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Evaluation of Late Mesozoic and Cenozoic Tectonism: Atlantic Inner Coastal Plain Margin Near Richmond, Virginia

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EVALUATION OF LATE MESOZOIC AND CENOZOIC TECTONISM; ATLANTIC INNER COASTAL PLAIN MARGIN NEAR RICHMOND, VIRGINIA

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ABSTRACT

EVALUATION OF LATE MESOZOIC AND CENOZOIC TECTONISM;
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A combined geologic, geophysical, and geomorphic analysis of the Virginia Inner Coastal Plain margin near Richmond was conducted to investigate the presence of basement structures and to evaluate their influence on the overlying sedimentary package and present-day landscape. Basement structures were investigated through a synthesis of compiled geologic data from published and unpublished sources, regional geophysical maps, and anomalous linear courses of major drainages in the study area. Small scale structures, primarily fracture sets, were measured in the basement rocks and clay rich deposits of the overlying Coastal Plain units to determine prominent orientations within each unit, evaluate common trends perpetuated upward through the section, and to compare observed dominant orientations with identified large scale basement structures. Topographic and rectified drainage linears were annotated on 1:24,000 scale topographic maps of the study area to evaluate the influence of observed and inferred structures on the area geomorphology.

Structural contour and isopach maps generated for pre-Cretaceous through Lower Eocene units contained similar anomalies in surface gradient and unit thickness. Identified structural anomalies and gradients correlated well with similarly oriented geophysical features providing evidence for the presence of buried Coastal Plain structures. Basement structures identified included north-northeast and northwest oriented faults that appear to bound and transect a north-northeast trending early Mesozoic basin or set of basins. These faults are believed to represent zones of weakness that were formed during the Paleozoic closure of the Iapetus Ocean and

subsequently reactivated during early Mesozoic rifting. A NW-SE compressional stress regime that has persisted since the Cretaceous has resulted in a reverse sense of movement along appropriately oriented basement structures. Relative displacements along the basement blocks appear to have been propagated upward through the sedimentary package in the form of observed zones of faulting and flexuring. Stratigraphic offsets tend to decrease upsection indicating recurrent movement along the structures has occurred. Structural highs, produced by periodic uplift of the basement blocks, are believed to have influenced Coastal Plain sediment depositional patterns, particularly those active during the middle and late Tertiary.

Observed fracture sets in the Petersburg Granite and clay rich sediments of the overlying Coastal Plain units occur in one of four dominant structural trends (N-S, NE-SW, NW-SE, E-W) coincident with large scale structures found in the study area and throughout the Virginia Coastal Plain. The persistence of the preferred structural trends through the sedimentary package indicates that similar tectonic forces have controlled their formation.

Stream drainage lines and topographic linears are preferentially oriented in one of three major trends (N-S, NE-SW, NW-SE) similar to those observed for the large and small scale structures strongly suggesting that a structural control has been exercised during the development of these geomorphic features. Major drainage courses traversing the study area were also observed to be controlled by the presence of identified Coastal Plain structures. In the south, the Appomattox River is deflected along a six mile linear reach coincident with the previously documented Dutch Gap fault. To the north, the James River is diverted to the south for ten miles along the western boundary of an observed basement uplift before continuing its regional southeasterly course. Generally southeast trending linear courses of major drainages are correlative with similarly oriented basement and outcrop scale structures.

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INTRODUCTION

The Atlantic Coastal Plain has been the site of numerous geologic, hydrogeologic, and geophysical investigations through the years. Early work in the mid-Atlantic region consisted of paleontologic, stratigraphic, and biostratigraphic studies of the late Mesozoic and Cenozoic fluvial-marine units exposed along major tributaries of the Chesapeake Bay (Rogers, 1884; McGee, 1888; Darton, 1891). Major northwest trending salients and intervening broad downwarps such as the Cape Fear Arch and Salisbury Embayment were among the first structures described in the literature (Clark and others, 1912; Spangler and Peterson, 1950; Murray, 1961). Cretaceous and post-Cretaceous faults of minor displacement were documented from a few widely scattered localities during the first half of this century (e.g. York and Oliver, 1976).

Regional Studies

More recent studies have revealed northeast trending zones of flexuring and faulting in the Coastal Plain sediments (e.g. Jacobeen, 1972; Mixon and Newell, 1977; Prowell and O'Connor, 1978). Small scale displacements have been observed to decrease upsection indicating recurrent movement on the structures. Some of the zones of deformation were originally detected through detailed geologic mapping of fault exposures as well as anomalous facies changes, thicknesses, dip reversals, and distribution of the Coastal Plain rock units (Mixon and Newell, 1977; Prowell and O'Connor, 1978; Ward and Blackwelder, 1980). Other studies have involved combinations of stratigraphic, biostratigraphic, geophysical, remote sensing, and groundwater quality techniques to interpret buried Coastal Plain structures. Regional aeromagnetic and gravity surveys, as well as seismic profiles, have been employed by several workers to delineate basement rock composition, buried basement provinces, and influence of these features on the overlying Coastal Plain cover

(e.g. Jacobeen, 1972; Popenoe and Zietz, 1977; Hamilton and others, 1983; Hansen, 1988). Remote sensing methodologies have also been combined with other investigative tools to identify buried Coastal Plain structures (e.g. Spoljaric and others, 1976; Lane, 1984; Mullen, 1986). Upward propagation of buried structures has been shown to be manifested at the surface as river course deflections, rectilinear stream segments, or anomalous textural and tonal alignments (Rumsey, 1971; Venkatakrishnan, 1984).

Virginia Studies

Studies conducted in the Virginia Coastal Plain provide evidence that the distribution and thicknesses of Cretaceous and Cenozoic deposits in the Salisbury Embayment have been tectonically controlled (Cederstrom, 1945; Ward and Blackwelder, 1980; Ward, 1984, 1985). Several pre-Miocene depositional units of the Salisbury Embayment have been shown to pinch out in the present study area (Cederstrom, 1945; Teifke, 1973; Ward and Blackwelder, 1980; Ward, 1984, 1985). A northwest striking basement fault has been documented along the southern margin of the embayment parallel to the James River near Hampton Roads (Cederstrom, 1945). Venkatakrishnan (1984) mapped a lineament zone coincident with this fault (James River Lineament Zone) and noted it lies on strike with a landward continuation of the oceanic Norfolk Fracture Zone suggesting that a structural control has been exerted on the southern terminus of the Salisbury Embayment.

Local Studies

The current study area consists of eight 7.5 minute quadrangles located along the Virginia Inner Coastal Plain margin near Richmond, Virginia. Figure 1 depicts the study area. Coastal Plain structures have been mapped in the southern portion of the present study area (Dischinger, 1979; Shomo, 1982). Dischinger documented two north-trending high angle reverse faults in Cretaceous and Cenozoic sediments near Hopewell, Virginia (Dutch Gap and City Point-Bailey Creek faults). Shomo defined the presence of a buried rift basin within the geophysical low in the eastern portion

FIGURE 1: Location map depicting the boundarys of the study area. The Fall Line marks the inner margin of the Virginia Coastal Plain.

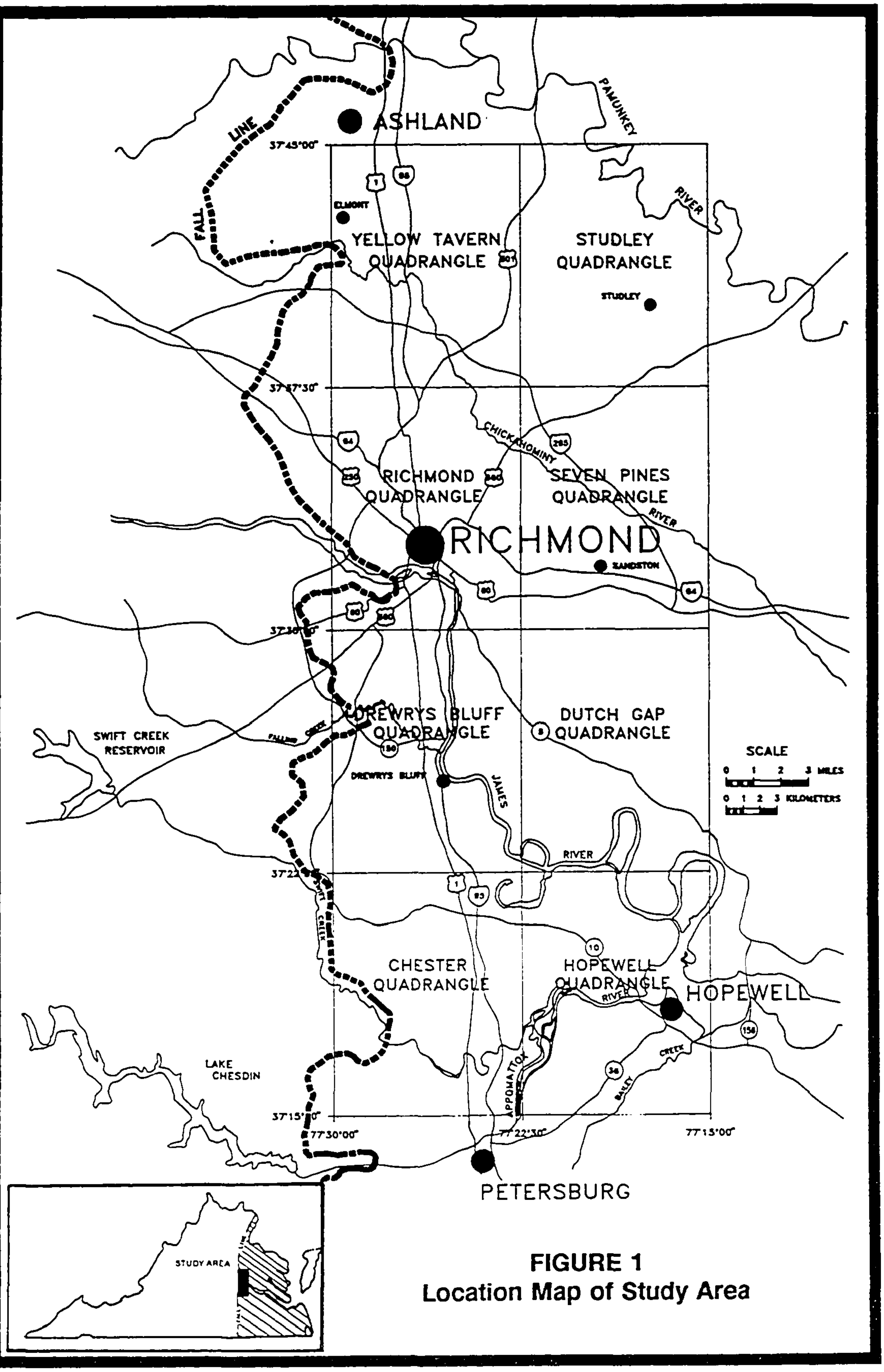


FIGURE 1
Location Map of Study Area

of the study area near Sandston. She speculated that the basin was bound to the east and west by border faults marked by geophysical gradients and zones of deformation in the Coastal Plain sediments. In the southern portion of the basin, Shomo postulated the western and eastern boundary faults coincide with the Dutch Gap and City Point-Bailey Creek fault zones of Dischinger. A northwest trending reach of the James River in the southeastern portion of the study area near Dutch Gap was also proposed to be the site of basement faulting (Dischinger, 1979; Shomo, 1982).

Present Study

The northern extent of Dutch Gap and City Point-Bailey Creek fault zones has not been determined. Although a buried Triassic basin has been documented in the study area, its influence on the subsequent deposition of Cretaceous and Cenozoic sediments and present-day landscape has not been thoroughly evaluated. In addition, the presence of northwest-oriented basement structures in this area and their effect on Coastal Plain deposition has not been documented.

The objective of the current study was to elicit evidence for post-Jurassic tectonism through a synthesis of geologic, geophysical, and remote sensing data. Eight mappable pre-Cretaceous through Quaternary units were recognized in the study area based on published and unpublished sources. During the course of the study, contour maps and cross sections were constructed from compiled data to identify basement features and their effect on the thickness and distribution of Coastal Plain sediments. Evidence for similarly oriented fracture sets and other small scale structures was collected from outcrops previously documented in the study area. Structural control of the buried structures on surface topography and drainage patterns was evaluated through the analysis of rectified drainage and topographic linears mapped during the present study.

PREVIOUS INVESTIGATIONS

The North American Atlantic Coastal Margin has traditionally been thought of as a passive, structurally simple, seaward thickening wedge of unconsolidated late Mesozoic and Cenozoic sediments mantling a pre-Cambrian crystalline basement (e.g. Darton, 1891; Murray, 1961; Harris and others, 1979). Generally, the depositional units were noted to strike north to northeast and dip gently to the east to southeast. Dips were observed to increase with age and were interpreted to be the result of periodic subsidence due to sediment loading (e.g. Wentworth, 1930; Cederstrom, 1943; 1945; Brown and others, 1972).

Some early studies postulated a tectonic control for the updip limit of the Coastal Plain sediments (McGee, 1888; Darton, 1891). An alignment of abrupt southwestward course deflections of the Delaware, Susquehanna, and Potomac rivers as they cross the Fall Zone, was observed to mark the landward extent of the Coastal Plain. McGee (1888) appears to have been the first to suggest that the geomorphic lineament was the surface expression of buried geologic structure. He noted that a line of dislocation, marked by steep slopes along the Piedmont margin, formed a "line of dislocation coinciding approximately with the Fall Line". Darton (1891), found that McGee's line of dislocation was actually "some miles west" of the river deflection lineament exhibited by faulting in the crystalline basement rocks, Potomac Formation, and Appomattox Formation (Upper Tertiary sand and gravel unit).

Other early investigators of Coastal Plain tectonism noted faults at a few widely scattered outcrops along the Atlantic coast (e.g. Cederstrom, 1939 and 1945; Darton, 1951; White 1952). Documented offsets included a reverse fault of small throw in unconsolidated sediments along the

Fall Zone at Triangle, Virginia (Cederstrom, 1939); reverse faulting in the Potomac Formation at Drewrys Bluff on the James River and near Quantico, Virginia (Cederstrom, 1945a); reverse faulting of basement gneiss over Pleistocene terrace gravels near Washington, D.C. (Darton, 1951); reverse faulting of Coastal Plain gravels near Wilson, North Carolina and fluvial gravels near Clifton Forge, Virginia (White, 1952). A summary of reported Cretaceous and Cenozoic faults in eastern North America is presented in York and Oliver (1976).

More recent geologic investigations conducted in the Atlantic Coastal Plain have defined a stratigraphic framework that reflects a complex onlap-offlap depositional history related to basement tectonics (Brown and others, 1972; Ward, 1984; 1985; Ward and Strickland, 1986). These studies reveal that the Atlantic Coastal Plain is underlain by a series of structural basins and intervening arches that have influenced depositional environments and sedimentary trends throughout the Cretaceous and Cenozoic (Ward and Strickland, 1986; Owens and Gohn, 1986). Regional geologic structures identified in the Atlantic Coastal Plain are presented in Figure 2. Comparison of onlap histories of the Salisbury, Albermarle, and Charleston embayments indicates that the various basins and arches have acted independently (Ward, 1985). Relative sea level curves (Vail and Mitchum, 1979; Ward, 1984) indicate that the frequency of sea level changes in the Salisbury Embayment is greater than those of the adjacent Albemarle Embayment and the Atlantic Coastal Plain as a whole. *Figure 3 illustrates changes in relative sea level during the Tertiary.* Ward (1985) proposed that this relationship indicates that the Salisbury Embayment has been tectonically active independent of adjacent parts of the remaining Coastal Plain Province and that the intervening sea level changes reflect localized, basement controlled, tectonic activity.

Geologic and hydrogeologic studies conducted in the Virginia Coastal Plain provide further evidence that the distribution and thicknesses of Cretaceous and Cenozoic deposits in the Salisbury Embayment have been tectonically controlled (Cederstrom, 1945; Teikfe, 1973; Ward and Blackwelder, 1980; Ward, 1984, 1985; Meng and Harsh, 1988). Several pre-Miocene depositional

FIGURE 2: Map of the Western Atlantic Margin illustrating primary basement structures (from Ward and Strickland, 1985). The study area is located along the southern terminus of the Salisbury Embayment.

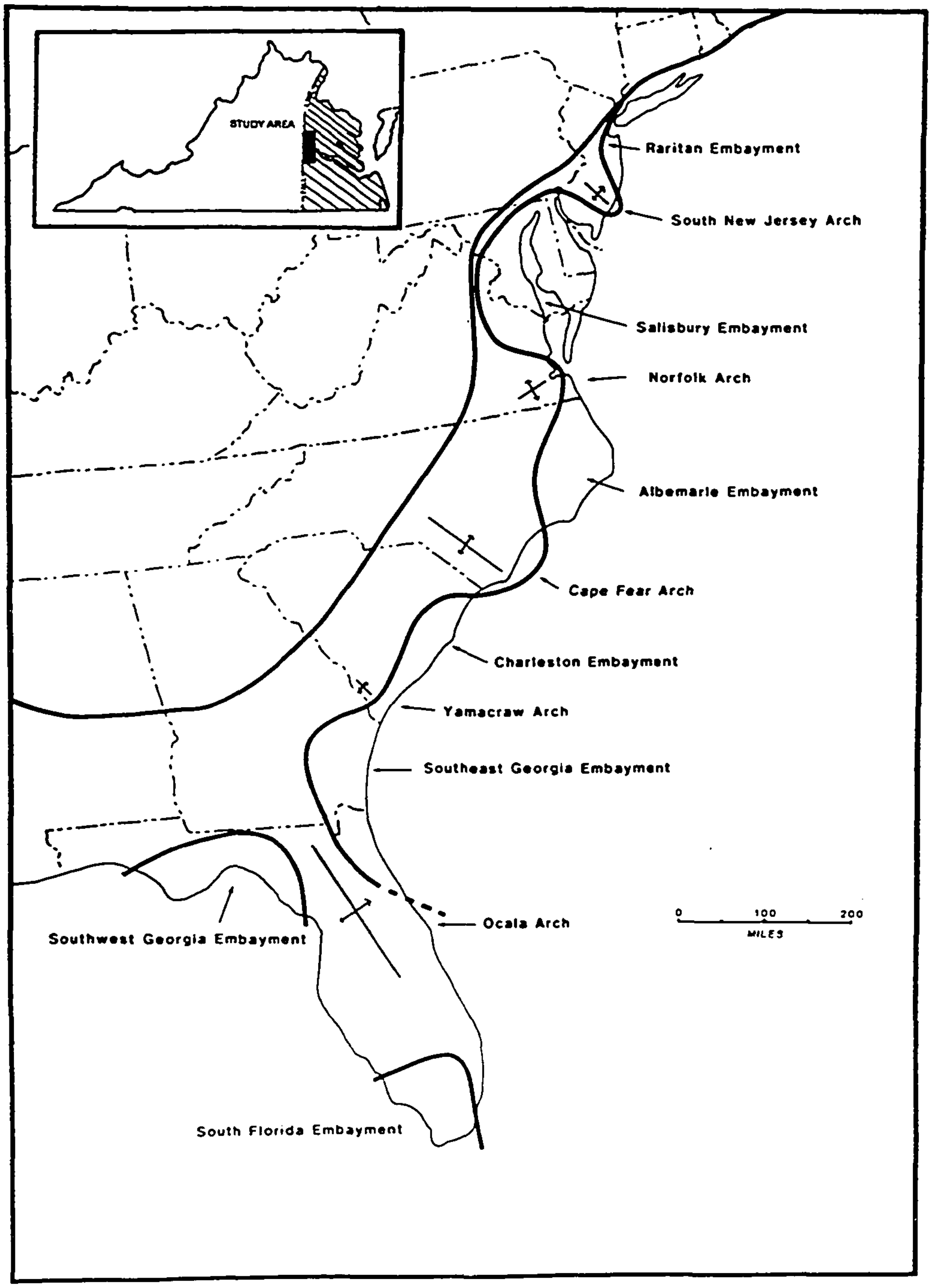


FIGURE 2
Primary Basement Tectonic Features

FIGURE 3: Sea level fluctuation curves for major embayments depicting the onlap-offlap history of the Atlantic Coastal Plain (from Ward, 1984).

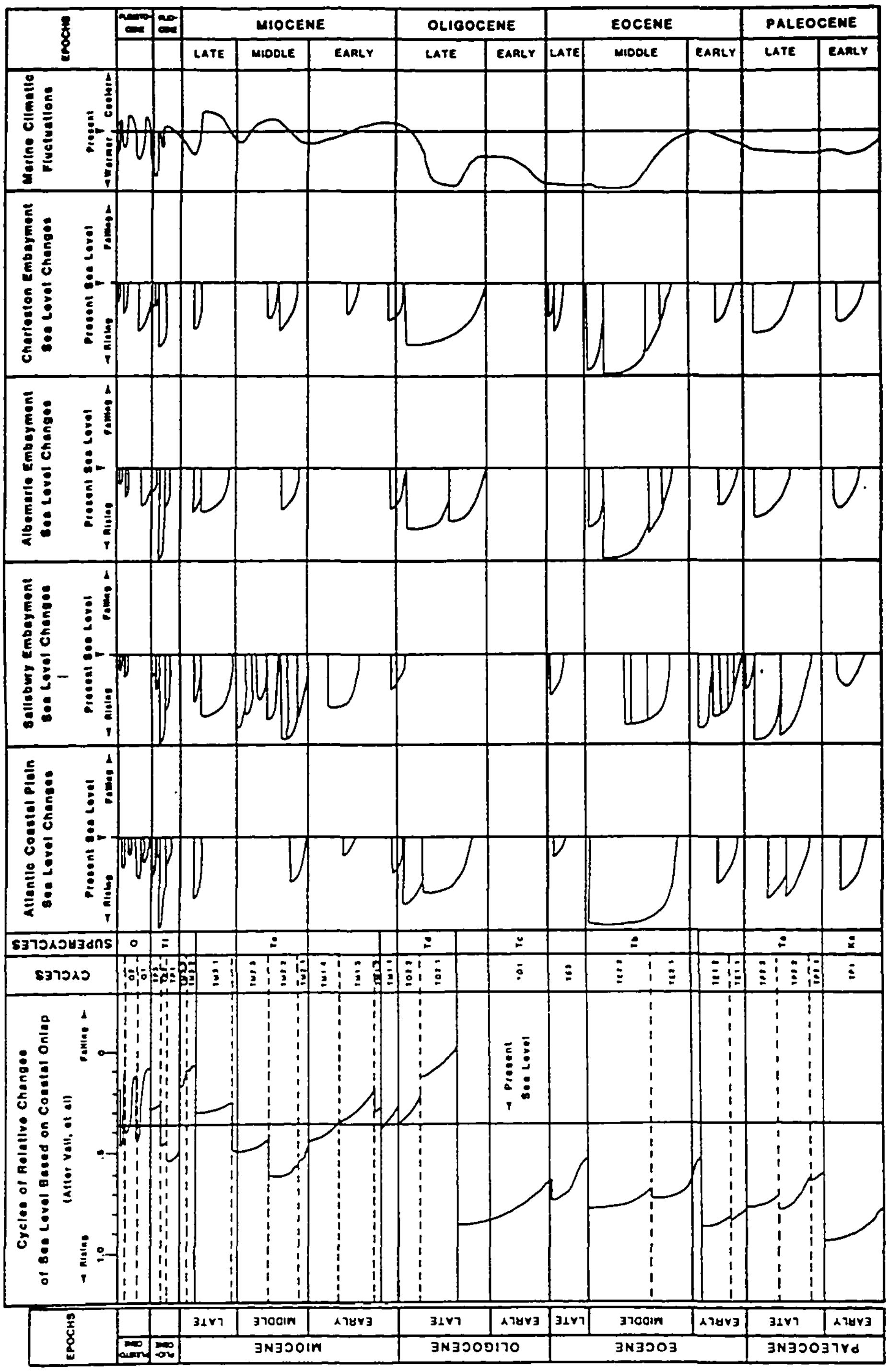


FIGURE 3
Onlap-Offlap History of Atlantic Coastal Plain

units of the Salisbury Embayment have been shown to pinch out to the south along the James River marking the northern flank of the Norfolk Arch (Cederstrom, 1945; Teifke, 1973; Ward and Blackwelder, 1980; Ward, 1984, 1985). Cederstrom (1945) proposed the presence of a basement fault parallel to the James River near Hampton Roads based on stratigraphic relationships across the river. Ward (1984) noted a change in lithology and fauna across the Norfolk Arch and suggested it had prevented the mixing of sediments and waters of the Salisbury and Albemarle embayments. Detailed mapping of the Chesapeake Group (Newell and Rader, 1982; Ward, 1984; 1985) revealed a depocenter shift from the Salisbury Embayment to the Albemarle Embayment during the Miocene. Newell and Rader (1982) suggested that the migration of depocenters was related to basement tectonics with relative uplift of the Salisbury Embayment and subsidence of the Norfolk Arch.

Zones of deformation observed in the Cretaceous and Cenozoic sediments are believed to have resulted from reactivation of Mesozoic and pre-Mesozoic faults and discontinuities in a contemporary NW-SE compressional stress regime (Mixon and Newell, 1977; Prowell and O'Connor, 1978; Hamilton, 1981; Ratcliffe, 1981; Wentworth and Mergner-Keefer, 1983). Documented reverse faults tend to be aligned with the structural grain of the Appalachian Orogen and Early Mesozoic basins. Mesozoic basin margin faults have been noted to offer the best opportunity for renewed activity based on orientation, abundance, youth, and geometry (Wentworth and Mergner-Keefer, 1983). Lindholm (1978), in developing a model for the formation of Triassic-Jurassic rift basins, observed that border faults dip essentially parallel to foliation of the underlying Paleozoic rocks. He postulated that these zones of weakness were exploited during regional extension. Mixon and Newell (1977) suggested a possible causative relationship between observed Coastal Plain deformational belts and zones of weakness in the crystalline basement rocks.

Behrendt and others (1983) proposed a tectonic model to explain Cretaceous and Cenozoic reactivation of Triassic or older fault zones in coastal South Carolina based on documented Basin

and Range structures in the western United States. In their model, one or several zones of low angle thrust faults, rooted in a basal decollement, were created during Paleozoic closing of the Iapetus Ocean. Subsequent Triassic and Jurassic extensional tectonism related to the opening of the Atlantic Ocean created listric, northeast trending, high angle, normal faults that splayed into the master decollement. Extensional movement on the decollement was believed to allow for the formation of secondary northeast trending, northwest and southeast dipping structures. These features were speculated to bound down-dropped, rotated, crustal blocks and intervening grabens with the down-dropped blocks being subsequently filled with rift sediments. Following the extrusion of extensive basalt flows during the Jurassic, a renewed northwest-southeast oriented compressional stress field was assumed to have created reversed movement on the high angle normal faults, decollement, and other zones of weakness. Not all of the older faults were believed to have been reused in either the Mesozoic or Cenozoic tectonic events (Wentworth and Mergner-Keefer, 1983). The authors cited the Cooke and Helena Banks fault zones as examples of reactivated structures as indicated by geometries that flatten with depth and their probable association with Triassic structures.

Recent studies in Coastal Plain seismicity (Hamilton, 1981; Wentworth and Mergner-Keefer, 1983) have led to the suggestion that Mesozoic and older basement structures may occur at regularly spaced intervals of 16 to 31 miles. Klitgord and Behrendt (1979) used magnetic basement depth estimates to define the presence of northeast trending horst and graben structures with similar spacings along the offshore continental margin beneath the Jurassic post-rift unconformity. Hansen (1988) documented the presence of a buried Mesozoic basin near Queen Anne, Maryland. The western border fault system was found to lie on strike with a prominent northeast-trending gravity gradient and other early Mesozoic age structures including the Brandywine fault system (Jacobeen, 1972) and the Taylorsville and Richmond basins. The gravity gradient was observed to generally parallel the Appalachian Orogen and Culpeper-Gettysburg-Newark basin trend, 22 miles to the west. Based on these relationships, Hansen postulated that a belt of buried Mesozoic basins

is present beneath the Coastal Plain cover. Studies conducted in the mid-Atlantic Coastal Plain have revealed the presence of buried north-northeast oriented structures at similar spacings as suggested by Wentworth and Mergner-Keefer (1983). Provided in the following text is a discussion of these identified structures. Table 1 summarizes salient features of representative structures. Documented structures in the Virginia Coastal Plain are presented in Figure 4.

Inner Coastal Plain

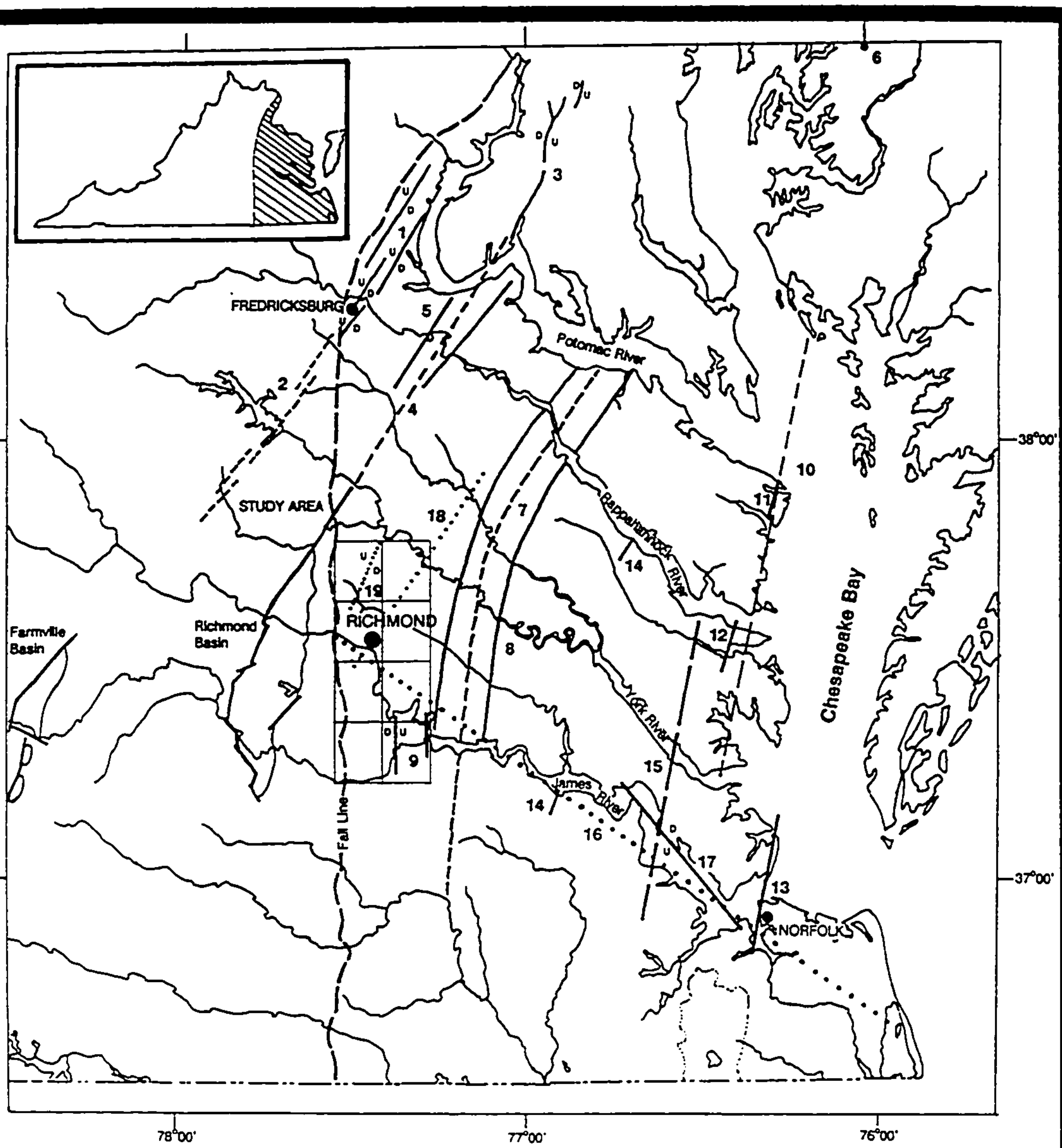
Mixon and Newell (1977) mapped a northeast trending zone of deformation in the Inner Coastal Plain near Stafford, Virginia (Figure 4, #1; Table 1). They cited a similar structural trend between the western border faults of the Farmville Triassic basin to the southwest and the Stafford Fault zone. Along strike with these features, the authors noted the presence of the Spotsylvania geophysical lineament (Neuschel, 1970) and North Anna Reservoir monocline (Newell, 1979) as depicted in Figure 4 (#2).

Approximately 12 miles to the southeast, Mixon and Newell (1977) proposed that a Mesozoic border fault system extends from the western boundary faults of the Richmond Triassic basin northeastward under the Coastal Plain cover to the buried Brandywine fault zone (Figure 4, #3; Table 1). The structure was believed to be marked by an eastward dipping gravity gradient (Figure 4, #4). Mixon and Powars (1984) subsequently documented a zone of deformation in the Cretaceous and Cenozoic sediments along the gravity gradient near Port Royal, in northern Virginia (Figure 4, #5; Table 1). Triassic-Jurassic sediments were encountered subjacent to the Port Royal structure. To the northeast, Hansen (1988) noted the western boundary faults of the Queen Anne structure lie along a continuation of the northeast trending gravity gradient and proposed a belt of buried Triassic basins extends the length of the Richmond-Brandywine-Queen Anne trend (Figure 4; #6) .

Table 1. Documented Atlantic Coastal Plain Structures

(located in pocket attached to rear cover)

FIGURE 4: Map illustrating documented structures and geophysical anomalies in the Virginia Coastal Plain. Borders of the eight 7.5 minute quadrangle maps outline the study area.



