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

GEOLOGY OF THE STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

PAUL A. DANIELS, JR., and
EMIL ONUSCHAK, JR.

REPORT OF INVESTIGATIONS 38
TEXT

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

CHARLOTTESVILLE, VIRGINIA
1974

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

GEOLOGY OF THE STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

PAUL A. DANIELS, JR., and
EMIL ONUSCHAK, JR.

REPORT OF INVESTIGATIONS 38
TEXT

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

CHARLOTTESVILLE, VIRGINIA
1974

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF PURCHASES AND SUPPLY
RICHMOND
1974

Portions of this publication may be quoted if credit is given to the Virginia Division of Mineral Resources. It is recommended that reference to this report be made in the following form:

Daniels, P. A., Jr., and Onuschak, Emil, Jr., 1974, Geology of the Studley, Yellow Tavern, Richmond, and Seven Pines quadrangles, Virginia: Virginia Division of Mineral Resources Rept. Inv. 38, 75 p.

DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

Richmond, Virginia

MARVIN M. SUTHERLAND, *Director*
JERALD F. MOORE, *Deputy Director*
A. S. RACHAL, JR., *Executive Assistant*

BOARD

WILLIAM H. STANHAGEN, Falls Church, *Chairman*
FREDERICK W. WALKER, Richmond, *Vice Chairman*
D. HENRY ALMOND, Richmond
MAJOR T. BENTON, Suffolk
A. R. DUNNING, Millwood
ARTHUR P. FLIPPO, Doswell
ADOLPH U. HONKALA, Richmond
J. H. JOHNSON, West Point
FREDERIC S. REED, Manakin-Sabot
COLLINS SNYDER, Accomac
SHERMAN WALLACE, Cleveland
E. FLOYD YATES, SR., Powhatan

CONTENTS

	PAGE
Abstract	1
Introduction	1
Methods of study	4
Acknowledgments	6
Stratigraphy	7
"Basement" rocks	9
Paleozoic rocks	14
Petersburg granite	14
Triassic rocks, undivided	15
Cretaceous System	15
Patuxent Formation	15
Cretaceous(?) and Tertiary systems	19
Mattaponi Formation	19
Tertiary System	21
Nanjemoy Formation	21
Clayey silt (transgressive sediments)	21
Tertiary and Quaternary systems	28
Sand and gravel (regressive sediments)	28
Quaternary System	35
Alluvium	35
Structure	36
Economic geology	37
Stone	37
Clay	38
Sand and gravel	38
Ground water	39
Miscellaneous	39
Environmental geology	42
Land capability	42
Flood-prone areas, landforms, and drainage basins	42
"Basement" rocks	44
Patuxent Formation	47
Clayey silt (transgressive sediments)	50
Sand and gravel (regressive sediments)	51
Alluvium	54
References	55

PAGE

Appendix I: Selected geologic logs 57
Appendix II: Geologic summaries 66
Index 74

ILLUSTRATIONS

(Plates are in separate pocket)

PLATE		PAGE
1.	Geologic map of the Studley quadrangle, Virginia	In pocket
2.	Geologic map of the Yellow Tavern quadrangle, Virginia	In pocket
3.	Geologic map of the Richmond quadrangle, Virginia	In pocket
4.	Geologic map of the Seven Pines quadrangle, Virginia	In pocket
4A.	Interpretive sections, Seven Pines quadrangle, Virginia	In pocket
5.	Structure-contour map of the "basement"	In pocket
6.	Generalized depth-to-"basement" map	In pocket
7.	Structure-contour map of the Patuxent Formation	In pocket
8.	Generalized depth-to-Patuxent Formation map	In pocket
9.	Thickness map of the Patuxent Formation	In pocket
10.	Structure-contour map of the clayey silt (Miocene transgressive sediments)	In pocket
11.	Generalized depth-to-clayey silt (Miocene transgressive sediments) map	In pocket
12.	Map showing landforms, flood-prone areas, and watersheds	In pocket
13.	Possible natural-hazards map	In pocket

FIGURE		PAGE
1.	Index map	2
2.	Depositional system	4
3.	Relationship of fluvial, transgressive, and regressive Coastal Plain sediments	8
4.	Composite lithologic and electrical log	12
5.	Tertiary-Quaternary regressive sediments overlying Petersburg granite	13
6.	Relationships of Patuxent deltaic lobes and "basement highs"	18
7.	Basal gravel of Mattaponi Formation	20
8.	Diastem and pebble in Miocene clayey silt unit (transgressive sediments)	22

PAGE

9. Miocene clayey silt unit (transgressive sediments) pinching out against Petersburg granite 23
10. Blotchy mottling in Tertiary-Quaternary sand and gravel unit (regressive sediments) 30
11. Tidal-flat prodelta deposits in Tertiary-Quaternary sand and gravel unit (regressive sediments) 31
12. Mottling in bioturbated sediments, Tertiary-Quaternary sand and gravel unit (regressive sediments) 31
13. Cross-bedded channel fill, Tertiary-Quaternary sand and gravel unit (regressive sediments) 32
14. Iron-manganese-cobalt stringers in cross-beds of the Tertiary-Quaternary sand and gravel unit (regressive sediments) 32
15. Iron-manganese-cobalt laminae of the Tertiary-Quaternary sand and gravel unit (regressive sediments) 33
16. Iron-manganese-cobalt liesegang banding in the Tertiary-Quaternary sand and gravel unit (regressive sediments) 33
17. Deltaic beds of the Tertiary-Quaternary sand and gravel unit (regressive sediments) 34
18. Delta model, Tertiary-Quaternary sand and gravel unit (regressive sediments) 34
19. Aggrading and intersecting stream channel deposits, Tertiary-Quaternary sand and gravel unit (regressive sediments) 35
20. Boulder gravels, Tertiary-Quaternary sand and gravel unit (regressive sediments) 36
21. Unconfined compressive strength of the Petersburg granite as a function of Rock Quality Designator 45
22. Sediment packing, Patuxent Formation 48
23. Sediment packing with filled pore spaces, Patuxent Formation 48
24. Sanitary landfill 51
25. Slumping across the upper contact of the clayey silts 52

TABLES

PAGE

1. Geologic formations in the Studley, Yellow Tavern, Richmond, and Seven Pines quadrangles 10
2. Measured stratigraphic section of Tertiary and Quaternary transgressive and regressive sediments 24
3. Depositional environmental progression 27
4. Potential uses of clay materials from the Studley, Richmond, and Seven Pines quadrangles 40
5. Relationship between Rock Quality Designator, unconfined compressive strength, and average bearing allowable value for bedrock samples from the Richmond area 46

GEOLOGY OF THE STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

By

Paul A. Daniels, Jr., and Emil Onuschak, Jr.

ABSTRACT

The Studley, Yellow Tavern, Richmond, and Seven Pines 7.5-minute quadrangles, Virginia, are located in Hanover, Henrico, and King William counties and the city of Rchmond, almost entirely within the Coastal Plain province but with a small part in the Piedmont province. Stratigraphic units range in age from Paleozoic through Holocene, and include the Paleozoic Petersburg granite, Triassic "red beds," Lower Cretaceous Patuxent Formation, and several Upper Cretoceous (?)-Tertiary-Quaternary sedimentary formations.

Contours on the top of the Paleozoic and Triassic rocks ("basement") show a somewhat irregular surface which has a regional dip at less than 1° to the east. Most irregularities on this surface probably represent paleotopography. Similarly, contours on the top of the younger stratigraphic units show ancient valleys.

Crushed stone, sand and gravel, clay for brick, and molding sand have been produced, although only sand and gravel is currently being quarried. Potential mineral resources include crushed and dimension stone, sand and gravel, clay for tile or face brick, glauconite and shell beds for fertilizer, shell marl for agricultural lime, and diatomaceous earth.

The geology has had and will continue to have a significant impact upon the urban development of Richmond and adjacent areas. If geologic factors are accounted for prior to development there can be decreased social and economic costs, and a reduction of environmental problems.

INTRODUCTION

The Studley (Plate 1), Yellow Tavern (Plate 2), Richmond (Plate 3), and Seven Pines (Plate 4) 7.5-minute quadrangles are located on the western edge of the Coastal Plain province in east-central Virginia (Figure 1). A small part of the area lies in the Piedmont province. The quadrangles include portions of Hanover, Henrico, and King William counties and are bounded by latitudes 37°30′ and 37°45′ N. and longitudes 77°15′ and 77° 30′ W. They encompass a combined area of approximately 237

square miles, which includes Richmond, the state capital (population approximately 250,000 in 1970) and several smaller municipalities: Atlee, Elmont, Mechanicsville, Sandston, Seven Pines, and Studley.

Major highway access is provided by Interstate Highways 64 and 95 and U. S. Highways 1, 33, 60, 250, and 301. Railroad service is provided by the Richmond, Fredericksburg and Potomac Railroad, Chesapeake and Ohio Railway, Seaboard Coast Line Railroad, and Southern Railway. Other access is via the James River and Richmond Municipal Airport (Byrd Field).

The topography is characterized by a broad, moderately dissected upland which regionally has an eastward slope of approximately 9 feet per mile; locally, it has steeper slopes toward the major drainages. Dissection of this upland has created valleys and broad interfluves that comprise about 75 percent of the area. Maximum and minimum elevations, and total relief values for the four quadrangles are as follows:

Quadrangle	*Elevation in feet* *Maximum*	*Minimum*	*Relief in feet* *Total*
Studley	195	0	195
Yellow Tavern	240+	80	160
Richmond	250+	7	243
Seven Pines	200	50	150

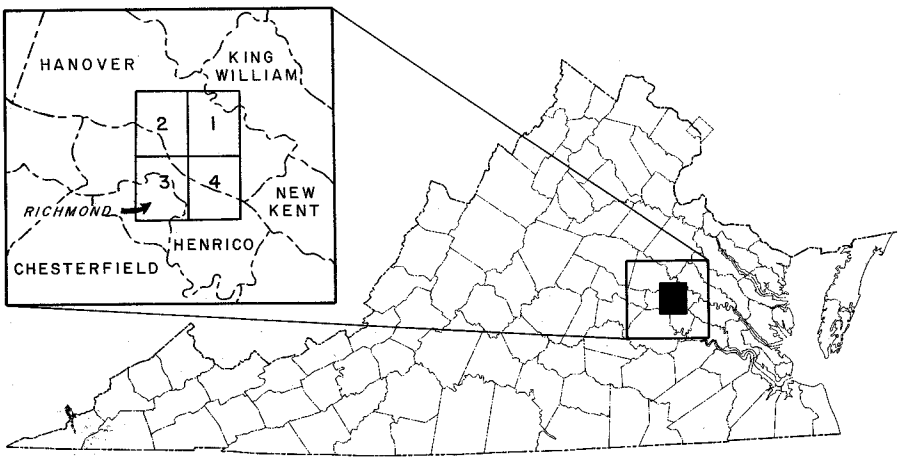


Figure 1. Index map showing location of the Studley (Plate 1), Yellow Tavern (Plate 2), Richmond (Plate 3), and Seven Pines (Plate 4) 7.5-minute quadrangles, Virginia.

The area is drained by the James, Pamunkey, and Chickahominy rivers. Major rapids in the James River (SW ¼ of Richmond quadrangle, Plate 1) prevent further upstream navigation and mark the Fall Line between the Piedmont and Coastal Plain physiographic provinces. The James River is tidal downstream from Mayo's Island and has a mean tidal range of 3.2 feet at Richmond. The southeastward-flowing Chickahominy River divides the mapped area into two land-use categories, urban to the southwest and rural and agricultural to the northeast. Some plain or terrace development is present along the valleys of major rivers. Outcrops along the drainages are few due to colluvial cover, dense vegetation, or soil development.

The purposes of this study are to produce geologic maps to serve as a partial inventory of the physical setting of Richmond and its environs, and to determine if lithostratigraphic units defined in the subsurface (Teifke, 1973) can be correlated with surface outcrops. This report presents information and discussions on how the basic geology influences urban development, construction practices, development of mineral resources, land use, zoning, waste disposal, industrialization, and planning.

Field work was begun in June 1972 and was completed by the senior writer in August 1973. Exposures were examined and two thick stratigraphic sections were measured and described. Most geologic information was from man-made exposures, such as highway and railroad cuts, construction-site and related excavations, reservoir spillways, and other man-made drainageways. Subsurface information was obtained from borings made for water wells and a variety of civil engineering projects. Five additional boreholes reaching "basement" were drilled under contract to the Virginia Division of Mineral Resources. Split-spoon and circulated samples were obtained from most boreholes at 5- and 10-foot intervals. Numbers preceded by the letter "W" (W-1769) designate boreholes of which drill cuttings and copies of lithologic and geophysical logs are on file with the Virginia Division of Mineral Resources.

The most detailed previous study of the entire area is an unpublished thesis by Brown (1939). Darton (1911) described the stratigraphy and economic resources of the Richmond area. Other studies which are pertinent to this paper are by Gernant, Gibson, and Whitmore (1971) who worked on biofacies and paleoenvironmental interpretations of the Miocene and Drobnyk (1965) who made physical descriptions and interpretations of

the Aquia Formation and Marlboro Clay Member. Goodwin (1970) mapped igneous, metamorphic, and Triassic terranes to the west and Weems (written communication, 1973) mapped both Piedmont rocks and Coastal Plain sediments in the Hanover Academy and Ashland quadrangles to the north.

Extensive urban changes have taken place in the Richmond area since those reports. Much of the Shockoe Valley contains fill material (Plate 1, cross section C-C'), as well as extensive excavation for brickyards and construction sites. Thus, many of the surface exposures that were described by previous investigators have been covered or removed. Subsurface information from recent boreholes confirm some conclusions reached by earlier workers.

METHODS OF STUDY

The geologic maps (Plates 1, 2, 3, 4) were prepared using depositional systems as basic map units. A depositional system (Figure 2) is a naturally-occurring, large-scale group of genetically related facies defined by physical characteristics that, in

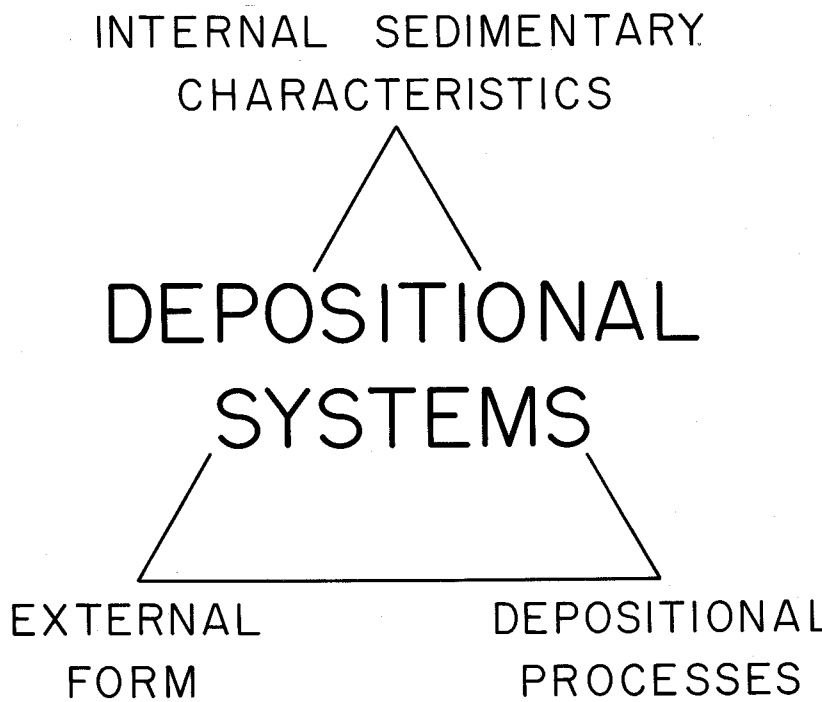


Figure 2. Depositional system defined by physical characteristics.

combination, are distinctive of individual depositional environments and the active processes that prevailed in those environments (Fisher and McGowen, 1967, p. 106). This concept emphasizes the grouping together of physical units, rather than correlating sediments of the same "age." Depositional systems, using physical parameters as a basis, was of particular advantage in mapping sediments of Miocene and younger age. (For more information on the delineation and mapping of depositional systems in the Coastal Plain of Virginia, see Onuschak, 1973.)

Stratigraphic test borings were selected for study by means of the following criteria: (1) confirmed accuracy of well location and elevation, (2) geographic distribution, (3) total depth, and (4) completeness and quality of information available. The boreholes that were used include 162 engineering test borings, 76 public water wells, and 5 Virginia Division of Mineral Resources test borings. These 243 boreholes were finally selected from an initial total of several hundred. Most of the water-well samples were submitted by two drilling firms—Sydnor Hydrodynamics, Inc. of Richmond and Mitchell's Well and Pump Company of Colonial Heights. Sampling interval for most of the water wells was 10 feet. Virginia Division of Mineral Resources stratigraphic test borings were drilled by the H and E Corporation of Richmond. The tests had split-spoon cores and cuttings samples collected at depth intervals averaging 5 feet from the surface to "basement."

Laboratory studies included grain-size analyses, microscopic examination, and x-ray diffraction. Lithologic logs of water-well samples were compiled and sample descriptions were prepared on examination of washed and unwashed materials with the binocular microscope. The petrographic microscope was used to verify the suspected presence of diatoms. Sulfates, phosphates, iron oxides and hydroxides, and dolomite were identified in some instances by combinations of optical and x-ray diffraction techniques (Teifke, 1973, p. 7). X-ray diffraction was primarily utilized for the identification of clay minerals. Complete grain-size analyses, sieve and pipette, were conducted on 37 samples.

In areas where surface exposures are sparse the location of surface geologic contacts was inferred by projecting the elevation of the appropriate geologic contact from nearby boreholes. Also, the geologic maps (Plates 1-4) were compared with existing soils surveys and a close correlation was found. The geologic maps prepared in this manner are *interpretations* of basic data.

It should be kept in mind that the interpretations presented in the maps and other illustrations are valid at the scales at which they are presented. Enlargement of the maps without further field investigations constitutes an over-extension of the data upon which the interpretations are based and inaccuracies will result. Maps in this report are useful as planning tools and as guides to areas where further studies would be essential for a particular type of resource development and *are not* a substitute for local, detailed site analysis.

Subsurface information was compiled into maps having lines of equal numeric value (e.g., elevation, thickness, depth, . . .) related to an arbitrary datum (e.g., sea level, ground surface, . . .). These maps allow the user to infer subsurface characteristics.

Three subsurface structure-contour maps (Plates 5, 7, 10) were drawn and four isochore (including three "depth to") maps (Plates 6, 8, 9, 11) were constructed from borehole data. Convergence maps of sediment thickness (LeRoy and Low, 1954, p. 207-209) were constructed. Eight cross sections (Plates 1, 2, 3, 4A) were prepared at the same horizontal scale as the geologic maps but with a vertical exaggeration of 20x to allow portrayal of thin units.

Subsurface data can be generally classified into two categories: (1) "hard" data based on actual penetrations of the geologic units in question, and (2) convergence data that is generated through the combination of two or more preexisting map interpretations. Maps generated using convergence techniques should be considered at least one order removed from the reliability of map interpretations generated from "hard" data.

ACKNOWLEDGMENTS

The assistance of the following individuals and organizations is acknowledged. Bruce K. Goodwin, Department of Geology, College of William and Mary assisted in resolution of stratigraphic problems along common mapping borders. Fred May, John M. Wunder, and James S. Brown, Jr., assisted with field and laboratory work. Subsurface information and drilling records were obtained from Page Herbert, Herbert and Associates, Ltd., Virginia Beach; Thomas Rogers, Virginia Electric and Power Company, Richmond; A. A. Elliott, H and E Corporation, Richmond; Howard R. Freeland, Virginia Department of Highways,

Richmond; William A. McKay, Virginia Department of Highways, Colonial Heights; and Clement Tingley, Department of Public Works, Richmond. U. S. Soil Conservation Service county soils agents Kenton Inglis, Henrico County; W. E. Cummins, Hanover County; and George J. Chudoba, Chesterfield County (Mathews, 1970) contributed soils information and advice as to its interpretation. Robert L. Hodges, Virginia Polytechnic Institute and State University Extension Service, provided valuable guidance in the field on the distribution of selected soil materials in Hanover County. Some quantitative subsurface information for the Richmond quadrangle included in this report was originally compiled by A. C. Munyan and W. H. Vogelsang for the Virginia Division of Mineral Resources (contract report, 1973).

STRATIGRAPHY

"Basement" rocks similar to those presently exposed to the west in the Piedmont Province underlie the wedge of Coastal Plain sediments in the study area. Igneous and metamorphic rocks of Paleozoic age (granite, monzonite, biotite gneiss, ultramafic intrusive) and consolidated sedimentary rocks of possible Triassic age, which contain "red beds," are present.

The preserved stratigraphic section of Coastal Plain sediments changes upward from the fluvial depositional system through estuarine/marine and back to fluvial again (Figure 3). Deposition of sediments was dominated by fluvial processes throughout the Lower Cretaceous Epoch. The fluvial depositional system (Patuxent Formation) contains sediments that are generally brightly colored and are heterogeneous in character and extent. Coarse, clastic sediments of the Patuxent Formation were probably laid down in prograding deltas where ancient drainages emptied into shallow-water bodies. As centers of deposition shifted laterally and seaward through time, and the sediments were reworked by marine processes, the distribution of Patuxent sediments began to take on the external geometric character of a wedge which has a dip and becomes thicker eastward from its Piedmont source.

Deposition of sediments was dominated by marine and estuarine processes throughout the early and middle Tertiary Period. The estuarine and marine depositional systems in the study area produced sediments that are generally of drab colors, laterally and vertically homogeneous, and are well sorted texturally.

Overlying the Patuxent Formation is the Mattaponi Formation. This unit is the result of a widespread marine transgression that deposited sediments in the Richmond area during the Paleocene and Eocene epochs. Aside from a basal gravel (Teifke, 1973, p. 19), the unit consists of a clayey, drab-colored, quartz-glauconite sand. Its upper surface is an erosional unconformity.

Later, during Eocene time, another marine transgression deposited the Nanjemoy Formation. Similar to the Mattaponi Formation lithologically, this "greensand" is very clayey and glauconitic. Its upper surface is topped by an erosional unconformity.

In middle Miocene time, another marine transgression occurred that deposited sediments which have previously been called the "Miocene marl" (A. C. Munyan and W. H. Vogelsang, contract report, 1973) and the Calvert Formation (Darton, 1911), and may also contain sediments of the St. Marys Formation. These transgressive sediments differ from the Nanjemoy and Mattaponi formations in generally not being glauconitic and in not having an erosional unconformity at their upper surface in all areas. It is composed of drab gray, green, and blue clayey sands and silts.

As the sea withdrew eastward, sedimentation in the Rich-

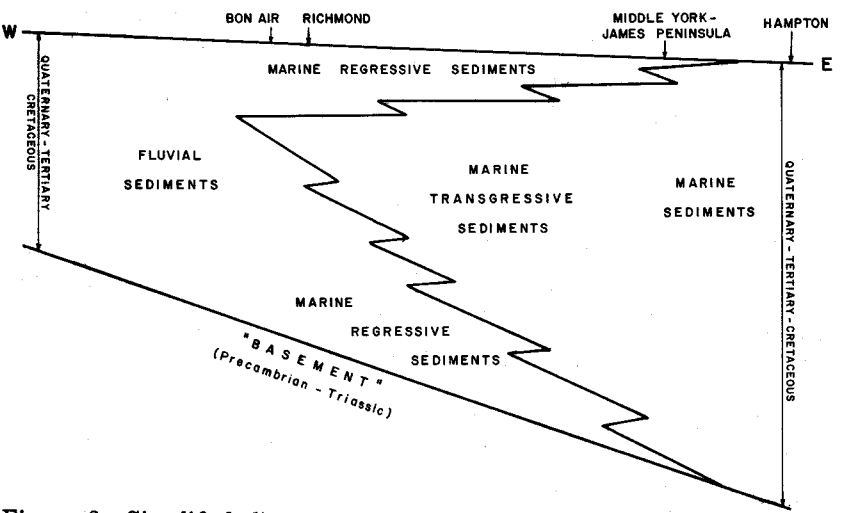


Figure 3. Simplified diagram showing the relationship of fluvial, transgressive, and regressive Coastal Plain sediments in Virginia.

mond area was again dominated by the fluvial depositional system and the Tertiary-Quaternary regressive sediments were deposited. In previous literature these sediments have been referred to as the Columbia Group, Brandywine Formation, and Lafayette Formation. The post-Miocene regressive sediments consist largely of terrigenous, clastic materials. The regressive phase probably began in the Richmond area in late Miocene time and is continuing through Holocene time. Since the close of Miocene time, this continuum has been one of degradation, that is, the reworking and redistribution of regressive sediments to form late Tertiary and Quaternary alluvium.

Upland gravels of Tertiary age have been described and mapped west of the study area by Goodwin (1970, p. 19-23). These gravels are in part fluvial, but probably also include residual lag deposits. Similar materials of iron-stained pebble to cobble gravel with abundant brownish-red clay matrix of Tertiary age is mapped at one locality only (Willow Lawn Shopping Center, along the extreme western border of the Richmond quadrangle, Plate 3). Because of its limited extent and maximum thickness of about 2 feet, the gravel is not discussed further in this report.

A generalized description of the units delineated in the study area as related to Teifke's (1973) regional study of the Coastal Plain is presented in Table 1. Figure 4 is a composite subsurface log showing typical electrical responses and lithology of the units which comprise the sedimentary column in the Richmond area.

"BASEMENT" ROCKS

Rocks that underlie the sedimentary section (Cretaceous through Quaternary systems) are referred to as the "basement." In this report, "basement" is defined as consisting of the Petersburg granite of Paleozoic age, semi-indurated "red beds" of Triassic age, and derived saprolites. Upon these rock types the Coastal Plain sediments were unconformably deposited.

The Petersburg granite of Paleozoic age (Goodwin, 1970), including gneissic facies, is the oldest unit. Under the Coastal Plain near Sandston semi-indurated "red beds" and associated rocks of Triassic age were encountered in boreholes. The presence of Triassic rocks has been recognized (Goodwin, 1970) in the nearby Piedmont Province just west of Richmond (approximately 12 miles west of Sandston). These younger rocks probably occur in structural (downfaulted or downwarped) and/or

Table 1.— Geologic formations in the Studley, Yellow Tavern, Richmond, and Seven

Age	Series	Name: Teifke (1973)	Name: this report
Quaternary	Pliocene-Holocene	Columbia Group	Alluvium
			Sand and gravel (regressive sediments)
Tertiary	?—?	Yorktown Formation	(absent)
	Miocene	Calvert Formation	Clayey silts (transgressive sediments)
			(absent)
	Eocene	Nanjemoy Formation	Nanjemoy Formation
			Marlboro Clay Member
	Paleocene	Mattaponi Formation	Mattaponi Formation
?—? Cretaceous(?) ?—?	?—? Upper(?)		? (absent)
Cretaceous	Lower	"transitional beds"	(absent)
		Patuxent Formation	Patuxent Formation
Precambrian-Triassic		"basement"	"basement"

Pines quadrangles.

Character
Organic and poorly sorted fluvial sediments ranging from clay to gravel.
Light- to bright-colored oxidized sediments, mainly sands and gravels, some clay; dominantly fluvial.
Drab gray, bluish-gray, and greenish-gray silts, clays, and silty clays; commonly well consolidated. Some plant fragments; mollusks common to locally abundant in shell beds. Minor glauconite. Diatomaceous silty clays and *Siphogenerina* near base. Coarse, well-sorted, quartzo-phosphatic, subrounded, locally fossiliferous basal sand.
Quartz-glauconite sands and clayey silts; shell beds common. May be capped by thin limestone. Large concretions common. Simple, nonintricate glauconite forms predominate; commonly weathered.
Light-gray to pink clay; generally pure or with glauconite interlaminations.
Drab glauconitic clays and quartz-glauconite sands; thin shell beds and limestones common. Glauconite forms are lobate, intricate, and unweathered.
Basal gravel with some phosphatic boulders. Mainly medium- to coarse-grained gravels. Light brown to cream in outcrop; light gray to white in subsurface. Feldspathic. Slickensided clay balls common. Interbeds of red, purple, gray, green, and yellow.
Igneous and metamorphic rocks of Paleozoic age; partly consolidated sediments of Triassic(?) age.

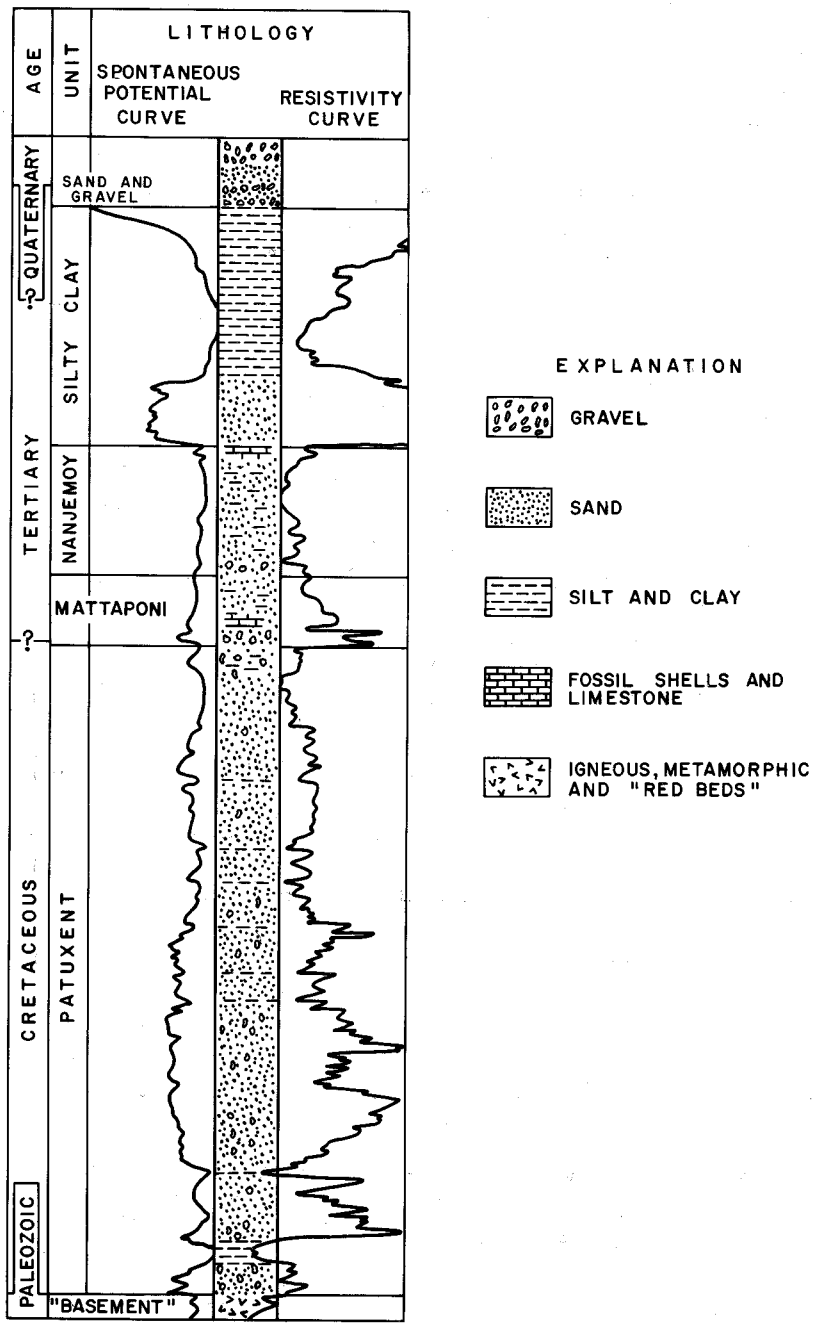


Figure 4. Composite lithologic and electrical log of the Coastal Plain sediments.

topographic lows and their contact with the older rocks is unconformable.

At most localities, particularly in "red bed" areas, "basement" rocks are overlain by the Cretaceous Patuxent Formation. Near the Fall Line the Petersburg is unconformably overlain by Miocene marine transgressive sediments or younger Tertiary-Quaternary regressive sediments (Figure 5).

