorite; few foraminifers, including *Siphogenerina, Nonion*; very diatomaceous.

263-273 Clay, silt- and sand-free with subordinate greenish-gray clayey silt, dull-pink; trace of glauconite; few shell and plant fragments; trace of diatoms in pink clay.

273-284 Clay, moderately silty, slightly sandy, light-gray; traces of glauconite, carbonaceous material, and muscovite; few plant fragments; trace of diatoms.

284-305 Clay, slightly silty, trace of sand; light-gray with greenish cast; traces of glauconite and carbonaceous material; few plant and shell fragments; *Siphogenerina* common; very diatomaceous.

305-315 Clay, very silty, light-gray; trace of sand; locally ferruginous (goethitic-limonitic laminae); trace of muscovite and carbonaceous material; few plant fragments; trace of diatoms.

315-326 Clay; interlaminae of very sandy, dark-gray clay and essentially sand-free, light-gray clay; limonitic clay abundant; a few carbonaceous fragments, pelecypod shell fragments, and *Siphogenerina*; diatom content not determined.

326-336 Clay, slightly silty, light-gray; trace of sand; trace of shell material; very diatomaceous.

336-347 Sand, very slightly clayey, light-gray to medium-gray; medium- to coarse-grained, fairly well-sorted, subrounded to rounded; clear quartz, with traces of glauconite, phosphorite; 10 percent coarse pelecypod shell fragments; a few foraminifers.

347-358 Sand and shell, clean, light-gray; medium- to very coarse-grained, fairly well-sorted, subangular to subrounded; clear quartz, with 5 percent glauconite and a trace of phosphorite; about 30 percent pelecypod shell fragments, and a very few foraminifers and ostracods.

NANJEMOY FORMATION (358-421′)

358-378 Sand, very slightly clayey, dark-gray; 40 percent medium- to coarse-grained, fresh to moderately decomposed glauconite; 55 percent coarse- to very coarse-grained, clear to yellow-, brown-, and green-stained, subrounded to well-rounded and polished quartz; 5 percent rounded quartz granules and phosphorite; few pelecypod and scaphopod shell fragments, and very few foraminifers and ostracods.

378-399 Sand, clean, tan, medium- to coarse-grained, well-sorted; 70-75 percent clear to brown- and yellow-stained subangular to sub-

Depth (in feet)

rounded quartz; 25-30 percent medium-grained glauconite and goethite after glauconite; shell fragments and foraminifers rare.

399-410 Sand, clean, gray; 5 percent quartz granules; coarse- to very coarse-grained, fairly well-sorted; 40 percent glauconite and goethite after glauconite; 50 percent rounded, stained quartz; 5 percent fragments of pelecypods, ramose bryozoans, and few foraminifers; few fragments of arenaceous (glauconitic) limestone.

410-421 Sand, trace of clay, dark-gray; 70 percent medium-grained, very well-sorted and 30 percent coarse- to very coarse-grained, rounded to well-rounded; stained quartz; few foraminifers and shell fragments.

MATTAPONI FORMATION (421-640')

421-431 Sand, trace of clay, black; 90-95 percent fresh, coarse-grained, well-sorted glauconite; and 5-10 percent quartz; foraminifers rare.

431-441 Sand, trace of clay, dark-gray, a few quartz granules; 65 percent medium- to coarse-grained glauconite and subordinate goethite after glauconite; 35 percent medium- to very coarse-grained, stained rounded quartz; a few shell fragments and foraminifers.

441-462 Sand, clean, black, medium-grained, well-sorted; 75 percent fresh glauconite; 25 percent clear, subangular to subrounded quartz; trace of shell; foraminifers moderately abundant; a few ostracods; interval 452 to 462 is moderately silty.

462-473 Clay, compact, brownish-gray; moderately glauconitic; abundant silt-size muscovite; traces of pyrite and phosphorite; few plant fragments and foraminifers.

473-483 Sand and shell, clean, dark-gray; 70 percent coarse-grained, well-sorted fresh glauconite; 5 percent quartz; 25 percent abraded pelecypod shell fragments; trace of feldspar; very few foraminifers and bryozoans.

483-494 Shell and sand, 40 percent coarse-grained black glauconitic sand with subordinate quartz; 55 percent abraded pelecypod shell fragments; 5 percent dark-gray, silt- and sand-free, slightly glauconitic clay.

494-504 Sand; moderately silty and clayey (tan clay), grayish-brown, with very few granules and very small pebbles of quartz, fine- to coarse-grained, rather poorly-sorted; 40 percent dark- to medium-green glauconite; 40 percent angular to subrounded clear quartz; 20 percent abraded pelecypod shell fragments; small amounts of feldspar, pyrite, muscovite, and garnet; few bryozoans and fish teeth; foraminifers and ostracods common but not abundant.

504-536 Sand, clayey (tan clay), grayish-brown; fine- to coarse-grained, moderately sorted; 30 percent fresh glauconite; 70

Depth (in feet)

percent angular to subrounded quartz; some feldspar; shell fragments common; a few fragments of limonitic clay and a few of arenaceous (glauconitic) limestone; very few bryozoans, foraminifers, and plant fragments; interval 515 to 536 is very clayey.

536-546 Sand, medium- to coarse-grained, moderately sorted; moderately abundant matrix of mottled clay with grayish-brown aspect; 60-70 percent variably rounded clear quartz; 20 percent fresh glauconite; 10-20 percent fresh to moderately decomposed glauconite; traces of blue quartz, muscovite, garnet, pyrite; a very few shell fragments and foraminifers.

546-582 Clay, moderately sandy; mottled gray and dull reddish-brown; sand is 70-80 percent fine- to very fine-grained quartz, 20-30 percent glauconite and minor muscovite; plant fragments common; a few shell fragments and foraminifers.

582-592 Sand and clay; clay (30 percent) mottled gray and reddish-brown; sand (70 percent), fine- to coarse-grained, poorly sorted, feldspathic (white, weathered) and slightly glauconitic; small amounts chert and blue quartz; minor hematite, magnetite, pyrite, muscovite.

592-603 Clay, slightly sandy, mottled gray and reddish-brown; sand fraction is 60 percent fine grained, fairly well sorted, clear, angular quartz; 40 percent glauconite; minor muscovite, traces of phosphorite, feldspar, vivianite; a few shell and plant fragments and foraminifers.

603-624 Sand and clay, clay (50 percent), variegated reds, browns, yellows, grays, greens; sand (50 percent), fine- to coarse-grained, poorly sorted, variably rounded; sand fraction consists of 60 percent quartz, 25 percent feldspar, 15 percent glauconite, much of quartz and feldspar stained yellow to brown; minor hematite, blue quartz, chert, magnetite; a few plant fragments; interval 613-624 is 65 percent clay, 35 percent sand.

624-640 Clay, very slightly sandy, brightly variegated white, reds, browns, greens, grays; some glauconite.

PATUXENT FORMATION (640-673')

640-650 Sand, very slightly clayey, grayish-brown; medium- to coarse-grained, fairly well-sorted, subangular to subrounded; abundant fresh potassic feldspar; 5 percent glauconite; traces of garnet, pyrite, muscovite.

645-655 Clay, moderately silty and sandy, brightly variegated; slightly glauconitic; shell fragments common.

655-673 Sand, very slightly sandy, brownish-gray, coarse- to very coarse-grained, well-sorted, subrounded; feldspathic; 5 percent glauconite; trace of garnet; interval 665-673 is very coarse-grained.

REPOSITORY NUMBER: W-2051 COUNTY: Nansemond

OWNER: Atlantic Coast Line Railway ELEVATION: 50 feet G.L.

DRILLER: Norfolk and Western Railway TOTAL DEPTH: 240 feet

LOCATION: 6.0 miles south of Holland, on Atlantic Coast Line spur to Franklin.

Depth (in feet)

COLUMBIA GROUP (0-10′)

0-10 Sand, fine- to very fine-grained, very well-sorted, angular; moderately abundant matrix of orangish-brown clay; trace of muscovite.

YORKTOWN FORMATION (10-110′)

10-20 Clay, very sandy, gray, mottled orange-brown; sand is fine- to very fine-grained, well-sorted, angular; accessory muscovite; abundant anhydrite pseudomorphs after gypsum; 5-10 percent pelecypod valves and shell fragments; foraminifers moderately abundant.

20-50 Clay, silty and sandy, greenish-gray; fine- to very fine-grained, very well-sorted, angular; accessory glauconite and muscovite; abundant anhydrite pseudomorphs after gypsum; 5 percent pelecypod shell fragments and few echinoid spines; foraminifers moderately abundant; interval 30-40, moderately sandy, 15-20 percent pelecypod shell fragments; interval 40-50, slightly sandy, 5 percent pelecypod shell fragments and few small gastropods.

50-80 Clay, very slightly sandy, greenish-gray; sand is fine- to very fine-grained, well-sorted, angular; accessory muscovite and glauconite; abundant anhydrite pseudomorphs after gypsum; 5 percent small pelecypod shell fragments; interval 70-80, moderately sandy, 20 percent small pelecypod shell fragments.

80-100 Shell and sand; moderately abundant matrix of greenish-gray clay; 60 percent coarse pelecypod-gastropod shell debris; 40 percent fine- to medium-grained, fairly well-sorted sand; sand is 80 percent clear to greenish, angular quartz, and 20 percent fresh glauconite; anhydrite pseudomorphs after gypsum are common; foraminifers moderately abundant; interval 90-100, clay is gray and greenish-brown, sand is 90 percent quartz and 10 percent glauconite.

100-110 Clay, silty, moderately sandy, greenish-brown; sand is generally fine-grained, fairly well-sorted and angular; clear to greenish-quartz with 10 percent glauconite, 3-5 percent fresh gypsum and minor muscovite; 5-10 percent pelecypod shell fragments, very few foraminifers.

CALVERT FORMATION (110-165′)

110-150 Clay, compact, slightly to moderately sandy, gray; sand is fine-grained, well-sorted, angular; 3-5 percent glauconite, gypsiferous; few shell fragments.

Depth (in feet)

150-160 Sand, very fine- to coarse-grained, rather poorly sorted (skewed fine); moderately abundant matrix of light-brown, dolomitic silt and, subordinately, of blackish-brown bituminous matter; 65 percent very clear, subangular to subrounded quartz, 10 percent pelletal and bone phosphorite, and 10 percent light- to medium-green glauconite; sand is locally a dolomitic sandstone; few shell fragments.

160-165 Sand, very abundant matrix of brown dolomitic silt and blackish-brown bituminous matter with pockets and lenses of light bluish-gray glauconitic clay; in part, a well-indurated, sandy, dolomitic siltstone; sand is medium-grained, moderately sorted; 70 percent angular to subrounded, very clear quartz, 10 percent bone and pelletal phosphorite, few foraminifers (*Nonion*, *Uvigerina*) and poorly preserved shell fragments.

MATTAPONI FORMATION (165-230′)

165-180 Sand, locally yellowish-green, yellow, and orange-brown, medium- to coarse-grained, fairly well-sorted; abundant matrix of green clay; 80 percent dark- to light-green autochthonous glauconite, 10 percent quartz; numerous phosphatic concretions and small nodules (minor gypsum and pyrite).

180-200 Limestone, sandy, light grayish-green; fossiliferous; glauconitic; nodular phosphorite and encrusting pyrite are common.

200-210 Sand, fine- to very coarse-grained, poorly sorted; moderately abundant matrix of drab purplish-gray clay; 40 percent clear to greenish quartz, 40 percent dark-green glauconite, small amount of bone and nodular phosphorite; a few fragments of shell and shell limestone; foraminifers common, but not abundant.

210-230 Sand, coarse- to very coarse-grained, moderately sorted; moderately abundant matrix of drab purplish-gray clay; 50 percent quartz, 40 percent glauconite, small amount of bone and nodular phosphorite; foraminifers common, but not abundant; few fragments of shell and shell limestone; interval 220-230; medium- to very coarse-grained, fairly well-sorted (skewed fine), 60 percent quartz, 30 percent glauconite.

"TRANSITIONAL BEDS" (230-240′)

230-240 Clay, sandy, brightly mottled, with yellow aspect; sand is very fine to very coarse-grained, poorly sorted; 30 percent quartz, 15 percent dark- to bluish-green glauconite, slightly micaceous; minor nodular and bone phosphorite; few poorly preserved foraminifers; few fragments of shell and glauconitic limestone; at 240 feet grades into dark-gray fissile clay with a few carbonized wood fragments.

REPOSITORY NUMBER: W-2056 COUNTY: Middlesex
OWNER: Carlston ELEVATION: 8 feet G.L.
DRILLER: Fetterholf Brothers TOTAL DEPTH: 542 feet
LOCATION: In northeast section of Urbanna on Rappahannock River; east of 76°35′, south of 37°40′.

Depth (in feet)

YORKTOWN FORMATION (0-61′)

0-10	Sand, clean, tan, fine- to medium-grained, well-sorted, angular to subangular; clear quartz with accessory magnetite and muscovite.
10-20	Sand, light-brown; fine-grained, well-sorted, angular, sparse binder of ferruginous clay; clear quartz with accessory magnetite, muscovite, and light-green glauconite.
20-30	Sand, light grayish-brown, fine-grained, well-sorted, angular, trace of clay; minor hornblende, weathered glauconite, muscovite; trace of echinoid spines, shell fragments, and foraminifers.
30-51	Sand, gray, fine-grained, fairly well-sorted, angular to subangular, trace of clay; clear to greenish quartz with small amounts of glauconite and muscovite; 10 percent pelecypod shell fragments; few echinoid spines and ostracods; interval 41-51 contains 25 percent shell fragments.
51-61	Sand and shell, very slightly clayey, tan; 50 percent sand, fine-grained, well-sorted, angular; 50 percent pelecypod shell fragments, and a few echinoid spines and *Turritella*.

CALVERT FORMATION (61-256′)

61-82	Shell and clay, 50 percent pelecypod shell fragments, 50 percent brownish-gray sand-free clay; very few foraminifers and gastropods; trace of diatoms; interval 71-82 contains 65 percent shell, 35 percent clay.
82-112	Clay, brownish-gray, small percentage of fine-grained sand; traces of glauconite, pyrite, carbonaceous material; 15 percent shell fragments; very few foraminifers; trace of diatoms; interval 92-102 contains 30 percent shell fragments; interval 102-112 contains 15 percent shell fragments.
112-164	Clay, trace of fine-grained sand, gray; traces of phosphorite and glauconite; 10 percent shell fragments, few foraminifers; very slightly diatomaceous; interval 123-133, diatomaceous, trace of shell material.
164-194	Clay, pulverulent, pale-gray, trace of fine-grained sand; very diatomaceous; foraminifers (*Nonion, Uvigerina*) common but not abundant; interval 174-184 foraminifers moderately abundant (*Nonion, Uvigerina, Bolivina, Virgulina*); interval 184-194 foraminifers abundant (*Nonion, Uvigerina, Bolivina, Virgulina, Dentalina, Nodosavia, Cibieides, Textularia*).
194-215	Diatomaceous earth, moderately foraminiferal (*Siphogenerina lamellata* zone) with a few *Nonion, Uvigerina*.

Depth (in feet)

215-225 Sand and shell, moderately clayey (brownish-gray clay); 60 percent pelecypod shell fragments; 40 percent medium- to coarse-grained, fairly well-sorted, subangular to subrounded sand, clear quartz with 5 percent phosphatic bone fragments.

225-235 Sand, medium to coarse-grained, fairly well-sorted, subangular to rounded; binder of greenish-gray clay; clear quartz with few phosphatic nodules, bone and shell fragments.

235-256 Sand, fine- to very coarse-grained, poorly sorted, variably rounded; abundant matrix of dark greenish-gray clay; clear quartz; 5 percent pelecypod shell fragments; foraminifers common but not abundant; a few echinoid spines and ostracods.

NANJEMOY FORMATION (256-348′)

256-276 Sand, clayey, fine- to medium-grained, moderately sorted, angular to subrounded; clay is locally calcareous; calcarenitic (bioclastic), slightly to moderately glauconitic; 10 percent shell fragments and fragments of sandy shell limestone; poorly preserved foraminifers abundant; abraded echinoid spines common.

276-287 Sand and shell, fine- to very coarse-grained, poorly sorted, variably rounded; abundant matrix of tan clay; about 30 percent shell material, mostly pelecypods with a few bryozoans, echinoid spines and plates, and fragments of sandy shell limestone; clear quartz with 5 percent fresh glauconite; shell and bone fragments common; poorly preserved (reworked) foraminifers common.

287-297 Sand and limestone, 60 percent fine- to very coarse-grained, poorly sorted, rounded sand; 40 percent sandy, moderately fossiliferous limestone containing quartz, goethite after glauconite, bryozoans, pelecypods, and a few algal structures; clear to stained quartz and goethite after glauconite in subequal amounts; minor phosphorite; poorly preserved foraminifers moderately abundant.

297-348 Sand, fine- to very coarse-grained, poorly-sorted, rounded; moderately abundant matrix of dark-gray clay; coarse fraction comprises well rounded and polished goethite after glauconite, and stained quartz; fine fraction comprises moderately altered glauconite and subordinate quartz; moderately foraminiferal including some planktonic forms.

MATTAPONI FORMATION (348-461′)

348-358 Sand, medium- to coarse-grained, moderately sorted; gray clay binder; blackish-green autochthonous glauconite with subordinate quartz; a few foraminifers.

358-389 Clay, very sandy, light-brown; sand is medium- to very coarse-grained, moderately sorted; predominantly fresh, autochthonous glauconite; few large pelecypod shell fragments.

Depth (in feet)

389-420 Clay, very sandy, gray; sand is fine- to very coarse-grained, poorly sorted; 50 percent fine- to medium-grained, angular quartz; 50 percent medium- to very coarse-grained, fresh, autochthonous glauconite; trace of muscovite; a few shell fragments, phosphatic nodules, fish teeth, bryozoans, and foraminifers (*Robulus, Nodosaria*) interval 399-410, sand fraction is coarser, more glauconitic.

420-461 Clay, interlaminated pink and greenish-gray; moderately sandy (pink) to sandy (greenish-gray); sand is dark-green, autochthonous glauconite, with subordinate quartz; few foraminifers (*Robulus, Nodosaria*) ; intervals 420-440, very sandy, 10 percent coarse shell material; interval 440-451, very sandy, 20 percent coarse shell material; interval 451-461, very sandy, very slightly feldspathic, 5 percent shell material.

PATUXENT FORMATION (461-542′)

461-490 Sand, clean, gray, coarse-grained, fairly well-sorted, subangular to subrounded; feldspathic; 5 percent glauconite; interval 471-481 is course- to very coarse-grained.

490-492 No sample

492-542 Sand and gravel, gray; trace of clay; 50 percent granule gravel; 50 percent coarse- to very coarse-grained, subangular to subrounded sand; both fractions feldspathic; sand fraction moderately glauconitic; garnet common; interval 502-512 is very slightly glauconitic.

542 Clay, sandy, mottled gray and brown; sand is poorly sorted, very glauconitic.

REPOSITORY NUMBER: W-2071 COUNTY: Henrico

OWNER: County of Henrico ELEVATION: 140 feet G.L.

DRILLER: Sydnor Hydrodynamics, Inc. TOTAL DEPTH: 652 feet

LOCATION: 200 feet east of Antioch Drive, 500 feet north of Interstate Highway 64.

Depth (in feet)

COLUMBIA GROUP (0-60′)

0-10 Sand, fine- to very coarse-grained, poorly sorted, subangular to rounded; abundant matrix of yellowish-brown clay; weathered feldspar common but not abundant; some blue quartz; accessory magnetite, and a few micaceous rock fragments and grains of garnet; interval 7-10, clay matrix is bright, variegated, trace of granule gravel.

10-20 Clay, sandy, orangish-brown, mottled white; sand is fine-grained, fairly well-sorted, angular; minor feldspar, muscovite, magnetite, glauconite.

20-30 Gravel and sand, abundant matrix of orange and white clays; 60 percent fine-grained gravel, 2-20 mm, consisting of quartz, quartzite, and weathered chert; 40 percent fine- to very coarse-

Depth (in feet)

grained, poorly sorted, poorly rounded sand; slightly feldspathic; traces of muscovite and magnetite.

30-40 Gravel, tan, fine-grained (2-10 mm), well-sorted, rounded; mainly quartz with subordinate chert and feldspar and a few rock fragments.

40-60 Sand, very slightly clayey, orangish-brown, medium- to coarse-grained, fairly well-sorted, angular to subrounded; 20 percent fine-grained (2-10 mm), rounded gravel consisting of quartz, feldspar and rock fragments; clear quartz, with minor feldspar; traces of chert, magnetite, garnet; interval 50-60 contains 5 percent granule gravel.

YORKTOWN FORMATION (60-70')

60-70 Sand, mottled yellowish-brown, medium-grained, fairly well-sorted, subangular to subrounded; sparse matrix of slightly carbonaceous gray clay; clear quartz, minor feldspar, trace of glauconite.

CALVERT FORMATION (70-90')

70-90 Clay, sandy, gray; sand is fine- to coarse-grained, rather poorly sorted, variably rounded; slightly feldspathic; trace of glauconite.

NANJEMOY FORMATION (90-143')

90-110 Sand, fine- to coarse-grained, fairly well-sorted; moderately abundant matrix of brownish-gray clay; 60 percent clear quartz, 35 percent blackish- to light-green glauconite and minor amounts of nodular phosphorite, carbonaceous material, and muscovite; shell and plant fragments common; foraminifers common, but not abundant; interval 100-110 contains 15 percent shell fragments and abundant foraminifers.

110-143 Sand and shell, gray, slightly clayey, with 5 percent well-rounded quartzose granule gravel; sand is very fine- to very coarse-grained, angular to well-rounded; 55 percent clear to greenish quartz; 15 percent dark-green glauconite; nodular and bone phosphorite common; 25 percent pelecypod-gastropod shell fragments; forminifers common, but not abundant; interval 120-130 sand is 40 percent quartz, 30 percent glauconite; interval 130-143 contains 40 percent quartz, 30 percent glauconite; plant fragments abundant.

MATTAPONI FORMATION (143-230')

143-157 Sand, clayey, fine- to medium-grained, well-sorted; a few quartz granules; 75 percent dark-green autochthonous glauconite; 20 percent clear, angular quartz with minor pyrite, muscovite, and nodular and bone phosphorite; 5 percent pelecypod and gastropod shell fragments; foraminifers common, but not abundant; interval 150-157, 85 percent glauconite, 12 percent quartz with lenses of light-gray, slightly glauconitic clay, and about 2 percent shell fragments.

Depth (in feet)	
157-160	Clay and sand, interlaminated light-gray, orange, and yellow; 60 percent slightly sandy to sand-free clays; 40 percent greenish-gray clayey sand; sand is fine-grained, fairly well-sorted, composed of 50 percent glauconite and about 50 percent quartz with abundant pyrite, accessory muscovite, and nodular and bone phosphorite; pelecypod shells and other shell fragments common; foraminifers common; few fragments of calcitic, glauconitic sandstone.
160-180	Clay and sand, 70 percent moderately glauconitic orange clay with considerable silt-size muscovite; interlaminated with 15 percent greenish-gray, coarse-grained, quartzo-micaceous, glauconitic, silt and 10 percent essentially pure, light-gray clay and a trace of yellow silty clay; 5 percent light-gray, sandy limestone fragments; a few pelecypod shell fragments and small pebbles of quartz, quartzite, and phosphorite; pyrite abundant; a few foraminifers; interval 170-180, 40 percent orange clay, 45 percent greenish-gray silt; *Robulus* and *Nodosaria* prominent.
180-190	Sand, clayey, dark-gray, 55 percent fine- to medium-grained, fairly well-sorted, clear to greenish, angular quartz; 35 percent dark- to medium-green autochthonous glauconite, minor amounts of muscovite, pyrite, and nodular and bone phosphorite; 10 percent pelecypod shell fragments and a few foraminifers.
190-220	Sand, clayey, dark-gray, fine- to coarse-grained, moderately sorted; a few lenses of orange, glauconite-bearing clay; 50 percent clear to greenish, angular quartz; 50 percent dark-green, autochthonous glauconite; a few shell fragments and foraminifers; interval 200-220, 10 percent each pelecypod-gastropod shell fragments and gray, arenaceous, glauconitic limestone.
220-230	Clay, compact, generally sand-free, dark-gray, locally sandy to gravelly; sand consists of fine- to coarse-grained, poorly sorted, clear to greenish quartz and fresh glauconite; 10 percent each of shell fragments and fragments of calcitic glauconitic sandstone; lignitic fragments common; few foraminifers.
PATUXENT FORMATION (230-640′)	
230-260	Gravel and sand, very slightly clayey, well sorted, fairly well-rounded; coarse-grained sand to granule gravel; abundant fresh, potassic feldspar; slightly glauconitic; accessory garnet, tourmaline, and pyrite.
260-310	Sand, slightly clayey, gray, coarse-grained, well-sorted, subangular to subrounded; trace of fine-grained gravel; feldspathic; slightly glauconitic; interval 265-270, 20 percent gravel (2-10 mm); interval 270-280, 20 percent gravel (2-5 mm); interval, 280-290, 25 percent gravel (2-5 mm); interval 290-300, 30 percent gravel (2-8 mm); interval 300-310, 35 percent gravel (2-8 mm).

Depth (in feet)	
310-340	Sand and gravel, very slightly clayey, orangish-brown (iron-stained); 70 percent coarse-grained sand; 30 percent granule gravel with a few pebbles up to 10 mm; fairly well-sorted, subrounded; very feldspathic, slightly lithic, very slightly glauconitic; interval 320-340, 40 percent sand, 60 percent fine-grained gravel.
340-370	Gravel and sand, very slightly clayey, grayish-brown; 70 percent gravel, fine-grained (2-10 mm), angular to rounded; 30 percent sand, medium- to very coarse-grained, moderately sorted, angular to rounded; gravel is moderately lithic, slightly feldspathic; sand is moderately feldspathic, slightly lithic; accessory garnet; interval 360-370, moderately abundant matrix of gray clay, 50 percent sand, 50 percent gravel.
370-410	Sand, slightly clayey, gray; coarse- to very coarse-grained, fairly well-sorted, subangular to rounded; 15 percent granule gravel; feldspathic; few rock fragments; accessory garnet; interval 380-390 contains 50 percent granule gravel; interval 390-400 contains 50 percent fine-grained gravel (2-8 mm); interval 400-410 contains 40 percent fine-grained gravel (2-8 mm).
410-430	Sand and gravel, abundant matrix of reddish-brown, variegated clay; 70 percent fine- to very coarse-grained sand; 30 percent fine-grained (2-10 mm) gravel; sand is feldspathic, especially in the coarser classes, and very slightly glauconitic and micaceous; gravel is feldspathic and moderately lithic; interval 420-430, moderatley abundant matrix of variegated clay, 60 percent sand, 40 percent gravel.
430-490	Sand and gravel, slightly clayey; 60 percent coarse- to very coarse-grained, fairly well-sorted sand; 40 percent fine-grained (2-6 mm) well-sorted gravel; very feldspathic; a few rock fragments; accessory garnet and muscovite; minor glauconite; interval 470-480, 50 percent sand, 50 percent gravel; interval 480-490, 35 percent sand, 65 percent gravel (2-5 mm).
490-540	Sand, medium- to very coarse-grained, moderately sorted, subangular to subrounded; moderately abundant matrix of dark-gray clay, 20 percent well-sorted granule gravel; feldspathic; accessory garnet; trace of glauconite; interval 500-540, very slightly clayey, gray 10 percent fine grained.
540-560	Gravel and sand, slightly clayey, gray; 60 percent well-sorted granule gravel; 40 percent coarse- to very coarse-grained sand, very feldspathic; metamorphic rock fragments common; accessory garnet and pyrite; interval 550-560 metamorphic and igneous rock fragments moderately abundant.
560-580	Sand, slightly clayey, brown; coarse- to very coarse-grained, fairly well-sorted, subangular to subrounded; iron-stained grains abundant; blue quartz common; feldspathic; rock fragments (schist and chert) common; accessory garnet; interval 470-480 is medium- to coarse-grained, well sorted.

Depth (in feet)

580-620 sand, clean gray coarse- to very coarse-grained, well-sorted, subangular to subrounded; feldspathic; slightly lithic (schist and chert); accessory garnet.

620-640 Sand, clean, gray; medium- to very coarse-grained, moderately sorted, angular to subrounded; feldspathic; slightly lithic (schist and chert); accessory garnet; small amount of fine- to medium-grained glauconite; interval 630-640, fine to very coarse-grained; abundant fragments of quartz-feldspar-biotite schist, and some of chert.

NEWARK GROUP (640-652′)

640-652 Gabbro or anorthosite, dark-gray to dark greenish-gray; medium-grained.

REPOSITORY NUMBER: W-2103 COUNTY: Gloucester

OWNER: Clay Bank ELEVATION: 7 feet G.L.

DRILLER: Fetterholf Brothers TOTAL DEPTH: 424 feet

LOCATION: at Clay Bank

COLUMBIA GROUP (0-25′)

0-25 Sand, slightly clayey, tan, fine- to coarse-grained, poorly sorted; trace of granule gravel; encrustations of goethite common; small amount of light-green glauconite; some blue quartz and decomposed feldspar in gravel fraction.

YORKTOWN FORMATION (25-197′)

25-45 Sand, slightly clayey, greenish-gray; 2-3 percent fine- to medium-grained light-green glauconite; traces of muscovite and magnetite; 10 percent shell fragments.

45-66 Sand, slightly clayey, greenish-gray, fine- to coarse-grained, poorly sorted, angular to rounded; 5-10 percent medium-grained glauconite; aragonite needles common; black vivianite common; 15 percent autochthonous gastropod and pelecypod shells, a few fragments of black shells and phosphorite; *Textularia* present.

66-83 Sand, slightly clayey, dark-gray; fine- to coarse-grained, poorly sorted, angular to well-rounded; 5 percent glauconite; aragonite needles common; brown vivianite common; 25 percent autochthonous gastropod and pelecypod shells.

83-105 Sand, moderately clayey, greenish-gray; fine-grained, well-sorted, angular; minor glauconite, trace of muscovite; 3-5 percent small shell fragments; few ostracods, foraminifers, echinoid spines, and bone fragments.

105-145 Clay, compact, sand-free, light-gray; subordinate laminae of moderately clayey, greenish-gray, fine-grained, well-sorted sand; minor nodular pyrite; *Nonion* common; a few bone and shell fragments; interval 125-135, nodular pyrite common; *Nonion* and *Bolivina* common; interval 135-145, greenish-gray; nodular pyrite common; *Nonion* common, a few *Textularia*.

Depth (in feet)

138-148 Sand, clayey, greenish-gray; fine- to medium-grained, fairly well-sorted; 80 percent clear subangular quartz, 5 percent fragmented phosphorite; *Siphogenerina*, *Uvigerina*, *Nonion* abundant; few *Robulus* and *Dentalina*.

145-155 Clay, greenish-gray; trace of fine quartz sand; 5 percent shell fragments, few foraminifers (*Nonion*, *Bolivina*) and ostracods.

148-158 Sand and shell, slightly clayey, greenish-gray; 20 percent pelecypod shell fragments; 80 percent medium- to coarse-grained, moderately sorted, subangular to subrounded clear quartz sand; phosphorite fragments common; a few fragments of dolomitic sandstone; very few foraminifers.

155-187 Clay, silty, greenish-gray; interval 165-180, trace of fine-grained, green-tinted quartz sand; a few foraminifers; interval 180-187, traces of fine-grained, green-tinted quartz sand, and fine- to coarse-grained, clear quartz sand with minor fragmented phosphorite; foraminifers (*Nonion*, *Bolivina*, *Textularia*) common.

187-197 Sand and shell, slightly clayey, greenish-gray; 70 percent medium-grained, moderately sorted, clear quartz sand; 20 percent pelecypod shell fragments; fragmented phosphorite is common.

CALVERT FORMATION (197-279′)

197-228 Clay, pulverulent, buff; diatomaceous; foraminifers common (*Nonion*, *Uvigerina*); interval 207-228, foraminifers abundant (*Nonion*, *Robulus*, *Uvigerina*, *Bolivina*).

228-238 Clay, pulverulent, buff; diatomaceous; foraminifers abundant (*Siphogenerina* dominant).

238-258 No sample.