1. Stafford Fault Zone (Mixon & Newell, 1977)
2. North Anna Reservoir Monocline (Newell, 1979)
3. Brandywine Fault Zone (Jacobeen, 1972)
4. Gravity Gradient (Johnson, 1973)
5. Skinkers Neck-Port Royal Structure (Mixon & Powars, 1984)
6. Queen Anne Structure (Hansen, 1988)
7. Gravity-Magnetic High (Zietz and others, 1977; Johnson, 1977)
8. Monocline (Newell and Rader, 1982)
9. Dutch Gap & Bailey Creek Faults (Dischinger, 1979)
10. Chesapeake Bay Gravity Anomaly (Johnson, 1977)
11. Basement Fault (Dysart and others, 1983)
12. Piankatank River Structure (Lane, 1984)
13. Norfolk Hinge (Rogers and Spencer, 1971)
14. Localities of Dip Reversal (Ward & Blackwelder, 1980)
15. York-James Monocline (Ward & Blackwelder, 1980)
16. James River Lineament Zone (Venkatakrishnan, 1984)
17. Hampton Roads Fault (Cederstrom, 1945)
18. Landsat Lineament (Venkatakrishnan, 1984)
19. Unnamed Fault (Mixon and others, 1989)

FIGURE 4
Virginia Coastal Plain Structures

Middle Coastal Plain

Approximately 19 miles east and parallel to the Richmond-Brandywine-Queen Anne structural trend, lies a gravity and magnetic high that extends from Sussex County, Virginia northward to the Potomac River [Figure 4, #7] (Johnson, 1973; Zietz and others, 1977). This geophysical feature is termed the Central Virginia Gravity-Magnetic High. Based on borehole data, the anomaly has been determined to mark a suite of rocks composed of interbedded metagabbros and metabasalts, with local occurrences of amphibolites and dense schists (Hubbard and others, 1978). Davison (1985) speculated that the mafic unit represents a sliver of oceanic crust obducted onto the North American plate during closure of the Iapetus Ocean forming an Alleghenian suture zone between it and a proposed microplate (Chesapeake microplate).

Newell and Rader (1982) recognized a zone of monoclinal flexuring in Coastal Plain sediments over the gravity-magnetic high (Figure 4, #8). The monocline, marked by abrupt thickness and facies changes in the Late Tertiary units, was proposed to extend the length of the anomaly. Evidence exists to suggest that a belt of buried Mesozoic rift basins occupies a gravity-magnetic low bound by the Richmond-Brandywine-Queen Anne trend to the west and the Central Virginia Gravity-Magnetic High to the east (Hansen, 1988). Borehole data collected along this feature from Prince George County, Virginia northward to the Potomac River indicates the presence of Triassic-Jurassic age sediments (Brown and others, 1972; Teifke, 1973; Daniels and Onuschak, 1974; Hubbard and others, 1978). Shomo (1982) defined the presence of a buried rift basin within a prominent geophysical trough in the study area extending from Prince George to Sandston based on drilling and geophysical evidence. She speculated that the basin was bound to the east and west by border faults marked by geophysical gradients and zones of deformation in the Coastal Plain sediments. In the southern portion of the basin, the western and eastern boundary faults were postulated to coincide with the Dutch Gap and City Point-Bailey Creek fault zones previously mapped by Dischinger (1979) [Figure 4, #9; Table 1]. Dischinger (1979) speculated that the uplifted portion of Dutch Gap fault zone was underlain by a horst block of a buried Triassic basin.

Approximately 2.5 miles east of the Dutch Gap fault, Dischinger noted a downward flexure of the basement surface and an abrupt thickening of overlying sediments over the gravity-magnetic high. He suggested that this structural feature represented a second fault zone, the City Point-Bailey Creek fault, that may mark the eastern margin of the basin. The City Point-Bailey Creek fault lies along strike with the monocline mapped by Newell and Rader (1982).

Outer Coastal Plain

Approximately 19 miles east of the Central Virginia Gravity-Magnetic High lies a gravity-magnetic trough beneath the Chesapeake Bay (Figure 4, #10). At the head of the bay, Higgins and others (1974) speculated that a NE-SW trending magnetic low corresponded with a buried Baltimore gneiss dome bound to the southeast by high angle faults. The flat magnetic signature of the geophysical trough was believed to reflect a thickening of Coastal Plain sediments, or perhaps a Triassic basin. To the south, Dysart and others (1983) conducted a seismic survey along the western flank of the Chesapeake Bay Gravity Anomaly near Smith Point, Virginia (Figure 4, #11). Analysis of the data revealed an indurated 295 feet thick unit of Triassic (?) age overlying a crystalline basement at a depth of 3117 feet. Two normal faults were noted to bound a basement fault block. Deformation of Cretaceous age and younger sediments, however, was not observed on the assumed Triassic age structure. South of the Smith Point structure, along the same gravity gradient, Lane (1984) documented deformation of Coastal Plain sediments along a north trending deflection of the Piankatank River (Figure 4, #12; Table 1). An east-west oriented cross section constructed by others across the feature indicated flexuring of Cretaceous and younger sediments (Brown and others, 1972). Further to the south along the same trend near Hampton, Rogers and Spencer (1971) found evidence for a zone of basement faulting (Norfolk Hinge) based on borehole, geophysical, and groundwater quality data (Figure 4, #13). The pre-Cretaceous basement slope across the Norfolk Hinge was shown to increase by almost 100 percent in less than 10 miles. To the west, Coastal Plain sediments appear to be monoclinally warped over the geophysical gradient. Ward and Blackwelder (1980) noted outcrops of the Yorktown Formation along the York, James,

and Rappahannock rivers, near the geophysical lineament, exhibit areas of localized dip reversal and rapid facies changes (Figure 4, #14). The zones of dip reversal define a north-south trending flexure termed by Ward and Blackwelder (1980) as the York-James River monocline (Figure 4, #15).

Northwest Trending Structures

Other pre-existing zones of weakness associated with continental collision have been postulated to be associated with Cretaceous and Cenozoic tectonism. Sykes (1978) noted that intraplate earthquakes and igneous intrusions tend to be concentrated along inferred crustal weaknesses such as fault zones, suture zones, failed rifts, and other tectonic boundaries. At some localities, transform faults were believed to be aligned with pre-existing tectonic lineaments in the continental crust. An example of this association is the alignment of the Romanche Fracture Zone with the eastern edge of the West African Craton (Venkatakrishnan, 1984). Oceanic fracture zones also appear to be associated with large scale basement structures such as salients and embayments. Landward continuation of the Norfolk Fracture Zone (NFZ) coincides with the northern flank of the Norfolk Arch. A small circle extension of the Blake Spur Fracture Zone (BSFZ) corresponds with the northern limb of the Yamacraw Arch (Ward and Strickland, 1986). The South Carolina-Georgia and Central Virginia seismic belts (Bollinger, 1973) were found to be located along continental extensions of the BSFZ and NFZ. Jurassic and Eocene age alkaline rocks in western Virginia were also found to be on strike with the NFZ (Sykes, 1978).

The southern terminus of the Central Virginia Gravity-Magnetic High is abruptly deflected to the southeast along strike with the NFZ. Northwest-southeast trending linear magnetic "breaks" on line with the NFZ disrupt, separate, and offset relative magnetic highs and lows in this area. Figure 5 illustrates these aeromagnetic features of the Coastal Plain basement. Davison (1985) suggested that these "breaks" represent conjugate shear faults produced during the collision of the North American plate and a proposed Chesapeake plate. Two basement wells drilled near the

FIGURE 5: Aeromagnetic map of the Virginia Coastal Plain (from Zietz and others, 1977). Arrows annotate northwest-trending breaks in prominent north-northeast trending anomalies.

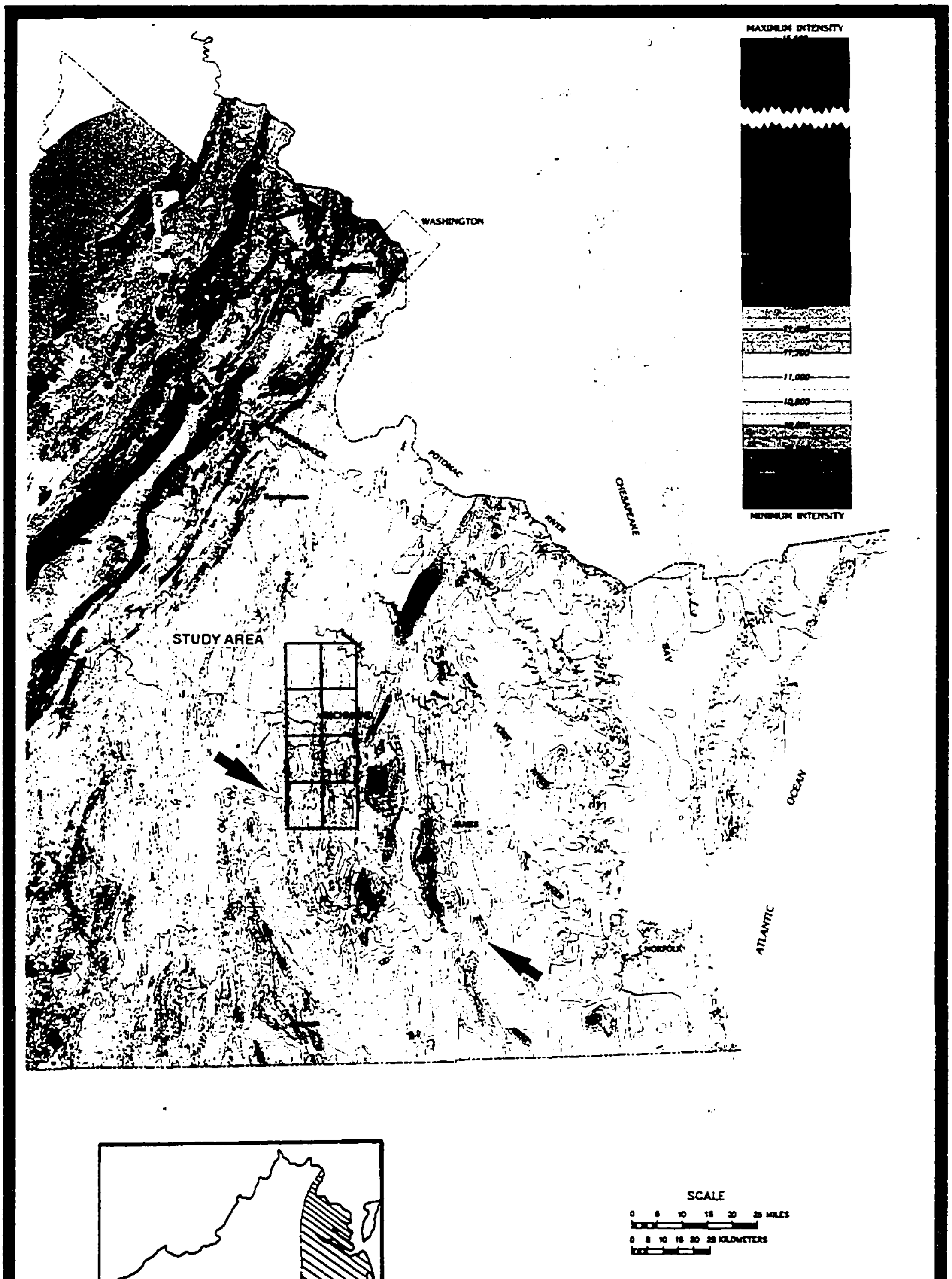


FIGURE 5
Aeromagnetic Map of the Virginia Coastal Plain

southern terminus of the gravity-magnetic high intercepted biotite schists. Davison speculated that these schists may be pressure-metamorphosed Mississippian age Petersburg Granite formed when the plates slid past each other. Venkatakrishnan (1984), in conducting a remote sensing study of the Virginia Coastal Plain, noted a lineament zone that lies on strike with the NFZ parallel to the James River (Figure 4, #16).

Other Coastal Plain structures have been documented along this feature. Cederstrom (1945) documented the presence of a fault parallel to a northwest trending reach of the James River near Hampton Roads based on driller logs and geophysical data (Figure 4, #17; Table 1). He noted that north of the river there was an abrupt thickening and downward warping of sediments over a down-dropped basement block. Displacement along the structure increased to the east. Rogers and Spencer (1971) also found evidence for the Hampton Roads fault based on groundwater quality data. Shomo (1982) speculated on the presence of a basement fault on strike with the Hampton Roads structure along a northwest trending reach of the James River near Dutch Gap based on an isopach map of the Lower Cretaceous Patuxent Formation (Teifke, 1982).

Remote Sensing Investigations

Remote sensing techniques have been combined with geologic and geophysical data to infer the presence of buried basement structures in the mid-Atlantic Coastal Plain Province. Early workers recognized the presence of geomorphic lineaments in the Atlantic Coastal Plain (McGee, 1888; Darton, 1891; Hobbs, 1904). Hobbs (1904) noted the existence of three major trends along which linear geomorphic features were aligned and suspected they had a geologic origin. Brown and others (1972), in an extensive study of the internal and external geometry of the Coastal Plain sediments, noted alignments of positive and negative basement features along the same trends noted by Hobbs (1904).

Spoljaric and others (1976) conducted a remote sensing study of the Delmarva Peninsula using LANDSAT-1 imagery. Evaluation of surface geomorphic features and drainage patterns revealed the presence of north-trending, northwest-trending, and northeast-trending lineament sets. Several northwest and northeast trends were correlated with subsurface basement faults based on subsurface geologic mapping of Claiborne through Miocene age sediments. A set of mapped northeast-trending lineaments that parallel a regional geomorphic lineament, marked by the southwest deflection of the Delaware, Susquehanna, and Potomac rivers, were correlated with basement structures previously documented by Spoljaric (1973) and Higgins and others (1974).

Newell and Rader (1982) annotated linear topographic features in the Virginia Coastal Plain and compared them to tectonic joints measured in Chesapeake Group sediments. Prominent northwest and northeast trends were recognized in both data sets. Northwest-trending linear features were noted to coincide with similar trending linear reaches of drainages in the area. Subsurface structures mapped in the Coastal Plain sediments were also found to have similar northeast and northwest orientations inferring a possible relation. The principal structure, a northeast-trending monocline, is defined by a regional break in slope of subsurface units (Figure 4, #8). This feature was noted to coincide with a similar trending gravity-magnetic high. The monocline was speculated to represent a basement fault system at depth. Northwest trending, southeast plunging, troughs and arches were found to be present superimposed on the northeast-trending monocline. It was speculated that the trough like structures are related to conjugate faults along the major northeast trending structure.

Mullen (1986) conducted a comprehensive remote sensing study in the southern portion of Newell and Raders' study area. Geomorphic lineaments, tonal alignments, and rectified stream segments were annotated on aerial photographs. Five statistically significant trends were recognized including N30-60E, N40-60W, N10-30W, E-W, and N-S. The N30-60E and N40-60W trends correlate well with those of similar orientation observed by Newell and Rader (1982).

Annotated photographic linears were found to be aligned with mapped geophysical lineaments in the study area. Mullen speculated that the correlation of the photogeologic and geophysical trends represents strong evidence that a substantial portion of airphoto lineaments and rectified stream segments are controlled by basement features.

A regional remote sensing study of the Virginia Coastal Plain and Piedmont was conducted by Venkatakrishnan (1984). Four major lineament sets, annotated on LANDSAT images, were recognized. These trends included N55W, N10W, N30E, and N40-70E. The trends were noted to correspond quite well with the major fault systems recognized by Sheridan (1974) and the trends delineated by Brown and others (1972). The N55W set was found to correspond with the continental continuation of Atlantic oceanic fracture zones. The N10W set was noted to correspond with the "hinge-zones" of Brown and others (1972). The N30E set was found to correlate well with pre-existing Appalachian orogenic fabric present in the basement rocks underlying the Coastal Plain cover. The origin of the N40-70E set could not be definitively determined, but, it was believed to be related to conjugate left-lateral shears associated with the present-day NW-SE compressional axis.

REGIONAL SETTING

The study area is located along the Fall Zone in east central Virginia. The Fall Zone is annotated by a series of rapids along major drainages and marks the boundary between the Piedmont and Coastal Plain Physiographic Provinces. The regional physiography and related geology of the study area is presented in Figure 6.

West of the Fall Zone, the Piedmont has been physiographically subdivided into the Chesterfield terrain, Triassic lowlands, and Tuckahoe Island lowlands (Johnson and others, 1986). The Chesterfield terrain, primarily underlain by the Petersburg Granite, is characterized by a rolling upland at elevations ranging from 100 to more than 300 feet and a relief of 300 feet. Rocks of the Mesozoic Richmond and Taylorsville basins make up the Triassic lowlands at elevations ranging from 100 to 300 feet with a local relief of more than 300 feet. Floodplains of the James, Appomattox, and other rivers in the Piedmont comprise the Tuckahoe Island lowlands, at elevations ranging from 130 feet to the west to sea level along the Fall Zone.

In contrast, east of the Fall Zone the topography is dominated by a succession of relatively flat plains marked by coast wise and riverine scarps that decrease in age and elevation seaward and toward major rivers (Figure 6). These geomorphic features represent a series of transgressive and regressive events that have resulted in the deposition of an easterly thickening wedge of Cretaceous and Cenozoic deposits (Johnson and others, 1986). In the study area, the highest surface is the Richmond Plain found at elevations ranging from 180 to 250 feet. The Richmond Plain, underlain by regressive deposits of the Yorktown Formation, is relatively flat to gently undulatory with a local relief of 110 feet. The Broad Rock scarp, found at an elevation of 180 feet, separates the Richmond

FIGURE 6: Map of the study area depicting local geology and physiography (after Mixon and others, 1989). The surface trace of the Dutch Gap fault (Dischinger, 1979) is shown in the southeast corner of the map. An arrow indicates the location of Bailey Creek.

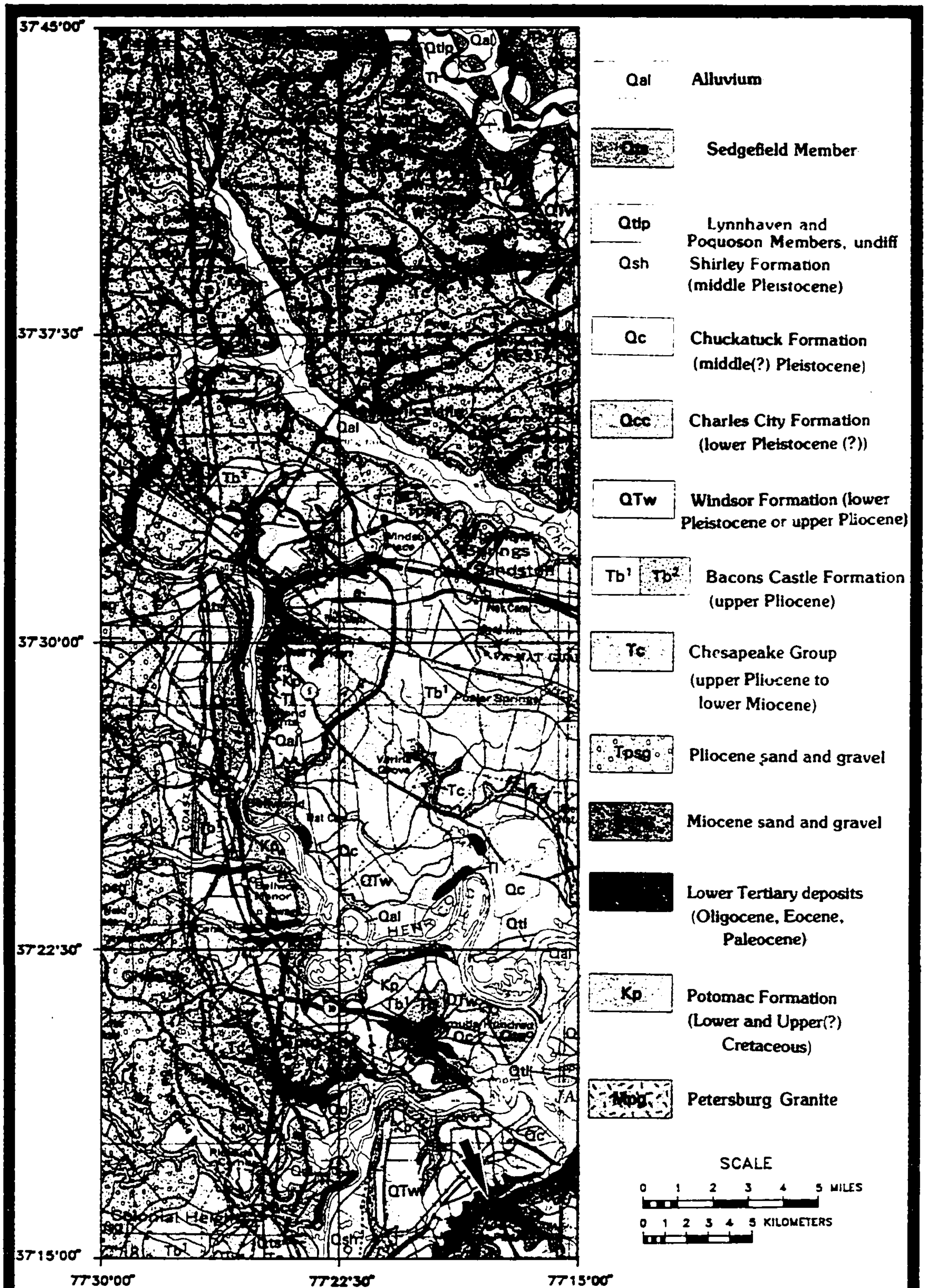


FIGURE 6
Regional Geology Map

Plain from the next highest surface, the Norge Uplands. The Norge Uplands, underlain by the Bacons Castle Formation, is a relatively flat plain with elevations ranging from 100 to 180 feet and a local relief of up to 160 feet. Along the Pamunkey, James, and Appomattox rivers a series of five riverine terraces are present ranging in elevation from 25 to 100 feet. These surfaces are underlain by Quaternary fluvial-estuarine deposits (Mixon and others, 1989).

Four major drainages traverse the study area. In the north, the Pamunkey River follows a highly sinuous, generally southeast trending course across the Inner Coastal Plain and crosses only the northeastern most portion of the study area near Studley (Figure 6). To the south, lies the Chickahominy River with a course that generally parallels the Pamunkey. At the point where the Chickahominy River crosses the Fall Zone, its valley broadens abruptly from 0.1 to 1 mile (Figure 6). A northeast trending linear valley wall marks the head of the enlarged drainage. Southeast of this point, the underfit Chickahominy River meanders southeasterly through an anomalously wide, northwest trending linear valley. The point at which the Chickahominy River valley broadens is on strike with north-trending linear reaches of the James and Appomattox rivers to the south. The James River follows a generally southeast trending course as it descends the Fall Zone into Richmond. Upon entering the Coastal Plain, the James River is deflected abruptly to the south and follows a linear course for approximately 10 miles (Dischinger, 1979). At Drewrys Bluff, the James resumes a southeasterly course flowing through three large northeast trending meanders before being joined by the Appomattox River at Hopewell (Figure 6). Cederstrom (1945) observed a fault in the Cretaceous sediments near Drewrys Bluff (Figure 1). Dischinger speculated that the southeast trending reach of the James from Drewrys Bluff to Hopewell is structurally controlled. The Appomattox River illustrates a similar course deflection upon descending the Fall Zone near Petersburg (Figure 6). A 6 mile long north trending linear reach of the river has been documented to be a surface expression of the Dutch Gap fault (Dischinger, 1979).

Data regarding the type and nature of subsurface rocks present in the study area is provided by aeromagnetic and Bouguer gravity maps of the Virginia Coastal Plain [Figures 7 and 8] (Zietz and others, 1978; Johnson, 1977). North-trending anomalies dominate the magnetic and gravity signatures of the basement rocks most notably of which is the Central Virginia Gravity-Magnetic High. The Central Virginia Gravity-Magnetic High is located in the eastern portion of the study area and marks the presence of mafic rocks (Hubbard and others, 1978). Davison (1985) speculated that the rocks represent an Alleghenian suture zone. Northwest-trending linear magnetic breaks disrupt, separate, and offset the regional geophysical anomaly and other relative magnetic highs and lows in the study area. One such feature coincides with a southeast trending reach of the James River from Drewrys Bluff to Hopewell. Others parallel the generally southeast trending courses of the Chickahominy and Pamunkey rivers. Davison (1985) speculated that these breaks represent conjugate shear fractures formed during the closure of the Iapetus Ocean. A magnetic trough in the central portion of the study area flanks the Central Virginia Gravity-Magnetic High to the west and is bound to the east and west by magnetic highs. Triassic-Jurassic rocks have been documented to occupy at least a portion of the magnetic low (Shomo, 1982). In the southern portion of the study area, the flanking north-trending magnetic gradients have been postulated to mark border faults of a buried Mesozoic structure. Zones of deformation have been documented in the Coastal Plain sediments over these features (Dischinger, 1979). A similar magnetic pattern can be seen across the James River to the north. The western flanking aeromagnetic high coincides with a southward trending linear reach of the James River and may also mark the occurrence of basement faulting.

FIGURE 7: Aeromagnetic map of the study area (from Zietz and others, 1977). Boundaries of the eight 7.5 minute quadrangles outline the study area.

FIGURE 7
Aeromagnetic Map of Study Area

FIGURE 8: Bouguer gravity map of study area (from Johnson, 1977). Boundaries of the eight 7.5 quadrangles outline the study area.

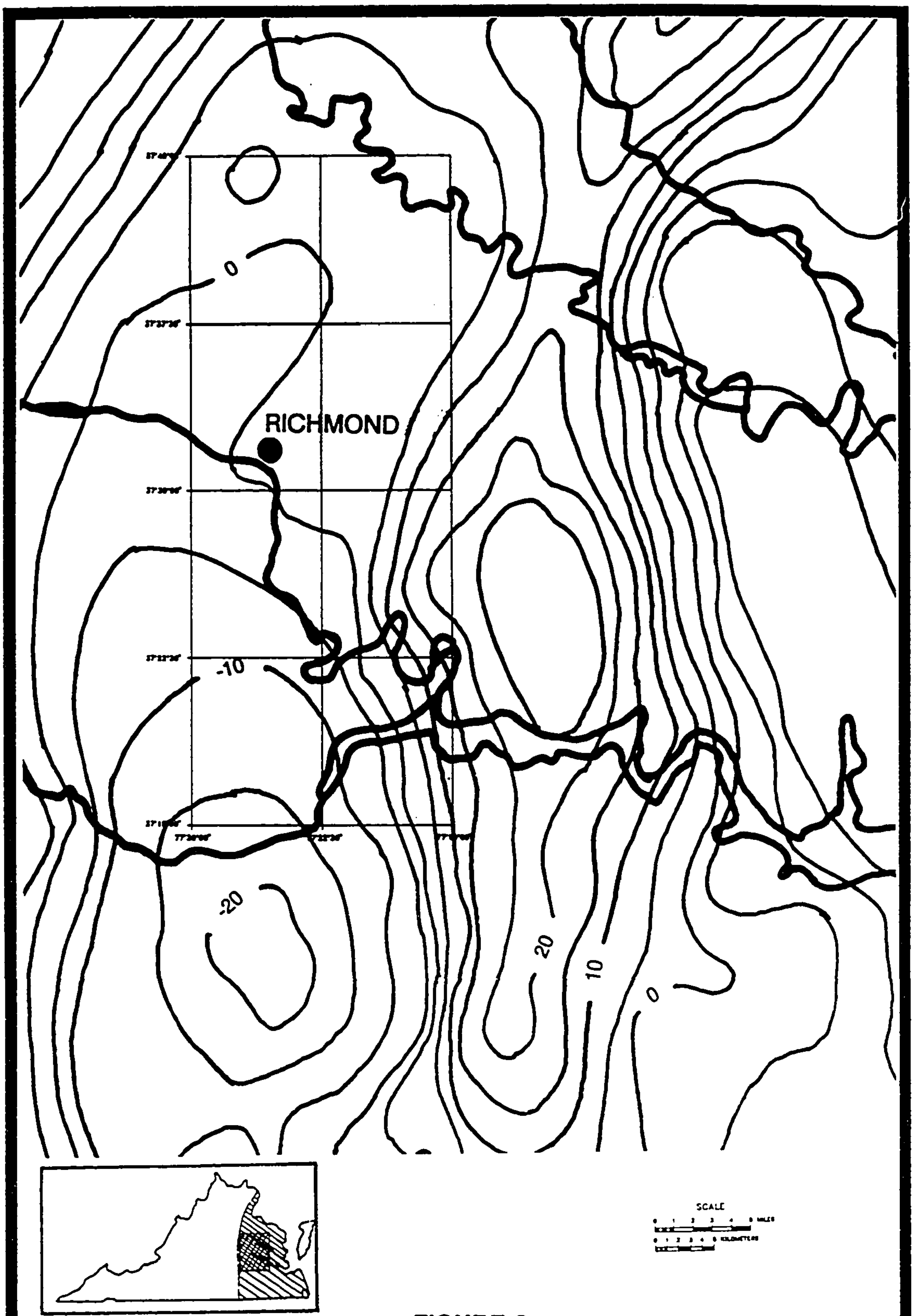


FIGURE 8
Bouguer Gravity Map of Study Area

STRATIGRAPHY

Early Coastal Plain workers recognized the presence of five mappable units in the Virginia Coastal Plain (e.g. Darton, 1891). These included the Cretaceous Potomac Formation; the Tertiary Pamunkey, Chesapeake, and Appomattox Formations; and the Quaternary Columbia Formation. Clark and Miller (1912) subsequently raised the Potomac Formation, Pamunkey Formation, Chesapeake Formation, and Columbia Formation to group status. The Cretaceous Potomac Formation was subdivided into the Patuxent and younger Potapaco formations; the Eocene Pamunkey Formation was divided into the Aquia and younger Nanjemoy formations; the Miocene Chesapeake Formation was subdivided from oldest to youngest, into the Calvert, St. Marys, and Yorktown formations; and the Quaternary Columbia Formation was split up into the Sunderland Formation, Wilmico Formation, and Talbot Formation. More recent studies (Cederstrom, 1957; Teifke, 1973; Reinhardt and others, 1980; Gibson and others, 1980; Ward, 1984, 1985; Johnson and Peebles, 1984; Mixon and others, 1989) have further refined the stratigraphy of the Virginia Coastal Plain subdividing and renaming units based on stratigraphic and biostratigraphic relations. A generalized stratigraphic column summarizing the evolution of the Coastal Plain unit taxonomy is presented in Table 2.

Area Stratigraphy

Detailed geologic mapping has been conducted in the study area by several workers (Daniels and Onuschack, 1974; Dischinger, 1979, 1987; Ward, 1984, 1985; Johnson and Peebles, 1984; Johnson and others, 1987). The Middle Eocene Piney Point Formation, Upper Oligocene Old Church Formation, and Middle Miocene Choptank and St. Marys formations have been noted to be absent in the study area. The Middle Miocene Calvert Formation is not found south of the James

Table 2. Generalized Stratigraphic Column of Coastal Plain Units

(located in pocket attached to rear cover)

River (Dischinger, 1979; Ward, 1984). Daniels and Onuschak (1974) did not map the Late Miocene Eastover Formation in the northern portion of the study area. The unit has since been recognized in this area by Ward (1984) in exposures along the Pamunkey River. The earlier workers' failure to distinguish the unit may be attributable to their mapping methods. Dischinger (1979) reported the presence of the Cobham Bay Member of the Eastover Formation (Virginia St. Marys Formation) on the down faulted side of the Dutch Gap fault in the southern portion of the study area. He also mapped the Pliocene Yorktown Formation on the down thrown side of the Dutch Gap fault and along Bailey Creek to the southeast. The Yorktown Formation is apparently absent in the northern portion of the study area (Daniels and Onuschak, 1974; Ward, 1984; Johnson and Peebles, 1984; Johnson and others, 1987).

Pliocene regressive units and Pleistocene fluvial-marine deposits have been mapped differently by various authors working in the area. Daniels and Onuschak (1974) combined all deposits of similar depositional origin, regardless of age, into a single unit termed Sand and Gravel. Different stipple patterns were used to distinguish upland and terrace deposits. Dischinger (1979) recognized five terraces along the James and Appomattox rivers and assigned them relative ages based on topographic position. Subsequent compilation of a regional Coastal Plain map (Mixon and others, 1989) has led to the assignment of geologic units to the terraces. These workers correlated upland gravels that cap drainage divides throughout the study area at elevations ranging form 180 to 250 feet with a regressive phase of the Yorktown sea (Pliocene sand and gravel). Surficial deposits forming a high plain from 100 to 180 feet were correlated with the Upper Pliocene Bacons Castle Formation. Lower terraces found along the James, Appomattox, and Pamunkey rivers that range in elevation from 25 to 100 feet were related to the Quaternary Tabb Formation, Shirley Formation, Chuckatuck Formation, Charles City Formation, and Windsor Formation.

Stratigraphic Zonations of Present Study

The present study combines the usage of depositional systems as mappable units (Daniels and Onuschak, 1974) with the formational boundary selections of Dischinger (1979), Ward (1984), and Mixon and others (1989) where possible. Mappable units as defined in this study include pre-Cretaceous basement, Potomac Formation, Aquia Formation, Marlboro Clay, Nanjemoy Formation, Chesapeake Group, Upper Tertiary Undifferentiated, and Quaternary Undifferentiated. A generalized lithologic column for the Inner Coastal Plain units used in this study including descriptions, resistivity patterns, and drillers remarks is presented in Figure 9.

Notable differences in stratigraphic zonations from previous investigations include (1) the grouping of early Miocene (?) through Pleistocene units; (2) the selection of mappable units based on the absence of several Eocene through Miocene units and the limitations of the current data base; (3) previous studies have shown that the Piney Point, Old Church, Choptank, and St. Marys formations are not present in the study area; (4) available data for the northern portion of the study area does not allow for the discrimination of the Calvert and Eastover formations; the Yorktown Formation has not been mapped north of the James River (Daniels and Onuschak, 1974; Ward, 1984). Therefore, these formations have been grouped into one mappable unit, the Chesapeake Group; (5) younger Pliocene and Pleistocene sand and gravel deposits have been grouped into the Upper Tertiary Undifferentiated and the Quaternary Undifferentiated based on a lack of stratigraphic control and as an attempt to simplify the section. Resolution of these units is not deemed necessary since post-Miocene deformation has not been observed in the area (Dischinger, 1979).

On documented Coastal Plain structures, the greatest offset has been shown to have occurred in the Cretaceous through the early Tertiary sediments (Table 1; Jacobeen, 1972; Mixon and Newell, 1977; Dischinger, 1979). Where possible, these units have been mapped at the formation level to provide the best possible stratigraphic control. Detailed mapping of the middle Tertiary and younger sediments is beyond the scope of this investigation.

FIGURE 9: Generalized lithologic column of the study area. Presented in the figure are lithologic descriptions, dominant resistivity patterns, and driller remarks for lighologic units encountered in the area.