The thickness of the sediments which overlie the "basement" are shown on Plate 6. Relatively thin areas of sediment can be categorized two ways: (1) primary, due to "basement" highs; and (2) secondary, due to present topographic lows. An example of the former occurs over the "basement" high near Mechanicsville in the SW quarter of the Yellow Tavern and NW quarter of the Richmond quadrangles, and in the east-central Seven Pines quadrangle. Relatively thin areas of sediment due to topographic lows are typified by those along the Chickahominy River, Campbell Creek, Totopotomy Creek, and Pamunkey River. Sediment thicknesses shown on Plate 6 in the area between the last contour (50 feet) and "basement" outcrop (zone of zero overburden) are highly variable. Erratic values, therefore, should be considered characteristic.

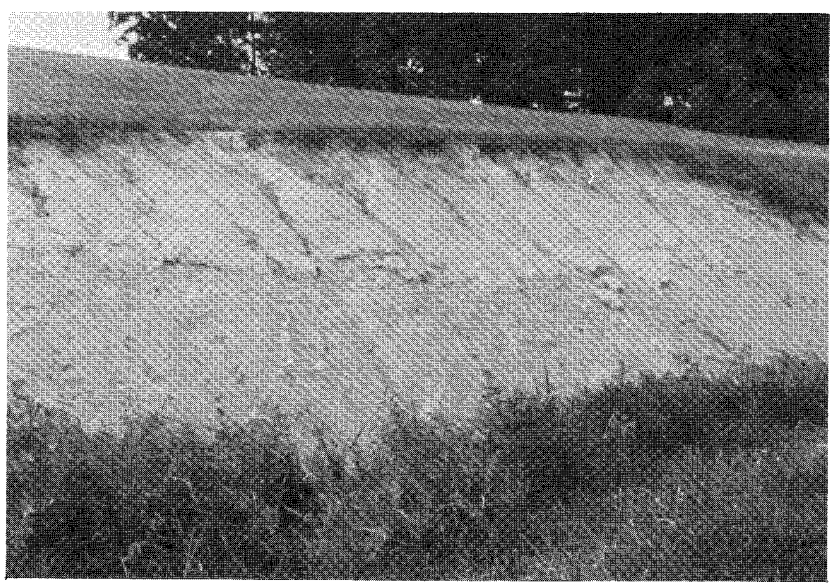


Figure 5. Tertiary-Quaternary regressive sediments overlying Petersburg granite along Parham Road, Richmond quadrangle (Plate 3).

topographic lows and their contact with the older rocks is unconformable.

At most localities, particularly in "red bed" areas, "basement" rocks are overlain by the Cretaceous Patuxent Formation. Near the Fall Line the Petersburg is unconformably overlain by Miocene marine transgressive sediments or younger Tertiary-Quaternary regressive sediments (Figure 5).

The thickness of the sediments which overlie the "basement" are shown on Plate 6. Relatively thin areas of sediment can be categorized two ways: (1) primary, due to "basement" highs; and (2) secondary, due to present topographic lows. An example of the former occurs over the "basement" high near Mechanicsville in the SW quarter of the Yellow Tavern and NW quarter of the Richmond quadrangles, and in the east-central Seven Pines quadrangle. Relatively thin areas of sediment due to topographic lows are typified by those along the Chickahominy River, Campbell Creek, Totopotomy Creek, and Pamunkey River. Sediment thicknesses shown on Plate 6 in the area between the last contour (50 feet) and "basement" outcrop (zone of zero overburden) are highly variable. Erratic values, therefore, should be considered characteristic.

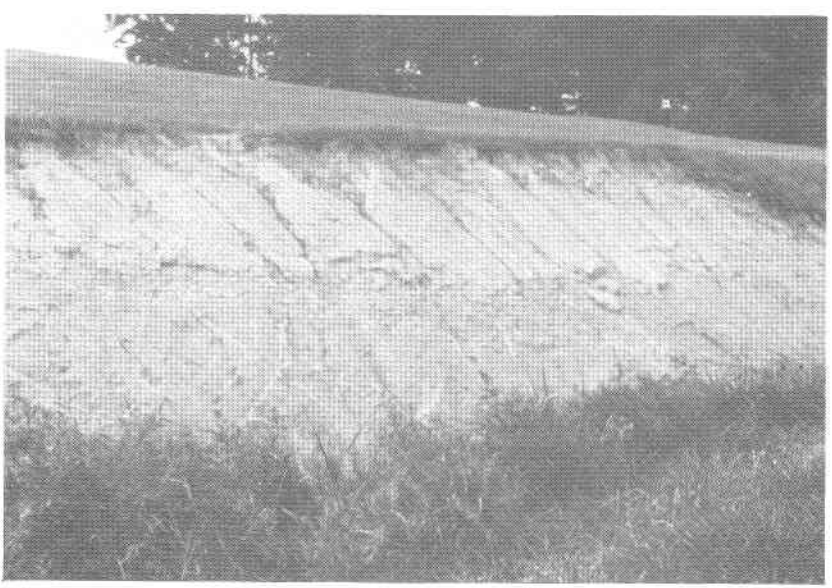


Figure 5. Tertiary-Quaternary regressive sediments overlying Petersburg granite along Parham Road, Richmond quadrangle (Plate 3).

PALEOZOIC ROCKS

Petersburg Granite

The "basement" consists mostly of the Petersburg granite, which is granitic igneous and metamorphic rocks or a derived saprolite. Exposures of the Petersburg are restricted to the western quarter of the mapped area (Plates 2, 3) and primarily occur in drainages (e.g. North Run, Plate 2; Chickahominy River, Plate 2; Upham Brook, Plate 3; James River, Plate 3). Along North Run at the Lakewood Country Club, a porphyritic, pink-granite phase of the Petersburg granite crops out only along the west side of the stream. A few other exposures occur as inliers (e.g., Joseph Bryan Park, Plate 3), which are restricted primarily to the Richmond quadrangle where granite outcrops are present at higher elevations than in other parts of the study area, particularly south of the James River.

Observed joints in the Petersburg either have a steep dip or are horizontal. The nearly vertical joints have either a northerly or easterly trend.

The Petersburg granite has several facies, the most prevalent being a porphyritic orthoclase granite (North Run area, Plate 3), quartz monzonite, and quartz-biotite gneiss (French Hay area, Plate 2). The granite is generally uniform and without foliation, medium-grained, and pink to gray. The gneiss has good to excellent foliation with some compositional bands (biotite) exceeding one-quarter inch in thickness, quartz, and medium to coarse feldspar grains.

The Petersburg granite weathers to a saprolite which commonly is red, iron-stained, clayey, medium-grained sand. In its most weathered form it may contain no identifiable structures and is therefore very difficult to distinguish from some regressive sediments that have been transported for only a short distance ("granite wash"). The saprolite is interpreted as a major source from which the Coastal Plain sediments were derived. The "basement" rocks, particularly the Petersburg granite, mineralogically represent both the adequate and nearby source of quartz and potassic feldspar that would have been required to supply the quartzo-feldspathic sediments found in the study area. The saprolites represent a plausible source of iron, the presence of which is evidenced by extensive iron-oxide mottling.

Although highly fractured in some areas (borings for the Ninth Street Bridge found considerable variance in rock integ-

rity), the Petersburg granite provides the most stable foundation for construction as compared to the sedimentary portion of the stratigraphic section. This unit supports most of the heaviest buildings in the Richmond metropolitan area. Depth to "basement" locally may vary at a construction site by up to 20 feet or more (A. C. Munyan and W. H. Vogelsang, contract report, 1973), probably a result of uneven weathering. The only sure method of locally determining depth to, and integrity of, bedrock is by an adequate rock-coring program.

TRIASSIC ROCKS, UNDIVIDED

Where the Petersburg granite is not encountered, partly consolidated "red beds" of Triassic age underlie the Patuxent Formation. The Triassic rocks do not crop out at the surface; however, several boreholes penetrated them (Plate 4A, Appendices 1 and 2). The distribution of these rocks appears to be restricted to the eastern third of the mapped area.

The Triassic "red beds" are heterogeneous and indurated when compared to the younger, overlying Patuxent Formation. They are well indurated as shown by drilling times of 8 minutes per foot in the 250- to 400-foot range. (Equipment used to achieve these drilling rates on stratigraphic test W-3903 included a Failing 1250 hydraulic rotary drilling rig equipped with a tricone rotary drill bit under 75 to 100 lbs pressure.) For comparison, granitic saprolites of the Petersburg granite drill at 4 to 8 minutes per foot.

The sediments are mixed sandstones and mudstones. The mudstones appear to have some incipient fissility. Hematitic staining is prevalent with some minor cementation. Degree of decomposition varies greatly. Sorting is very poor, yielding a low order of textural maturity (Folk, 1965, p. 102). X-ray diffraction of cutting samples (W-2683, 510- to 540-foot depth) indicates the presence of quartz, illite, calcite, potassic feldspar (trace), and plagioclase(?). Although generally red in color, these sediments include interbedded clay layers of yellow, purple, gray, and green.

CRETACEOUS SYSTEM

PATUXENT FORMATION

The Patuxent Formation of Lower Cretaceous age unconformably overlies the "basement" rocks and is unconformably

overlain by Upper Cretaceous(?) and Tertiary sediments. The Patuxent is absent in the western part of the area and is more than 400 feet thick along the eastern margin (Plate 8). It is exposed along the James River, Gillie Creek, and Almond Creek (Plate 3).

The Patuxent consists primarily of coarse, feldspathic fluvial sands and gravels with subordinate interbedded fluvial or lacustrine clays. The detrital grains vary from light brown to tan to buff in outcrop and light gray to cream in the subsurface. Interbeds of clay are generally yellowish tan, light gray, and pale green; others, ranging from red to purple, gray, green, and yellow, are present in some places, but are probably restricted to areas where the sediment supply was derived from Triassic terranes. Matrix usually consists of whitish kaolinitic clays derived from the weathering of potassic feldspars. Textural maturity is variable owing to the range in depositional environments. The sediments are generally immature compositionally, containing significant amounts of potassic feldspars and rock fragments (subarkose to arkosic arenite). Compositional variation is mainly due to sediment provenance and parent material. Fossils are rare and are represented by fragments of plant varieties characteristic of a warm, wet climatic regime (Glaser, 1969, p. 75). Minor and sporadic glauconite occurrences support hypotheses that the unit had at least some estuarine influences along the margins of some depocenters. The dominance, however, of voids in gravel deposits; coarse, cross-bedded sands; gray, slickensided clay balls; and pebble to boulder gravels is characteristic of a fluvial depositional system with significant bed-load transport, possibly braided streams in an alluvial fan and deltaic plain setting.

Genesis of the Patuxent Formation appears to be related to progradation of deltaic lobes into a nearshore marine environment. Configuration of the top of the Patuxent can be seen in Plate 7. Complications shown in the contour patterns are due to the presence of more than one pattern. Other than primary depositional features (e.g., abandoned channels and deltaic lobes), there is a pattern of postdepositional effects. The latter pattern includes incision by younger streams (e.g., Gillie Creek and Almond Creek) and erosion between the Fall Line and the updip limits of the formation where material has been removed and/or reworked as part of younger marine transgression or regression.

Some sand-rich channel fills form structurally high areas that are digitate in outline. These highs result, in part, from

differential compaction of texturally heterogeneous sediments. In other words, as sediment continued to accumulate, the coarse-grained materials were compacted the least. This phenomena would be particularly evident in areas where deltaic lobes extend into low areas around "basement" highs (Figure 6, Plate 7). In such relationship the coarsest sediments would be transported in the highest flow regimen (generally as bed-load in a channel) into a topographic low whereas finer sediment would be winnowed toward areas of lower energy away from the major axis of flow. As topographic lows are filled, the higher areas are subsequently buried. The deposition of finer materials along the flanks of the deltaic lobes will enhance the formation of mud flats over the highs. Sediment compaction due to burial and/or desiccation will cause the deposits with a high percentage of fine materials to have the greatest loss of volume. A map of Patuxent thickness (Plate 8) will then depict a relatively thin sediment over the area where mainly fine sediment was deposited. Other types of interlobate areas will have a similar response.

The abandoned channel centrally located in the Seven Pines quadrangle on Plate 7 probably represents the drainageway that fed sediment to the central sediment lobe. The early existence of this channel is illustrated by a westward deflection in the contour patterns on the top of the "basement" for the Richmond area (Plate 5), as is the sediment-filled channel to the south which aligns with the James River. Both of these channels therefore are relatively older than the Patuxent drainage along the north portion of the Seven Pines quadrangle (Plate 7) where there is no deflection of the "basement" contours (Plate 5). Another feature that is illustrated on the structure-contour map of the Patuxent (Plate 7) is a structural low area corresponding in position to the present valley of the Chickahominy River. This may illustrate a paleodrainageway around the south and west sides of the "basement" high in the Mechanicsville area. Deflections are also present in "basement" structural contour patterns along the same trend.

Plate 8 shows the variation in thickness of the Patuxent Formation. Abandoned channels and interlobate embayments are generally sand-poor and contain a relatively thin stratigraphic section, whereas the lobate areas are sand-rich and thick. An excellent example is the sand-rich thick sediment that fills the "basement" paleochannel for the ancestral James River drainage

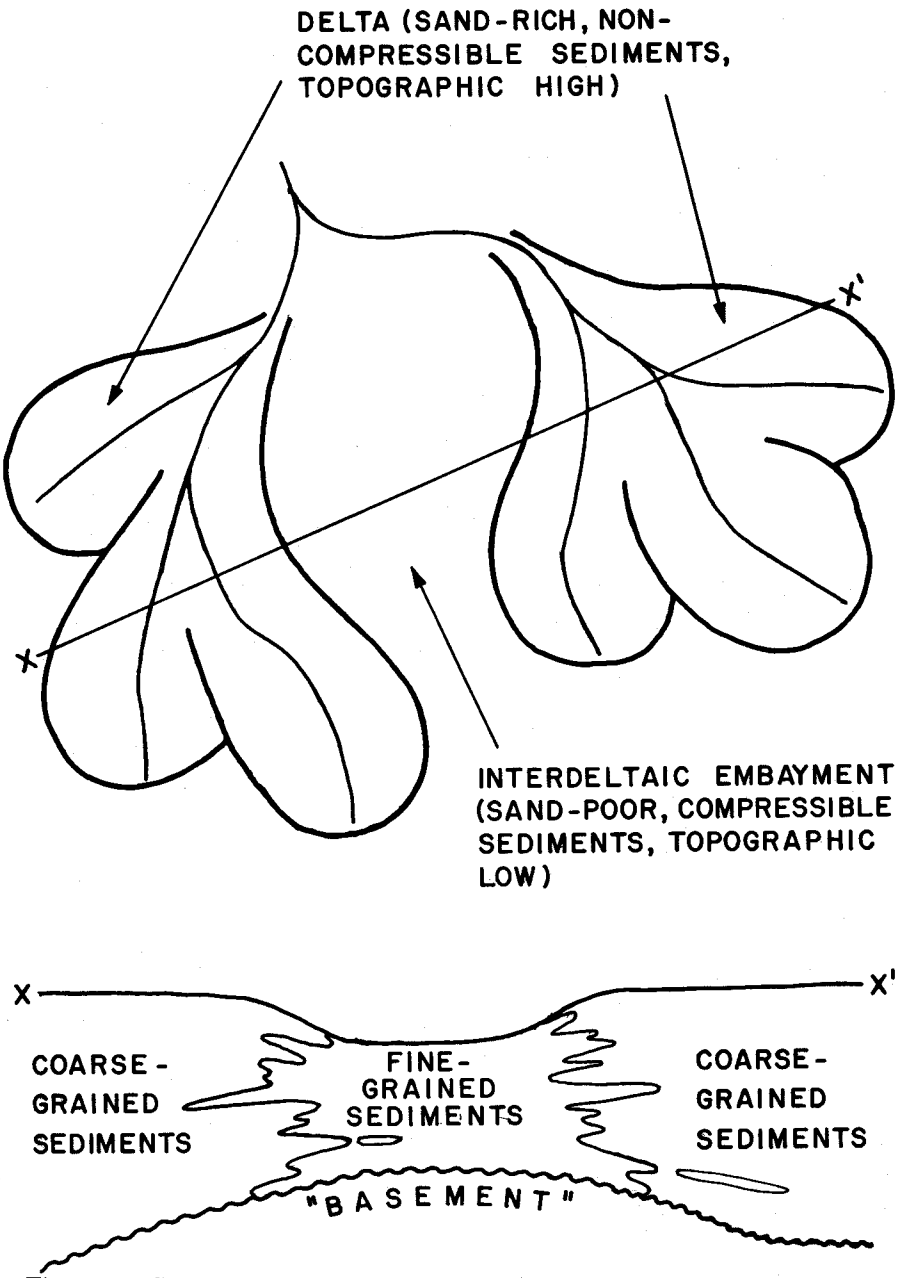


Figure 6. Generalized relationships of Patuxent deltaic lobes and "basement highs."

(Plates 5 and 8). Contrastingly, the abandoned channel across the northern Seven Pines area (Plate 8, SE quarter) is low and thin. This is interpreted as being due to a relatively younger age. Primary deposits are thin over "basement" highs at Mechanicsville and in the central Seven Pines area.

Another feature observed on the Patuxent thickness map (Plate 8) is a wide, flat area in the eastern half of the Yellow Tavern quadrangle (NW quarter) which could be either a primary or secondary feature. If it was formed by meandering streams (primary), for example, sand-rich areas of relatively constant thickness and lateral continuity could be expected. In the Seven Pines quadrangle (Plate 8, SE quarter), there appears to be a relatively thick area along a dip-reversal trend.

CRETACEOUS (?) AND TERTIARY SYSTEMS

MATTAPONI FORMATION

The Mattaponi Formation of Upper Cretaceous (?), Paleocene, and Eocene age overlies the Patuxent Formation; the contact is marked by an erosional unconformity representing a considerable time span. The upper surface of the Mattaponi Formation is also an erosional unconformity. The overlying unit is the Nanjemoy Formation, the Marlboro Clay Member, or the clayey silt unit (transgressive sediments). The Mattaponi pinches out to the west against the underlying Patuxent Formation in the western portions of the Richmond and Yellow Tavern quadrangles.

Mattaponi, Nanjemoy, and Aquia are all formation names that have been applied to greenish-gray, glauconitic, silty sands in the Coastal Plain of Virginia. The Mattaponi has been used in previous publications mainly as a subsurface term, the Nanjemoy for both surface and subsurface, and the Aquia almost exclusively for outcrops. In this report the surface exposures of the Mattaponi and Nanjemoy Formations are mapped as a single, undifferentiated unit. These formations are also mapped as undifferentiated in the subsurface when stratigraphic separation by the intervening Marlboro Clay Member was not detected.

The Mattaponi Formation consists of drab gray and green, very glauconitic, clayey silt to fine sand. Near the base of this unit a fossiliferous layer commonly occurs. Whether or not the shell detritus is present, a green-stained (glauconite) basal gravel is usually present (Figure 7). The fossiliferous layer and

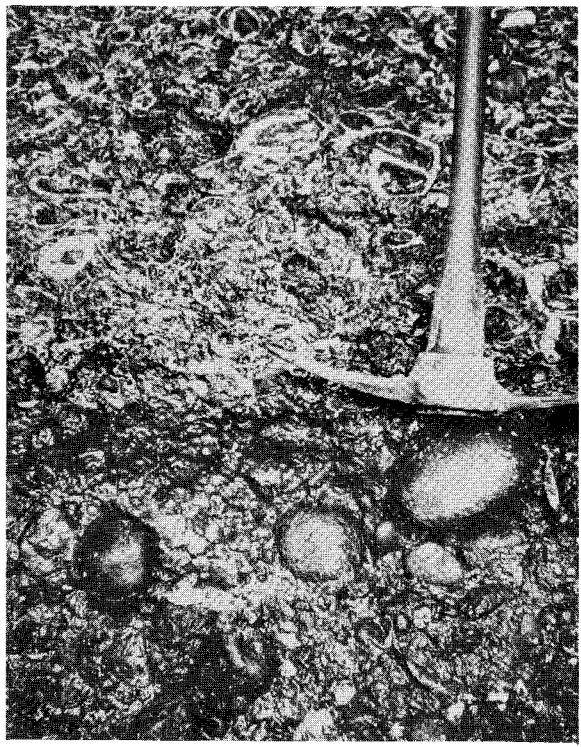


Figure 7. Basal gravel of Mattaponi Formation along Pamunkey River about 0.5 mile east of Wickham Crossing, Ashland 7.5-minute quadrangle.

the basal gravel make possible excellent correlations of the Mattaponi Formation between surface and subsurface points. The gravel layer contains clasts up to boulder sizes and is of variable thickness. It probably represents high-energy nearshore conditions with the coarse sediment possibly derived from the underlying fluvial sequence (Patuxent Formation) as the Mattaponi marine transgression continued. Figure 7 shows both the basal gravel and the overlying shell bed. The shell bed probably represents somewhat deeper water (neritic?) conditions. Thin limestones are common. The glauconite in the Mattaponi is generally silt to medium sand and light to very dark green. Glauconite forms tend to be botryoidal, intricate, and unweathered, which are characteristics of no significant exposure time for oxidation or abrasion due to transportation. In zones of abundant glauconite concentration quartz is subordinate.

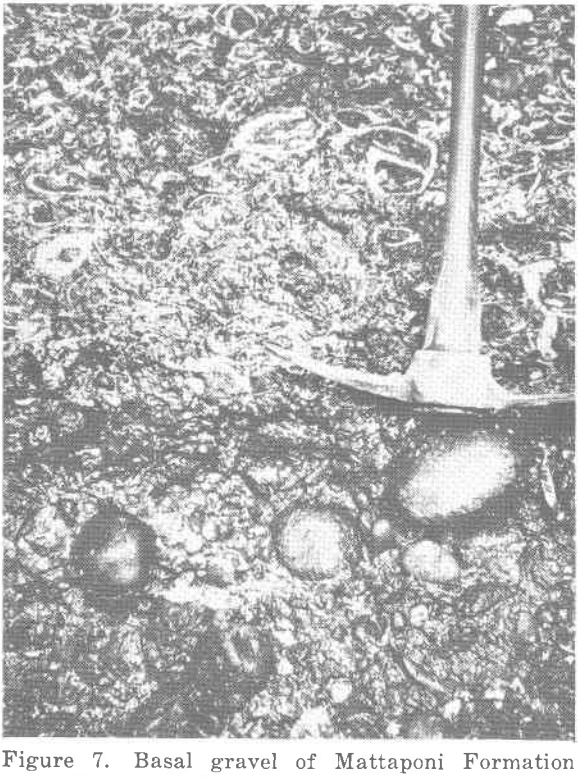


Figure 7. Basal gravel of Mattaponi Formation along Pamunkey River about 0.5 mile east of Wickham Crossing, Ashland 7.5-minute quadrangle.

the basal gravel make possible excellent correlations of the Mattaponi Formation between surface and subsurface points. The gravel layer contains clasts up to boulder sizes and is of variable thickness. It probably represents high-energy nearshore conditions with the coarse sediment possibly derived from the underlying fluvial sequence (Patuxent Formation) as the Mattaponi marine transgression continued. Figure 7 shows both the basal gravel and the overlying shell bed. The shell bed probably represents somewhat deeper water (neritic?) conditions. Thin limestones are common. The glauconite in the Mattaponi is generally silt to medium sand and light to very dark green. Glauconite forms tend to be botryoidal, intricate, and unweathered, which are characteristics of no significant exposure time for oxidation or abrasion due to transportation. In zones of abundant glauconite concentration quartz is subordinate.

The maximum thickness (70 feet) of the Mattaponi Formation was penetrated in borehole W-2349 (Plate 1, northwestern part). Based on regional studies by Teifke (1973, Plate 8) it is as much as 160 feet in thickness along the eastern margin of this area.

TERTIARY SYSTEM

NANJEMOY FORMATION

The Nanjemoy Formation of Eocene age is defined in the mapped area in the subsurface only, and is stratigraphically separated from the underlying Mattaponi Formation at most places by the Marlboro Clay Member. The Marlboro Clay, as the lowest member of the Nanjemoy Formation, is one of the most persistent lithologic markers in the Coastal Plain of Virginia. Drill cuttings from the central Studley quadrangle (W-3068) indicate a thickness for the Marlboro of about 30 feet. This thickness is variable due to thinning from either the top or the base of the unit.

Lithologically, the Nanjemoy Formation is very similar in appearance to the underlying Mattaponi Formation. The Nanjemoy is drab grayish-green, very glauconitic, generally fine- to medium-grained, clayey silt and quartz sand. It is very fossiliferous and contains shell and thin limestone beds. Teifke (1973, p. 22) notes that simple, less intricate, and less-fresh forms of glauconite (allochthonous?) seem to be more common in the Nanjemoy than in the Mattaponi. Maximum thickness of the Nanjemoy Formation (excluding the Marlboro Clay Member) is 60 feet (W-3068, Plate 1, central part).

The Marlboro Clay Member lies below the glauconite-quartz sands and is a very pure, impermeable, pink or light-gray clay. Pink and gray clay and very fine glauconite plates are interlaminated at some localities.

CLAYEY SILT (TRANSGRESSIVE SEDIMENTS)

Transgressive marine sediments of Miocene age include the Calvert Formation of Darton (1911, p. 18) and Brown (1939), and younger transgressive sediments that may be equivalent to the St. Marys Formation. These sediments in the mapped area are very similar in lithology, are of Miocene age, and are locally referred to as the "Miocene marl." Diastems within the Miocene

transgressive unit have been observed at some sites (Figure 8). The significance of these surfaces, however, is unclear and efforts to map them in the field have not, as yet, been successful.

The transgressive sediments unconformably overlie the Nanjemoy, Mattaponi, Patuxent, and Petersburg formations. Geologic contact relationships with the overlying regressive sediments (sand and gravel) vary from one locality to another. This unit underlies the flat uplands often at shallow depths (Plate 11).

The unit can be seen pinching out against granite at Interstate Highway 64 and Acca Yards (Figure 9, Plate 1). It generally thickens eastward through the study area to a maximum thickness of approximately 130 feet in the Studley quadrangle. Regionally, the base of the Miocene transgressive strata has an eastward dip of 8 feet per mile (Cederstrom, 1957, p. 29). Local

Figure 8. Diastem and pebble in Miocene clayey silt unit (transgressive sediments), spillway at Gravetts Millpond, Hanover 7.5-minute quadrangle.

transgressive unit have been observed at some sites (Figure 8). The significance of these surfaces, however, is unclear and efforts to map them in the field have not, as yet, been successful.

The transgressive sediments unconformably overlie the Nanjemoy, Mattaponi, Patuxent, and Petersburg formations. Geologic contact relationships with the overlying regressive sediments (sand and gravel) vary from one locality to another. This unit underlies the flat uplands often at shallow depths (Plate 11).

The unit can be seen pinching out against granite at Interstate Highway 64 and Acca Yards (Figure 9, Plate 1). It generally thickens eastward through the study area to a maximum thickness of approximately 130 feet in the Studley quadrangle. Regionally, the base of the Miocene transgressive strata has an eastward dip of 8 feet per mile (Cederstrom, 1957, p. 29). Local

Figure 8. Diastem and pebble in Miocene clayey silt unit (transgressive sediments), spillway at Gravetts Millpond, Hanover 7.5-minute quadrangle.

Figure 9. Miocene clayey silt unit (transgressive sediments) pinching out against Petersburg granite, Acca Yards, Richmond.

variations in dip rate and direction can be seen in the interpretive sections on Plates 2, 3, and 4a.

The transgressive sediments are exposed in natural drainages and man-made cuts. Where not exposed at the surface, they are unconformably overlain by alluvium or fill, and either conformably or unconformably overlain by various facies of the Tertiary-Quaternary sand and gravel unit (regressive sediments).

The structure of the clayey silt (Miocene transgressive) unit (Plate 10) is generally a subdued reflection of the present topography. The maximum elevation of the unit is approximately 180 feet along the western margin (Plates 2, 3). It has a gentle eastward dip to an elevation of about 140 feet. Where ancient and present streams have incised the transgressive unit below these elevations, unconformable contacts with overlying sediments have been observed; many of these are marked by a coarse, iron oxide-stained, based conglomerate. Erosional contacts commonly have a dip toward present drainages. A few filled and abandoned channels that were cut into the transgressive sediments have been observed at the surface and interpreted in the subsurface. At interfluvial localities that appear to have never been dissected, conformable contacts are observed where sediments of estuarine-marine character grade stratigraphically upwards into terrigen-

Figure 9. Miocene clayey silt unit (transgressive sediments) pinching out against Petersburg granite, Acca Yards, Richmond.

variations in dip rate and direction can be seen in the interpretive sections on Plates 2, 3, and 4a.

The transgressive sediments are exposed in natural drainages and man-made cuts. Where not exposed at the surface, they are unconformably overlain by alluvium or fill, and either conformably or unconformably overlain by various facies of the Tertiary-Quaternary sand and gravel unit (regressive sediments).

The structure of the clayey silt (Miocene transgressive) unit (Plate 10) is generally a subdued reflection of the present topography. The maximum elevation of the unit is approximately 180 feet along the western margin (Plates 2, 3). It has a gentle eastward dip to an elevation of about 140 feet. Where ancient and present streams have incised the transgressive unit below these elevations, unconformable contacts with overlying sediments have been observed; many of these are marked by a coarse, iron oxide-stained, based conglomerate. Erosional contacts commonly have a dip toward present drainages. A few filled and abandoned channels that were cut into the transgressive sediments have been observed at the surface and interpreted in the subsurface. At interfluvial localities that appear to have never been dissected, conformable contacts are observed where sediments of estuarine-marine character grade stratigraphically upwards into terrigen-

ous clastic sediments of the Tertiary-Quaternary regressive unit. At the intersection of U. S. Highway 301 and the Chickahominy River there is a transitional zone that separates sediments of marine dominance below from those of fluvial dominance above (Table 2). Sediments in this transitional zone (3.7 feet thick) grade upwards with increasing grain size, amount of oxidation, and leaching of shell material reflecting increased depositional energy. Sedimentation apparently was continuous from the middle Miocene through Holocene for this area, forming a classical transgressive-regressive sequence.

Table 2.—Measured stratigraphic section and borehole along U. S. Highway 301 about 0.3 mile southwest of the Chickahominy River and Hanover-Henrico county boundary (Plate 2).

Measured surface section	*Thickness (Feet)*
Tertiary and Quaternary sand and gravel (regressive sediments) (15.0 feet)	
Sand, red, medium-grained, subangular, friable	2.1
Clay; gray mottles; red sand lamination at middle	0.6
Sand, dark-red, medium- to coarse-grained, subrounded	0.4
Clayey sand, dark-red, medium- to coarse-grained, subrounded	0.7
Clay; gray mottles at base; some sand laminae	1.2
Clay, very sandy with red-stained quartz	0.5
Sand, light-gray, fine- to medium-grained	0.3
Sand, dark-red, coarse- to very coarse-grained, rounded	0.2
Sand, tan, medium- to coarse-grained; some pebble-size clay clasts	0.3
Hardpan; medium-grained sand and granule-pebble gravel; black coating on grains	0.2
Sand and gravel, light brownish-gray; medium- to coarse-grained sand and rounded pebble gravel; lower contact irregular on a small scale; lower contact most obviously marked by color change; few large (4 inches maximum diameter) clay clasts in upper part of unit; top 0.5 foot is distinctly more yellow and contains more clay clasts than other portion of bed	4.1
Sand and gravel; reddish-orange at base grading to yellowish-orange at top; fine-grained sand to rounded cobble gravel; black material coating grains at base	3.4
Sand, orange, very fine- to fine-grained, mottled	1.0
Transitional beds containing both regressive and transgressive sediments (3.7 feet)	
Sand, argillaceous, light-gray, very fine- to fine-grained; undulatory basal contact; small mollusks (internal molds); orange and yellow mottles; trace of rounded pebble gravel at upper contact; lower part contains a layer of burrows filled with coarse-grained sand and oxidized around edges	2.2

	Thickness (Feet)
Sand, very argillaceous, dark-gray; undulatory contact with underlying plastic clay	1.1
Clay, tan; irregular contact with underlying sand	0.2
Sand, reddish-orange, very fine-grained; thin hardpan at base	0.2
Miocene clayey silt (transgressive sediments) (34.3 feet)	
Clay, very sandy, plastic; sparsely fossilliferous (molds and internal casts), small pelecypods most numerous; scattered, very fine-grained sand laminae; sparsely fossiliferous; micaceous	8.1
Clay, sandy, plastic; internal fossil molds and casts; sand is very fine grained	3.1
Clay, nonplastic; harder than overlying and underlying beds; subconchoidal fracture, internal fossil molds and oxidized fossils	5.4
Clay, plastic, slightly silty; very fossiliferous, both species and individuals abundant, very fragile original shells preserved; includes pelecypods, gastropods, and bryozoans	7.7
Test boring	
Sand, grayish-green, fine-grained, fossiliferous, (pelecypods)	1.5
Clay, sandy; sand is fine grained; fossil fragments locally very abundant	1.5
Sand, clayey, dark grayish-green, fine-grained; abundant fossil fragments; contains shell gravel in lower 0.5 foot	2.5
Clay, sandy; sand is fine-grained; some sand laminae; abundant fossil fragments	1.0
Clay, plastic; very few fossil fragments; slightly silty in lower part	3.5

The 240-foot contour has been tentatively chosen as the maximum extent of marine transgression because many points along this contour are marked by a break in topographic slope, which appears to be more or less continuous throughout the study area. On each side of this break recognizable Coastal Plain sediments occur at elevations lower than 240 feet and saprolites of Piedmont rocks occur at higher elevations.