258-269 Sand, slightly clayey, brownish-gray, medium- to coarse-grained, moderately sorted, subangular to subrounded; clear quartz with 2-3 percent fragmented phosphorite, few shell fragments and small foraminifers.

269-279 Sand, moderately clayey, greenish-gray; fine- to very coarse-grained, poorly sorted, angular to rounded; clear quartz with 2-3 percent fragmented phosphorite; foraminifers moderately abundant.

NANJEMOY FORMATION (279-361′)

279-351 Clay, sandy, dark-gray with purple cast; sand is fine- to coarse-grained, poorly sorted; clear quartz, with subordinate light- and dark-green glauconite, and minor amount of fragmented phosphorite; abundant foraminifers (*Dentalina bevani* dominant); few shell fragments; interval 289-300, sand consists of 60 percent quartz, 40 percent glauconite; interval 300-310, sand consists of 60 percent medium- to very coarse-grained quartz and 40 percent medium-grained glauconite; abundant pyrite; interval 310-320, moderately sandy; sand consists of 40 percent medium- to very coarse-grained quartz

Depth (in feet)

and 60 percent fine- to medium-grained, light- and dark-green glauconite; minor pyrite; interval 320-330, sandy; sand consists of 50 percent medium- to very coarse-grained quartz and 50 percent fine- to medium-grained, dark- and light-green glauconite; minor pyrite; shell fragments common; interval 330-351, silty and very sandy; sand is fine- to medium-grained, moderately sorted; 40 percent quartz, 40 percent dark- and light-green glauconite, 20 percent foraminifers, ostracods, and small shell fragments; pyrite moderately abundant; phosphorite common.

351-361 Sand, slightly to moderately clayey, brownish-gray, coarse-very coarse-grained, fairly well-sorted; 45 percent quartz, 45 percent bioclasts, 10 percent dark-green glauconite; foraminifers common; minor phosphorite and pyrite.

MATTAPONI FORMATION (361-402′)

361-381 Sand, very slightly clayey; black; medium-grained, well-sorted; 95 percent blackish-green glauconite, 5 percent quartz; interval 371-381 contains 75 percent glauconite, 15 percent quartz, 10 percent fragments of phosphatic, glauconite-bearing sandstone.

381-402 Sand, slightly clayey; gray; 85 percent medium-grained, well-sorted, dark-green glauconite, 15 percent medium- to coarse-grained quartz; interval 392-401, 60 percent fine- to mediun-grained, fairly well-sorted, dark-green glauconite, 40 percent fine- to medium-grained, angular quartz.

PATUXENT FORMATION (402-424′)

402 Gravel and sand, slightly clayey, gray: subrounded; 50 percent very coarse-grained sand and granule gravel, very feldspathic; abundant garnet; minor tourmaline.

402-412 Sand, slightly clayey, brownish-gray, with 5 percent fine-grained gravel; fine- to very coarse-grained, poorly sorted; very feldspathic; 5 percent weathered glauconite; minor garnet and muscovite.

412-424 Sand, clean, gray; medium- to very coarse-grained, poorly sorted; very feldspathic; minor garnet; trace of glauconite; interval 424, coarse- to very coarse-grained, moderatley sorted.

REPOSITORY NUMBER: W-2168 CITY: Portsmouth
OWNER: Virginia Chemical Company ELEVATION: 10 feet G. L.
DRILLER: R. L. Magette Well Drilling Co. TOTAL DEPTH: 1015 feet
LOCATION: On company property, 600 feet north of water tower cluster.

0-40 No samples

YORKTOWN FORMATION (40-330′)

40 Shell and sand, coarse shell fragments and medium- to very coarse-grained sand; grades into granule gravel; a few echinoid spines; 50 percent cinders and slag.

Depth (in feet)	
60	Sand, slightly clayey, brownish-gray; medium- to very coarse-grained; 70 percent abraded bioclasts, 30 percent subrounded quartz.
80, 100	Sand, slightly to moderately clayey, gray; medium-grained, moderately sorted; 50 percent bioclasts, 50 percent subangular to subrounded quartz; foraminifers and ostracods moderately abundant.
120, 140	Sand, moderately clayey, gray, fine- to coarse-grained, moderately-sorted, 65 percent clear, subangular quartz, 35 percent bioclasts, very slightly glauconitic; foraminifers and ostracods common; 5-10 percent coarse shell fragments; interval 140, fine- to medium-grained, fairly well-sorted; slightly glauconitic.
160	Sand, moderately clayey, gray; fine- to medium-grained, well-sorted, angular to subangular; clear to greenish quartz with 5 percent bioclasts, 5 percent glauconite, trace of muscovite; 5 percent coarse shell fragments; few foraminifers; echinoid spines common.
180, 200, 220	Clay, locally sandy, brownish-gray; sand is fine- to medium-grained, moderately sorted, angular to subangular; very slightly glauconitic; 10-15 percent shell fragments (pelecypods, scaphopods, *Turritella*, bryozoans), few foraminifers and ostracods, few plant fragments.
240	Clay, very compact, slightly sandy, gray; sand is fine-grained, fairly well-sorted, angular; slightly glauconitic; few shell fragments, very few foraminifers.
260	Sand, clayey, brown; fine-grained, very well-sorted, angular; very slightly glauconitic; 15 percent shell fragments, few foraminifers, mostly *Textularia*; *Turritella* common; few fragments of bone phosphorite.
280, 300, 320	Clay, silty, slightly sandy, brownish-gray; sand is fine- to medium-grained, moderately sorted, angular to subangular; traces of glauconite, muscovite; 10 percent coarse shell, including *Turritella*; foraminifers common.
CALVERT FORMATION (300-450′)	
340, 380, 400, 420	Clay, very slightly sandy, greenish-gray; sand is fine-grained, well-sorted, angular; trace of glauconite; a few foraminifers and shell fragments; interval 420, foraminifers fairly abundant, mostly *Siphogenerina*.
440	Sand, medium- to very coarse-grained, moderately sorted, subangular to rounded; abundant matrix of greenish-brown clay; with 5 percent bone phosphorite and 5 percent fine-grained glauconite; foraminifers abundant, few shell fragments.
MATTAPONI FORMATION (450-520′)	
460	Sand, medium- to very coarse-grained, poorly sorted, variably rounded, sparse matrix of gray clay; clear quartz, with minor glauconite; small amounts feldspar and bone phosphorite; foraminifers common, few shell fragments.

Depth (in feet)

480	Clay, variably sandy, greenish-gray; sand is fine- to very coarse-grained, poorly sorted; 10 percent glauconite, slightly feldspathic; pyrite common; limestone fragments common; foraminifers moderately abundant.
500	Sand, fine to coarse-grained, poorly sorted; abundant matrix of drab greenish-gray and brownish-gray clays; 70 percent clear quartz, 25 percent dark-green glauconite, 5 percent fresh feldspar, minor amount of bone and nodular phosphorite; traces of muscovite and pyrite; foraminifers common.

"TRANSITIONAL BEDS" (520-640')

520, 540	Clay, silty, very slightly sandy, gray with purplish cast; very fine-grained muscovite is prominent, foraminifers common; interval 520, foraminifers very abundant, ostracods common.
560	Sand, fine- to medium-grained, well-sorted, angular to subangular; very abundant matrix of purplish-gray clay; slightly feldspathic and glauconitic; a few foraminifers.
580, 600	Clay, silty, slightly to moderately sandy, bright yellowish-orange, white, and gray; sand is fine-grained, farily well-sorted, angular; slightly glauconitic; foraminifers common; interval 600 contains some red and lavender clays.
620	Clay, very sandy, bright, variegated; sand is fine- to medium-grained, moderately sorted, angular to subangular; moderately micaceous and feldspathic; slightly glauconitic; foraminifers common.

PATUXENT FORMATION (640-1015')

640,660	Sand, very slightly clayey, gray; coarse- to very coarse-grained, fairly well-sorted, subangular to subrounded; moderately feldspathic; accessory garnet.
680, 700	Sand, slightly clayey, brown, medium- to very coarse-grained, fairly well-sorted, subangular to subrounded; feldspathic; very slightly glauconitic.
720, 740, 760, 780	Sand, slightly to moderately clayey, grayish-brown, coarse- to very coarse-grained, fairly well-sorted, subangular to subrounded; feldspathic; very slightly glauconitic; accessory garnet; trace of kyanite; interval 740 very slightly clayey; interval 760 very slightly clayey, 5 percent granule gravel; interval 780 very slightly clayey.
800, 820	Sand, slightly to moderately clayey, greenish-gray, medium- to coarse-grained, fairly well-sorted, subangular to subrounded; feldspathic; very slightly glauconitic; accessory garnet and epidote; interval 820 slightly clayey; medium- to very coarse-grained.
840	Clay, compact, locally sandy, greenish-gray, locally red and yellow; sand is fine- to coarse-grained, moderately sorted, skewed fine, poorly rounded; slightly feldspathic and glauconitic; muscovite common; minor amounts of pyrite and chloritized biotite.

Depth (in feet)	
860	Clay, sandy, light grayish-green; sand is fine- to very coarse-grained, poorly sorted, variably rounded; moderately feldspathic; slightly glauconitic; traces of mica and pyrite.
880	Sand, medium- to very coarse-grained, moderatley sorted, subangular to subrounded; moderately abundant matrix of drab, greenish clay; feldspathic; very slightly glauconitic.
900, 920	Sand, very slightly clayey, brownish-gray, coarse- to very coarse-grained, fairly well-sorted, subangular to subrounded; grades into granule gravel; very feldspathic; minor glauconite; accessory garnet; interval 920, coarse-grained, well-sorted.
940	Sand, very slightly clayey, grayish-green, medium- to coarse-grained, moderately sorted, subangular; feldspathic; very slightly glauconitic; accessory garnet.
960,980	Sand, very slightly clayey, grayish-green, coarse- to very coarse-grained, moderately sorted, subangular; grades into granule gravel; feldspathic; very slightly glauconitic; accessory garnet; interval 980, medium- to coarse-grained, well-sorted.
1000	Clay, variably sandy, gray and grayish-green; trace of granule gravel; sand is fine- to coarse-grained, poorly sorted, poorly rounded; moderately feldspathic; very slightly glauconitic; muscovite common; minor garnet.
1015	No sample

REPOSITORY NUMBER: W-2218 COUNTY: Isle of Wight

OWNER: Smithfield Apartments Corp. ELEVATION: 65 feet G.L.

DRILLER: Pittman Wood & Metal Products Co. TOTAL DEPTH: 412 feet

LOCATION: 400 feet east of intersection of State Highway 10 and State Road 673, and 200 feet south of State Highway 10.

COLUMBIA GROUP (0-10′)

0-10	Sand, slightly to moderately clayey, yellowish-brown; fine- to coarse-grained, fairly well-sorted, skewed fine, angular to rounded; clear and yellow-tinted quartz with minor amounts of feldspar and blue quartz.

YORKTOWN FORMATION (10-170′)

10-30	Shell, clean, brown; 80 percent well-sorted, rounded, and decomposed pelecypod and bryozoan shell fragments, 1-4 mm; 20 percent medium-grained, fairly well-sorted, subangular to subrounded quartz sand; few echinoid spines.
30-40	Shell, slightly to moderately clayey; trace of sand; gray, coarse pelecypod shells and angular shell fragments, and a few gastropods (including *Turritella*), bryozoans, and echinoderms.
40-50	Clay, greenish-gray; very little sand or coarse-grained silt; 15 percent coarse shell material (pelecypods and *Turritella*); a few foraminifers.

Depth (in feet)

50-60 Clay, silty, moderately sandy, gray; sand is fine- to very fine-grained, well-sorted, angular; 70 percent clear quartz, and 30 percent shell material—echinoid spines, foraminifers (predominantly *Nonion*), and small shell fragments; small amounts of mica and glauconite; very few large shell fragments.

60-70 Shell and sand, binder of gray clay; 70 percent coarse, angular pelecypod-shell debris; 30 percent fine- to coarse-grained, moderately sorted, angular to subangular clear quartz sand; very slightly glauconitic; echinoid spines and foraminifers common.

70-100 Shell and sand, binder of gray clay; 70 percent coarse, angular pelecypod-shell debris; 30 percent fine- to coarse-grained, moderately sorted, angular to subangular clear quartz sand; very slightly glauconitic; echinoid spines and foraminifers common; interval 80-100, sand is fine- to medium-grained, fairly well sorted.

100-130 Shell and sand, sparse binder of gray clay; 50 percent coarse pelecypod (gastropod-scaphopod) shell debris, and 50 percent fine- to coarse-grained, moderately sorted, angular to subrounded clear quartz sand; very slightly glauconitic; a few echinoid spines and foraminifers; interval 110-120, moderately abundant matrix of greenish-gray clay; interval 120-130, abundant matrix of greenish-gray clay.

130-170 Sand and shell, clayey, dark greenish-gray; 60 percent fine- to very fine-grained, very well-sorted, angular, clear quartz sand; 40 percent pelecypod-shell fragments, very slightly glauconitic; traces of fragmental phosphorite and muscovite; a very few bone fragments; interval 150-160, 30 percent small shell fragments, 70 percent sand.

CALVERT FORMATION (170-280′)

170-190 Clay, silty and sandy, greenish-gray; sand is very fine- to medium-grained, well-sorted, angular to subangular; clear quartz with small amounts of glauconite and fine-grained phosphorite; 15 percent pelecypod-shell fragments and a few echinoid spines and foraminifers.

190-200 Clay, fairly compact, silty, moderately sandy, greenish-gray; sand is fine- to coarse-grained, poorly sorted, angular to subrounded; very slightly glauconitic; traces of pyrite and phosphorite; 5-10 percent pelecypod shell fragments and a few foraminifers.

200-230 Clay, sandy, gray; sand is fine- to medium-grained, well-sorted, angular to subangular; clear quartz with minor amounts of bone and pelletal phosphorite, nodular pyrite, and fine-grained glauconite; 5-10 percent pelecypod shell fragments and a few foraminifers; interval 210-220, moderately sandy.

230-260 Clay, moderately silty and sandy, dark greenish-gray; sand is fine- to medium-grained, fairly well-sorted, angular; clear quartz, with minor amounts of phosphorite, glauconite, mus-

Depth (in feet)

covite, and nodular pyrite; 5 percent shell fragments; interval 240-250, very silty with 10 percent shell fragments; interval 250-260, very silty with 5 percent shell fragments.

260-280 Sand and shell, abundant matrix of dark, greenish-gray clay; 30 percent pelecypod, gastropod, and bryozoan-shell fragments; 60 percent medium- to coarse-grained, moderately sorted, subangular to subrounded clear quartz; 10 percent bone, nodular, and shell phosphorite; locally a dolomitic sandstone; pyrite nodules common; few foraminifers, mostly *Siphogenerina*; interval 270-280, moderately clayey with 60 percent shell and 40 percent fine- to coarse-grained sand.

NANJEMOY FORMATION (280-300′)

280-290 Sand and shell, abundant matrix of dark greenish-gray clay; 50 percent medium- to coarse-grained, moderately sorted, subangular to subrounded clear quartz; 10 percent yellowish-brown to light-green glauconite; 10 percent fragmental phosphorite; 30 percent molluscan shell fragments and few foraminifers.

290-300 Sand, slightly clayey, brownish-gray, medium- to coarse-grained, fairly well-sorted; 60 percent black, green, yellowish-green, and yellowish-brown glauconite and 40 percent clear and orange-tinted, angular to rounded quartz; few pelecypod shell fragments.

MATTAPONI FORMATION (300-370′)

300-310 Sand, dark-gray; trace of clay; 75 percent medium- to coarse-grained, fairly well-sorted, black glauconite; 25 percent fine- to coarse-grained, poorly sorted clear quartz; trace of bone and shell phosphorite; few worn pelecypod shell fragments and very few foraminifers.

310-320 Sand, gray; abundant quartz silt; 50 percent very fine- to medium-grained, moderately sorted, angular, clear quartz; 50 percent fine- to coarse-grained, greenish-black glauconite; few bryozoans, foraminifers, ostracods, echinoid spines, and molluscan-shell fragments.

320-340 Sand, slightly silty, dark-gray; 90 percent medium- to coarse-grained, well-sorted, black glauconite; 10 percent quartz; trace of shell; interval 330-340, moderately silty; glauconite is medium- to very coarse-grained; 5 percent shell fragments.

340-370 Sand, trace of clay, dark-gray; medium-grained, well-sorted; dark-, medium-, and light-green glauconite; interval 350-360, medium- to coarse-grained, dark-green glauconite predominant; interval 360-370, medium- to coarse-grained, 75 percent predominantly dark-green glauconite, 25 percent clear, angular quartz, and trace of feldspar.

PATUXENT FORMATION (370-412′)

370-410 Sand, gray trace of clay; coarse-grained, well-sorted, subangular to subrounded; moderately feldspathic; 5-10 percent

Depth (in feet)

coarse-grained, black glauconite; accessory garnet and muscovite; interval 380-390, 5 percent glauconite; interval 390-400, 5 percent glauconite, feldspathic.

410-412 No sample

REPOSITORY NUMBER: W-2238 COUNTY: Caroline

OWNER: Mrs. Jessie S. Steward ELEVATION: 200 feet G. L.

DRILLER: Mitchell's Well & Pump Co. TOTAL DEPTH: 375 feet

LOCATION: Webb Motel; 6000 feet northeast of State Highway 2 on State Highway 301.

COLUMBIA GROUP (0-50′)

0-10 Sand, clayey (orangish-brown), fine- to very coarse-grained, poorly sorted; coarse-grained feldspar and blue quartz common; trace of glauconite.

10-30 Sand, moderately clayey (pinkish-orange), fine- to coarse-grained, poorly sorted; slightly feldspathic; interval 20-30 contains trace of fine-grained gravel.

30-50 Sand, slightly clayey (orange); fine- to coarse-grained, moderately sorted; slightly feldspathic; interval 40-50, very fine- to coarse-grained, poorly sorted.

CALVERT FORMATION (50-120′)

50-60 Sand, moderately clayey, greenish-gray, fine- to very fine-grained, very well-sorted; clear and greenish quartz with traces of glauconite and muscovite.

60-70 Clay, slightly sandy, light bluish-gray; sand is fine-grained, well-sorted; clear and greenish quartz with 2-3 percent glauconite; traces of lignitic material and phosphorite.

70-80 Clay, sandy, greenish-gray; sand is fine-grained, well-sorted; clear and greenish quartz; few phosphatic nodules and bone fragments; trace of glauconite; 10 percent small shell fragments.

80-100 Sand, moderately clayey, dark brownish-gray; fine- to very fine-grained, well-sorted; clear and greenish quartz with a trace of glauconite, few bone and shell fragments; interval 90-100, grayish-brown, quartz is clear to yellowish.

100-110 Silt, clayey, pale greenish-gray, coarse-grained, well-sorted.

110-120 Sand, clayey (dark brownish-gray); fine-grained, well-sorted; 5 percent fine-grained gravel, mainly phosphate nodules; 90 percent quartz, 10 percent glauconite; abundant concretionary pyrite; trace of muscovite.

NANJEMOY FORMATION (120-150′)

120-130 Silt and sand, clayey (dark brownish-gray); coarse-grained silt and very fine-grained sand; very well-sorted; very slightly micaceous and glauconitic; trace of bone phosphorite.

Depth (in feet)

130-150 Sand, clayey, dark-gray, fine- to very fine-grained, well-sorted; clear and greenish quartz; slightly glauconitic and micaceous; 5-10 percent small shell fragments and very few foraminifers; 140-150, 10-15 percent shell fragments, foraminifers common.

MATTAPONI FORMATION (150-200′)

150-170 Sand, clayey, dark-gray, fine- to medium-grained, well-sorted; 65 percent clear and greenish quartz; 35 percent dark-green glauconite, muscovite common; 5-10 percent small shell fragments, foraminifers common; interval 160-170, very dark-gray, fine-grained, well-sorted.

170-190 Sand, moderately clayey, very dark-gray, fine-grained, well-sorted; 75 percent clear and greenish quartz, 25 percent glauconite; muscovite common; few shell fragments and foraminifers; interval 180-190, medium gray, fine- to medium-grained fairly well-sorted, 15 percent small shell fragments.

190-200 Sand, clayey (dark-gray), fine- to medium-grained, fairly well-sorted; 60 percent clear and greenish quartz; 40 percent dark-green glauconite, abundant muscovite; 5 percent shell fragments; foraminifers common.

"TRANSITIONAL BEDS" (200-350′)

200-210 Sand, clayey, buff, very fine- to very coarse-grained, poorly sorted; trace of granule gravel; slightly glauconitic in finest fraction, moderately feldspathic in coarser fractions; pyrite common; few plant fragments.

210-220 Clay, moderately sandy, yellowish-brown; sand is fine-grained, well-sorted; clear quartz with some feldspar and a trace of glauconite.

220-230 Clay, sandy, hematitic, light brownish-red, mottled light-gray and white; sand is very fine- to very coarse-grained, poorly sorted; 50 percent quartz; 5 percent feldspar; 45 percent pelletal hematite; trace of glauconite.

230-250 Clay, compact, slightly sandy, mottled light-gray, yellow, and red; trace of granule gravel; sand is very fine- to very coarse-grained, poorly sorted; 50 percent quartz, 50 percent hematite; minor feldspar; trace of glauconite; interval 240-250, light-gray clay is predominant, sand is 70 percent quartz, 30 percent hematite.

250-260 Clay, compact, mottled gray and yellowish-brown; trace of sand.

260-270 Clay, compact, mottled reddish-brown, yellowish-brown, and gray; trace of sand.

270-280 Clay, compact, gray and yellowish-brown.

280-300 Clay, silty, moderately sandy to sandy, light-brown; sand is fine- to very fine-grained, very well-sorted; moderately feldspathic; trace of muscovite; interval 290-300, sandy, moderately feldspathic, a few plants fragments.

Depth (in feet)	
300-310	Clay, compact, slightly sandy, purplish-brown; sand is very fine- to coarse-grained, poorly sorted; 70 percent quartz, 25 percent hematite; 5 percent feldspar.
310-320	Clay, compact, medium-gray.
320-330	Clay, brownish-gray and yellowish-brown; small amount of fine-grained, well-sorted quartz sand.
330-340	Clay, compact, light-gray.
340-350	Clay, moderately sandy to sandy, pale brownish-gray; sand is white, fine- to very fine-grained, very well-sorted; trace of muscovite.
PATUXENT FORMATION (350-375′)	
350-360	Sand, clean, white, fine- to coarse-grained, fairly well-sorted, skewed fine; moderately feldspathic in coarse fraction; accessory magnetite.
360-370	Sand, light-tan, medium- to coarse-grained, well-sorted, subangular; trace of clay; slightly to moderately feldspathic.
370-375	Sand, clean, pale reddish-brown; medium- to very coarse-grained, moderately sorted, subangular to subrounded; slightly to moderately feldspathic.

PART 2

PALEOGEOLOGY OF EARLY CRETACEOUS THROUGH MIOCENE TIME

By

ROBERT H. TEIFKE

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PALEOGEOLOGY OF EARLY CRETACEOUS THROUGH MIOCENE TIME

By

Robert H. Teifke

ABSTRACT

Relationships between the distribution of sediments and the tectonic framework in which they were deposited are shown on paleogeologic and paleostructure maps.

The Patuxent Formation and "transitional beds" of Early Cretaceous age represent a period of relatively active tectonism and rapid deposition of terrigenous detritus during which the major features of the Precambrian-Paleozoic "basement" surface were obscured. A substantial pre-existing "basement" low and an unknown amount of additional subsidence during Cretaceous time are inferred from the thickness of the Patuxent Formation. By their location, three-dimensional configuration, and lithologic properties, the "transitional beds" reflect the waning stages of rapid deposition of terrigenous sediments.

Late Cretaceous (?) and Tertiary deposition, characteristically marine, occurred in a series of transgressive phases in which first the Mattaponi, and then the Nanjemoy, Calvert, and Yorktown sediments were deposited over the area. The Mattaponi basin was of wide extent. Between Mattaponi and Nanjemoy time, the regional tectonic framework changed to produce an areally restricted basin with its deepest portion to the north. From Nanjemoy, through Calvert, to Yorktown time the tectonic framework changed to produce a gradually expanded basin whose deepest portion shifted progressively southward. Effects of basement evolution on sediment distribution during the Tertiary are subtle but nevertheless correlate satisfactorily with the distribution of formations and their characteristics as presently mapped.

INTRODUCTION

The area of this report is mainly that part of the Coastal Plain province of Virginia extending from the Piedmont province on the west eastward to the Chesapeake Bay, and from the Potomac

River on the north southward to the Virginia-North Carolina boundary (Plate 1; Part 1, Figure 1). The Coastal Plain of Virginia on the west bank of the Potomac River north of Fredericksburg was not mapped. Most of the area of Chesapeake Bay and the Eastern Shore Peninsula to the east is one of poor deep-well control. New data, however, from Tangier Island in Chesapeake Bay (W-3375) and from Temperanceville in northern Accomack County (W-3180) have allowed expansion of the study area northeastward to the Eastern Shore Peninsula.

The region is transected by four major rivers that flow southeastward to Chesapeake Bay and divide the region into four geographic units: Potomac River, Northern Neck peninsula, Rappahannock River, Middle peninsula, York River, York-James peninsula, James River, and Southside Virginia. To facilitate discussion within this report, the Coastal Plain has been subdivided into 12 blocks defined by the parallels 37°00′, 37°30′, and 38°00′, and the meridians 76°15′ and 77°00′.

The main purpose of this study is to document the Cretaceous-Tertiary tectonic development of the Coastal Plain of Virginia in order to better understand the relationships between its structural evolution and its lithostratigraphy and sediment distribution. Also, knowledge of the tectonic framework in which sedimentation occurred is of value in predicting the lithologic character of the sedimentary sequence in areas where few or no data are available.

All sediments between the "basement" and the top of the Miocene Yorktown Formation are discussed. The "basement" consists mainly of granitic rocks of Precambrian-Paleozoic age, with metasedimentary and metavolcanic rocks occurring locally. Semi-indurated "red beds", tentatively assigned to the Newark Group of Triassic age, are present in graben-like structures below a major unconformity and therefore are more closely related to the Precambrian-Paleozoic rocks than to the overlying Mesozoic strata. The overlying sedimentary succession comprises, in order of ascending stratigraphic position, the Patuxent Formation, "transitional beds", Mattaponi Formation, Nanjemoy Formation, Calvert Formation, Yorktown Formation, and Columbia Group. These units have been defined and described in Part 1. The upper Miocene Yorktown Formation and the post-Miocene Columbia Group constitute the present surface of erosion and have been partially treated by Oaks and Coch (1973) and Onuschak (this report, Part 3).

METHODS OF INVESTIGATION

Subsurface data from Part 1 served as the principal basis for two additional series of maps depicting, respectively, (1) the paleogeology of the Coastal Plain and (2) the paleostructural evolution of the "basement".

The first series of four paleogeologic maps (Plates 18-21), was prepared by tracing the zero isopach lines of each formation. Each map depicts the geology of each surface of unconformity upon which succeeding strata were deposited. Considered in reverse order, Plates 18-21 present the distribution of geologic formations as it would appear if, beginning with the Yorktown, increasingly older units were peeled off, one by one, down to the pre-Mattaponi surface. The pre-"transitional beds" surface is easily visualized by figuratively removing the "transitional beds" from Plate 18; accordingly, a separate map depicting this stage was not prepared. Neither does the pre-Columbia Group surface require a separate map, as the distribution of its formations is shown on the current geologic map of Virginia (Virginia Division of Mineral Resources, 1963). Each paleogeologic map is, strictly speaking, a subcrop map that shows only the *present* distribution of each formation and not its original distribution.

The second series of five paleostructure maps* (Plates 13-17) illustrates change in the configuration of the "basement" surface from the beginning of "transitional beds" deposition (Plate 13) to the begining of Yorktown deposition. The first map of this series (Plate 13), showing Patuxent thickness, was made by algebraically subtracting the "basement" surface shown on Glaser's map (1969) (Plate 12) from the Patuxent structure (Plate 2). Plates 14-17 each, in turn, shows the effect of the graphical addition of the thickness of the next higher unit to the total thickness of the underlying sediment wedge. Thus this map series depicts, in sequence, the shape of the "basement" immediately prior to deposition of the "transitional beds" and the Mattaponi, the Nanjemoy, the Calvert, and the Yorktown formations. Plate 12 is a slightly modified version of Glaser's (1969) map of the present structure of the "basement".

All maps are drawn to the same scale as that used for earlier maps (Part 1). A 100-foot contour interval is used throughout,

* A paleostructure map is one that shows ". . . by thickness contour lines, the structure of the lower boundary surface *at the time* the upper boundary surface was formed as a horizontal plane" (Levorsen, 1960, p. 4).

and the minus 1500- and minus 2500-foot contour lines are coded with symbols to facilitate comparisons among maps. The values of the contour sequence are arbitrary and do not refer to any external datum such as sea level; each map would be equally valid and depict the same structural configuration if any other comparable sequence of values was employed, provided that the contour interval remained the same. For example, the thickness variation between the two coded contours will in any event be 1000 feet. Thus, *differences* between contours on any one map and *differences* between the value of the same point on any two maps are real and accurate.

PALEOGEOLOGY

The structural interpretations presented here are based on the assumption that the described stratigraphic intervals were bounded initially by essentially flat upper surfaces and that isopach maps of progressively thicker intervals depict the structure of the base of the total interval at the time of formation of the upper surface. In general, a series of isopach maps depicting accumulation of a sequence of marine units such as the Tertiary formations of the Coastal Plain of Virginia conforms to this requirement, whereas isopach maps of sequences of nonmarine sediments, such as the Cretaceous, can be expected to have a certain amount of relief on their upper surfaces. Relief on the Cretaceous surfaces on the Coastal Plain of Virginia is relatively low (Plates 2 and 3) as compared to the broad regional structures revealed by the isopach maps of overlying units (Plates 7 and 8). It seems extremely improbable that the main features shown on these maps are anything other than "basement" structures.

The geologic development of the area can best be seen by examining sequences of maps that most closely pertain to each major stage in the development of the Coastal Plain rather than by examining individual maps.

EARLY CRETACEOUS TIME

Change in the configuration of the "basement" and in the areal distribution of formations from the beginning of Patuxent deposition to the beginning of Mattaponi deposition, that is, throughout the entire Early Cretaceous epoch, is illustrated in Plates 13, 14, and 18. The total sedimentary interval is pre-

dominantly nonmarine, rests nonconformably upon "basement" rocks, and is overlain by Tertiary formations of marine origin. It constitutes a wedge of genetically related strata with several internal characteristics distinctive of a nonmarine origin, including abrupt vertical and lateral changes in lithology and thickness, lack of fossils, and predominance of feldspar over glauconite.

Patuxent Formation

The paleostructure of the "basement" at the beginning of "transitional beds" sedimentation is illustrated in Plate 13, which shows the thickness of the Patuxent Formation of Early Cretaceous age, the lower unit of the nonmarine succession. The map indicates a surface with two major elements: a broad, but distinct, embayment situated mainly north of 37°30′, and an eastward-trending positive element or basement "high" south of 37°30′. The latter feature is very broad and poorly defined west of 76°45′ but is quite prominent eastward; it roughly corresponds in position to the "Fort Monroe high" (Richards and Straley, 1953, p. 105). The axis of thickening, trending southeastward from the intersection 37°00′-76°15′ defines the head of an embayment on the southern flank of the Fort Monroe high. This feature is part of the embayment described by Richards (1967) as the "Hatteras low"; it also has been referred to as the "Albemarle embayment".

The broad westward deflection of the contours in the northern half of the map area and their increasingly close spacing northeastward at least as far as the Eastern Shore show a relatively rapid thickening of the Patuxent in that direction, indicating a correspondingly steep declivity in the paleostructure of the "basement". This feature is too broadly regional to be other than a major reentrant on the "basement". It coincides in position and configuration with Richards' (1948) "Salisbury embayment" and most of the Coastal Plain of Virginia occupies its southern flank.