(located in pocket attached to rear cover)

Basement Rocks

In the Atlantic Coastal Plain, rocks that underlie the Cretaceous through Quaternary units are referred to as the basement. The Basement Rocks of the study area include the Paleozoic Petersburg Granite, semi-indurated Triassic-Jurassic "red beds", and their derived residuums.

Geologic maps (Daniels and Onuschak, 1974; Mixon and others, 1989) and borehole data (Hubbard and others, 1978; Brown and others, 1972; Shomo, 1982) indicate the study area is primarily underlain by the Petersburg Granite. Exposures of the Petersburg are restricted to the western quarter of the mapped area and primarily in drainages of the Chickahominy, James, and Appomattox rivers (Figure 6). Over much of the study area, the Petersburg is nonconformably overlain by the Cretaceous Potomac Formation. In the western portion, however, onlap of the Chesapeake Group and Upper Tertiary Undifferentiated has brought these units in contact with the granite.

The Petersburg Granite has several facies including the dominant porphyritic orthoclase granite, quartz monzonite, and quartz-biotite gneiss (Daniels and Onuschak, 1974). Foliation trends have been measured at outcrops located at James River Park, Falling Creek Wayside, and Lake Chesdin dam (this study). Foliation trends were found to range from N20E to N35E with near vertical dips. The Petersburg Granite weathers to a red, iron stained, clayey, medium grained sand sapprolite. When highly weathered it may not contain any identifiable structures making difficult to distinguish it from "granite wash" (Daniels and Onuschak, 1974).

In areas where the Petersburg Granite is not encountered, the Potomac Formation is nonconformably underlain by partly consolidated Triassic-Jurassic red beds (Daniels and Onuschak, 1974). Triassic-Jurassic age rocks do not crop at the surface in the study area. Exposures of Triassic-Jurassic rocks overlain by Coastal Plain sediments are found, however, to the north near Doswell, Virginia; a distance of 4 miles. Borehole data indicates the presence of a buried Triassic-

Jurassic basin near Sandston (Hubbard and others, 1978, Shomo, 1982). An exploratory gas well drilled over the eastern margin of the basin penetrated 680 feet of Triassic-Jurassic red beds and 640 feet of granite wash before encountering a hornblende and biotite rich granite gneiss assumed to be the Petersburg Granite (Shomo, 1982).

The presumed Triassic-Jurassic rocks have been correlated with the Newark Supergroup (Teifke, 1973). The red beds have been described as a series of interbedded mudstones, sandstones, and conglomerates (Shomo, 1982). Most intervals were noted to be poorly sorted, containing mud, sand, and gravel sized clasts. Although the sediments are generally red in color, interbedded yellow, purple, gray, and green clays are present.

Potomac Formation

The Lower Cretaceous age Potomac Formation is the basal Coastal Plain unit of the Salisbury Embayment. Early workers defined the Potomac Group as a lithologic unit that occupies the interval between the Newark Group and the Cretaceous greensands of New Jersey separated from each by a hiatus (McGee, 1888; Darton, 1891, 1893). In Maryland, the Potomac Group is divided into four formations: the Patuxent, Arundel, Patapasco, and Raritan. These formations are not recognized in Virginia and the entire Cretaceous section is referred to as the Potomac Formation (Dischinger, 1987). In the northern portion of the study area the Patuxent Formation of Teifke (1973) and Daniels and Onuschak (1974) has been correlated with the Potomac Formation. The Potomac nonconformably overlies the Basement Rocks and over much of the study area is overlain by the middle Paleocene Aquia Formation, separated by an unconformity representing 45 my (Dischinger, 1979). Along the uplifted block of the Dutch Gap fault, erosion has removed the Tertiary section placing the Potomac Formation in contact with the lower Pleistocene Windsor Formation. The Potomac Formation is exposed in a narrow outcrop belt along the Pamunkey, James, and Appomattox rivers where they cross the Fall Zone. The unit is more extensively exposed near the confluence of the James and Appomattox rivers on the uplifted block of the Dutch Gap fault (Figure

6). In the western most portion of the study area, the formation is absent. To the east the clastic wedge thickens to more than 440 feet near Studley (Figure 1).

The Potomac Formation is composed of light gray to white, massively bedded, coarse, arkosic, clayey sands with gravels common. Bright, variable colored (red, green, black, yellow, orange, and gray) clays can be interbedded with the sands. Gravel beds commonly contain large, blocky, clay clasts and lignitized wood fragments. Driller logs refer to the Potomac Formation as hard or tough, coarse, gray sands that may contain gravels and tight or hard, light to drab colored clays. Occasionally gray, white, red, green, or brown colored clays are present at the upper boundary of the unit (Figure 9). Resistivity logs show blocky, low to moderately high resistance patterns indicating massively bedded sands, clayey sands, and clays with sharp lithologic contacts (Meng and Harsh, 1988).

Aquia Formation

The Upper Paleocene age Aquia Formation rests unconformably over an irregularly eroded surface of the Potomac Formation. The Aquia is overlain unconformably by the lower Eocene Nanjemoy Formation. Along the Dutch Gap fault, where erosion has removed much of the Tertiary, the Aquia is overlain unconformably by the Quaternary Undifferentiated (Figure 6). The Aquia Formation crops out extensively along the banks of the Pamunkey River from the confluence of the North and South Anna rivers east to Hanover. Other exposures are present along the James and Appomattox rivers near the Fall Zone. Thicknesses of the unit range from a featheredge in the west to more than 150 feet near Studley (Figure 1). Paleocene and Eocene greensands of the Aquia and Nanjemoy formations, and the intervening Marlboro Clay comprise the Pamunkey Group. The Aquia Formation was originally believed to be of Eocene age (Clark and Miller, 1912). Cederstrom (1957) recognized Paleocene age borehole samples of the unit and named subcrops of the Aquia Formation as the Mattaponi Formation (Table 2). Subsequently, Reinhardt and others (1980) reintroduced the Aquia Formation to the literature, assigning a Paleocene age to the unit.

The Aquia Formation consists of an olive-gray to olive-black, fine to very fine, glauconitic, micaceous, well sorted sand. Shell beds are common and the lower Piscataway Member can contain an olive-gray calcareous marl and an occasional basal conglomerate (Figure 9). Driller logs denote the Aquia as soft, running or caving, fine, black sands or green sands that often contain shells and/or hard streaks (Figure 9). Resistivity patterns of the unit are illustrated by wave shaped peaks of medium intensity commonly in a series of 2-3 waves with sharp spikes indicating the presence of shell beds (Meng and Harsh, 1988). Near the Fall Zone a pronounced U-shaped wave at the base marks a basal conglomerate.

Marlboro Clay

The greensands of the Aquia and overlying Nanjemoy formations are separated by an intervening thin, massive, grey to red clay, known as the Marlboro Clay. The Marlboro Clay is easily distinguished from the other units both geologically and geophysically and is found throughout the study area. These attributes make it an excellent marker bed, and hence a mappable unit, in the study area. The contact of the Marlboro Clay with the underlying Aquia Formation is gradational (Dischinger, 1987). The upper contact is extensively bioturbated with burrows filled with glauconitic sand and quartz and phosphate pebbles of the overlying Nanjemoy Formation.

The Marlboro Clay is exposed along the banks of the Pamunkey River near Hanover and along the James River near the mouth of Bailey Creek (Figure 1). Maximum thicknesses of the Marlboro Clay range from 10 feet at Bailey Creek to approximately 30 feet near Studley. The unit consists of a silvery-grey to pale red plastic clay interbedded with yellow-grey to reddish silt. Drillers log the unit as a slick or sticky pink, grey, or white clay. It is characterized by a flat or low resistivity pattern [Figure 9] (Meng and Harsh, 1988).

Nanjemoy Formation

The Nanjemoy Formation unconformably overlies the Marlboro Clay and is unconformably overlain by members of the Miocene Chesapeake Group. In the northern portion of the study area, the lower middle Miocene Calvert Formation rests unconformably on the Nanjemoy. Although absent in the study area, the middle Eocene Piney Point Formation and Oligocene Old Church Formation have been observed in outcrops to the east near Old Church (Ward, 1984). South of the James River, where the Calvert Formation is absent, the Nanjemoy Formation is unconformably overlain by the upper Miocene Eastover Formation (Virginia St. Marys) (Figure 6). Along Bailey Creek southeast of Hopewell, partial erosion of the Tertiary sequence has resulted in the Nanjemoy Formation to be in contact with the Pliocene Yorktown Formation or younger Quaternary Undifferentiated (Figure 6).

The Nanjemoy crops out along the Pamunkey River from Hanover to Old Church. The unit is also present along the down-dropped side of the Dutch Gap fault near the confluence of the Appomattox and James rivers and along Bailey Creek to the southeast. Maximum thicknesses of the Nanjemoy range from 45 feet at Bailey Creek to 65 feet near Studley (Figure 1).

The Nanjemoy Formation consists of dark olive-grey to olive-black, silty, clayey, glauconitic, micaceous, fine sand containing concretions and phosphate pebbles. Drillers refer to the unit as dark green or brownish-green, silty clays or sandy clays commonly containing shell and black sand layers (Figure 9). Resistivity patterns are low or flat relative to the Aquia Formation reflecting the higher silt and clay content (Meng and Harsh, 1988). Erratic anomalies on the normally flat profile represent the shell and black sand layers.

Chesapeake Group

The Chesapeake Group consists of transgressive marine sediments of Miocene and Pliocene age. Included in the Chesapeake Group are the Old Church; Calvert, Choptank, St. Marys,

Eastover, Yorktown, Chowan River, and Bacons Castle formations (Ward, 1984; Johnson and others, 1986). Half of these formations are absent in the study area. In the northern portion of the study area, the lower middle Miocene Calvert Formation onlaps successively older units toward the west. In the Richmond area, the Calvert nonconformably overlies the Petersburg Granite (Figure 6). The Calvert Formation is unconformably overlain by the upper Miocene Eastover Formation and, to the west, possibly the Upper Tertiary Undifferentiated. Outcrops of the Calvert Formation are found north of the study area along the Pamunkey River from Hanover to Montague Landing. In the study area, the unit is exposed along the Chickahominy River and drainages near Richmond (Figure 6). South of the James River, where the Calvert Formation is absent, the overlying upper Miocene Eastover Formation is in unconformable contact with deposits of the Pamunkey Group and older units. The Eastover Formation is found throughout the study area and is correlative with Dischinger's (1987) Virginia St. Marys Formation. Exposures of the Eastover Formation are found along the Pamunkey, James, and Appomattox rivers. In the southeastern portion of the study area near the mouth of Bailey Creek, the Eastover Formation pinches out placing the Nanjemoy Formation in contact with the lower (?) and upper Pliocene Yorktown Formation. Both formations are absent on the uplifted block of the Dutch Gap fault (Figure 6). North of the James River, where the Yorktown Formation is absent, the Eastover Formation is unconformably overlain by the Upper Tertiary Undifferentiated. Although the Yorktown Formation is absent in the northern portion of the study area, a thin section of the unit (5 feet) has been observed in a barrow pit along the Chickahominy River, approximately 6 miles to the east (Johnson and others, 1987). To the south, the Yorktown Formation unconformably overlies the Eastover Formation. The Yorktown Formation is unconformably overlain by the Upper Tertiary Undifferentiated. Along the Pamunkey, James, and Appomattox rivers Pleistocene deposits of the Quaternary Undifferentiated rest unconformably on the Chesapeake Group and older units.

Due to an inability to differentiate the Calvert, Eastover, and Yorktown formations using the current database, these formations have been combined into one mappable unit, the Chesapeake

Group. This unit correlates with the clayey silt of Daniels and Onuschak (1974). As a whole, this unit thickens from a featheredge along the Fall Zone to 80 feet in the south near Bailey Creek and 140 feet near Studley (Figure 1).

The Chesapeake Group is composed of light olive-grey to blue-grey, very fine to fine, clayey, silty, shelly sands, clayey silts, and diatomaceous clays. Drillers characterize the units as blue, grey, or green silty clays and clays occasionally containing sands or shell layers. Resistivity patterns posses a relatively flat profile illustrating the predominant silty clays and clayey sands. Low amplitude peaks mark interbedded sands and silt layers. The pattern becomes more erratic upsection indicating an increase in shell and bioclastic sand content (Figure 9).

Upper Tertiary Undifferentiated

The Upper Tertiary Undifferentiated is the uppermost stratigraphic unit over most of the study area capping drainage divides at elevations ranging from 100 to 240 feet (Mixon and others, 1989). The unit is unconformably underlain by the Chesapeake Group. To the west, however, where the Chesapeake Group pinches out, the Upper Tertiary Undifferentiated rests unconformably on the Petersburg Granite (Figure 6).

Previous investigators working in the study area have combined the Upper Tertiary and Quaternary deposits into one mapping unit. Daniels and Onuschak (1974) used the term Sand and Gravel to refer to these regressive sediments and divided them into upland deposits and terrace deposits based on topographic position. Dischinger (1979) recognized five terrace surfaces south of the James River ranging in elevation from 10 to 180 feet. Pliocene and Pleistocene deposits were mapped in accordance with the various terraces levels and assigned relative numbers I - V with V being the oldest surface. Terrace IV has a surface ranging in elevation from 90 to 140 feet and can be correlated with a sand and gravel facies of the upper Pliocene Bacons Castle Formation (Johnson and others, 1987; Mixon and others, 1989). Terrace V has a surface that ranges in

elevation from 140 to 180 feet and is thought to represent a regressive phase of the Yorktown Formation. Mixon and others (1989) have mapped these sand and gravel deposits as the Pliocene sand and gravel. In this study, the Bacons Castle Formation and Pliocene sand and gravel have been combined into one mappable unit, the Upper Tertiary Undifferentiated.

The Upper Tertiary Undifferentiated forms an extensive blanket across the study area with variations in thickness related to paleodrainages. Maximum thicknesses for the unit have been found to range from 40 feet in the south to 85 feet near Elmont in the Yellow Tavern Quadrangle (Figure 1). The Upper Tertiary Undifferentiated is composed of yellow and orange sandy clays, laminated clayey silts and sands, and crossbedded sands and gravels. Drillers refer to the unit as yellow to orange clays, sands, and gravels. Resistivity profiles are blocky and spikey reflecting the massive sands and gravels interbedded with silts and clays [Figure 9] (Meng and Harsh, 1988).

Quaternary Undifferentiated

Pleistocene formations of the Quaternary Undifferentiated form riverine terraces along the Pamunkey, James, and Appomattox rivers. The Quaternary Undifferentiated unconformably rests on various older units depending on terrace elevation and areal distribution of the unit. Terraces of lower elevation are underlain by successively younger deposits (Figure 6). These sediments were deposited in paleovalleys of the York and James rivers under fluvial-estuarine conditions (Johnson and Peebles, 1984).

Formations that comprise the Quaternary Undifferentiated include the Windsor, Charles City, Chuckatuck, Shirley, and Tabb formations. Detailed structural analysis of these formations is beyond the scope of this study, hence, they have been combined into one mappable unit. Terraces I, II, and III of Dischinger (1979) and younger sediments of Daniels and Onuschak (1984) can be correlated with the Quaternary Undifferentiated. Sand and gravel deposits found along the major drainages forming terraces ranging in elevation from 10 to 90 feet were included in the Quaternary

Undifferentiated unit. Holocene river deposits of the major drainages of the study area, however, were not included.

The Quaternary Undifferentiated is comprised of tan, yellow, and orange, poorly sorted, fine-coarse, quartz sands and gravels interbedded with silty, sandy clays. Drillers characterize sediments of the unit as yellow to orange clay, sands, and gravel. Blocky and spikey resistivity profiles reflect the massive sands and gravels interbedded with silts and clays [Figure 9] (Meng and Harsh, 1988).

METHODS OF INVESTIGATION

Geophysical Lineaments

Geophysical gradients and anomalies can represent subsurface lithologic variations and/or buried structures. Magnetic anomalies represent susceptibility differences within the measured units, whereas, gravity anomalies represent different densities. In general, the basement rocks have higher magnetic and gravity signatures than the unconsolidated Coastal Plain units. Gradients produced by the juxtaposition of units with contrasting geophysical signatures can mark the presence of buried structures. Discussions of the geophysical relationships are provided in Dobrin (1976) and Telford and others (1976). Geophysical anomalies in the Coastal Plain are generally considered to represent buried geological structures hidden beneath the sedimentary cover (e.g. Cederstrom, 1945b, Higgins and others, 1974; Newell and Rader, 1982; Popenoe and Zietz, 1977; Wentworth and Mergner-Keefer, 1983). Observed gradients can be produced by either topographic relief or by lithologic change across the units being measured (Mullen, 1986).

Geophysical lineaments were annotated on published aeromagnetic and gravity maps (Johnson, 1977; Zietz and others, 1977). These lineaments were denoted by linear trends, breaks in trend, or displacement in alignments of the geophysical anomalies. Lineament data collected was correlated with gradients on structural contour and isopach maps to infer the presence of buried basement structures.

Tectonic Framework

Data Compilation

Data used in the development of the tectonic framework was collected from both published and unpublished sources. Published data included borehole logs and outcrop sections of previous investigations (Cederstrom, 1945, 1957; Brown and others, 1972; Teifke, 1973; Daniels and Onuschak, 1974; Hubbard and others, 1978; Ward, 1984; Johnson and others, 1987; Dischinger, 1987; Meng and Harsh, 1988). Where data gaps were present, the use of unpublished data was required. Approximately 19% (28 out of 145 records) of the data used in the construction of contour maps and cross sections was from unpublished sources. Unpublished data sources included well completion records from various government agencies, a water well drilling firm, and an unpublished masters thesis (U.S.G.S. Water Resources, Richmond, VA; Virginia Division of Mineral Resources, Charlottesville, VA; Virginia Water Control Board, Richmond, VA; Sydnor Hydrodynamics, Inc., Richmond, VA; Shomo, 1982).

Well completion records were selected on the basis of completeness and the accompaniment of geophysical logs. In addition, only data points that could be located on a 1:24,000 scale map were chosen. Each of the government sources used had well completion records plotted on 1:24,000 scale topographic maps. Selected data points were transferred from the source maps to maps of similar scale to retain accuracy of location and surface elevation. Data points were transferred from the quadrangle maps to a study area base map using a scalable map reducer-enlarger to maintain spatial relationships. Figure 10 presents data points used in this study.

The compiled data base did not allow for the discrimination of formational contacts within the transgressive marine Chesapeake Group, regressive marine upper Tertiary units, or the fluvial-estuarine Pleistocene formations. Selection of mappable units was based on the concept of depositional systems employed by Daniels and Onuschak (1974). A discussion of the mapping units used in this study is presented in the Stratigraphy chapter.

FIGURE 10: Map of study area depicting points of well data collection. Well data is presented in Appendix A.

(located in pocket attached to rear cover)

Mapping units of published data were correlated with those of this study. At localities where two or more references had mapped a particular borehole, the data was cross referenced to insure similar unit contacts had been selected. Selection of mappable unit boundaries from unpublished data involved combining geologic descriptions from the driller log with the profile of geophysical logs. Discussions of this mapping technique can be found in Keys and MacCary (1971), Driscoll (1986), and Meng and Harsh, (1988). Lithologic descriptions, drillers remarks, and geophysical profiles for selected geologic units are summarized in Figure 9. Logs mapped by this method were compared with nearby published sections and surface data. At localities where contacts could not be discerned, the data was discarded. Geologic data compiled for this study is presented in Appendix A. Representative geologic logs for the study area are provided in Appendix B.

Tectonic Framework Analysis

A structural framework for the study area was developed through the construction of structural contour maps, isopach maps, and cross sections for eight recognized mappable units. Anomalous surface gradients, unit thicknesses, structural highs and lows were mapped on each contour plot and compared with those of other units to identify common features and to infer their origin. Common structural anomalies and gradients were, in turn, correlated with mapped geophysical lineaments to investigate the presence and define the geometry of buried Coastal Plain structures.

Structural contour and isopach maps were completed for the pre-Cretaceous Basement through early Tertiary units only. Deposition of the Upper Tertiary Undifferentiated was predominantly fluvial which produced variations in distribution and thickness of the unit attributable to the paleodrainages (Johnson and others, 1986). Determination of a tectonic imprint on this unit would be tenuous at best using the current database. Deformation of the Upper Tertiary Undifferentiated is presumed to be minimal. Dischinger (1979) noted that one of the faults in the Dutch Gap fault zone was truncated by this unit and exhibited no displacement. Tectonic forces

are believed to have influenced the current configuration of the Chesapeake Group, however, subsequent deposition of the Upper Tertiary Undifferentiated has obscured the tectonic imprint. Therefore, structural contour and isopach maps of the unit were not constructed. Evaluation of Miocene tectonism has been restricted to interpretation of the 12 cross sections constructed for the study area.

Formation surface elevations and thickness of the eight mapping units were digitized to provide a database to be used in the construction of structural contour and isopach maps. Data was digitized using a Numonics Model 1224 Electronic Digitizer and base maps with a scale of 1:63,360. Digitized data was contoured using the Surfer program (Golden Software, 1990) on a personal computer. A computer contouring package was used in order to limit biased contouring and more importantly for convenience. Since data was digitized using longitude and latitude coordinates, a scale factor of y = 1.248x was used to prevent distortion of the grid. A grid spacing of 0.5 degrees was used which provided sufficient resolution but did not overtax the personal computer. The irregularly spaced data was gridded employing a Kriging technique which produces smooth contours. A limitation of computer generated graphics was the production of undesired contouring artifacts. Output from the gridding software was subsequently downloaded to AutoCAD software for graphics enhancement (Autodesk, 1990). The resultant plots were used to produce maps at a scale of 1:112,640.

Twelve cross sections were constructed in order to visualize the structural framework of the study area. Data compiled in Appendix A and published geologic maps (Daniels and Onuschack, 1974; Dischinger, 1987; Mixon and others, 1989) were used to complete the sections. East-west sections were drafted at a scale of 1:126,720 and north-south sections were constructed at a scale of 1:190,000; both with a vertical exaggeration of 106X.

Outcrop Structures

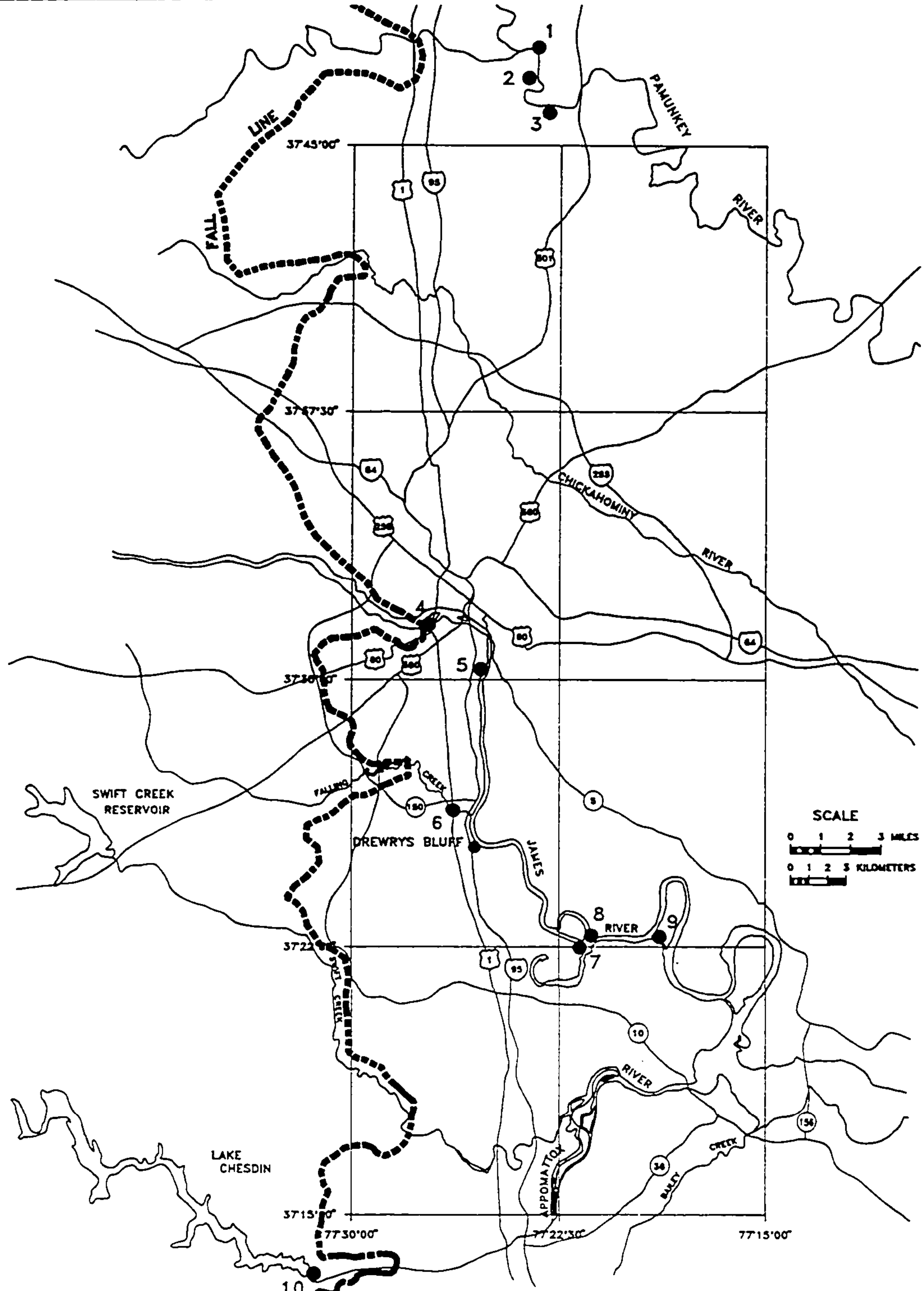
Field Collected Data

Exposures of the Petersburg Granite and Coastal Plain units were examined where they crop out as bluffs and pavement surfaces along the James, Pamunkey, and Appomattox rivers. The purpose of the field work was to investigate the presence and type of tectonic structures in the rock units and to correlate these with large scale basement structures identified in the study area.

Only localities of known geology were selected for analysis. Along the Pamunkey River, sections published by Ward (1984) were chosen for study. In the southern portion of the study area, locations along the James River east of Drewrys Bluff mapped by Dischinger (1979) were evaluated. Exposures of the Petersburg Granite used in this study were identified using a regional geologic map (Mixon and others, 1989). In all, field data was collected at 10 localities in the study area. Figure 11 illustrates points of field data collection.

Field observations were directed toward the recognition and measurement of tectonic features in the crystalline and sedimentary rocks. Data was collected employing a Brunton compass. Measurements of strike and dip (attitude) were made of each planar feature. Tectonic features observed in the Petersburg Granite included fracture sets, faulting, and biotite foliation. Near horizontal exfoliation (unloading) fractures in the granite were not incorporated in the study. By contrast, only fracture sets were observed in clay- rich members of the Potomac Formation, Marlboro Clay, Calvert Formation, and Eastover Formation. For the most part, sand-rich lithologies did not exhibit fracturing, however, faint fracture ghosts were observed in the fine sand of the Eastover Formation. Due to the small number of fractures observed in the Eastover Formation, these measurements were not included in the analysis. Findings of the field investigation are presented in Appendix C.

FIGURE 11: Area map depicting field data collection points. Outcrops selected along the Pamunkey River are presented in Ward (1984). Collected field data is presented in Appendix C.



1. WARD STOP 1 (WARD, 1984)
2. WARD STOP 2 (WARD, 1984)
3. WARD STOP 3 (WARD, 1984)
4. JAMES RIVER PARK
5. TIDEWATER MATERIALS QUARRY
6. FALLING CREEK WAYSIDE
7. DUTCH GAP DAY MARKER 151
8. VARINA FARMS
9. JONES NECK CUTOFF (BUOY 146)
10. LAKE CHESDIN DAM

FIGURE 11
Outcrop Location Map

Attempts were made to locate faults documented by Cederstrom (1945) and Dischinger (1987) in the Potomac Formation. In the case of the Drewery Bluff fault (Cederstrom, 1945) the outcrop is presently obscured by the subsequent construction of an asphalt bulk storage facility at the locality (Figure 11).

Statistical Analysis of Measured Structures

Planar features recognized in the rock units were plotted in azimuth frequency rose diagrams and subjected to statistical analysis in order that common trends could be recognized. Measured planar features were divided into 18 azimuthal classes, each with an angular length of 10 degrees, to allow for the depiction of qualitatively significant peaks and troughs. Selection of this interval provided for small variations in a particular trend, yet it reduced the chance of grouping two significant peaks. Venkatakrishnan (1984) recognized that broad ranges of azimuths were statistically significant as opposed to narrow ones and speculated that this phenomenon was attributed to small, but significant variations in shallow fracture orientations as deeper reactivated basement structures are propagated upward through the sediment package.

Rose diagrams, although an excellent visual aid, do not allow for the quantitative determination of the significance of observed trends. In order to determine the significance of each, the databases were subjected to a nonparametric χ^2 test. The χ^2 test determines significant departures from a random distribution (Davis, 1986). The test statistic is calculated by the following equation:

$$\chi^2 = \Sigma^{18}_{j=1} (O_j - E_j)^2 / E_j$$

O_j = Observed length-weighted frequency

E_j = Expected frequency for j^{th} class

Where j represents each azimuth class

Randomly distributed structural features would have an equal probability of occurring in any of the eighteen azimuthal classes. The expected frequency (E_j) is based upon the total length of all linear

features from each 10° azimuth class. The observed (O_i) value is the actual length-weighted frequency for a given azimuth. Failure of the test would imply that the observed and expected values are from separate populations, hence, the data is not randomly distributed.

Linear Features

Linear features annotated on topographic maps, aerial photos, LANDSAT images, and geophysical maps have been used by several workers in various geologic settings to infer the presence of buried structures (e.g. Spoljaric and others, 1976; Newell and Rader, 1982; Venkatakrishnan, 1984). Lattman and Nickelson (1958), in a study of the Appalachian Plateau, were able to compare mapped airphoto linears in the soil mantle with fractures measured in outcrops of the underlying bedrock. Babcock and Sheldon (1976), in a similar study conducted near Fort MacKay, Alberta, observed that mapped airphoto lineaments were the surface expression of buried joint sets and faults. Other workers have shown that even in areas of thick sediment accumulation, airphoto and LANDSAT derived lineaments are often related to underlying fractures and faults that have propagated upward through the sedimentary cover following basement reactivation (Rumsey, 1971; Spoljaric and others, 1976; Newell and Rader, 1982; Venkatakrishnan, 1984).

Linear Annotation

Linear features, as mapped in the form of topographic linears and rectified drainage segments, were compiled to evaluate semiquantitatively significant trends and to correlate these trends with inferred basement structures. Mullen (1986), in mapping lineaments on 1:125,000 scale areal photographs, noted that linear features could be the result of two different mechanisms: either manmade or created by the forces of nature. Manmade features are typically easily identified and sufficient evidence should be present to determine their origin. Natural linear features can be of structural and nonstructural origin. Erosional effects of a sea stand or fluvial channeling can create a nonstructural linear scarp. Displacement of stratigraphic units due to differential compaction or faulting may create a structural scarp at the surface. Determination of a structural origin for

annotated linear features was based on a comparison of dominant trends with mapped erosional scarps (Mixon and others, 1989) and large and small scale structures identified in the study area.

As a part of the current study, topographic linears and rectified stream segments were annotated on 1:24,000 topographic maps. Geomorphic expressions used in the mapping of topographic linears included those described by Schowengerdt and Glass (1983) and are presented below.

1) abrupt, angular changes in the stream drainage pattern.
2) long, straight, or gently curved streams.
3) abrupt truncation of streams, ridgelines, or hills.
4) alignment of topographic features.
5) straight or persistent escarpments or cliffs.
6) straight or slightly curved breaks in otherwise unbroken terrain.

Stream segments were rectified using a "line of sight" technique (Venkatakrishnan, personal communique). This method involves annotating linear reaches of a channel as if one were standing on the bank of the river and looking down stream. Linear segments were defined by bends in the river where the viewer could see no further downstream. Only perennial streams, mapped as solid blue lines on the quadrangle sheets, were selected for analysis. Operator error (bias) can be introduced during the annotation of linear features as trends are recognized and preferentially mapped. In order to eliminate, as much as possible, the introduced bias, the maps were rotated periodically during interpretation.

Topographic linears and rectified stream segments annotated on the eight quadrangles were combined to form base maps of the study area. Topographic linears and rectified stream segments were digitized separately, in a Cartesian (x,y) coordinate system, employing a Numonics Model 1224

Electronic Digitizer. An arbitrary zero point was selected in the southwest corner of each plot and linear features were mapped in lengths of miles.

Statistical Analysis of Annotated Linears

Linear features recognized in the current investigation included 894 rectified stream segments and 882 topographic linears. These linear elements were plotted in rose diagrams and subjected to statistical analysis in order that common trends could be recognized and compared to structural features recognized in the field and mapped during the course of this study. It should be noted, however, that a detailed analysis of lineament densities and spatial variability was beyond the scope of this study.

Analysis of linear features can be conducted using either frequency (number of linear per azimuth class) or length-weighted frequency distributions. Venkatakrishnan (1984) recognized that length-weighted distributions of linear features appeared to be structurally more important than short linears, which comprise a statistically larger sample, but are more evenly distributed in an area. He noted that significant length-weighted trends, could be correlated with linears on subsurface structural contour maps, basement trends obtained from geophysical maps (aeromagnetic and gravity), and inferred dominant direction of fracturing in the basement. Length-weighted frequency distributions were used in the analysis of each data set.

Annotated linear features were divided into 18 azimuthal classes, each with an angular length of 10 degrees. The use of 10 degree angular segments allowed for the depiction of qualitatively significant peaks and troughs and a comparison of significant linear trends with those observed in other Coastal Plain investigations (Venkatakrishnan, 1984; Lane, 1984; Mullens, 1986). As previously mentioned, rose diagrams do not allow for the quantitative determination of the significance of observed trends. In order to determine the significance of each, the databases were

subjected to a nonparametric χ^2 test. A discussion of this test is presented in the Outcrop Structures section of this chapter.

RESULTS AND INTERPRETATION

Geophysical Lineaments

Northeast and northwest oriented geophysical lineaments were annotated on Bouguer gravity and total intensity aeromagnetic maps of the study area (Figures 12 and 13). In general, magnetic susceptibility contrasts provided better resolution of inferred buried basement structures, although major features were visible on both aeromagnetic and Bouguer gravity maps.