The approximate updip, western boundary of the unit (Plate 10) contains sediments that are increasingly continental. The deposits are generally of high compositional maturity and low textural maturity. Sediments deposited in the transition zone between continental and marine conditions (nearshore) are mapped with other materials of the Tertiary-Quaternary regressive unit due to their similar lithologic characteristics, including prodeltaic sands, tidal flat silts and sands, and some littoral sands and lagoonal deposits. Although in some areas a nearshore facies

may have been preserved, the formation limits are commonly erosional (Plate 2, section A-A′). The transgressive unit has been breached along the Pamunkey River (Plate 10) and nearly breached along the Chickahominy River. Further evidence of erosion can be seen along the east side of the Chickahominy Valley (Plate 2) and east of Mechanicsville (Plate 4) where the contact with the overlying Tertiary regressive unit is anomalously low. Buried channels have also been interpreted on the structure-contour map of the top of the transgressive unit (Plate 10).

Upon reaching maximum marine transgression the sea began to withdraw after perhaps only a brief still-stand. This would account for the lack of any well-developed strandline complex (beach, dune, ridge, and swale topography). Regressive materials of fluvial origin were deposited in shallow water; were redistributed by waves and longshore currents as blanket or tabular deposits such as tidal flats and prodelta sand sheets; and covered by continental delta plain accumulation, alluvial fan, and braided-stream deposits. These sediments are generally texturally and compositionally immature, laterally discontinuous, and often cross-bedded; they are either sinuous or wedge-shaped in form. Continual lowering of base level caused reworking of the regressive materials and redeposition of sediments at lower elevations (Table 3). Continued erosion incised the surface of the underlying transgressive unit.

The Miocene transgressive unit is primarily comprised of well-sorted silts, clays, and very fine sands that are drab blue, gray, and green. At some localities these materials have a sulfurous odor. A basal sand facies in the unit has well-sorted, subrounded, medium- to coarse-grained sand, commonly several feet thick. It may represent a nearshore sand wedge, including beach and other strand-line deposits. This facies has been recognized by Gernant, Gibson, and Whitmore (1971, p. 17) and Teifke (1973, p. 25).

The clay contains quartz and montmorillonite as major constituents, plagioclase and microcline feldspar (1 to 10 percent each), and minor amounts of illite and kaolinite. In an excavation near the Capitol grounds dolomite is associated with vertebrate fossils and bladed vivianite crystals.

The massive clayey silts are highly fractured in some areas. Iron-oxide stains and precipitates have been formed along these fractures from migrating waters. The maximum thickness of

Table 3.—Depositional environmental progression.

Type of sediment	Environmental Dominance	Environmental Energy	Textural Character	Character
Deltaic-fluvial	Terrestrial	High	Coarse	TOP OF EXPOSURE. Sands and gravels, red, coarse-grained; highly cross-bedded.
Littoral				Sands and gravels; moderate sorting and rounding; predominantly quartz, white microcline feldspar rare; medium grained.
Tidal flat-prodelta sheet				Clayey silts; some fossils (limited suites); iron-oxide mottling; burrows?; concretions.
Marine-estuarine	Marine	Low	Fine	Clays, dark-colored, fossiliferous (pectens and turritellas). BASE OF EXPOSURE.

the Miocene transgressive unit that has been penetrated is 125 feet in the northeast quarter of the Yellow Tavern quadrangle (W-3366).

Fossils are common to locally abundant and their good to poor preservation is directly related to the degree of exposure and leaching of original shell material. Baleen whale and porpoise bones, plant fossils, and mollusks have been reported in the lowest part of this unit (personal communication, Robert E. Weems). The following mollusks were identified by Weems from an outcrop along U. S. Highway 301, about 0.3 mile southwest of the Chickahominy River and Hanover-Henrico county boundary (Plate 2): *Amphiblestrum constrictum, Anadara idonea* Conrad, *Balanus concavus, Callinectes sapidus, Callocardia subnasuta, Cancellaria* sp., *Chione(?) alveata, Chlamys (Lyropecten) santamaria, Corbula conradi, Dentalium attenuatum* (Say), *Lucinoma contracta, Membranipora* sp., *Nucula proxima, Odontaspis* sp., *Spisula (Hemimactra) rappahonnockensis, Turritella plebeia carinata,* and *T. variabilis* Conrad. The Fairhaven diatomaceous member of the Calvert Formation as defined by Dryden and Overbeck (1948) represents a lower stratigraphic interval of the transgressive unit and is exposed in Shockoe Valley. It is generally light gray and weathers to yellowish-buff. In some areas the concentration of microscopic plants called diatoms has been sufficient to cause a noticeable lessening of the specific gravity of the sediments. Darton (1911, p. 22) provides a list of diatoms and rhizopods from these beds in Richmond.

TERTIARY AND QUATERNARY SYSTEMS

SAND AND GRAVEL (REGRESSIVE SEDIMENTS)

Regressive deposits of Tertiary and Quaternary age (Miocene-Holocene) include the Brandywine Formation (Brown, 1939), Lafayette formation (Darton, 1911), and Columbia Group (Cederstrom, 1957; Teifke, 1973). Excluding inliers, this unit blankets most of the study area. It unconformably overlies the Petersburg granite along the western part, the Patuxent Formation along the James River and its tributaries, the Nanjemoy and Mattaponi formations along the Pamunkey River, and the Miocene transgressive unit. Contacts between these two units are mostly at erosional unconformities near present and ancient drainageways, but are conformable and gradational in areas that remained

interfluvial from Miocene transgressive time. Generally, the unconformable contacts dip toward the drainageways.

The more obvious of the subunits in the regressive unit are the alluvial terraces along the Pamunkey River. The terraces appear to be at least in part erosional, being cut along or in close proximity to geologic contacts of the Nanjemoy Formation and Miocene transgressive unit. This erosion was followed by the deposition of a veneer of fluvial sediments. The upper terrace ranges in elevation from about 90 to 120 feet and is capping the Miocene transgressive unit. A second terrace is delineated from about 40 to 60 feet in elevation and has an erosional base that closely approximates an expected Nanjemoy/Mattaponi-Miocene transgressive unit contact in this area (sections A′-A″ and E-E′, Plate 1). A terrace is presently being formed in the area and is covered by alluvium.

The Tertiary-Quaternary regressive unit includes the fluvial depositional system, and the high-energy, nearshore, and strandline environments (littoral). The latter are part of the marine depositional system in the classical sense, but have some continental affinities. The unit consists of buff to red, iron oxide-stained sediments that range in size from clay to boulder gravels. The sediments of this unit form an extensive blanket. At many sites these sediments are iron-oxide mottled, having both reticulate and blotchy forms (Figure 10). Reticulate mottling is particularly common in prodelta or tidal flat (Figure 11) deposits, and is mainly due to bioturbation (Figure 12). Concretions and burrow fillings are common.

The sediments are lithic and feldspathic, and may be coarsely cross-bedded in channel fills (Figure 13). The only fossils observed were tubes of *Scolithus linearis* in boulders and cobbles of the Erwin Formation, a quartzite of Cambrian age which crops out in the Blue Ridge mountains. In several areas blotches, stringers in cross-beds, laminae, liesegang banding, or other accumulations (Figures 14, 15, and 16) of "black" sand was observed. An analysis by O. M. Fordham determined that the black material was an inorganic coating that contained manganese, iron, and cobalt.

The maximum thickness of regressive sediments penetrated was 80+ feet (W-1570) in the northeast quarter of the Yellow Tavern quadrangle (Plate 2). The regressive unit is interpreted to have prograded eastward as the Miocene sea withdrew from the area. Small- to medium-sized deltas probably formed off the

Figure 10. Blotchy mottling in Tertiary-Quaternary sand and gravel unit (regressive sediments) along Interstate Highway 195, Richmond quadrangle (Plate 3).

mouths of all drainages emptying into the sea. Such a depositional environment was examined along U. S. Highway 1 in the central part of the Yellow Tavern quadrangle (Figures 17 and 18).

Although most of the drainages in this area are usually characterized by low flow regimes, some valleys with underfit streams may be the result of previous periods of greater average discharge and competency. Sedimentological evidence that supports this theory can be seen at the head of the Chickahominy Valley (Sliding Hill area) in central Yellow Tavern quadrangle. The regressive unit in this area includes cross-bedded sands and gravels, and a clay-clast intraformational conglomerate. Also, an anomalously thick section of regressive sediments is shown on Plate 11. Large filled channels (Plates 10 and 11) also indicate a previously more active hydraulic setting.

Figure 10. Blotchy mottling in Tertiary-Quaternary sand and gravel unit (regressive sediments) along Interstate Highway 195, Richmond quadrangle (Plate 3).

mouths of all drainages emptying into the sea. Such a depositional environment was examined along U. S. Highway 1 in the central part of the Yellow Tavern quadrangle (Figures 17 and 18).

Although most of the drainages in this area are usually characterized by low flow regimes, some valleys with underfit streams may be the result of previous periods of greater average discharge and competency. Sedimentological evidence that supports this theory can be seen at the head of the Chickahominy Valley (Sliding Hill area) in central Yellow Tavern quadrangle. The regressive unit in this area includes cross-bedded sands and gravels, and a clay-clast intraformational conglomerate. Also, an anomalously thick section of regressive sediments is shown on Plate 11. Large filled channels (Plates 10 and 11) also indicate a previously more active hydraulic setting.

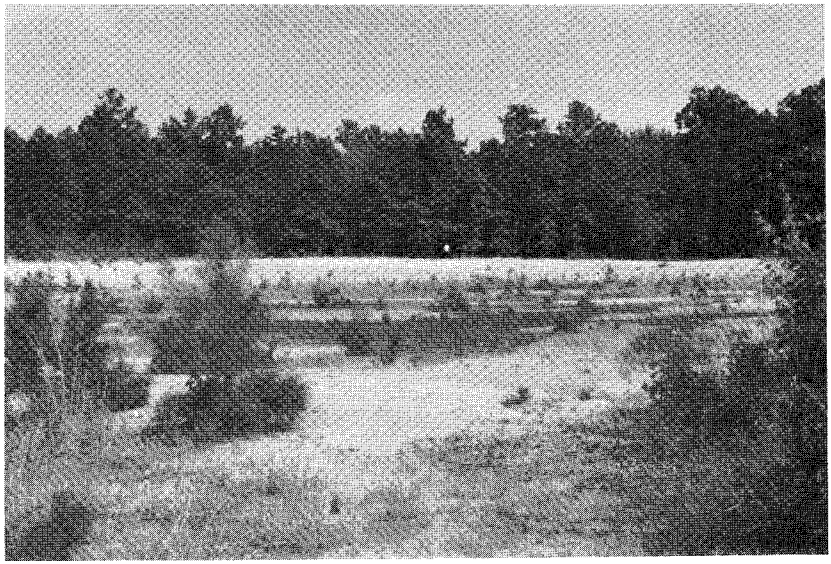


Figure 11. Tidal-flat prodelta deposits in Tertiary-Quaternary sand and gravel unit (regressive sediments) near junction of Interstate Highway 95 and State Road 640, Yellow Tavern quadrangle.

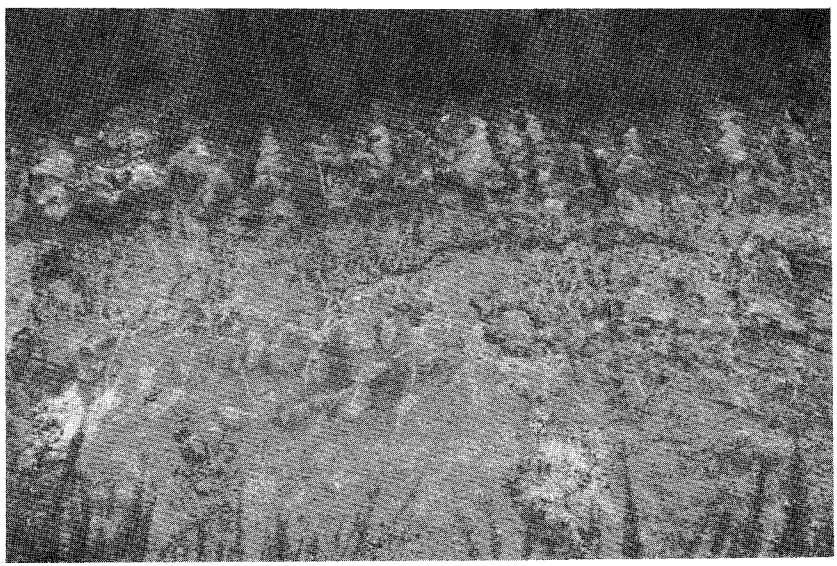


Figure 12. Mottling in bioturbated sediments, Tertiary-Quaternary sand and gravel unit (regressive sediments) near Sliding Hill, Yellow Tavern quadrangle (Plate 2).

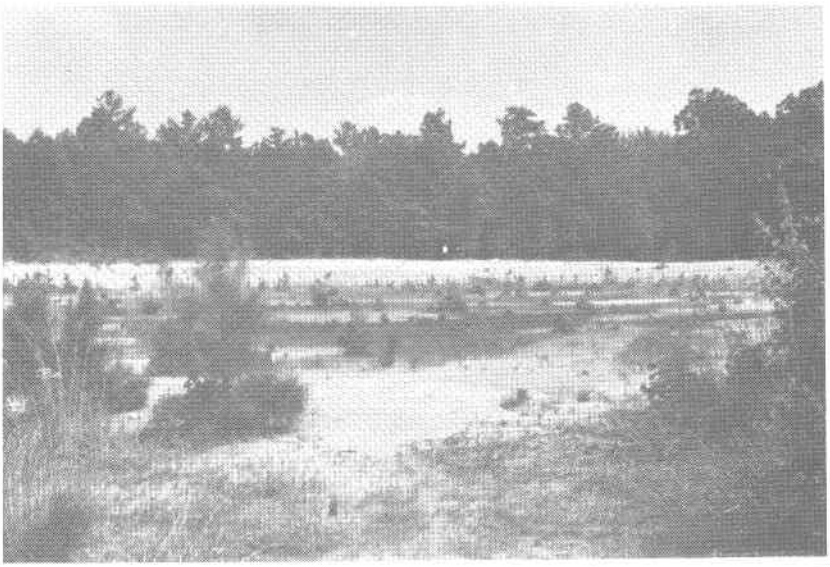


Figure 11. Tidal-flat prodelta deposits in Tertiary-Quaternary sand and gravel unit (regressive sediments) near junction of Interstate Highway 95 and State Road 640, Yellow Tavern quadrangle.

Figure 12. Mottling in bioturbated sediments, Tertiary-Quaternary sand and gravel unit (regressive sediments) near Sliding Hill, Yellow Tavern quadrangle (Plate 2).

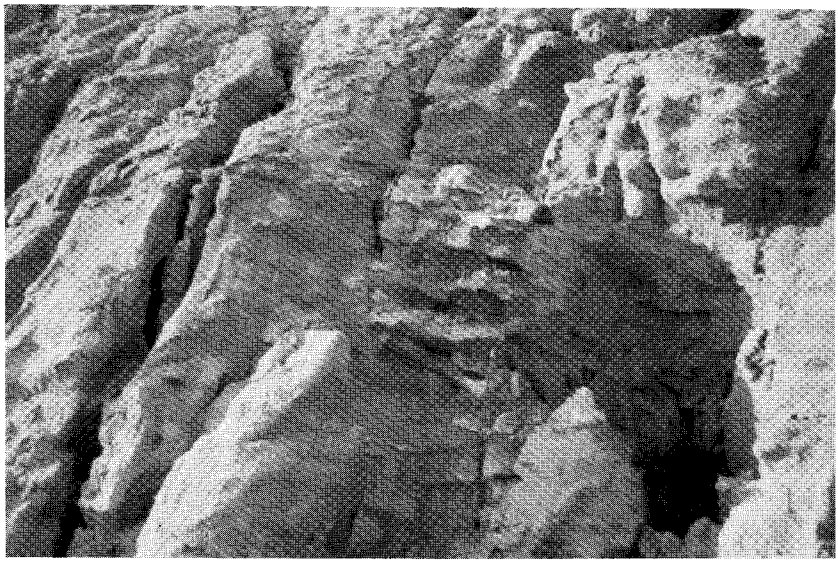


Figure 13. Cross-bedded channel fill, Tertiary-Quaternary sand and gravel unit (regressive sediments) along Interstate Highway 195, Richmond quadrangle.

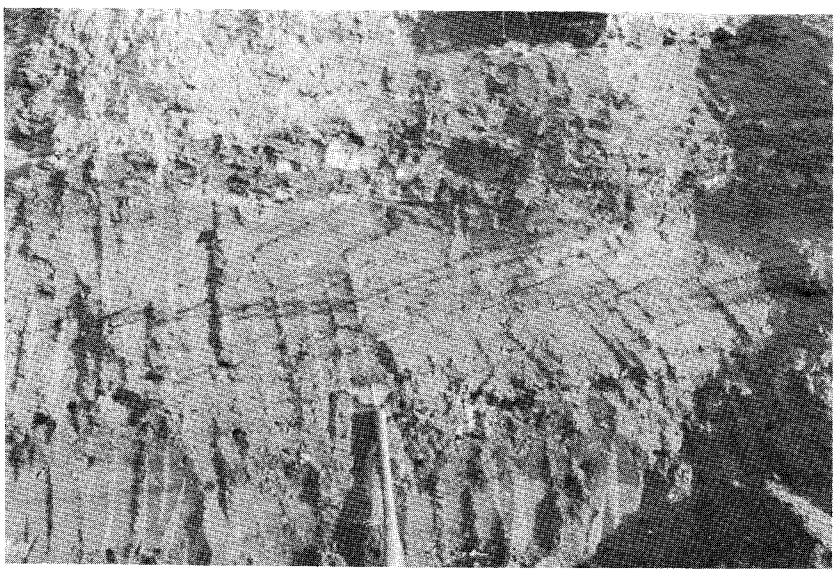


Figure 14. Iron-manganese-cobalt stringers in cross-beds of the Tertiary-Quaternary sand and gravel unit (regressive sediments), Richmond quadrangle.

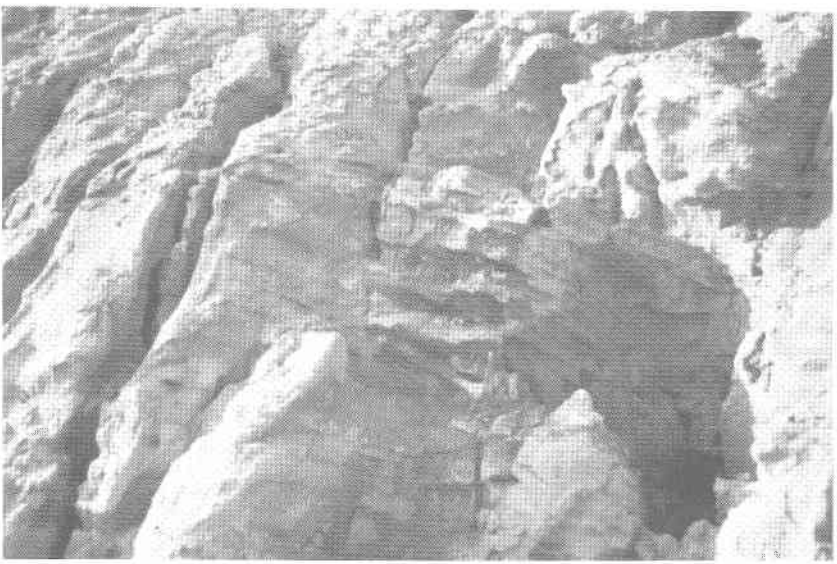


Figure 13. Cross-bedded channel fill, Tertiary-Quaternary sand and gravel unit (regressive sediments) along Interstate Highway 195, Richmond quadrangle.

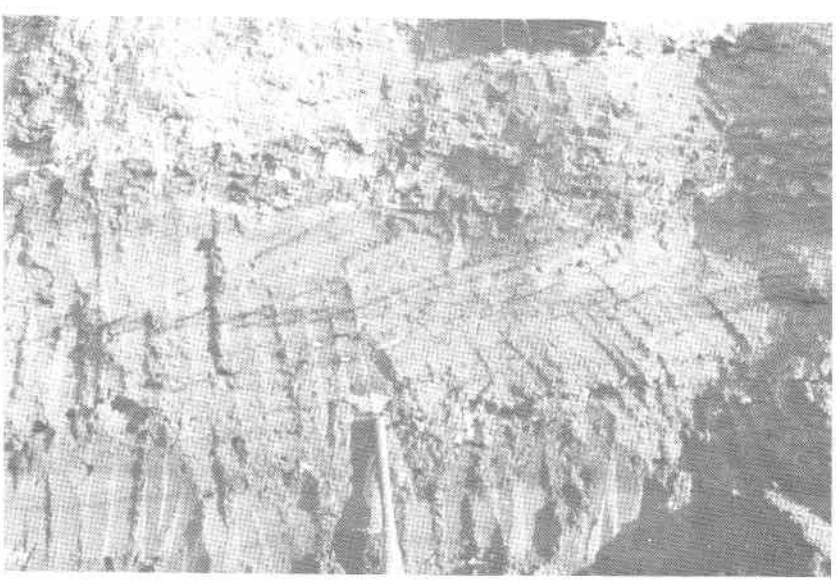


Figure 14. Iron-manganese-cobalt stringers in cross-beds of the Tertiary-Quaternary sand and gravel unit (regressive sediments), Richmond quadrangle.

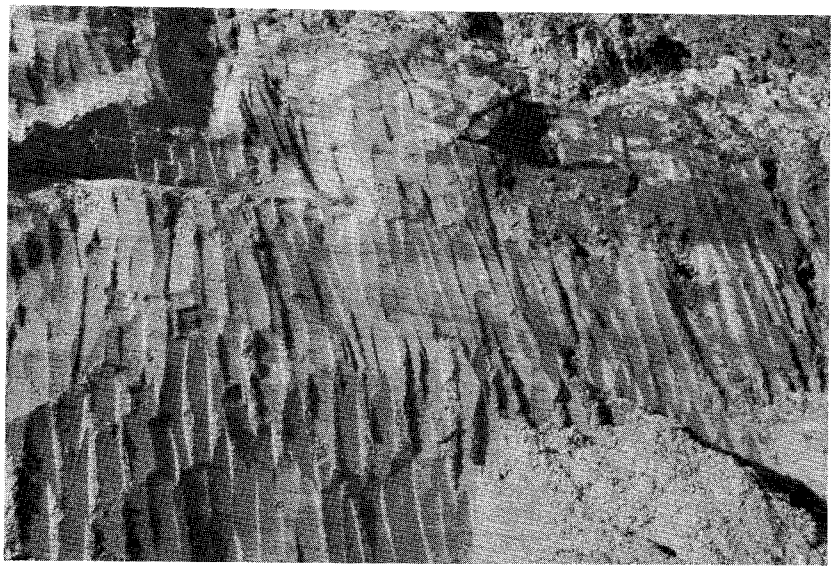


Figure 15. Iron-manganese-cobalt laminae of the Tertiary-Quaternary sand and gravel unit (regressive sediments), Richmond quadrangle.

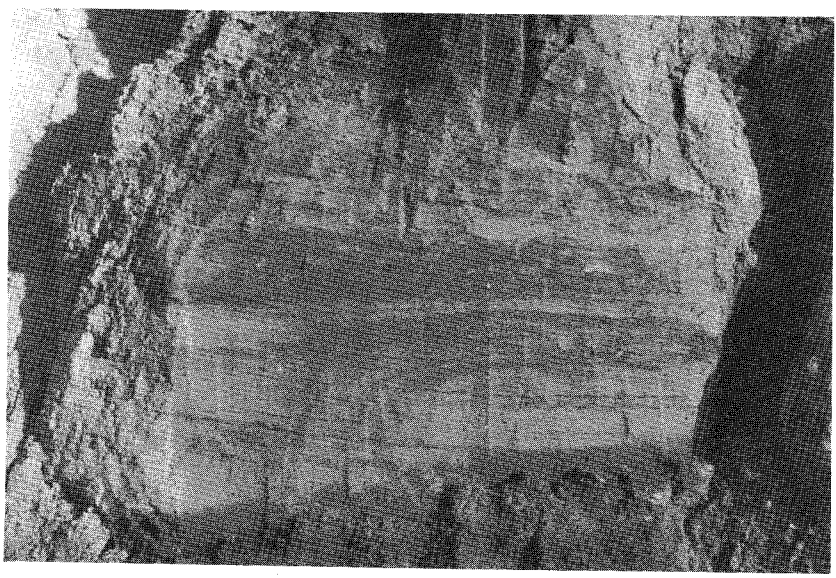


Figure 16. Iron-manganese-cobalt liesegang banding in the Tertiary-Quaternary sand and gravel unit (regressive sediments), Richmond quadrangle.

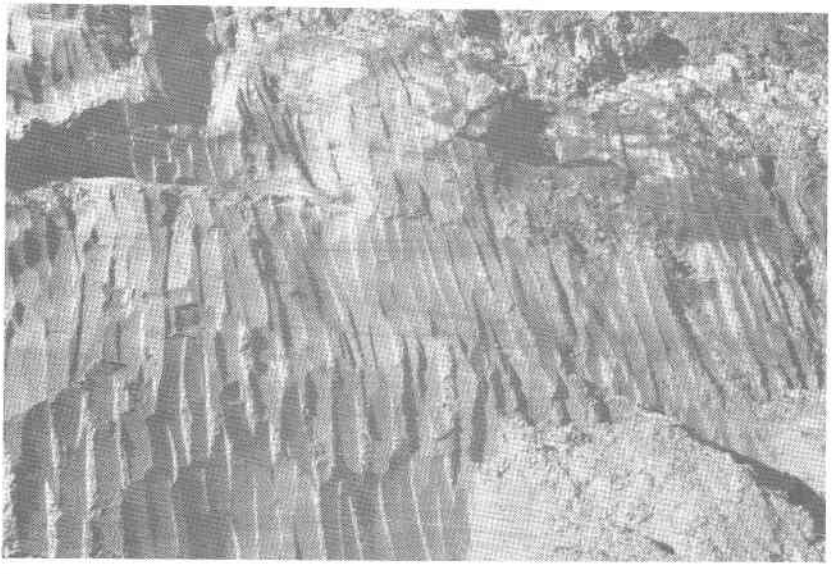


Figure 15. Iron-manganese-cobalt laminae of the Tertiary-Quaternary sand and gravel unit (regressive sediments), Richmond quadrangle.

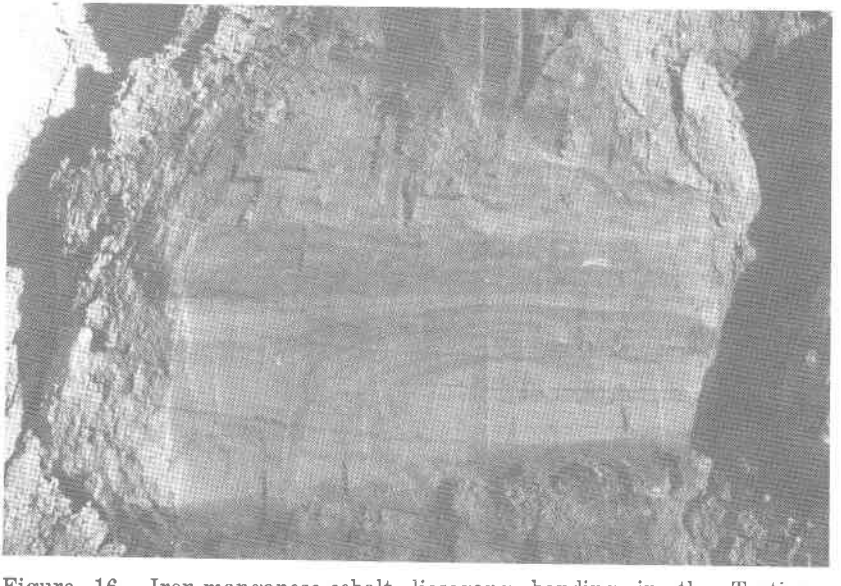


Figure 16. Iron-manganese-cobalt liesegang banding in the Tertiary-Quaternary sand and gravel unit (regressive sediments), Richmond quadrangle.

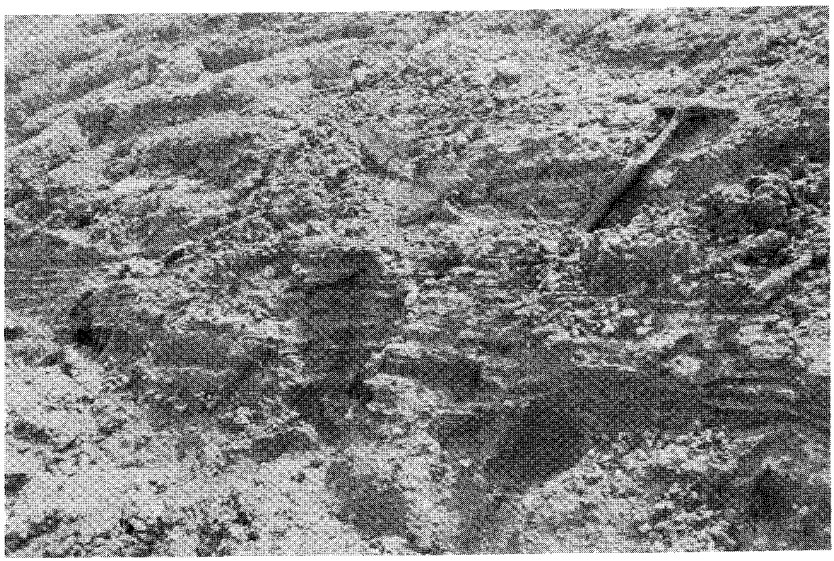


Figure 17. Deltaic beds of the Tertiary-Quaternary sand and gravel unit (regressive sediments) along U. S. Highway 1, central Yellow Tavern quadrangle (shows the red and green sand of Figure 18).

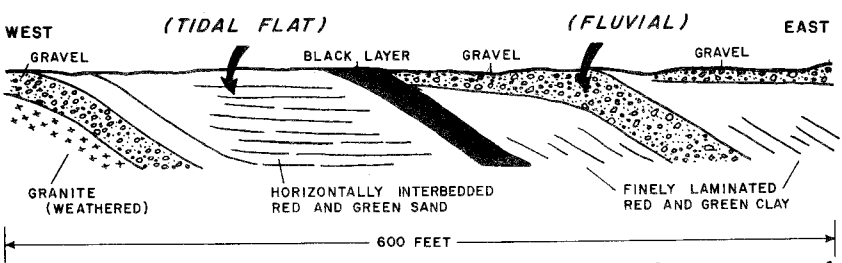


Figure 18. Diagrammatic sketch of delta model, Tertiary-Quaternary sand and gravel unit (regressive sediments) along U. S. Highway 1, central Yellow Tavern quadrangle.