The Patuxent simply filled pre-existing "lows" on the "basement" surface shown in Plate 13. The presence of probable Jurassic strata (Maher, 1965) in the deeper parts of the Salisbury embayment and Hatteras low indicates that these features

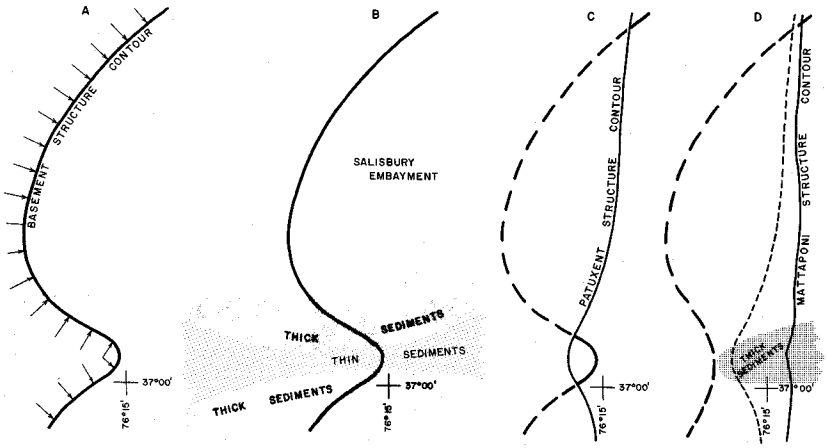

Figure 3. Effects of basement configuration on sediment distribution during the Cretaceous and early Tertiary periods.

A. Shape of basin in which the Patuxent Formation was deposited (its influence on the distribution of Lower Cretaceous sediments is shown by the arrows).

B. Thickness distribution of Lower Cretaceous sediments as related to the underlying "basement" structure.

C. Configuration of Patuxent surface and its relationship to "basement" structure.

D. Thick development of Upper Cretaceous and lower Tertiary sediments corresponds to reentrant on Cretaceous surface.

predate the Patuxent. Also, several characteristics of the Patuxent's upper surface (Plate 2)—its north-south contour pattern, regional slope to the east, and numerous second-order irregularities—are not readily relatable to the shape of the "basement," indicating that the major basins were largely pre-Patuxent structural elements and that Patuxent sedimentation eventually exceeded any attendant subsidence and largely concealed the "basement" structure by the beginning of the "transitional beds" period.

The dispersal and distribution of terrigenous detritus arriving from the west during the Patuxent-"transitional beds" period of deposition were influenced to some extent by the Fort Monroe high. The high tended to deflect the influx of sediment northward and southward away from its axis and toward the major basins on its flanks. A limited area directly east of this structure received a relatively small volume of terrigenous sediment. The effect of the structure on sediment dispersal patterns decreased progressively during this period of deposition. Eventually, of course, the entire structure was covered by up to 1300 feet of Patuxent sediment (Plate 2). The reentrant on the Lower Cretaceous surface coincident with the nose of the Fort Monroe high immediately north of 37°00′-76°15′ (Plate 2) is interpreted to be a result of the lower net volume of terrigenous sediment deposited in the lee of the Fort Monroe high. Figure 3 A-C depicts this interpretation.

"Transitional Beds"

The effects of "transitional beds" deposition on "basement" configuration are local and minor (compare Plates 13 and 14). The central part of the map shows no change in "basement" structure and is interpreted as having been an area of nondeposition and erosion during "transitional beds" time.

The "transitional beds" isopach map (Plate 7) shows that maximum thicknesses of "transitional beds" were deposited in the Hatteras low and the Salisbury embayment and were separated by the Fort Monroe high which was still positive during and after "transitional beds" deposition (Plate 14). The low and uniform rate of change in isopach values in the direction of thinning suggests that the formation limits in both the north and the south are depositional rather than erosional. The regional slope, topography, and drainage pattern of the underlying Patuxent surface strongly affected the thickness and areal distribution of the "transitional beds." In the north and south, subsidence of the "basement" during "transitional beds" time is indicated by the westward displacement of the paleostructure contours (compare Plates 13 and 14). The "transitional beds" are interpreted here as the record of the final stage of a long period of terrigenous clastic sedimentation and basin filling which began

with deposition of the lowermost Patuxent strata. Plate 14 shows the pre-Mattaponi paleostructure of the "basement" and Plate 18 shows the pre-Mattaponi paleogeology of the Coastal Plain.

LATE CRETACEOUS (?) AND TERTIARY TIME

The tectonic framework of Late Cretaceous (?) and Tertiary deposition is dominated by the Fort Monroe high and the effects of this high on the configuration of the marine basin and the distribution of the Upper Cretaceous(?)-Tertiary marine formations.

Compared to the distinct relationships between "basement" evolution and sediment distribution that characterize Early Cretaceous time, relationships between "basement" structure and Late Cretaceous (?)-Tertiary sedimentation patterns are subtle. This is attributed to the low mobility of the "basement" beneath the Coastal Plain during this time, and to the limited thicknesses of the Upper Cretaceous(?)-Tertiary marine units in the area. Extensive thin units deposited in a tectonically quiescent setting might be expected to reflect, in their distribution patterns and thickness variations, comparatively subtle underlying structures, and to have been particularly sensitive to subsequent minor crustal movements. Conditions of this type apparently prevailed south of the James River during the Tertiary.

Mattaponi Formation

Change in "basement" configuration from the beginning of Mattaponi deposition to burial of the Mattaponi beneath younger strata is shown in Plates 14 and 15. The coded contours indicate "basement" subsidence of 50 to 100 feet in most places. However, in the area immediately north of 37°00′-76°15′, an unusually thick local development of Mattaponi strata at the east end of the Fort Monroe high indicates "basement" subsidence of at least 200 feet in that local area. The suppression of the Fort Monroe high, which had considerable effect on sediment dispersal during the Cretaceous Period, is the most significant adjustment of the "basement" documented in this report. These events and relationships are shown in Figure 3, C and D.

The Mattaponi marine transgression was very widespread, as shown in Plate 19. Mattaponi strata rest directly upon rocks of the Piedmont province in many places. The original distribu-

tion of the formation apparently was slightly more extensive, as indicated by the irregularity of the formation limit in the northern two-thirds of the map area and by the abutment of thickness contours against the formation limit.

The upper surface of the Mattaponi (Plate 4), with the exception of a prominent deflection of the shallower contours along a line trending northeastward from Petersburg, is much more regular than its base. This difference in regularity is consistent with the lithologies and inferred depositional modes of the Mattaponi. In contrast to the underlying Patuxent-"transitional beds" sequence which consists mainly of feldspathic terrigenous clastics laid down in fluvial to marginal marine environments, the Mattaponi comprises glauconite-bearing marine strata. Local thickness irregularities of the Mattaponi (Plate 8) are difficult to ascribe to the quiet marine environments in which the formation is thought to have been formed. They can, however, be related directly and consistently to the surface expression of the underlying Cretaceous units, as can be seen by comparing the Mattaponi isopach with the Patuxent and "transitional beds" structure maps. As examples, Mattaponi strata north of 37°30′ commonly are 200 feet or greater in thickness, corresponding to some of the most prominent low areas on the Cretaceous surface, whereas the higher Cretaceous surface south of 37°30′ is overlain by 100 feet or less of Mattaponi. The notable exception to the relatively thin development of these beds in the south is the 200- to 400-foot thickness of Mattaponi strata in the vicinity of Hampton Roads (Figure 3, D), where the unit fills a rather marked embayment on the Patuxent-"transitional beds" surface. The overall relative thinness of the Mattaponi and its blanket-like configuration indicate that older tectonic elements were reflected at the surface only weakly.

Nanjemoy Formation

The distribution of the Nanjemoy Formation is illustrated in Plate 20; it is limited to the Salisbury embayment and overlies the Mattaponi Formation in all but two small areas along the Fall Line where Nanjemoy strata rest upon the Patuxent. The virtual absence of the Nanjemoy from the Fort Monroe high to the south strongly suggests rejuvenation of this feature during Nanjemoy time.

The Nanjemoy upper surface (Plate 5), except that part of the unit undergoing active erosion (above the zero contour),

slopes eastward quite regularly, shows no prominent structural features, and is quite similar, in general, to the configuration of its lower surface. Expectedly, therefore, thickness variation in the Nanjemoy (Plate 9) east of the zone of active erosion is quite gradual, ranging up to 160 feet in conformance with the subtle relief on the Mattaponi substratum. The exceptional characteristic on this map is a relatively abrupt northward increase in thickness, amounting to as much as 150 feet in ten miles, across a zone trending east-northeastward from the intersection 37°30′-77°00′. This zone of marked thickening can readily be attributed to an additional Nanjemoy section deposited in a low area on the northern flank of the sharply defined, second-order, linear element on the underlying Mattaponi surface (Plate 4). The southern limit of the Nanjemoy, toward which the unit thins gradually and uniformly, similarly corresponds to another poorly defined positive element on the substratum. The linearity and subparallelism of these two features is suggestive of fault activity during Nanjemoy time. However, neither the present "basement" structure (Plate 12), nor the pre-Calvert paleostructure map of the "basement" (Plate 16) indicates faulting along these lineations.

Deposition of the Nanjemoy was attended by rather uniform subsidence of the "basement", mainly on the order of 50 to 100 feet and, locally, up to 150 feet. Some increase in the regularity of the "basement" paleostructure was effected during this period (Plate 16). Change in "basement" configuration south of the James River cannot be documented. Presumably, the area was tectonically stable, as indicated by preservation of a relatively thin cover of Mattaponi strata south of the James.

Calvert Formation

The Calvert Formation is shown on Plate 21 as a widely distributed unit overlying successively lower units westward to form the Piedmont-Coastal Plain contact in most places north of Richmond. Mainly, it lies directly upon the Nanjemoy north of the James River and upon the Mattaponi south of the river. Calvert strata are absent in the southwestern part of the Coastal Plain either because of erosion or nondeposition.

Calvert deposition was attended by fairly regular subsidence of the "basement" without any basic change in configuration (Plates 16 and 17). The greatest subsidence occurred northeast

of a line drawn through 77°00′-38°00′ and 76°15′-37°00′, where 200 to 300 feet of Calvert strata were deposited.

Uniform subsidence of about 100 feet across the large central part of the map area indicates that the southern flank of the Salisbury embayment was quite stable tectonically during this period. Compared to the underlying Nanjemoy, the Calvert is more widely distributed southward and was deposited over the nose of the Fort Monroe high (Plate 21). This is interpreted as the beginning of a southward shift of the Tertiary depocenter in the study area.

Structurally, the Calvert has a broadly embayed and undulatory surface consistent with its origin in marine waters of moderate depth (Plate 6). Regional slope is somewhat south of east and the present structure is reflected by several main elements of the modern drainage pattern, which are thereby tentatively dated as being middle Miocene in age.

The Calvert reflects the principal structural elements of the "basement"—Salisbury embayment, Fort Monroe high, and Hatteras low (Plate 10). Variations of lesser magnitude in Calvert thickness, while not directly relatable to "basement" configuration, are readily correlated with changes in the shape of the substratum—the Calvert tends to be thick across structural lows on the underlying surface and to thin over the highs.

The implication of this relationship for the southwestern portion of the area, where the Calvert is absent, is that the southwestern Coastal Plain had remained emergent since the earlier rejuvenation of the Fort Monroe high during Nanjemoy time. The preservation, in most places, of a thin blanket of Mattaponi indicates that the emergent area was neither very mobile nor too prominent during Calvert time. The extent of this subdued high may be considered as roughly equivalent to the present limit of the Calvert (Plates 10 and 21). The gradual and uniform rate of change in thickness toward the present limit of the formation supports this interpretation, and demonstrates the profound effect that weakly expressed structural elements can have on the distribution of gently dipping thin strata.

In the southeast, subsidence was nonuniform, especially near the nose of the Fort Monroe high, where several second-order structures were suppressed and a few new ones were formed. These changes imply a limited degree of tectonic instability and

numerous local adjustments of the "basement" beneath an average of 200 feet of Calvert strata. The net effect was an increase in the regularity of the paleostructure of the "basement" (Plate 17).

Tertiary Sequence

A more complete evaluation of the foregoing map relationships can be made if the Calvert is placed in stratigraphic context to emphasize its relationship to the Nanjemoy on the one hand and to the Yorktown on the other. The Nanjemoy, Calvert, and Yorktown constitute a generally transgressive marine sequence which through time was increasingly widely distributed, particularly in the southern part of the map area. Southward expansion of the marine environment during this period was not, of course, without interruptions. The stratigraphic complexity and lithologic diversity of the Nanjemoy, for example, suggest deposition in a variety of marine environments under conditions of fluctuating sea level, while the basal Calvert stratum, a blanket sand by its configuration, texture, and mineralogy, indicates a period of tectonic stability throughout the study area prior to deposition of the diatomaceous Calvert strata. In general, however, the distribution of these formations and their mutual stratigraphic relationships are evidence of a southwestward migration of the Tertiary basin of deposition that culminated in deposition of marine Yorktown strata as far westward as what is now the Piedmont province in southern Virginia, and restriction of the basin in northern Virginia and southern Maryland.

SUMMARY

Post-early Mesozoic geologic history of the Coastal Plain of Virginia may be divided into two main parts on the basis of tectonic setting and the nature of the sediments that formed in each period: a thick, mainly terrigenous Lower Cretaceous sequence and a thin, mainly marine Upper Cretaceous (?)-Tertiary sequence.

The Patuxent sequence was deposited during a period of rapid accumulation of mainly terrigenous clastics in a variety of relatively high-energy nonmarine environments. The requirement of a steep depositional slope initially would have been met by the existence of such pre-Cretaceous "basement" features as the Salisbury embayment and the Hatteras low. Aggradation

of these basins during Patuxent time probably was attended by additional "basement" subsidence, which would have tended to maintain the steep depositional slope, delay final aggradation of the basin, and increase the total thickness of the Cretaceous section.

Sedimentation eventually exceeded subsidence, however, and the clastic succession filled the pre-existing "basement" lows. The increasing importance of sedimentation over subsidence is reflected in stratigraphic variation in such rock properties as texture, composition, and the intra-formational relationships of units. The "transitional beds" are interpreted as the record of the final stage of basin filling. They were deposited on a lower depositional slope and in lower-energy environments as the nonmarine basin approached grade.

The predominantly nonmarine processes that characterized the Cretaceous Period were replaced, at the beginning of the Tertiary Period, by marine conditions which prevailed until the end of Yorktown time. The marine basin was most extensive during Mattaponi time, because the Mattaponi strata underlie virtually the entire Coastal Plain of Virginia, including most of the area south of the James River. The Fort Monroe high had little effect on either basin configuration or the areal extent of the formation. General "basement" structure, however, affected the thickness distribution of the Mattaponi by its influence on the configuration of the pre-Mattaponi surface. The preservation of very thin Mattaponi in the southwestern part of the map area suggests that this area remained relatively stable tectonically at least until such time as these strata were covered by the Yorktown.

Mattaponi deposition was followed by contraction of the marine basin so that its southern margin was approximately along the axis of the Fort Monroe high. Nanjemoy sedimentation occurred mainly north of that line. This suggests rejuvenation of the high during the Nanjemoy period.

Thickness data on the basal Calvert show a coarse sandy lithozone up to 60 feet thick and striking northward. It shows no significant changes in thickness or lithology across the southern limit of the Nanjemoy. This suggests, as does a comparison of the Nanjemoy isopach and the Mattaponi structure (Plates 4 and 9), that the Nanjemoy basin was *barely* confined on the

south, and that any tectonic rejuvenation that might have accompanied deposition of the Nanjemoy had ceased by the end of the period.

Following deposition of the basal Calvert, the basin of deposition expanded northward while in the south, it remained essentially as it had been since the end of Nanjemoy time. In the north, the main part of the Calvert Formation overlies the basal sand lithozone for considerable distances whereas in the south, the limit of the basal lithozone and the limit of the Calvert itself are essentially coincident. This is thought to reflect the continued influence of the Fort Monroe high as a broad subtle feature.

The final stage in the development of the Tertiary basin involved the most widespread transgression in the south since the Mattaponi period, and attendant emergence of the northwestern part of the area during Yorktown time. No more than a very low degree of regional tilting to the south would have been required to cause this shift in position of the basin. The distribution of the Yorktown as it appears on the present geologic map of Virginia (Virginia Division of Mineral Resources, 1963) probably approximates the shape of the basin in which the formation was deposited.

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APPENDIX I

GEOLOGIC SUMMARIES

The following data were not available when Part 1 of this report was prepared. The wells are located on Plates 12-17 and were used in construction of those maps.

EXPLANATION

W-3375	Numbers preceded by the letter "W" refer to those wells whose samples are on file in the Division's repository.
post-Ty	Top of Columbia Group
Ty	Top of Yorktown Formation
Tc	Top of Calvert Formation
Tn	Top of Nanjemoy Formation
Tm	Top of Mattaponi Formation
trans	Top of "transitional beds"
LK	Top of Patuxent Formation
base	Top of "basement"
nd	Formation top not determined
TD	Total depth of well in feet

	Elevation of top (in feet)	Thickness (in feet)
W-3180		
post-Ty	52	160
Ty	−108	630
Tc	−738	480
Tn	−1218	250
trans	−1468	270
LK	−1738	4280
base	−6018	202 drilled
TD 6272		
W-3375		
post-Ty and Ty	5	140
Tc	−135	465
Tn	−600	195
Tm	−795	60
trans	−855	80
LK	−935	50 drilled
TD 990		

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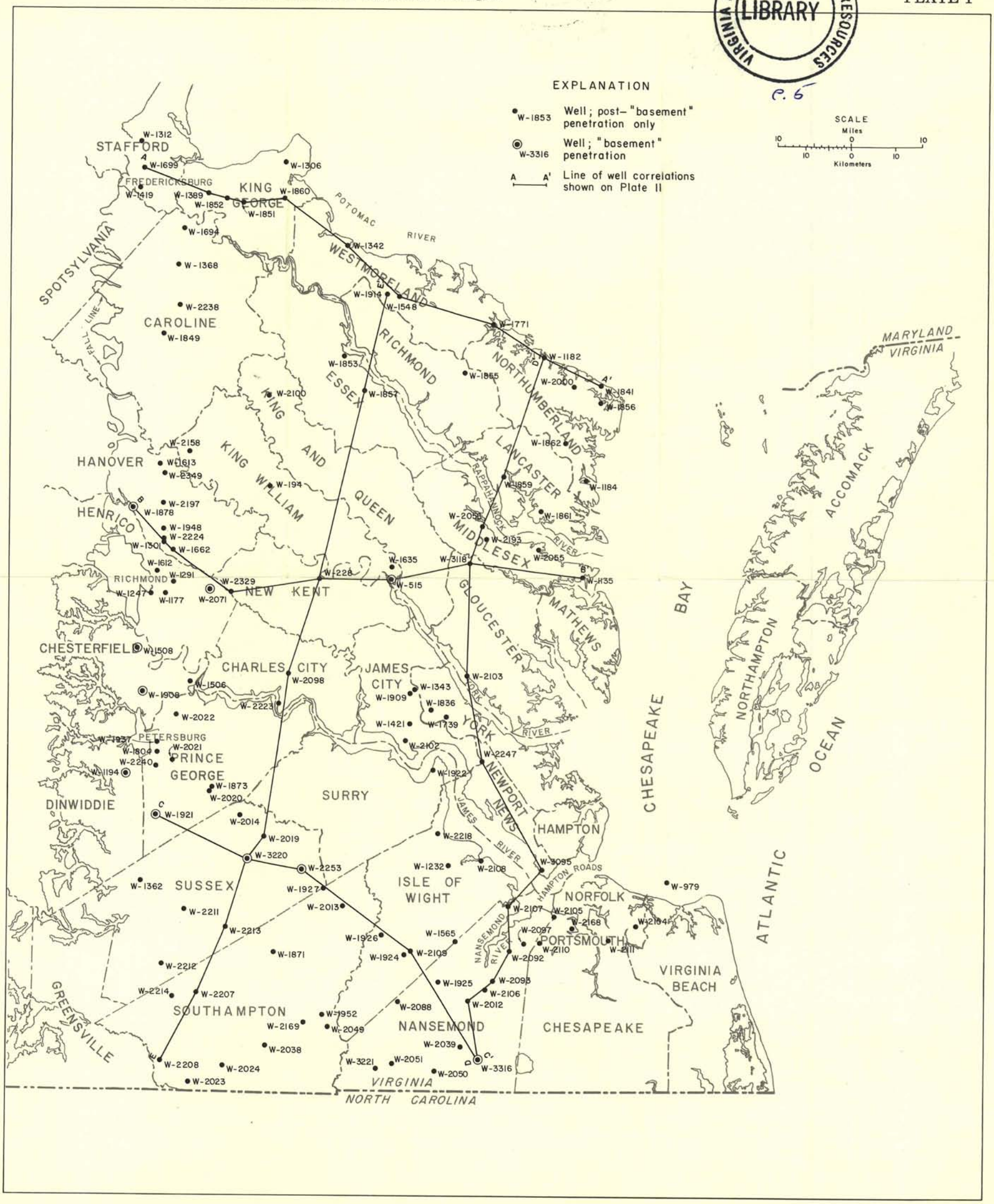

CONTROL WELLS AND LINES OF WELL CORRELATIONS
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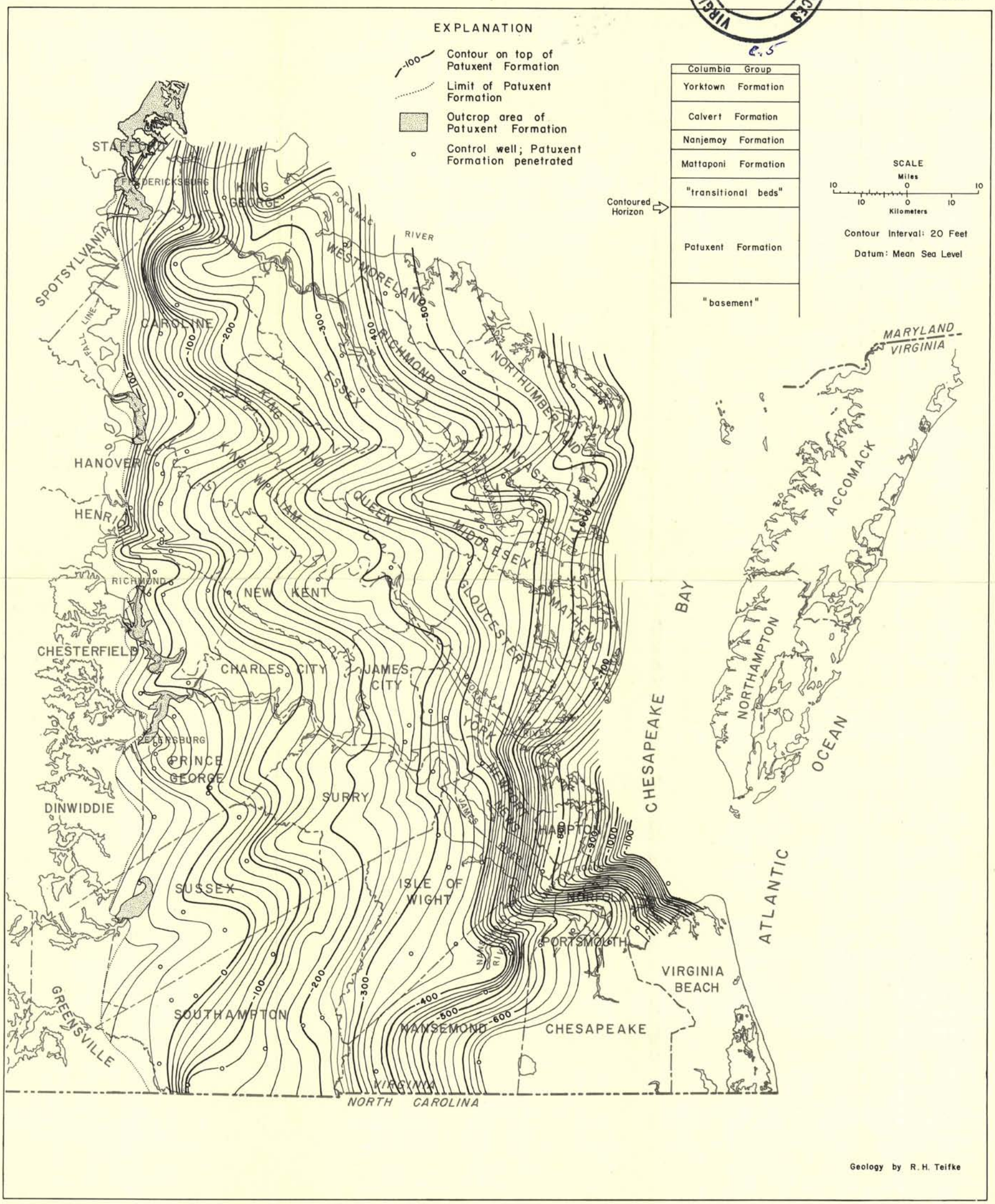

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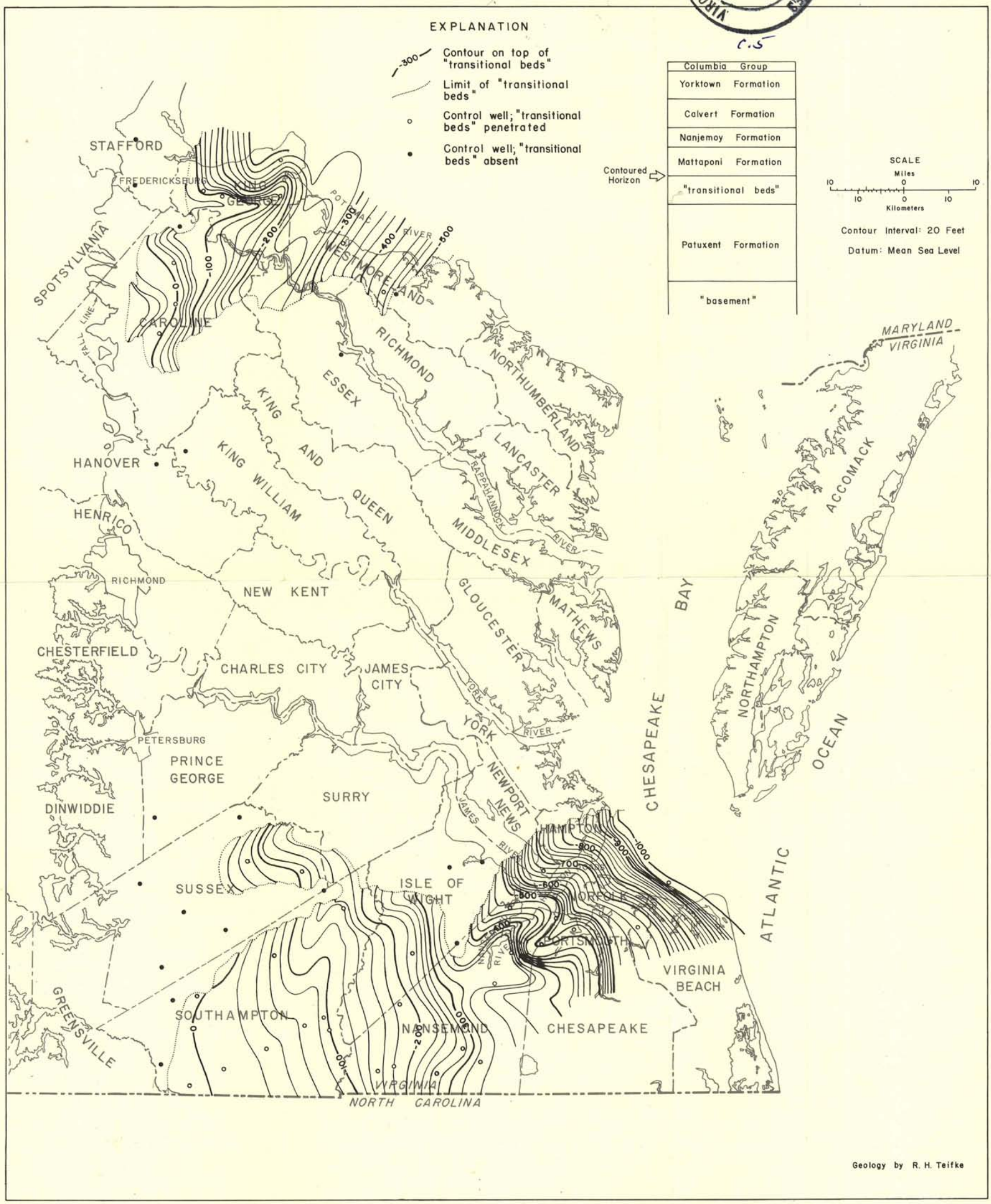

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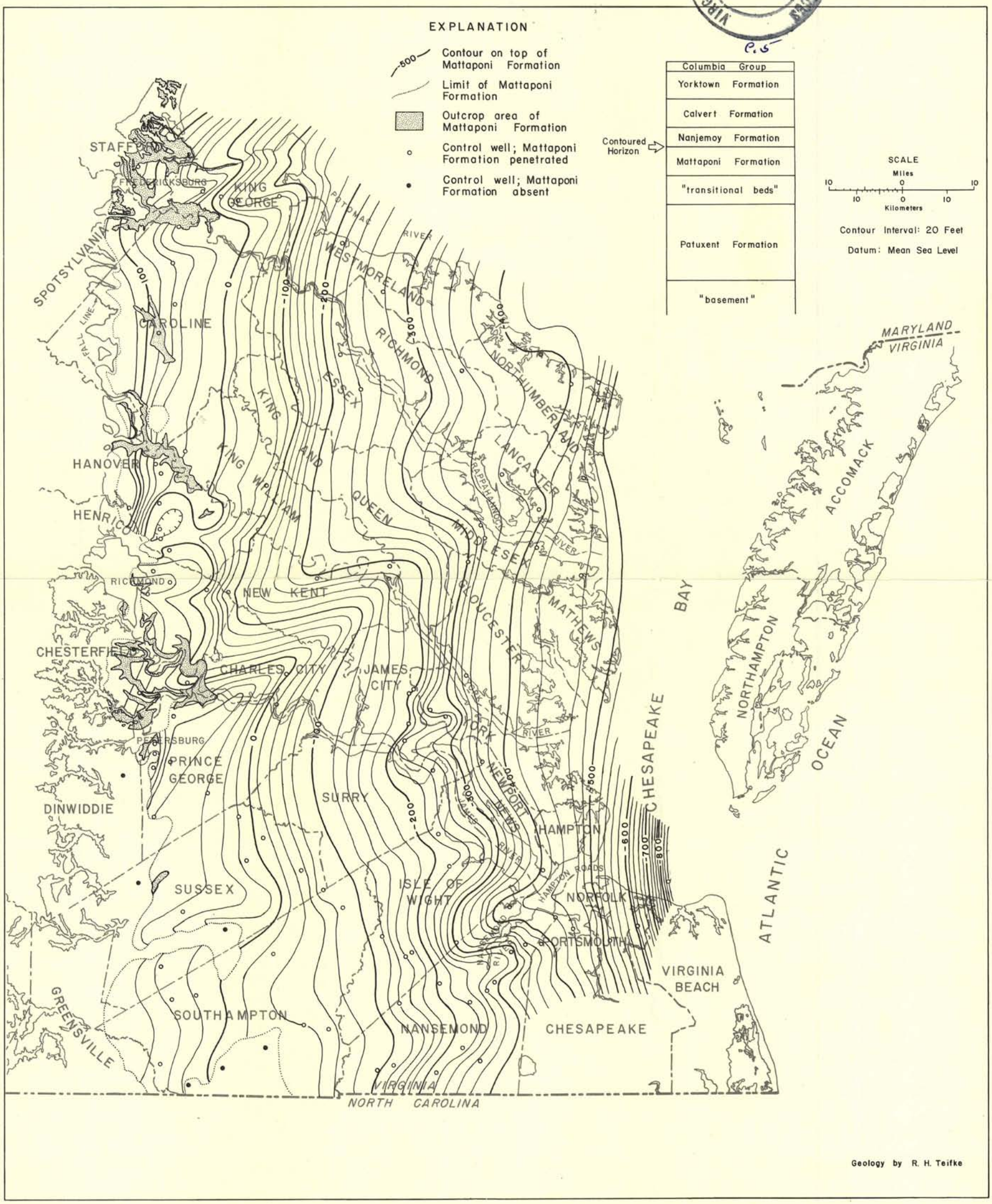