Two prominent geophysical anomalies were observed on both maps and include the north-northeast trending Central Virginia Gravity-Magnetic High and a west flanking similarly oriented gravity-magnetic trough. These features contain and are bound by north-northeast trending geophysical lineaments. The Central Virginia Gravity-Magnetic High has been demonstrated to mark the presence of a suite of mafic rocks (Hubbard and others, 1978). Newell and Rader (1982) noted that the regional geophysical high coincides with a pronounced flexuring of Coastal Plain sediments. In general, north-northeast trending lineaments coincide with biotite foliation in the Petersburg Granite, a fault in the Potomac sediments at Drewrys Bluff (Cederstrom, 1945b), western boundary faults of the Richmond and Taylorsville Triassic basins, and the Appalachian fabric. Triassic-Jurassic rocks have been documented to occupy at least a portion of the aeromagnetic trough (Shomo, 1982). In the south, north-trending aeromagnetic gradients that flank the trough to the west and east have been correlated with the Dutch Gap and City Point-Bailey Creek faults (Dischinger, 1987).

North-northeast trending geophysical gradients appear to be disrupted, separated, and offset by northwest-trending lineaments. These lineaments coincide with a northwest-trending fault observed in the study area, northwest-trending border faults of the Richmond basin, the Hampton

FIGURE 12: Aeromagnetic map of the study area illustrating annotated geophysical lineaments (from Zietz and others, 1977). North and northeast trending lineaments are shown using short dashed lines. Those trending northwest are indicated with long dashed lines. Boundaries of the eight 7.5 minute quadrangles outline the study area.

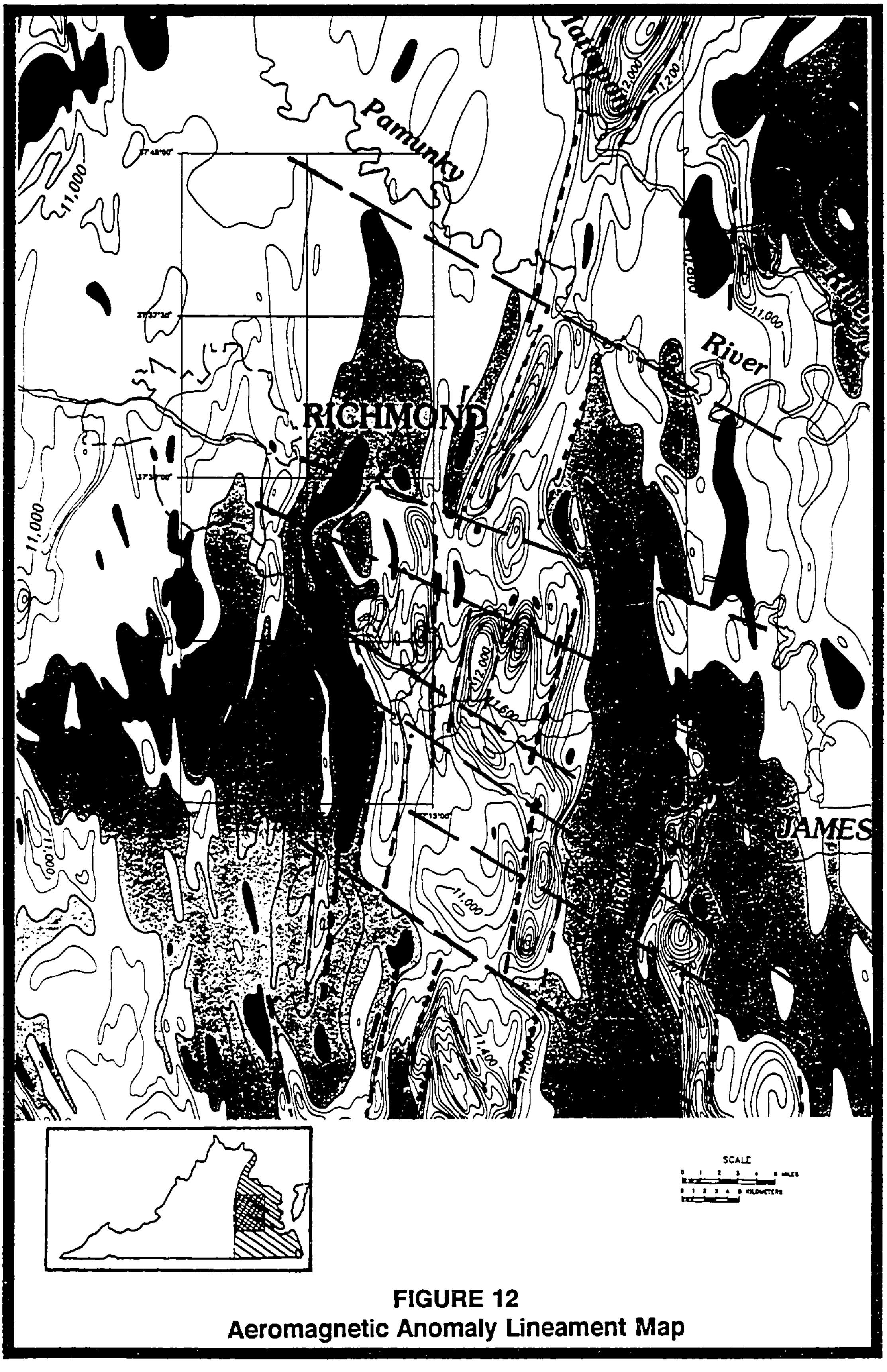


FIGURE 12
Aeromagnetic Anomaly Lineament Map

FIGURE 13: Bouguer gravity map of study area illustrating annotated geophysical lineaments (from Johnson, 1977). North and northeast trending lineaments are shown using short dashed lines. Those trending northwest are indicated with long dashed lines. Boundaries of the eight 7.5 quadrangles outline the study area.

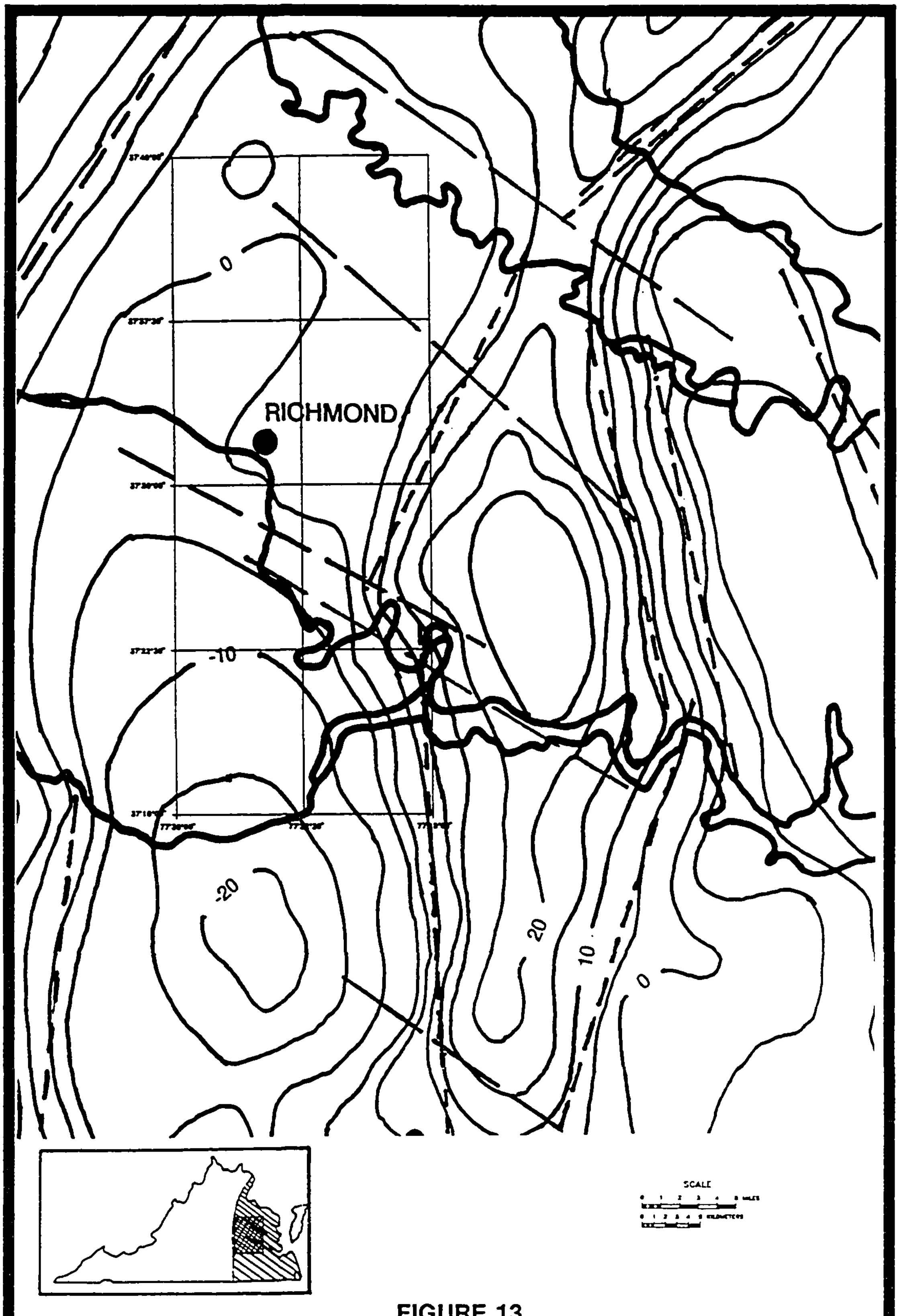


FIGURE 13
Bouguer Gravity Anomaly Lineament Map

Roads Fault (Cederstrom, 1945b), and the James River Lineament Zone (Venkatakrishnan, 1984). One such feature corresponds with a southeast trending reach of the James River from Drewrys Bluff to Hopewell. Others parallel the generally southeast trending courses of the Chickahominy and Pamunkey rivers.

When combined, the north-northeast and northwest-trending geophysical lineaments appear to mark the margins of fault bounded basement blocks. If so, these blocks may or may not have been reactivated by late Mesozoic and Cenozoic tectonism. Subsequent movement along these features would be expressed by deformation of the overlying sediment package.

Tectonic Framework

Structural contour and isopach maps of the pre-Cretaceous basement surface and lower Cretaceous through lower Tertiary units define the pre-Miocene tectonic framework of the study area. Figures 14 through 22 illustrate the erosional surfaces and thickness distributions of these units. Cross sections A-A' through K-K', drafted from select borehole data, aide in visualization of the tectonic framework of the study area (Plates 1 through 12). Locations of the cross section traverses are presented in Figure 23. Comparison of the contour plots and cross sections reveals an interesting and complex relationship between basement features and post-Jurassic sediment distribution. Contour maps of the lower Cretaceous and lower Tertiary units posses similar anomalies in surface gradient and unit thickness suggesting that although they are separated temporally by hiatuses of up to 45 my, common factors have influenced their deposition. Three major anomalies are pervasive through the pre-Miocene sediment package. These anomalies are annotated on the contour plots as A, B, and C for comparison. Their trends are denoted by heavy dashed lines. Common gradients along these features are labeled numerically with the trend for each gradient indicated by a light dashed line. Elements of the structural features coincide with aeromagnetic and gravity anomalies. Two of the structural anomalies coincide with previously

FIGURE 14: Structural contour map of the Basement surface. Structural anomalies which are dominant throughout the overlying sedimentary package are indicated with heavy lines and annotated with the letters A, B, and C. Common gradients are indicated with light dashed lines and numbered for comparison with other maps.

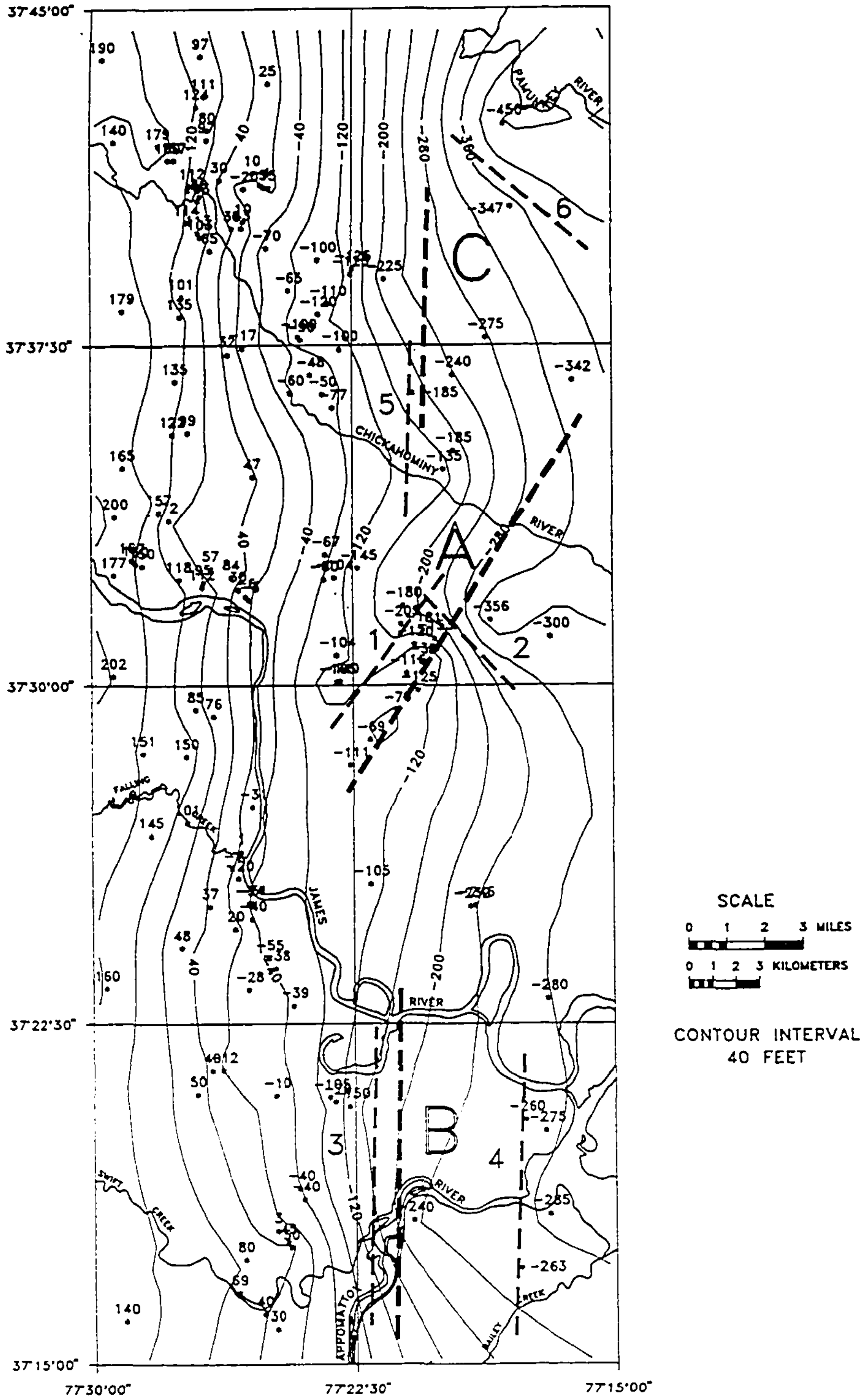


FIGURE 14
Basement Surface
Structural Contour Map

FIGURE 15: Structural contour map of the Potomac Formation surface. Structural anomalies which are dominant throughout the overlying sedimentary package are indicated with heavy lines and annotated with the letters A, B, and C. Common gradients are indicated with light dashed lines and numbered for comparison with other maps.

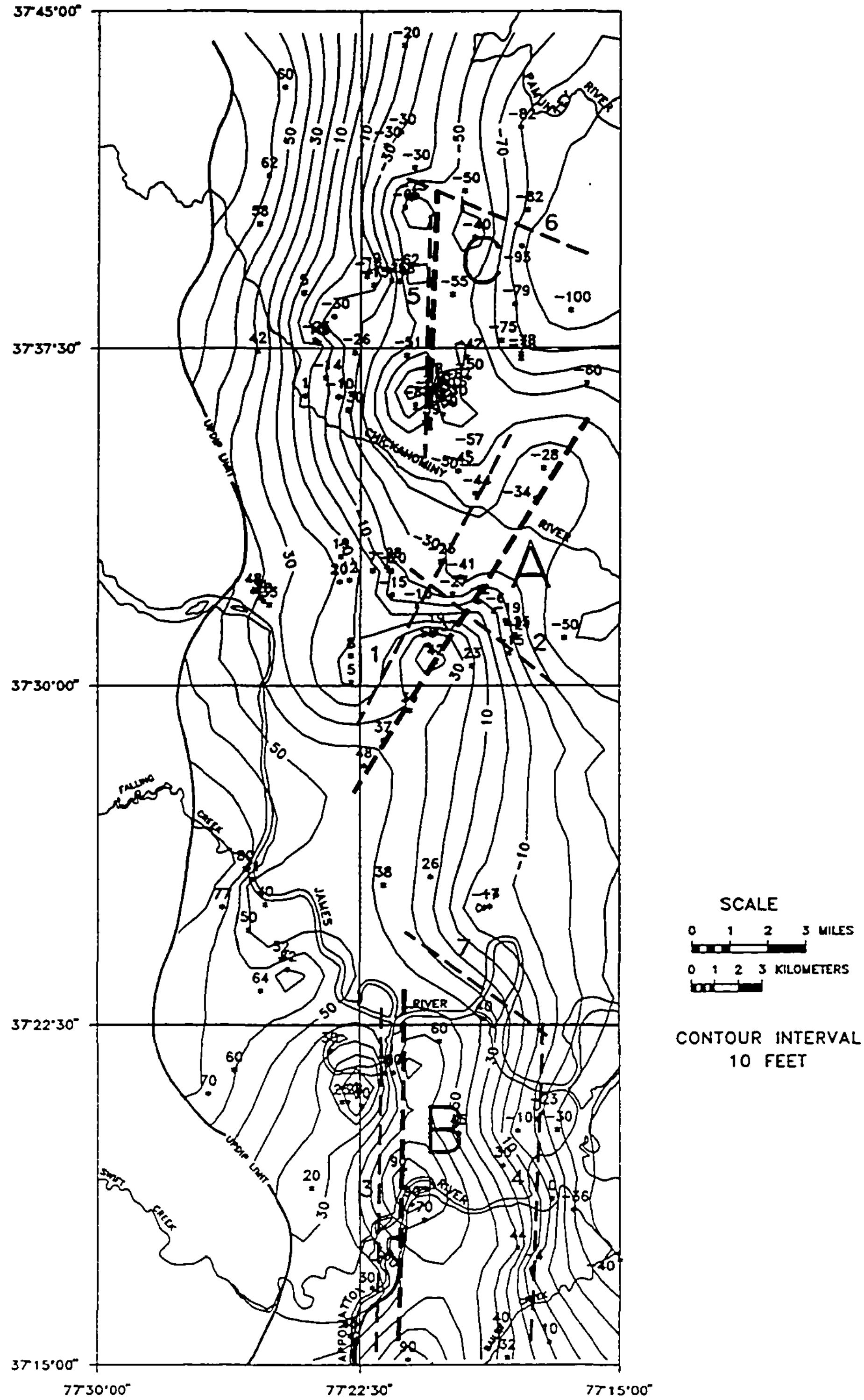


FIGURE 15
Potomac Formation
Structural Contour Map

FIGURE 16: Isopach map of the Potomac Formation. Structural anomalies which are dominant throughout the overlying sedimentary package are indicated with heavy lines and annotated with the letters A, B, and C. Common gradients are indicated with light dashed lines and numbered for comparison with other maps.

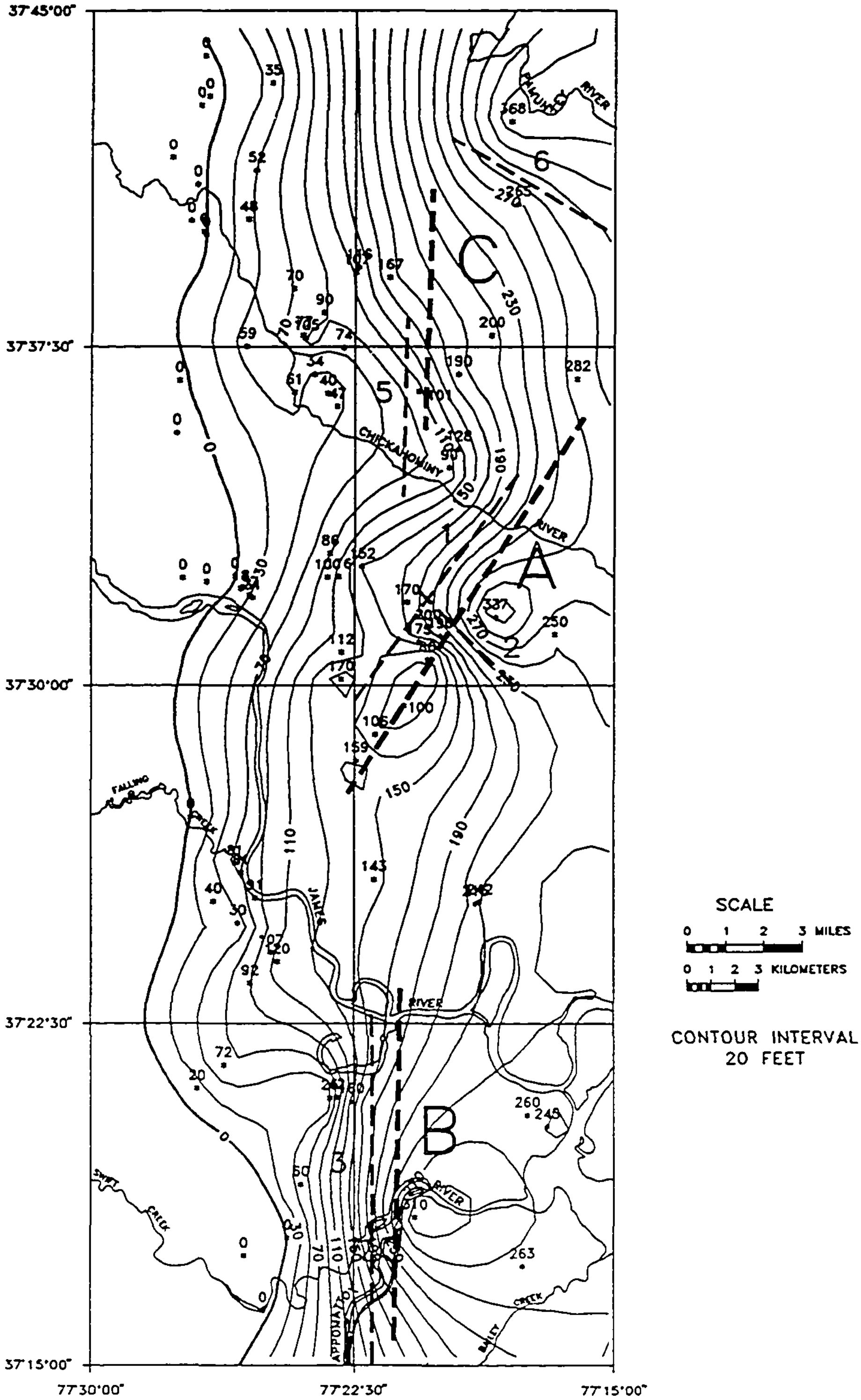


FIGURE 16
Potomac Formation Isopach Map

FIGURE 17: Structural contour map of the Aquia Formation surface. Structural anomalies which are dominant throughout the overlying sedimentary package are indicated with heavy lines and annotated with the letters A, B, and C. Common gradients are indicated with light dashed lines and numbered for comparison with other maps.

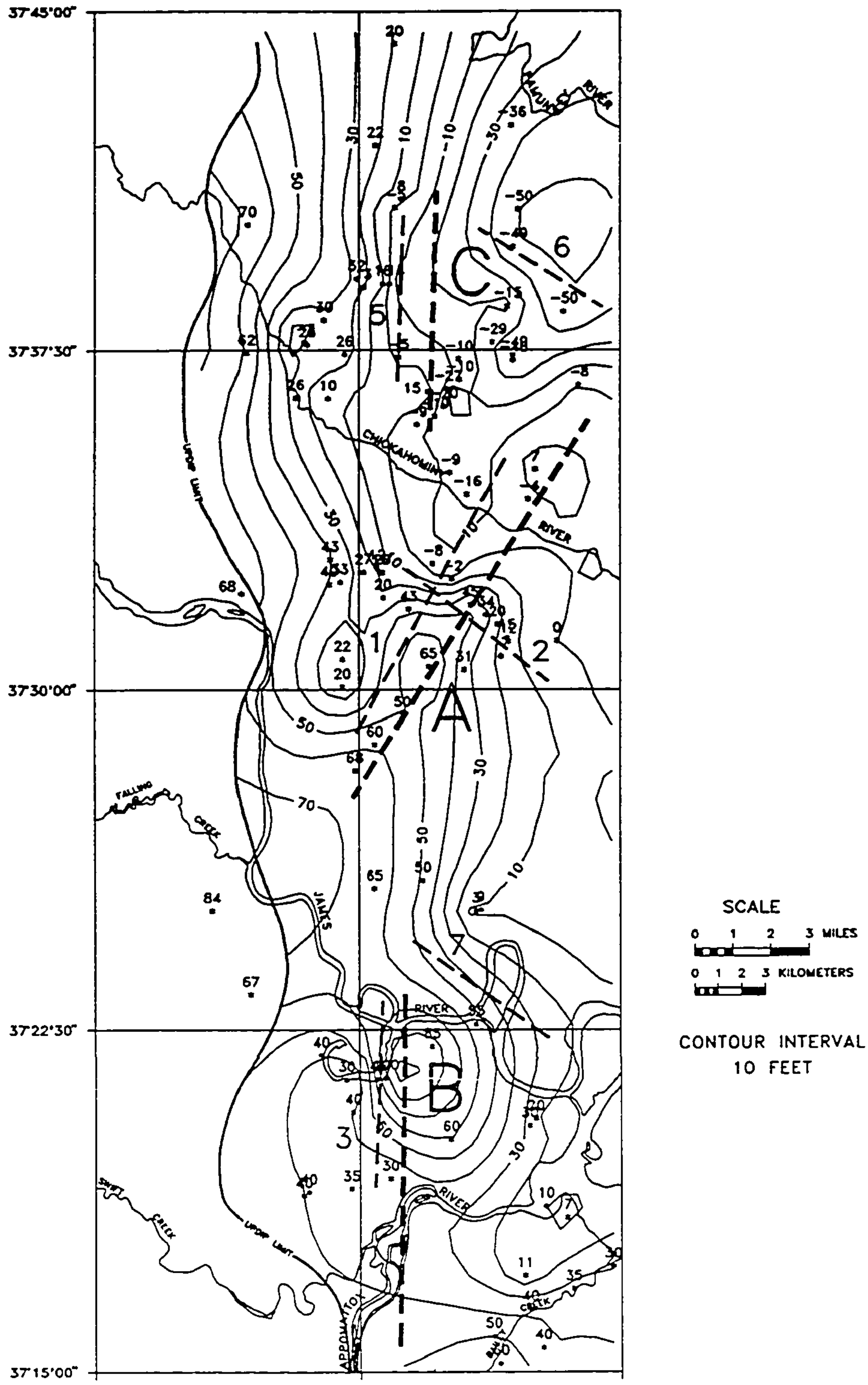


FIGURE 17
Aquia Formation
Structural Contour Map

FIGURE 18: Isopach map of the Aquia Formation. Structural anomalies which are dominant throughout the overlying sedimentary package are indicated with heavy lines and annotated with the letters A, B, and C. Common gradients are indicated with light dashed lines and numbered for comparison with other maps.

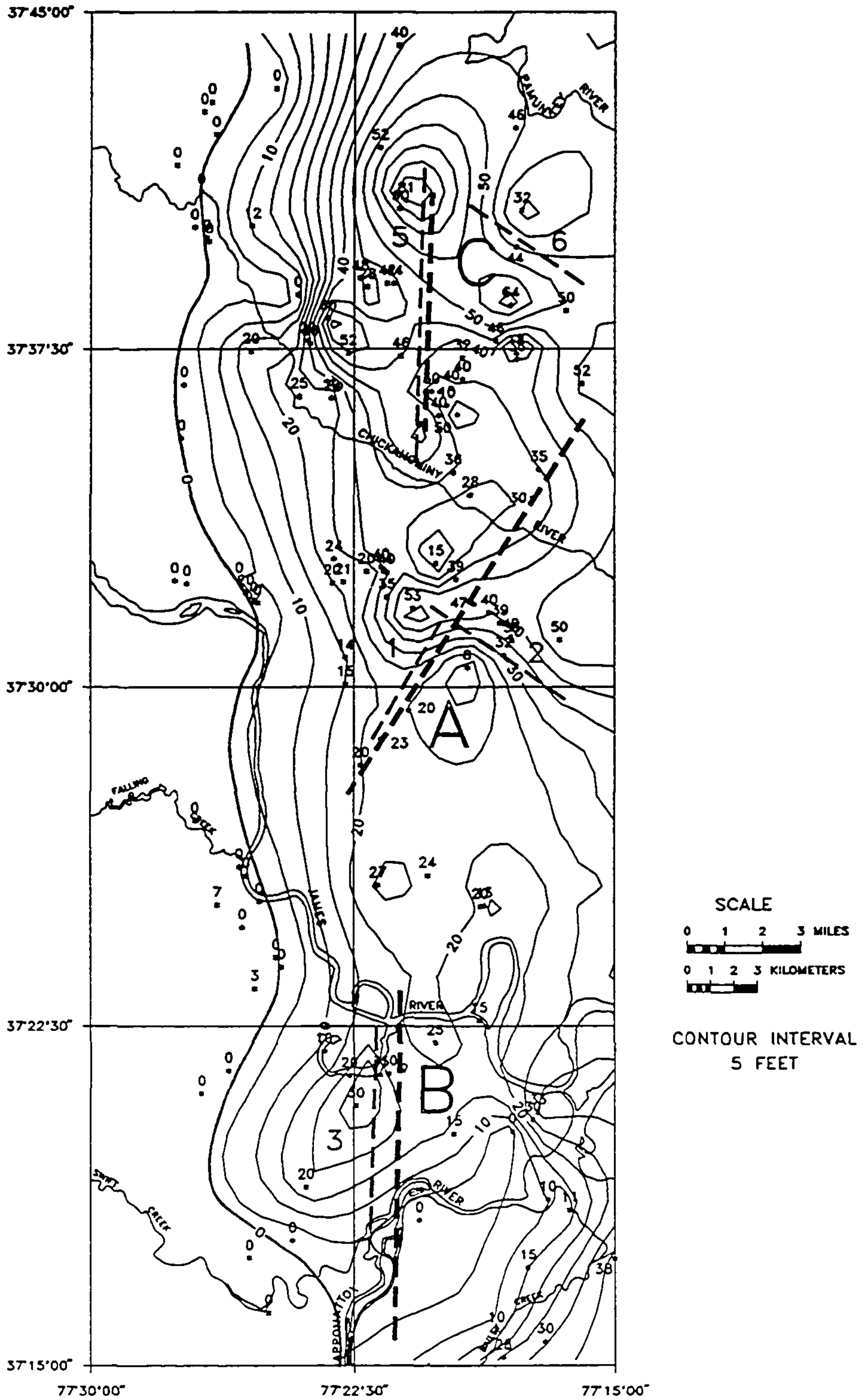


FIGURE 18
Aquia Formation Isopach Map

FIGURE 19: Structural contour map of the Marlboro Clay surface. Structural anomalies which are dominant throughout the overlying sedimentary package are indicated with heavy lines and annotated with the letters A, B, and C. Common gradients are indicated with light dashed lines and numbered for comparison with other maps.

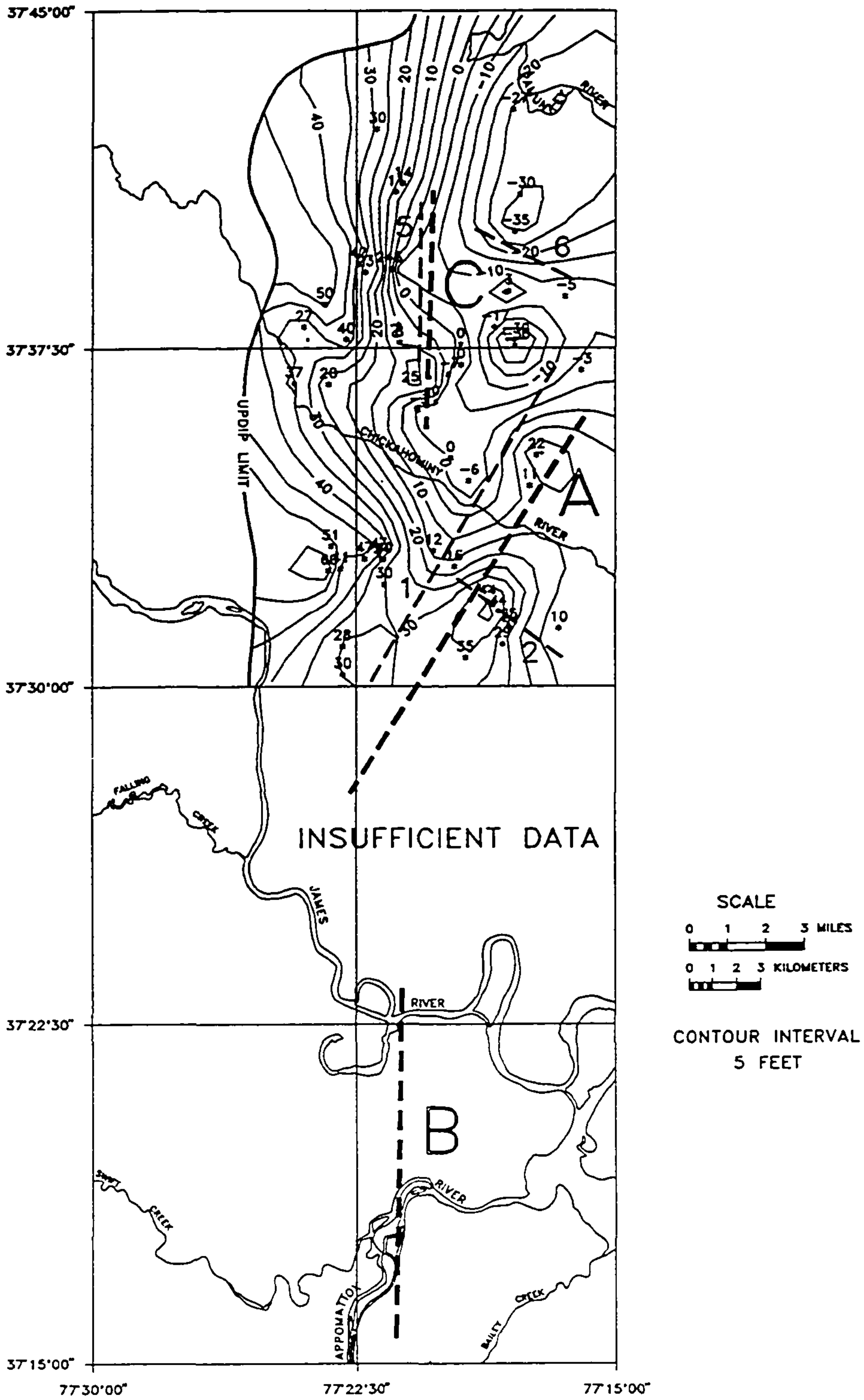


FIGURE 19
Marlboro Clay
Structural Contour Map

FIGURE 20: Isopach map of the Marlboro Clay. Structural anomalies which are dominant throughout the overlying sedimentary package are indicated with heavy lines and annotated with the letters A, B, and C. Common gradients are indicated with light dashed lines and numbered for comparison with other maps.