Another interesting feature is iron-oxide coatings deposited in liesegang-type bands on some of the medium- to coarse-grained sands. As this type of banding (cuts across bedding) characterizes the sensitivity of a water-saturated medium to influxes of meteoric water, it may represent supportive evidence for the deltaic interpretation for the fluvial sediments observed along the western margin of the study area. Between the James River and Upham Brook in the Richmond quadrangle (Plate 3), there

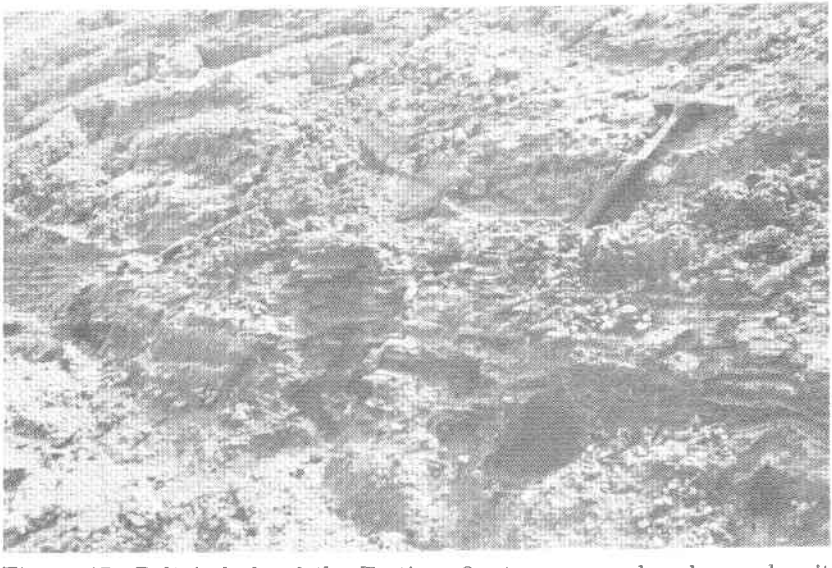


Figure 17. Deltaic beds of the Tertiary-Quaternary sand and gravel unit (regressive sediments) along U. S. Highway 1, central Yellow Tavern quadrangle (shows the red and green sand of Figure 18).

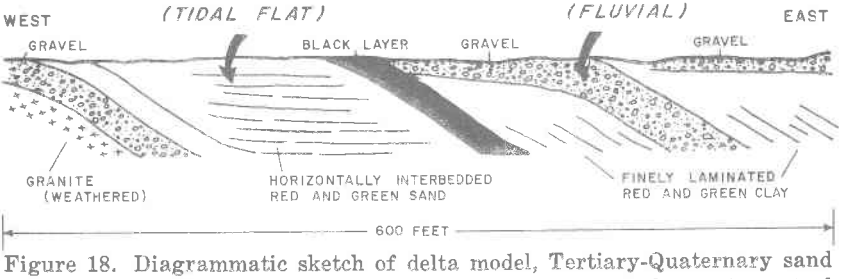


Figure 18. Diagrammatic sketch of delta model, Tertiary-Quaternary sand and gravel unit (regressive sediments) along U. S. Highway 1, central Yellow Tavern quadrangle.

Another interesting feature is iron-oxide coatings deposited in liesegang-type bands on some of the medium- to coarse-grained sands. As this type of banding (cuts across bedding) characterizes the sensitivity of a water-saturated medium to influxes of meteoric water, it may represent supportive evidence for the deltaic interpretation for the fluvial sediments observed along the western margin of the study area. Between the James River and Upham Brook in the Richmond quadrangle (Plate 3), there

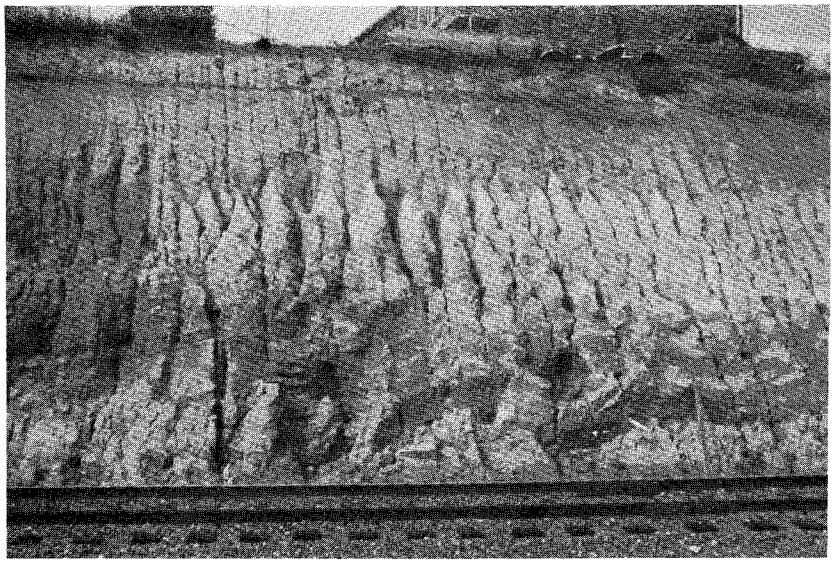


Figure 19. Aggrading and intersecting stream channel deposits, Tertiary-Quaternary sand and gravel unit (regressive sediments), Richmond quadrangle.

existed a complex depositional network of aggrading and intersecting channel deposits (Figure 19), massive sand deposits (stream-mouth bars), boulder gravels (Figure 20), clay plugs, high degree of bioturbation, channel fills that form perched water tables, and other features that are typical of deltaic environments. An ancestral James River drainage is thought to have caused the formation of these features.

QUATERNARY SYSTEM

ALLUVIUM

Organic and poorly sorted fluvial sediments ranging from clay to gravel in size occur in stream channels or as a veneer on flood plains. These sediments and geomorphic features formed from them are in part ephemeral. Their composition and volume, at any point, can vary rapidly and in proportion to fluctuations in the hydraulic regime. Because of such fluctuations, alluvial deposits are commonly heterogeneous. The following facies have

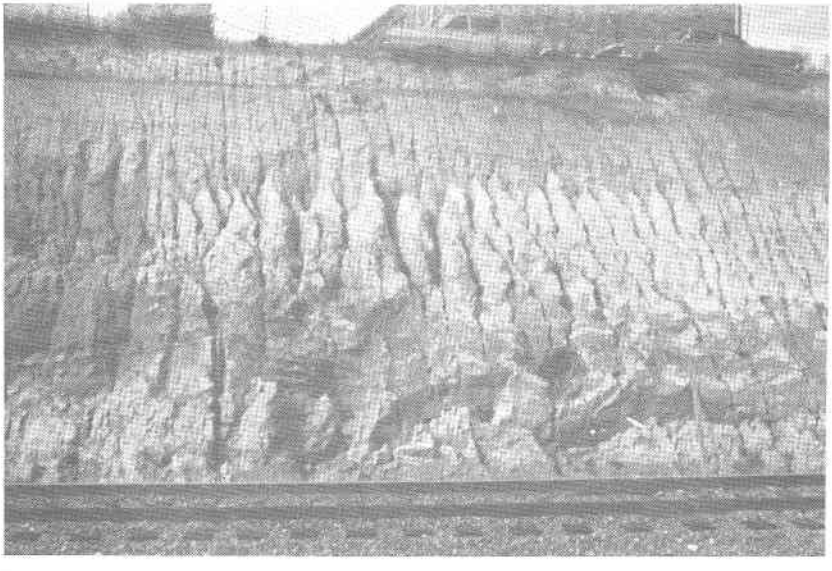


Figure 19. Aggrading and intersecting stream channel deposits, Tertiary-Quaternary sand and gravel unit (regressive sediments), Richmond quadrangle.

existed a complex depositional network of aggrading and intersecting channel deposits (Figure 19), massive sand deposits (stream-mouth bars), boulder gravels (Figure 20), clay plugs, high degree of bioturbation, channel fills that form perched water tables, and other features that are typical of deltaic environments. An ancestral James River drainage is thought to have caused the formation of these features.

QUATERNARY SYSTEM

ALLUVIUM

Organic and poorly sorted fluvial sediments ranging from clay to gravel in size occur in stream channels or as a veneer on flood plains. These sediments and geomorphic features formed from them are in part ephemeral. Their composition and volume, at any point, can vary rapidly and in proportion to fluctuations in the hydraulic regime. Because of such fluctuations, alluvial deposits are commonly heterogeneous. The following facies have

Figure 20. Boulder gravels, Tertiary-Quaternary sand and gravel unit (regressive sediments), Richmond quadrangle.

been separately mapped (Plates 1, 3): alluvial fan (a), abandoned channel (c), point bar (p), and natural levee (n).

STRUCTURE

The top of the "basement" (Plate 5) is a somewhat irregular surface that has a regionally eastward dip at less than 1° (interpretive sections, Plates 1, 2, 3, 4a). This "basement" surface ranges in elevation from about 240 feet in outcrop along the western boundary of the study area to below −620 feet near the eastern margin. The eastern part of the map (Plate 5) has a regular contour pattern, whereas greater subsurface control in the westernmost portion results in more irregular contour characteristics. Comparison of the "basement" structure map with

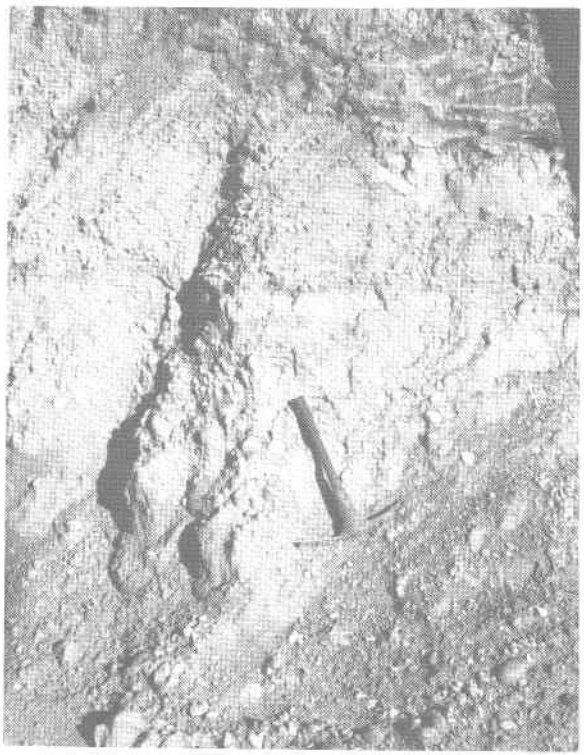


Figure 20. Boulder gravels, Tertiary-Quaternary sand and gravel unit (regressive sediments), Richmond quadrangle.

been separately mapped (Plates 1, 3): alluvial fan (a), abandoned channel (c), point bar (p), and natural levee (n).

STRUCTURE

The top of the "basement" (Plate 5) is a somewhat irregular surface that has a regionally eastward dip at less than 1° (interpretive sections, Plates 1, 2, 3, 4a). This "basement" surface ranges in elevation from about 240 feet in outcrop along the western boundary of the study area to below −620 feet near the eastern margin. The eastern part of the map (Plate 5) has a regular contour pattern, whereas greater subsurface control in the westernmost portion results in more irregular contour characteristics. Comparison of the "basement" structure map with

the present topography shown on the geologic maps (Plates 1, 2, 3, 4) shows some interesting relationships between existing and ancient drainageways. Probable paleodrainageways are located in the NE quarter of the Richmond quadrangle (ancient Chickahominy River), southern Seven Pines quadrangle (ancient James River), and in other areas. The Chickahominy has "basement" expression in the Richmond area, but tends to lose definition in the Yellow Tavern quadrangle. In contrast other streams, such as Upham Brook, have no obvious "basement" expression.

Areas of highest elevations where "basement" rocks were encountered are in Richmond south of the James River. Other relatively high areas were found near Ashland (NW quarter of the Yellow Tavern quadrangle) and in the Mechanicsville area (NE quarter of the Richmond and NW quarter of the Seven Pines quadrangles).

The structure-contour map of the Miocene transgressive unit (Plate 10) shows erosional lows that correspond to present drainages. Channels that were erosionally cut into the top of the Miocene transgressive unit are filled with thick regressive sediments (Plate 10). Some of these channels are: (1) along the eastern side of the Chickahominy Valley in the Yellow Tavern quadrangle—the ancient drainageway turns eastward north of the "basement" high near Mechanicsville and trends eastward across the northern portion of the Seven Pines quadrangle; (2) west of Acca Yards (NW quarter of the Richmond quadrangle) southeastward to the head of Shockoe Valley; (3) due east from the bend in the James River in central Richmond, across the southern portion of the Seven Pines quadrangle; and (4) a north-south trend across Interstate Highway 64, east of Stoney Run—an obvious feature in surface outcrop. All of the abovementioned ancient drainageways have some surface expression.

ECONOMIC GEOLOGY

STONE

The Petersburg granite is a potential source of crushed and dimension stone. There are no active quarries in the formation, and most abandoned quarries have been filled in, some by sanitary landfill operations. Quarrying is presently being done, however, in adjacent Piedmont localities. Plate 6 provides an approximation of the depth of overburden that would require re-

moval to quarry the "basement" rocks. These depths are very shallow along the right bank of the James River in south Richmond, and in the northwestern portion of the Yellow Tavern quadrangle.

CLAY

The saprolite of the Petersburg granite has good potential for face brick. Good dark-tan color with only 10 percent total shrinkage at 2000°F (slow firing) was obtained from a clay sample of a highly weathered saprolite of this unit (Table 4, R-5007). This clay was plastic, showed no drying defects, and had good dry strength. If manufacture of brick utilizing this material should prove feasible, extensive reserves may be expected.

The Miocene transgressive unit is a source of material for quarry tile or building and face brick. A sample (R-5006) from southeast Richmond had an orange-tan color with 12.5 percent total shrinkage and 2.27 bulk density at 2100°F. The sample had low plasticity, no drying defects, and good dry strength. Another sample (R-2968) from east-central Seven Pines quadrangle produced a similar test (Johnson and Tyrrell, 1967, p. 90). If this clay is desirable for development, preliminary information from Plate 11 may be useful to determine overburden depth in a given area.

The Tertiary-Quaternary regressive sediments have been used for brick clay for many years. Darton (1911) discusses several operations that previously existed in the Richmond area. Johnson and Tyrrell (1967, p. 88-89) report slow fire tests on three samples (R-2966, R-2967, and R-2968) from the Seven Pines quadrangle (Plate 4), south of the Chickahominy River, and two samples (R-2861 and R-2862) from the Studley quadrangle (Plate 1).

SAND AND GRAVEL

The Patuxent Formation has an abundance of sand and gravel, and lies at shallow depths near the Fall Line and along the valley of the James River (Plate 9). Sand and gravel is presently being obtained from the Patuxent along the left bank of the James River between Almond Creek and Gillie Creek in southeast Richmond. Possible disadvantages include the variable feldspar and/or clay content (especially clay balls), which may be of significant amounts in some areas.

Sand and gravel for construction aggregate is plentiful in the Tertiary-Quaternary regressive unit, and has been used by several companies. Because of ground-water flow near the contact with the Miocene transgressive unit, pits of depth sufficient to reach this contact require pumping (Plate 11). The areas with potentially the thickest deposits and with the least clay content are those formed under depositional conditions of relatively high energy. Filled channels of ancient drainages are one of the most likely areas for such deposits to be found. Areas where subsurface channel deposits might be expected and an interpretation of the possible thickness of the channel fills are delineated on Plates 10 and 11.

GROUND WATER

The Patuxent Formation represents the principal aquifer for the area and is capable of supplying significant quantities of potable water for domestic, industrial, and municipal supplies. This unit is exposed in outcrop along the James River (Plates 7, 9, and 12).

The Mattaponi (Aquia) Formation is of some limited importance as an aquifer for domestic and municipal ground water supplies in the Mechanicsville, Highland Springs, and Sandston areas (Cederstrom, 1957, p. 26).

The Tertiary-Quaternary regressive sediments are a common source of near-surface ground water.

MISCELLANEOUS

The Mattaponi and Nanjemoy formations may have some potential for agricultural uses of their glauconite and shell beds as fertilizer or shell marl for lime. In the past the Mattaponi has been used for molding sand. Selected analyses and physical tests on four samples of molding sands are given by Darton (1911, p. 44). Extensive deposits of diatomaceous earth in the Miocene transgressive sediments may be of potential commercial value if the material has sufficient purity.

Table 4.—Potential uses of clay materials from the Studley, Richmond, and Seven Pines quadrangles (some data compiled from Johnson and Tyrell, 1967, p. 80-90).

Repository Number*	Location	Mapping Unit	Sample Interval	Potential Use
R-2861	Roadcut, north side of State Road 643, 4.0 miles west of Studley and about 0.7 road mile west of intersection with State Road 651.	Tertiary-Quaternary sand and gravel (regressive)	Across about 6 feet of sandy clay	Flue lining
R-2862	Roadcut, west side of State Road 615, 1.2 miles southwest of Studley and about 1.3 road miles north of intersection with State Road 627.	Tertiary-Quaternary sand and gravel (regressive)	Across 12 feet of clay and sandy clay	None
R-2966	Settling pond, West Sand & Gravel Co., Inc., 1.3 miles southwest of Highland Springs, off the south side of State Road 654 and about 0.1 road mile west of intersection with State Road 655.	Tertiary-Quaternary sand and gravel (regressive)	Representative sample from settling pond	None
R-2967	Pit of West Sand & Gravel Co., Inc., 1.5 miles southwest of Highland Springs, off southwest side of State Road 654 about 0.4 road mile west of intersection with State Road 655	Tertiary-Quaternary sand and gravel (regressive)	Representative sample of light-gray clay exposed in pit	None
R-2968	Same locality as R-2967	Miocene clayey silt (transgressive)	Sampled upper 4 feet of greenish-gray clay	Face brick

R-5006	In bank off the northwest side of East Richmond Road about 0.05 mile northwest of intersection with Jennie Scher Road in Richmond	Miocene clayey silt (transgressive)	Representative sample taken about 1 foot below the contact with the Tertiary-Quaternary regressive unit	Quarry tile, building brick, "Antique" face brick
R-5007	At base of cut for Interstate Highway 195 (northwest bank) just north of intersection with Broad Street in Richmond	Petersburg granite (saprolite)	Representative sample taken at base of cut for Interstate Highway 195 about 25 feet below level of Broad Street overpass	Face brick

*Samples are on file in the Virginia Division of Mineral Resources repository where they are available for examination.

ENVIRONMENTAL GEOLOGY

LAND CAPABILITY

Environmental geology is concerned with the application of geologic information to nongeologic goals. It commonly is a part of studies such as the delineation of flood plains, areas susceptible to slumping and subsidence, aquifer recharge areas, and foundation conditions for dams and large buildings. In all these applications, the geologic information is used to define the *capability* of a piece of land, that is, its inherent physical characteristics and how these either add to or detract from any proposed project or activity. The purposes of defining land capability are to determine what engineering modifications may be required for a particular project, and to determine the *total* cost of a project rather than just the immediate, direct cost. Very often the best choice as to how to use a piece of land will be that choice in greatest harmony with the land capability. In addition, boundaries between land capability units shown on a geologic map may coincide with certain legal boundaries and thus offer a natural, objective basis for deciding various questions of regulatory policy and land ownership.

Knowledge of land capability is also necessary for *multiple land use* to occur, wherein the same piece of land is used for a number of purposes, each in its own turn. A sand pit, otherwise acceptable, being used for a sanitary landfill, then covered and used for construction sites, or an abandoned quarry being filled with water to form a private lake to act as the focal point of a later housing development are two common examples.

Successful natural resource management and land-use planning should be characterized by flexibility. Neither the geology of an area nor the physical characteristics of the geologic units are constant. Incorporation of geologic data and flexibility are important contributions that reports like this can make to formulation of natural resource management guidelines and land-use plans.

FLOOD-PRONE AREAS, LANDFORMS, AND DRAINAGE BASINS

The streams in the mapped area can be divided into two groups, based upon the appearance of their valleys as shown on topographic maps. The first group include the James, Chickahominy,

and Pamunkey rivers that flow in wide valleys with flat bottoms; a comparatively small rise in the water level will cause these rivers to flood extensive areas. The second group includes streams such as North Run, Totopotomoy Creek, and many smaller, unnamed streams that flow in relatively narrow, V-shaped valleys. A rise of water level will flood only a relatively limited area unless the flood waters overflow the valleys onto adjacent uplands.

Various ways to define and map flood-prone areas have been developed. The method based on flood profiles and backwater curves is the most exact and quantitative. It is used by the U. S. Army Corps of Engineers that has prepared a number of flood plain reports for streams within the mapped area (1965, 1966a, 1966b, 1968a, 1968b). However, this method is also expensive and slow. In order to provide some sort of definition of flood-prone areas throughout the mapped area, an alternative approach was used which is faster and less expensive, but also less exact. Where comparisons are possible, flood-prone areas in this report compare favorably with those defined by the U. S. Army Corps of Engineers.

The map of flood-prone areas (Plate 13) was prepared by first locating all points where topographic contour lines cross stream channels and thus show the approximate elevations of the streams at these points. Arbitrary values of 10 and 20 feet were added to the stream elevation values and topographic contour lines representing these new values were located. By tracing these new contour lines, changing from one to another as necessary to maintain a constant 10- or 20-foot increment above the present channel, a map was prepared which shows the areas that would be flooded if a given stream rose 10 or 20 feet above its present level. Some of the smaller streams may not ever flood this much, but the larger streams, such as the James River, may flood more. For this reason, an additional increment of 40 feet for the James River shows the area that would be flooded if the river rose to 40 feet above its present level.

Flooding is a natural, recurring process. There are methods for calculating the average recurrence interval for a flood of a given size, but exactly when any given size flood will occur cannot be predicted. Because of this, floods should be handled by accomodation rather than by attempts at prevention. That is, structures and activities should be built and carried on in flood-prone areas in such ways as to be least damaged by floods, whenever they occur. Close to stream level the chance of any area

being flooded is usually one or more times every year. At higher and higher elevations, the chances of being flooded progressively decrease. So, buildings can be raised on pilings or foundations to the height required for any risk of flooding that is deemed acceptable or they can be surrounded by dikes or floodwalls of various heights. Selected recreational facilities such as ball parks are generally suitable for flood-prone areas because intermittent interruptions due to flooding will generally not cause any great harm or expense.

Further examination of topographic maps for the area covered in this report makes clear there are four main landforms present in the Richmond area. There are relatively high, flat uplands (such as the ones upon which are located the City of Richmond and Byrd Field); low, flat lowlands (such as the floor of the Chickahominy River Valley); the intervening slopes; and rolling topography with variable slopes west of the Fall Line.

The map of landforms (Plate 13) was made by first outlining the flat lowlands shown on the topographic maps. In many places this line coincides with the maximum extent of the flood-prone areas. Then, a higher elevation contour line was traced which just encircles the heads of all streams. Areas between these two lines are slopes, areas at highest elevations are flat uplands, and areas at lower elevations are flat lowlands. Of these three landforms, slopes are the most susceptible to erosion. The uplands are relatively flat, and because of this flatness inadequate drainage may result if soils are locally abundant in clay to allow only low rates for infiltration of precipitation. Piedmont landforms are located to the west of the mapped area. Comparison of the landforms map (Plate 13) with the geologic maps (Plates 1, 2, 3, 4) shows that the clayey silt (Miocene transgressive unit) frequently crops out in slope areas, which may emphasize any tendency of the clay to slump, especially when it is disturbed.

"BASEMENT" ROCKS

The transition from loose surface sediment to hard rock may be so gradual in places that it is very difficult to identify the top of hard rock. In such cases, "hard rock" or "bedrock" is defined in terms of methods or equipment used to excavate it. A certain resistance as measured by the Standard Penetration Test or a specified degree of difficulty of excavation with a specified piece of power equipment may be used to define "bedrock" that is locally acceptable for a given project.

The strength of rocks and sediments is determined by (1) internal properties such as porosity and unconfined compressive strength which are independent of geometric arrangement, and (2) external properties such as orientation of bedding and cleavage and the nature of contacts. Bulk, internal properties are usually measured by standard engineering tests performed in a laboratory whereas external properties are usually measured in the field.

When a rock core is extracted from a borehole, less than 100 percent of the thickness that was cored is usually recovered because of small chips of rock that either drop out of the core barrel or are crushed within it. If fragments of core 4 inches and less in length are eliminated from consideration and the remaining rock that was recovered is calculated as a percentage of the total thickness cored, the resulting value is called the Rock Quality Designator, or RQD.

The RQD and the unconfined compressive strength have both been measured on many bedrock samples in the Richmond area (A. C. Munyan and W. H. Vogelsang, contract report, 1973) and a close correlation has been found (Figure 21). The unconfined compressive strength of bedrock samples can be estimated in the field simply by calculating the RQD for cores recovered from boreholes. Table 5 (A. C. Munyan and W. H. Vogelsang,

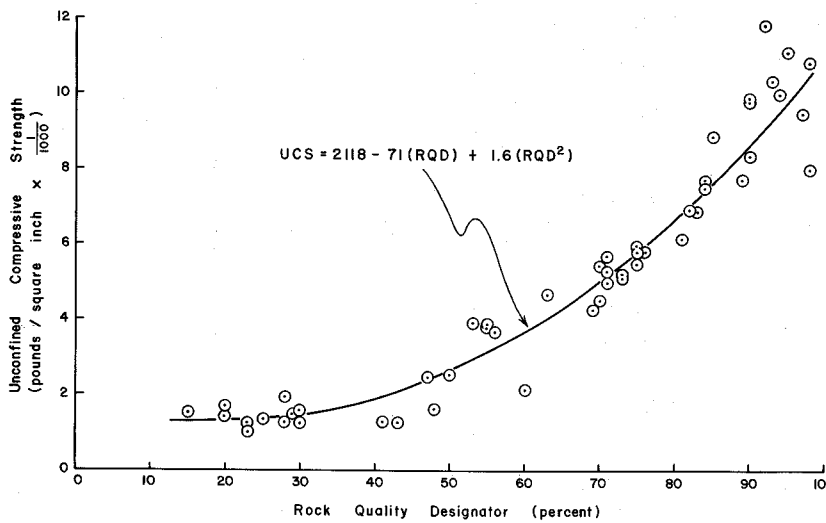


Figure 21. Unconfined compressive strength of the Petersburg granite in Richmond, Virginia as a function of Rock Quality Designator (data from A. C. Munyan and W. H. Vogelsang, contract report, 1973).

Table 5.—Relationship between Rock Quality Designator (RQD), unconfined compressive strength, and average bearing allowable value for bedrock samples from the Richmond, Virginia area.

RQD (percent)	Rock Quality	Unconfined Compressive Strength (pounds/square inch)	Average Bearing Allowable Value (thousands of pounds)	Type
25	very poor	1–1500	10–30	1–2
25–50	poor	1500–2500	30–50	2–3
50–75	fair	2500–5000	50–70	3
75–90	good	5000–8500	70–90	3–4
90–100	excellent	8500	> 90	4

contract report, 1973) may also be used for estimating unconfined compressive strength of bedrock in the Richmond area from RQD information.

The four rock types listed in Table 5 are empirically defined (A. C. Munyan and W. H. Vogelsang, contract report, 1973) as follows:

Type 1: Saprolite; thoroughly weathered rock; often has the appearance of firm rock but is readily excavated by pick or shovel.

Type 2: Soft rock; has the appearance of firm rock but can be drilled with nondiamond drill bits; cores can be recovered without disintegrating.

Type 3: Firm rock; frequent joints; edges of core rounded at joint planes; requires diamond drilling.

Type 4: Hard, sound rock; occasional joints; cores are clean and separate sharply at edges; requires diamond drilling.

Depth to "basement" or bedrock (Plate 6), the shape of its surface (Plate 5), and its strength are important to know for many applications. When excavating, for example, whether at a single site as for a foundation or along a line as for a pipeline or utility line, it is important for a contractor to know whether he will encounter loose sediment or hard rock because of the different excavation methods required. Loose sediment can be excavated with power equipment but hard rock will usually require blasting with a corresponding increase in cost. Design of proper foundations, especially for large industrial facilities, is influenced both by the depth to bedrock and by its strength at a proposed site. If bedrock is excessively deep or weak at a proposed site, excessive excavation may be required to reach sound rock, with an accompanying increase in costs, or a more complicated, and therefore more expensive, foundation may have to be designed.

PATUXENT FORMATION

The coarse sand and gravel comprising the Patuxent Formation has two principal uses as a foundation bed and as a source of aggregate. Where sorting is good and all particles of sediment are very nearly the same size, the particles are in point-to-point contact with each other. Thus, the weight of the sedimentary mass is supported entirely by the sedimentary particles themselves (Figure 22). Because in this case there is little or no

room for rearrangement of the grains, sediment like this does not undergo volume change or settlement when a load (such as a building) is applied. Blow counts from Standard Penetration Tests of the Patuxent Formation at some localities in the Richmond area range upward to more than 100 blows per foot in such cases. Elsewhere, where sorting is poor, finer grained material

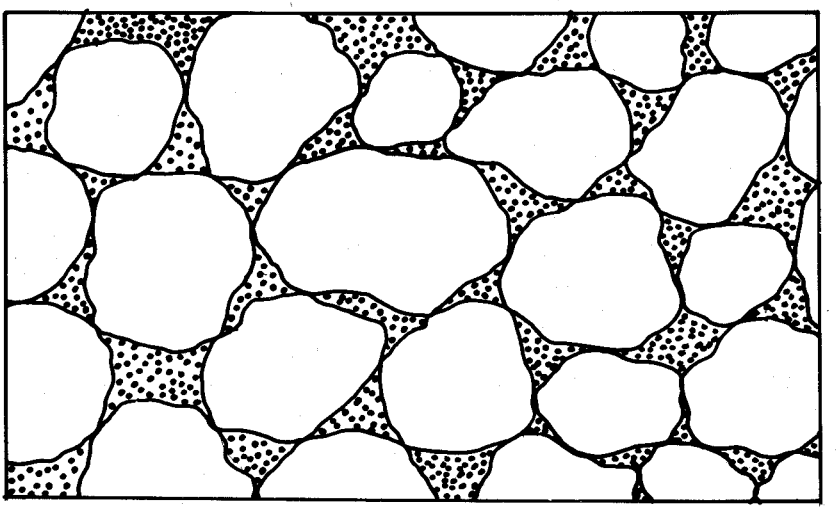


Figure 22. Diagram of sediment packing, Patuxent Formation.

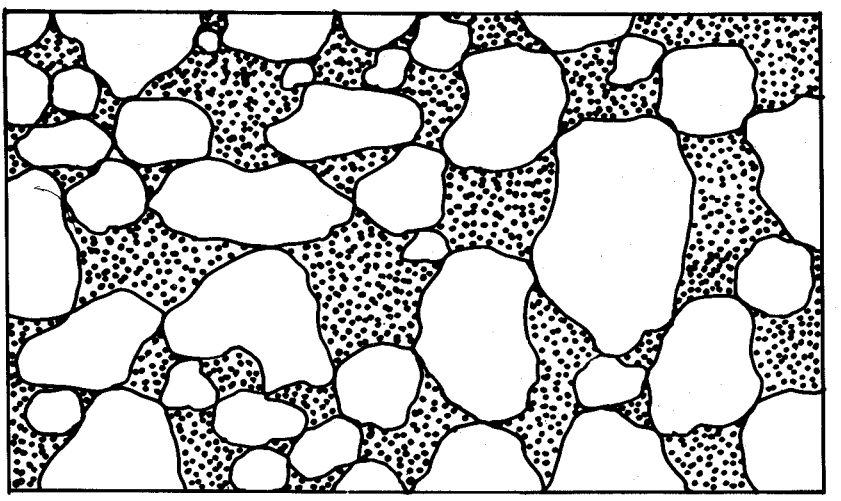


Figure 23. Diagram of sediment packing with filled pore spaces, Patuxent Formation.

or water under pressure fills the pore spaces between the larger particles (Figure 23). In this case, more rearrangement of sedimentary particles is possible when a load is applied or when water pressure is reduced, leading to subsidence that may be appreciable. Blow counts from Standard Penetration Tests in poorly-sorted Patuxent may be as low as 26 blows per foot. The wide range in blow counts illustrates the need for, and the importance of, detailed site analyses as part of the preparation for any construction project. The map showing the depth to the Patuxent Formation (Plate 9) is valuable for locating general areas where the formation may be at depths considered generally feasible for use as a foundation bed.