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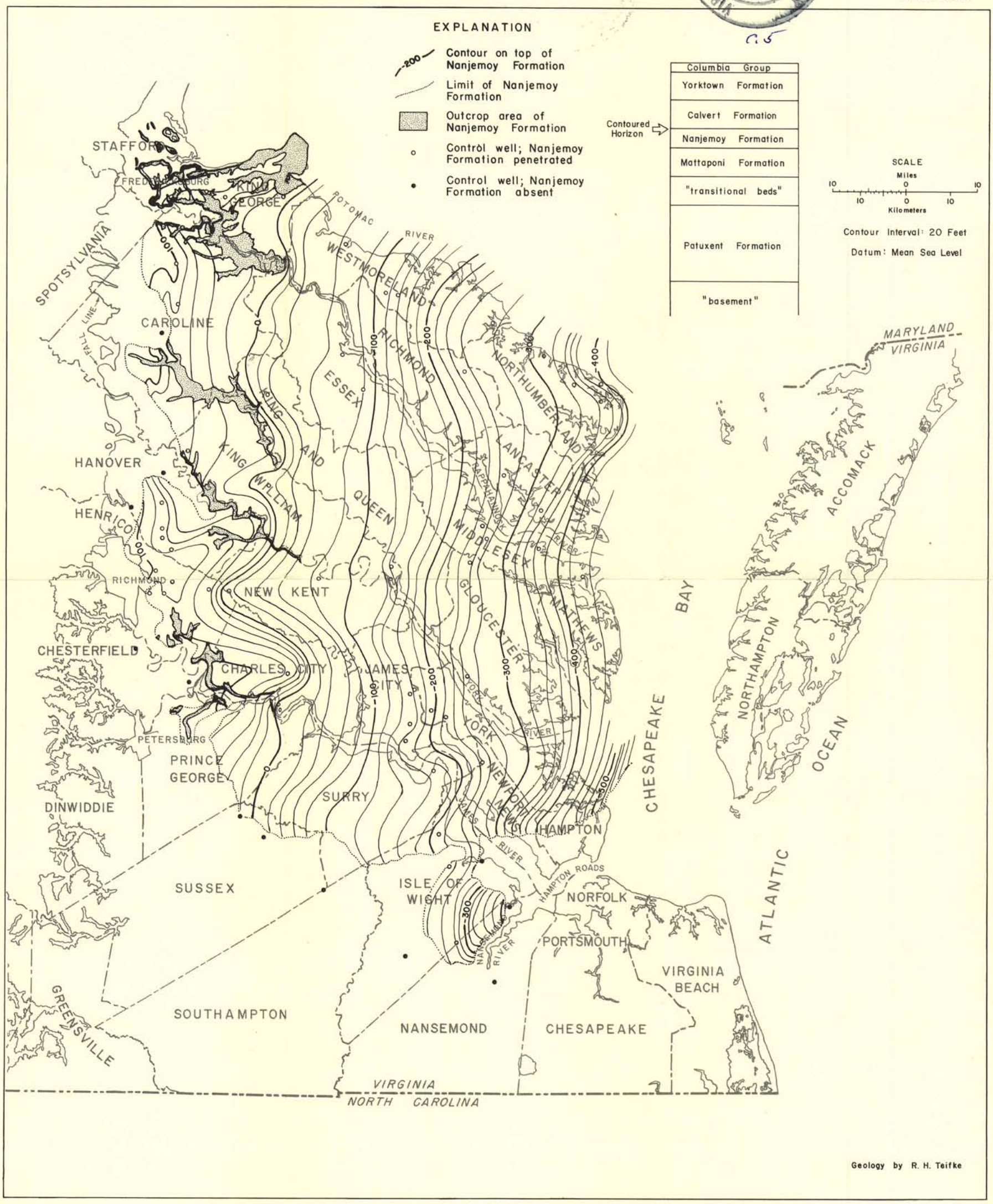

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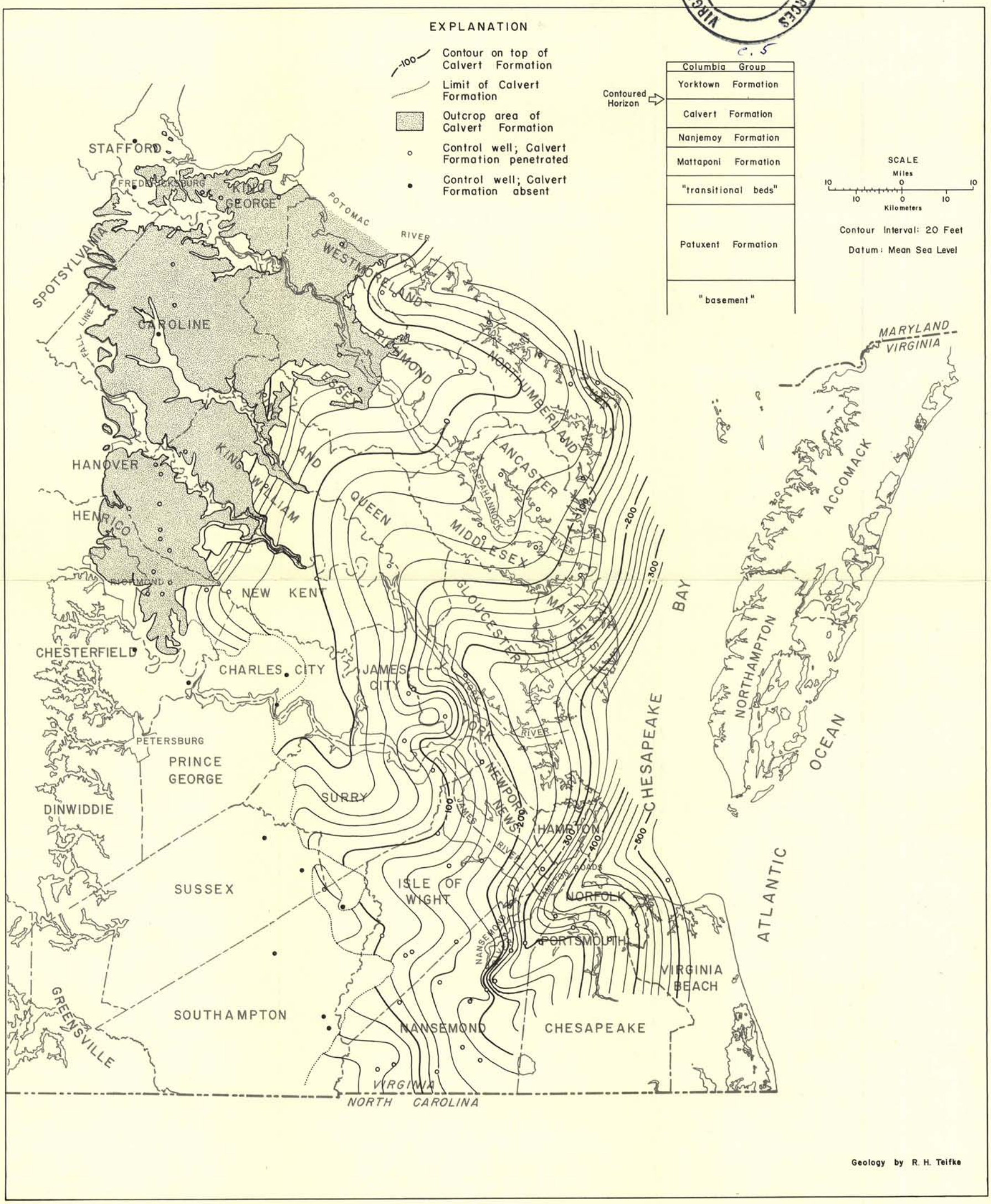

STRUCTURE-CONTOUR MAP OF THE CALVERT FORMATION
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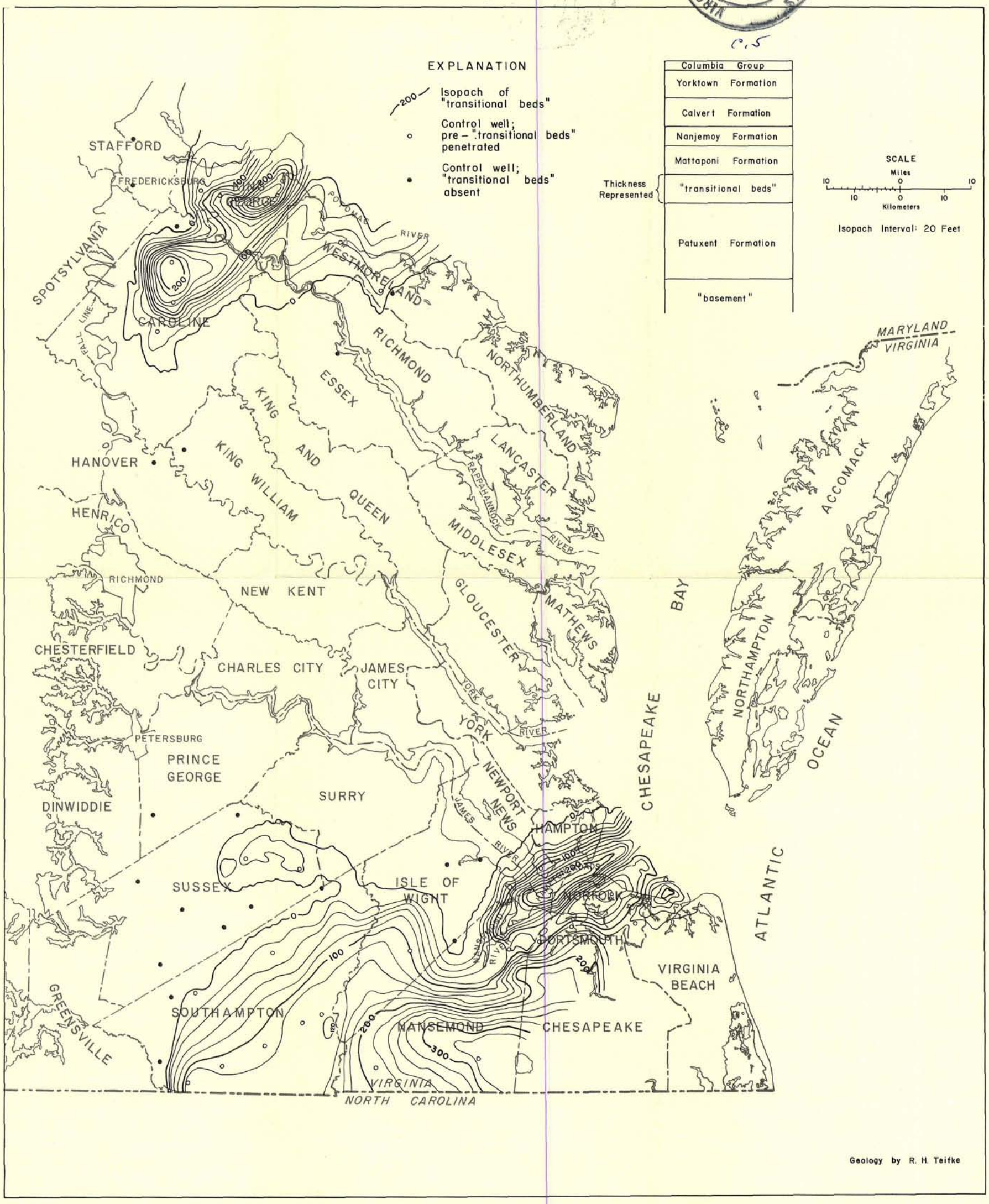

ISOPACH MAP OF THE "TRANSITIONAL BEDS"
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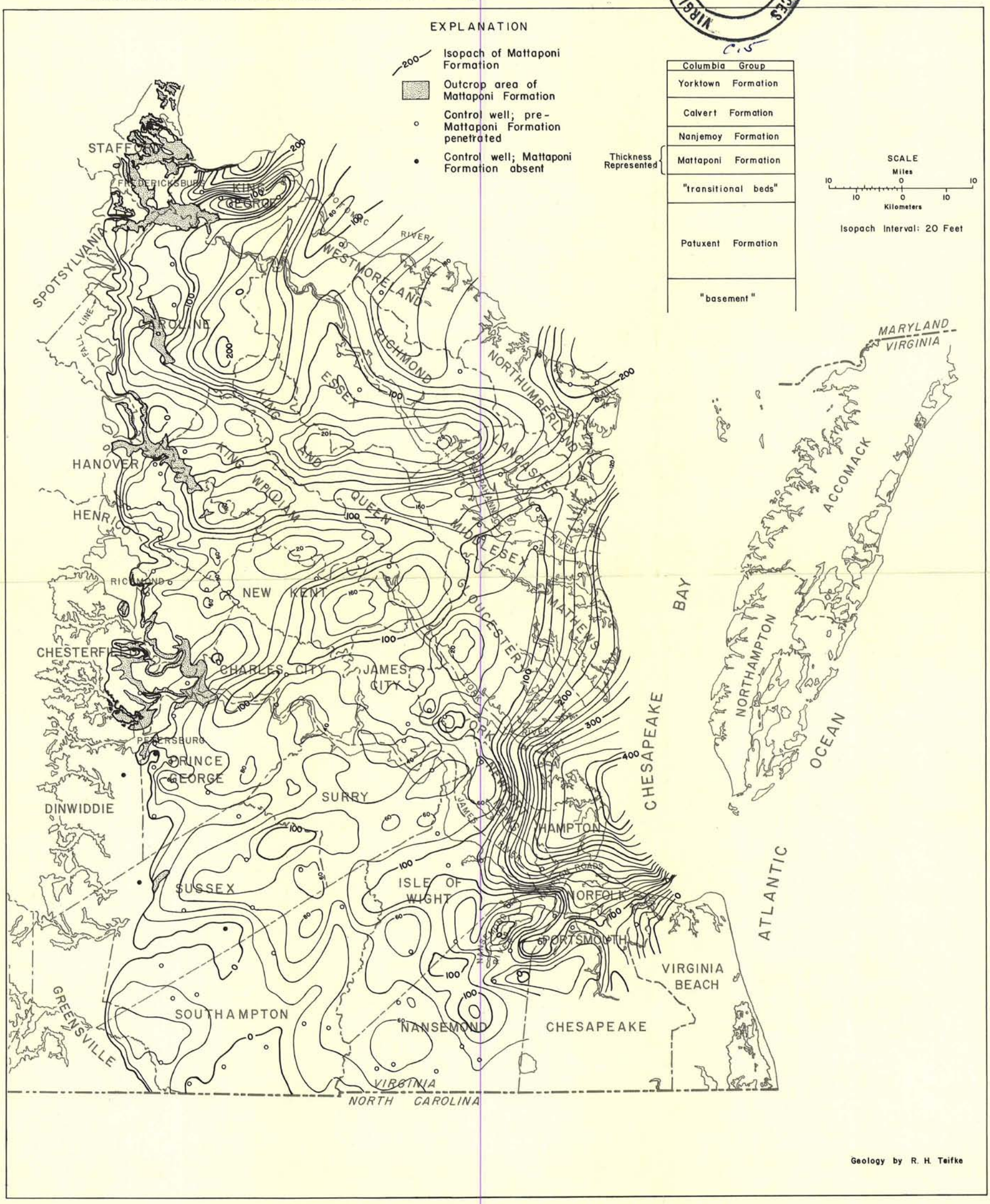

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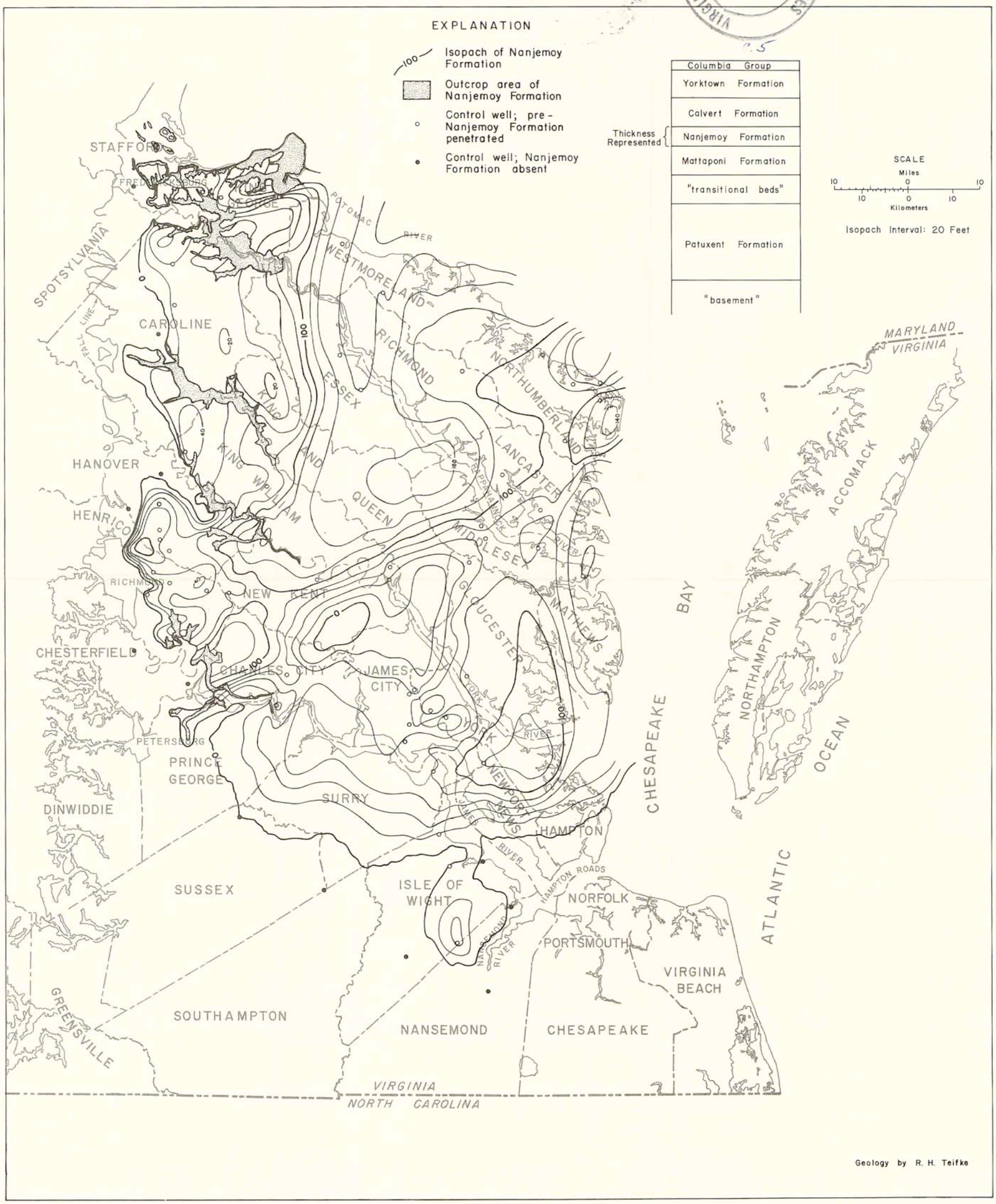

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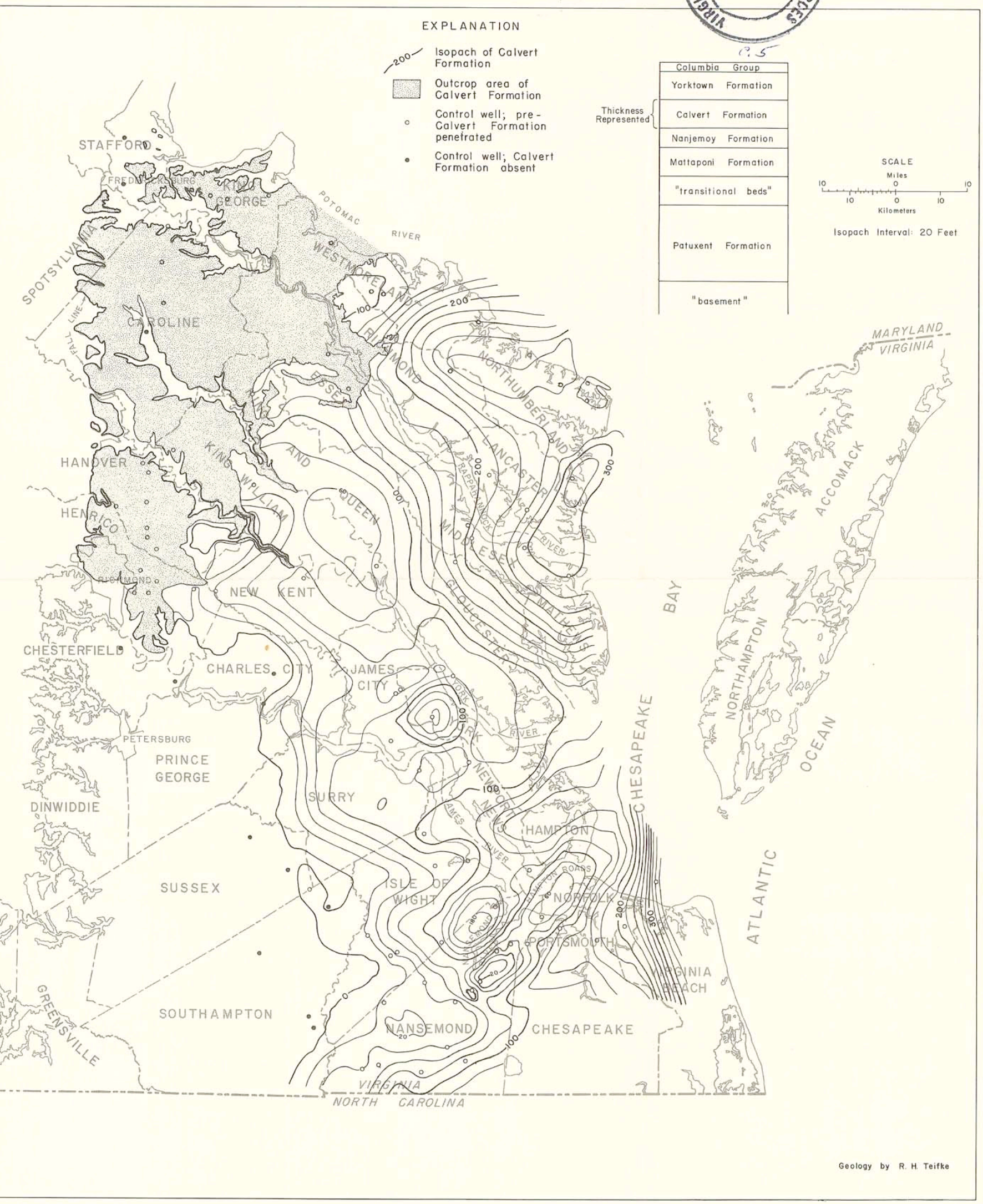

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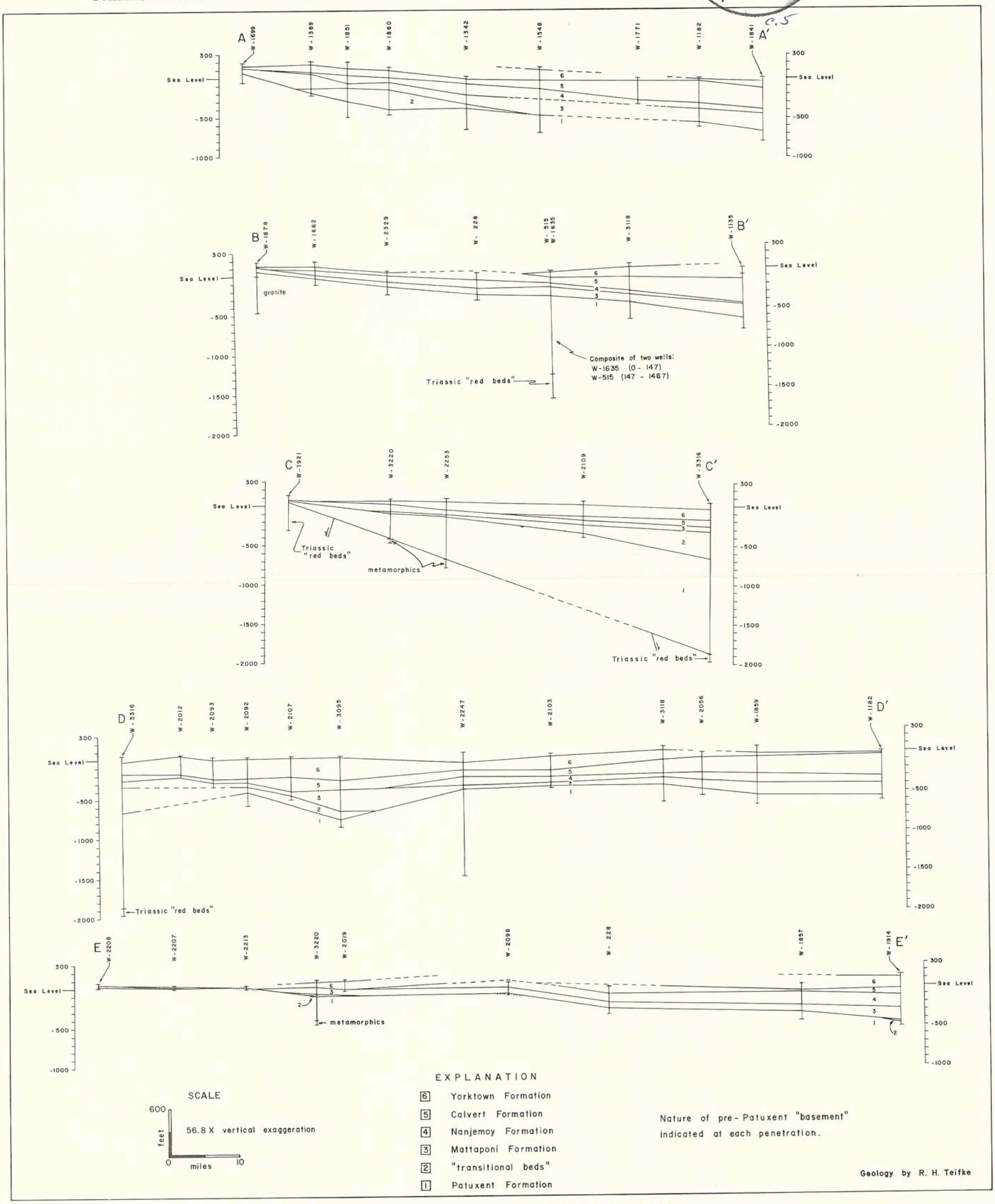

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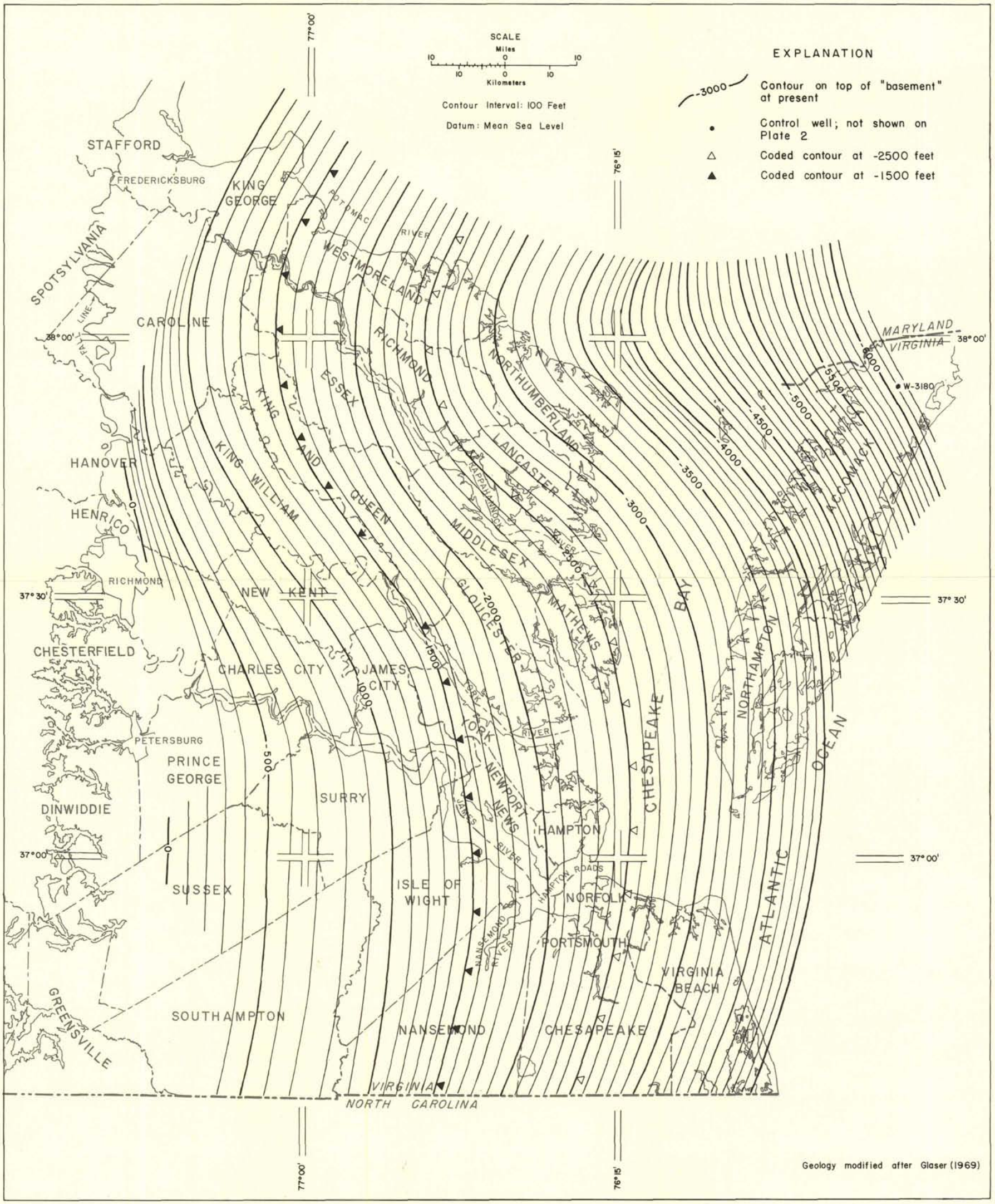

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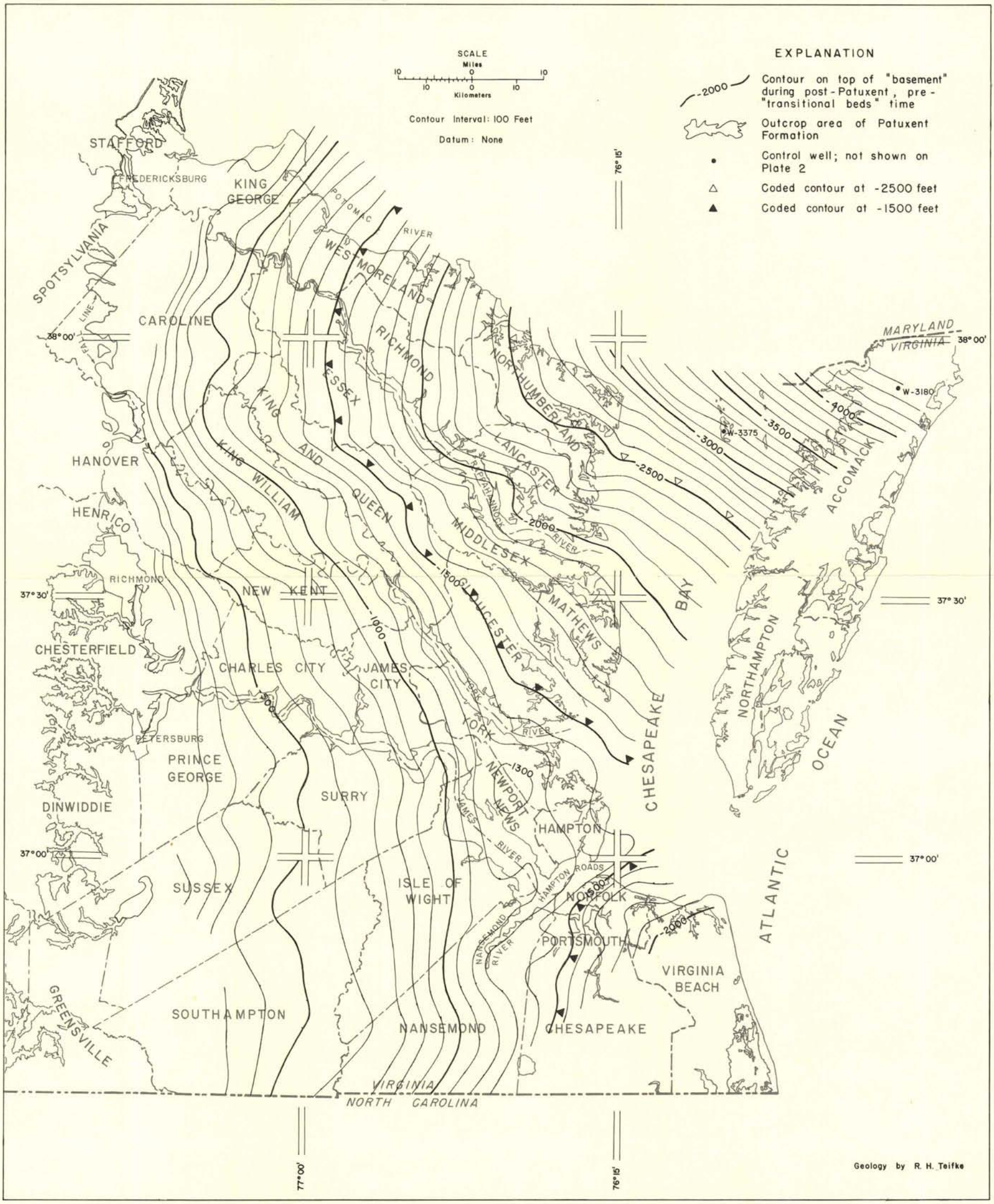