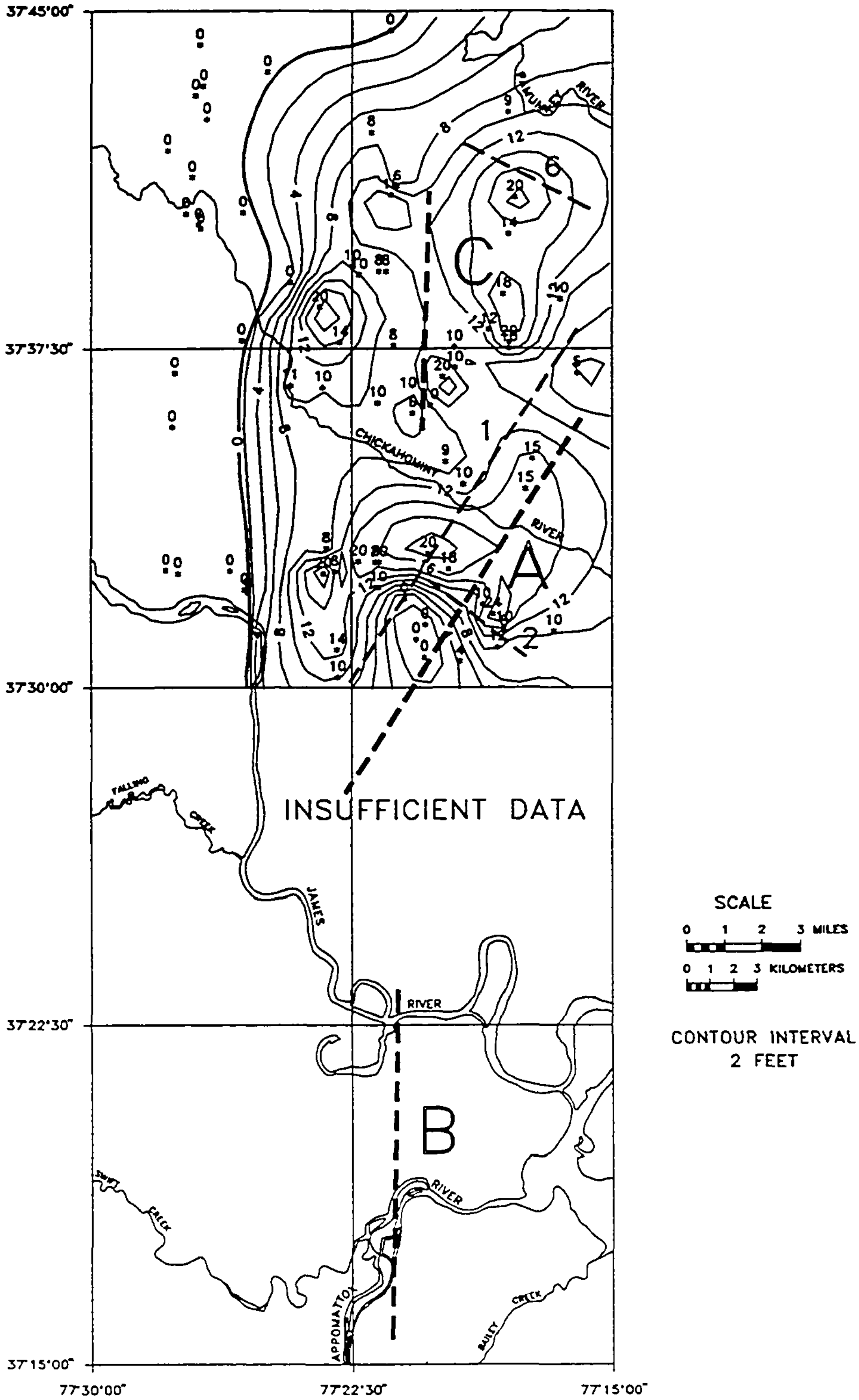


FIGURE 20
Marlboro Clay Isopach Map

FIGURE 21: Structural contour map of the Nanjemoy Formation surface. Structural anomalies which are dominant throughout the overlying sedimentary package are indicated with heavy lines and annotated with the letters A, B, and C. Common gradients are indicated with light dashed lines and numbered for comparison with other maps.

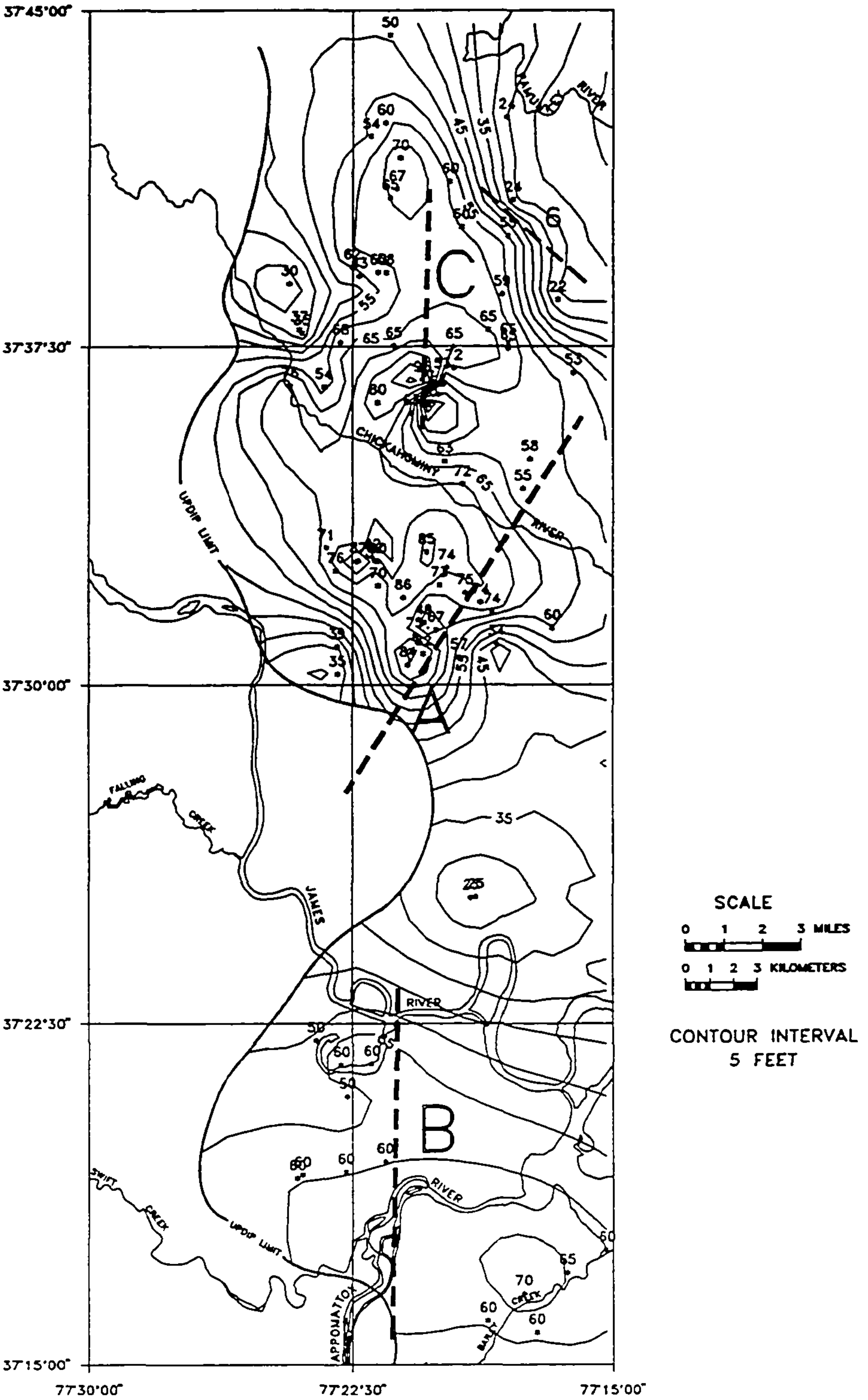


FIGURE 21
Nanjemoy Formation
Structural Contour Map

FIGURE 22: Isopach map of the Nanjemoy Formation. Structural anomalies which are dominant throughout the overlying sedimentary package are indicated with heavy lines and annotated with the letters A, B, and C. Common gradients are indicated with light dashed lines and numbered for comparison with other maps.

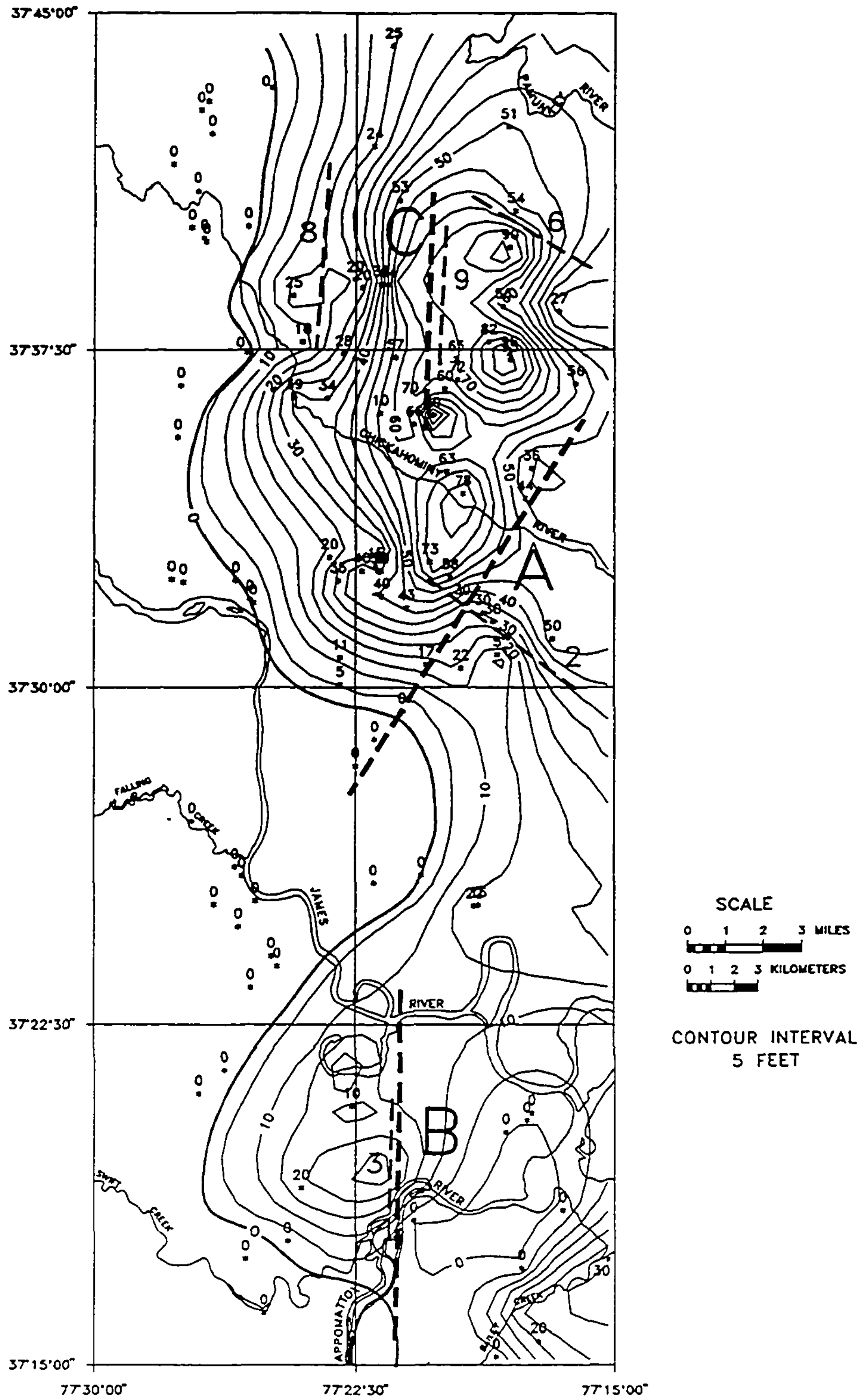


FIGURE 22
Nanjemoy Formation Isopach Map

FIGURE 23: Map of the study area illustrating the location of the twelve constructed cross sections. These sections are presented as Plates 1 through 12.

(located in pocket attached to rear cover)

documented basement features including a buried Triassic-Jurassic basin (Shomo, 1982) and the Dutch Gap fault (Dischinger, 1979) implying a causative relationship.

Basement Rocks

Regionally, the basement surface slopes easterly at a rate ranging from 34 to 66 feet per mile (Figure 14). In the central portion of the study area, however, the gradient is reversed over a northeast trending high in the basement surface (A). This feature is flanked to the northwest by a northeast trending trough formed by a gradient of 54 feet per mile to the west (1). To the northeast, an oversteepend gradient of 180 feet per mile (2) truncates the high. The structural high is coincident with a aeromagnetic low and gravity gradient of similar orientation and a buried Mesozoic basin (Shomo, 1982) [Figures 12 and 13]. Gradient 1 is correlative with the northwest boundary of the aeromagnetic low and the basin. Granite bedrock is present to the north and northwest. Gradient 2 coincides with a northwest-trending aeromagnetic lineament formed by breaks in north-trending anomalies. Triassic-Jurassic rocks have been encountered in boreholes northeast of gradient 2 (W2683, W3574, W3904; Figure 10).

A second structural anomaly (B) believed to be related to an early Mesozoic basement feature is found in the southern portion of the study area. The western boundary of this structure is expressed at the surface as the Dutch Gap fault. Its presence, however, is obscured on the basement surface map due to a lack of sufficient data in this area. Borings CDER HP1 and 52G4, located approximately a half mile and 3 miles east of the fault trace, were advanced to elevations of -240 and -263 feet, respectively, without intercepting bedrock (Figure 10; Appendix A). This data suggests that the bedrock surface gradient along the fault (3) is not gradual but steep, perhaps 80 feet per mile, and gentle to the east (10 feet per mile) forming a north trending structural low. Available borehole data does not reveal the type of bedrock flooring the structural low. This structural anomaly is correlative with the aeromagnetic trough of similar orientation (Figure 12). The aeromagnetic signature of the basement rocks indicates they are Triassic-Jurassic redbeds

(Dischinger, 1979). These rocks occupy the same aeromagnetic low as the basin to the north. Triassic-Jurassic redbeds have also been encountered in the same aeromagnetic low approximately 5 miles to the south (Shomo, 1982). The eastern margin of the structural feature is also obscured on the basement structural contour map. Borehole data indicates that granite bedrock is present east of this basement feature (W3411, W4397, and CDER HP20; Figure 10). By combining the geological and geophysical evidence, it can be inferred that a fault bound Triassic-Jurassic basin occupies the basement structural low.

To the north of anomaly A is a subtle structural high, anomaly C. This feature is vaguely illustrated by a gentling of the basement surface slope to 28 feet per mile (5). Other contour plots illustrate a subtle high in this area (Figures 15, 17, 18, 19, 20, 21 and 22). Insufficient data is available in this vicinity to define the extent and nature of this basement feature. Geophysical evidence for this structure is also inconclusive. The feature generally corresponds with a north-northeast trending aeromagnetic gradient but its relationship with the gravity map is unclear (Figures 12 and 13). The structure exists in granite bedrock and may represent basement faulting along the Triassic-Jurassic basin. Northeast of structural high C the basement surface slopes to the northeast at a rate of 72 feet per mile (6). This gradient corresponds with a similarly oriented aeromagnetic lineament (Figure 12) and may mark the presence of basement faulting.

Potomac Formation

Contours of the Potomac Formation surface generally mimic those of the basement, however, a larger database provides better resolution of disturbances in gradient (Figure 15). This plot best illustrates the relationship between basement features and post-Jurassic sediment distributions. Generally, the surface of the Potomac Formation slopes to the east at a rate 15 to 20 feet per mile. In the central portion of the study area, northeast trending structural high A is present. This high is marked by a northeast-trending west sloping gradient of 10 to 58 feet per mile (1) and

correlates with the northwest margin of the buried Mesozoic basin. The high is transected by a steep northwest trending gradient with a slope of 30 feet per mile (2).

In the south, north trending structural high B is present over an inferred Mesozoic structure. An apparent reversed gradient of more than 70 feet per mile (3) flanks the structural high to the west and correlates with the Dutch Gap Fault. The actual gradient is much greater along the fault. To the east, an oversteepened gradient of more than 45 feet per mile (4) coincides with the opposite boundary of the basement feature suggesting a structural influence (City Point-Bailey Creek Fault). The structural high is bound to the north by a northeast sloping gradient of 20 feet per mile (7). Although this gradient is not evident on the basement surface map, it does coincide with a northwest trending break in the aeromagnetic low (Figure 12).

North of the Triassic-Jurassic basin in the central portion of the study area is a second north-trending structural high in the Potomac surface (C). This feature is flanked to the west by a gradient reversal of 15 to 30 feet per mile (5). The structure is bound to the north by a south sloping gradient (6) of 36 feet per mile. As previously mentioned, this gradient coincides with a northwest-trending aeromagnetic lineament. Although strong evidence of a basement structure does not exist, this data indicates that external factors such as basement faulting influenced sediment distribution in this area.

Comparison of the Basement and Potomac structural contour plots with the Potomac isopach map supports the hypothesis that the sediment distribution has been structurally controlled. Figure 16 illustrates the thickness distributions of the Potomac Formation. In general, the Potomac Formation thickens at a rate of 48 feet per mile to the east. An abrupt change in thickness of the Potomac Formation occurs over the Triassic-Jurassic basin in the central portion of the study area (A). The unit thins by over 70 feet across gradient 1. A sudden thickening of the Potomac by 257 feet is observed across gradient 2. In the southern portion of the study area, the Potomac thickens

by over 150 feet across the Dutch Gap fault (3). To the north, the rate at which the Potomac thickens diminishes to 18 feet per mile across the southern portion of structural high C. Northeast of C, the unit thickens to the northeast at a rate of 48 feet per mile (6).

Aquia Formation

Structural contours of the Aquia Formation surface exhibit similar disturbances in regional gradient as those of the Potomac Formation implying a common origin (Figure 17) In general, the Aquia surface slopes to the east at a rate of 12 to 16 feet per mile. As in the case of the Basement and Potomac surfaces, a west sloping gradient (1) is present along the structural high over the Mesozoic basin in the central portion of the study area (A). Gradient 1 slopes approximately 28 feet per mile to the northwest. Similarly gradient 2 cross cuts the high, in this case at a rate of 20 feet per mile, sloping off the high predominantly to the northeast.

In the south, a reversed gradient of 198 feet per mile occurs along the Dutch Gap fault (3). The structural high is truncated to the north by a northeast sloping gradient of 20 feet per mile (7). This gradient was also observed on the Potomac surface. The Aquia surface east of the Dutch Gap fault has been altered by Pleistocene erosion obscuring the detection of any flexuring of the unit. The same is true for the Nanjemoy Formation (Figures 21 and 22). In the north, the Aquia surface slope (5) diminishes to 7 feet per mile over structural high C. East of this feature, the surface of the Aquia slopes to the northeast at a rate of 18 feet per mile (6).

As in the case of the Potomac Formation, the thickness distribution of the Aquia has been controlled by the presence of basement features (Figure 18). The Aquia thickens to the east at an approximate rate of 6 feet per mile. The unit thins across gradient 1 over structural high A to less than 10 feet and thickens abruptly across gradient 2 to 50 feet. In the south, the Aquia reaches a thickness of 40 feet (3) west of the Dutch Gap fault and is absent over much of the uplifted fault

block. To the north, the Aquia thins by 10 to 30 feet over structural high C. The unit also thins to the northeast at a rate of 12 feet per mile across gradient 6.

Marlboro Clay

Structural contours on the Marlboro Clay exhibit similar interruptions in surface gradient as those on older units implying a continued influence of basement features on sediment distribution (Figure 19). Insufficient data was available for the Marlboro Clay in the southern half of the study area, therefore, structural contour and isopach maps were generated for the northern half only. Regionally, the Marlboro Clay surface slopes to the east at a rate of 15 feet per mile. Over structural high A, a west sloping gradient (1) of a maximum of 20 feet per mile is present. As with the other units, the high is transected by a northeast sloping gradient (2) of 14 feet per mile. At structural high C, the east sloping gradient is disrupted and appears to diminish to 9 feet per mile (5) over this feature. East of C, the unit slopes to the northeast at a rate of 18 feet per mile.

The thickness distribution of the Marlboro Clay, like those of older units, has been influenced by the presence of basement features. Figure 20 illustrates the association. The Marlboro Clay thickens to the east at an approximate rate of 3 feet per mile. The unit thins abruptly over structural high A across gradient 1 and is absent on the apex of the feature. As in the case of previously discussed units, the Marlboro thickens abruptly along the high (2) to 24 feet. The Marlboro Clay also appears to thin over structural high C. West of this feature, the Marlboro attains a thickness of 20 to 30 feet and thins to 6 to 8 feet over the structure. Northeast of C, this unit thins at an approximate rate of 4 feet per mile across gradient 6.

Nanjemoy Formation

Basement influence on the Nanjemoy Formation sediment distribution is less pronounced than on older units (Figure 21). Surfaces of the older Coastal Plain sediments are seen to generally descend from the Fall Zone to the east (Figures 15, 17, and 19). By contrast, in the north the

Nanjemoy surface rises from an elevation of 30 to 70 feet at an approximate rate of 10 feet per mile before descending to the east at a much greater rate of 21 feet per mile. The apex of the surface coincides with structural high C. An interesting relationship between structural high C and the Nanjemoy Formation is also observed in the isopach map (Figure 22). In the north, the unit thickens at an average rate of 10 feet per mile west of the high, thickens relatively suddenly adjacent to the high (35 feet per mile), and maintains a relatively constant thickness over the high of approximately 65 feet. East of the high, the unit thins abruptly at a rate of 25 feet per mile to a thickness of 24 feet. The thinning corresponds with the increased surface gradient suggesting the presence of a steep erosional surface such as a scarp. A similar relationship is observed at structural high A. At this locality, the apparent scarp bounds the structure to the south. The Nanjemoy is thin or absent over the southern portion of the high. This data suggests that these structural highs have affected post-Eocene sedimentation. In the south, the Nanjemoy Formation is observed at similar elevations on either side of the Dutch Gap fault (B), although the unit is absent on the uplifted fault block. West of the fault, the unit reaches a maximum thickness of 30 feet prior to encountering the structure.

Structural Interpretation

Various factors could produce the thickness anomalies observed in the Coastal Plain units over the basement features. Possible causes include: 1) onlap, 2) offlap and/or erosion, 3) convergence, 4) compaction/draping, 5) faulting, and 6) errors in selecting stratigraphic time-units (Sonnenburg and Weimer, 1981). Without the benefit of a detailed facies analysis of the units, it is difficult to discern the effects of the first three controlling factors. A preponderance of evidence is available, however, that demonstrates basement faulting has influenced the post-Jurassic structural framework. The most obvious indicator of this relationship is the Dutch Gap fault in the southern portion of the study area. Geological and geophysical evidence suggests the fault marks the western boundary of a buried Triassic-Jurassic basin indicating a causative relationship. Similar reactivated basement structures have been documented at other localities in the Virginia Coastal

Plain (Figure 4: #1, #3, #5, #12). An anomalously thick sequence of Potomac sediments occupies the structural trough (Figure 16). Younger units thin abruptly across the structure due to subsequent reverse faulting. In fact they are absent over much of the uplifted block (Figures 18 and 22). To the east, apparent basement faulting along the eastern margin of the buried basin is manifested as an oversteepened gradient of the Potomac surface (Figure 15). Due to the effects of Pleistocene erosion and insufficient data, the relationship between this fault and younger Coastal Plain sediments is unclear. Dischinger (1979) noted that Upper Tertiary and Quaternary terrace deposits truncate the Dutch Gap Fault and mark the cessation of tectonic activity. Uplift along the fault bound basement block has not only affected the thickness of the Coastal Plain units but has also controlled the geomorphology of the area. Upon descending the Fall Zone, the Appomattox River is diverted to the north along the Dutch Gap fault prior to its confluence with the James River at Hopewell (Figure 4).

Geological, geophysical, and geomorphic relationships observed on Dutch Gap structure can be employed to infer the presence of similar buried Coastal Plain structures to the north. Structural high A in the central portion of the study area is correlative with a buried Triassic-Jurassic basin (Figure 14). Related northeast-trending gradient 1 and northwest-trending gradient 2 appear to recur in the structural contour and isopach maps of the Coastal Plain units (Figure 15 through 22). A third, less prominent, gradient (7) also appears to be related to this structure (Figures 15 and 17). Gradient 1 coincides with the northwest margin of the basin as defined by geological and geophysical evidence. This gradient also corresponds with a northeast-trending Landsat lineament mapped by Venkatakrishnan (1984) (Figure 4, #18). Cederstrom (1945) documented a northeast-trending reverse fault in Potomac sediments at Drewrys Bluff that lies on strike with gradient 1. Gradient 2 coincides with a northwest-trending aeromagnetic anomaly and linear reach of the Chickahominy River. During the field investigations of this study, a northwest-trending fault was observed in the Petersburg Granite at the Tidewater Materials Quarry on the James River (Appendix C; Figure 11). Gradient 7, like gradient 2, corresponds with a northwest-trending aeromagnetic

anomaly. This gradient marks a change in trend of the aeromagnetic trough from north to northeast (Figure 12). Gradient 7 also parallels a southeast trending reach of the James River, lies on-strike with the Hampton Roads Fault (Cederstrom, 1945), and coincides with the James River Lineament Zone (Venkatakrishnan, 1984). Figure 4 illustrates these associations. Based on these relationships, gradients 1, 2, and 7 are interpreted to represent basement faults.

Basement to cover relationships at structural high C in the north are less well defined than those to the south. Borehole data indicates the area is floored by granite (Appendix A, Figure 10). A lack of contrasting basement lithologies has resulted in a relatively subdued geophysical signature (Figures 12 and 13). Disturbances in the Coastal Plain sediments across gradient 6 do correspond with a northwest trending geophysical lineament. This trend also corresponds with the generally southeastern course of the Pamunkey River. When combined, the geological, geophysical, and geomorphic data provides evidence that structural high C and gradient 6 mark the sites of basement faulting.

Outcrop Structures

Orientation data collected in the field was plotted in the form of azimuthal frequency diagrams to allow for the depiction and comparison of dominant fracture orientations in the rock units. Azimuthal frequency diagrams of the four rock units studied are presented in Figure 24. Results of the chi-square statistical analyses conducted on each dataset at the 99% confidence level indicate the structures are not randomly distributed but lie in one of three to five dominant orientations. Dominant structural orientations observed in each rock unit are summarized in Table 3.

Comparison of the four plots (Figure 24) reveals the presence of four common dominant structural trends: N-S (N10W-N10E), NE-SW (N20-40E), E-W (N60E-N60W), and NW-SE (N20-50W). Lane (1984) noted similarly oriented fracture sets in an iron-cemented sandstone of the Yorktown Formation where it crops out along the Piankatank River.

FIGURE 24: Azimuthal frequency rose diagrams for field measured structures. Number of measured structures (N) and average azimuthal frequencies are presented for each lithologic unit.

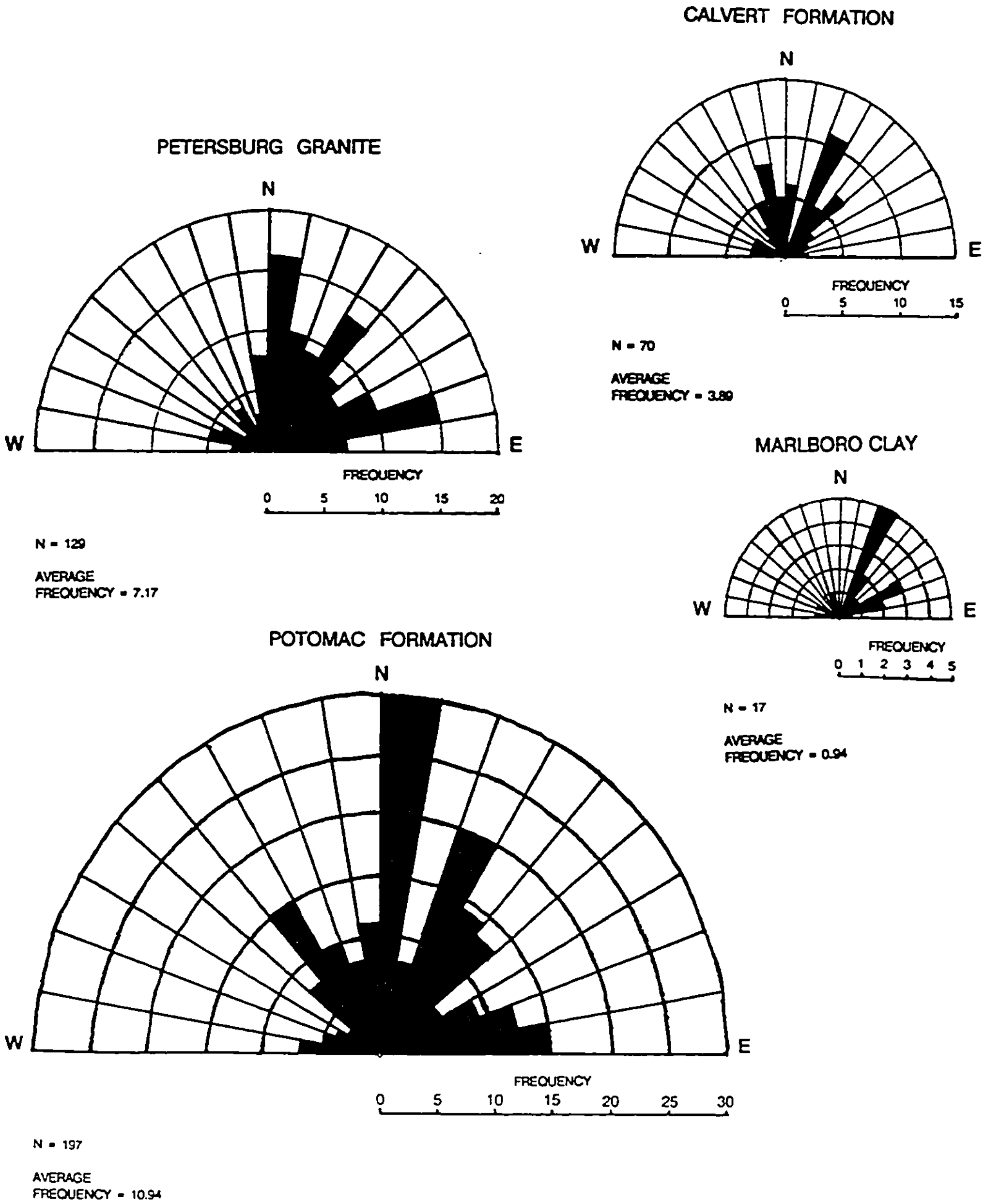


FIGURE 24
Azimuthal Frequency Rose Diagrams of Field Measured Structures

TABLE 3

DOMINANT FIELD MEASURED STRUCTURAL ORIENTATIONS

UNIT	# OF OBSERVS	DOMINANT ORIENTATIONS	COMMENTS
PETERSBURG GRANITE	129	N10W-N20E N30-40E N60-80E N20-50W* N60-80W*	N30-40E Trend parallel to biotite foliation. N20-30W trending fault observed at the Tidewater Materials Quarry.
POTOMAC FORMATION	197	N10W-N10E N20-50E N70E-N80W N20-40W	Fracture sets observed in black and green clays of unit.
MARLBORO CLAY	17**	N20-40E N60-80E N10-20W* N60-80W*	
CALVERT FORMATION	70	N10E-N30W N20-50E N60-90W	

* Dominant trends relative to other northwest oriented structures.

** Data collected from one locale only.

The most prevalent of these is the NE-SW oriented trend. Several other structures documented in the eastern Piedmont and Coastal Plain of Virginia have a similar orientation (Figure 4). Locally, this trend corresponds with biotite foliation observed in the Petersburg Granite, faulting of Potomac sediments at Drewrys Bluff (Cederstrom, 1945b), western border faults of the Richmond and Taylorsville Triassic basins, the Hylas Mylonite Zone, and the Appalachian fabric in general.

The N-S trend is most pronounced in the Petersburg Granite and Potomac Formation. This trend is correlative with the Dutch Gap fault in the southern portion of the study area, western border faults of the southern portion of the Richmond Basin, and a Mesozoic (Triassic) dike swarm in the Piedmont to the west(King, 1968, 1970).