Sand and gravel, similar to crushed stone, must be recovered as close as possible to its point of use because ordinary sand and gravel, as from the Patuxent Formation, has a low value per unit volume which cannot justify large transportation costs. Urban construction is a major market for these resources, so sand and gravel pits are often located close to major urban areas (e.g., southeast corner of Plate 3). It is perhaps inevitable that some sand and gravel operations come to lie in the path of urban expansion, with competition or conflict with other land uses as the possible results. Other projects may compete with the sand and gravel operations for use of the land, or these operations may be deemed too much of a nuisance to an expanding area of nearby residential housing. Judicious creation and use of natural resource zones can do much to insure that an area's natural resources are not prematurely excluded from development and that they will be available for use when they are needed.

The Patuxent Formation is an aquifer, a unit that contains appreciable amounts of recoverable ground water. The depth to the Patuxent (Plate 9) can be used to estimate anticipated drilling depths, drilling costs, and subsequent pumping costs. The structure contours on top of the Patuxent (Plate 7) can influence selection of locations where wells should be drilled. It is possible to estimate potential yields of water wells to be drilled, on the assumption that a thicker mass of sediment will yield more water than a thinner mass of the same sediment (Plate 8).

Where the Patuxent Formation is to be used as a base for a foundation, it should be recognized that flooding of excavations may occur because of the ground water in the formation. If construction of certain industrial facilities is contemplated on or near recharge areas where the Patuxent crops out, adequate

provision must be made to prevent infiltration of toxic material into the aquifer along with normal recharge.

CLAYEY SILT (TRANSGRESSIVE SEDIMENTS)

As far as is known, the Miocene transgressive unit is "sensitive" throughout the Richmond area (A. C. Munyan and W. H. Vogelsang, contract report, 1973). That is, it can liquify without the addition of water when it is shaken or disturbed by either natural causes, such as earthquakes, or by man-made causes, such as drilling or blasting. Sensitive sediments usually have a high clay content that has a particular structure which is subject to collapse when disturbed. When undisturbed, however, the clayey silt is ". . . capable of carrying heavy building loads on spread footings" (Casagrande, 1965, p. 24). Standard Penetration Tests, which are somewhat misleading because the drilling process itself disturbs the sediment, vary from 7 to 22 blows per foot (Casagrande, 1965, p. 5). It underlies the flat uplands commonly at shallow depths (Plate 11).

The clayey silt is impermeable to water and, because of its position in the middle of the vertical succession of sediments, it separates overlying water-bearing sands and gravels from the underlying Patuxent aquifer. This is very important, for it means shallow and deep ground-water resources can be managed separately. Specifically, this means the combination of ground-water extraction and waste disposal activities should be avoided where they are in proximity to each other.

The depth to the top of the clayey silt map (Plate 11) should be a valuable tool when searching for new sanitary landfill sites and in construction. Where the unit is close to the surface, the clayey silt makes an excellent floor for sanitary landfills, as shown by one example on the east side of Richmond (Figure 24). Water moving through a landfill dissolves or reacts with certain constituents of the contained wastes and is turned into leachate, a sometimes toxic liquid that should not escape from the landfill uncontrolled. An impermeable clay floor in a landfill prevents downward percolation of leachate and the possible pollution of underlying ground-water resources.

Two kinds of problems may occur during construction as a result of the physical properties of the clayey silt. First, its sensitivity must be taken into account when designing foundations for structures. And secondly, because of its impermeable char-

Figure 24. Sanitary landfill, Richmond.

acter, water in overlying sands and gravels will drain into and flood any excavation that exposes the contact between the top of the clayey silt and the base of the overlying sands. Such drainage of water can also undermine the sands and cause them to slump. For these reasons, care must be taken when constructing basements or when grading sites for construction in areas where the clayey silt is close to the surface (Plate 11). Some locations in the Richmond area have experienced repeated undermining and slumping where a natural slope across the upper contact of the clayey silt was cut away to permit construction of a building (Figure 25).

SAND AND GRAVEL (REGRESSIVE SEDIMENTS)

The sand and gravel unit underlies a large portion of the present land surface within the mapped area. Commonly, this unit is both porous and permeable, properties that make it capable of yielding and absorbing large amounts of water. Many local areas are surrounded, or nearly surrounded, by present stream channels that have been cut down through the sediments, isolating them from nearby adjacent deposits. Water that infiltrates this unit is retained in the unit above the underlying clayey silt. This

Figure 24. Sanitary landfill, Richmond.

acter, water in overlying sands and gravels will drain into and flood any excavation that exposes the contact between the top of the clayey silt and the base of the overlying sands. Such drainage of water can also undermine the sands and cause them to slump. For these reasons, care must be taken when constructing basements or when grading sites for construction in areas where the clayey silt is close to the surface (Plate 11). Some locations in the Richmond area have experienced repeated undermining and slumping where a natural slope across the upper contact of the clayey silt was cut away to permit construction of a building (Figure 25).

SAND AND GRAVEL (REGRESSIVE SEDIMENTS)

The sand and gravel unit underlies a large portion of the present land surface within the mapped area. Commonly, this unit is both porous and permeable, properties that make it capable of yielding and absorbing large amounts of water. Many local areas are surrounded, or nearly surrounded, by present stream channels that have been cut down through the sediments, isolating them from nearby adjacent deposits. Water that infiltrates this unit is retained in the unit above the underlying clayey silt. This

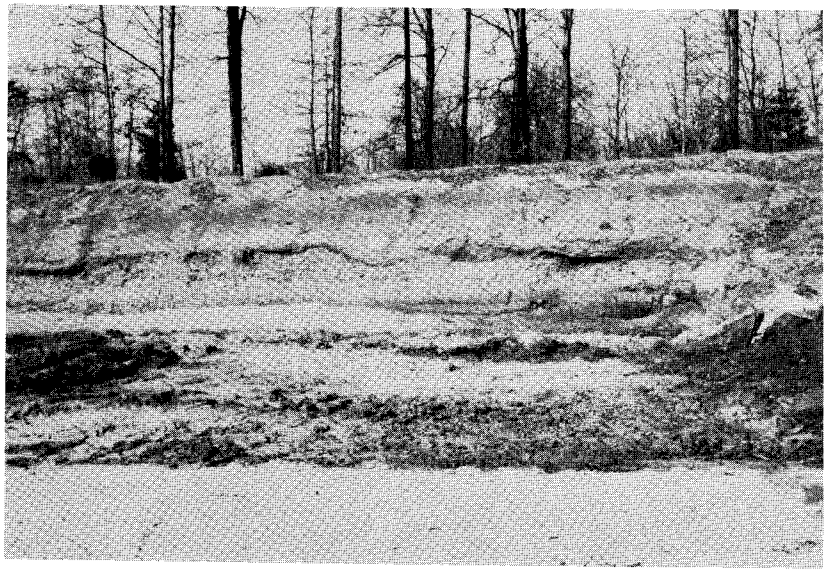


Figure 25. Slumping across the upper contact of the clayey silts unit (transgressive sediments), Richmond.

fresh water is a valuable resource because it can and often does supply the water requirements of individual residences and farms. The porosity and permeability of the sand and gravel makes it generally well-suited to the operation of septic tanks, a necessary means of waste disposal in areas that do not have centralized sewage systems. A potential problem exists when the same body of sediment yields domestic water supplies and is also used for waste disposal. As long as the demand for water in an upland area remains small, a serious problem is not likely to develop. But, as development and population densities increase, it becomes more and more likely that one or a combination of the following will result: (1) the quantity of shallow ground water that is available will become inadequate for the increased demand, (2) the sediments will be incapable of accepting the increased amount of effluent from septic tanks past a certain quantity, (3) the shallow ground water will become polluted from septic tank effluent and will become unfit for domestic use, (4) sewage systems and centralized treatment plants will become necessary, and (5) water supplies will have to be obtained from deeper aquifers or from surface reservoirs. The thickness of the sand and gravel

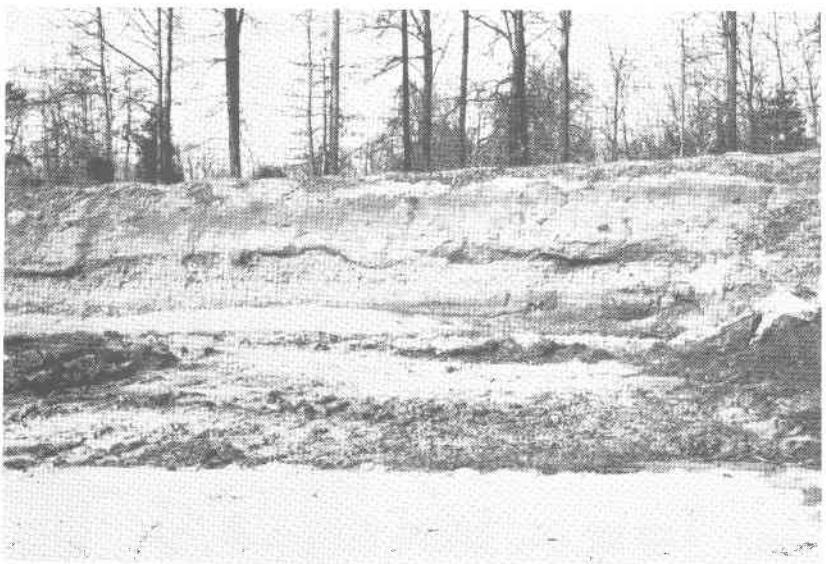


Figure 25. Slumping across the upper contact of the clayey silts unit (transgressive sediments), Richmond.

fresh water is a valuable resource because it can and often does supply the water requirements of individual residences and farms. The porosity and permeability of the sand and gravel makes it generally well-suited to the operation of septic tanks, a necessary means of waste disposal in areas that do not have centralized sewage systems. A potential problem exists when the same body of sediment yields domestic water supplies and is also used for waste disposal. As long as the demand for water in an upland area remains small, a serious problem is not likely to develop. But, as development and population densities increase, it becomes more and more likely that one or a combination of the following will result: (1) the quantity of shallow ground water that is available will become inadequate for the increased demand, (2) the sediments will be incapable of accepting the increased amount of effluent from septic tanks past a certain quantity, (3) the shallow ground water will become polluted from septic tank effluent and will become unfit for domestic use, (4) sewage systems and centralized treatment plants will become necessary, and (5) water supplies will have to be obtained from deeper aquifers or from surface reservoirs. The thickness of the sand and gravel

unit overlying the clayey silt unit is shown on Plate 11. This thickness can be used to calculate the volume of the sediments in order to estimate anticipated yields of shallow ground water or amounts of liquid wastes the sediments could accept.

Distribution of ground water in the sand and gravel unit and separation of potentially contaminated and uncontaminated water in different areas is largely influenced by the landforms that are present, namely, uplands and river terraces such as occur along the Pamunkey River (Plate 1). If possible, care should be taken to protect uncontaminated shallow ground water. If pollutants are unavoidably introduced, great care should be taken during the project design and construction stages to minimize pollution and provision should be made for monitoring ground water quality in the vicinity. In picking a site for an industrial plant or a sanitary landfill these installations could be placed above the lowest terraces that are vulnerable to flooding (Plate 13) and below the uplands where ground water is being extensively used for domestic purposes in the expanding urban areas adjoining Richmond.

Toward its base, the unit consists of a mixture of sand and clay which is exposed near the tops of many valley walls. Casagrande (1965, p. 5-6) has described this portion of the unit as having, in its undisturbed state, the appearance of slightly cemented, compact, brittle, fine-grained sand that, upon remolding, turns into very soft clay of medium to low plasticity. Standard Penetration Tests give 4 to 14 blows per foot.

In the middle of the unit is an interval of sand and gravel that caps the present upland areas and higher river terraces, such as those along the Pamunkey River (Plate 1). Casagrande (1965, p. 7) has described this interval as being very compact, with Standard Penetration Resistance values of 10 to over 100 blows per foot, and capable of having vertical cuts without support.

The uppermost part of the unit consists of sands and clays that are laterally discontinuous and have erratic physical properties (Casagrande, 1965, p. 7). Values from Standard Penetration Tests range from 7 to 32 blows per foot (Casagrande, 1965, p. 8), with the lower values obtained from layers that have a high clay content and the higher values obtained from layers that have a high sand content. Some of the clay layers are sensitive and are susceptible to the same sudden losses of strength upon being disturbed as is the clayey silt.

ALLUVIUM

Flat lowlands, mostly covered with alluvium, are characterized by the same poor drainage as the uplands, and because of nearness of the water table to the surface, the lowlands are commonly swampy. At the juncture between slopes and lowlands (Plate 13), small streams that flow down the slopes in V-shaped valleys and onto the lowlands sometimes deposit sediment in alluvial fans (Plate 3). Alluvial fans have a variable water content, and if their equilibrium is disturbed (for example, by excavation around the edges, heavy traffic, addition of weight such as large buildings, or increase in the water content even from seemingly innocent sources such as watering of lawns), they are vulnerable to slumping and possibly to massive downslope movements. The alluvial fans recognized to date in the Richmond area are all small and represent a relatively minor potential hazard.

REFERENCES

Brown, W. R., 1939, Coastal Plain geology of the Richmond area, Virginia: Unpublished M.A. thesis, Univ. of Virginia.

Casagrande, L., 1965, Subsoils and foundation design in Richmond, Virginia: Richmond, Froehling, Robertson, Whittet and Shepperson, 25 p.

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

Darton, N. H., 1911, Economic geology of Richmond, Virginia and vicinity: U. S. Geol. Survey Bull. 483, 48 p.

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

Dryden, A. L., Jr., and Overbeck, R. M., 1948, Detailed geology *in* The physical features of Charles County: Maryland Dept. Geology, Mines and Water Resources, p. 53-56.

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.

Folk, R. L., 1965, Petrology of sedimentary rocks: Austin, Texas, Hemphills, 170 p.

Gernant, B. E., Gibson, T. G., and Whitmore, F. C., Jr., 1971, Environmental history of Maryland Miocene: Maryland Geol. Survey Guidebook 3, 58 p.

Glaser, J. D., 1969, Petrology and origin of Potomac and Magothy (Cretaceous) sediments, middle Atlantic Coastal Plain: Maryland Geol. Survey Rept. Inv. 11, 101 p.

Goodwin, B. K., 1970, Geology of the Hylas and Midlothian quadrangles, Virginia: Virginia Division of Mineral Resources Rept. Inv. 23, 51 p.

Johnson, S. S., and Tyrell, M. E., 1967, Analyses of clay and related materials—eastern counties: Virginia Division of Mineral Resources, Mineral Resources Report 8, 232 p.

LeRoy, L. W., and Low, J. W., 1954, Graphic problems in petroleum geology: New York, Harper and Brothers, 238 p.

Mathews, H. L., 1970, Soils of Chesterfield County, Virginia: Virginia Polytech, Inst. and State Univ. Coop. Ext. Service Rept. 11, 320 p.

Onuschak, E., Jr., 1973, Pleistocene-Holocene environmental geology, *in* Geologic studies, Coastal Plain of Virginia: Virginia Division of Mineral Resources Bulletin 83, pt. 3, p. 103-153.

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

U. S. Army Corps Engineers, 1965, James River at Richmond, Virginia: U. S. Army Corps Engineers, Flood Plain Information.

U. S. Army Corps Engineers, 1966a, Gillie Creek, Henrico County, Virginia: U. S. Corps Engineers, Flood Plain Information.

U. S. Army Corps Engineers, 1966b, North Run, Henrico County, Virginia: U. S. Army Corps Engineers, Flood Plain Information.

U. S. Army Corps Engineers, 1968a, Upham Brook, Henrico County, Virginia: U. S. Army Corps Engineers, Flood Plain Information.

U. S. Army Corps Engineers, 1968b, Chickahominy River west of Bottoms Bridge, Henrico County, Virginia: U. S. Army Corps Engineers, Flood Plain Information.

APPENDIX I

SELECTED GEOLOGIC LOGS

The following descriptions of samples from selected water wells is included in order that the reader might better visualize the rocks in the mapped area. The wells, as identified by the Division's repository numbers, are W-1477, W-1878, W-2683, and W-3546. Geologic summaries of these wells are in Appendix II. The initials "G. L." after the surface elevation indicate that the datum is ground level.

REPOSITORY NUMBER: W-1477 COUNTY: Henrico
OWNER: Glenwood Golf Course ELEVATION: 153 feet G. L.
DRILLER: Sydnor Hydrodynamics, Inc. TOTAL DEPTH: 227 feet
QUADRANGLE: Richmond (Plate 3) DESCRIPTION: R. H. Teifke
LOCATION: Approximately 550 feet west of Creighton Road and 1.0 mile north of Cool Lane.

Depth (in feet)

TERTIARY-QUATERNARY SAND AND GRAVEL (REGRESSIVE SEDIMENTS) (0-37 feet)

0–10 Sand, buff, argillaceous; fine to medium grained, fairly well sorted, angular to subangular; moderate amount of weathered feldspar; small amount of magnetite and muscovite.

10–37 Sand and gravel, buff; medium to very coarse grained; subangular to subrounded sand (about 50 percent) and subrounded to rounded gravel up to 15 mm diameter (about 50 percent), small amount of weathered white feldspar in both fractions; interval 20-37 contains scattered flakes, slightly argillaceous.

MIOCENE CLAYEY SILT (TRANSGRESSIVE SEDIMENTS) (37–82 feet)

37–40 Sand, gray, moderately argillaceous; fine-grained with scattered rounded pebbles up to 20 mm diameter; angular, well-sorted; limonitic zone present somewhere within interval.

40–70 Clay, gray, silty, small amount of coarse sand; trace of glauconite.

70-82 Sand, gray, very argillaceous; very fine to fine grained, well sorted, angular; about 5 percent fine-grained, black carbonophosphorite; small amounts of glauconite, muscovite, and yellowish-brown epidote.

NANJEMOY FORMATION (82–104 feet)

82–96 Sand, dark-gray, very argillaceous; very fine grained, well sorted, angular; 2-5 percent fine-grained, black carbonophosphorite; small amounts muscovite, glauconite, and epidote.

MARLBORO CLAY MEMBER (96–104 feet)

96–100 Clay, light-gray; virtually sand-free.

Depth (in feet)

100–104 Clay, pinkish- to orangish-gray; virtually sand-free; brown siderite crusts.

MATTAPONI FORMATION (104–136 feet)

104–120 Sand, dark-gray, moderately argillaceous; fine grained, moderately sorted, subangular; about 15 percent glauconite; small amounts pyrite, muscovite, biotite, epidote, and phosphorite; very few foraminifers.

120–130 Sand and gravel; broken, rounded fragments of quartz and quartzite (about 50 percent) and fine-grained, moderately sorted, argillaceous sand (about 50 percent); sand glauconitic (30-40 percent) and contains small amounts of phosphorite, mica, and epidote; few shell fragments.

130–136 Sand and gravel, slightly argillaceous; fine- to very coarse-grained, poorly sorted, angular to subrounded sand (70-75 percent), and broken rounded fragments of quartz (25-30 percent); abundant greenish quartz; slightly glauconitic, feldspathic, and pyritic; small amount of pelecypod shell fragments.

PATUXENT FORMATION (136–220 feet)

136–150 Clay, brownish-gray, very sandy; about 10 percent broken pebbles of quartz and quartzite; sand, medium-grained, moderately sorted, poorly rounded, slightly glauconitic, feldspathic, and micaceous (muscovite and biotite).

150–160 Sand, gray, coarse- to very coarse-grained, fairly well-sorted, subangular to subrounded; about 5 percent potassic feldspar.

160–170 Gravel and sand, broken rounded fragments (up to 30 mm) of quartz and quartzites (about 70 percent), and coarse, rather poorly sorted, argillaceous sand (about 30 percent); considerable amount of highly decomposed feldspar in sand fraction.

170–180 Gravel (20 percent) and sandy-clay (80 percent).

180–190 Sand, gray, slightly argillaceous, coarse- to very coarse-grained, well-sorted, subangular to subrounded; slightly arkosic (white, weathered potassic feldspar.)

190–200 Granitic residuum, quartz and tan clay; no other minerals distinguishable.

200–210 Granitic residuum, quartz and gray clay; some potassic feldspar and biotite.

210–220 Granitic residuum, quartz, potassic feldspar, biotite, a little hornblende, and drab gray clay.

BASEMENT (220–227 feet)

220–227 No sample.

REPOSITORY NUMBER: W–1878 COUNTY: Hanover
OWNER: Beechwood Development Corp. ELEVATION: 185 feet G. L.
DRILLER: Sydnor Hydrodynamics, Inc. TOTAL DEPTH: 640 feet
QUADRANGLE: Yellow Tavern (Plate 2) DESCRIPTION: R. H. Teifke
LOCATION: Approximately 2.5 miles NW of U. S. Highway 301; 500 feet SW of State Road 637.

Depth (in feet)

TERTIARY-QUATERNARY SAND AND GRAVEL (REGRESSIVE SEDIMENTS) (0–50 feet)

0–10 Sand, yellowish-brown, clayey, very fine- to medium-grained, fairly well-sorted, angular to subangular; trace of feldspar; limonitic.

10–20 Sand, light brownish-gray, slightly to moderately clayey; 10 percent granule gravel; medium to very coarse grained, moderately sorted, subrounded; moderately feldspathic.

20–50 Sand, yellowish-brown, moderately clayey; 5–10 percent fine-grained gravel; medium-grained, moderately sorted; slightly feldspathic; interval 30–50, about 25 percent fine gravel.

MIOCENE CLAYEY SILT (TRANSGRESSIVE SEDIMENTS) (50–120 feet)

50–60 Sand, medium-gray, clayey, fine-grained, well-sorted, angular; traces of muscovite, feldspar, and shell material.

60–100 Sand, light-gray, clean, fine- to medium-grained well-sorted, subangular, traces of magnetite, feldspar, muscovite, black phosphatic material, and shell fragments; interval 70–80, very slightly clayey; interval 80–100, slightly clayey.

100–110 Sand, grayish-brown, moderately clayey, fine to medium grained, fairly well sorted, angular; traces of shell and black, carbono-phosphatic material.

110–120 Clay, brownish-gray, moderately sandy; sand is quartzose, poorly sorted; trace of shell fragments; diatomaceous.

MATTAPONI FORMATION (120–127 feet)

PATUXENT FORMATION (127–170 feet) (Top of formation defined on basis of other information.)

120–150 Gravel and sand; gravel (60–70 percent) is grayish brown, moderately clayey and is fine (2–10 mm), angular (broken rounds?) to subrounded quartz with bluish-gray quartzite and some chert sand; sand (30-40 percent) is fine to coarse, poorly sorted, poorly rounded and slightly feldspathic with traces of phosphorite and glauconite; interval 130–140 is 70 percent sand, 30 percent gravel; interval 140–150 is 60 percent gravel, 40 percent sand.

150–170 Sand, white, clean; 20 percent fine, lithic gravel (2–10 mm); medium- to very coarse grained, moderately sorted, subrounded; moderately feldspathic; traces of glauconite, garnet, and pyrite; interval 160–170 is 5 percent granule gravel.

PETERSBURG GRANITE (170–640 feet)

170–240 Granite, pink; quartz, microcline and biotite; interval 180–190, trace of epidote; interval 190–200, contains vein quartz; interval 200–220, trace of epidote.

240–310 Hornblende gneiss, dark-gray, coarse-grained; hornblende, pink and white feldspar, quartz, and biotite; trace of pyrite; interval 270–310, some granite chips.

Depth (in feet)

310–640 Granite, pale-pink, coarse-grained; quartz, feldspar, biotite, muscovite, and hornblende; interval 320–330, mostly white granite; interval 330–340, very pink granite; interval 340–350, trace of pyrite; interval 480–490, increase of hornblende; interval 620–640, biotite-gneiss fragments.

REPOSITORY NUMBER: W–2683 COUNTY: Henrico
OWNER: County of Henrico ELEVATION: 154 feet G. L.
DRILLER: Sydnor Hydrodynamics, Inc. TOTAL DEPTH: 540 feet
QUADRANGLE: Seven Pines (Plate 4) DESCRIPTION: R. H. Teifke
LOCATION: Approximately 60 feet NW of Bond Street and 200 feet NE of Defense Drive.

Depth (in feet)

TERTIARY-QUATERNARY SAND AND GRAVEL (REGRESSIVE SEDIMENTS) (0–47 feet)

0–10 Clay, light-gray, mottled orangish-brown and subordinately red; small amount of angular quartz silt.

10–30 Sand, pale orangish-brown, slightly clayey, fine- to very coarse-grained, rather poorly sorted, angular to subangular; mainly clear, blue, and iron-stained quartz (orange, red, yellow, brown); muscovite and magnetite present; interval 20–30, mainly coarse to very coarse grained.

30–50 Sand, orangish-brown (deeply stained), slightly clayey, coarse- to very coarse-grained, fairly well-sorted, subangular to subrounded; grades into granule gravel; iron-stained quartz of several types, with some detrital chert, other rock fragments, and weathered feldspar; interval 40–50 is similar except it is a well-sorted, subrounded granule gravel, which is more intensely stained (orange) than overlying sand and has a small amount of gray sandy clay.

MIOCENE CLAYEY SILT (TRANSGRESSIVE SEDIMENTS) (47–80 feet)

(Top of formation defined on basis of other information.)

50–70 Clay, gray; uniformly silty (medium-grained, angular quartz silt); about 15 percent iron-stained granule gravel fairly evenly distributed through the clay; traces of glauconite, muscovite, magnetite, diatoms, and plant remains.

70–80 Sand; binder of medium-gray silty clay; very fine to medium grained, fairly well sorted, angular to subangular; clear to very pale-green quartz with 5 to 10 percent fragmental phosphorite; trace amounts (2 percent) of glauconite, magnetite, kyanite, garnet, epidote(?), sphene(?), and shell fragments (all fine to very fine grained).

NANJEMOY FORMATION (80–134 feet)

80–90 Clay, brownish-gray, silty and slightly sandy; laminae of very light-gray to white silt and sand-free clay; sand component is

Depth (in feet)

medium to very fine grained, moderately sorted, moderately glauconitic; muscovite common.

90–100 Sand and silt, gray, moderately clayey; coarse silt to medium sand; fairly well-sorted; 65 to 75 percent medium- to light-green glauconite and 25 to 35 percent clear angular quartz; traces of muscovite and pyrite.

100–110 Sand and silt, gray, moderately clayey; coarse silt to medium sand; about 40 percent medium- to light-green glauconite and 60 percent angular quartz; quartz is finer grained (coarse silt to fine sand) and better sorted than the glauconite; micaceous; scattered nodules and other fragments of phosphorite.

MARLBORO CLAY MEMBER (110–134 feet)

110–130 Sand, silt, and clay, interlaminations of dark brownish-gray, clayey, glauconitic silt to fine sand; very light-gray essentially sand-free clay and pinkish-orange sand-free clay. Laminations of glauconitic silt-sand are similar to interval 90–110, but contain 10 to 20 percent chalky shells and shell fragments; interval 120–130, pink clay is much more abundant.

130–140 Sand, silt, and clay, interlaminations of dark brownish-gray clayey glauconitic silt to fine sand; medium to very coarse, poorly sorted, quartzo-feldspathic sand with matrix of pale-yellow clay, and subordinate laminae of pinkish-orange and very light-gray clay; a few chalky shell fragments in dark-gray silt-sand and a a few small pebbles in the coarse sand.

MATTAPONI FORMATION (134–173 feet) (Top of formation defined on basis of other information.)

140–160 Sand, dark brownish-gray, moderately silty, slightly clayey; about 25 percent chalky molluscan shell debris including *Turritella* sp.; very fine- to medium-grained, well-sorted; about 50 percent pale-green and clear quartz; about 50 percent medium- to dark-green glauconite, mainly comparable in size to the quartz, but ranging to 1.0 mm; free crystals of gypsum are common; traces of bone fragments, plant fragments, nodular phosphorite, pyrite, and muscovite; a few small lenticulinid foraminifers; interval 150–160, trace of glauconite-pigmented granule gravel.

160–170 Gravel; matrix of gray sand as described in the interval 140–150 feet; fine-grained (1 to 10 mm) polymict gravel; subrounded to rounded grains and reangulated fragments (broken rounds) of quartz, potassic feldspar, quartzite, phosphorite, other rock fragments, and worn shells; many grains of all types are permeated with submicroscopic glauconite; relatively large clasts of garnet and sphene(?) common.

PATUXENT FORMATION (173–510 feet) (Top of formation defined on basis of other information.)

170–180 Sand, sparse matrix of pale-yellowish clay; trace of glauconite-stained gravel described in interval 160–170 feet; fine to coarse

Depth (in feet)

grained, moderately sorted, subangular to subrounded; clear quartz and fresh to slightly decomposed potassic feldspar; about 5 percent glauconite; accessory garnet and sphene(?); interval 180–190, medium to very coarse grained; grades into about 5 percent granule gravel.

190–370 This interval, represented by 18 samples, consists predominantly of medium- to very coarse-grained sands and fine-grained gravels; particle size ranges to about 10 mm, and either the sand or the gravel fraction may be volumetrically dominant in a given sample. The sediments are mainly pale yellow, tan or light gray, as determined by the color of the sparse clay matrix. They are feldspathic, moderately lithic, particularly in the gravel fraction, and very slightly glauconitic to nonglauconitic. Plant fragments are present, and garnet is an accessory mineral.

370–410 This interval 370–410 feet, represented by four samples, is a chaotic structureless mass of detritus ranging in grain size from clay through fine gravel. Colors in hand specimen are reddish brown or reddish gray. Grain size and color are so nonpersistent that it is difficult to define a framework-matrix relationship. The finer material—silty clays and silts—is intimately blended as to texture and color. This material is abundantly charged with a great diversity of coarser fragments of poorly rounded quartz, rock fragments, and feldspars; and smaller amounts of phosphate nodules, glauconite, pyrite nodules, hematite pellets, muscovite, and other unrecognizable fragments. The feldspars and glauconite are fresh to intensely decomposed. Plant fragments, including in-place roots, were observed. At least half of the coarser clastic particles are blocky, irregular, or platey fragments of various clay types. Mainly they are nonrounded and contain very little sand; they include the following types: grayish-yellow and greenish-yellow (very abundant); dark-gray micaceous, slightly glauconitic; pinkish-orange; pale-green; brick-red; ash-gray; lavender; tan; and reddish-brown.

410–430 Sand, slightly clayey; tan with brown mottles; scattered clay clasts; fine- to coarse-grained, rather poorly sorted, angular to subrounded; moderately feldspathic; traces of glauconite, muscovite, and garnet; interval 420-430, slightly to moderately clayey, with 5 to 10 percent granule gravel.

430–440 Sand and gravel; sparse matrix of light-gray clay; about 80 percent medium- to very coarse-grained sand and 20 percent granule gravel; subangular to subrounded; feldspathic; slightly lithic; garnet common.

440–460 Sand and gravel; moderately abundant matrix of tan, variegated silty clay; about 80 percent fine- to very coarse-grained, poorly sorted sand and 20 percent granule gravel; angular to subangular; feldspathic; moderately lithic; traces of muscovite, garnet, glauconite, and nodular phosphorite; interval 450–460, about 30 percent granule gravel.

Depth (in feet)

460–480 Sand and gravel; moderately abundant matrix of pale brownish-gray silty clay, mottled yellow, brown, gray, green, orange; about 75 percent medium to very coarse, moderately sorted sand and 25 percent poorly rounded granule gravel; feldspathic; slightly lithic; plant fragments common; minor amounts of garnet, glauconite, and muscovite; interval 470–480, silty clay matrix is reddish-brown and more abundant, clay clasts are common.