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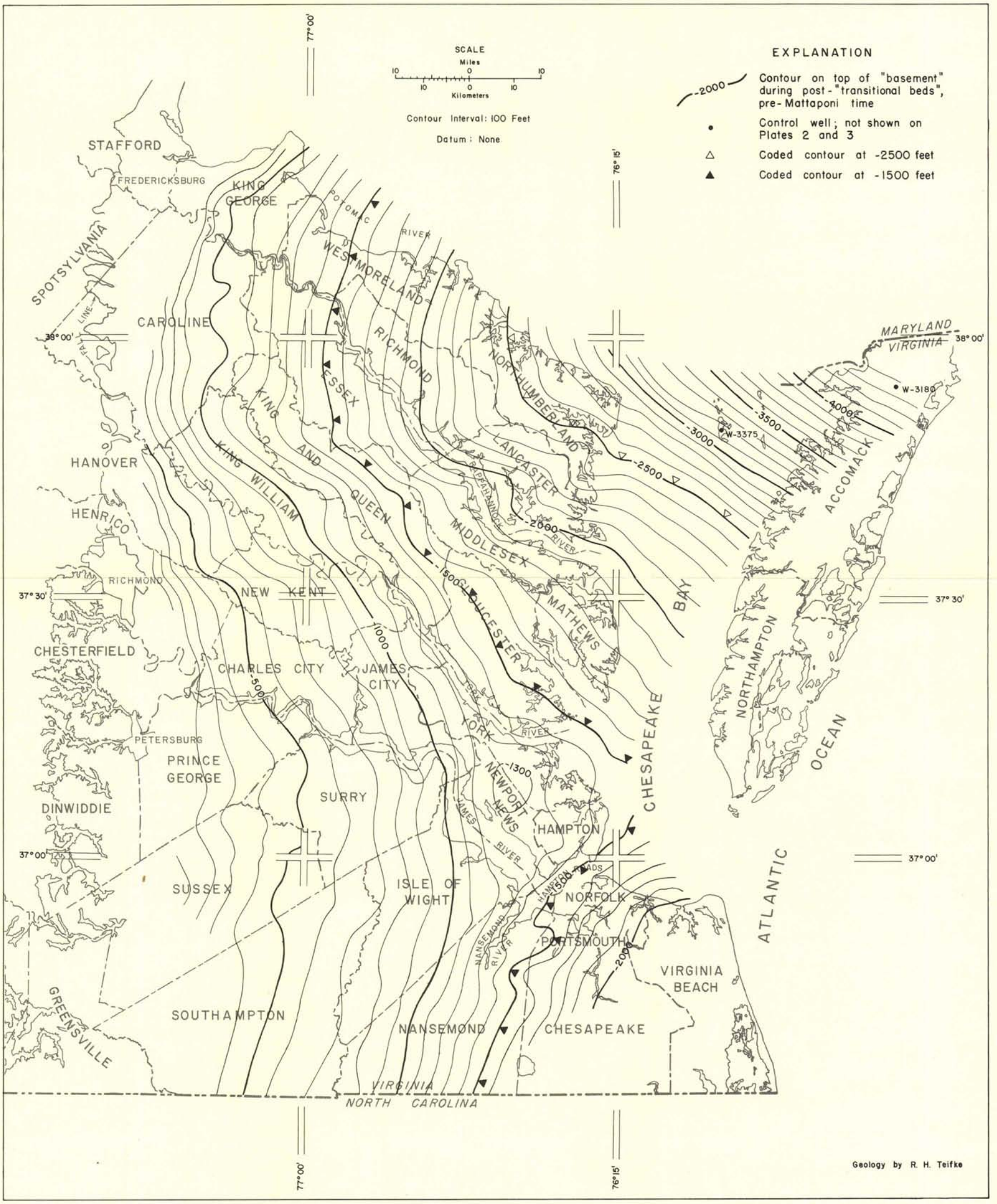

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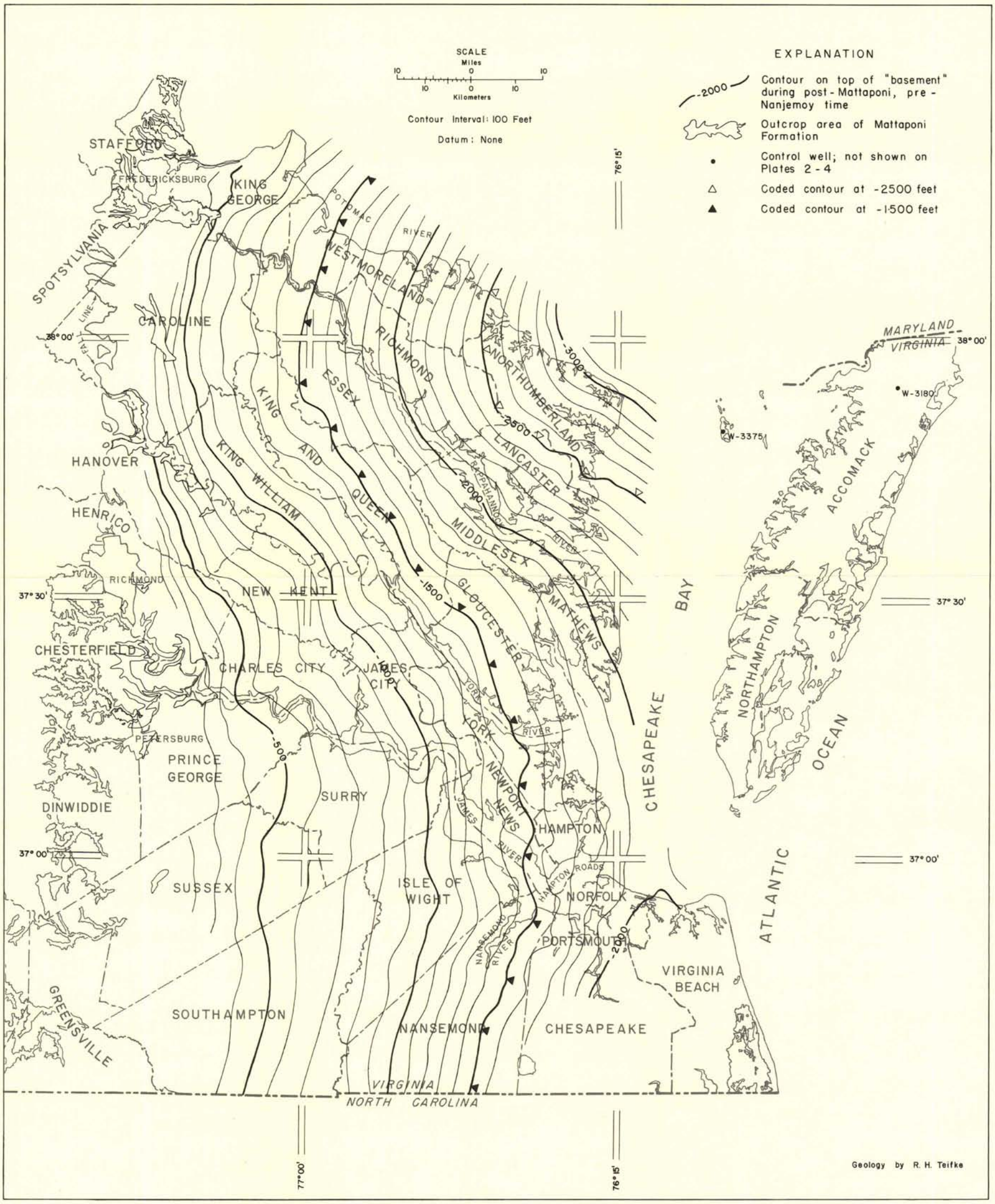

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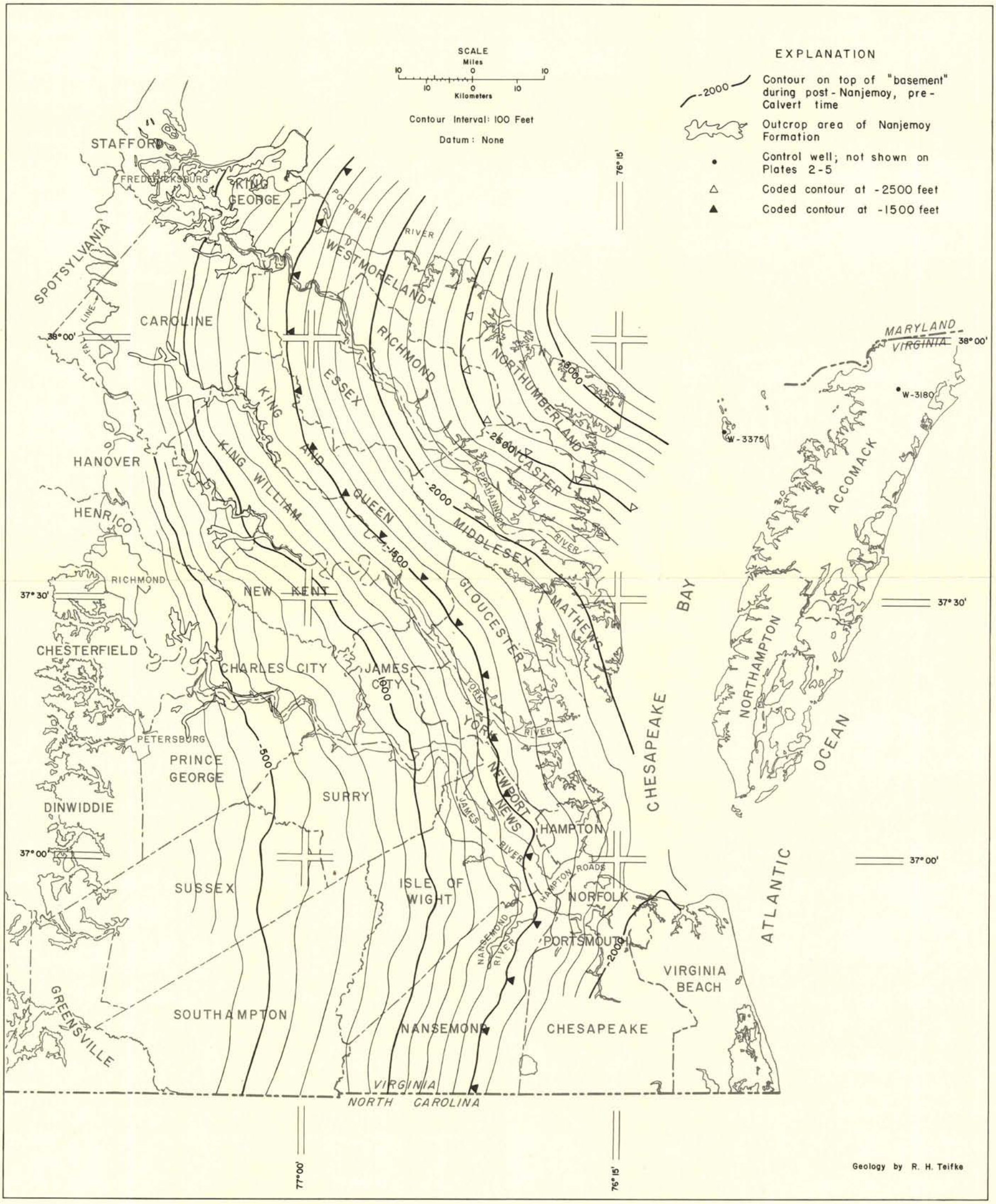

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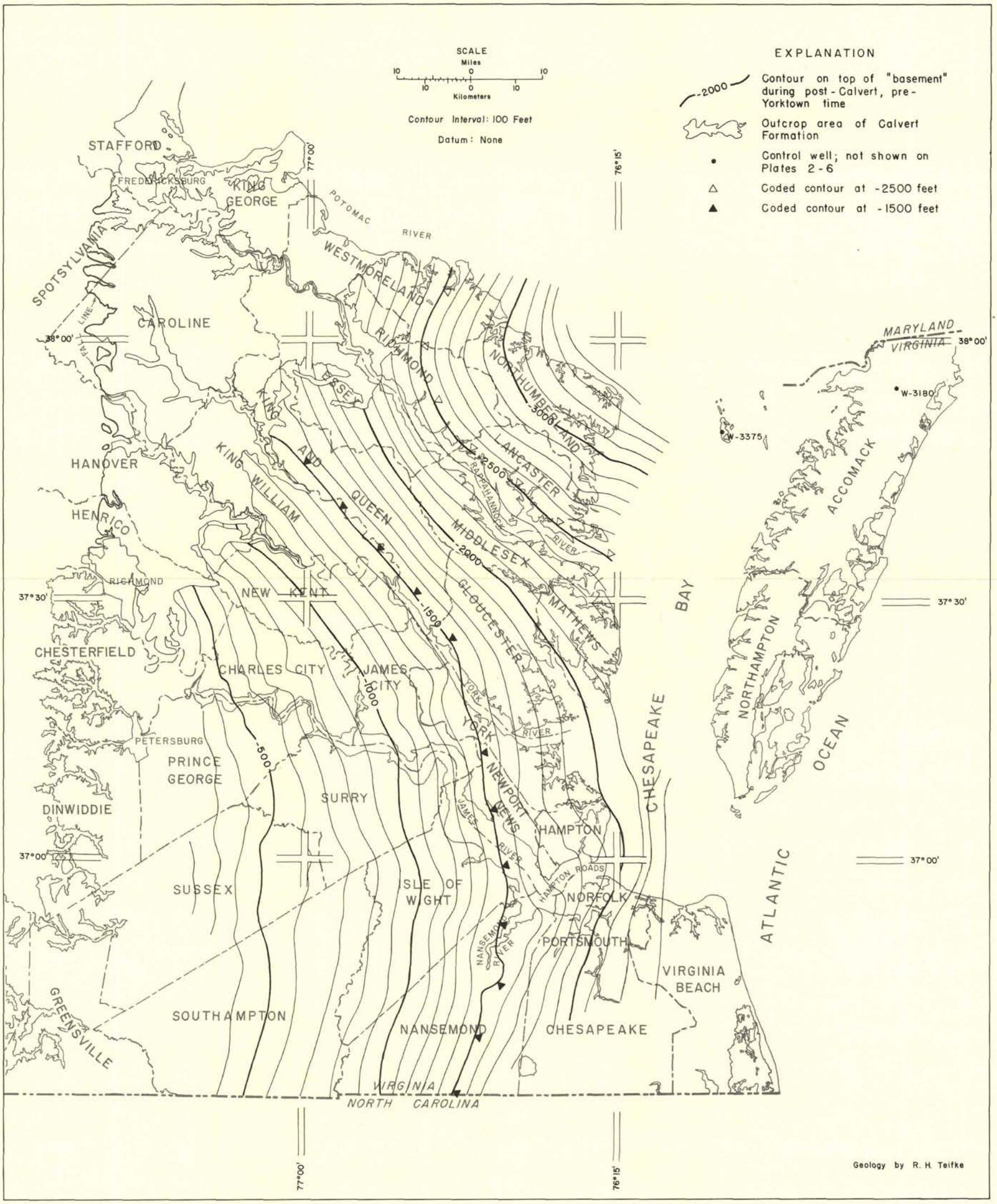

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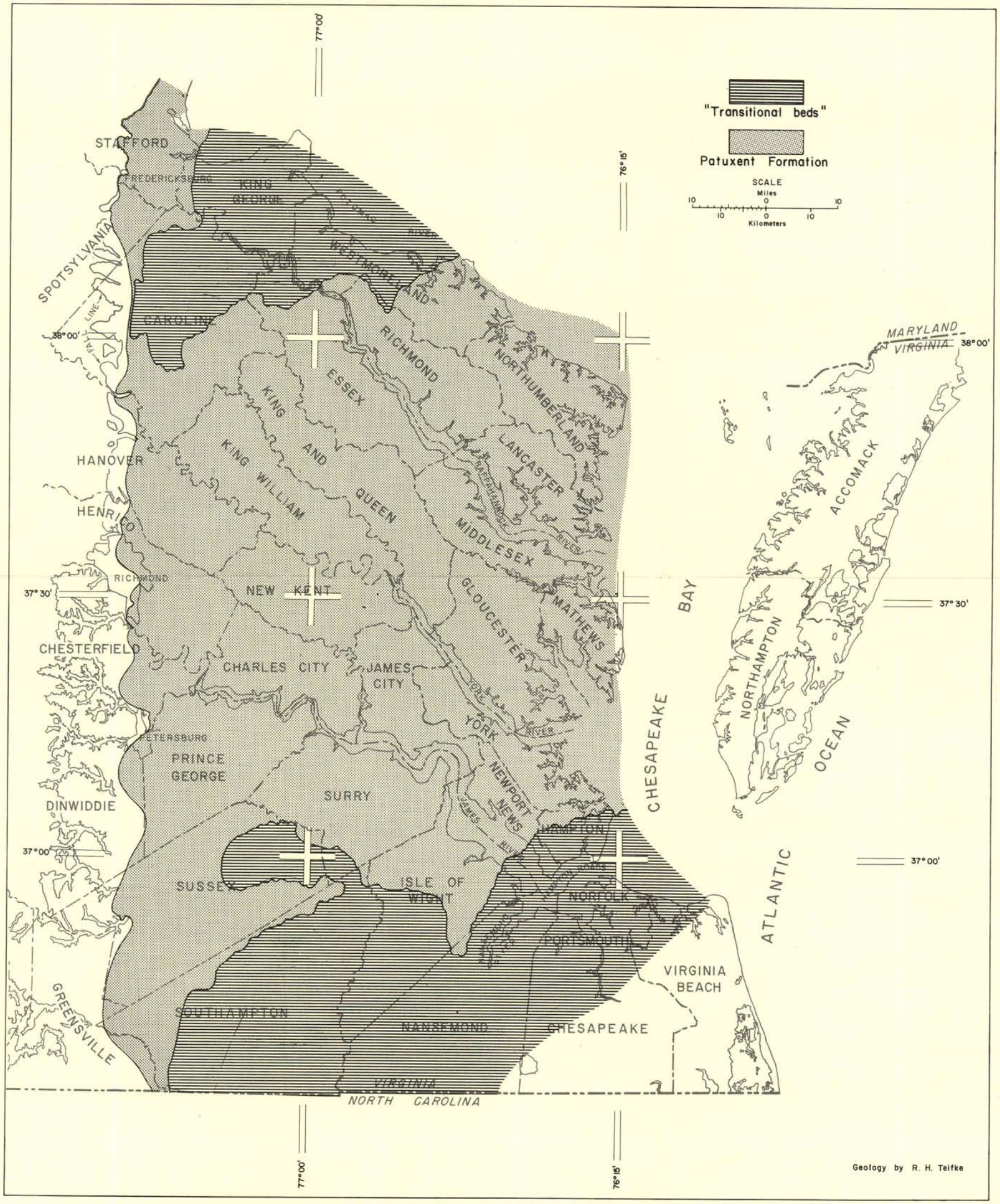

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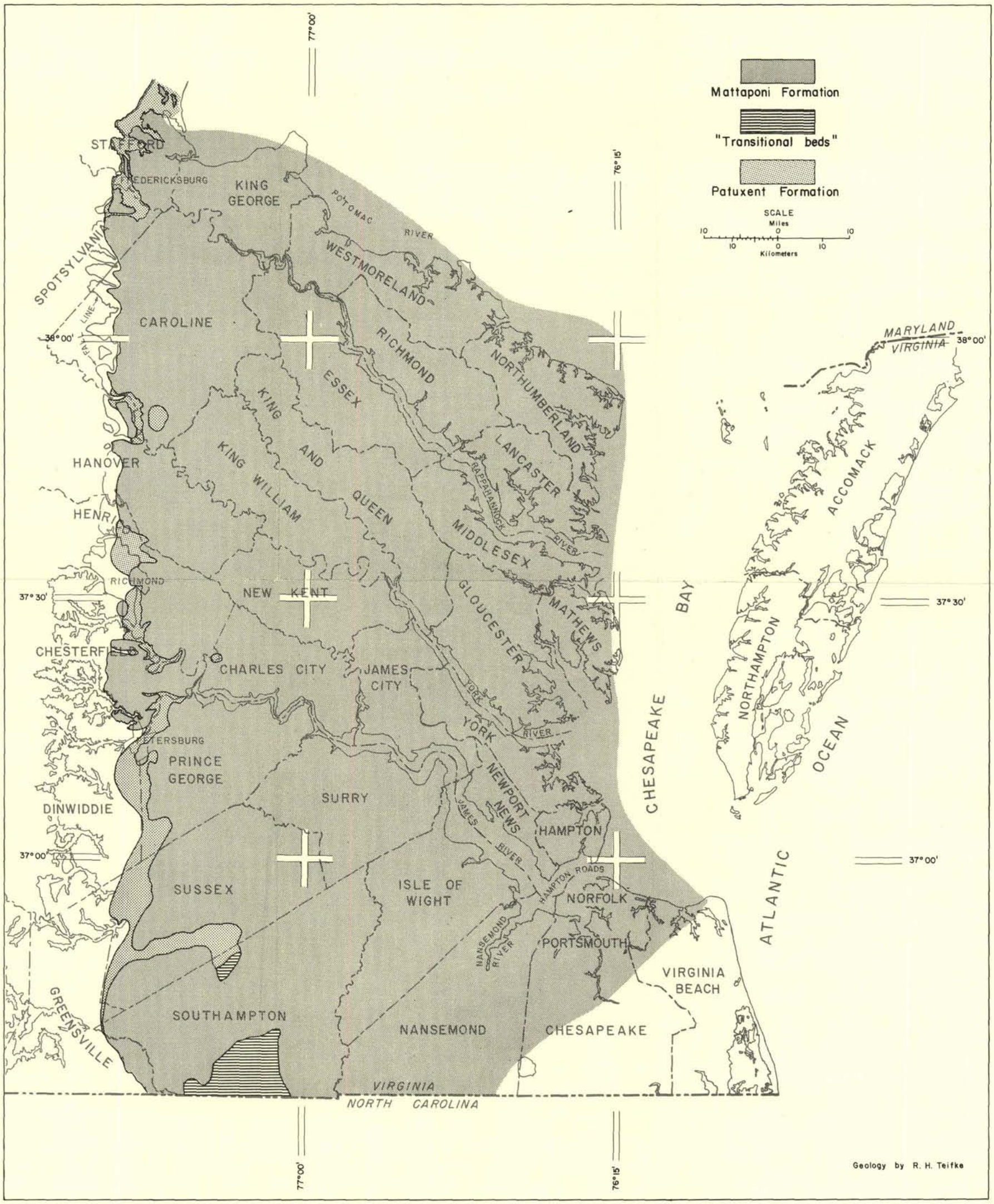

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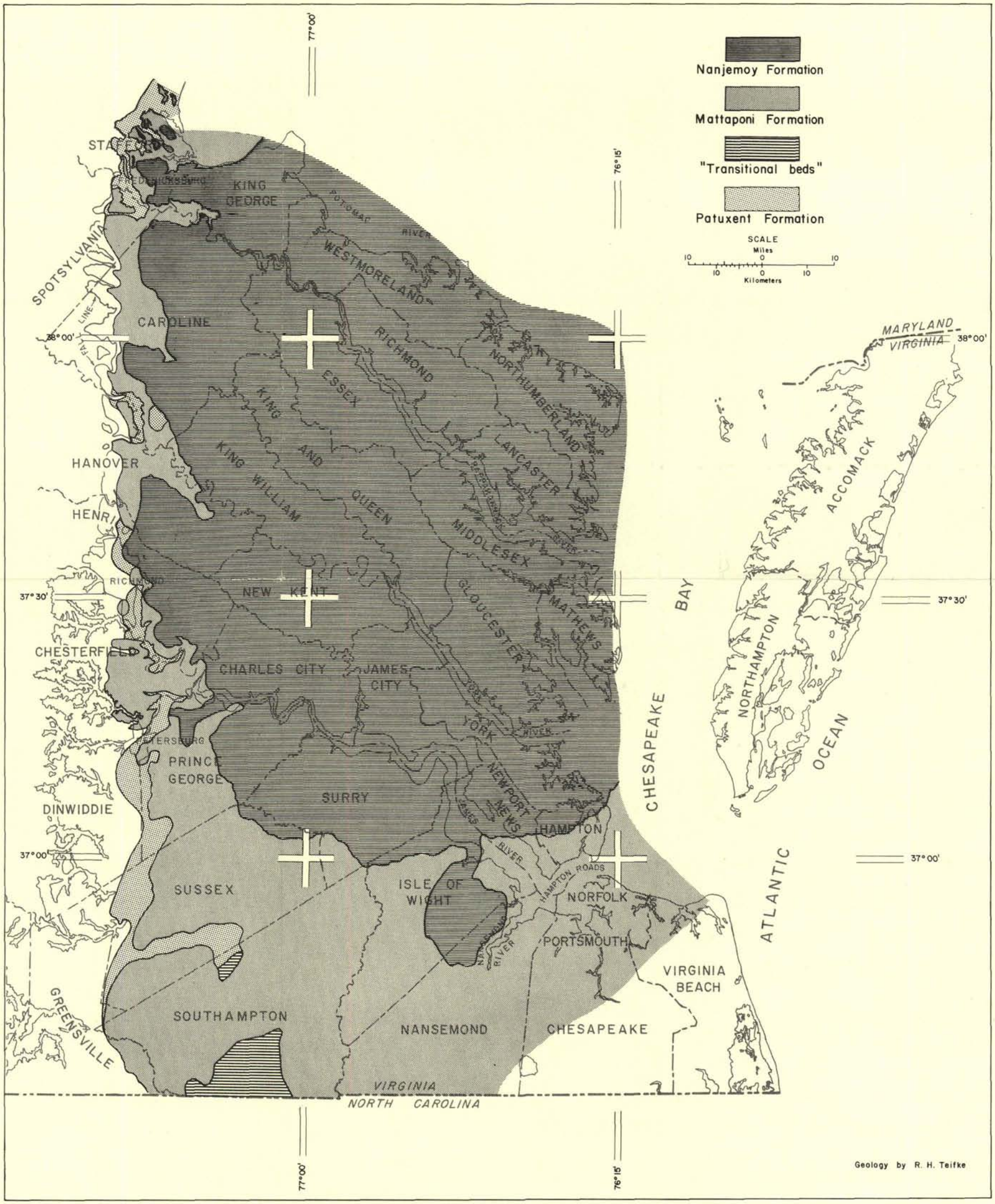

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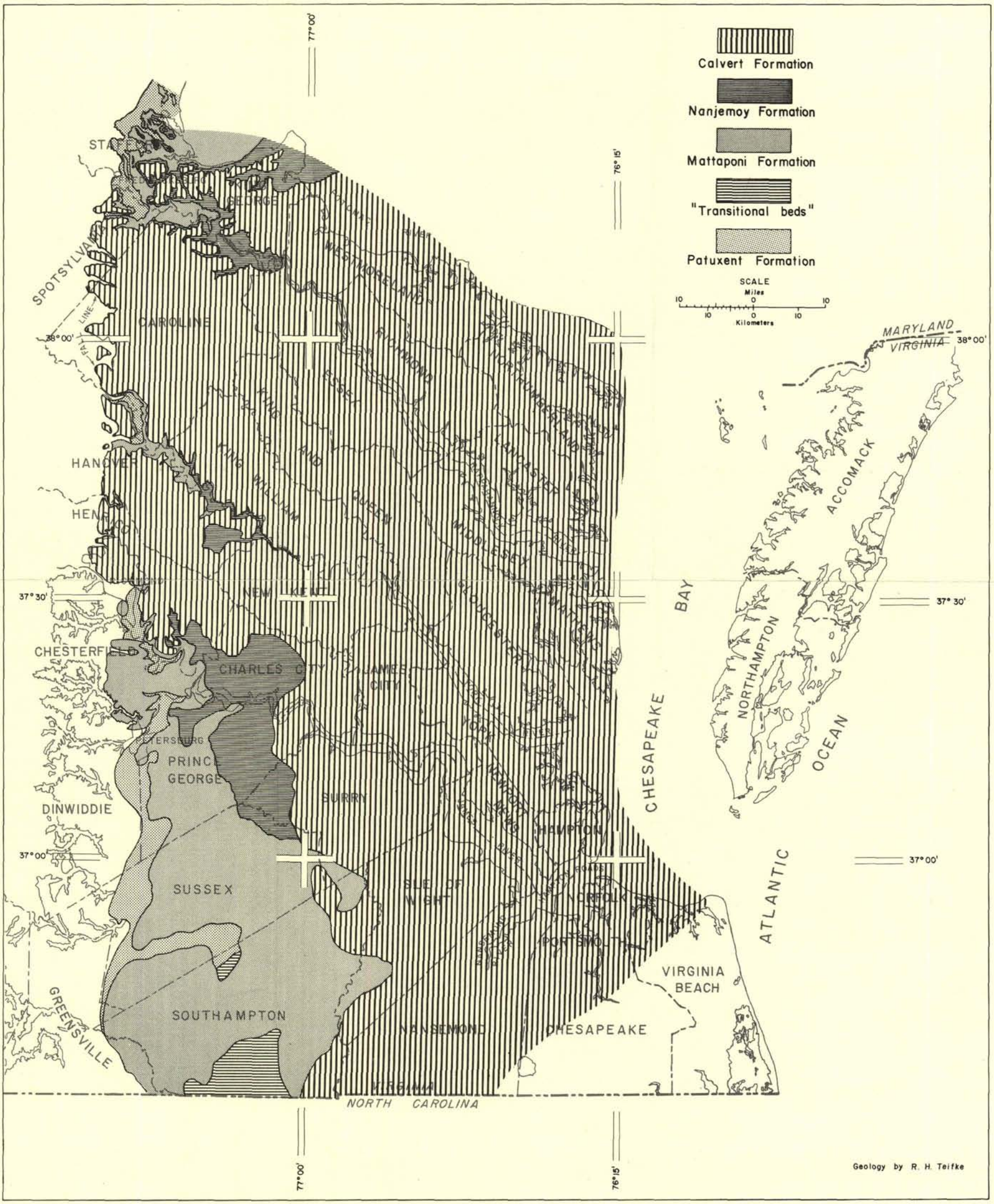

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GEOLOGIC STUDIES, COASTAL PLAIN OF VIRGINIA

BULLETIN 83 (PART 3)

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CHARLOTTESVILLE, VIRGINIA
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PART 3

PLEISTOCENE-HOLOCENE ENVIRONMENTAL GEOLOGY

By

EMIL ONUSCHAK, JR.

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PLEISTOCENE-HOLOCENE ENVIRONMENTAL GEOLOGY

By

Emil Onuschak, Jr.