The NW-SE structural trend is best exhibited in the Potomac Formation. A fault of similar orientation was observed in the Petersburg Granite at the Tidewater Materials exposure (#5, Figure 11). The amount of displacement along the fault could not be determined due to the homogeneous appearance of the rock. Northwest-trending border faults in the Richmond Basin that offset north-trending faults have a similar orientation. In addition, this trend coincides with the Hampton Roads Fault (Cederstrom, 1945b) and James River Lineament Zone (Venkatakrishnan, 1984). Figure 4 illustrates these relationships. This trend also corresponds with inferred transcurrent faults formed during the collision of the Chesapeake Microplate and the North American continent (Davison, 1985).

East-west oriented structures comprise the widest ranging and least understood azimuthal class. Their relationship with other documented Coastal Plain and Piedmont structures is unclear. Venkatakrishnan (1984) did note similarly oriented hinge lines that occasionally controlled Coastal Plain sedimentation.

Linear Features

Topographic Linears

Topographic linears annotated on the eight 7.5 minute quadrangle maps of the study area are shown in Figure 25. Length-weighted frequency distributions of the topographic linear features are presented in Table 4 and depicted in Figure 26. Two broad trends were noted to occur in the study area. At a 99% confidence level, the trends proved not to be randomly distributed but aligned in one of two major orientations: NE-SW (N20-70E) and NW-SE (N30-70W). These trends coincide with topographic features mapped by Newell and Rader (1982) in the Virginia Coastal Plain north of the study area.

A majority of the topographic linears mapped have a northeast orientation (N20-70E). This trend corresponds to statistically significant air photo and LANDSAT lineaments of similar orientation annotated by Mullen (1986) and Venkatakrishnan(1984). Structures measured in the rock units of the study area as well as other documented Coastal Plain structures (Figure 4) also share this orientation.

Northwest-trending topographic linears (N20-70W) were also found to be dominant. As in the case of northeast-trending linears, this broad trend coincides with statistically significant air photo and LANDSAT lineaments mapped by Mullen (1986) and Venkatakrishnan (1984). Field measured structures, documented Coastal Plain structures (Figure 4), and major river courses are found to have a common orientation. It should be noted that riverine scarps also share this orientation, however, the predominance of this trend in various databases indicates other factors have influenced its presence.

A pronounced N-S oriented trough is evident on the length-weighted frequency plot (Figure 26). Mullen (1986) also noted that north-trending air photo lineaments were not significant. It is not

FIGURE 25: Map of the study area depicting annotated topographic linears. Dominant trends are illustrated in the length-weighted frequency rose diagram.

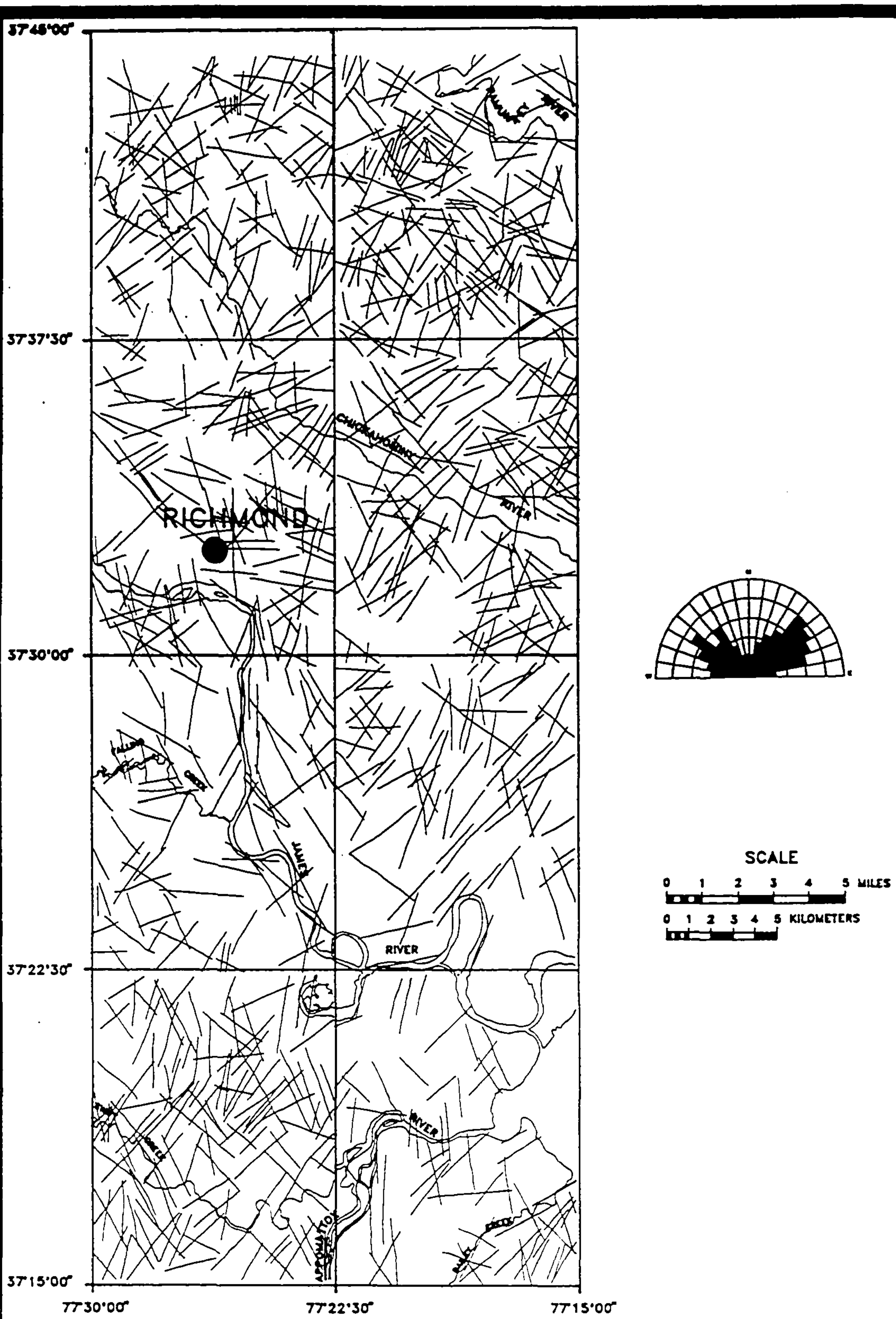


FIGURE 25
Topographic Linear Plot

TABLE 4

TOPOGRAPHIC LINEAR ORIENTATIONS

CLASS INTERVAL (DEGREES)	AZIMUTH-FREQUENCY	% OF TOTAL	LENGTH-WEIGHTED FREQUENCY	% OF TOTAL
NORTH:				
0–10	22	2.49	23.59	2.67
10–20	34	3.85	35.59	4.03
20–30	44	4.99	45.86	5.20
30–40	57	6.46	54.53	6.18
40–50	82	9.30	81.75	9.27
50–60	72	8.16	75.08	8.51
60–70	69	7.82	69.27	7.85
70–80	60	6.80	61.80	7.01
80–90	33	3.74	29.39	3.33
EAST:				
WEST:				
90–80	47	5.33	40.97	4.64
80–70	50	5.67	46.12	5.23
70–60	55	6.24	58.58	6.64
60–50	69	7.82	71.38	8.09
50–40	46	5.22	46.61	5.28
40–30	58	6.58	58.94	6.68
30–20	36	4.08	35.84	4.06
20–10	23	2.61	22.51	2.55
10–0	25	2.83	24.22	2.75
NORTH:				
ΣFREQUENCY = 882		ΣLENGTH = 1236.75 MILES		

FIGURE 26: Length-weighted frequency rose diagram of topographic linears annotated in the study area.

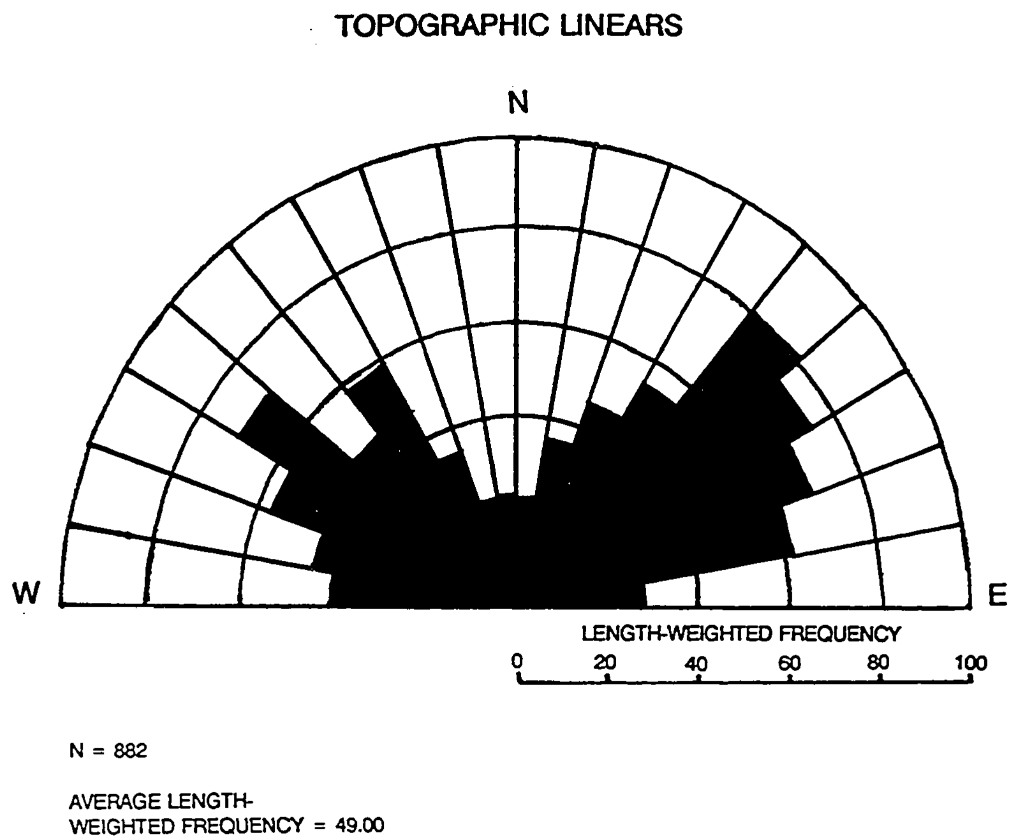


FIGURE 26
Length-Weighted Frequency Rose Diagram of Topographic Linears

clear why this orientation is not significant especially when considering north-trending features such as the Dutch Gap Fault and fracture sets in the rock units have been observed in the study area.

Rectified Drainage Linears

Rectified drainage linears annotated in the study area are depicted in Figure 27. Three major trends of stream segment orientations were identified in the study area and include N-S (N10W-N10E), NE-SW (N30-70E), and NW-SE (N20-40W). Length-weighted frequency distributions are presented in Table 5 and are graphically depicted in Figure 28. At a 99% confidence level, the drainage segments proved not to be randomly distributed.

A broad peak of moderate amplitude formed by NW-SE and E-W trending drainage segments is shown in Figure 28. These orientations are interpreted to represent the regional drainage trend as well as structurally controlled stream courses. Other Coastal Plain workers have recognized this trend as statistically significant (Mullen, 1986; Venkatakrishnan, 1984). As with topographic linears and field measured structures, a prominent northeast-trending (N30-70E) peak is found on the frequency distribution plot. This trend also corresponds with statistically significant rectified drainage segments annotated by others in the Virginia Coastal Plain (Mullen, 1986; Venkatakrishnan, 1984; Lane, 1984).

Prominent N-S trending drainage segments mark deflections of major drainages in the study area. As previously discussed, these linears coincide with a documented Coastal Plain structure and a geophysical lineament. This trend was also a dominant orientation for structures observed in the rock units of the study area. Large meanders in the James River near Hopewell also share this orientation (Figure 27). Other Virginia Coastal Plain workers have mapped similarly oriented statistically significant rectified drainage segments (Mullen, 1986; Venkatakrishnan, 1984; Lane, 1984).

FIGURE 27: Map of the study area depicting rectified drainage linears. Dominant trends are illustrated in the length-weighted frequency rose diagram. Boundaries of the eight 7.5 quadrangles outline the study area.

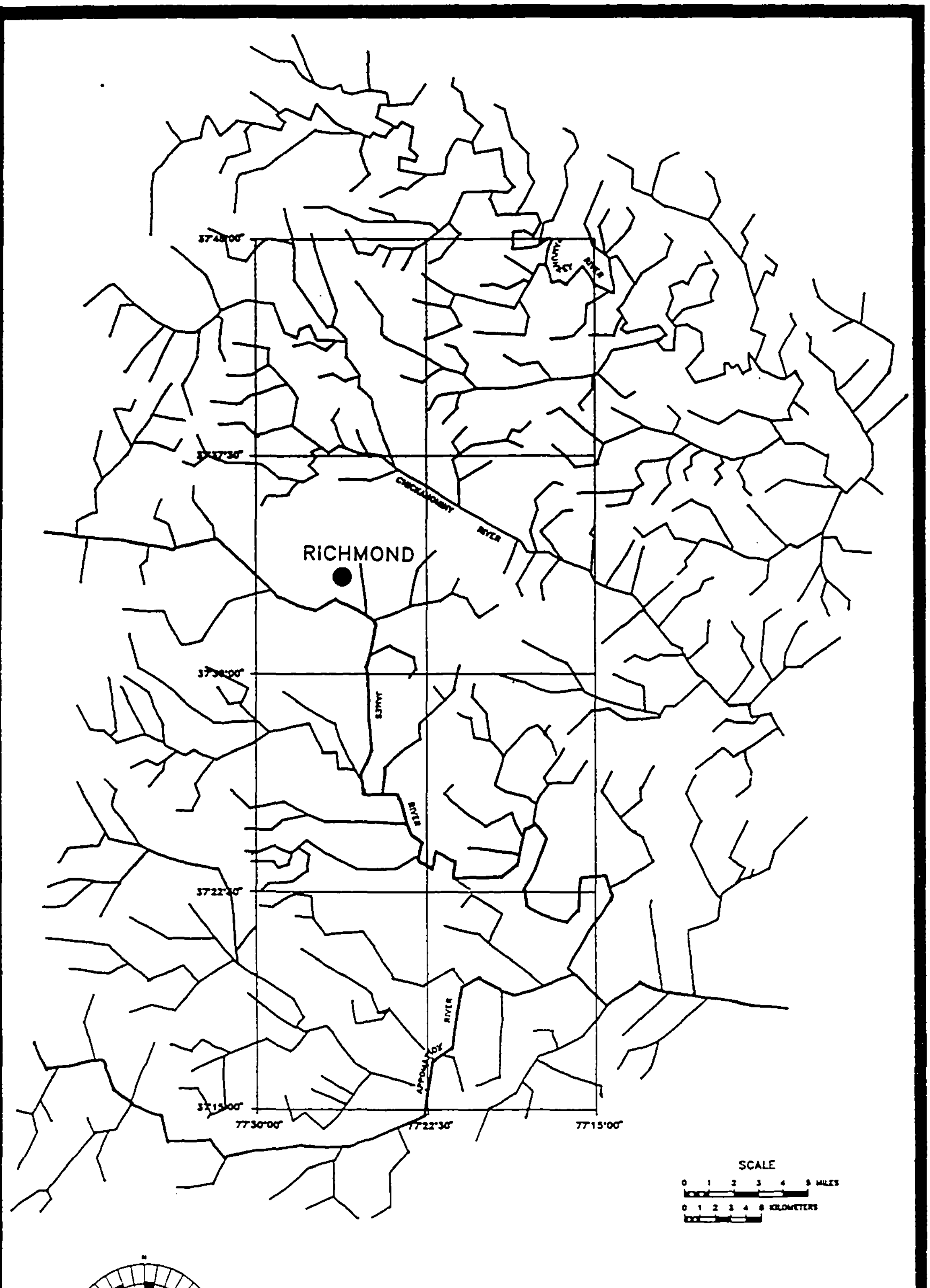


FIGURE 27
Rectified Drainage Linear Plot

TABLE 5

RECTIFIED DRAINAGE LINEAR ORIENTATIONS

CLASS INTERVAL (DEGREES)	AZIMUTH-FREQUENCY	% OF TOTAL	LENGTH-WEIGHTED FREQUENCY	% OF TOTAL
NORTH: 0–10	64	7.16	61.13	6.84
10–20	37	4.14	38.54	4.31
20–30	38	4.25	40.08	4.48
30–40	58	6.49	57.99	6.49
40–50	56	6.26	58.12	6.50
50–60	65	7.27	65.75	7.35
60–70	56	6.26	54.67	6.11
70–80	42	4.70	30.71	3.43
EAST: 80–90	38	4.25	38.61	4.32
WEST: 90–80	43	4.81	41.57	4.65
80–70	48	5.37	43.68	4.89
70–60	47	5.26	44.16	4.94
60–50	46	5.15	45.94	5.14
50–40	53	5.93	47.61	5.33
40–30	48	5.37	57.77	6.46
30–20	60	6.71	62.53	6.99
20–10	48	5.37	49.45	5.53
NORTH: 10–0	47	5.26	55.68	6.23
ΣFREQUENCY = 894			ΣLENGTH = 942.06 MILES	
AVG. LENGTH = 52.34 MILES				

FIGURE 28: Length-weighted frequency rose diagram of rectified drainage linears annotated in the study area.

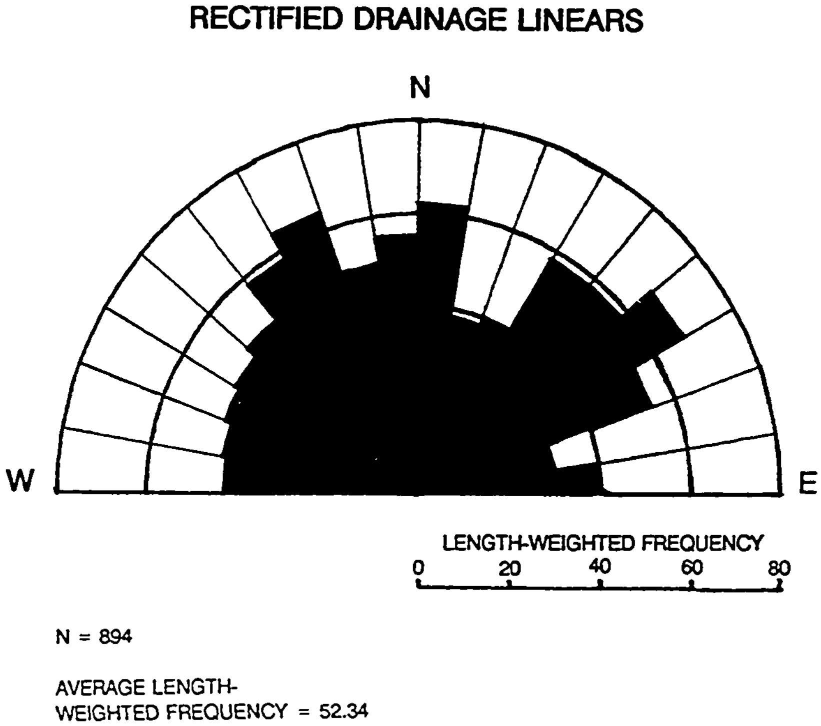


FIGURE 28
Length-Weighted Frequency Rose Diagram of Rectified Drainage Linears

An examination of the rectified drainage plot (Figure 27) reveals that major drainage ways are deflected along north-trending linear reaches upon descending the Fall Zone. A northward deflection of the Appomattox River marks the presence of the Dutch Gap Fault. Near Richmond, the James River is diverted to the south along a linear reach that corresponds with an aeromagnetic lineament. This south-trending linear reach is located west of an area noted in the current study to be periodically uplifted (structural high A) and is interpreted to be structurally controlled.

DISCUSSION

Anomalies in thickness and erosional surface trends of the Coastal Plain sediments are coincident with observed and previously documented basement features. These apparent zones of deformation are believed to mark the sites of reactivated basement faults. Interpretive structural contour and isopach maps of the basement surface and Coastal Plain sediments have been constructed to illustrate the location of inferred basement structures and their effect on the overlying pre-Miocene units. Figures 29 through 37 depict these relationships as discussed in the following text. Borehole and geophysical data indicate the presence of Triassic-Jurassic sediments in the central and eastern portions of the study area. These deposits are believed to occupy a north to northeast trending basin or set of basins. The occurrence of Triassic-Jurassic rocks is annotated in Figure 29 with a hatchured pattern.

Although it is difficult to determine the actual morphology of the basin(s), certain analogous features are found in subaerially exposed Mesozoic basins to the west and can be used to characterize observed structures. The western margin of the buried early Mesozoic structure(s) is coincident with the Dutch Gap fault in the southern portion of the study area and inferred basement faults to the north. In the south, the eastern margin of the structure is also presumed to be fault bound. Similarly oriented boundary faults are present along the western margins of the Richmond and Taylorsville basins (Figure 4). Based on existing rift basin models (Lindholm, 1978; Behrendt and others, 1983), these faults are presumed to dip toward the center of the basin(s) and are listric with depth. Lindholm (1978) noted that Triassic-Jurassic rift basin border faults tend to parallel foliation in the underlying Paleozoic rocks and have exploited these zones of weakness during regional extension.

FIGURE 29: Interpretive structural contour map of the Basement surface depicting inferred structures. A buried Triassic-Jurrasic basin(s) is highlighted with a hatchured pattern.

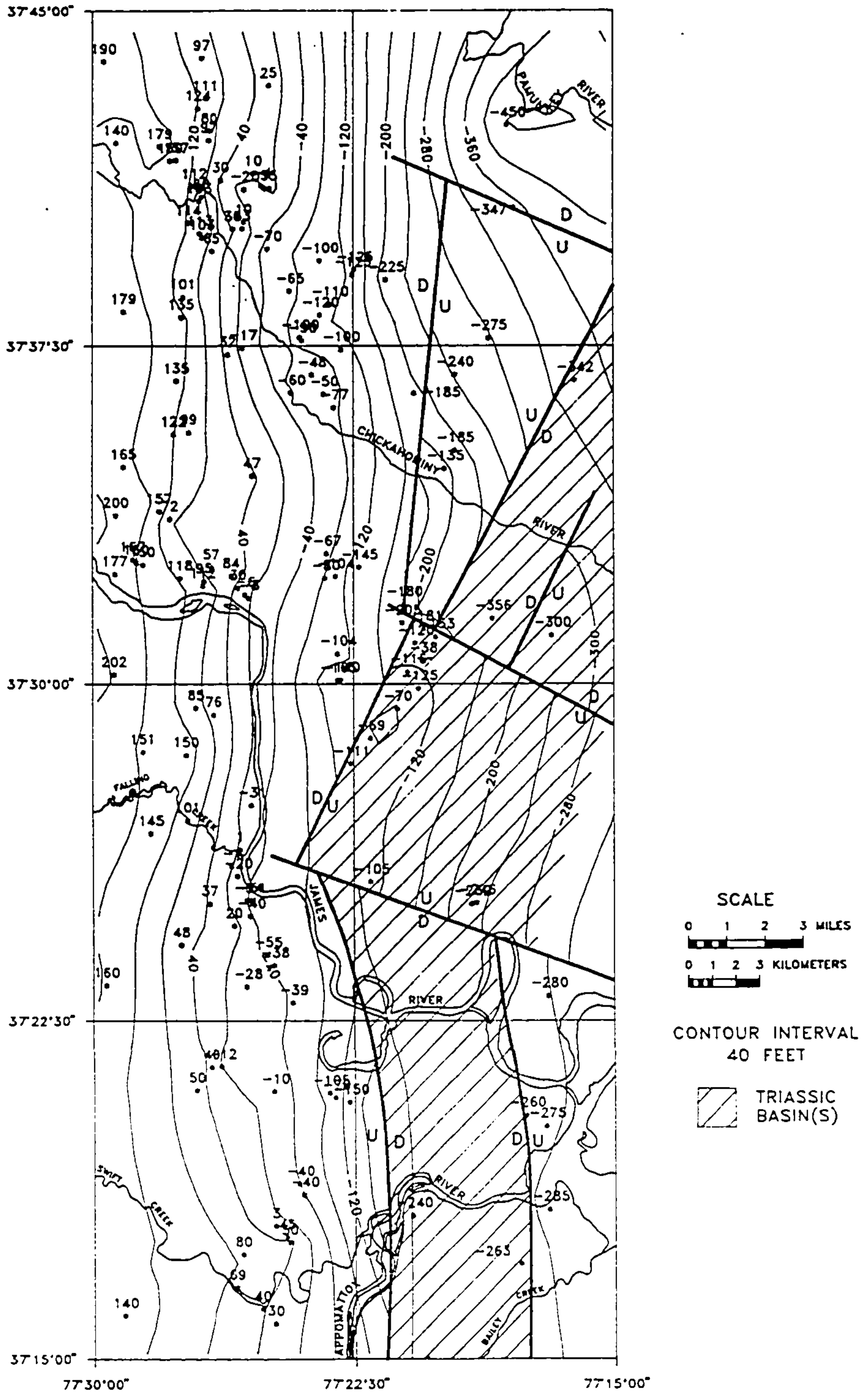


FIGURE 29
Interpretive Basement Surface
Structural Contour Map

FIGURE 30: Interpretive structural contour map of the Potomac Formation surface depicting inferred structures.

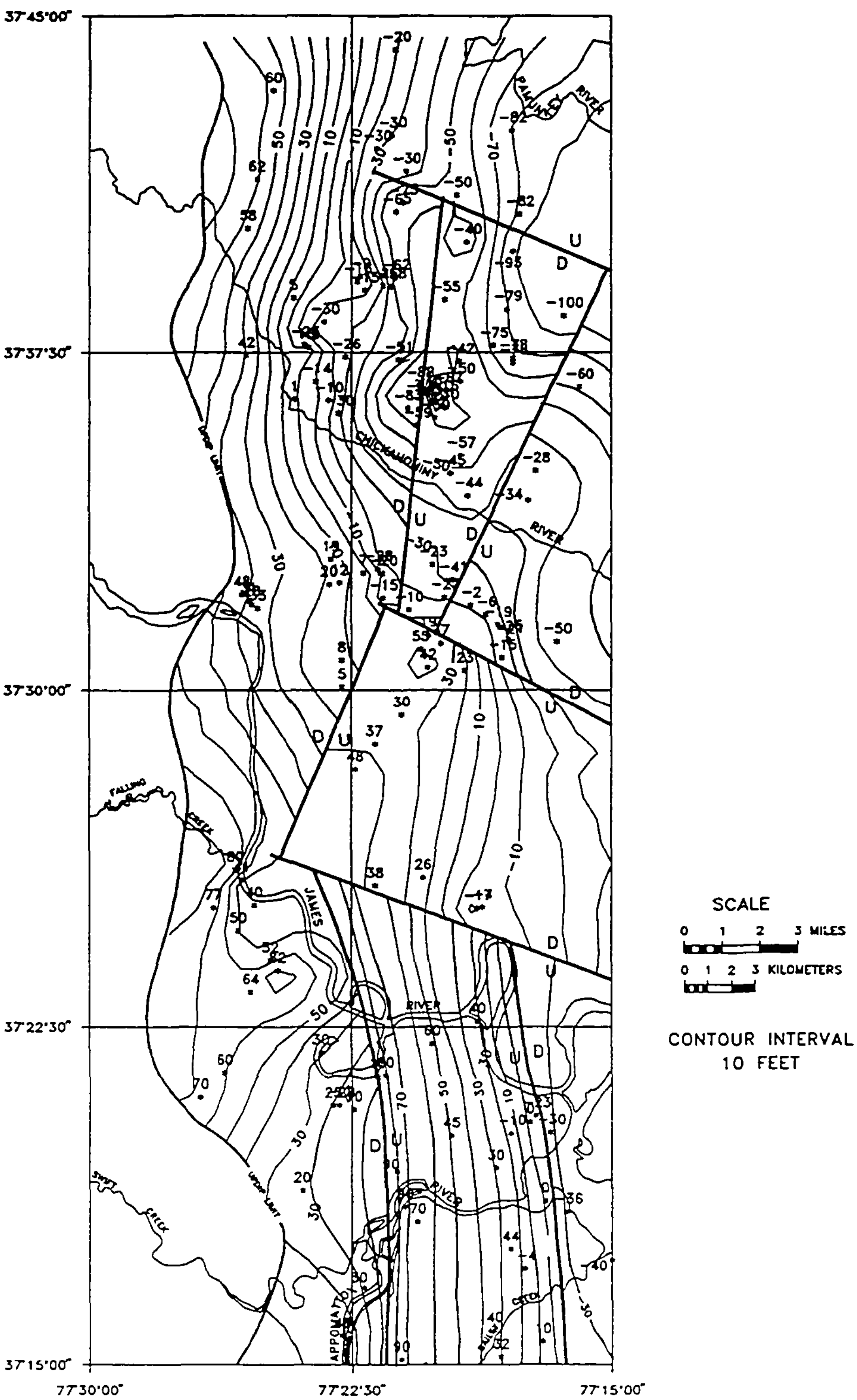


FIGURE 30
Interpretive Potomac Formation
Structural Contour Map

FIGURE 31: Interpretive isopach map of the Potomac Formation depicting inferred structures.

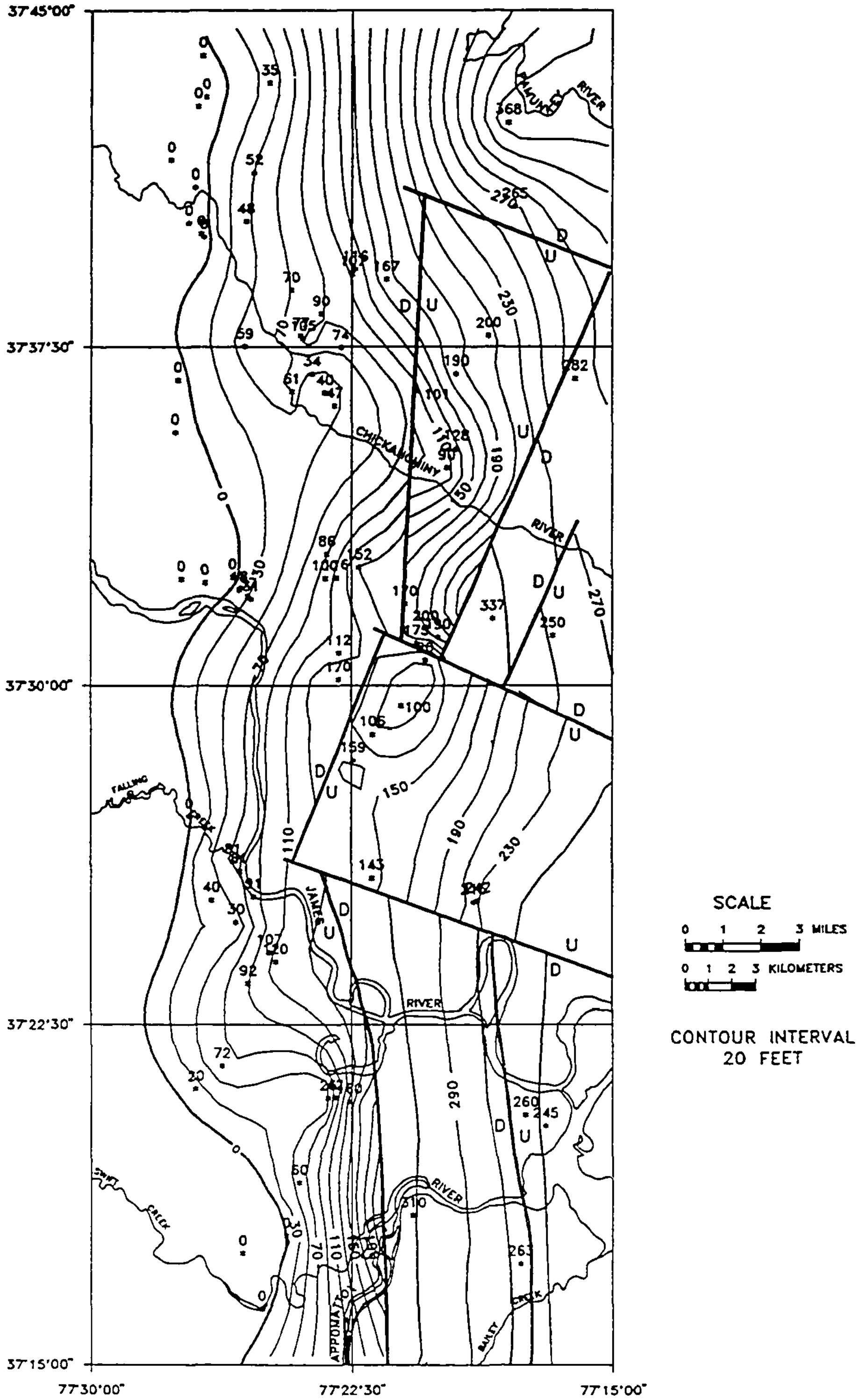


FIGURE 31
Interpretive Potomac Formation
Isopach Map

FIGURE 32: Interpretive structural contour map of the Aquia Formation surface depicting inferred structures.