480–510 Sand and gravel, abundant matrix of variegated silty clay; sand is very fine to very coarse, poorly sorted, and grades into granule gravel; percentage of gravel indeterminable because "washed" sample contains too much matrix; feldspathic; clay clasts of various types are present, and probably abundant; fine-grained, light- to medium-green glauconite is common; nodular and bone phosphorite, muscovite, garnet, rock fragments, hematite pellets, and pyrite concretions are present.

TRIASSIC ROCKS ("BASEMENT") (510–540 feet)

510–540 Sand and clay, sand fraction is very tightly bound by abundant matrix of multicolored silty clay (pale-reddish aspect in hand specimen); "sand" is fine to very coarse, poorly sorted (unsorted), variously rounded, and grades into small percentages of granule-size material; sand is moderately feldspathic (slightly to intensely decomposed), and slightly decomposed fine- to medium-grained glauconite is common; rock fragments are fairly abundant, and include clay clasts of various types, fragments of decomposed granitic rock, black aphanitic rock fragments, and fragments, of red clay shale and pale-green to bluish-green shale; clay matrix contains many small pockets of glauconitic silt; pelletal hematite, nodular pyrite, phosphorite fragments, garnet, muscovite, and coal fragments; interval 520–540, red shale fragments more abundant.

REPOSITORY NUMBER: W–3546
OWNER: Sydnor Hydrodynamics, Inc.
DRILLER: Sydnor Hydrodynamics, Inc.
COUNTY: Hanover
ELEVATION: 193 feet G. L.
TOTAL DEPTH: 337 feet
DESCRIPTION: R. H. Teifke

QUADRANGLE: Studley (Plate 1)

LOCATION: Approximately 350 feet south of State Road 606; 2,600 feet east of State Road 640.

Depth (in feet)

TERTIARY-QUATERNARY SAND AND GRAVEL (REGRESSIVE SEDIMENTS) (0–60 feet)

0–10 Silt and sand; silt to fine-grained sand; abundant matrix of brick-red clay; nonclay fraction well sorted.

10–20 Sand and silt; silt to fine-grained sand; sparse binder of multicolored clay (orange, yellow, tan); well sorted.

20–40 Sand, tan; sparse binder and some discrete laminae of tan and white clays; fine to very fine grained with pockets and laminae

Depth (in feet)

of coarser, slightly feldspathic sand; blue quartz common in coarse laminae.

40–50 Sand, tan; grades into granular gravel (10 percent); fine to very coarse grained, poorly sorted; blue quartz and decomposed feldspar common; a few rock fragments and accessory minerals.

50–60 Gravel and clay; 70–80 percent well-sorted granule gravel, mainly subrounded to rounded quartz and decomposed feldspar; 20–30 percent orange-brown silty clay; ferricrete common.

MIOCENE CLAYEY SILT (TRANSGRESSIVE SEDIMENTS) (60–150 feet)

60–70 Sand, gray, with brown mottles; sparse binder of gray clay; 10 percent well-sorted granule gravel (caving?); very fine grained, very well sorted, angular; micas, feldspar, and minute shell fragments present.

70–90 Sand, gray, with very sparse clay binder; 10 percent granule gravel (caving?); very fine grained, very well sorted; muscovite common; interval 80–90, more clayey, with about 5 percent chalky shell fragments, including *Turritella*.

90–100 Sand and silt, brownish-gray, with sparse clay binder; 10 percent granule gravel (caving?); silt to very fine-grained sand, very well-sorted, with about 5 percent chalky shell fragments.

100–120 Sand and silt, brownish-gray, with sparse clay binder; 10 percent granule gravel (caving?), silt to very fine-grained sand, very well-sorted; about 5 percent chalky shell fragments; interval 110–120, fairly clayey and coherent, with pale-orange mottling common.

120–130 Clay, light-gray, mottled orange; uniformly silty (fine silt), with about 5 percent granule gravel; subordinate laminae of dark-gray to greenish-gray coarse silt to fine-grained sand; a few diatoms and chalky shell fragments.

130–140 No sample.

140–150 Clay, light-gray, papery, slightly silty, with laminae of greenish-gray clayey and silty sand; about 5 percent chalky shell fragments, trace of diatoms, and fragmental phosphorite.

NANJEMOY FORMATION (150–180 feet)

150–160 Sand; abundant matrix of gray to greenish-gray clay, a few small pebbles, and chalky shell fragments; fine grained, moderately sorted; moderately glauconitic and micaceous, trace of phosphorite.

160–170 Silt and sand; moderately abundant matrix of gray clay; coarse silt to very fine-grained sand, very well-sorted, about 5 percent glauconite, 5 percent muscovite, traces of shell and fragmental phosphorite.

MARLBORO CLAY MEMBER (170–180 feet)

170–180 Clay, very light-gray, slightly mottled brownish-orange; silty, contains some sand-size green glauconite; numerous interlaminations of grayish-green to olive-green clayey glauconitic silt to

Depth (in feet)

fine sand; slightly micaceous; minor amount of coarse-grained secondary phosphorite.

MATTAPONI FORMATION (180–235 feet)

180–190 Sand, dark-gray, silty, slightly clayey; locally a calcitic glauconite-bearing siltstone; fine to very fine grained, well sorted; clear and greenish angular quartz with 10–15 percent light- to dark-green glauconite and 2–3 percent mica; a few foraminifers (including *Robulus* sp.), shell fragments (including *Turritella* sp.), and bone fragments.

190–230 Sand and silt, dark brownish-gray, slightly clayey; a very few chalky shell fragments; silt to very fine sand, very well-sorted; clear and greenish angular quartz with 10–15 percent green glauconite, including 3–5 percent 1 mm polylobate aggregates; a very few *Robulus* sp.; interval 200–210, 10 percent chalky shells and shell fragments, mainly molluscan—pelecypods and *Turritella* sp.; interval 210–220, 35–40 percent chalky shells and shell fragments, mainly pelecypods and *Turritella* sp., and a few solitary corals, fish teeth, and vertebrae; interval 220–230, 40–45 percent chalky shell material and a few vertebrates; small pockets of carbonaceous matter are common.

PATUXENT FORMATION (235–337 feet) (Top of formation defined on basis of other information.)

230–240 Gravel and sand; tan, no clay; about 50 percent medium- to very coarse-grained, subrounded sand; about 50 percent fine-grained (2–10 mm), rounded gravel; sand is slightly glauconitic and feldspathic; gravel consists of several quartz types, rock fragments, and a little feldspar.

240–260 Sand and gravel; tan, slightly clayey; 70 percent coarse-grained, well-sorted, subrounded sand; 30 percent fine-grained (2–10 mm) gravel; sand is slightly feldspathic, very slightly glauconitic; gravel consists mainly of reangulated (broken rounds of) quartz and several types of rock fragments; interval 250–260, gravel is finer-grained (2–6 mm) and rounded.

260–337 From 260–337 the sequence consists predominantly of tan and light-gray sandy gravels with little or no clay. Gravel-size material consists in large part of broken rounds (cobble or boulder beds); sand fractions are mainly coarse to very coarse and moderately sorted to well sorted; downward, feldspar becomes much more prominent in both fractions, and glauconite virtually disappears; fragments of sand-free pale-green clay are present in the following intervals: 280–290, 300–310, and 330–337.

APPENDIX II

GEOLOGIC SUMMARIES

(Only selected water wells used in mapping)

EXPLANATION

W–236	Numbers preceded by the letter "W" refer to those wells whose samples are on file in the Division's repository.
sg	Top of Tertiary-Quaternary sand and gravel (regressive sediments)
cs	Top of Miocene clayey silt (transgressive sediments)
Tn	Top of Nanjemoy Formation
Tma	Top of Marlboro Clay Member
TKm	Top of Mattaponi Formation
Kptx	Top of Patuxent Formation
base	Top of "basement" rocks
Tr?	Probable Triassic rocks
abs	Stratigraphic unit absent
nd	Top of stratigraphic unit not determined
TD	Total depth of borehole in feet

All elevations are relative to sea level datum.

	Elevation of top (in feet)
W–199	
sg	170
cs	130
Tn	22
Tma	–5
TKm	–15
Kptx	–100
TD 356	
W–236	
sg	160
cs	102
Tn	nd
Tma	25
TKm	17
TD 190	
W–338	
sg	165
cs	111
Tma	nd
TKm	nd
Kptx	–84
base	–185
TD 350	

	Elevation of top (in feet)
W–493	
sg	150
cs	107
Tn	nd
Tma	nd
TKm	nd
Kptx	–88
TD 308	
W–509	
sg	165
cs	115
Tn	75
Tma	–2
TKm	45
Kptx	–2
TD 326	
W–510	
sg	159
cs	99
Tn	34
Tma	29
TKm	17
Kptx	–15
TD 322	

	Elevation of top (in feet)
W–511	
sg	165
cs	124
Tn	74
Tma	16
TKm	–2
Kptx	–41
TD 350	
W–590	
sg	187
cs	127
Tn	nd
Tma	nd
TKm	nd
Kptx	–43
TD 384	
W–749	
sg	173
cs	113
Tn	53
Tma	–7?
TKm	–27
Kptx	–67
TD 320	
W–750	
sg	175
cs	85
Tn	65
Tma	35?
TKm	25
Kptx	–45
TD 320	
W–858	
sg	149
cs	109
Tn	49
Tma	abs
TKm	nd
Kptx	19
base (Tr?)	–104
TD 370	
W–969	
sg	190
cs	142
Tn	nd
Tma	nd
TKm	nd
Kptx	–30
base	–77
TD 608	
W–1008	
sg	155
cs	105
Tn	nd
Tma	25
TKm	15
Kptx	–25
TD 292	
W–1009	
sg	163
cs	113
Tn	73
Tma	nd
TKm	nd
Kptx	–27
TD 375	
W–1123	
sg	153
cs	106
Tn	76
Tma	41?
TKm	33
Kptx	12
base	–104
TD 255	
W–1157	
sg	157
cs	112
Tn	67
Tma	nd
TKm	nd
Kptx	37
base (Tr?)	–153
TD 350	
W–1177	
sg	164
cs	144
Tn	84
Tma	nd
TKm	nd
Kptx	–27
base (Tr?)	–116
TD 326	

	Elevation of top (in feet)
W–1247	
sg	125
cs	105
Tn	35
Tma	30
TKm	20
Kptx	5
base	–165
TD 296	
W–1291	
sg	155
cs	130
Tn	86
Tma	abs
TKm	43
Kptx	–10
base (Tr?)	–180
TD 340	
W–1301	
sg	175
cs	125
Tn	nd
Tma	nd
TKm	nd
Kptx	–83
TD 320	
W–1302	
sg	155
cs	145
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	135
TD 300	
W–1305	
sg	182
cs	147
Tn	abs
Tma	abs
TKm	62
Kptx	42
base	–18
TD 508	
W–1472	
sg	195
cs	135
Tn	30
Tma	abs
TKm	abs
Kptx	5
base	–65
TD 395	
W–1477	
sg	153
cs	116
Tn	71
Tma	57
TKm	49
Kptx	17
base	–67
TD 227	
W–1532	
sg	209
cs	156
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	111
TD 500	
W–1570	
sg	220
cs	abs
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	140
TD 225	
W–1612	
sg	157
cs	127
Tn	87
Tma	47
TKm	27
Kptx	7
base(?)	–145
TD 302	
W–1658	
sg	133
cs	abs
Tn	abs
Tma	abs

	Elevation of top (in feet)
TKm	abs
Kptx	abs
base	103
TD 300	
W–1659	
sg	133
cs	abs
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	113
TD 350	
W–1662	
sg	163
cs	123
Tn	63
Tma	0
TKm	–9
Kptx	–45
base	–135
TD 298	
W–1695	
sg	180
cs	abs
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	179
TD 250	
W–1769	
sg	162
cs	112
Tn	92
Tma	12?
TKm	–8
Kptx	–23
TD 314	
W–1770	
sg	188
cs	141
Tn	nd
Tma	nd
TKm	18?
Kptx	–32
TD 370	

	Elevation of top (in feet)
W–1791	
sg	200
cs	150
Tn	nd
Tma	50
TKm	30
Kptx	–30
base	–120
TD 632	
W–1799	
sg	165
cs	155
Tn	35
Tma	nd
TKm	25
Kptx	–5
base	
TD 275	
W–1800	
sg	165
cs	135
Tn	nd
Tma	nd
TKm	nd
Kptx	15
base	–85
TD 708	
W–1815	
sg	200
cs	140
Tn	30
Tma	25?
TKm	20
Kptx	–10
TD 274	
W–1839	
sg	120
cs	110
Tn	nd
Tma	60
TKm	40
Kptx	20
base	–80
TD 213	
W–1840	
sg	abs
cs	120

	Elevation of top (in feet)
Tn	nd
Tma	nd
TKm	nd
Kptx	40
TD 189	
W–1842	
sg	150
cs	120
Tn	80
Tma	70?
TKm	60?
Kptx	0
TD 249	
W–1878	
sg	185
cs	135
Tn	abs
Tma	abs
TKm	65
Kptx	58
base	15
TD 640	
W–1898	
sg	162
cs	abs
Tn	82
Tma	abs
TKm	nd
Kptx	42
base (Tr?)	–108
TD 300	
W–1948	
sg	175
cs	125
Tn	65
Tma	nd
TKm	–26
Kptx	–50
TD 306	
W–2068	
sg	195
cs	155
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	113
TD 322	
W–2069	
sg	211
cs	abs
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	202
TD 150	
W–2197	
sg	185
cs	155
Tn	65
Tma	nd
TKm	–5
Kptx	–65
TD 320	
W–2224	
sg	170
cs	120
Tn	40
Tma	nd
TKm	–20
Kptx	–50
base	–240
TD 412	
W–2237	
sg	140
cs	125
Tn	nd
Tma	nd
TKm	nd
Kptx	–14
base	–48
TD 260	
W–2248	
sg	208
cs	178
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	108
TD 218	

	Elevation of top (in feet)
W–2349	
sg	160
cs	120
Tn	nd
Tma	abs
TKm	50
Kptx	–20
TD 266	
W–2417	
sg	170
cs	120
Tn	40
Tma	11
TKm	0
Kptx	–10
base	–50
TD 600	
W–2478	
sg	202
cs	172
Tn	nd
Tma	abs
TKm	nd
Kptx	abs
base	97
TD 282	
W–2501	
sg	161
cs	106
Tn	nd
Tma	nd
TKm	nd
Kptx	–59
TD 304	
W–2573	
sg	165
cs	135
Tn	95
Tma	25
TKm	15
Kptx	–15
TD 286	
W–2574	
sg	175
cs	abs
Tn	55
Tma	nd
TKm	–20
Kptx	–30
TD 324	
W–2617	
sg	183
cs	105
Tn	nd
Tma	nd
TKm	nd
Kptx	–57
base	–185
TD 370	
W–2683	
sg	154
cs	107
Tn	74
Tma	44
TKm	20
Kptx	–19
base (Tr?)	–356
TD 540	
W–2800	
sg	175
cs	115
Tn	nd
Tma	nd
TKm	nd
Kptx	–15
TD 245	
W–2841	
sg	181
cs	147
Tn	nd
Tma	nd
TKm	nd
Kptx	–9
base	–125
TD 451	
W–2926	
sg	190
cs	abs
Tn	abs
Tma	abs
TKm	abs
Kptx	nd
base	80
TD 250	

	Elevation of top (in feet)
W–2932	
sg	202
cs	abs
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	172
TD 400	
W–2936	
sg	150
cs	124
Tn	60
Tma	40
TKm	20
Kptx	–20
TD 286	
W–3068	
sg	165
cs	120
Tn	25
Tma	–55?
TKm	–65
Kptx	–91
TD 452	
W–3087	
sg	157
cs	132
Tn	37
Tma	27
TKm	–3
Kptx	–23
base	–100
TD 257	
W–3107	
sg	152
cs	122
Tn	82
Tma	24
TKm	16
Kptx	2
TD 295	
W–3277	
sg	208
cs	187
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	122
TD 250	
W–3284	
sg	140
cs	110
Tn	70
Tma	30
TKm	20
Kptx	–15
TD 310	
W–3366	
sg	190
cs	165
Tn	abs
Tma	abs
TKm	abs
Kptx	40
base	25
TD 405	
W–3401	
sg	170
cs	60
Tn	30
Tma	0?
TKm	–10
Kptx	–50
TD 330	
W–3546	
sg	193
cs	133
Tn	43
Tma	23
TKm	13
Kptx	–42
TD 337	
W–3574	
sg	160
cs	100
Tn	60
Tma	10
TKm	0
Kptx	–50
base (Tr?)	–300
TD 610	

	Elevation of top (in feet)
W–3637	
sg	162
cs	133
Tn	18?
Tma	nd
TKm	nd
Kptx	–62
TD 362	
W–3638	
sg	188
cs	138
Tn	48?
Tma	nd
TKm	nd
Kptx	–42
TD 394	
W–3654	
sg	182
cs	abs
Tn	abs
Tma	abs
TKm	abs
Kptx	abs
base	150
TD 200	
W–3664	
sg	157
cs	107
Tn	62
Tma	47
TKm	12
Kptx	–28
TD 330	
W–3782	
sg	167
cs	82?
Tn	77
Tma	nd
TKm	nd
Kptx	–3
TD 315	
W–3900	
sg	56
cs	28
Tn	24
Tma	–27
TKm	–36
Kptx	–82
base	–448
TD 504	
W–3901	
sg	178
cs	154
Tn	24
Tma	–30
TKm	–50
Kptx	–82
base	–449
TD 628	
W–3902	
sg	90
cs	87
Tn	76
Tma	37
TKm	26
Kptx	1
base	–40
TD 155	
W–3903	
sg	162
cs	115
Tn	75
Tma	abs
TKm	nd
Kptx	55
base (Tr?)	–120
TD 404	
W–3904	
sg	170
cs	101
Tn	53
Tma	–3
TKm	–8
Kptx	–60
base (Tr?)	–344
TD 600	

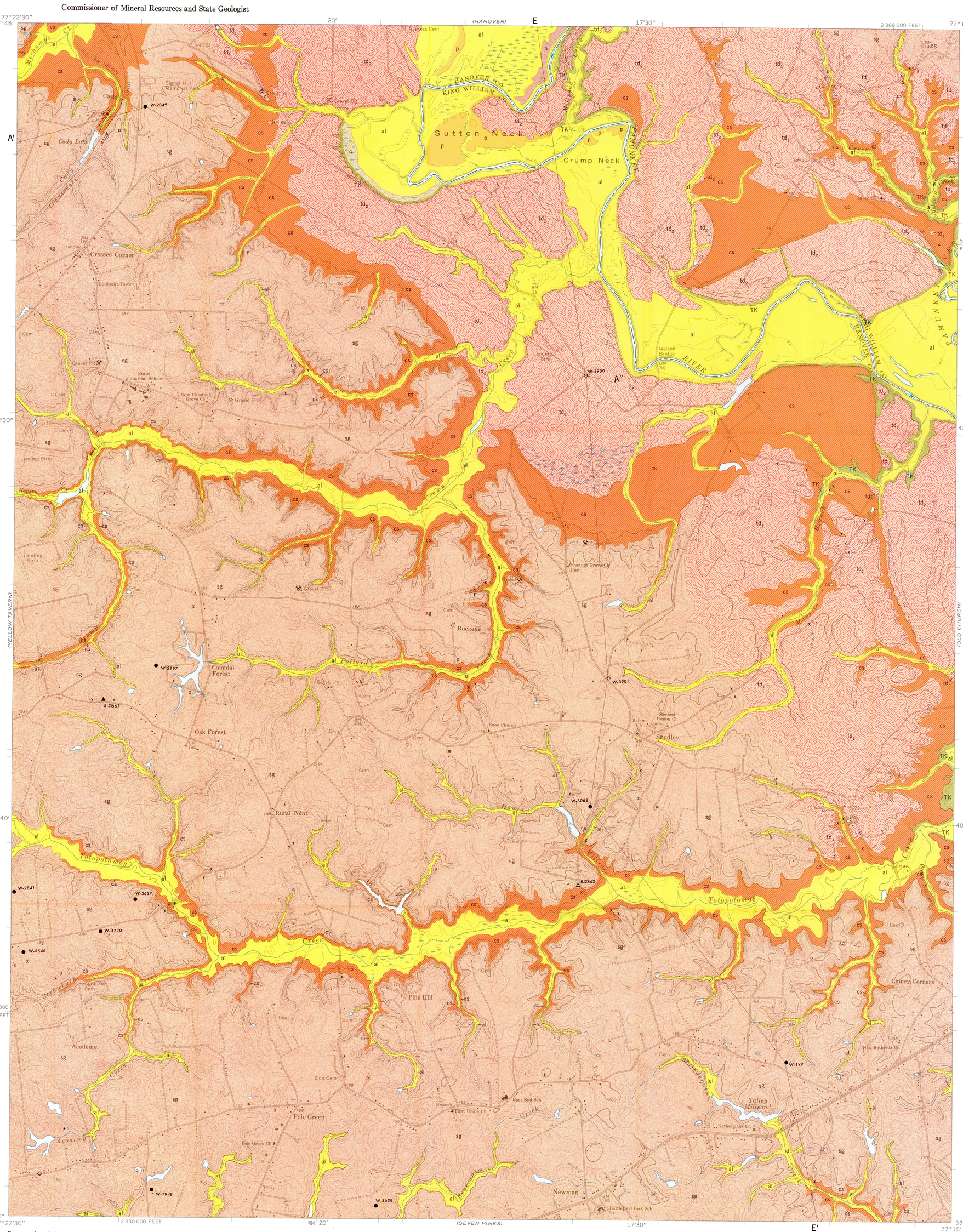
INDEX

PAGE

Acca Yards 22, 23
Alluvium 9, 35-36, 54
Almond Creek 16
Aquia Formation 4, 19
Ashland 37
Ashland quadrangle 4
Atlee 2
"Basement" 7, 9-15, 38, 44-47
Brandywine Formation 9, 28
Brick clay 38
Calvert Formation 8, 21, 28
Campbell Creek 13
Chesterfield County 1
Chickahominy River 3, 13, 14, 17, 24, 26, 42
Coastal Plain province 1, 3
Columbia Group 9, 28
Depositional system 4
Diastem 21, 22
Diatoms 28
Diatomaceous earth 39
Elmont 2
Erwin Formation 29
Estuarine/marine depositional system 7
Fairhaven diatomaceous member 28
Fall Line 3, 13
Fluvial depositional system 7, 9
Gillie Creek 16
Glauconite 19, 20
"Granite wash" 14
Gravetts Millpond 22
Hanover Academy quadrangle 4
Hanover County 1
Hanover quadrangle 22
Henrico County 1
James River 3, 14, 16, 17, 34, 38, 42
Joseph Bryan Park 14
King William County 1
Lafayette formation 9, 28
Marlboro Clay Member 4, 19, 21

Mattaponi Formation 8, 19-21
Mayo's Island 3
Mechanicsville 2, 13, 19, 26, 37
"Miocene marl" 8
Mollusks 28
Nanjemoy Formation 8, 19, 21
Ninth Street Bridge 14
North Run 14, 43
Pamunkey River 3, 13, 26, 29, 43
Patuxent Formation ..... 7, 15 -19, 38, 47-50
Petersburg granite 9, 13, 23, 37
Piedmont province 1, 3, 7
Porpoise (fossil bones) 28
"Red beds" (Triassic) 7, 9, 15
Regressive sediments
(Tertiary-Quaternary) 9, 13, 24, 28-35, 38, 39, 51-53
Rhizopods 28
Richmond 2, 3
Rock Quality Designator 45-47
St. Marys Formation 8, 21
Sandston 2, 9
Saprolite 14, 38
Seven Pines 2
Shockoe Valley 4
Sliding Hill 30
Standard Penetration Resistance 53
Standard Penetration Test 48, 49, 53
Stone
crushed 37
dimension 37
Studley 2
Totopotomy Creek 13, 43
Transgressive sediments (Miocene) 8, 21-28, 38, 39, 50-51
Upham Brook 14, 34, 37
Upland gravels (Tertiary) 9
Vetebrate fossils 26
Vivianite 26
Whale (fossil bones) 28

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist



Base map from U. S. Geological Survey, 1964
Studley Quadrangle, 7½ Minute Series

Williams & Heintz Map Corporation

Copyright 1974
Commonwealth of Virginia

GEOLOGIC MAP OF THE STUDLEY QUADRANGLE, VIRGINIA

Geology by Paul A. Daniels, Jr. and Fred E. May

MN GN
6° 107 MILS
1°25' 25 MILS
UTM GRID AND 1964 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 10 FEET

VIRGINIA
QUADRANGLE LOCATION

1974

EXPLANATION

QUATERNARY

Alluvium

al, *organic and poorly sorted fluvial deposits ranging from clay to gravel;* p, *point-bar sands and gravels;* c, *abandoned-channel clays, sands and gravels;* n, *natural-levee clays and sands.*

Sand and gravel

Regressive sediments: fluvial clays, clayey silts, sands, and gravels; sorting and composition variable laterally and vertically. sg, *upland deposits;* td1, *terrace deposits along Pamunkey River formed on Miocene sediments;* td2, *terrace deposits along Pamunkey River formed on Eocene sediments.*

TERTIARY

Clayey silt

Transgressive sediments: marine, drab gray, green, and blue clayey silts; fossiliferous in part firm, well-sorted basal sand.

Tertiary and Cretaceous(?) sediments

TK: includes Tn, Tma, and TKm.

Tn *(in sections A'-A" and E-E' only): drab grayish-green, glauconitic clayey silt and quartz sand; fossiliferous; some thin limestone beds (Nanjemoy Formation).* Tma *(in sections A'-A" and E-E' only): pink to light-gray clay, in part interlaminated with very fine-grained glauconite (Marlboro Clay Member).*

TKm *(in sections A'-A" and E-E' only): drab, grayish-green, glauconitic clayey silt and quartz sand; basal conglomerate; fossiliferous; thin limestone and shell beds common (Mattaponi Formation).*

CRETACEOUS

Patuxent Formation
(In sections A'-A" and E-E' only)

Fluvial, white to light-gray sands and gravels with interbedded clay; plant fragments.

PALEOZOIC

Petersburg granite
(In section A'-A" only)

Biotite-microcline granite, quartz monzonite, and biotite gneiss.

CONTACTS

Solid where exposed, dashed where approximate, dotted where inferred

STRATIGRAPHIC CONTROL

W-199 / W-3900 — Borehole; W, repository number; ●, water well; ○, test boring

X — Outcrop sample or stratigraphic section that was examined

X F — Fossil locality

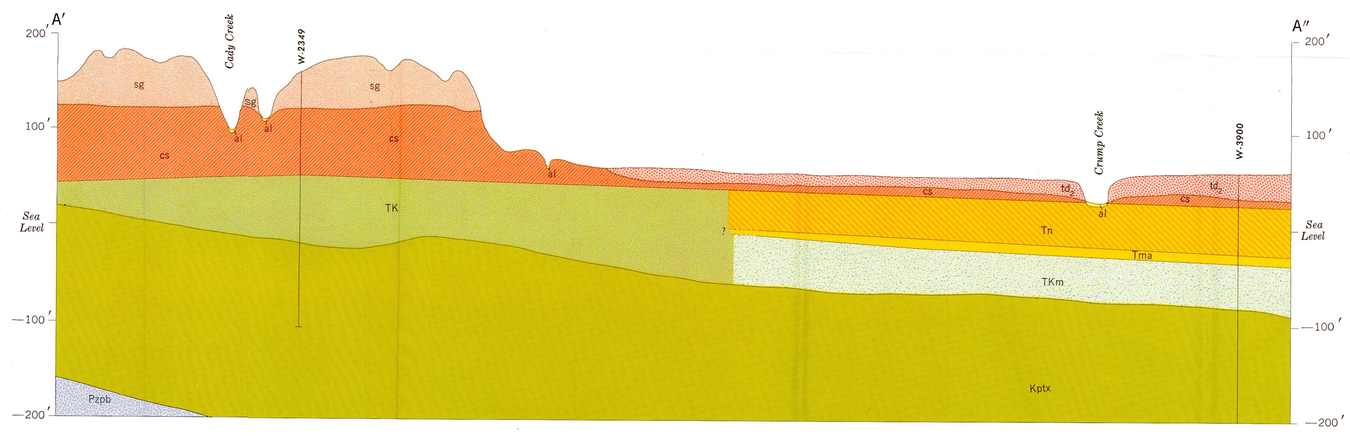
R-2862 — R, repository number of sample

R-2861 — Sample of raw material having potential commercial use; R, repository number

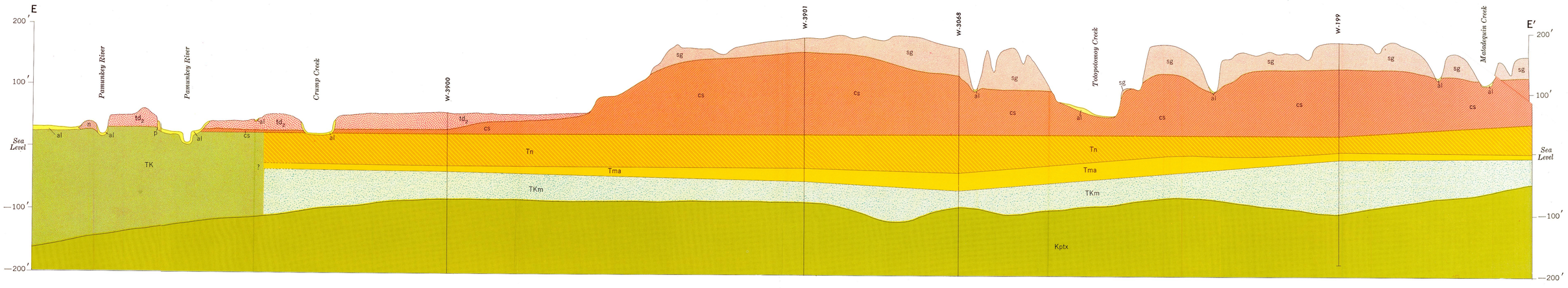
W-199 — Borehole along line of interpretive section; W, repository number

QUARRIES

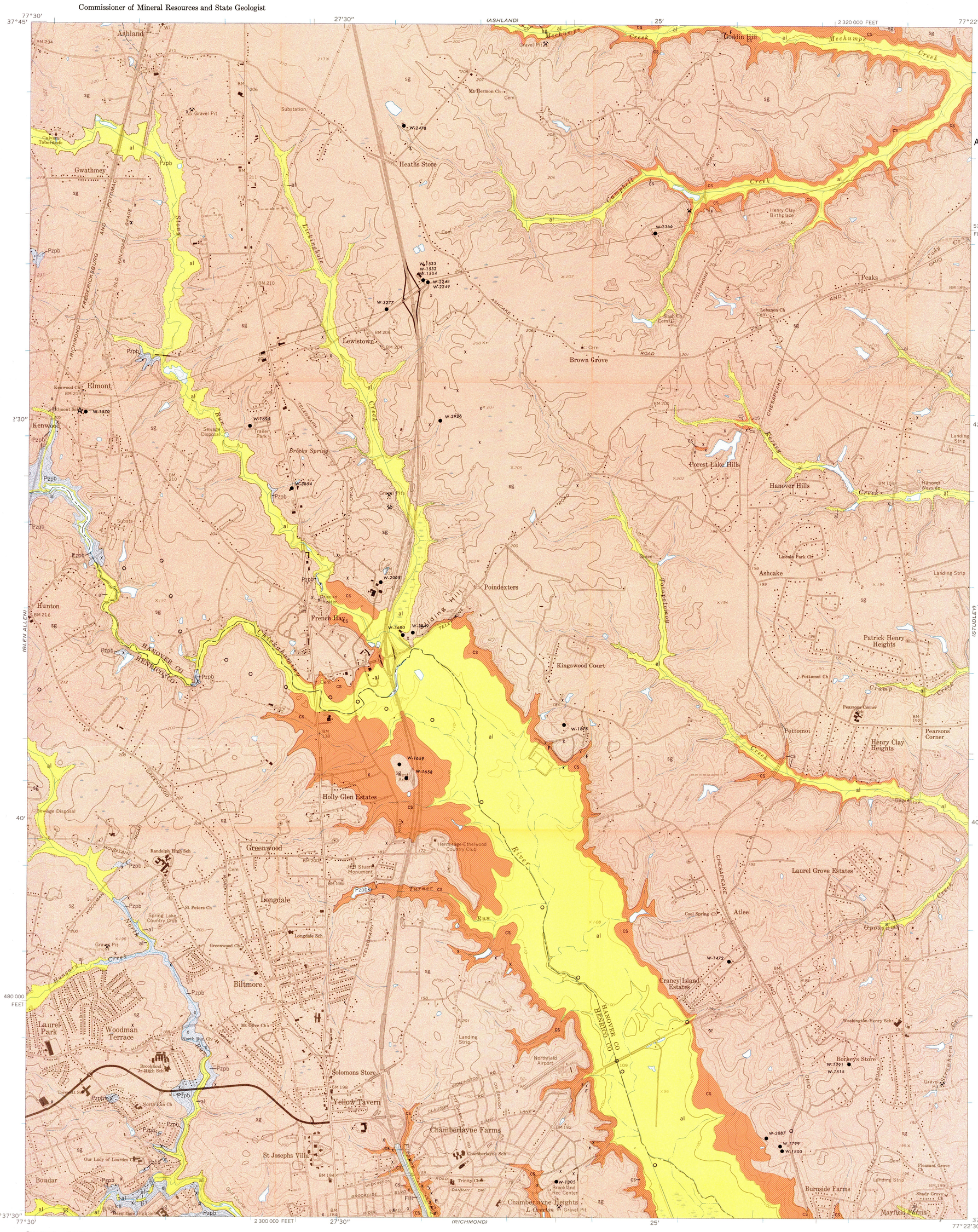
Abandoned quarry in clay, sand, or gravel



INTERPRETIVE SECTIONS WITH 20x VERTICAL EXAGGERATION



COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist



Base map from U.S. Geological Survey 1963
Seven Pines Quadrangle, 7½ Minute Series

Williams & Heintz Map Corporation

Copyright 1974
Commonwealth of Virginia

GEOLOGIC MAP OF THE YELLOW TAVERN QUADRANGLE, VIRGINIA

Geology by Fred E. May and Paul A. Daniels, Jr.