ABSTRACT

Detailed geologic mapping completed to date on the Coastal Plain of Virginia shows it is possible to subdivide and map the Pleistocene-Holocene sediments on the basis of sedimentary parameters. These parameters reflect the processes that were active during deposition of the sediments. Units defined in this way can be grouped into *depositional systems* that consist of large-scale, naturally occurring assemblages of genetically related facies. Each depositional system has a number of characteristic criteria by which it can be recognized on modern topographic maps and aerial photographs.

Maps of depositional systems are an effective way to portray the physical geology of an area, to selectively identify additional areas requiring detailed mapping, and to derive a wide variety of environmental geologic maps that have practical information which can be used by persons concerned with land-use applications.

INTRODUCTION

Mapping physical characteristics of sediments and relating each characteristic to the processes that formed it can be used to subdivide and map the Pleistocene and Holocene sediments of the Coastal Plain of Virginia (Figure 4). Combining individual facies into large-scale, naturally occurring groups

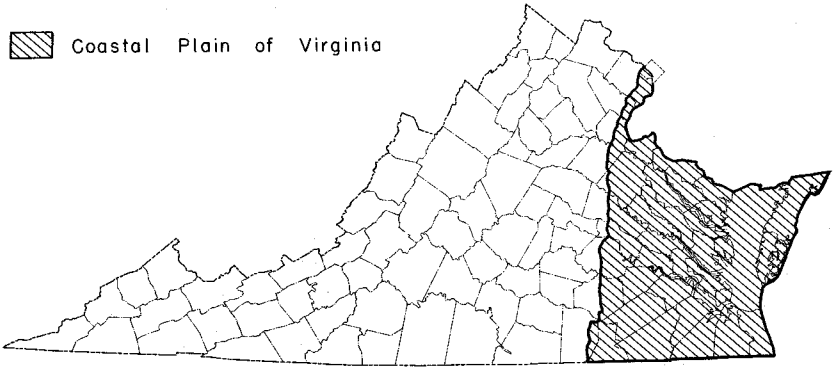

Figure 4. Index map of area covered by Part 3 of this bulletin.

called *depositional systems* is a valuable way of organizing large amounts of data and establishing the physical geologic framework of an area. In addition, the physical geology of an area, expressed in terms of depositional systems, provides an independent inventory that forms the basis for deriving various resource capability and feasibility maps that have important environmental applications.

The purposes of the present study are to (1) define some of the depositional systems of Pleistocene-Holocene age indicated by recent detailed geologic mapping in eastern Virginia, (2) compile maps of these depositional systems on a reconnaissance basis for the Coastal Plain of Virginia, and (3) derive regional environmental geologic maps from the basic geologic map of depositional systems. In addition to showing what is known about the surficial geology of the Coastal Plain, these maps indicate what is not known at present and thus help in setting priorities for future, more detailed mapping and in anticipating the nature of the mapping that will be required.

METHODS

Fourteen detailed geologic maps, recently published by the Virginia Division of Mineral Resources on 7.5-minute topographic quadrangle bases (Coch, 1968; Bick and Coch, 1969; Goodwin, 1970; Coch, 1971; and Johnson, 1972) form most of the field data incorporated in this report. Relationships were established in these areas among the internal sedimentary characteristics, the three-dimensional shapes, and the exposed surface features of the sedimentary bodies that were mapped. The active processes that affected the sediments were inferred from these relationships and the resulting interpretations were used to define several depositional systems. These systems were mapped over the entire Coastal Plain on a reconnaissance basis, largely by means of the geomorphic criteria established for each system in the fourteen recently mapped quadrangles. Descriptions of depositional models from other areas (Kraft, 1971a; Bernard and others, 1970) provided valuable supporting data.

Modern, detailed 7.5-minute topographic quadrangle maps at a scale of 1:24,000 are available for the entire Coastal Plain; approximately 196 quadrangles were closely examined for geomorphic criteria in the determination of each depositional system. Additionally, aerial photographs at scales of 1:62,500 (photo indices) and 1:24,000 are also available for most of the Coastal Plain and were also examined. In general, aerial photographs are of more help in showing shallow subaqueous features along the shorelines and detailed topographic maps are of more help showing features landward of the shorelines.

DEPOSITIONAL SYSTEM CONCEPT

Many geologic investigations involve strata, or layers, of sedimentary rocks or loose, unconsolidated sediments. These layers may be defined as geologic formations if they are lithologically homogeneous, prevailingly but not necessarily tabular, and show lateral continuity. Lateral continuity, or "mappability," is regarded as a test of the validity of the definition of a geologic formation (American Commission on Stratigraphic Nomenclature, 1970). It is often assumed that such layers are the same age throughout much of their lateral extent, are of nearly uniform thickness, and were originally formed as horizontal layers. Lateral persistence usually can be assumed for marine

formations deposited well within a basin or in a cratonic area. Gross physical characteristics of depositional environments in these settings tend to be uniform and laterally persistent, qualities reflected in the resulting strata.

Sediments deposited at the edges of basins, however, are noted for their lack of lateral persistence and for their abrupt changes in composition and thickness which reflect the changes of the depositional environments and active processes along the edge of a basin. For many years geologists have studied areas along present coast lines where sediments are now being deposited in an effort to better understand how sedimentary rocks were formed in the past. Modern sediments deposited in coastal environments exhibit the same variability in their properties that is shown by ancient basin-edge deposits.

In an effort to provide a meaningful method of subdividing modern sediments, to systematically organize the growing volume of data from studies of these sediments, and to provide a basis for applying these data to interpretation of ancient rocks, the concept of depositional systems has evolved. Although the term *depositional system* is rather new, the concept is not, and can be found expressed in the literature of the middle 1950's. Only in recent years, however, has the concept been more fully developed and the scope of its applicability more fully explored.

Sediments that are deposited in various individual environments can be grouped together into associations called depositional systems. A *depositional system* is a naturally occurring, large-scale group of genetically related facies defined by physical characteristics that, in combination, are distinctive of individual depositional environments and the active processes that prevailed in those environments (Fisher and McGowen, 1967, p. 106).

Such associated individual facies have been formed by the same general types of active processes. For example, river point bars, natural levees, and overbank flood-plain deposits are three of the related facies formed along rivers and make up a part of a fluvial depositional system. Each of these facies can be defined in terms of sedimentary characteristics that reflect the fluvial processes that formed them. The active processes referred to in discussing depositional systems are generally categorized as "marine", "fluvial", "deltaic", or some similar term denoting origin or genesis.

As used in this report, a *depositional system* is only one kind of *natural system*. A *natural system*, as defined by Fisher and others (1972, p. 31) ". . . reflects the natural association and origin of specific mapped . . . units. The origin of the various natural units . . . determines their main features, composition, and character; hence, their origin is basic to considerations of resource evaluation and use." They consider natural systems to be made up of four basic kinds of units: (1) physical units, (2) biologic units, (3) active-process units, and (4) man-made features. The depositional systems of Pleistocene age as used in the present report are defined on the basis of physical units. The systems are interpreted and have environmental implications based upon the three-dimensional distribution of the units composing them. The depositional systems of Holocene age in this report are defined on the basis of both physicial and active-process units and, similarly, are interpreted and have environmental implications based upon the three-dimensional distribution of both physical units and active processes.

The depositional system concept has a number of valuable characteristics in that it provides a means (1) for inventorying the physical geologic framework of an area, (2) for extrapolating various physical properties through areas where they have not been measured, (3) for considering the potential effects of man-made changes that might be imposed on the presently existing natural systems, and (4) for anticipating the responses of these systems to any such imposed changes. From studies of depositional systems represented in ancient rocks and the stratigraphic changes in them which represent sequential variations through time, geologists can make some estimate of the kind and size of changes to be expected in the future on the present Coastal Plain. It is important to do so because areas such as the Coastal Plain of Virginia are not static geologically, but are active, rapidly changing, evolving areas.

The concept of depositional systems is the relation between the active depositional processes that affected sediments during the history of their development and the physical features of the resulting deposits which reflect those processes, namely, their sedimentary characteristics and their three-dimensional shapes.

If the original external forms of sedimentary bodies can be observed, even indirectly, appropriate depositional systems

can be defined and rapidly mapped at a reconnaissance level. The sedimentary characteristics of each facies can then be reasonably inferred on the basis of many studies of modern sediments, such as summarized by Visher (1965). This approach has been used successfully in the subsurface for mapping rocks as old as Pennsylvanian (Brown, 1969), and at the surface for mapping Quaternary sediments.

If the original external forms of sedimentary bodies can no longer be readily observed, then field examination is necessary to determine the internal sedimentary characteristics and the vertical variation in these characteristics at different geographic locations. Detailed columnar sections reflect the geographic as well as stratigraphic distribution of facies (Visher, 1965, p. 41, Kraft, 1971a, p. 84). Once the internal sedimentary sequences are known, it is possible to infer the three-dimensional shapes and spatial distributions of facies and thus, the depositional systems. This approach has been used successfully in surface mapping of rocks as old as early Paleozoic (McGowen and Groat, 1971).

An annotated bibliography is included as Appendix I and consists mainly of papers describing (1) entire depositional systems, (2) specific depositional environments and component facies of various depositional systems, and (3) depositional systems in the Middle Atlantic and Coastal Plain of Virginia area.

DEPOSITIONAL SYSTEM FRAMEWORK

Early geologic investigations of the Coastal Plain of Virginia were strongly influenced by interpretation of the regional geomorphology. A number of terraces were observed and each was related to deposition of sediments in shallow-marine environments during successive transgressions by the sea (Clark and Miller, 1912, p. 219-222). All the sediments on each terrace were considered to form a single formation which was given the same name as the terrace (Clark and Miller, 1912, p. 48). Recent detailed geologic work, beginning with Moore (1956) and continuing to the present (Coch, 1968; Bick and Coch, 1969; Goodwin, 1970; Coch, 1971; and Johnson, 1972), however, emphasizes genetic facies mapping and shows that each terrace includes several formations. A single formation, in turn, generally contains several facies, each of which is partly the result of

certain active processes characteristic of the depositional environment in which each facies was deposited. Modern geologic maps of the fourteen quadrangles that have been completed, plus supplemental information from other areas, make it possible to group the mapped facies of Pleistocene-Holocene age into depositional systems. Small outcrops of Miocene and Pliocene units that are not part of the systems are included in the mapped area and are not differentiated because of the map scale.

The sediments that are exposed at the surface of the present Coastal Plain of Virginia formed as the sea repeatedly transgressed onto and regressed from the land. An individual transgressive-regressive cycle is the basic unit of Coastal Plain sedimentation. During a transgression, the sea moves landward onto a preexisting erosion surface. Older sedimentary units are partly or wholly destroyed by erosion during this transgression and may be incorporated as part of new deposits that form in various shallow marine environments. These environments include barrier islands, beaches, lagoons, tidal passes, tidal deltas, marshes, and nearshore shallow marine.

The transgressed older units continue to exist landward of the limit of maximum transgression. In this report, all such units are grouped together as *older depositional systems, undifferentiated* (Plate 22), and are not defined in detail. Fluvial to estuarine to marine depositional environments are represented in sediments ranging in age from Cretaceous to Pleistocene.

Under conditions apparently prevalent on the Atlantic Coastal Plain, the preserved result of a transgression is a wedge of mostly marine sediments that becomes thinner in a landward direction where it overlaps the older depositional systems. One such wedge of sediments is herein named the *transgressive marine depositional system* of Pleistocene age. The present strike of individual facies within the system is characteristically parallel to the present coast. The system as a whole slopes gently seaward. Although particular properties may vary between individual facies within the system, it is possible to show that the facies are genetically related by considering the lateral and vertical sedimentary sequences of which they are a part, and by similarities in lithologic components, fossil contents, degree of weathering, and sedimentary properties that indicate the same types of processes affected all the facies. This

sort of information forms a basis for stratigraphic work by making it possible to establish equivalence between different facies and a relative chronologic sequence between different depositional systems.

During a regression, the sea retreats from the land. Streams extend themselves across the surface that is newly exposed to erosion and near the sea they may grade into estuaries. The point bars, levees, flood plain, and other deposits related to such streams on the Coastal Plain of Virginia make up the *fluvial-estuarine depositional system* of Pleistocene age, the preserved result of a regression. Regionalyy, the system shows a pattern of separated linear trends, approximately parallel to each other and all perpendicular to the present strike of the facies in the transgressive marine depositional system.

The *fluvial depositional system* of Holocene age is defined as comprising all the present streams and their associated sedimentary deposits, including point bars, some marshes, and flood plains. Seaward, the largest streams grade into estuaries. In this report, these estuaries are considered to be part of the marine-estuarine depositional system that is described in the following section. Nevertheless, their existence strongly influences the dynamics of the fluvial system.

An estuary has been defined by Pritchard (1967) as ". . . a semi-enclosed coastal body of water which has a free connection to the open sea and within which sea water is measurably diluted with fresh water from land drainage." Estuarine circulation is dominated by two types of currents: fresh water flowing seaward from the land, and salt water moving landward from the sea in response to tidal fluctuations. Pritchard and Carter (1971, p. IV-1 to IV-10) have defined four estuarine circulation patterns, A, B, C, and D, based upon the relative strengths of the river flow and the tidal currents affecting an estuary. Type A is totally river-dominated and type D is totally tide-dominated.

Similar to all moving currents, either the river currents or the tidal currents in estuaries can transport sediment. Configuration of channel bottom and bank sediments, easily visible in aerial photographs, can be used to deduce the directions of current flow. In portions of the Rappahannock and York estuaries, sediment configuration indicates a landward current flow along the north bank of these two estuaries and a sea-

ward flow along their south bank. In type B and C estuaries, oriented mostly east-west in the northern hemisphere, salt water will tend to move landward along the bank to the left of an observer facing seaward, while fresh water will tend to flow seaward along the opposite bank of the estuary (Schubel, 1971, p. VI-13). In type B and C estuaries, respectively called partially mixed and vertically homogeneous, the fresh water-salt water interface is oriented longitudinally along the estuary and varies from inclined (type B) to vertical (type C). Classification of a particular estuary may vary throughout the year as the river flow goes through its seasonal variation. Pritchard and Carter (1971, p. IV-6) have found the James to be a type B estuary, at least part of the year.

In type B estuaries, according to Schubel (1971, p. VI-11), "Fine suspended particles, discharged into the estuary by rivers, which settle into the lower layer are carried back upstream by its net upstream flow leading to accumulation of sediment on the bottom between the upstream and downstream limits of the salt intrusion." Similarly, for type C estuaries (Schubel, 1971, p. VI-13), "One would expect then, that shoaling would be most severe near the limit of salt intrusion on the side of the estuary to the left of an observer facing seaward in the Northern Hemisphere."

Relatively small amounts of sediment introduced into and dispersed by the fluvial depositional system, plus the interposition of type B and C estuarine circulation patterns between the streams and the ocean, makes the formation of deltas unlikely, so thick regressive-offlap deposits have not been formed by the fluvial system on the Coastal Plain of Virginia. Without a continual influx of deltaic sediment to redistribute, longshore currents expend their excess energy eroding the shoreline (Plate 24).

Present-day longshore currents themselves, along with tidal currents, estuarine currents, tidal passes, tidal deltas, beach complexes, lagoons, and some marshes are but a few of the component facies and active processes of the *marine-estuarine depositional system* of Holocene age. This system includes the area, processes, and related sedimentary deposits of the nearshore Atlantic Ocean, Chesapeake Bay, and all estuaries, bays, and lagoons.

Most of the sediment being dispersed by the marine-estuarine depositional system seems to be originally introduced from adjacent areas along the coast by eroding longshore currents. This sediment is deposited, at least temporarily, in a number of individual environments, including beach complexes, tidal deltas, and estuarine deposits. Abundant sand in the mouth of the James River estuary (Nichols, 1967, p. 4) is one such deposit.

MAPPING CRITERIA FOR DEPOSITIONAL SYSTEMS

Specific geomorphic criteria for each of the four depositional systems just defined were established in the 14 quadrangles where modern geologic maps are available (Coch, 1968; Bick and Coch, 1969; Goodwin, 1970; Coch, 1971; and Johnson, 1972). As mapping proceeds in the future and the amount of geologic data for the Coastal Plain increases, it is to be expected these four initial depositional systems will be modified, refined, and subdivided to reflect increasingly detailed knowledge of Coastal Plain geology. The marine-estuarine depositional system, for example, might in the future be subdivided into offshore marine, barrier island-bay-lagoon, and estuarine depositional systems. Criteria for each of the four depositional systems are given below and summarized in Table 3.

TRANSGRESSIVE MARINE DEPOSITIONAL SYSTEM

The transgressive marine depositional system contains sediments that were deposited in a variety of shallow-marine environments in areas which are subaerially exposed today. These sediments are exposed in a broad, low outcrop band adjacent and roughly parallel to the present coastline. Individual formations have a blanket-like distribution and are laterally persistent. Because the present strike of the facies within the system is roughly parallel to the present coastline and perpendicular to much of the present drainage, preferential erosion along facies contacts is the cause of a characteristic trellis drainage pattern (Figure 5).

FLUVIAL-ESTUARINE DEPOSITIONAL SYSTEM

The fluvial-estuarine depositional system is analogous to the fluvial depositional system seen today. The two systems are closely associated geographically (Plate 22). Regionally, the

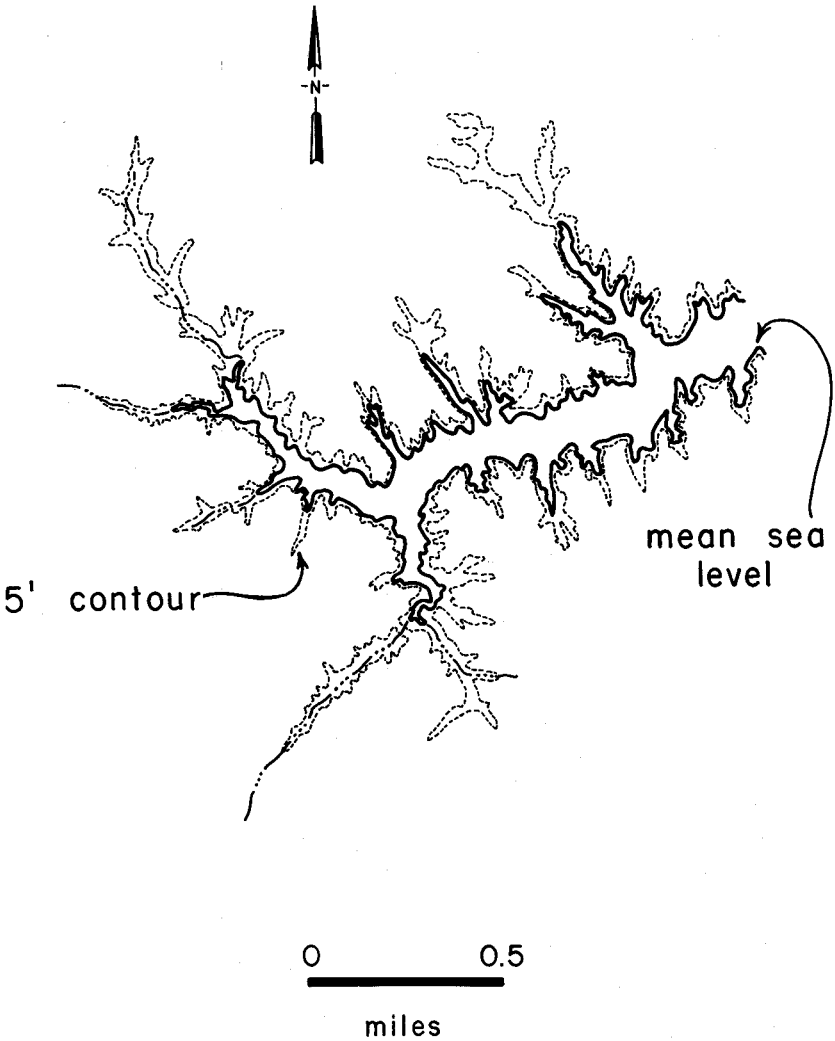

Figure 5. Trellis drainage pattern, transgressive marine depositional system; Poquoson West quadrangle.

fluvial-estuarine depositional system occurs in a series of linear valleys, roughly parallel to each other and all parallel to the regional slope. In plan view, the valleys are not now flooded but have scalloped edges reminiscent of meanders. However, point-bar patterns, cutoff meanders, and other exposed surface features of the present fluvial depositional system are

lacking. The subdued geomorphology is taken as evidence of the relatively older age of the fluvial-estuarine depositional system. Locally, the smallest channels of the present drainages are not strongly influenced by underlying sedimentary patterns and so form dendritic patterns upon sediments of the fluvial-estuarine system.

FLUVIAL DEPOSITIONAL SYSTEM

The fluvial depositional system comprises most of the present streams on the Coastal Plain along with their associated sedimentary deposits. Active processes in the system are channel flow (the stream proper), overbank flow (flooding), meandering (development of a sinuous channel with concurrent erosion and deposition), and downcutting (erosion). Related sedimentary facies include point bars, natural levees, flood-plain deposits, and sand bars.

Figure 6 shows some components of the fluvial depositional system along a section of the Chickahominy River in the central Coastal Plain. The channel flow has developed a meandering course with erosion and deposition characteristically alternating along either bank, at least originally. Deposition of sediment on the insides of river bends, or meanders, produces sand bodies called point bars. Sedimentary structures, grain size, and other sedimentary properties of point bars show characteristic sequences of variation (Visher, 1965, p. 49) that can be inferred on a reconnaissance basis from the distinctive curvilinear shape of a point bar which is so readily visible on topographic maps and aerial photographs.

Point bars of the fluvial depositional system are well shown in many places. Along the James River at Jamestown Island, for example, they are indicated by curvilinear areas of trees and intervening drainages (Figure 7). Deposition of sediment by lateral accretion occurs toward the convex sides of point bars and has occurred toward the lower right in Figure 7.

As a river meanders back and forth, some meander loops may be cut off and form oxbow lakes. These lakes are eventually filled with clay and are visible on the present Coastal Plain in every stage from a water-filled channel still tenuously connected to its parent river to a clay-rich area showing a distinctive curvilinear shape.

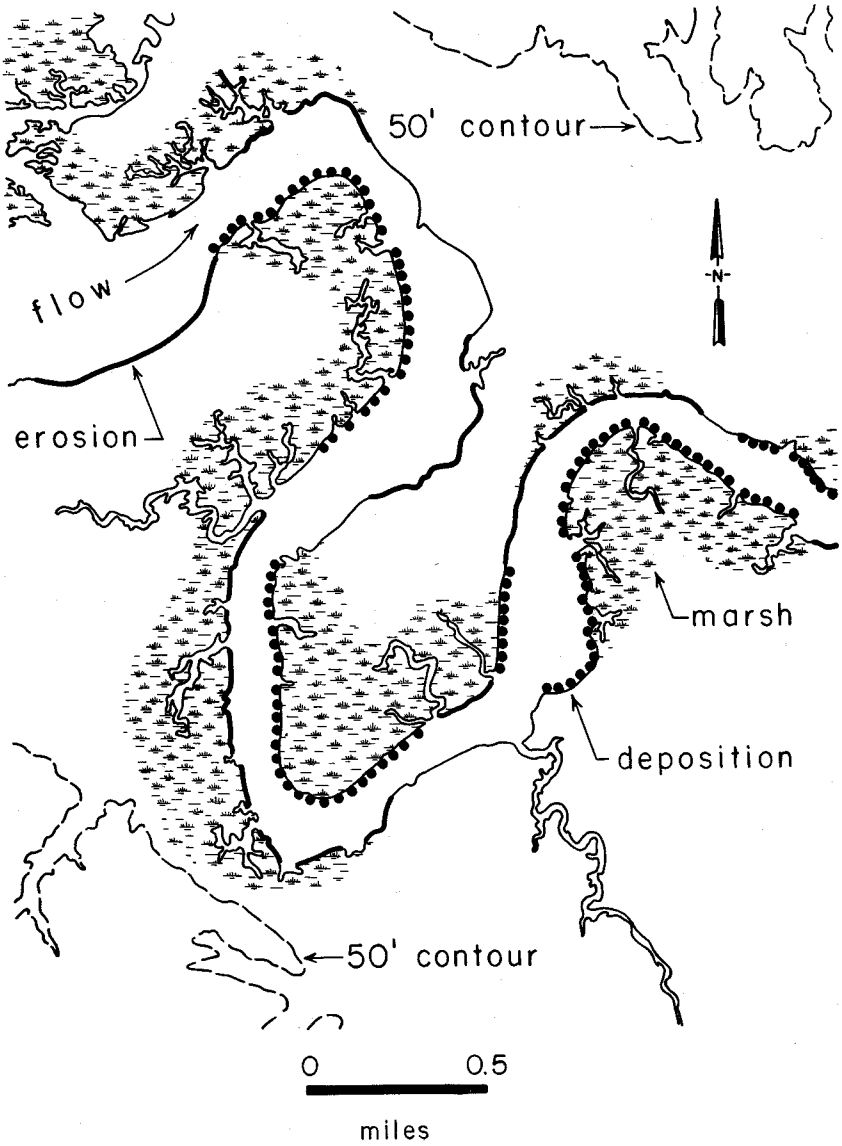

Figure 6. Some components of the fluvial depositional system: meandering stream, flood plain (approximately defined in this area by 50-foot topographic contours), alternating erosion and deposition along sides of channel (depositional areas are sites of point-bar formation); Chickahominy River, Walkers quadrangle.

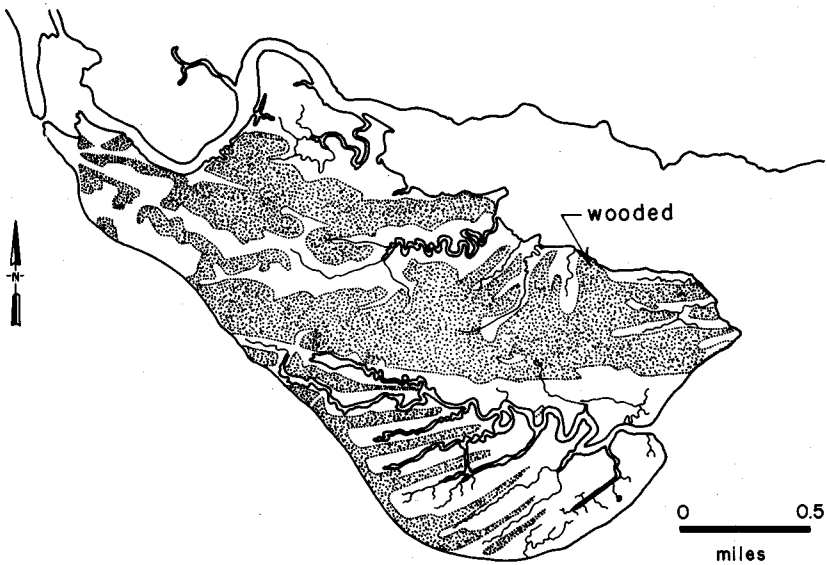

Figure 7. Point bars, fluvial depositional system, shown by arcuate wooded areas and intervening drainages; Jamestown Island, Hog Island, and Surry quadrangles.

Flood plains of the fluvial depositional system (Figure 6) show the maximum extent of past overbank flow. Simple flood-plain deposits are characteristically horizontally laminated silt and clay and form when sediment slowly settles from flood water during periods of overbank flow. This vertical accretion of blanketing sedimentary layers produces the characteristic, flat, low-relief flood-plain surface adjoining the stream channel on either side.

Seaward, the fluvial depositional system is being inundated by rising sea level. As the sea transgresses the land, the lowest areas—the river valleys—are flooded first. The most completely flooded valley segments show only occasional oval-shaped outlines along their edges to mark the former position of meanders. Slightly less flooded segments of former meandering streams show a distinctive, convolute plan view (Figure 8). In some inundated areas, scattered remnants of the fluvial depositional system, such as Jamestown Island, are still visible.

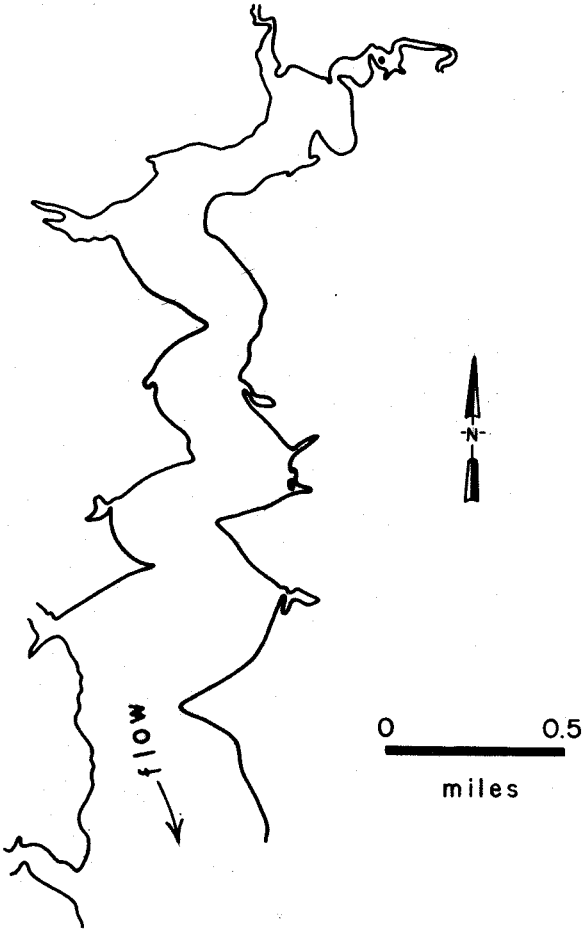

Figure 8. Convolute plan view of partially inundated river; North River, Ware Neck quadrangle.

MARINE-ESTUARINE DEPOSITIONAL SYSTEM

The marine-estuarine depositional system includes the present nearshore Atlantic Ocean, Chesapeake Bay, and all the other estuaries, bays, and lagoons and their associated sedimentary deposits. These deposits accumulate in environments ranging from subaqueous through intertidal to subaerial and have been described in detail by Oaks (1964, p. 41-68) in Virginia and by Kraft (1971b) in Delaware. Active processes in this system are tidal flood, tidal ebb, longshore currents, es-

tuarine currents, winds, and storms. Related sedimentary deposits include beaches and all their parts, barriers, marshes, storm washover fans, tidal deltas, tidal flats, and tidal and estuary channel deposits.

Present sea level along the Virginia coast is rising relative to the land (Oaks, 1964, p. 183). The leading edge of this marine transgression, and the landward limit of the marine-estuarine depositional system, is marked by the development of marshes, the first sign of long-term inundation (Kraft, 1971b, p. 2147). This is especially well shown along the Pamunkey and the Mattaponi rivers upstream from the point where they join to form the York River. Here, the fluvial depositional system (the rivers and their associated sediments) and the marine-estuarine system (the marshes) overlap in a zone about 14 miles wide. Similarly, to the south along the Chickahominy River,

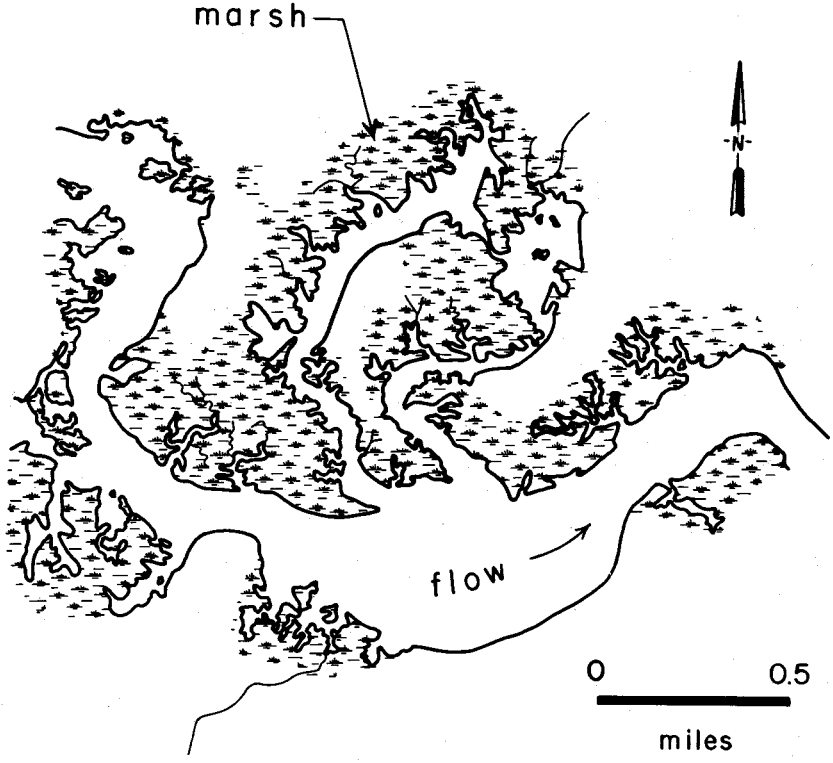

Figure 9. Incompletely cutoff meander of the fluvial depositional system being inundated by marshes of the marine-estuarine depositional system; Chickahominy River, Walkers quadrangle.

an incompletely cutoff meander of the fluvial system, still connected to its parent river, is being flooded by the marine-estuarine system (Figure 9) and filled by lateral accretion of marsh deposits. If this were a simple cutoff meander being filled in with sediments deposited by overbank flooding, its outline would appear much smoother (Figure 10). In this report the boundary between the fluvial and marine-estuarine systems has been placed at the landward limits of marine flooding that can be recognized by the geomorphic criteria given above because these criteria reflect a first-order change in the kind of active processes affecting the sediments.