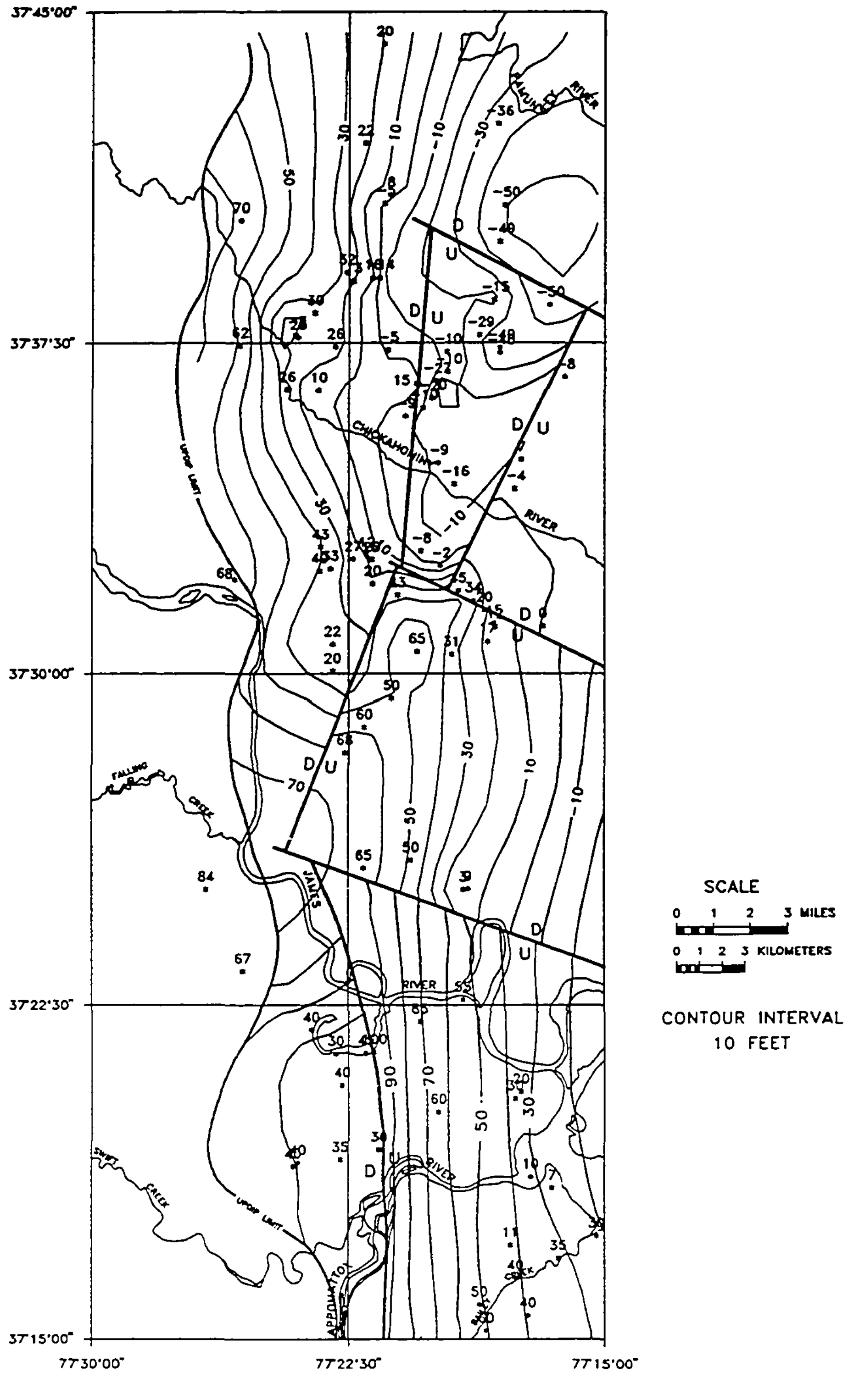


FIGURE 32
Interpretive Aquia Formation
Structural Contour Map

FIGURE 33: Interpretive isopach map of the Aquia Formation depicting inferred structures.

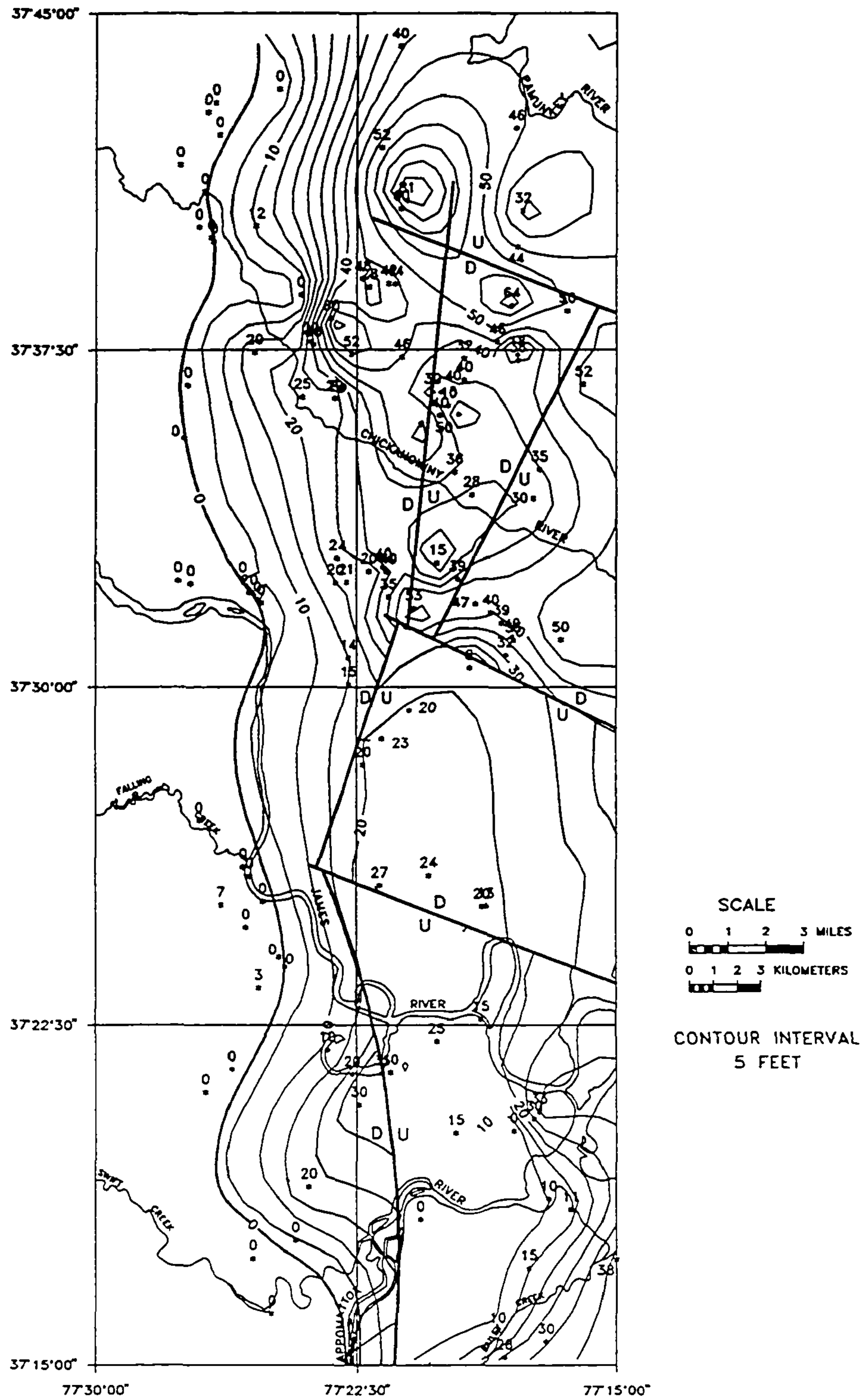


FIGURE 33
Interpretive Aquia Formation
Isopach Map

FIGURE 34: Interpretive structural contour map of the Marlboro Clay surface depicting inferred structures.

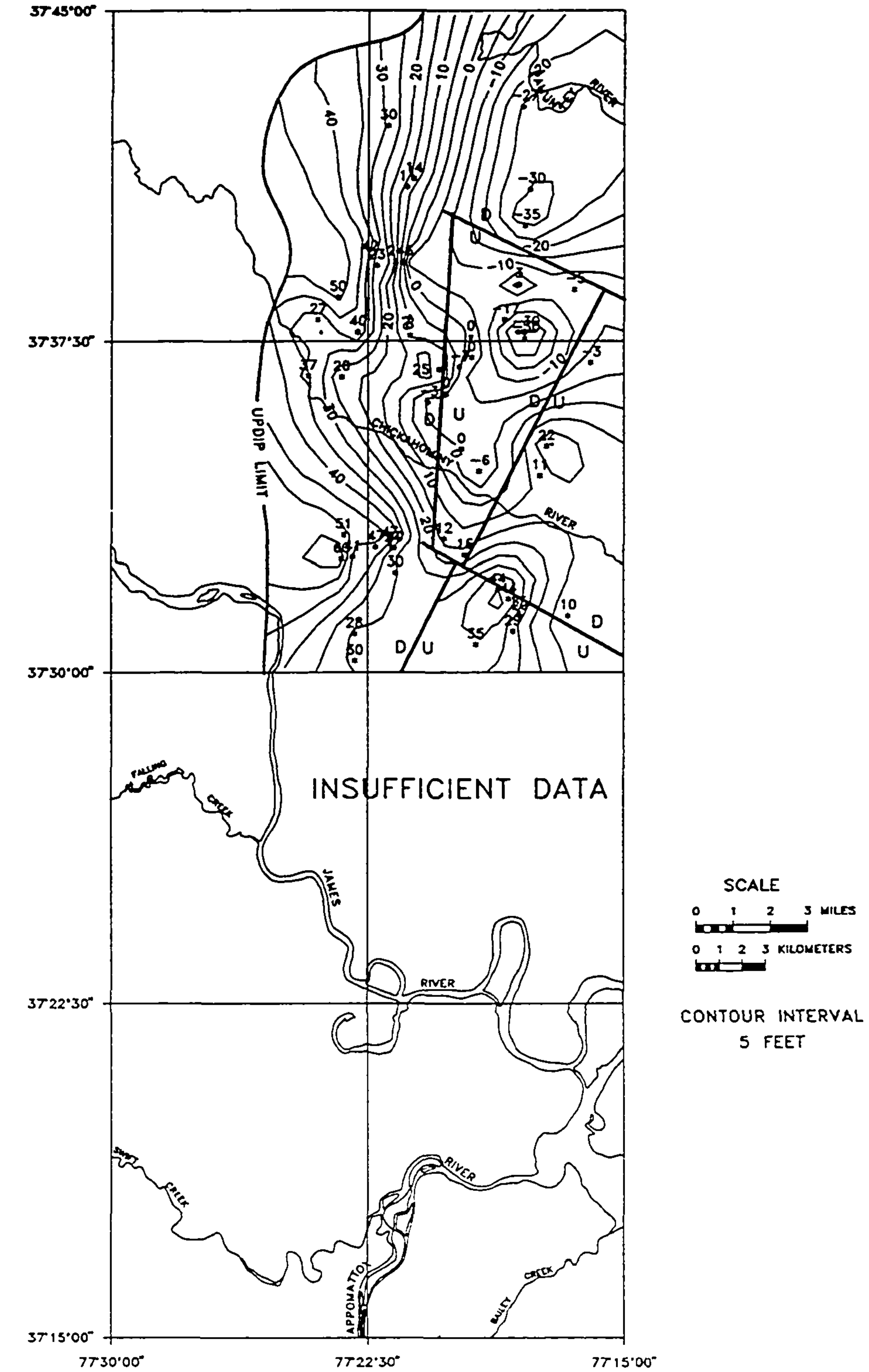


FIGURE 34
Interpretive Marlboro Clay
Structural Contour Map

FIGURE 35: Interpretive isopach map of the Marlboro Clay depicting inferred structures.

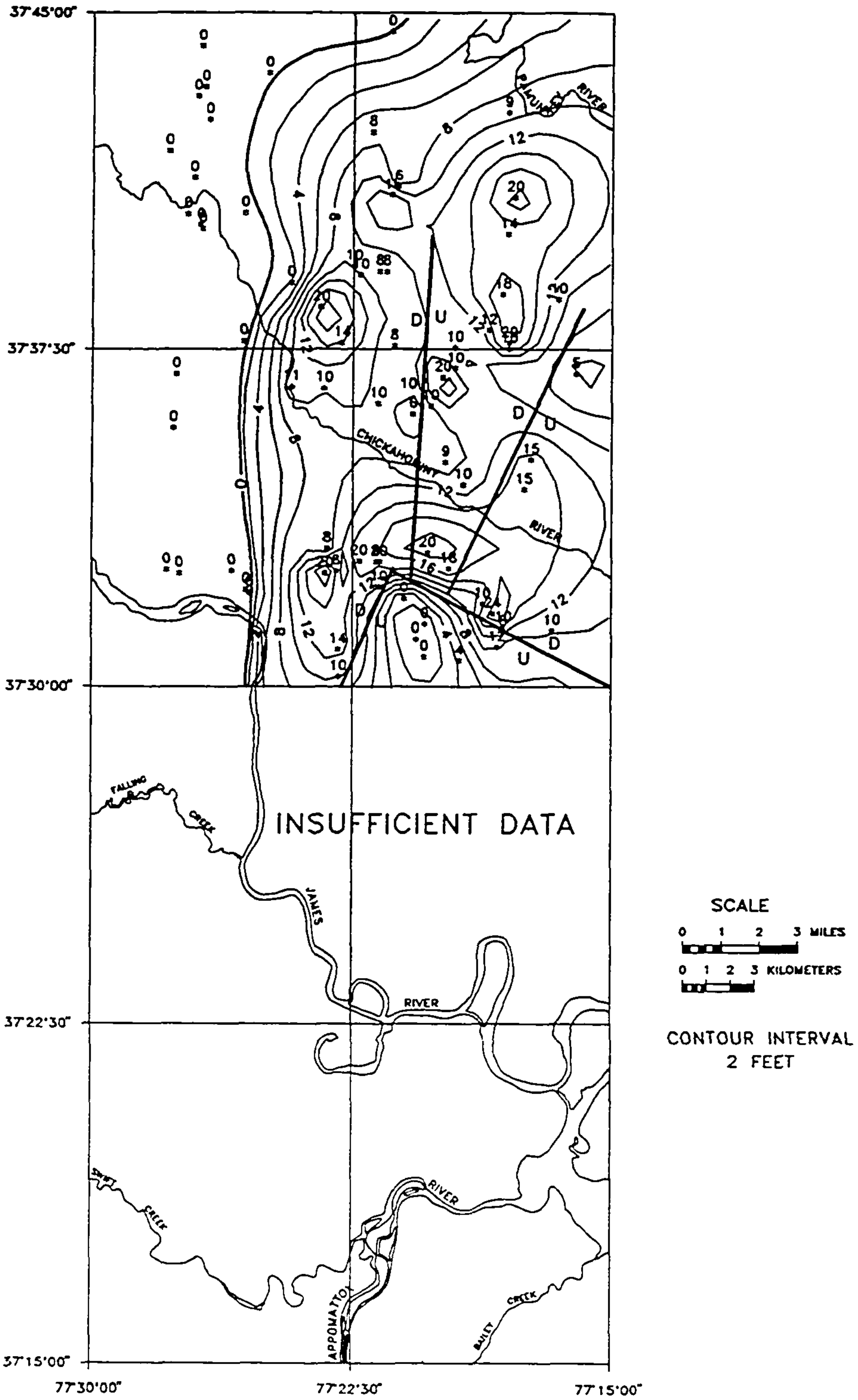


FIGURE 35
Interpretive Marlboro Clay
Isopach Map

FIGURE 36: Interpretive structural contour map of the Nanjemoy Formation surface depicting inferred structures.

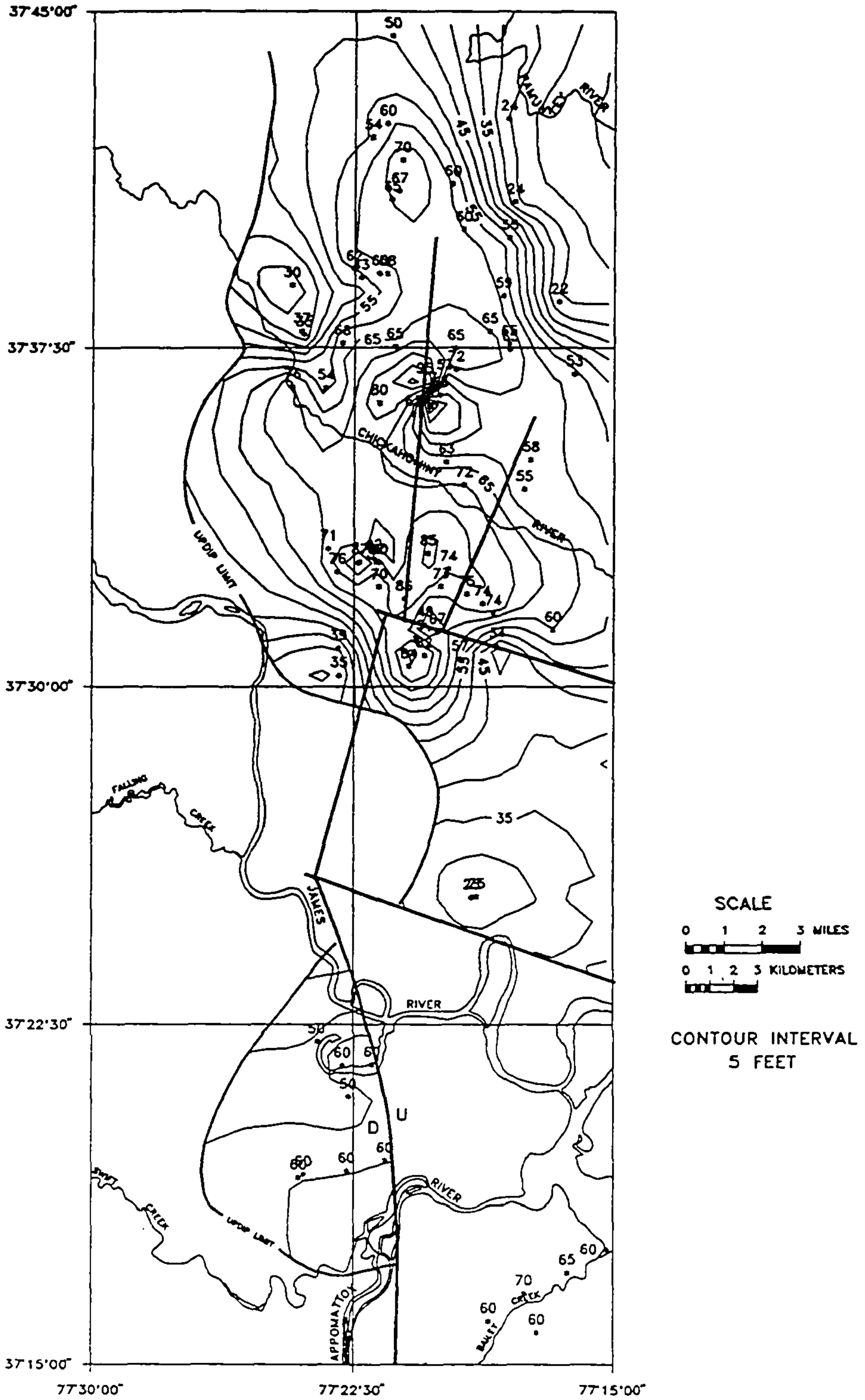


FIGURE 36
Interpretive Nanjemoy Formation
Structural Contour Map

FIGURE 37: Interpretive isopach map of the Nanjemoy Formation depicting inferred structures.

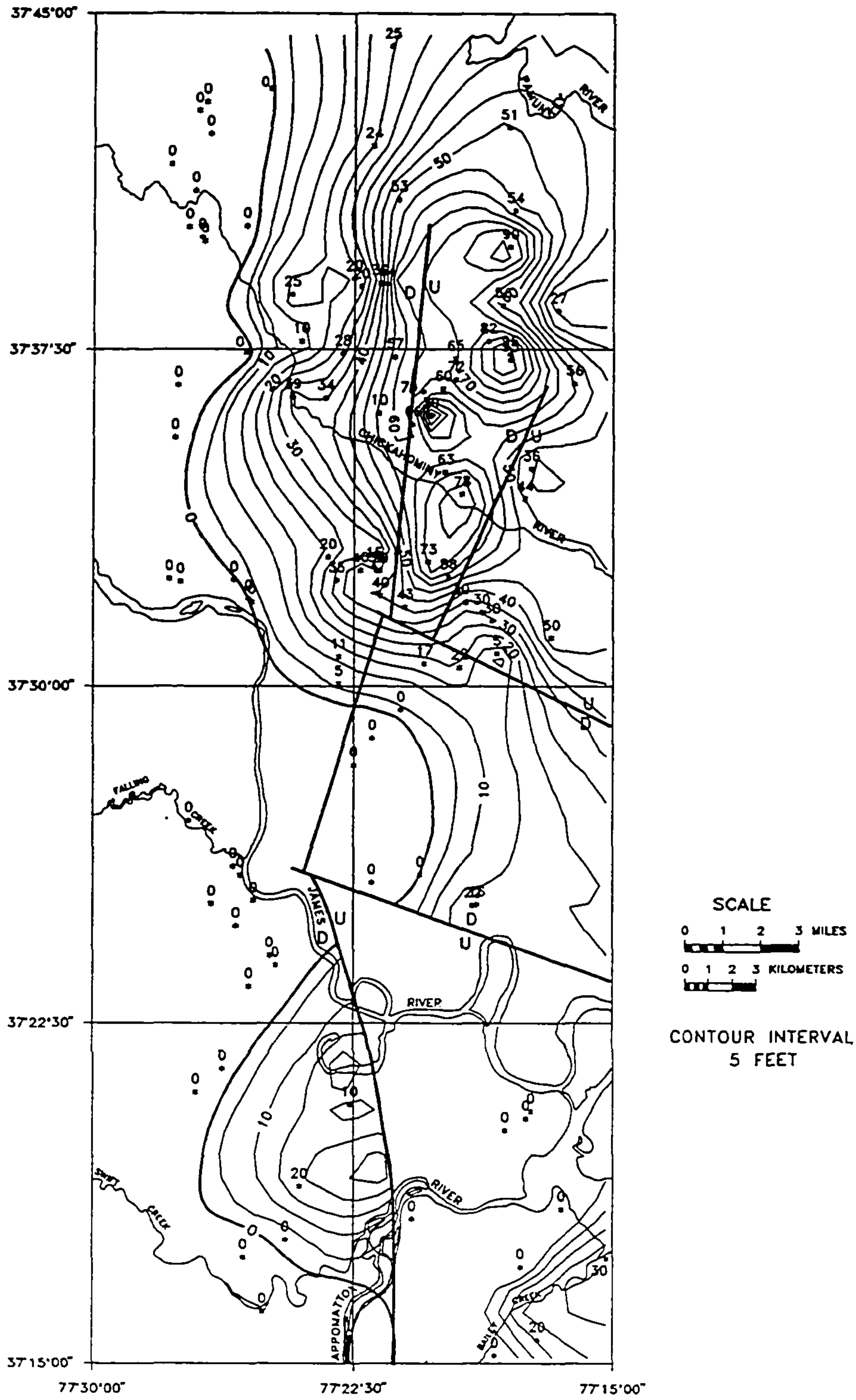


FIGURE 37
Interpretive Nanjemoy Formation
Isopach Map

Western boundary faults of the Richmond and Taylorsville basins are coincident with the Hylas Mylonite Zone, a pre-existing zone of weakness (Mixon and others, 1989). Hansen (1988) observed Mesozoic rift basins occur in northeast-trending arcuate bands throughout the mid-Atlantic Coastal Plain as evidenced by borehole and geophysical data. The spacings of these structures coincide with those noted by Wentworth and Mergner-Keefer (1983) for the occurrence of documented Cretaceous and Cenozoic Coastal Plain structures and recent seismic activity. Several Coastal Plain workers have documented zones of deformation in Cretaceous and Cenozoic sediments attributable to pre-existing Mesozoic and Paleozoic faults and discontinuities (Jacobeen, 1972; Mixon and Newell, 1977; Prowell and O'Conner, 1978; Hamilton, 1981; Ratcliff, 1981; Wentworth and Mergner-Keefer, 1983; Mixon and Powars, 1984). Mixon and others (1989) tentatively mapped a northeast-trending fault in the northwestern corner of the study area that may be related to these structures (Figure 29; Figure 4, #19). These zones of deformation are believed to have resulted from the reactivation of pre-existing zones of weakness in a contemporary NW-SE compressional stress regime. Zoback and Zoback (1981) have determined that the mid-Atlantic region has been subjected to NW-SE compressional forces for the past 100 million years. Documented Coastal Plain structures are summarized in Table 1.

In the central portion of the study area, inferred boundary faults have a similar orientation as biotite foliation in the Petersburg Granite (Figure 29). The biotite foliation could have provided a weakness in the rock fabric that was exploited by observed Mesozoic extensional structures. The early Mesozoic structural trough is also located along the western flank of the Central Virginia Gravity-Magnetic High (Figures 12 and 13). Davison (1985) postulated that this geophysical anomaly marks the presence of a suture zone formed during the Paleozoic closure of the Iapetus Ocean. Crustal faults and discontinuities formed at this time could have been exploited during early Mesozoic rifting to form the basin(s) margins. Davison also speculated that northwest trending shear fractures, marked by breaks in the north-trending geophysical patterns, were formed during the collision of the Chesapeake Microplate with the North American continent. A fault of similar

orientation, observed in the Petersburg Granite, provides evidence to substantiate the existence of these structures (Figure 11, #5). Northwest-trending basement faults are believed to transect the early Mesozoic structure(s). Similarly oriented faults are found along the western margin of the Richmond Basin (Mixon and others, 1989). Cederstrom (1945) documented a northwest-trending Coastal Plain structure along the James River near Hampton Roads (Figure 4, #17) and proposed it may mark the presence of basement faulting.

When combined, the northwest oriented structures appear to highlight the boundary shared by the northern flank of the Norfolk Arch and southern margin of the Salisbury Embayment (Figure 2). Venkatakrishnan (1984) mapped a lineament zone (James River Lineament Zone) coincident with this boundary and noted it lies on strike with a landward continuation of the oceanic Norfolk Fracture Zone. A major zone of historic seismicity (Central Virginia Seismic Zone) has also been proposed to coincide with this trend (Bollinger, 1973). In a detailed stratigraphic analysis of Tertiary sediments of the Virginia Coastal Plain, Ward (1985) deduced that the Salisbury Embayment has been tectonically active independent of the remaining Coastal Plain and that the intervening sea level changes reflect localized, basement controlled, tectonic activity. Inferred northwest striking faults are depicted in N-S oriented cross sections I-I', J-J', and K-K' (Plates 10, 11, and 12). In general, units thicken to the north-northeast across these structures into the Salisbury Embayment. This data indicates the presence of a large scale crustal discontinuity along the southern terminus of the Salisbury Embayment that has periodically controlled sedimentation.

A comparison of the interpretive structural contour and isopach maps reveals that movement along observed structures was consistent through Marlboro time. Relative displacements of the erosional surfaces and anomalous thinnings of the Potomac, Aquia, and Marlboro along north-trending structures are similar. These structures are interpreted to be basin boundary faults reactivated in a reverse sense. Offsets tend to decrease upsection into zones of apparent flexuring indicating recurrent movement along the structures (Plates 1 through 9). Northwest-trending

structures exhibit a persistent down to the northeast sense of displacement (Plates 10 through 12). As with the north-trending structures, relative displacements tend to decrease upsection.

In the south, the Potomac Formation thickens abruptly across the Dutch Gap fault (Plates 8 and 9). At first glance it would appear ironic that the unit would be thicker on the upthrown block of the fault. This anomaly is believed to be attributable to the depositional setting of the unit. This area is presumed to be underlain by a Mesozoic basin. It is possible that prograding deltas deposited the Potomac sediments in a topographic low over the basin resulting in a greater thickness of the unit than anticipated. This would suggest that reverse movement along the western boundary fault did not occur until at least some time during the Cretaceous.

Examination of structural contours and isopachs of the Nanjemoy Formation (Figures 36 and 37) reveals a more subtle yet complex syn- and/or post-Eocene structural history. In the north, this unit does not appear to exhibit offsets or thinning over the basement structures. In fact, the unit attains a maximum thickness in the northcentral portion of the study area. Cross sections B-B' through E-E' (Plates 2 through 5) and the structural contour map (Figure 35) shown that the erosional surface rises in elevation to the east, is highest over the northcentral portion of the study area, and decreases rapidly east of the high. The unit also thins abruptly east of the high (Figure 37). When combined, this data suggests the presence of an erosional scarp. A similar relationship is observed in the central portion of the study area. In this area, the apparent scarp trends east-west (Figures 36 and 37). The observed warping of the Nanjemoy and apparent scarps indicate that following the deposition of this unit continued uplift on basement structures in this area produced a structural high. This structural feature may have influenced subsequent depositional patterns. The high may have prevented the deposition of the Eocene Piney Point and Oligocene Old Church formations in the study area. The apparent erosional scarps may also mark a Miocene sea stand prior to breaching the high. Relative uplifts in the north and south at different times would also explain the absence of the Calvert Formation south of the James River and the Yorktown Formation

north of the James. Due to the selection of mapping units, however, a detailed analysis of structural control on post-Eocene units was not conducted.

North-trending and northwest-trending basement faults of the study area, when combined, appear to bound a mosaic of crustal blocks (Figure 29). The presence of a buried Mesozoic basin and observed anomalies in the overlying Coastal Plain units may be attributed to periodic movement on these blocks. The concept of basement block faulting is not original and has been used by previous authors to explain similar anomalies elsewhere in the Atlantic Coastal Plain (Brown and others, 1972; Venkatakrishnan, 1984; Mullen, 1986).

If this hypothesis is correct, two major episodes of tectonism with contrasting deformational styles have occurred since the late Paleozoic resulting in the realignment of the basement blocks and formation of the current tectonic framework. Based on this theory, during the early Mesozoic regional NW-SE extension allowed for certain basement blocks to subside. Rift sediments were subsequently deposited in the down-dropped blocks forming the observed Mesozoic basins. Following the formation of these basins, prograding deltas deposited the Cretaceous Potomac Formation atop the basement surface. A subsequent realignment of regional stresses to NW-SE compression resulted in periodic movement of the basement blocks in a reversed sense affecting the thickness and distribution of the overlying sediments during and following deposition. Brown and others (1972) have used a similar model to explain the internal and external geometry of depositional units throughout the Atlantic Coastal Plain. Dischinger (1979) noted that upper Tertiary and Quaternary terrace deposits truncate the Dutch Gap fault indicating that locally tectonism has not occurred since this time. Mixon and Newell (1977) observed a slight offset of Pleistocene gravels in the Stafford Fault zone to the north.

Small scale structures, primarily fracture sets, were observed in the Petersburg Granite and clay-rich sediments of the Potomac Formation, Marlboro Clay, and Calvert Formation. These

structures tend to occur in one of four dominant trends (N-S, NE-SW, NW-SE, and E-W) and provide evidence of active tectonism subsequent to the lower middle Miocene. Other Virginia Coastal Plain investigators have noted similar fracture set orientations in the Chesapeake Group sediments (Newell and Rader, 1982; Lane, 1984).

The NE-SW structural trend was found to be the most pervasive. Locally, this trend corresponds with biotite foliation in the Petersburg Granite, a fault in Potomac sediments at Drewrys Bluff (Cederstrom, 1945b), and northeast-trending Coastal Plain structures. Several other documented Coastal Plain structures have a similar orientation (Figure 4; Table 1). This trend also correlates with the Appalachian fabric. The NW-SE structural trend has a similar orientation as a fault observed in the Petersburg Granite and northwest-trending inferred basement structures. This trend also coincides with the Hampton Roads fault (Cederstrom, 1945) and the James River Lineament Zone (Venkatakrishnan, 1984). N-S oriented fracture sets can be correlated with large scale structures in the southern portion of the study area including the Dutch Gap fault. E-W trending large scale structures were not observed in the study area, although, Venkatakrishnan (1984) did note similarly oriented hinge lines elsewhere in the Virginia Coastal Plain that have periodically controlled sedimentation.

Large scale structures found throughout the Virginia Coastal Plain (Figure 4) and small scale structures noted locally have been demonstrated to be preferentially oriented in one of four major trends (NE-SW, NW-SE, N-S, and E-W). This relationship provides evidence to suggest that these features were formed by similar tectonic forces that have periodically controlled the reactivation of preferentially oriented basement structures. Although evidence has not been presented to correlate particular small scale features with underlying basement structures, the persistence of the preferred orientations suggests that conditions have existed to establish a predominant structural pattern throughout the sediment package.

Analysis of rectified drainage segments and topographic linears provides evidence that tectonic forces have also exerted an influence on the geomorphology of the study area. Topographic linears were noted to occur in broad NE-SW and NW-SE oriented trends. Statistical analysis of rectified drainage patterns indicates that stream segments are preferentially oriented in one of three major trends: NE-SW, NW-SE, and N-S. Non-random distributions of topographic linears and rectified stream segments similar to those observed for structural elements of the study area strongly suggest a structural control has been exerted during the development of these geomorphic features. Geomorphic lineaments have long been recognized in the Atlantic Coastal Plain (McGee, 1888; Darton, 1891; Hobbs, 1904). Hobbs (1904) noted the existence of three major lineament trends (N-S, NE-SW, and NW-SE) and suspected they had a geologic origin. Brown and others (1972) observed alignments of positive and negative basement features along the same trends noted by Hobbs suggesting a causative relationship. Basement control of stream courses and other geomorphic features has also been reported elsewhere in the Atlantic Coastal Plain, even where a thick section of sediments exists (Spoljaric and others, 1976; Newell and Rader, 1982; Lane, 1984; Venkatakrishnan, 1984; Mullen, 1986).

Direct evidence for structural control on drainage patterns is found by examining major river courses on the rectified drainage map. The Appomattox and James rivers are deflected along north-trending linear reaches upon descending the Fall Zone. A northward deflection of the Appomattox River near Hopewell marks the presence of the Dutch Gap Fault. Near Richmond, the James River is diverted to the south along a linear reach upon entering the Coastal Plain. Uplift of the basement block in the central portion of the study area (Figure 29) is believed to be responsible for this excursion. The James River resumes its southeasterly course along the southwest margin of the fault block. Prominent N-S oriented fractures in the rock units may have controlled the south-trending linear reach. Large meander bends in the James River near Hopewell are also oriented north-northeast and may have been controlled by similarly oriented rock fractures. Relative uplift of the centrally located basement block is also believed to have controlled the southeast-trending

reach of the Chickahominy River along its northeastern margin. To the north, relative displacement along a northwest-trending fault appears to have controlled the generally southeasterly course of the Pamunkey River. River course deflections elsewhere in the Atlantic Coastal Plain are also shown to be associated with documented structures (Higgins and others, 1974; Mixon and Newell, 1977; Mixon and Powars, 1984; Lane, 1984).

CONCLUSIONS

An integrated analysis of geologic, geophysical, and geomorphic data has revealed the presence of buried structures along the Atlantic Coastal Plain margin near Richmond, Virginia. North-northeast and northwest oriented basement faults, inferred from borehole logs, field observed structures, and geophysical anomalies, are seen to bound and transect a buried north-northeast trending early Mesozoic basin or set of basins. Structural elements of the basin(s) are presumed to be analogous to those of the Richmond and Taylorsville basins to the west suggesting that the north-trending boundary faults dip toward the basin center(s) and are listric with depth. Basin formation is believed to have occurred along pre-existing zones of weakness associated with the closure of the Iapetus Ocean during the late Paleozoic. Northwest-trending basement faults are interpreted to be near vertical shear fractures formed during the collision of the Chesapeake Microplate with the North American continent at this time (Davison, 1985). Anomalous thickness distributions and erosional surface trends observed in the overlying Coastal Plain sediments are coincident with the inferred basement structures implying a causative relationship.