MN GN
6° 107 MILS
1°29' 26 MILS
UTM GRID AND 1968 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET

VIRGINIA
QUADRANGLE LOCATION

1974

EXPLANATION

QUATERNARY

al — Alluvium
Organic and poorly sorted fluvial deposits ranging from clay to gravel.

sg — Sand and gravel
Regressive sediments: fluvial clays, clayey silts, sands, and gravels; sorting and composition variable laterally and vertically. sg, *upland deposits.*

TERTIARY

cs — Clayey silt
Transgressive sediments: marine, drab gray, green, and blue clayey silts; fossiliferous in part; firm, well-sorted basal sand.

CRETACEOUS

TK — Tertiary and Cretaceous(?) sediments
(In section A-A′ only)
Drab grayish-green, glauconitic clayey silt and quartz sand; fossiliferous.

Kptx — Patuxent Formation
(In section A-A′ only)
Fluvial, white to light-gray sands and gravels with interbedded clay; plant fragments.

CENOZOIC — MESOZOIC

PALEOZOIC

Pzpb — Petersburg granite
Biotite-microcline granite, quartz monzonite, and biotite gneiss.

CONTACTS

Solid where exposed, dashed where approximate, dotted where inferred

STRATIGRAPHIC CONTROL

● W-1570 — Borehole; w, repository number; ●, water well; ○, test boring

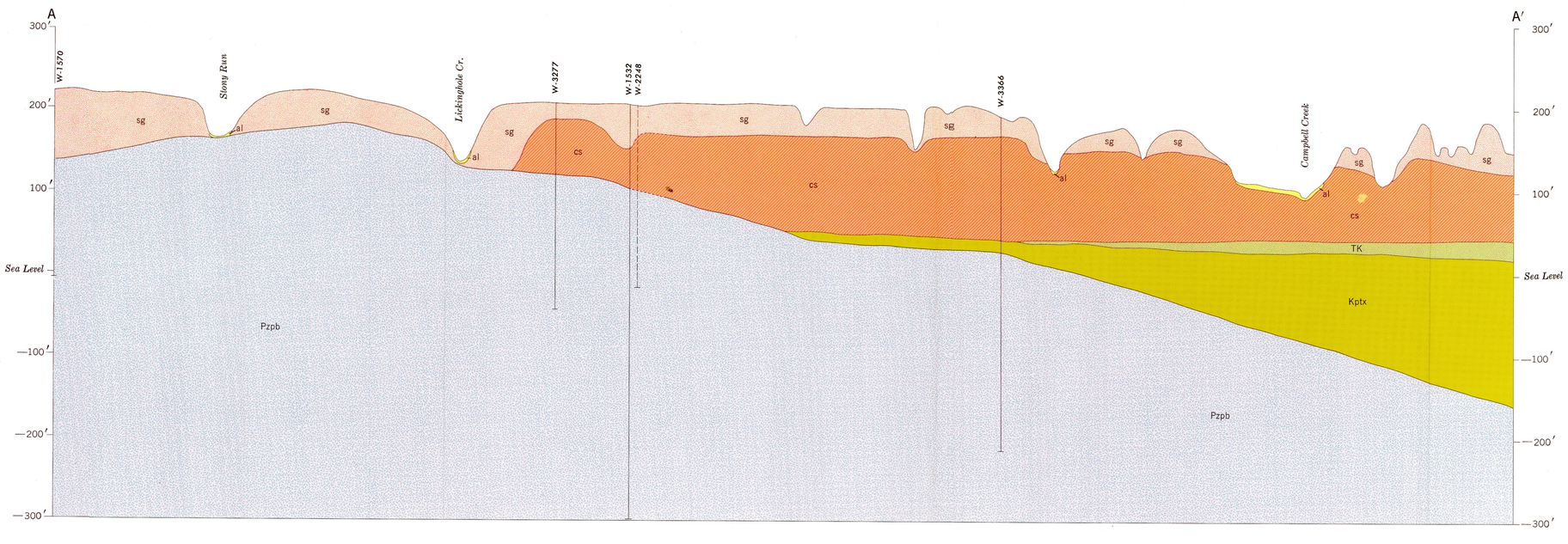
x — Outcrop sample or stratigraphic section that was examined

x F — Fossil locality

W-1570 — Borehole along line of interpretive section; w, repository number; projected perpendicularly into line of section where dashed

QUARRIES

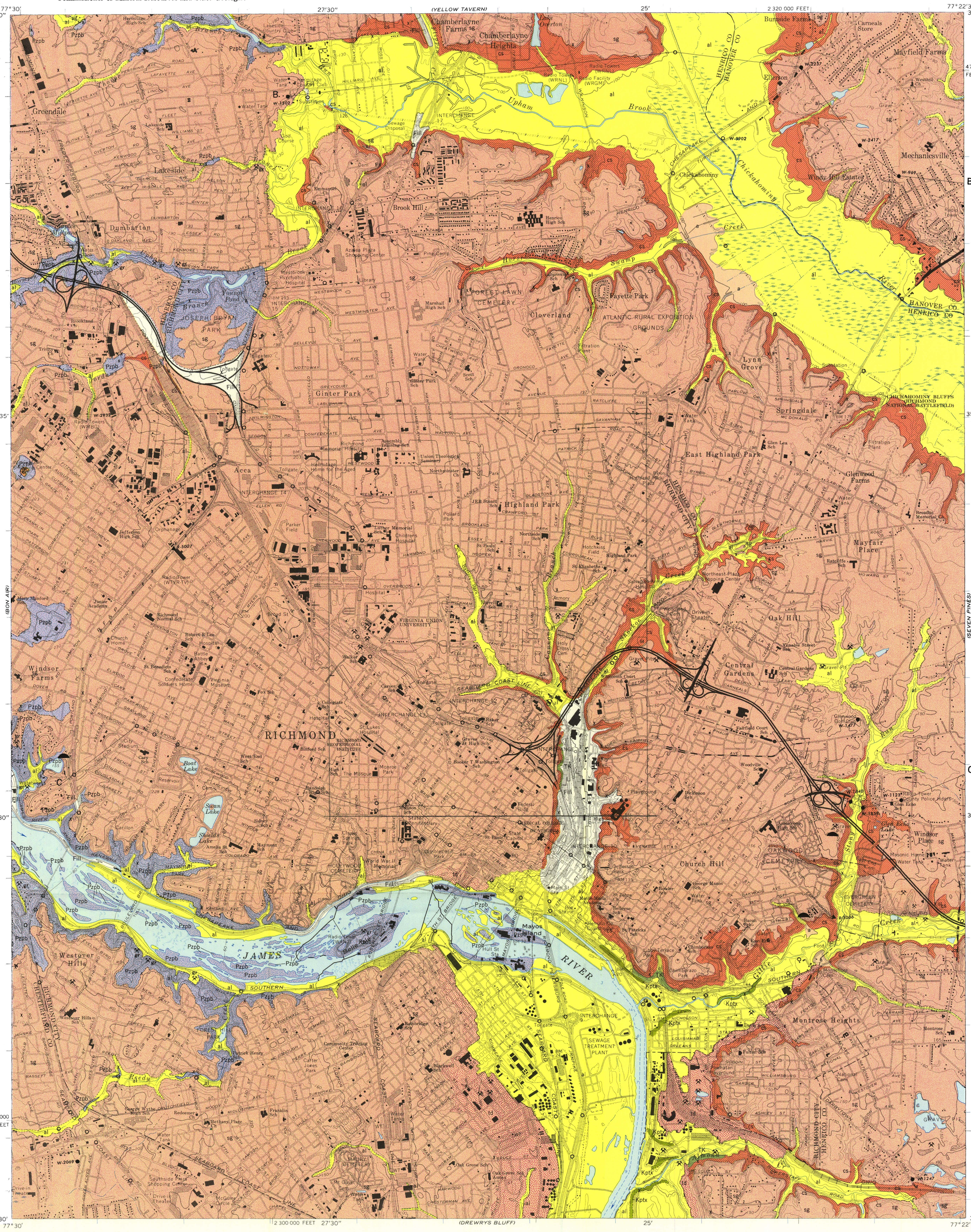
Abandoned quarry in clay, sand, or gravel



INTERPRETIVE SECTION WITH 20x VERTICAL EXAGGERATION

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

Richmond
VIRGINIA DIVISION OF MINERAL RESOURCES
LIBRARY
C.S.



Base map from U.S. Geological Survey, 1964
Richmond Quadrangle, 7½ Minute Series

Williams & Heintz Map Corporation

Copyright 1974
Commonwealth of Virginia

GEOLOGIC MAP OF THE RICHMOND QUADRANGLE, VIRGINIA

Geology by Paul A. Daniels, Jr.

1974

EXPLANATION

CENOZOIC — QUATERNARY

al | a — Alluvium

al, organic and poorly sorted fluvial deposits ranging from clay to gravel; a, alluvial-fan clays, sands, and gravels.

sg | td — Sand and gravel

Regressive sediments: fluvial clays, clayey silts, sands, and gravels; sorting and composition variable laterally and vertically. sg, *upland deposits;* td, *terrace deposits along James River.*

CENOZOIC — TERTIARY

cs — Clayey silt

Transgressive sediments: marine, drab gray, green, and blue clayey silts; fossiliferous in part; firm, well-sorted basal sand.

g — Gravels

Iron oxide-stained pebble to cobble gravel with brownish-red clay matrix.

TK | Tn | Tma | TKm — Tertiary and Cretaceous(?) sediments

TK: includes Tn, Tma, and TKm.

Tn *(in sections B-B′ and C-C′ only): drab grayish-green, glauconitic clayey silt and quartz sand; fossiliferous; some thin limestone beds (Nanjemoy Formation).* Tma *(in sections B-B′ and C-C′ only): pink to light-gray clay, in part interlaminated with very fine-grained glauconite (Marlboro Clay Member).*

TKm *(in sections B-B′ and C-C′ only): drab, grayish-green, glauconitic clayey silt and quartz sand; basal conglomerate; fossiliferous; thin limestone and shell beds common (Mattaponi Formation).*

MESOZOIC — CRETACEOUS

Kptx — Patuxent Formation

Fluvial, white to light-gray sands and gravels with interbedded clay; plant fragments.

PALEOZOIC

Pzpb — Petersburg granite

Biotite-microcline granite, quartz monzonite, and biotite gneiss.

CONTACTS

Solid where exposed, dashed where approximate, dotted where inferred

STRATIGRAPHIC CONTROL

● W-969 ○ W-3902 — Borehole; w, repository number; ●, water well; ○, test boring

x — Outcrop sample or stratigraphic section that was examined

x F — Fossil locality

▲ R-5006 — Sample of raw material having potential commercial use; R, repository number

W-969 — Borehole along line of interpretive section; w, repository number; projected perpendicularly into line of section where dashed

QUARRIES

Active quarry

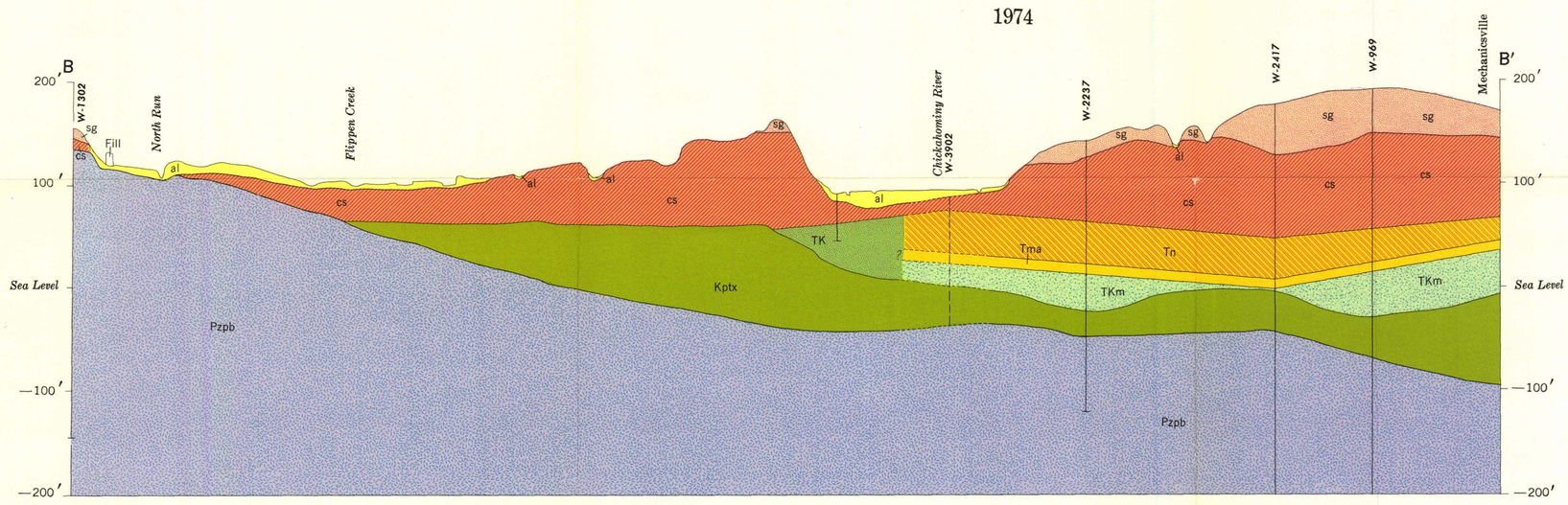
Carter Sand and Gravel Co., Inc. (sand and gravel)

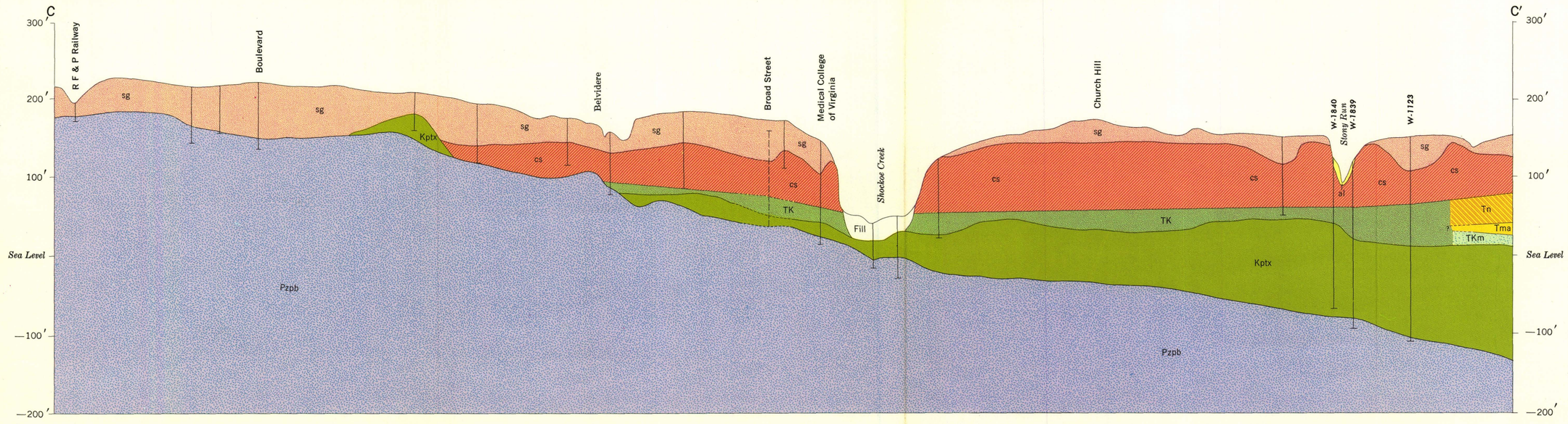
gr — Abandoned quarry in Petersburg granite

Abandoned quarry in clay, sand, or gravel

MISCELLANEOUS SITES

Sanitary landfill





SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET

VIRGINIA
QUADRANGLE LOCATION

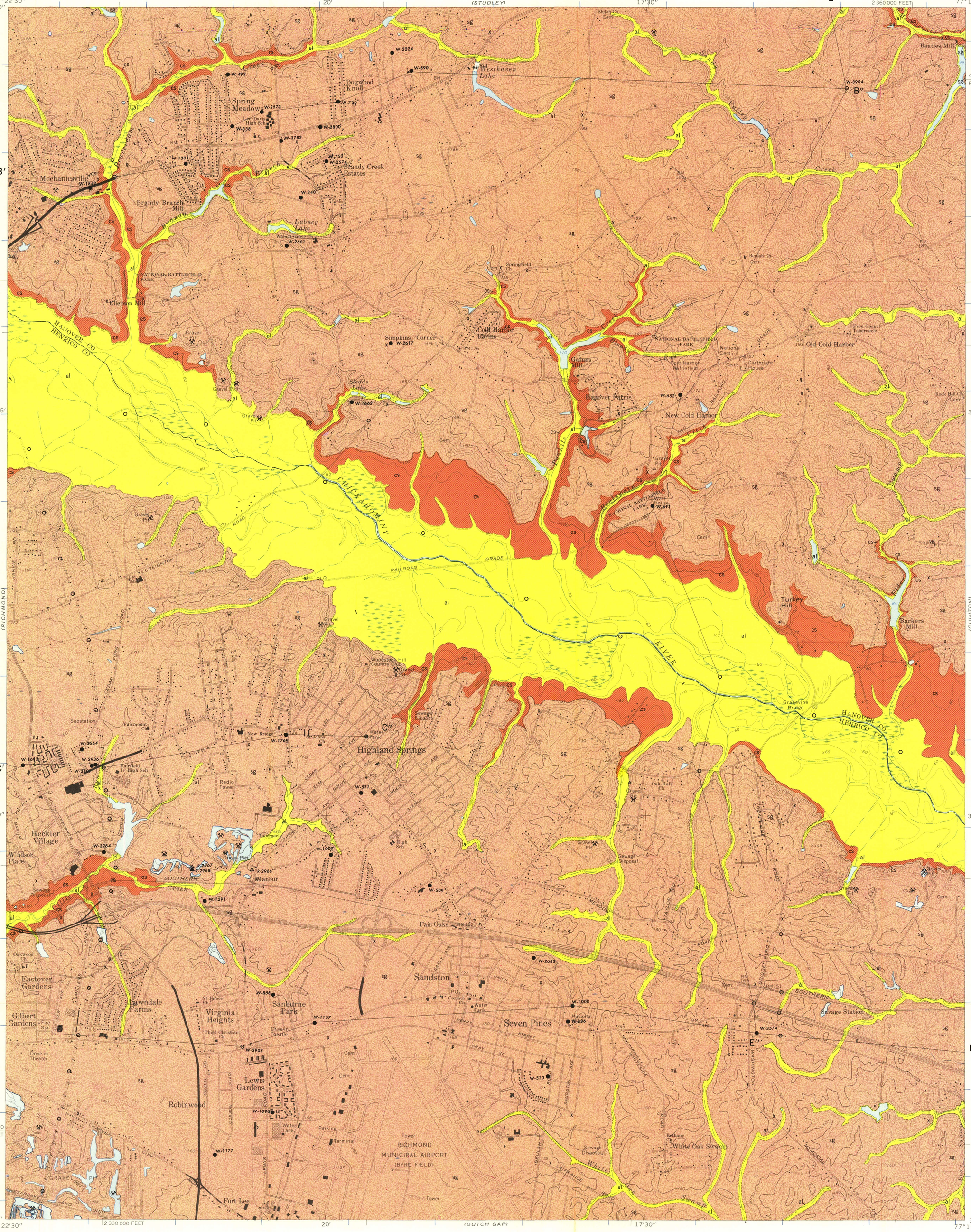
MN GN
6° 107 MILS
1°29′ 26 MILS

UTM GRID AND 1968 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

INTERPRETIVE SECTIONS WITH 20x VERTICAL EXAGGERATION

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

7 Pines
VIRGINIA DIVISION OF MINERAL RESOURCES LIBRARY
C.5



Base map from U. S. Geological Survey, 1964
Seven Pines Quadrangle, 7½ Minute Series

Williams & Heintz Map Corporation

Copyright 1974
Commonwealth of Virginia

GEOLOGIC MAP OF THE SEVEN PINES QUADRANGLE, VIRGINIA

Geology by Paul A. Daniels, Jr.

MN GN
6° 107 MILS
1°25' 25 MILS
UTM GRID AND 1968 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET

1974

VIRGINIA
QUADRANGLE LOCATION

See Plate 4A for Interpretive Sections

EXPLANATION

For Plates 4 and 4A

CENOZOIC — QUATERNARY

al — Alluvium
Organic and poorly sorted fluvial deposits ranging from clay to gravel.

sg — Sand and gravel
Regressive sediments: fluvial clays, clayey silts, sands, and gravels; sorting and composition variable laterally and vertically. sg, *upland deposits.*

CENOZOIC — TERTIARY

cs — Clayey silt
Transgressive sediments: marine, drab gray, green, and blue clayey silts; fossiliferous in part; firm, well-sorted basal sand.

TK (Tn, Tma, TKm) — Tertiary and Cretaceous(?) sediments (In interpretive sections)

TK: includes Tn, Tma, and TKm.

Tn: *drab grayish-green, glauconitic clayey silt and quartz sand; fossiliferous; some thin limestone beds (Nanjemoy Formation).* Tma: *pink to light-gray clay, in part interlaminated with very fine-grained glauconite (Marlboro Clay Member).*

TKm: *drab, grayish-green, glauconitic clayey silt and quartz sand; basal conglomerate; fossiliferous; thin limestone and shell beds common (Mattaponi Formation).*

MESOZOIC — CRETACEOUS

Kptx — Patuxent Formation (In interpretive sections)
Fluvial, white to light-gray sands and gravels with interbedded clay; plant fragments.

MESOZOIC — TRIASSIC

Ꞧu — Triassic rocks, undivided (In sections D-D' and E'-E'' only)
Partly consolidated "redbeds" consisting of red sandstone, red mudstone, and variegated shale.

PALEOZOIC

Fzpb — Petersburg granite (In sections B'-B'' and C'-C'' only)
Biotite-microcline granite, quartz monzonite, and biotite gneiss.

CONTACTS

Solid where exposed, dashed where approximate, dotted where inferred

STRATIGRAPHIC CONTROL

● W-3574 / ○ W-3904 — Borehole; w, repository number; ●, water well; ○, test boring

x — Outcrop sample or stratigraphic section that was examined

△ R-2966 — R, repository number of sample

▲ R-2968 — Sample of raw material having potential commercial use; R, repository number

W-1008 — Borehole along line of interpretive section; w, repository number; projected perpendicularly into line of section where dashed

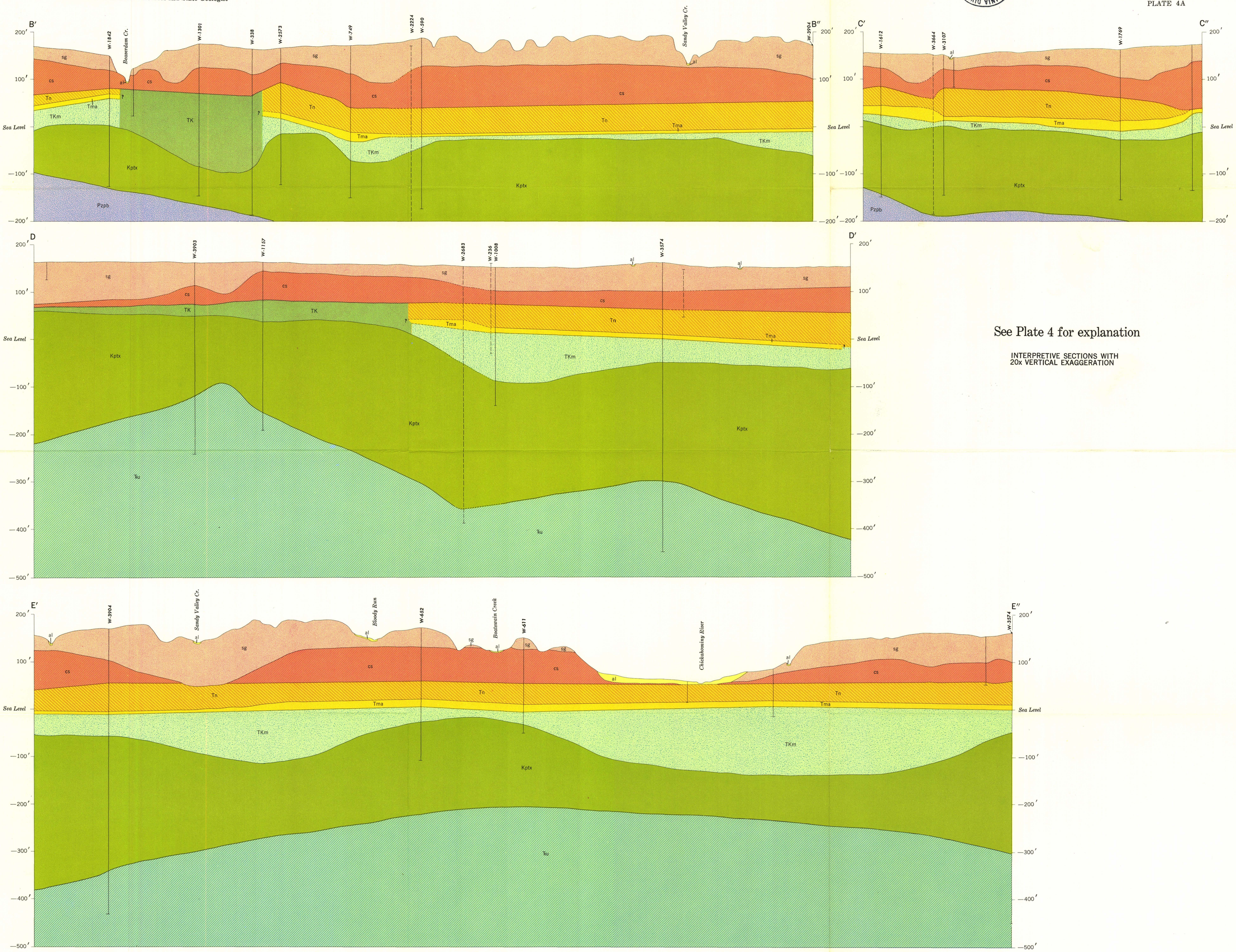
QUARRIES

Active quarry
Eastern Sales Corp. (sand and gravel)

Abandoned quarry in clay, sand, or gravel

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

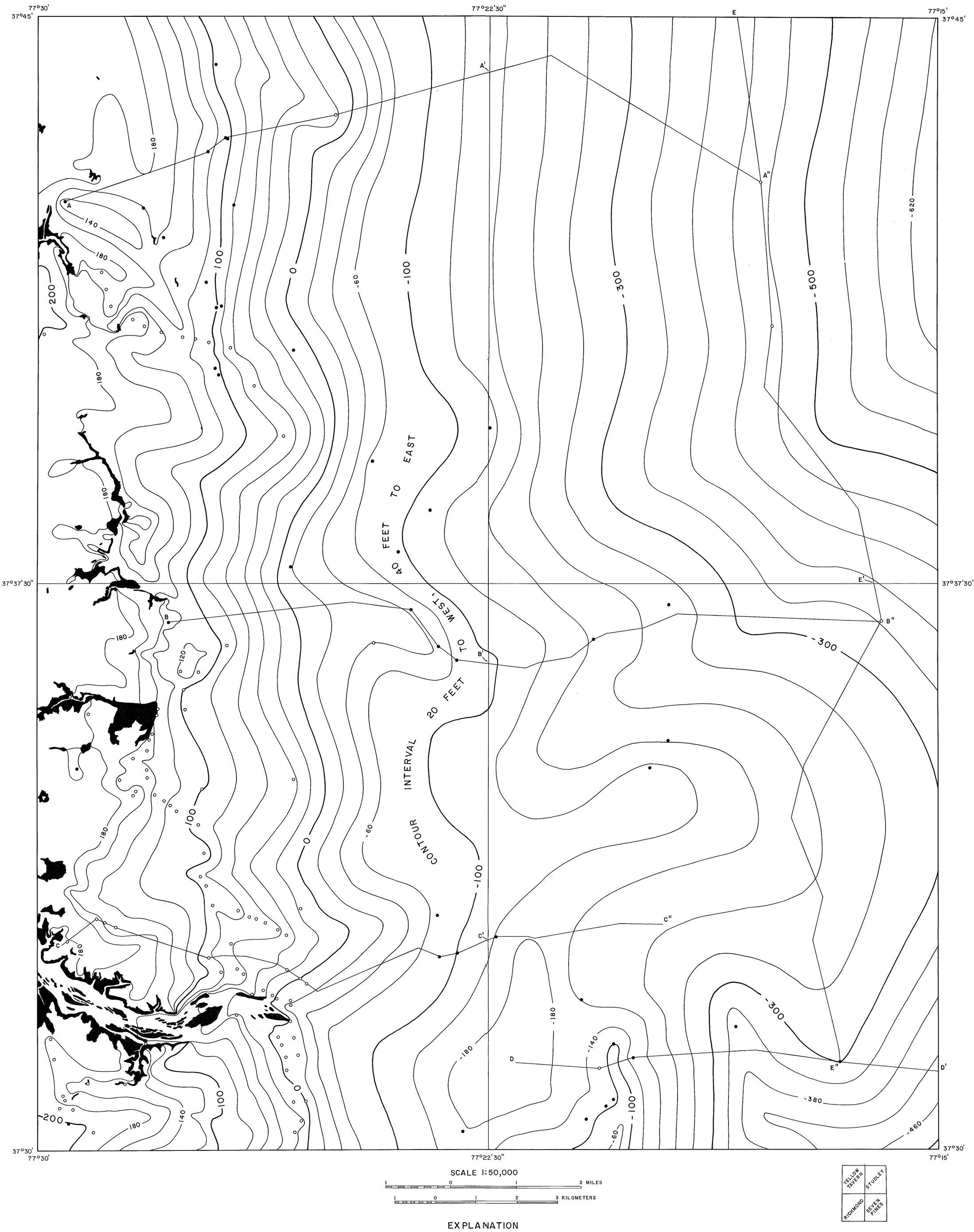
VIRGINIA DIVISION OF MINERAL RESOURCES LIBRARY



See Plate 4 for explanation

INTERPRETIVE SECTIONS WITH
20x VERTICAL EXAGGERATION

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

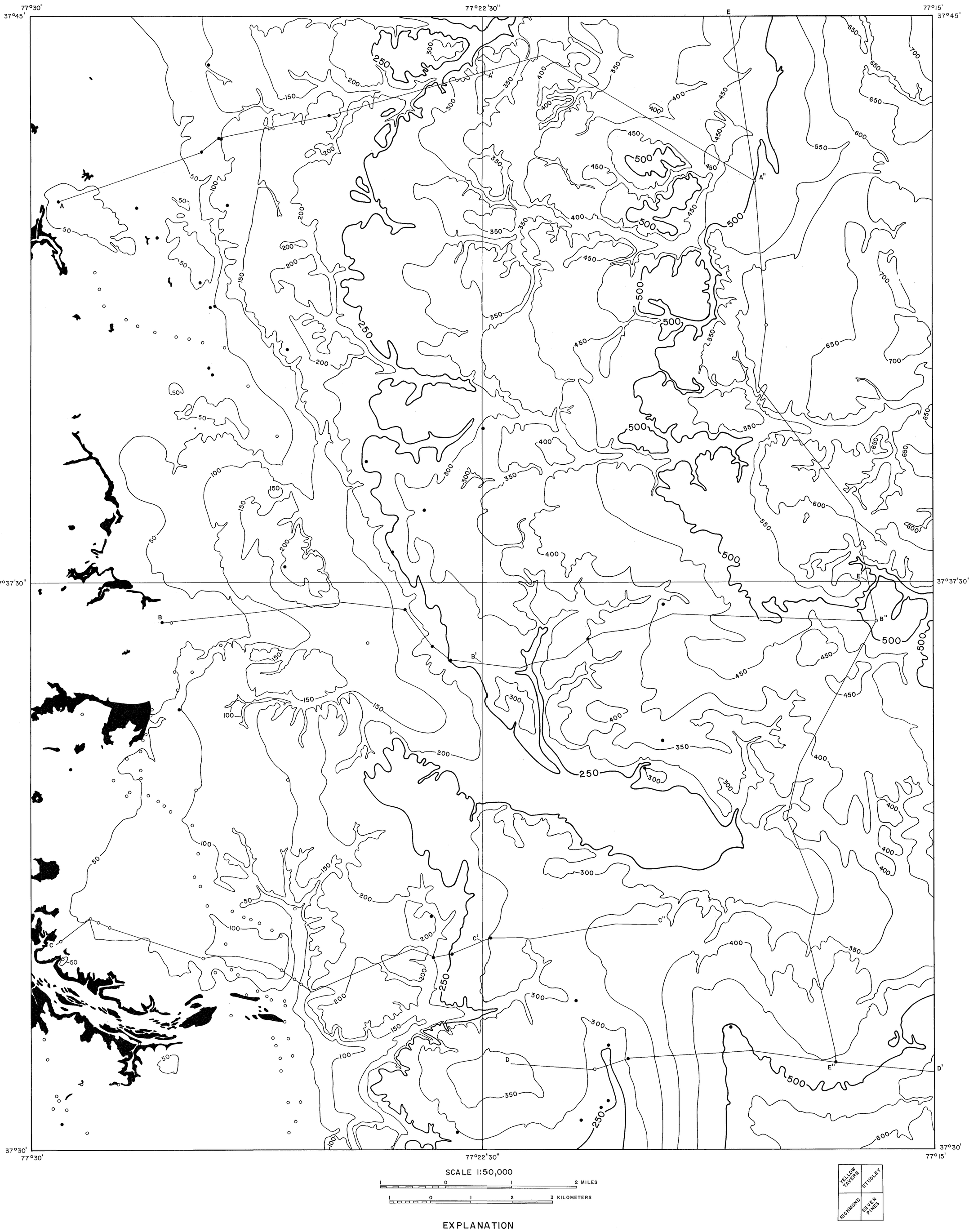


STRUCTURE-CONTOUR MAP OF THE "BASEMENT" STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

By Paul A. Daniels, Jr.