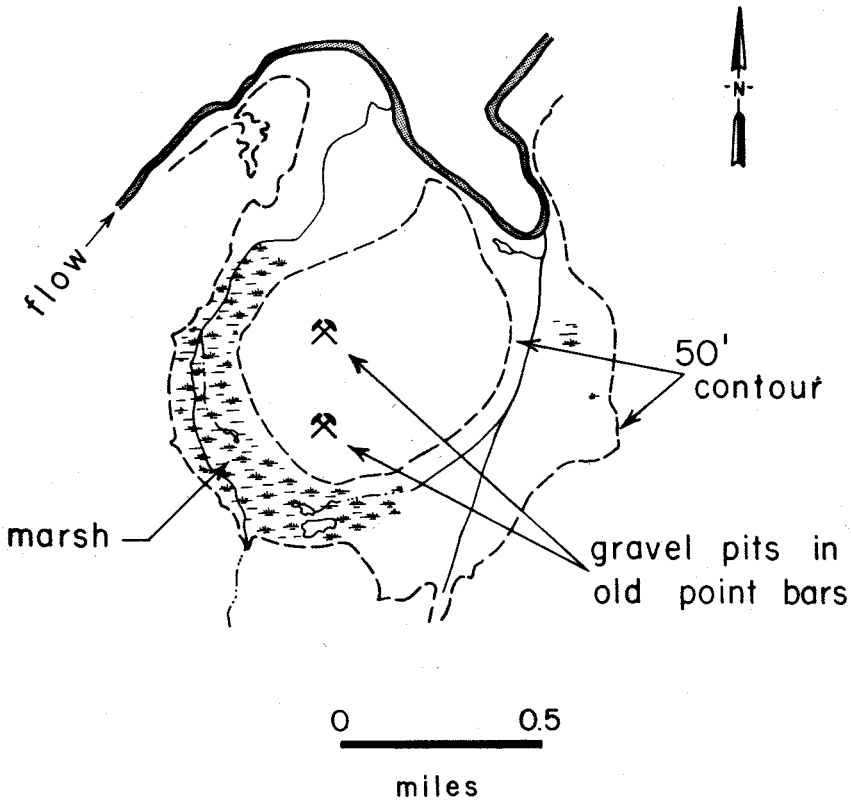

Figure 10. Cutoff meander with smooth outlines in plan view, fluvial depositional system; Mattaponi River, Sparta quadrangle.

Table 3. — Geomorphic criteria for mapping Pleistocene-Holocene depositional systems in the Coastal Plain of Virginia.

Transgressive marine depositional system

1. Low elevation.
2. Adjacent to the present coastline.
3. Present strike of individual facies parallel to the present coastline.
4. Trellis drainage pattern.

Fluvial-estuarine depositional system

1. Closely associated with the fluvial depositional system.
2. Present drainage locally shows a dendritic pattern.
3. Linear valleys, parallel to each other, elongate down the regional slope.
4. Valleys are not flooded and show scalloped edges in plan view.

Fluvial depositional system

1. Most of the present streams.
2. Curvilinear point bars.
3. Oxbow lakes.
4. Flood plains.

Marine-estuarine depositional system

1. The present ocean, bays, estuaries, and lagoons.
2. Landward limit of marshes.
3. Flooded valleys showing occasional oval outlines or convolute edges in plan view.

REGIONAL MAP OF DEPOSITIONAL SYSTEMS

The map of depositional systems of Pleistocene-Holocene age (Plate 22) shows the distribution of systems thus far defined for the Coastal Plain of Virginia. The systems are shown only where they can be definitely identified by the geomorphic criteria given in Table 3. All map units have been delineated by these criteria without regard to their geologic age. Instead, each unit shown belongs to a genetically related group of facies—a depositional system—and not necessarily to a group of sediments of precisely the same age.

Although the units on Plate 22 are defined by physical criteria devoid of any time connotation, the map shows a rough chronologic sequence defined by the present arrangement of the depositional systems. Thus, the sea clearly must have extended to the landward limit of the transgressive marine system at one time. Without any information to the contrary, the fluvial-estuarine system might be considered equivalent in age. It is then clear from examination of Plate 22 that there must have been a regression of the sea and some part of the transgressive

marine system was subaerially exposed. As a further record of this regression, drainages became extended seaward and the fluvial system began to form. Because of this drop in sea level, likely caused by the last Pleistocene glaciation, streams cut down into the underlying sediments of the fluvial-estuarine system and could no longer change their courses. This accounts for the close association of the fluvial and fluvial-estuarine systems.

As sea level began rising at the start of the present transgression, streams meandered widely in their valleys. Sea level continued to rise, flooding the downstream portions of streams, creating estuaries, and leaving behind isolated portions of the fluvial system, which are still exposed. As sea level approached its present level, some stream gradients were so reduced that many of the larger rivers were diminished and appear today as relatively small streams in anomalously large valleys. The present marine transgression is represented by the marine-estuarine system.

ENVIRONMENTAL IMPLICATIONS OF DEPOSITIONAL SYSTEMS

Thus far in this report, some depositional systems of Pleistocene-Holocene age have been defined for the Coastal Plain in Virginia and described in terms of the *geology*. However, a depositional system and all its component facies are defined by tangible, physical criteria and, as a result, each system and its component facies have a distinctive set of physical characteristics. Various of these characteristics are important and are of interest to a variety of persons who are not geologists. The purpose of this part of the report is to discuss the broad, regional environmental implications of the physical characteristics and active processes unique to each depositional system and how they are important to a variety of persons. For example, engineers and building contractors are interested in bulk properties of mapped units. Land developers and local public regulatory agencies are much interested in areal variations of physical properties and active processes that affect land uses. Even man-made characteristics that are seemingly unrelated to geology commonly have a relationship to depositional systems. The value placed on different building sites because of differences in elevation, the desirability of a certain activity or land use

in a certain area, and even such unlikely considerations as insurance premiums for liability against floods, landslides, and other natural hazards, can frequently be related to the geologic framework of an area.

The following discussions of examples for each depositional system should make it obvious that regulations and natural resource management guidelines must be flexible and must vary from area to area as the geology varies. Only in this way can maximum benefits be obtained from an area and minimum harmful changes imposed upon it. If rigid, uniform management codes are followed, needless and expensive "overbuilding" may result in some areas and foolish, potentially dangerous "underbuilding" may result in other areas.

TRANSGRESSIVE MARINE DEPOSITIONAL SYSTEM

The sediments in the transgressive marine depositional system are now observed in surroundings that are different from those in which they were originally formed. Hence, the active processes that deposited the sediments can only be inferred from the three-dimensional distribution of physical properties of the sediments. Additionally, the three-dimensional distribution of physical properties is also of prime environmental interest. Formations in this system are relatively thin as compared to their areal dimensions and are laterally persistent. Individual facies within each formation have a tabular shape: elongate along depositional strike, of intermediate width, and very thin. Physical characteristics tend to vary in a parallel manner: least variation along depositional strike, intermediate variation at right angles across facies boundaries, and most variation vertically across formation boundaries.

Such directional variation in porosity and permeability,[1] for example, will have important effects on exploitation of shallow ground water, sealing wastes in sanitary landfills, preferred directions of urban expansion, and the design of storm sewer systems.

Within the transgressive marine depositional system, natural or introduced fluids at shallow depths will generally move down-

[1] Porosity is a measure of the amount of empty space within a mass of sediment and reflects the amount of fluid the mass of sediment can hold. Permeability is a measure of how fast fluids can move through the sediment.

ward and seaward down the low primary dip of the system until they reach an impermeable barrier and then follow this barrier laterally along the depositional strike of the system. Where fluid infiltration and movement is desirable, this pattern can be used to determine the occurrence of shallow ground water and aid in the development of additional supplies. Water obtained from former beach sands, for example, will occur in trends parallel to the old shoreline and water obtained from sands in former river channels will occur in trends at right angles to the old shoreline (Hansen, 1971). The same pattern of regional variation of porosity and permeability can also help in generally locating septic tank drainage fields for maximum effectiveness of operation and indicate areas to avoid. However, because of its low elevation and its nearness to the sea, much of the transgressive marine system has a high water table which limits the effective operation of septic tanks and presents the possibility of contaminating near-surface ground-water supplies. Thus, sensible resource management and regulatory guidelines, such as building and zoning codes, are ultimately dependent upon the geology of the area.

Where fluid infiltration is not desirable, this same pattern of variation in porosity and permeability can help in locating dam sites, sanitary landfills, and industrial waste ponds. Such uses require material of low permeability which will retain fluids and prevent the uncontrolled escape of toxic wastes. And, if impermeable material is not naturally present at a site that must be chosen for other, usually economic, reasons, one alternative that is made possible by the thinness of the units in the transgressive marine system is to completely remove the permeable material at the surface. It must first be determined by on-site investigation that impermeable material underlies the surface unit. Generally, the geologic characteristics of any site will indicate the factors that must be considered in subsequent design and engineering of a particular project.

The transgressive marine system is divided into peninsulas whose headlands are commonly marshy and are bordered by broad tidal flats as a result of the low angle at which the land slopes beneath the sea. The marsh areas are extremely vulnerable to periodic flooding but are somewhat protected from daily wave and current erosion by the broad bordering tidal flats and natural marsh vegetation that acts to anchor sediment in place.

Tributaries of present streams that are eroding headward up the slope of the transgressive marine system tend to be oriented along the strike of the system and join their parent streams at right angles, producing a distinctive trellis drainage pattern (Figure 5). Some of these tributaries appear anomalously large in comparison to adjacent tributaries, where they are eroding the boundary between two units having contrasting physical characteristics. In addition, these individual large tributaries tend to be regionally aligned with each other along the strike of the transgressive marine system (Plate 22) and thereby make it possible to predict the location of boundaries between units within the system which have different bulk physical properties. With this understanding of the regional variation of physical properties, which derives from the regional geology, it would be possible to rapidly screen large areas for favorable building sites, for example. Then a minimum number of boreholes could be judiciously located to evaluate the detailed characteristics of specific sites with confidence that maximum information was being obtained at minimum cost. The headwater areas of these anomalously large tributaries are, of course, vulnerable to increased erosion. The speed of such erosion, as with many geologic processes, is best measured by periodic remapping and comparing of results against maps made in the past.

The landward limit of the transgressive marine system is marked by nearshore sediments and geomorphic features. The clean, well-sorted sands often characteristic of these areas are valuable as fill and the commonly increased elevations make the land more desirable for urban development. Since urban development and zoning regulations that accompany it can make exploitation of natural resources such as sand and gravel impossible, careful advance planning by local government and regulatory agencies is desirable to avoid needless potential conflicts, to assure full development of all natural resources, and to make possible the sequential use of the land for multiple purposes. In some localities natural resource zones have been formally defined to assure the community its natural resources of sand and gravel will be available when they are needed.

FLUVIAL-ESTUARINE DEPOSITIONAL SYSTEM

The sediments in the fluvial-estuarine depositional system are also now observed in surroundings that are different from those

in which they were originally formed. And, just as with the sediments in the transgressive marine system, the three-dimensional distribution of physical properties is of prime environmental interest and can be expected to vary in a manner parallel to the three-dimensional shapes of the individual sedimentary units within the fluvial-estuarine system. Individual units within the system have tabular to shoestring shapes and are regionally elongate and roughly perpendicular to the present coastline.

Sediments in the fluvial-estuarine system are similar to those in the other systems, but the components are mixed in different proportions. Sorting is commonly poorer and porosity and permeability are correspondingly lower. This is a potential asset for any activity that requires restricting infiltration of fluids such as waste disposal in sanitary landfills, but a potential source of difficulty for any activity that requires easy infiltration of fluids such as septic tank operation. Sand-rich sedimentary units, desirable as building sites, for example, because of their strength and other good foundation characteristics, can be expected to occur in the fluvial-estuarine system. Other sand-rich units with similar physical properties, although formed in different ways, can be expected to occur in the transgressive marine system. However, the regional trends of such sand-rich units will be at approximately 90 degrees to each other because of the fundamental geometries of the depositional systems involved. Ideally, building specifications and urban planning should show an awareness of this underlying geologic pattern by showing a parallel variation and pattern. As pointed out in the section on "Mapping Criteria," the fluvial-estuarine system exhibits a subdued geomorphology, so detailed on-site mapping of individual sedimentary units is usually necessary to determine the feasibility of a given project at a specific location within this system.

FLUVIAL AND MARINE-ESTUARINE DEPOSITIONAL SYSTEMS

The active processes depositing the sediments in the fluvial and marine-estuarine systems can be observed at the present time. In these two systems, it is the interplay between the active processes and the individual sedimentary units as well as the three-dimensional distribution of physical properties, that is of prime environmental importance. Here, the evolving nature of

the coastal area is obvious as the fluvial and marine-estaurine systems continually respond to the natural and man-made changes imposed upon them.

The present rivers and streams of the Coastal Plain generally transport only fine sand, silt, and clay, except during times of flood when larger sediment particles may be moved. The largest particles of sediment are deposited in the estuaries and do not reach Chesapeake Bay or the Atlantic Ocean. The point of maximum sediment deposition is determined by the prevailing type of estuarine circulation (Schubel, 1971). In the Rappahannock River the coarsest sediment is deposited in the middle portion of the estuary (Nelson, 1963, p. 308), but in the James River maximum deposition occurs in Burwell's Bay about 16 miles upstream from Newport News (Nichols, 1967, p. 4). Such deposition can form shoal areas that are potential hazards to navigation and can require dredging to correct. Clay and fine silt are transported completely through the estuaries. Although the total amount of sediment transported through the James estuary is estimated at more than 90 percent of the total sediment load supplied by the river (Nichols, 1967, p. 4), it is insufficient to build deltas. Longshore currents which might otherwise redistribute deltaic sediments expend their available energy eroding the shoreline. Sediment derived from shoreline erosion is transported laterally and stored for various lengths of time in beaches, spits, tidal flats, tidal deltas, barriers, and estuary channel deposits. These sedimentary deposits, in turn, affect the active processes by altering the geometry of the coastal area. Geometry, including size, shape, and orientation of barrier islands, shape and bathymetry of bays and lagoons, and bathymetry of the nearshore marine area, directly affects circulation patterns in the water areas. Water circulation patterns are of great environmental importance because they affect the cleansing of introduced pollutants—natural or man-made—from any local area in the fluvial and marine-estuarine systems and because they directly influence the erosion, transportation, and deposition of sediment, which is also both a natural and man-made phenomenon. Spoil piles of dredged material are the main source of sediment that is produced by man's activities and is incorporated into the fluvial and marine-estuarine systems.

Maps showing areas of sediment erosion, directions of transportation, and areas of deposition are of direct interest to all persons concerned with the stability of the shoreline for recrea-

tional and construction purposes, the recovery of natural resources such as sand and shells, and the disposition of spoil and other wastes by dumping; they are of indirect interest to persons such as commercial fishermen.

Hurricanes are significant geologic agents on the Coastal Plain of Virginia because of the large energy input to the active processes of the fluvial and marine-estuarine systems which they represent and because of their accompanying precipitation. The energy input intensifies normal, day-to-day processes such as erosion, transportation, and deposition of sediment, and speeds up their rate of operation. Wind-driven surface water and heavy precipitation caused by and usually accompanying hurricanes cause increased shoreline erosion, increased sediment influx from rivers, and flooding of low-lying flat areas. The increased discharge of rivers can increase river dominance of estuaries and change estuarine circulation patterns from type C to type B and thereby increase the sediment-trapping ability of an estuary at exactly the time when sediment influx from the river is a maximum (Schubel, 1971, p. VI-14). Also, the decrease in salinity caused by the large influx of fresh water can have devastating biologic effects on some marine organisms that have restricted tolerances to salinity fluctuations.

Hurricanes that affect the Coastal Plain of Virginia usually strike land south of Virginia and move northward roughly parallel to the coast. A notable recent exception was hurricane Camille which moved from west to east across Virginia in 1969. Hurricane winds move in a counter-clockwise direction. As a hurricane moves northward along the Virginia coast, several effects can be anticipated from these patterns.

First, hurricanes cause higher than normal tides, called storm tides or storm surges. Depending upon the exact path of a particular hurricane, surges can be expected first along the Atlantic coast and the western shore of Chesapeake Bay as the hurricane approaches from a southerly direction, and later along the eastern shore of Chesapeake Bay as the storm departs. If the normal tide cycle is at its high point when a hurricane passes through, storm surges can cause severe flooding, particularly in areas of low relief such as those that characterize the transgressive marine system (Plate 26). However, if the tidal cycle is at its ebb, flooding may be quite minor. Hence, the vertical range of tidal fluctuation represents a "storage pool" for potential floodwaters (Plate 24). Sediment from deeper offshore

areas can be moved landward by storm surges and either spread on beaches or, if a barrier island is present, transported to the lagoon behind the barrier through channels in the barrier which were opened by the storm. Portions of back-barrier lagoons can be turned into marshes or even filled in by this means and the resulting change in geometry, if it persists, can alter circulation patterns long after the storm is gone. As a hurricane passes over a local stretch of coast line, the predominantly southward-flowing longshore currents (Plate 24) may be made to flow northward temporarily, but any changes this may cause in the pattern of erosion and deposition are usually wiped out shortly after the passage of the storm.

Landward, the incised stream banks found in many areas of the fluvial system do offer some protection against flooding by rising streams. In the fluvial system, the point-bar areas (Plate 22) are the first to be flooded when the stream overflows its banks. These areas are often part of the flood plain that is cultivated for agricultural purposes and often judged desirable for building sites. The high probability of flooding in any given area should be taken into account before using point-bar areas for agricultural or construction purposes.

RESOURCE CAPABILITY MAPS

A depositional system is a group of genetically related geologic units that have generally similar origins and are defined by physical criteria. Other than the geologic implications of the depositional system concept as discussed in this report, there is an additional environmental implication. Namely, physically similar geologic units will react similarly to any imposed stress; therefore, similar units will tend to have similar capabilities. That is, they are *capability units,* as defined by Brown and others (1971, p. 1). Capability as used here refers to the use to which something can be put and is expressed in terms of limitations or negative restraints. The purpose of defining such limitations is *not* to say what may or may not be done with a specific piece of land, but rather to provide a measure of the total cost of doing a certain activity in a given area. The total cost of any activity is usually composed of direct financial costs to the persons directly involved plus indirect costs of time and money to others who are indirectly involved. This indirect, but very real, part of the total cost of any project is generally considered to be paid "by society." A judgment must be made in

each case whether or not the total cost of an activity is acceptable to all the persons who are affected. Such judgments are beyond the scope of this report, but environmental geologic information as contained herein does provide a valuable and objective partial basis for making such judgments.

Environmental geologic information is most often presented in the form of *derivative maps* that are derived from the basic geologic map of depositional systems (Plate 22). By combining certain classes of geologic information with other data, including known locations of mineral resources, climatological data, soils data, and slope information for example, derivative maps such as Plates 23-26 can be produced. These maps, particularly when the relationships between them are considered and interpreted, can be used to indicate the broad, regional capabilities or potential uses of portions of the Coastal Plain in Virginia. The resource capability maps presented here (Plates 23-26) are by no means the only ones that are possible to make. Complete evaluation of specific local areas, for example, must be done on more detailed, larger scale maps that may show such characteristics as depth to bedrock, depth to first clay, depth to ground water, ease of excavation, porosity, bulk density, location of known faults, and many other physical characteristics all dependent upon the local geology and that are individually pertinent to a wide variety of projects and activities.

SELECTED MINERAL RESOURCES

Sand and Gravel

Slightly less than 12.8 million tons of sand and gravel, valued at a little more than 20.2 million dollars, were produced in Virginia in 1971 (U. S. Bureau of Mines, 1973, p. 11). Much of this came from the Coastal Plain. The distribution of known sand and gravel pits (active and inactive), likely sand-rich areas where additional supplies of sand and gravel might be found, and the major urban areas of the Coastal Plain that are the most likely points of use of the sand and gravel which is produced are shown on Plate 23. For use in concrete more sand is recovered from river sediments than from marine sediments, generally because the grains are more angular and are without salt coatings. Marine sands are used mostly for fill. The sands and gravels of the fluvial and fluvial-estuarine depositional systems make excellent general-purpose construction materials;

favorable areas where additional supplies might be found are shown on Plate 23. Sands that have accumulated in a transgressive marine depositional system are usually too rounded to perform well as a component of concrete and any residual salt left from its deposition in marine environments would impair its quality.

The cluster of sand pits north of Newport News are in marine sands of a beach and nearshore marine facies (Johnson, 1972, Plate 2). One can draw several conclusions about the area: (1) this facies is a source of economically valuable sand, (2) additional sites of potentially similar sands are largely unexplored, and (3) possible future expansion northward of the Newport News-Hampton urban area could restrict the recovery of sand from this facies in that immediate vicinity where its potential value is the highest because of the low transportation costs. The graph on Plate 23 is an illustration of how far general-purpose sand and gravel of various values can be moved until the cost of the transportation is many times greater than the value of the sand and gravel itself. This is an instance where careful planning in advance of any such expansion will afford several choices for the inhabitants of the area. For example, sands can be extracted in advance of urbanization and thus provide sites for various public recreational facilities, industrial development, and even home-building. Rather than competition between land uses that are mutually exclusive, it is frequently possible, and certainly desirable, to derive many benefits from a tract of land by planning for sequential, multiple use of that tract.

Clay

Slightly more than 1.7 million tons of clay, valued at 1.8 million dollars, were produced in Virginia in 1971 (U. S. Bureau of Mines, 1973, p. 11). Clay is common in the Coastal Plain, but no commercial pits are now known to be in operation. The clay localities shown on Plate 23 are mostly in the area of older depositional systems that have not been mapped for this report and are where samples of clay have been recovered, tested, and found to be potentially suitable for a variety of ceramic products (Calver, Hamlin, and Wood, 1961; Johnson and Tyrrell, 1967).

ACTIVE PROCESSES

Active processes of the Coastal Plain can readily affect the activities of man, and the activities of man can influence—for better or worse—the natural processes of the Coastal Plain. Data concerning the geologic processes are needed before most man-made activities can be knowledgeably planned with full appreciation of their probable consequences.

The fundamental long-term active process on the Coastal Plain in Virginia is the raising of sea level relative to the land. This process is responsible for creating the estuaries with their distinctive circulation patterns and other unique physical characteristics. On the other hand, short-term processes include movement of longshore currents, estuarine currents, storms, and tides. These are the daily processes that erode, transport, and deposit sediment.

The map of active processes, Plate 24, shows the sediment dispersal systems operating today within the marine-estuarine depositional system. Sources of eroding sediment, directions of sediment dispersal, and areas of sediment deposition are shown. This information is of value to persons concerned with preservation of beaches, siltation and dredging of harbors and other navigable waterways, and construction of shoreline facilities such as piers, groins, and jetties.

The long stretch of eroding beach along the Atlantic Ocean in southeastern Virginia (Plate 24) is caused by a southward-moving longshore current generated by the southward deflection of the ebb tide flow from the mouth of Chesapeake Bay (Harrison and others, 1964, Figure 10, p. 20). This current is capable of great erosion because it carries relatively little sediment from inland source areas. Approximately five miles of Atlantic shoreline immediately south of the mouth of Chesapeake Bay is subjected to erosion by a northward-moving longshore current, created as an "eddy" of the same ebb tide flow. This current flows around the recurved spit of Cape Henry and then westward into Chesapeake Bay along the shoreline north of Norfolk. The relatively small amount of sediment transported and deposited by this current has caused minor progradation of Cape Henry toward the northwest.

Beach complexes that are not stabilized by vegetation are subject to rapid erosion. Marsh vegetation and dune grasses are

the two most important types of vegetation acting to naturally stabilize the present beach complexes. Artificial stabilization by means of groins, seawalls, and other types of construction must be done with great care and with the realization that coastal zones are constantly changing. If a man-made modification to a shoreline is introduced a corresponding natural response will almost certainly occur elsewhere.

Plate 24 may be used to predict the response of the system to any proposed man-made modifications. For example, cutting a new channel through a barrier, dredging naturally depositing sediment from a channel, and dumping spoil or waste material are activities that can cause a response in the marine-estuarine system. These activities tend to restrict or make less vigorous the circulation in bays, lagoons, and estuaries. This has the effect of limiting the amount and kind of wastes that can be disposed of in these areas, because restriction of the circulation limits the natural ability of the waters in these areas to cleanse and renew themselves.

Storms are significant geologic agents that are capable of producing lasting effects along the coast. Many of these effects and the mechanisms by which they are brought about on the Coastal Plain in Virginia have already been discussed under "Environmental Implications" of the fluvial and marine-estuarine depositional systems.

If a storm passes the coastal area during low tide, the volume of the tidal pool represents available storage capacity for precipitation that might otherwise cause flooding. The volume of the tidal pool has been calculated by multiplying the area of an expanse of water by the average tidal range for that area. To construct the contours shown on Plate 24, an arbitrary rectangular grid was drawn on the map and the volume of the tidal pool was calculated for each cell in the grid. A moving average of these values was calculated and contoured. The final contours (Plate 24) show the average volume of the tidal pool from place to place, expressed in inches of rainfall. Except for limited areas just along the shorelines of estuaries, it cannot be assumed however, that this much rain can fall during times of low tide before any flooding will occur. The low relief, gentle slopes, and consequently poor drainage of the outcropping transgressive marine system introduces a considerable lag between the time precipitation reaches the ground and the time it runs off into the

nearest estuary. This time lag is frequently the immediate cause of significant amounts of flooding. The tidal storage pool disappears during times of high tide, of course, so the timing of a storm in relation to the tidal cycle is very important.

LAND CAPABILITY

Soils

The map of depositional systems (Plate 22) shows geologic units that are defined by various physical criteria—units that have broadly similar origins and exhibit similar geologic characteristics, and therefore tend to develop similar soils. The land capability map showing soils (Plate 25) and the following discussion indicate some of the physical characteristics of the surficial materials in different areas. The ability to predict general physical properties in advance of detailed, and usually expensive, on-site measurements is very useful in general land development and, in particular, in excavation work, foundation design, and other construction and engineering activities.

The most common surficial materials are upland deposits consisting of gravel, sand, silt, and clay that form a mantle over most of the flat upland surfaces (Wentworth, 1930, p. 29). In places, they show a cobble or pebble gravel layer at the base, with grain size diminishing stratigraphically upward (Wentworth, 1930, p. 43), which is now considered to be one of several distinctive criteria of fluvial point-bar deposits (Visher, 1965, p. 49). Toward the southeast, sediments mapped as upland deposits are interpreted as being of marine and estuarine origin, at least in part (Johnson, 1972, p. 31). Much of the finest material at the top of the upland deposits is clay, most likely formed in place by soil-forming processes.

Thus, a compound origin is indicated for the upland deposits: deposition of sediment with soil-forming processes modifying the resulting deposits in place. This interpretation is consistent with some other observations that have been made. For example, the lower, and presumably younger, deposits contain less fine-grained material than higher ones (Wentworth, 1930, p. 77). This is consistent with the interpretation that less time has been available to develop soils on the younger, lower deposits than on the older, higher ones. Furthermore, soils developed on transported materials typically develop hardpans in their B-horizons (Gilluly, Waters, and Woodford, 1959, p. 50), and hardpans

do occur in some upland deposits of the Coastal Plain (Nikiforoff, 1955).

In the areas covered by upland deposits (Plate 25), soils can be expected to have at least one gravel layer at shallow depths, especially toward the northwest. A regional decrease in grain size of the upland deposits toward the southeast (Wentworth, 1930, p. 45) makes the occurrence of gravel in that direction progressively less likely.

Hardpans can be expected in the soils on the highest (oldest) upland deposits that are level. Hardpans do not form where these deposits are thin or where the surface has an appreciable slope (Nikiforoff, 1955, p. 53-56). They are impermeable and restrict the vertical movement of fluids at shallow depths; hence, they have a large effect upon the correct placement and operation of septic tanks for private residences and are of great importance in the urbanization of rural areas.

The first major clay that is encountered in excavations in the Coastal Plain, excluding clay that is part of the surface soil, is near the top of the Calvert Formation. Major amounts of clay can affect stability of the land, its tendency to form landslides, and its drainage characteristics, and represents potential problems in excavation work, foundation design, ground-water development, and subsurface disposal of domestic and industrial liquid wastes. Thick clays, however, are a potential advantage for the surface storage of wastes, as in sanitary landfills, because the clays form a seal that prevents movement of waste materials and thus prevents contamination of ground water (Figure 11). Some of the most favorable soils for sanitary landfills, in fact, occur in the upper Coastal Plain area of Virginia (Porter and Pettry, 1971, p. 11).

The Calvert Formation of Eocene-Miocene age is shown on Plate 25 as outcropping even where it is mantled by a very thin cover of upland deposits. It is present over most of the rest of the Coastal Plain, but lies beneath other formations at depth up to hundreds of feet. Locations of available boreholes with reliable data are shown on Plate 25 and the thicknesses of all sediments overlying the Calvert are indicated at each. These numbers, representing the depth in feet to the first major clay beneath the surface soil, show no strong regional pattern, but they do show large local variations in the thickness of cover over the formation. Toward the western edge of the Coastal

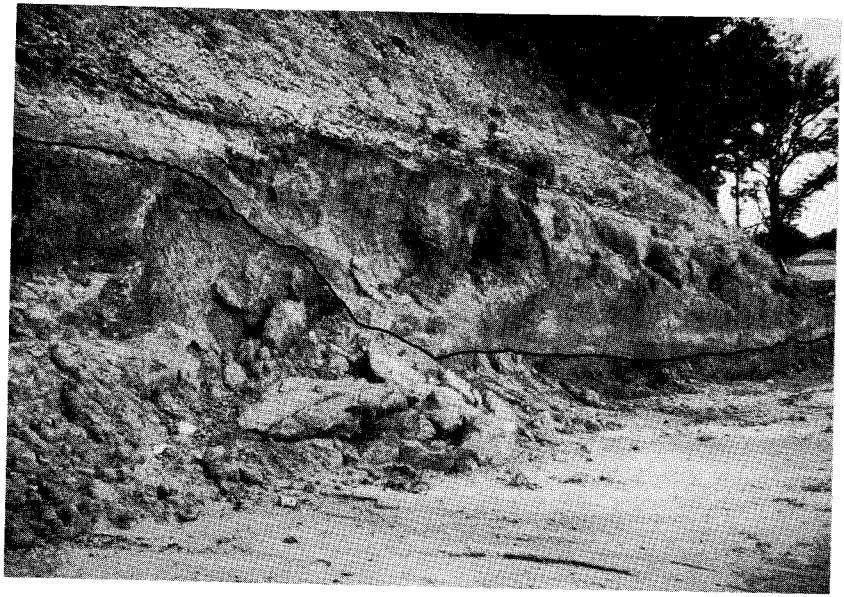

Figure 11. Permeable surficial deposit overlying impermeable clay in floor of sanitary landfill, Richmond.

Plain and within the area of its outcrop, the Calvert can occur very close to the surface beneath the thin, surficial upland deposits and thus affect surface works of man, but where the Calvert is more deeply covered, effects of clayey materials are more likely to be caused by clays formed in place in surface soils.