1974

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

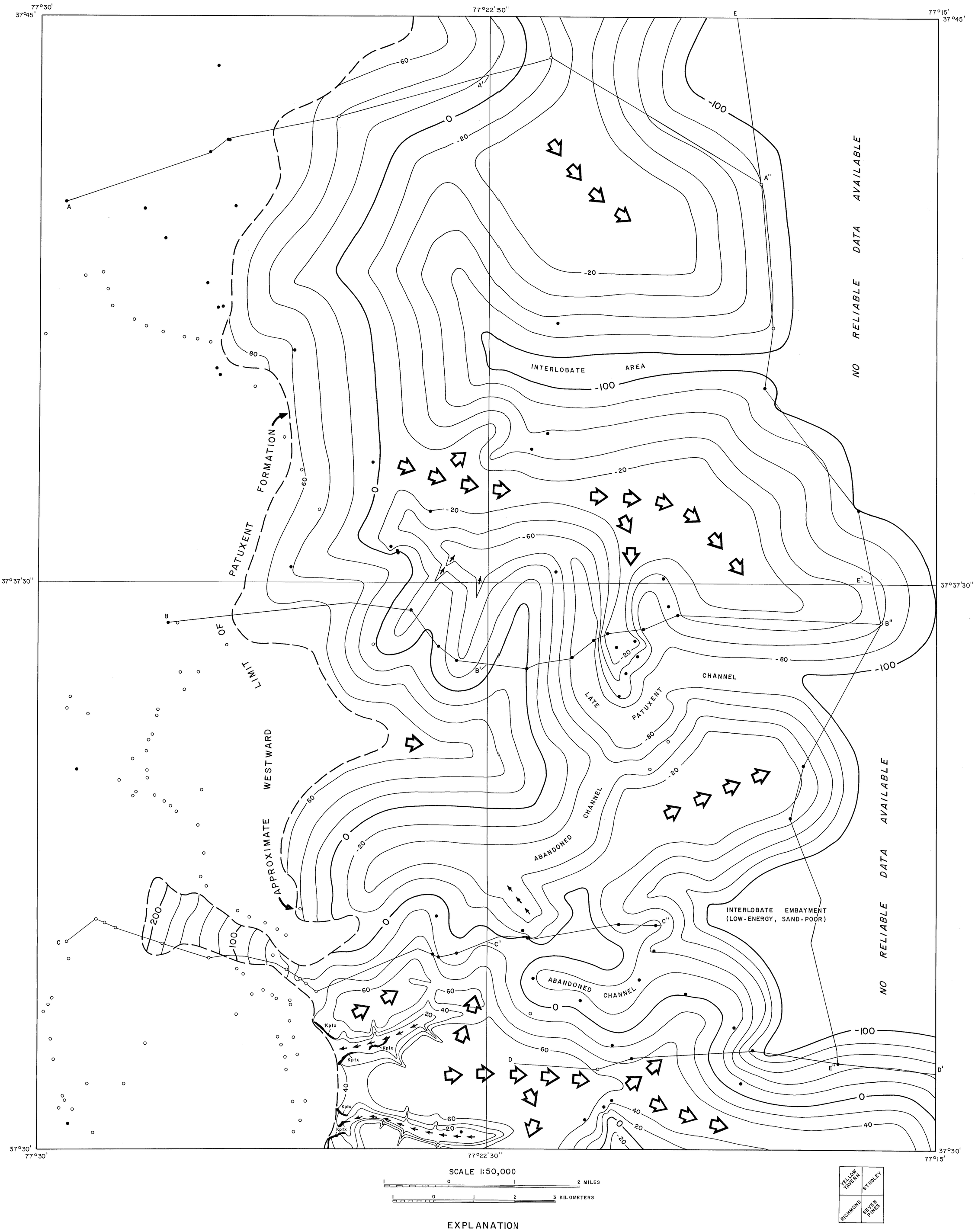


GENERALIZED DEPTH-TO-"BASEMENT" MAP
STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

By Paul A. Daniels, Jr.

1974

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

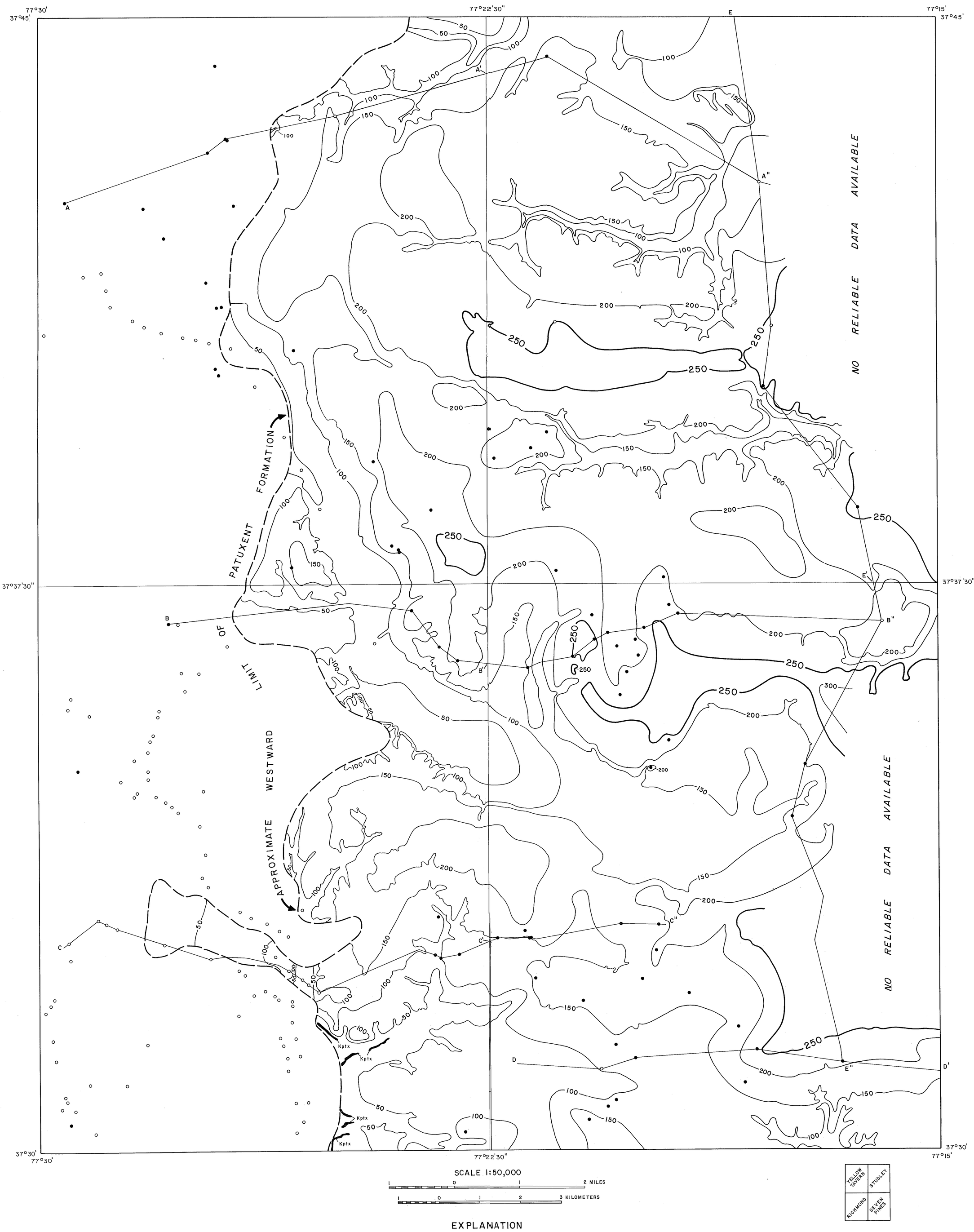


STRUCTURE-CONTOUR MAP OF THE PATUXENT FORMATION STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

By Paul A. Daniels, Jr.

1974

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

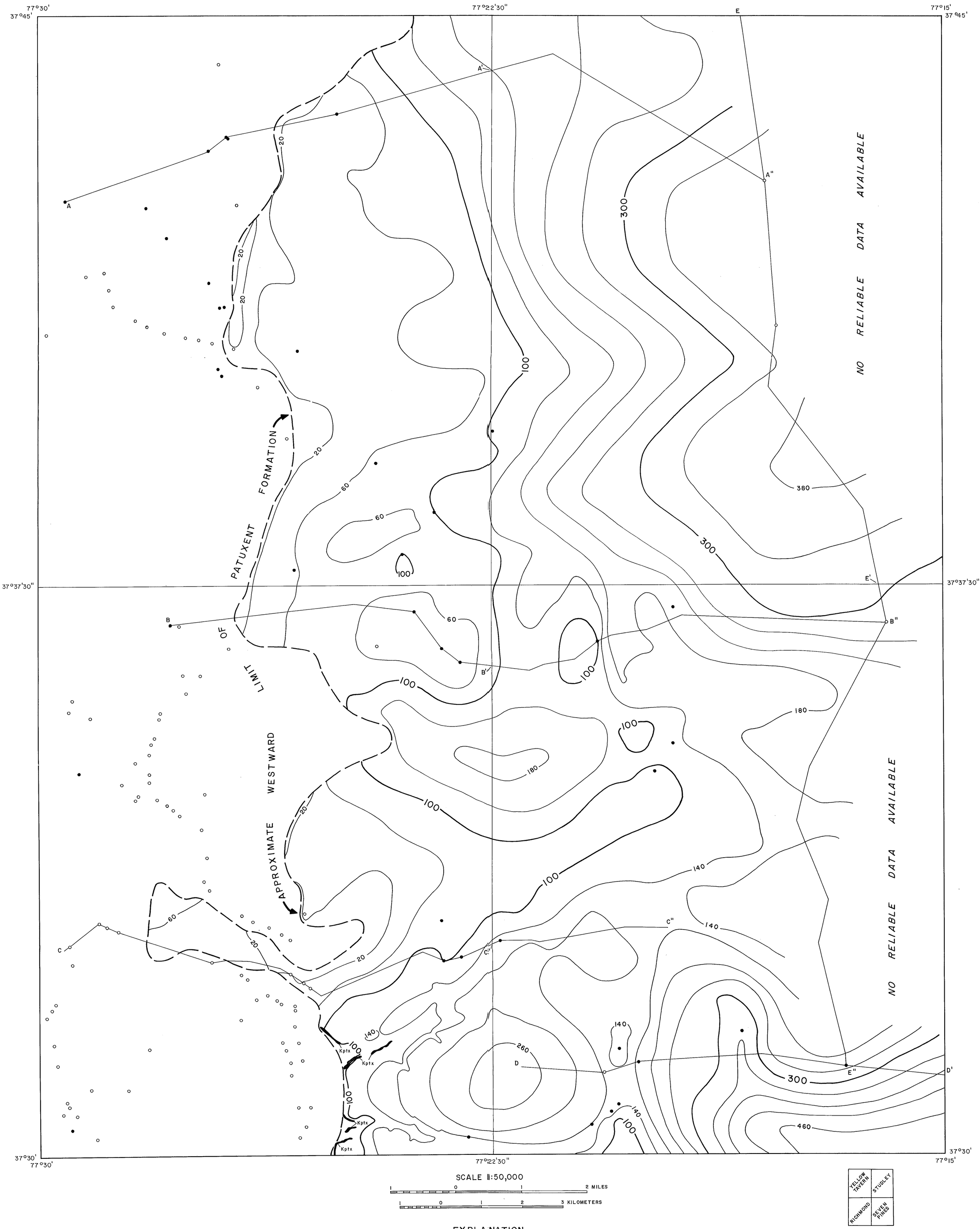


GENERALIZED DEPTH-TO-PATUXENT FORMATION MAP
STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

By Paul A. Daniels, Jr.

1974

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist



EXPLANATION

—100— Isopach of Patuxent Formation; interval 40 feet

Kptx Outcrop area of Patuxent Formation

D——D' Line of interpretive section

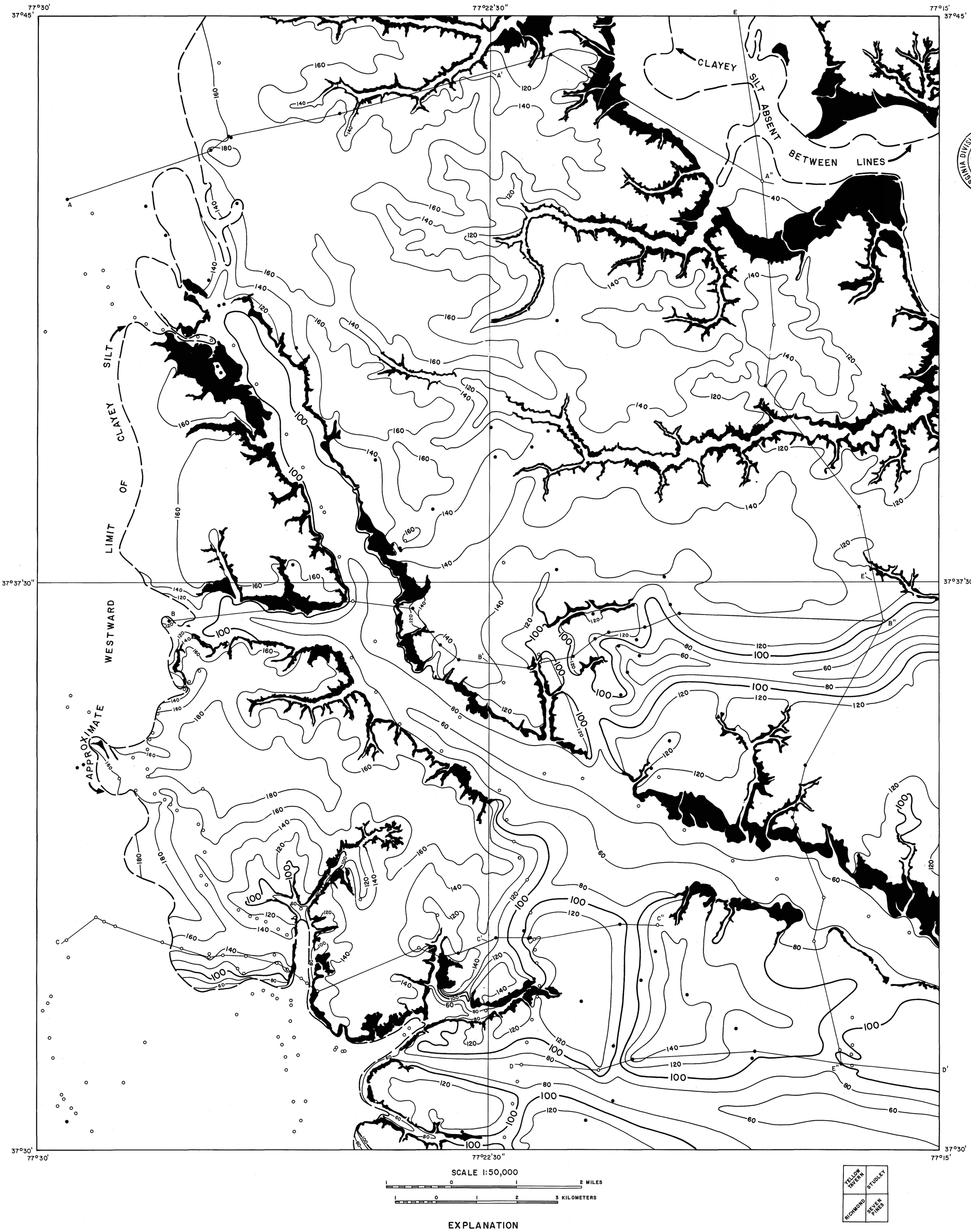
• Borehole; • , water well; ○ , test boring; ○ Patuxent Formation penetrated or absent

THICKNESS MAP OF THE PATUXENT FORMATION
STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

By Paul A. Daniels, Jr.

1974

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist



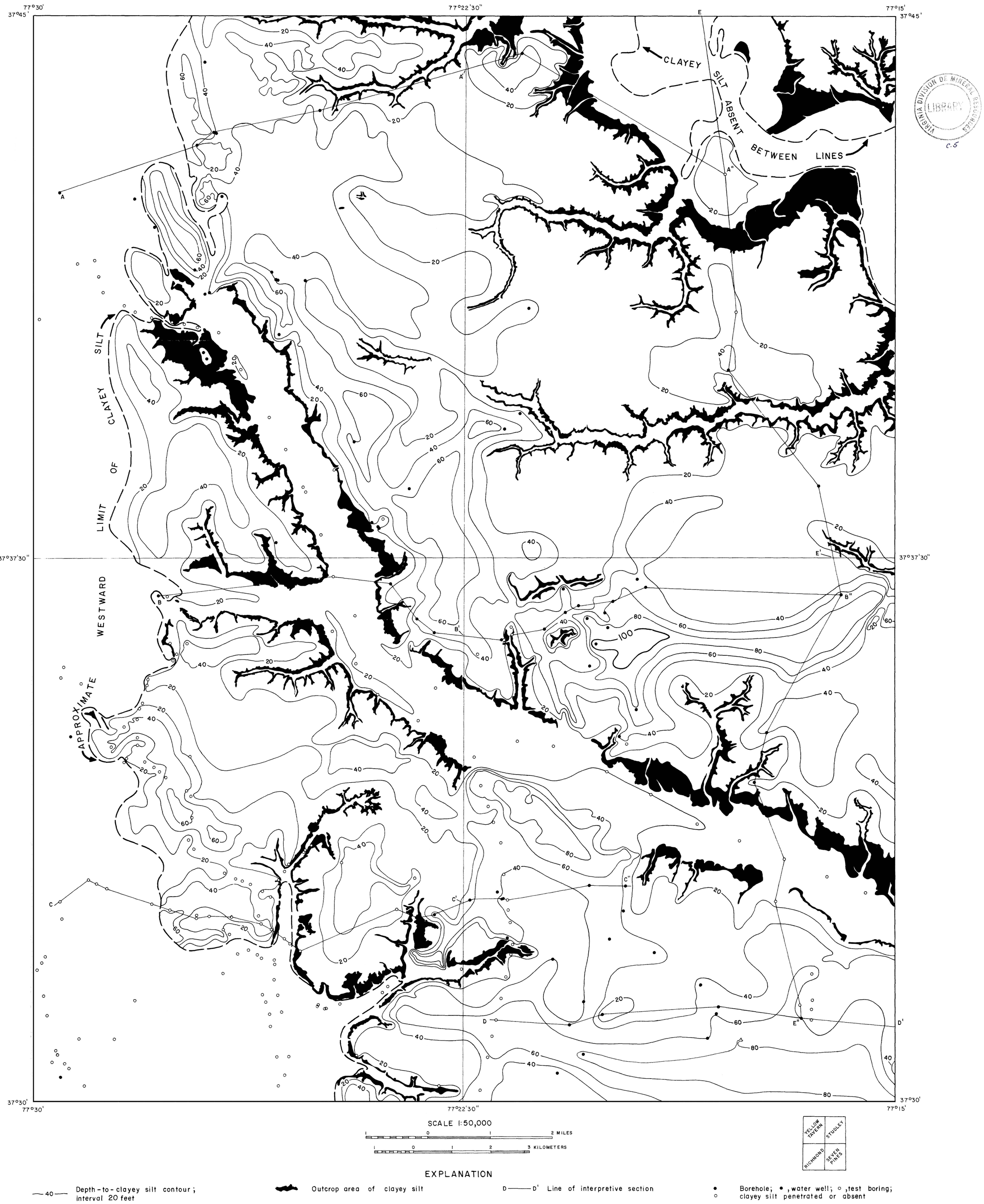
VIRGINIA DIVISION OF MINERAL RESOURCES
LIBRARY

STRUCTURE-CONTOUR MAP OF THE CLAYEY SILT (MIOCENE TRANSGRESSIVE SEDIMENTS) STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

By Paul A. Daniels, Jr.

1974

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist



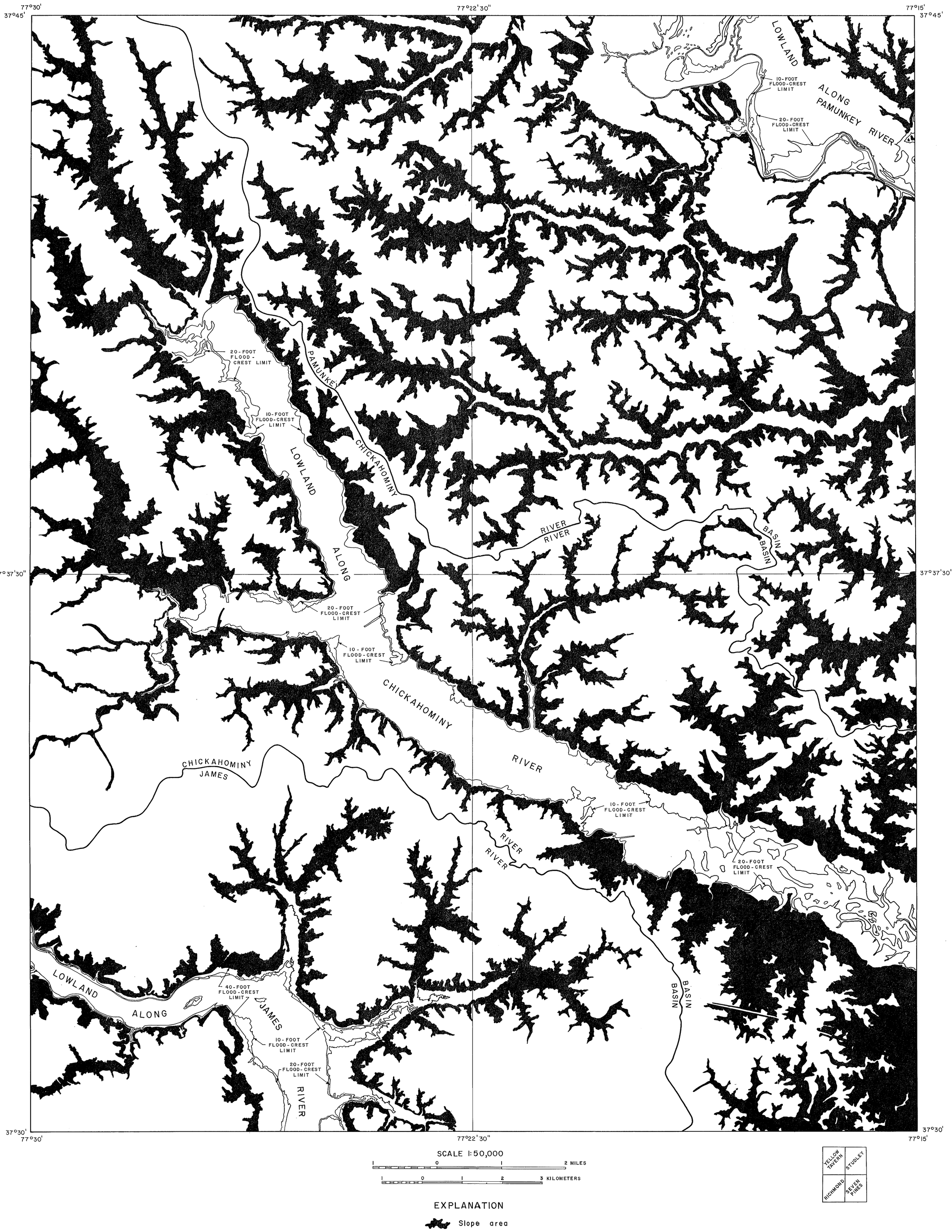
VIRGINIA DIVISION OF MINERAL RESOURCES LIBRARY C.5

GENERALIZED DEPTH-TO-CLAYEY SILT (MICOENE TRANSGRESSIVE SEDIMENTS) MAP STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

By Paul A. Daniels, Jr.

1974

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

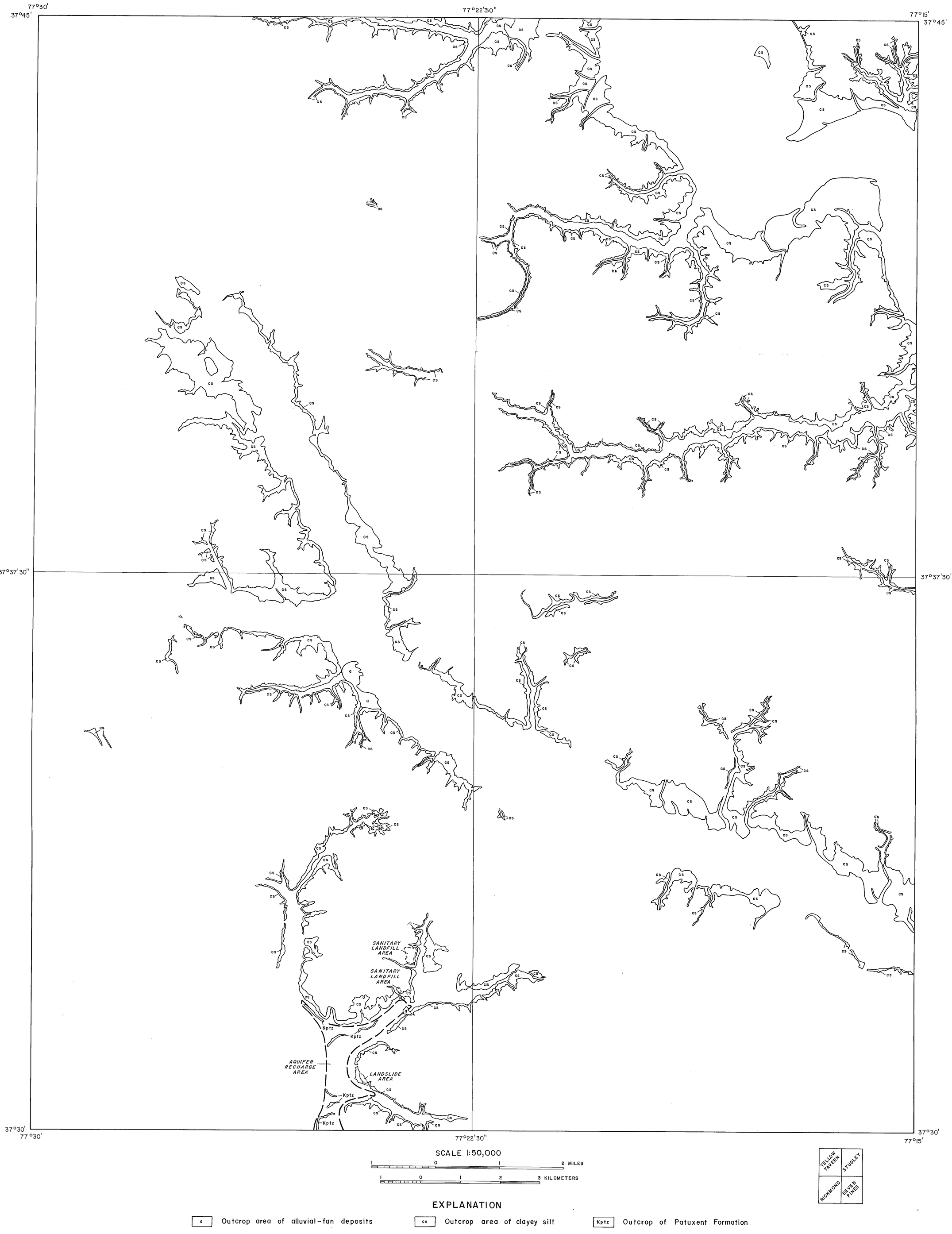


MAP SHOWING LANDFORMS, FLOOD-PRONE AREAS, AND WATERSHEDS STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

By Paul A. Daniels, Jr., and Emil Onuschak, Jr.

1974

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist



POSSIBLE NATURAL HAZARDS MAP
STUDLEY, YELLOW TAVERN, RICHMOND, AND SEVEN PINES QUADRANGLES, VIRGINIA

By Paul A. Daniels, Jr.

1974