The marsh areas shown on Plate 25 have some very important physical characteristics. Marsh materials are very compressible, will consolidate immediately under a load such as spoil accumulations or buildings, and, as a result of this, make an unsatisfactory base for most construction purposes unless appropriate engineering measures are taken. They have a high water content and poor natural drainage. Where marshes are being formed by flooding of fluvial point-bar areas, well-sorted firm sand can be expected underneath a relatively thin marsh cover.

The land areas in Virginia with no patterns on Plate 25 represent mostly sediments of the transgressive marine, fluvial-estuarine, and fluvial depositional systems. Sediments in these areas are mostly sand and silt, with various admixtures of clay and shells. Facies with a high proportion of sand, such as beach complexes, point bars, and most levees, have high strengths, relatively high porosities and permeabilities, and low compres-

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sibilities. Natural levees can be expected to decrease in height, width, thickness, and grain size in a downstream direction and simultaneously increase in clay content (Kolb and Van Lopik, 1966, p. 29). Point bars become more common upstream (Plate 22). The grain size of point-bar sediments increases with depth; therefore clean, homogeneous sand can be expected in the lowermost third or half of a point-bar sequence. Fluvial sediments in the upstream portions of valleys can be subdivided into an upper, fine-grained part and a lower, coarse-grained part when discussing physical properties. The median grain size in both these parts will likely become smaller seaward (Kolb and Van Lopik, 1966, p. 56).

In clay-rich facies where the clay was originally deposited in a marine, saline environment, the draining of the interstitial saline fluid caused by subsequent uplift of the deposit has sometimes led to sudden losses of strength and the formation of quick clays (Kolb and Van Lopik, 1966, p. 25-27). Sensitive, or quick, clays suffer sudden losses of strength due to damage or destruction of the clay structure, called remolding, by either natural or man-made causes. Uplifted marine clays can be expected to occur in portions of the transgressive marine system; the seaward, or estuarine, portions of the fluvial-estuarine system; and in marine portions of the older depositional systems. Detailed local mapping and laboratory examination is essential to determine if quick clays occur in a given local area. Sensitive, or quick, clays are different from thixotropic clays, although both may liquify without the addition of water (Krynine and Judd, 1957, p. 134-135).

Slopes

The map showing distribution of surface slopes on the Coastal Plain (Plate 26) was constructed by measuring the *maximum* surface slope in each 7.5-minute quadrangle and grouping these values, expressed as percentages, into classes ranging from 0 to 1 percent, 0 to 2 percent, 0 to 5 percent, 0 to 15 percent, and 0 to 25 percent. No slopes greater than 25 percent were found, except for cliffs of various heights along some drainages. The slope shown at any one place on the map is a *maximum* and any lesser slope may also occur. The maximum surface slope developed in an area seems to be dependent upon, and characteristic of, the depositional system present in the area. In addition, there are large regional changes in a pattern resembling the geologic

map of Virginia (Virgina Division of Mineral Resources, 1963). This indicates certain geologic formations and certain genetic facies units of a depositional system can be expected to have a distinctive, characteristic maximum surface slope on the Coastal Plain of Virginia.

Surface slopes directly affect the suitability of land for construction of all types. Gentler slopes present fewer problems in engineering and design activities and therefore are less expensive to incorporate into most land uses. Very low slopes (less than 2 percent) over a wide area, on the other hand, will cause poor drainage. Such areas are susceptible to frequent, local, and usually minor flooding. This should be considered, for example, when designing sanitary landfills or sewage disposal plants in such areas.

Surface slope, the nature of the underlying material, and water content are factors directly affecting the stability of the land surface. A gentle slope is usually stable under most conditions, but some surficial materials will flow laterally into a newly-opened excavation or down even a small slope under the added weight of new construction or accumulated spoil from dredging. Surficial material rich in sand might be stable at a given degree of slope, whereas clay-rich material under the same slope might be unstable. And water, even from presumably innocent sources such as lawn sprinklers, can make possible the downslope movement of otherwise stable material.

CONCLUSIONS

In addition to the stated purposes at the beginning, this report has a larger goal. That is, to indicate there is a middle ground between rigid preservation and totally unregulated use of the natural resources around us. Clearly, difficulties will be encountered if either of these extreme courses are perpetuated. Environmental geologic information can do much to show the nature of the natural resources available and how they can be best utilized to produce maximum benefits at minimum total costs.

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

APPENDIX I

ANNOTATED BIBLIOGRAPHY

Three types of entries are indicated by the following numbers in the margin to the left of each entry:

1. Original or recent papers describing entire depositional systems and dealing with applications of the depositional system concept.

2. Recent papers describing specific depositional environments and component facies of various depositional systems.

3. Papers describing depositional systems, component facies, or applications of the depositional system concept in the Middle Atlantic and Coastal Plain of Virginia area.

1, 2 Allen, J. R. L., 1965, Late Quaternary Niger delta, and adjacent areas—sedimentary environments and lithofacies: Am. Assoc. Petroleum Geologists Bull., vol. 49, p. 547-600.

Internal sedimentary characteristics of facies may vary within a single environment because of differences in the supplied sediment. It is preferable to define sedimentary environments in terms of unique associations of active processes that do not vary. Sedimentary environments are classified into superenvironments (depositional systems), environments, and subenvironments (individual component facies). Detailed descriptions of the sedimentary characteristics of each facies are given, and they are interpreted in terms of the active processes of each depositional system.

2 Bernard, H. A., and others, 1970, Recent sediments of southeast Texas: Texas Univ. Bur. Econ. Geology Guidebook 11, 47 p.

Internal sedimentary characteristics are well illustrated and described in detail for individual facies belonging to fluvial, deltaic, coastal interdeltaic, and marine depositional systems associated with a marine regressive shore zone. Individual facies are assembled into characteristic vertical sequences for each depositional system and are interpreted in terms of active processes that deposited the sediments. Extensive data describing the Galveston barrier-island complex and the Quaternary geology of northwestern Gulf of Mexico are appended.

3 Boggess, D. H., Adams, J. K., and Davis, C. F., 1964, Water-table, surface-drainage, and engineering soils map of the Rehoboth Beach area, Delaware: U. S. Geol. Survey Hydrol. Inv. Atlas HA-109.

Soils derived from sediments of fluvial and coastal marine depositional systems are shown on a map and the physical properties of interest to engineers are tabulated. Understanding the dynamics of the depositional systems and the internal and external characteristics of the resulting deposits make it possible to selectively locate boreholes for obtaining data and to interpolate physical properties between boreholes with some assurance of accuracy.

1, 2 Brown, L. F., Jr., 1969, Geometry and distribution of fluvial and deltaic sandstones (Pennsylvanian and Permian), north-central Texas *in* Geology of the American Mediterranean: Gulf Coast Assoc. Geol. Socs. Trans., vol. 19, p. 23-47; *reprinted as* Texas Univ. Bur. Econ. Geology, Geol. Circ. 69-4, 1969.

Fluvial, deltaic, interdeltaic, and shelf depositional systems are defined on the basis of external geometries and stratigraphic arrangement of individual facies, plus internal sedimentary characteristics, from both surface and subsurface data. A depositional model, showing relationships between the four depositional systems, is derived to explain the distribution of sandstones that are important as objectives in oil exploration and as conduits for subsurface movement of naturally occurring and introduced fluids. *Dip-fed sandstone* is introduced as a general name for elongate fluvial and deltaic sands that were deposited parallel to the depositional dip. A very brief discussion is included of the limitations of using formal stratigraphic classification for this type of study.

1, 2 Fisher, W. L., and McGowen, J. H., 1967, Depositional systems in the Wilcox Group of Texas and their relationship to occurrence of oil and gas: Gulf Coast Assoc. Geol. Socs. Trans. vol. 17, p. 105-125; *reprinted as* Texas Univ. Bur. Econ. Geology, Geol. Circ. 67-4, 1967. (A slightly modified version is reprinted in Am. Assoc. Petroleum Geologists Bull., vol. 53, p. 30-54, 1969.)

This paper was one of the first to use the term *depositional system.* Seven depositional systems are defined from surface and subsurface data and the component facies of each are described in terms of their physical characteristics. Stratigraphic and geographic aspects, and their effects on the occurrence of oil and gas, are discussed for each depositional system.

3 Hansen, H. J., 1971, Transmissivity tracts in the Coastal Plain aquifers of Maryland: Southeastern Geology, vol. 13, p. 127-149.

Physical characteristics of the formations of the Maryland Coastal Plain are reviewed from previous work. The formations are grouped into fluvio-deltaic, fluvio-marine, and marine depositional systems on the basis of origins interpreted from these physical characteristics. The external geometry of each depositional system is shown to affect the regional occurrence of ground water.

3 Jordan, R. R., 1964, Columbia (Pleistocene) sediments of Delaware: Delaware Geol. Survey Bull. 12, 69 p.

Surficial deposits are described in terms of their internal sedimentary characteristics at a number of locations. Geographic variation of these characteristics and limited data on external geometries are used to define fluvial, shoreline complex, and estuarine depositional systems. These depositional systems make it possible to relate various facies to each other, to predict general distribution of facies in areas of no data, and to reconstruct the geologic history of the sediments.

1, 2 Kolb, C. R., and Van Lopik, J. R., 1966, Depositional environments of the Mississippi River deltaic plain—southeastern Louisana, *in* Shirley, M. L., ed., Deltas in their geologic framework: Houston, Tex., Houston Geol. Soc., p. 17-61.

Individual facies of four depositional systems are defined by internal sedimentary characteristics and external geometries, and are described in detail. The distinctive physical properties of each facies are related to its geologic origin. Knowledge of the dynamics of each depositional system and the resulting physical properties of each facies make it possible to selectively locate fewer boreholes to obtain a given amount of data and to knowingly interpolate physical properties between boreholes.

2, 3 Kraft, J. C., 1971, A guide to the geology of Delaware's coastal environments: Delaware Univ. Coll. of Marine Studies, 220 p.

Stratigraphic distribution of facies in a marine transgressive shore zone is determined in individual borings. The facies are described in terms of their internal sedimentary characteristics. Vertical sequences of facies reflect geographic sequences of facies, as determined from multiple boreholes. Physical properties and distribution of facies are used to interpret active processes that influenced the shore zone during the Holocene, to reconstruct the sequential development of a transgressive shore zone, and to extrapolate to possible future changes.

2 McGowen, J. H., and Groat, C. G., 1971, Van Horn sandstone, West Texas—An alluvial fan model for mineral exploration: Texas Univ. Bur. Econ. Geology Rept. Inv. 72, 57 p.

Internal sedimentary characteristics are interpreted in terms of active processes that operated during deposition of the sediments. Stratigraphic and geographic distribution of these sedimentary characteristics is the basis for a process-defined depositional model (depositional system) of alluvial fan formation by fluvial processes next to a highland source area. Occurrence of heavy minerals is genetically related to the depositional model to serve as a guide for exploring other, similar deposits.

3 Owens, J. P., and Sohl, N. F., 1969, Shelf and deltaic paleoenvironments in the Cretaceous-Tertiary formations of the New Jersey Coastal Plain, Field Trip 2 *in* Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook... —Geol. Soc. America, Ann. Mtg., Atlantic City, 1969: New Brunswick, N.J., Rutgers Univ. Press, p. 235-278.

Deltaic and marine shelf depositional systems are subdivided into sedimentary environments on the basis of active processes and gross physical characteristics of corresponding facies. Individual component facies of each formation are defined in terms of compositions, internal sedimentary structures, and external geometries, and are assigned a position within a conceptual depositional model to emphasize the relationships between facies and between depositional systems.

1, 3 Schlee, John, 1957, Upland gravels of southern Maryland: Geol. Soc. America Bull., vol. 68, p. 1371-1409.

A detailed petrographic description of a fluvial depositional system, emphasizing stratigraphic and geographic variations of internal sedimentary characteristics. An early paper, concerning depositional systems, which may be profitable to read for comparison with more recent studies of fluvial sediments and processes.

2, 3 Schubel, J. R., conv., 1971, The estuarine environment—estuaries and estuarine sedimentation: Washington, Am. Geol. Inst., Short Course Lecture Notes, 324 p.

Estuaries are presented as a continuous spectrum of gradational types. Emphasis is on active processes and the reflection of these processes in various physical characteristics for each type of estuary. Data are drawn largely from upper Chesapeake Bay.

2, 3 Stanley, D. J., conv., 1969, The new concepts of continental margin sedimentation, application to the geological record—AGI short course lecture notes, Philadelphia, 1969: Washington, D.C., Am. Geol. Inst.

Lecture 2, *Shore zone sand bodies,* by J. R. Curray and lecture 4, *Inner shelf sedimentation,* by D. J. P. Swift emphasize active processes and external geometries of individual facies in nearshore marine depositional systems. Swift discusses the idea of equilibrium between the parts of a depositional system, which has important geologic implications. Abundant data from the Middle Atlantic coastal area are included.

1, 2 Visher, G. S., 1965, Use of vertical profile in environmental reconstruction: Am. Assoc. Petroleum Geologists Bull., vol. 49, p. 41-61.

A limited number of sequential sedimentary processes, such as transgression and regression, are recognized. Each unique sedimentary process produces a characteristic sequence of depositional environments that are reflected in characteristic stratigraphic sequences of facies. Individual facies are described in terms of physical characteristics, including faunal content. Stratigraphic sequences are used to infer the geographic distribution and geometry of component facies for six different depositional systems.

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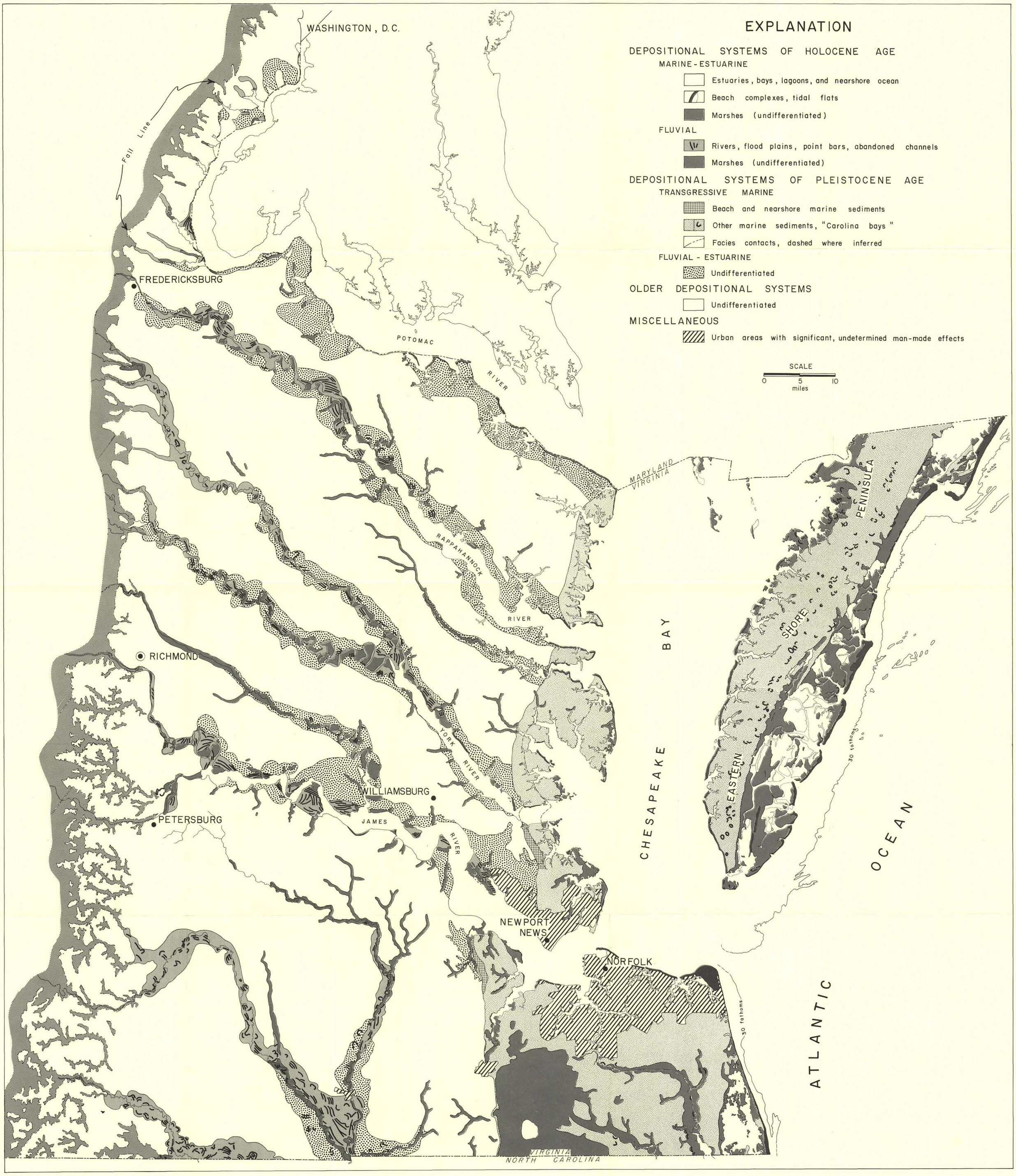

DEPOSITIONAL SYSTEMS MAP
COASTAL PLAIN OF VIRGINIA

By Emil Onuschak, Jr.
1973

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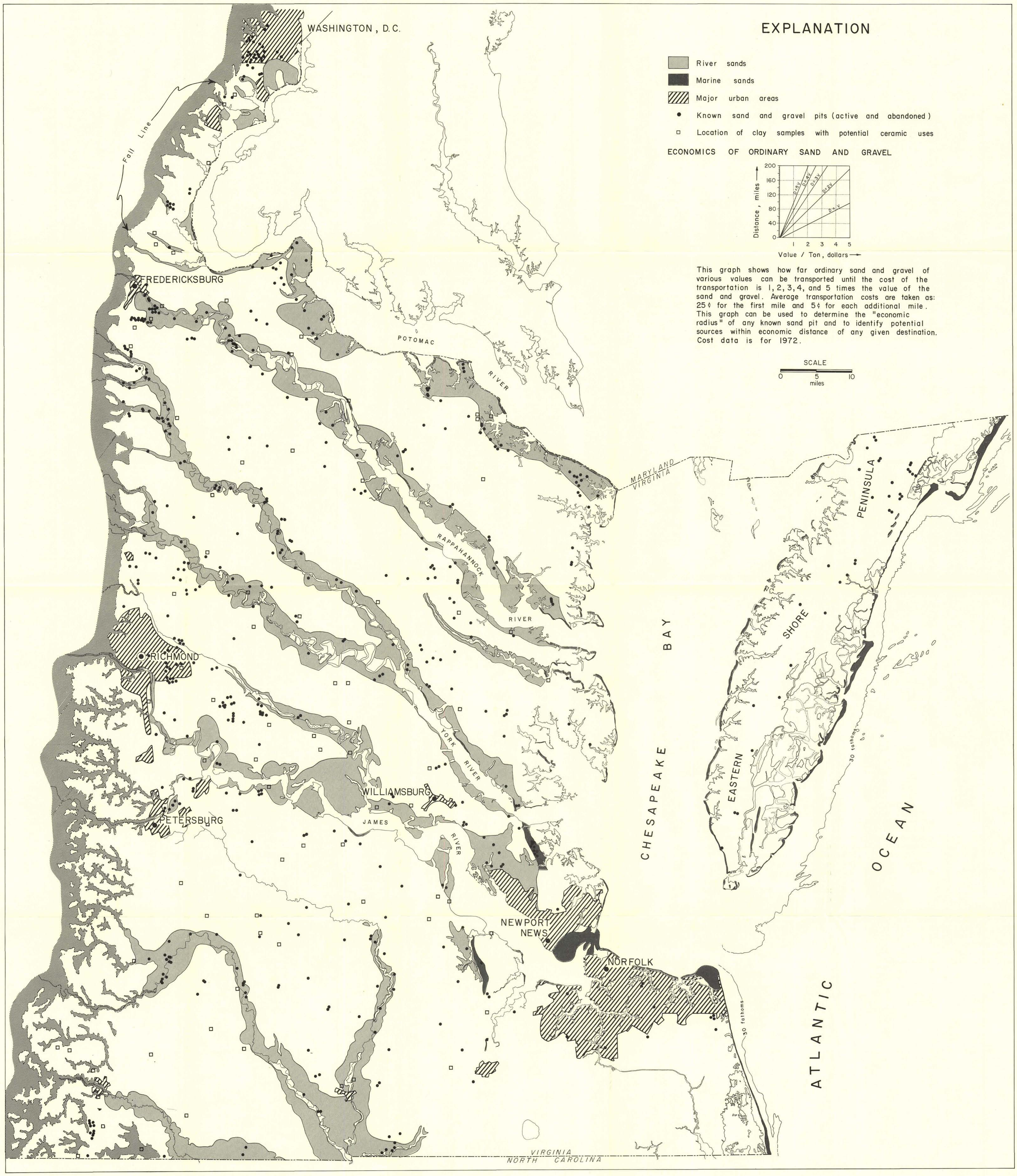

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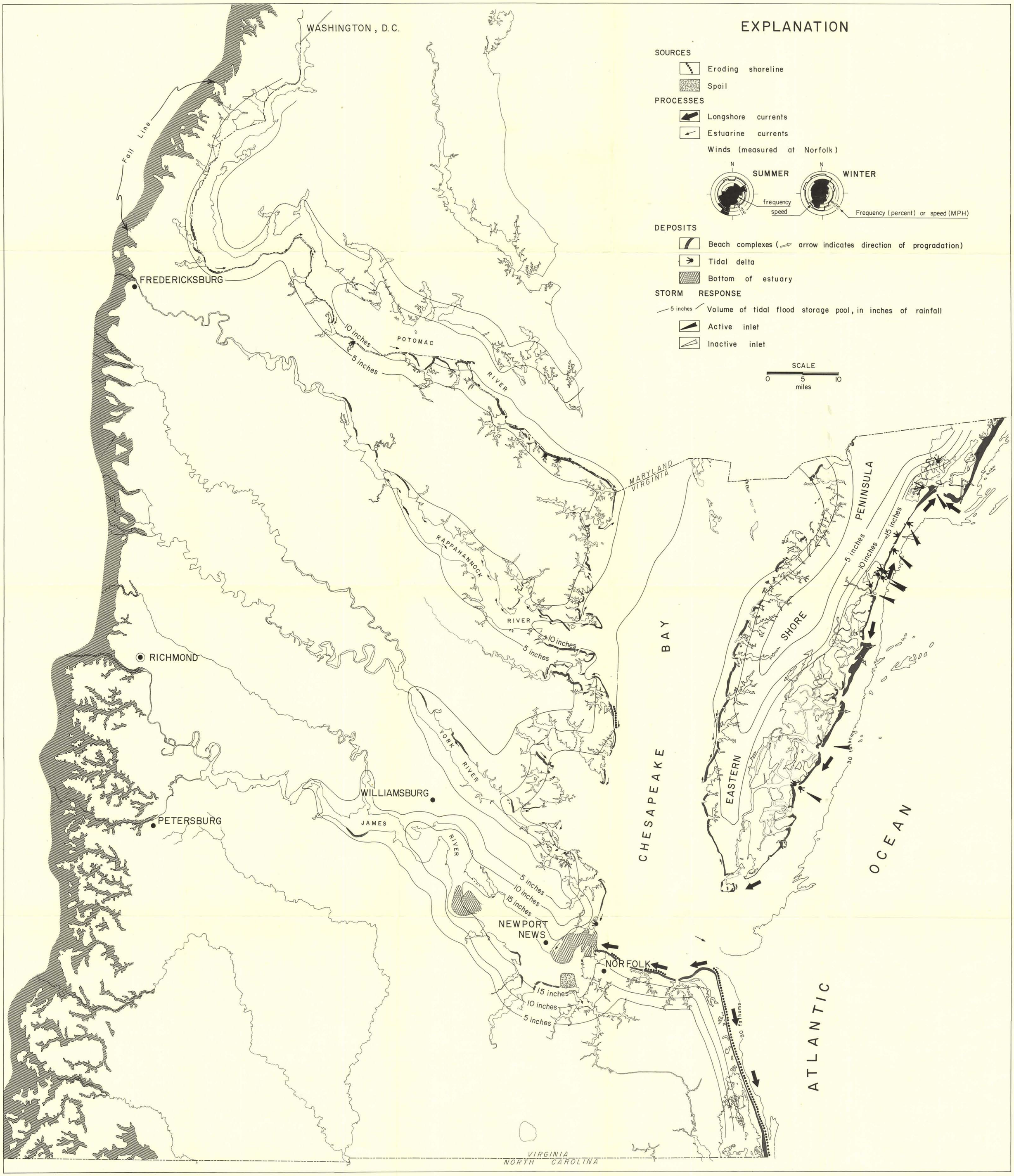

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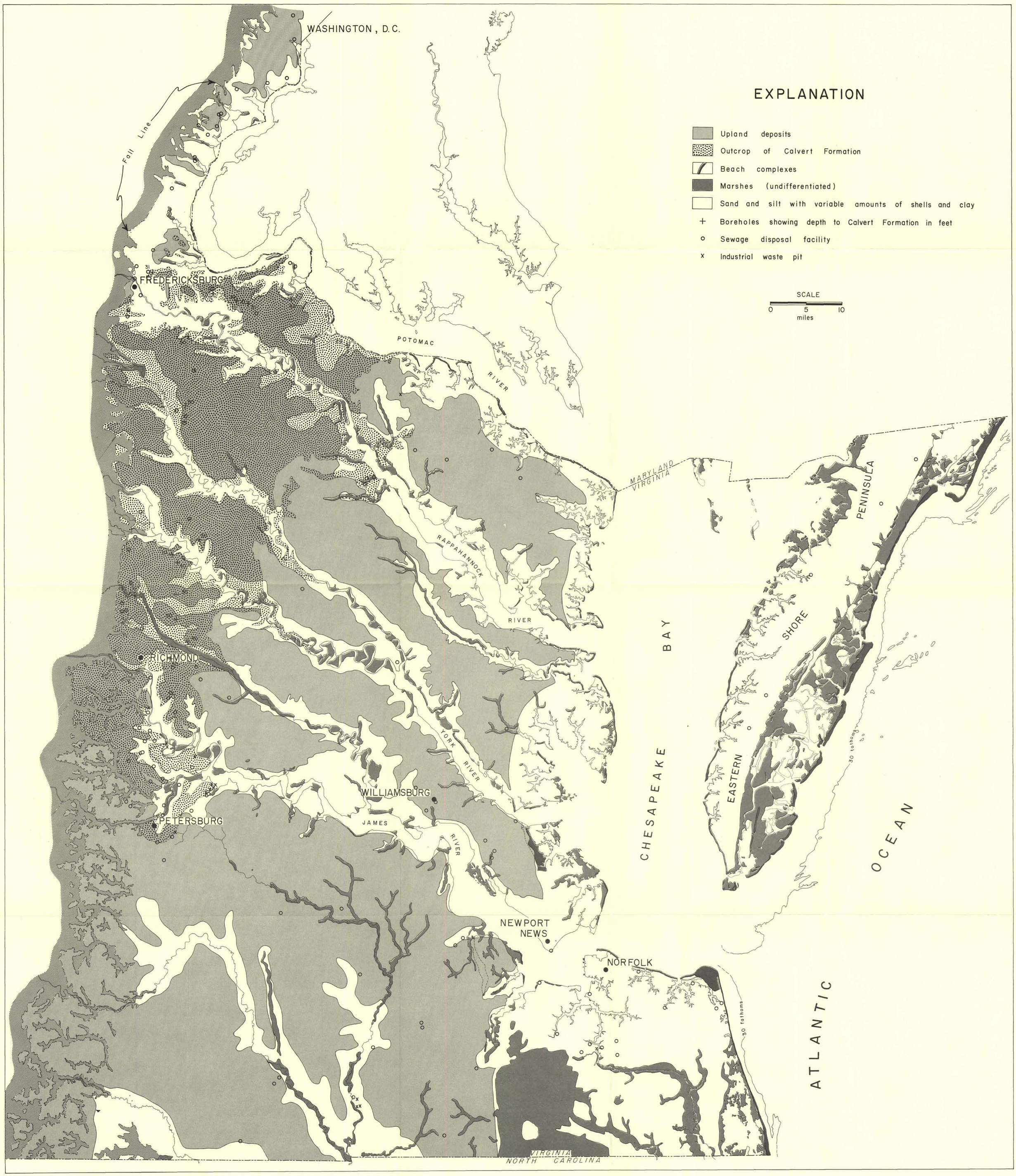

LAND CAPABILITY MAP – SOILS
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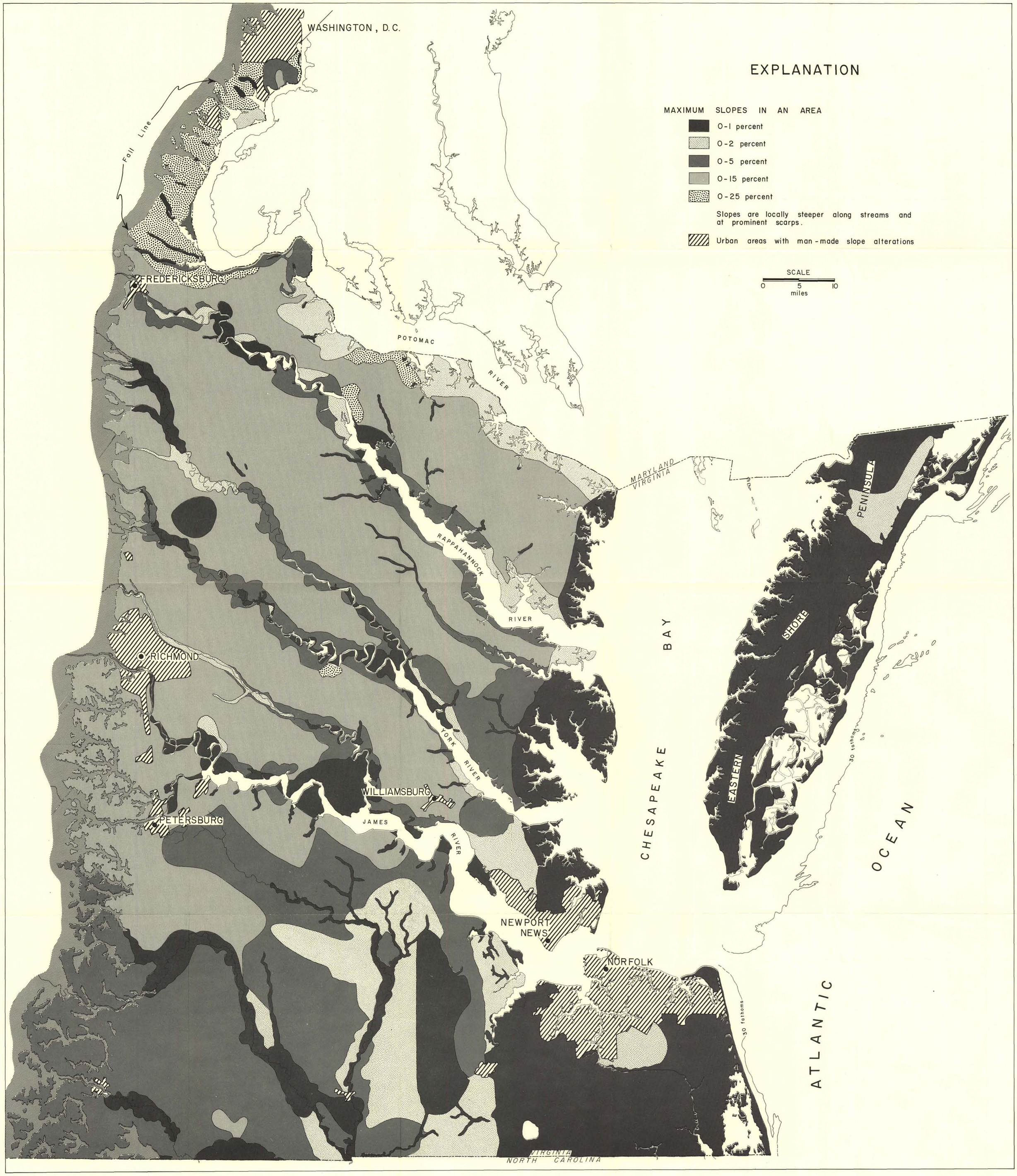

LAND CAPABILITY MAP – SLOPES
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