The basement structures appear to bound a mosaic of crustal blocks. Two major episodes of post-Paleozoic tectonism have resulted in the periodic realignment of the basement blocks and have influenced the deposition and structural geometry of the overlying units. During the early Mesozoic, NW-SE oriented extensional forces allowed for certain basement blocks to subside. Rift sediments were then deposited in the down-dropped structures. A subsequent realignment of the regional stresses to NW-SE compression during the Cretaceous resulted in a reversed sense of movement along the basement structures. Relative displacements along the basement blocks have been propagated upward through the sedimentary package in the form of faulting and flexuring.

Offsets tend to decrease upsection indicating recurrent movement along the structures. Structural highs produced by the uplift are believed to have influenced Coastal Plain sediment depositional patterns, particularly those dominant during the middle and late Tertiary. Previous study of the Dutch Gap fault (Dischinger, 1979) suggests that active tectonism has not occurred in the study area since the late Tertiary.

Fracture sets observed in the Petersburg Granite and clay rich sediments of the Potomac Formation, Marlboro Clay, and Calvert Formation occur in one of four dominant structural trends (N-S, NE-SW, NW-SE, E-W) implying a common origin. Observed dominant orientations are similar to those of large scale structures found in the study area and throughout the Virginia Coastal Plain. The persistence of the preferred structural trends through the sedimentary package indicates that similar tectonic forces have controlled their formation.

Stream drainages and topographic linears are preferentially oriented in one of three major trends (N-S, NE-SW, NW-SE) similar to those observed for the structural elements and strongly suggests that a structural control has been exercised during the development of these geomorphic features. Major drainage courses traversing the study area have also been demonstrated to be controlled by the presence of Coastal Plain structures. A six mile north-trending linear reach of the Appomattox River is correlative with the Dutch Gap fault. The James River is diverted to the south for ten miles along the western margin of a buried Mesozoic structure before resuming a southeasterly course. The general southeasterly courses of major drainages in the area coincide with observed northwest oriented basement structures.

This study has provided evidence for the existence of buried structures and their influence on the development of the present-day landscape of the Virginia Inner Coastal Plain margin. Although a structural control on the distribution and thickness of the sediments and geomorphology of the study area has been recognized, further evaluation of the tectonic history of this area is

warranted. In particular, a detailed stratigraphic analysis of the Chesapeake Group sediments should be conducted to allow for the determination of small scale displacements and facies changes attributable to inferred basement structures. Investigation of these relationships would aid in the refinement of the timing and nature of basement influence on the post-Eocene sediment distributions.

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APPENDIX A

WELL BOREHOLE DATA

Well Boreh

QUAD	COUNTY	WELL NUMBER	STRAT LOG	ELEC LOGS	TOTAL DEPTH (ft)	ELEV (ft)	BEDROCK DEPTH (ft)	BEDROCK ELEV (ft)	POTOMAC GP. DEPTH (ft)	POTOMAC GP. ELEV (ft)
Richmond	Henrico	USGS 51J4	N/A	N/A	322	195	123	72		
		USGS 51J1	N/A	N/A	500	140	280	-140		
		USGS 51J8/VDMR W1477 C184	HUB, good	Resist	227	153	220	-67	134	19
		USGS 51J3/VDMR C78	N/A	N/A	445	175	118	57		
		USGS 51J6	N/A	N/A	????	196	149	47		
		USGS 51J2	N/A	N/A	248	150	38	112		
		USGS 51J5	N/A	N/A	306	195	96	99		
		VDMR C219	good	Resist	264	156	260	-104	148	8
		VDMR C229	good	????	250	192	70	122	ABSENT	ABSENT
		VDMR C247	fair	????	405	230	30	200		
		VDMR C9	fair	N/A	697	200	43	157		
		VDMR W157\C220	fair	N/A	305	170	86	84	ABSENT	ABSENT
		VDMR W1123 C172	D & O, HUB	N/A	262	153	257	-104	141	12
		VDMR W2932 C200	D & O, HUB	N/A	400	195	30	165	ABSENT	ABSENT
		VDMR W1247	D & O	N/A	296	125	290	-165	120	5
		VDMR W1839	D & O	N/A	213	120	200	-80	100	20
		VDMR W1302	D & O	N/A	300	155	20	135	ABSENT	ABSENT
		DO #1	D&O XSEC C-C'	N/A	25	195	18	177	ABSENT	ABSENT
		DO #2	D&O XSEC C-C'	N/A	72	216	49	167	ABSENT	ABSENT
		DO #3	D&O XSEC C-C'	N/A	60	218	58	160	ABSENT	ABSENT
		DO #4	D&O XSEC C-C'	N/A	86	222	72	150	ABSENT	ABSENT
		DO #5	D&O XSEC C-C'	N/A	50	214	N/A	N/A	????	186(?)
		DO #6	D&O XSEC C-C'	N/A	82	200	82	118	ABSENT	ABSENT
		DO #7	D&O XSEC C-C'	N/A	81	166	71	95	ABSENT	ABSENT
		DO #8	D&O XSEC C-C'	N/A	133	158	128	30	110	48
		DO #9	D&O XSEC C-C'	N/A	51	45	51	-6	14	31
		DO #10	D&O XSEC C-C'	N/A	77	50	53	-3	22	28
		DO #11	D&O XSEC C-C'	N/A	100	130	N/A	N/A	97	33
	Chesterfield	VDMR W2069 C173	D & O	N/A	150	211	9	202	ABSENT	ABSENT
	Hanover	USGS 51J9/VDMR W2417 C117	D & O, HUB	Resist	600	170	220	-50	180	-10
		VDMR W2237 C93	D & O, HUB	N/A	260	140	188	-48	154	-14
		VDMR W3902	D & O, HUB	N/A	155	90	150	-60	89	1
		VDMR W969	D & O	N/A	608	190	267	-77	220	-30
Seven Pines	Henrico	USGS 52J30/VDMR C233	good	Resist	260	163	N/A		140	23
		USGS 52J4	good	SP	310	164	N/A		170	-6
		USGS 52J12/VDMR W3574 C207	D & O, SHOMO,HUB	Resist	610	160	460	-300	210	-50
		VDMR C217	D & O?	Resist	610	160	460	-300	210	-50
		USGS 52J8/VDMR W1177	D & O, SHOMO	N/A	326	164	280	-116	191	-27
		USGS 52J3/VDMR W236	D & O, CEDER57	N/A	190	155	N/A		176	-21
		VDMR C254	good	????	380	160	365	-205	ND	ND
		VDMR C260	good	N/A	313	162	287	-125	ND	ND
		VDMR W2683 C199	D & O, SHOMO, HUB	Resist	540	154	510	-356	173	-19
		VDMR W509 C321	D & O	N/A	326	165	N/A		167	-2
		VDMR W511 C322	D & O	N/A	350	165	N/A		206	-41
		VDMR W858 C162	D & O, SHOMO	N/A	369	149	330	-181	130	19
		VDMR W1008 C167	D & O	N/A	292	155	N/A		180	-25
		VDMR W1009 C168	D & O	N/A	375	163	N/A		190	-27
		VDMR W1157 C173	D & O	N/A	350	157	310	-153	120	37
		VDMR W1291 C176	D & O	Resist	340	140	320	-180	150	-10
		VDMR W1769 C189	D & O	Resist	314	162	N/A		185	-23
		VDMR W1898 C195	D & O, SHOMO	N/A	290	162	200	-38	120	42
		VDMR W3107 C203	D & O	N/A	295	152	N/A		150	2
		VDMR W3903	D & O, HUB	N/A	404	162	282	-120	107	55
		VDMR W510	D & O	N/A	322	159	N/A		174	-15
		VDMR W3284	D & O	N/A	310	140	N/A		155	-15

NOTE: Well data collection p

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D & O: Daniels and Onuschak, 1974
B, M & S: Brown, Miller, and Swain, 1972
CEDER45: Cederstrom, 1945a
CEDER57: Cederstrom, 1957
HUB: Hubbard and others, 1978
M & H: Meng and Harsh, 1988
MIXON 89: Mixon and others, 1989
OTHER: Logged by field geologist
SHOMO: Shomo, 1982
TEIFKE: Teifke, 1973

Well Borehole Data

GP.	POTOMAC GP.	POTOMAC GP.	PAMUNKEY GP.	PAMUNKEY GP.	PAMUNKEY GP.	CHESAPEAKE GP.	CHESAPEAKE GP.	CHESAPEAKE GP.	REGRESSIVE UNIT	REGRESSIVE UNIT	REGRESSIVE UNIT
t)	ELEV (ft)	THICKNESS (ft)	DEPTH (ft)	ELEV (ft)	THICKNESS (ft)	DEPTH (ft)	ELEV (ft)	THICKNESS (ft)	DEPTH (ft)	ELEV (ft)	THICKNESS (ft)
	19	66	82	71	52	37	116	45	0	153	37
	8	112	117	39	31	39	117	78	0	156	39
T	ABSENT	0	ABSENT	ABSENT	0	35	157	35	0	192	35
T	ABSENT	0	ABSENT	ABSENT	0	22	148	64	0	170	22
	12	116	77	76	64	47	106	30	0	153	47
T	ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	195	30
	5	170	90	35	30	20	105	70	0	125	20
	20	100	ND	ND	ND	10	110	ND	0	120	10
T	ABSENT	0	ABSENT	ABSENT	0	10	145	10	0	155	10
T	ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	195	18
T	ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	216	49
T	ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	218	58
T	ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	222	72
	186(?)	ND	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	214	ND
T	ABSENT	0	ABSENT	ABSENT	0	56	144	26	0	200	56
T	ABSENT	0	65	101	ND	26	140	39	0	166	26
	48	18	92	66	18	53	105	39	0	158	53
	31	37	ABSENT	ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0
	28	31	ABSENT	ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0
	33	ND	60	70	37	0	130	60	ABSENT	ABSENT	0
T	ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	211	9
	-10	40	116	54	64	50	120	66	0	170	50
	-14	34	ND	ND	ND	15	125	ND	0	140	15
	1	61	14	76	75	3	87	11	0	90	3
	-30	47	ND	ND	ND	48	142	ND	0	190	48
	23	ND	106	57	34	44	119	62	0	163	44
	-6	ND	90	74	80	40	124	50	0	164	40
	-50	250	100	60	110	60	100	40	0	160	60
	-50	250	100	60	110	60	100	40	0	160	60
	-27	89	80	84	111	20	144	60	0	164	20
	-21	ND	135	20	41	58	97	77	0	155	58
	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	-19	337	80	74	93	47	107	33	0	154	47
	-2	ND	90	75	77	50	115	40	0	165	50
	-41	ND	91	74	115	41	124	50	0	165	41
	19	200	100	49	30	40	109	60	0	149	40
	-25	ND	ND	ND	ND	50	105	ND	0	155	50
	-27	ND	90	73	100	50	113	40	0	163	50
	37	190	90	67	30	45	112	45	0	157	45
	-10	170	54	86	96	10	130	44	0	140	10
	-23	ND	93	69	92	50	112	43	0	162	50
	42	80	80	82	40	ABSENT	ABSENT	0	0	162	80
	2	ND	70	82	80	30	122	40	0	152	30
	55	175	87	75	20	47	115	40	0	162	47
	-15	ND	125	34	49	60	99	65	0	159	60
	-15	ND	70	70	85	30	110	40	0	140	30

ta collection points are located in Figure 10.

Well Borehole Data

QUAD	COUNTY	WELL NUMBER	STRAT LOG	ELEC LOGS	TOTAL DEPTH (ft)	ELEV (ft)	BEDROCK DEPTH (ft)	BEDROCK ELEV (ft)	POTOMAC GP. DEPTH (ft)	POTOMAC GP. ELEV (ft)	POTOMAC GP. THICKNESS (ft)
Seven Pines	Henrico	VDMR W1612	D & O	N/A	302	157	302	-145	150	7	152
		VDMR W2936	D & O	N/A	286	150	N/A		170	-20	ND
		VDMR W3664	D & O	N/A	330	157	N/A		185	-28	ND
	Hanover	USGS 52J5/W2501	D & O	Resist	304	161	N/A		220	-59	ND
		USGS 52J15/VDMR W338	D & O	Resist	350	165	350	-185	249	-84	101
		USGS 52J11/W2224	D & O	Resist	412	170	410	-240	220	-50	190
		USGS 52J31	good	Resist	306	82	N/A		126	-44	ND
		VDMR W1662	D & O	N/A	298	163	298	-135	208	-45	90
		VDMR W2617	D & O	N/A	370	183	368	-185	240	-57	128
		VDMR W3401	D & O	N/A	330	170	N/A		220	-50	ND
		VDMR W2574	D & O	N/A	324	175	N/A		205	-30	ND
		VDMR W1842	D & O	N/A	249	150	N/A		150	0	ND
		VDMR W1301	D & O	N/A	320	175	N/A		258	-83	ND
		VDMR W3782	D & O	N/A	315	167	N/A		170	-3	ND
		VDMR W2573	D & O	N/A	286	165	N/A		180	-15	ND
		VDMR W493	D & O	N/A	308	150	N/A		238	-88	ND
		VDMR W2800	D & O	N/A	245	175	N/A		190	-15	ND
		VDMR W749	D & O	N/A	320	173	N/A		240	-67	ND
		VDMR W3904	D & O, SHOMO, HUB	N/A	600	170	512	-342	230	-60	282
		VDMR W611	D&O, XSEC E-E'	N/A	200	150	N/A		184	-34	ND
		VDMR W652	D&O, XSEC E-E'	N/A	280	170	N/A		198	-28	ND
Studley	Hanover	SWCB ST19/VDMR W2349	D & O	N/A	266	160	N/A		180	-20	ND
		SWCB ST467	good	Resist	315	190	N/A		268	-78	ND
		SWCB ST505	good	Resist-SP	360	175	N/A		254	-79	ND
		SWCB ST508	good	Resist-SP	400	160	385	-225	218	-58	167
		SWCB ST6/VDMR W1948	D & O	Resist-SP	306	175	N/A		226	-51	ND
		USGS 52K10 \ W5317	good	Resist	370	190	N/A		268	-78	ND
		USGS 52K11	good	E-log	330	182	N/A		255	-73	ND
		USGS 52K14/SWCB 510	good	Resist	474	185	460	-275	260	-75	200
		USGS 52K2/VDMR W199	D & O	N/A	356	170	N/A		270	-100	ND
		USGS 52K3/VDMR W3068	D & O	Resist	452	165	N/A		258	-93	ND
		USGS 52K4/SWCB ST160/W2197	D & O	Resist	320	185	N/A		250	-65	ND
		USGS 52K5/VDMR W3546	D & O	Resist	337	195	N/A		210	-15	ND
		USGS 52K6/VDMR W1770	D & O	Resist	370	188	N/A		214	-26	ND
		USGS 52K8	good	Resist	380	145	N/A		200	-55	ND
		USGS 52K9	good	SP	270	172	N/A		202	-30	ND
		VDMR W3900	D & O, HUB	N/A	504	50	500	-450	132	-82	368
		VDMR W3638	D & O	N/A	394	188	N/A		230	-42	ND
		VDMR W2841	D & O	N/A	451	181	306	-125	190	-9	116
		VDMR W3637	D & O	N/A	362	162	N/A		224	-62	ND
		VDMR W3901	D & O, HUB	N/A	626	180	527	-347	262	-82	265
		VDMR W200	MIXON 89	N/A	250	190	N/A		220	-30	ND
		VDMR W4107	MIXON 89	N/A	330	195	N/A		225	-30	ND
		VDMR W4227	MIXON 89	N/A	330	180	N/A		230	-50	ND
		VDMR W3979	MIXON 89	N/A	320	180	N/A		220	-40	ND
Yellow Tavern	Hanover	USGS 51K7	good	Resist	451	182	305	-123	198	-16	107
		USGS 51K5	good	E-log	290	190	290	-100	216	-26	74
		USGS 51K6	good	Gamma	632	200	190	10	138	62	52
		USGS 51K1	N/A	????	195	191	195	-4			
		USGS 51K4	N/A	N/A	35	185	28	157			
		VDMR W1300 C80	HUB	????	334	190	290	-100			
		VDMR W1388 C82	HUB	????	525	190	324	-134			
		VDMR W1791 C99	D & O, HUB	????	632	200	320	-120	230	-30	90
		VDMR W1800 C101	D & O, HUB	????	708	160	250	-90	145	15	[illegible]
		VDMR W1878 C104	D & O, HUB	????	640	180	170	10	122	58	48
		VDMR W2068 C106	D & O, HUB	????	322	195	83	112	ABSENT	ABSENT	-

NOTE: Well data collection points are lo

D & O: Daniels and Onuschak, 1974
B, M & S: Brown, Miller, and Swain, 1972
CEDER45: Cederstrom, 1945a
CEDER57: Cederstrom, 1957
HUB: Hubbard and others, 1978
M & H: Meng and Harsh, 1988
MIXON 89: Mixon and others, 1989
OTHER: Logged by field geologist
SHOMO: Shomo, 1982
TEIFKE: Teifke, 1973

Well Borehole Data

C GP. (ft)	POTOMAC GP. ELEV (ft)	POTOMAC GP. THICKNESS (ft)	PAMUNKEY GP. DEPTH (ft)	PAMUNKEY GP. ELEV (ft)	PAMUNKEY GP. THICKNESS (ft)	CHESAPEAKE GP. DEPTH (ft)	CHESAPEAKE GP. ELEV (ft)	CHESAPEAKE GP. THICKNESS (ft)	REGRESSIVE UNIT DEPTH (ft)	REGRESSIVE UNIT ELEV (ft)	REGRESSIVE UNIT THICKNESS (ft)
0	7	152	70	87	80	30	127	40	0	157	30
0	-20	ND	90	60	80	26	124	64	0	150	26
5	-28	ND	95	62	90	50	107	45	0	157	50
0	-59	ND	98	63	122	55	106	43	0	161	55
8	-84	101	ND	ND	ND	54	111	ND	0	165	54
0	-50	190	98	72	122	50	120	48	0	170	50
5	-44	ND	72	10	54	12	70	60	0	82	12
8	-45	90	100	63	108	40	123	60	0	163	40
0	-57	128	ND	ND	ND	78	105	ND	0	183	78
0	-50	ND	140	30	80	110	60	30	C	170	110
5	-30	ND	120	55	85	ABSENT	ABSENT	0	0	175	120
0	0	ND	70	80	80	30	120	40	0	150	30
8	-83	ND	ND	ND	ND	50	125	ND	0	175	50
0	-3	ND	90	77	80	85	82	5	0	167	85
0	-15	ND	70	95	110	30	135	40	0	165	30
8	-88	ND	ND	ND	ND	43	107	ND	0	150	43
0	-15	ND	ND	ND	ND	60	115	ND	0	175	60
0	-67	ND	120	53	120	60	113	60	0	173	60
0	-60	282	117	53	113	69	101	48	0	170	69
4	-34	ND	95	55	89	25	125	70	0	150	25
8	-28	ND	112	58	86	40	130	72	0	170	40
0	-20	ND	ND	ND	ND	40	120	ND	0	160	40
8	-78	ND	125	65	143	65	125	60	0	190	65
4	-79	ND	116	59	138	48	127	68	0	175	48
8	-58	167	102	58	116	40	120	62	0	160	40
5	-51	ND	110	65	116	54	121	56	0	175	54
8	-78	ND	125	65	143	70	120	55	0	190	70
5	-73	ND	115	67	140	47	135	68	0	182	47
0	-75	200	117	68	143	60	125	57	0	185	60
0	-100	ND	148	22	122	40	130	108	0	170	40
8	-93	ND	110	55	148	45	120	65	0	165	45
0	-65	ND	120	65	130	30	155	90	0	185	30
10	-15	ND	152	43	58	62	133	90	0	195	62
4	-28	ND	116	72	98	47	141	69	0	188	47
0	-55	ND	90	55	110	40	105	50	0	145	40
2	-30	ND	104	68	98	47	125	57	0	172	47
2	-62	368	26	24	106	22	28	4	0	50	22
0	-42	ND	140	48	90	50	138	90	0	188	50
0	-9	116	ND	ND	ND	34	147	ND	0	181	34
24	-62	ND	144	18	80	29	133	115	0	162	29
32	-62	265	156	24	106	26	154	130	0	180	26
20	-30	ND	130	60	90	ND	ND	ND	ND	ND	ND
25	-30	ND	125	70	100	ND	ND	ND	ND	ND	ND
30	-50	ND	120	60	110	ND	ND	ND	ND	ND	ND
20	-40	ND	100	80	120	ND	ND	ND	ND	ND	ND
98	-18	107	120	62	78	36	146	84	0	182	38
16	-26	74	122	68	94	44	146	78	0	190	44
38	62	52	90	110	48	40	160	50	0	200	40
30	-30	90	ND	ND	ND	50	150	ND	0	200	50
45	15	105	ND	ND	ND	25	135	ND	0	160	25
22	58	48	115	65	7	45	135	70	0	180	45
SENT	ABSENT	0	ABSENT	ABSENT	0	40	155	ND	0	195	40

ata collection points are located in Figure 10.

Well Borehole Data

QUAD	COUNTY	WELL NUMBER	STRAT LOG	ELEC LOGS	TOTAL DEPTH (ft)	ELEV (ft)	BEDROCK DEPTH (ft)	BEDROCK ELEV (ft)	POTOMAC GP. DEPTH (ft)	POTOMAC GP. ELEV (ft)	POTOMAC GP. THICKNESS (ft)	PA
Yellow Tavern	Hanover	VDMR W2221 C110	HUB	????	300	190	185	5				
		VDMR W2478 C118	D & O, HUB	????	282	202	105	97	ABSENT	ABSENT	0	
		VDMR W2500 C124	HUB	????	653	110	165	-55				
		VDMR W2655 C128	HUB	????	310	110	80	30				
		VDMR W2656 C129	HUB	????	136	175	132	43				
		VDMR W2756 C136	HUB	????	250	200	69	131				
		VDMR W2757 C135	HUB	????	250	200	103	97				
		VDMR W2926 C137	D & O, HUB	????	250	190	110	80	ND	ND	ND	
		VDMR W3277 C142	D & O, HUB	????	250	210	86	124	ABSENT	ABSENT	0	
		VDMR W3366 C144	D & O, HUB	????	405	190	165	25	130	60	35	
		VDMR W3367 C145	HUB	????	300	200	170	30				
		VDMR 3547 C147	HUB	????	290	190	175	15				
		VDMR W3579 C149	HUB	????	330	180	200	-20				
		VDMR W3649 C153	HUB	????	200	130	27	103				
		VDMR W3680 C152	HUB	????	350	130	50	80				
		VDMR W3791 C157	HUB	????	431	190	300	-110				
		VDMR W3824 C162	HUB	????	310	160	68	92				
		VDMR W4394 C178	HUB	????	367	190	260	-70				
		VDMR W1534	D & O, MIXON 89	N/A	500	209	98	111	ABSENT	ABSENT	0	
		VDMR W4444	MIXON 89	N/A	185	210	20	190	ABSENT	ABSENT	0	
		VDMR W1570	D & O	N/A	225	220	80	140	ABSENT	ABSENT	0	
		VDMR W1695	D & O	N/A	250	180	1	179	ABSENT	ABSENT	0	
		VDMR W3654	D & O	N/A	200	182	32	150	ABSENT	ABSENT	0	
		VDMR W1472	D & O, HUB	N/A	395	195	260	-65	190	5	70	
		VDMR 1799	D & O	N/A	275	165	N/A		170	-5	ND	
		VDMR 3087	D & O	N/A	257	157	257	-100	180	-23	77	
	Henrico	USGS 51K3	N/A	N/A	82	198	63	135				
		USGS 51K2	N/A	N/A	118	165	100	65				
		VDMR W539 C323	HUB, good	N/A	239	205	26	179	ABSENT	ABSENT	0	
		VDMR W1658	D & O	N/A	300	130	30	100	ABSENT	ABSENT	0	
		VDMR C192	good	N/A	204	140	26	114	ABSENT	ABSENT	0	
		VDMR W1305 C178	D & O, HUB	N/A	508	183	200	-17	141	42	59	
		VDMR W1659 C165	D & O	N/A	240	130	20	110	ABSENT	ABSENT	0	
		VDMR C163	good	N/A	142	180	79	101				
		CDER YT7	N/A	N/A	200	190	158	32				
Chester	Chesterfield	USGS 51G1	N/A	N/A	100	57	54	3				
		USGS 51G3/VDMR C221	M&H, good	Resist	281	130	280	-150	120	10	160	
		SWCB CH143/VDMR W4906 C225	OTHER	N/A	92	100	20	80	ABSENT	ABSENT	0	
		SWCB CH144/VDMR C223	fair	N/A	63	50	10	40	ABSENT	ABSENT	0	
		SWCB CH126/VDMR W4540 C214	OTHER	N/A	240	85	40	45	ABSENT	ABSENT	0	
		SWCB CH87/VDMR W5223 C231	OTHER	N/A	360	160	110	50	90	70	20	
		SWCB CH92/VDMR C248	good	Resist-SP	260	165	N/A		140	25	25	
		SWCB CH67	fair	N/A	130	90	21	69				
		SWCB CH94	fair	N/A	355	190	50	140	ABSENT	ABSENT	0	
		VDMR W1908 C171/SWCB CH66	OTHER, HUB, SHOMO	N/A	140	80	120	-40	60	20	60	
		VDMR C197/SWCB CH43	good	N/A	237	80	120	-40				
		SWCB W935 C142	HUB, good	N/A	199	140	150	-10				
		CDER CH23	CEDER45	N/A	327	155	167	-12	95	60	72	
		CDER CH25	N/A	N/A	360	140	100	40				
		CDER CH34	N/A	N/A	172	90	40	50				
		CDER CH37	N/A	N/A	160	60	30	30				
		VDMR W584 C208	HUB	N/A	300	155	260	-105				
		VDMR W3088 C196	HUB, SHOMO	????	372	150	220	-70	178	-28	42	
		VDMR W3250 C197	HUB	????	237	80	140	-60				
Drewerys Bluff	Chesterfield	USGS 51H2	CEDER45	N/A	89	80	81	-1	0	80	81	
		USGS 51H7	good	esist-Gamm	500	90	144	-54				

REFERENCES

NOTE: Well data collection points are loc

D & O:	Daniels and Onuschak, 1974
B, M & S:	Brown, Miller, and Swain, 1972
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OTHER:	Logged by field geologist
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'ell Borehole Data

POTOMAC GP. ELEV (ft)	POTOMAC GP. THICKNESS (ft)	PAMUNKEY GP. DEPTH (ft)	PAMUNKEY GP. ELEV (ft)	PAMUNKEY GP. THICKNESS (ft)	CHESAPEAKE GP. DEPTH (ft)	CHESAPEAKE GP. ELEV (ft)	CHESAPEAKE GP. THICKNESS (ft)	REGRESSIVE UNIT DEPTH (ft)	REGRESSIVE UNIT ELEV (ft)	REGRESSIVE UNIT THICKNESS (ft)
ABSENT	0	ND	ND	ND	30	172	ND	0	202	30
ND	ND	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	190	110?
ABSENT	0	ABSENT	ABSENT	0	23	187	65	0	210	23
60	35	ABSENT	ABSENT	0	25	165	125	0	190	25
ABSENT	0	ABSENT	ABSENT	0	53	156	45	0	209	53
ABSENT	0	ABSENT	ABSENT	0	ND	ND	ND	ND	ND	ND
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	220	80
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	180	1
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	182	32
5	70	165	30	25	60	135	105	0	195	60
-5	ND	130	35	40	10	155	120	0	165	10
-23	77	120	37	60	25	132	95	0	157	25
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	205	26
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	130	30
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	140	26
42	59	121	62	20	36	147	85	0	183	36
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	130	20
10	160	90	40	30	40	90	50	0	130	40
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	100	20
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0			
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	85	40
70	20	ABSENT	ABSENT	0	50	110	40	0	160	50
25	25	110	55	30	85	80	25	0	165	85
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0			
20	60	40	40	20	ABSENT	ABSENT	0	0	80	40
60	72	ABSENT	ABSENT	0	65	90	30	0	155	65
-28	42									
80	81	ABSENT	ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0

;ollection points are located in Figure 10.

Well Borehole Data

QUAD	COUNTY	WELL NUMBER	STRAT LOG	ELEC LOGS	TOTAL DEPTH (ft)	ELEV (ft)	BEDROCK DEPTH (ft)	BEDROCK ELEV (ft)	POTOMAC GP. DEPTH (ft)	POTOMAC GP. ELEV (ft)	POTOMAC GP. THICKNESS (ft)
Drewerys Bluff	Chesterfield	USGS 51H40	U.S.G.S.	N/A	75	108	71	37	31	77	40
		USGS 51H6/VDMR W4762 C215	HUB, M&H,good	Resist	205	90	141	-51	50	40	91
		USGS 51H1	CEDER45	N/A	130	200	55	145	ABSENT	ABSENT	0
		USGS 51H3	good	N/A	219	70	90	-20	29	41	61
		VDMR W6761 C249	good	????	347	140	92	48			
		VDMR W7145 C251	good	Resist-SP	151	85	140	-55	33	52	107
		VDMR W1906 C172	HUB, fair	N/A	78	170	20	150			
		VDMR W1541 C155	HUB, good	N/A	402	90	70	20	40	50	30
		VDMR W1567 C165	fair	N/A	300	120	19	101	ABSENT	ABSENT	0
		VDMR W1508 C163	HUB, TEIFKE	N/A	393	92	130	-38	10	82	120
		VDMR W1297 C148	HUB, good	N/A	234	130	158	-28	68	64	92
		VDMR W1104 C144	good	N/A	390	160	75	85			
		VDMR C136	fair	N/A	71	200	49	151	ABSENT	ABSENT	0
		VDMR C123	fair	N/A	324	30	69	-39			
		VDMR C201	fair	N/A	300	200	40	160			
		VDMR W56 C211	HUB, fair	N/A	425	40	71	-31			
		CDER DB5	N/A	N/A	N/A	85	9	76			
		CDER DB11	N/A	N/A	747	15	14	1			
		CDER DB17	N/A	N/A	150	82	122	-40			
	Henrico	USGS 51H5/VDMR W616 C325	HUB, good	Resist	712	138	249	-111	90	48	159
Dutch Gap	Henrico	USGS 52H1	N/A	N/A	725	30	310	-280			
		USGS 52H8/VDMR C40	M&H, good	E-log	287	145	214	-69	108	37	106
		USGS 52H3/VDMR W3443 C206	HUB, good	Gamma?	340	150	220	-70	120	30	100
		USGS 52H2	CEDER57	N/A	346	118	223	-105	80	38	143
		VDMR C259	good	N/A	335	51	297	-246	55	-4	242
		VDMR C258	good	N/A	385	58	290	-232	75	-17	215
		VDMR W4950 C221	good	E-log	251	130	N/A		104	26	
Hopewell	Chesterfield	USGS 52G11/VDMR C203	good	E-log	215	24	N/A		47	-23	N/A
		VDMR W3411 C198	HUB, good	Resist	294	10	285	-275	40	-30	245
		VDMR W4397 C212	HUB, good	Resist	292	30	290	-260	30	0	260
		VDMR W4827 C220	good	Resist	260	50	N/A		60	-10	
	Prince George	USGS 52G4/CDER HP16	CEDER45	N/A	314	51	N/A		55	-4	
		CDER HP1	CEDER45	N/A	348	110	N/A		40	70	N/A
		CDER HP20	N/A	N/A	336	47	332	-285			
		CDER HP21/52G5	CEDER45	N/A	285	46	N/A		82	-36	N/A
		BMS T9	BROWN,MILLER,SWAIN	N/A	65	90	N/A		48	44	N/A

NOTE: Well data collection points are l

REFERENCES

D & O:	Daniels and Onuschak, 1974
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CEDER45:	Cederstrom, 1945a
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HUB:	Hubbard and others, 1978
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MIXON 89:	Mixon and others, 1989
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SHOMO:	Shomo, 1982
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l Borehole Data

POTOMAC GP. ELEV (ft)	POTOMAC GP. THICKNESS (ft)	PAMUNKEY GP. DEPTH (ft)	PAMUNKEY GP. ELEV (ft)	PAMUNKEY GP. THICKNESS (ft)	CHESAPEAKE GP. DEPTH (ft)	CHESAPEAKE GP. ELEV (ft)	CHESAPEAKE GP. THICKNESS (ft)	REGRESSIVE UNIT DEPTH (ft)	REGRESSIVE UNIT ELEV (ft)	REGRESSIVE UNIT THICKNESS (ft)
77	40	24	84	7	14	94	10	0	108	14
40	91	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	90	50
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	200	55
41	61	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	70	29
52	107	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	85	33
50	30	ABSENT	ABSENT	0	30	60	10	0	90	30
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0
82	120	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	92	10
64	92	63	67	3	42	88	21	0	130	42
ABSENT	0	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	200	49
48	159	70	68	20	30	108	40	0	138	30
37	106	85	60	23	30	115	55	0	145	30
30	100	100	50	20	38	112	62	0	150	38
38	143	ABSENT	ABSENT	0	50	68	30	0	118	50
-4	242	42	9	13	30	21	12	0	51	30
-17	215	55	3	20	35	23	20	0	58	35
26		80	50	24	40	90	40	0	130	40
-23	N/A	41	-17	6	26	-2	15	0	24	26
-30	245	10	0	30	ABSENT	ABSENT	0	0	10	10
0	260	20	10	10	ABSENT	ABSENT	0	0	30	20
-10		ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	50	60
-4		40	11	15	ABSENT	ABSENT	0	0	51	40
70	N/A	ABSENT	ABSENT	0	ABSENT	ABSENT	0	0	110	40
-36	N/A	39	7	43	ABSENT	ABSENT	0	0	46	39
44	N/A	22	68	24	ABSENT	ABSENT	0	0	90	22

:llection points are located in Figure 10.

APPENDIX B

SELECTED GEOLOGIC LOGS

WELL LOG NUMBER: W1878/C104

SURFACE ELEVATION: 180 feet

QUADRANGLE: YELLOW TAVERN

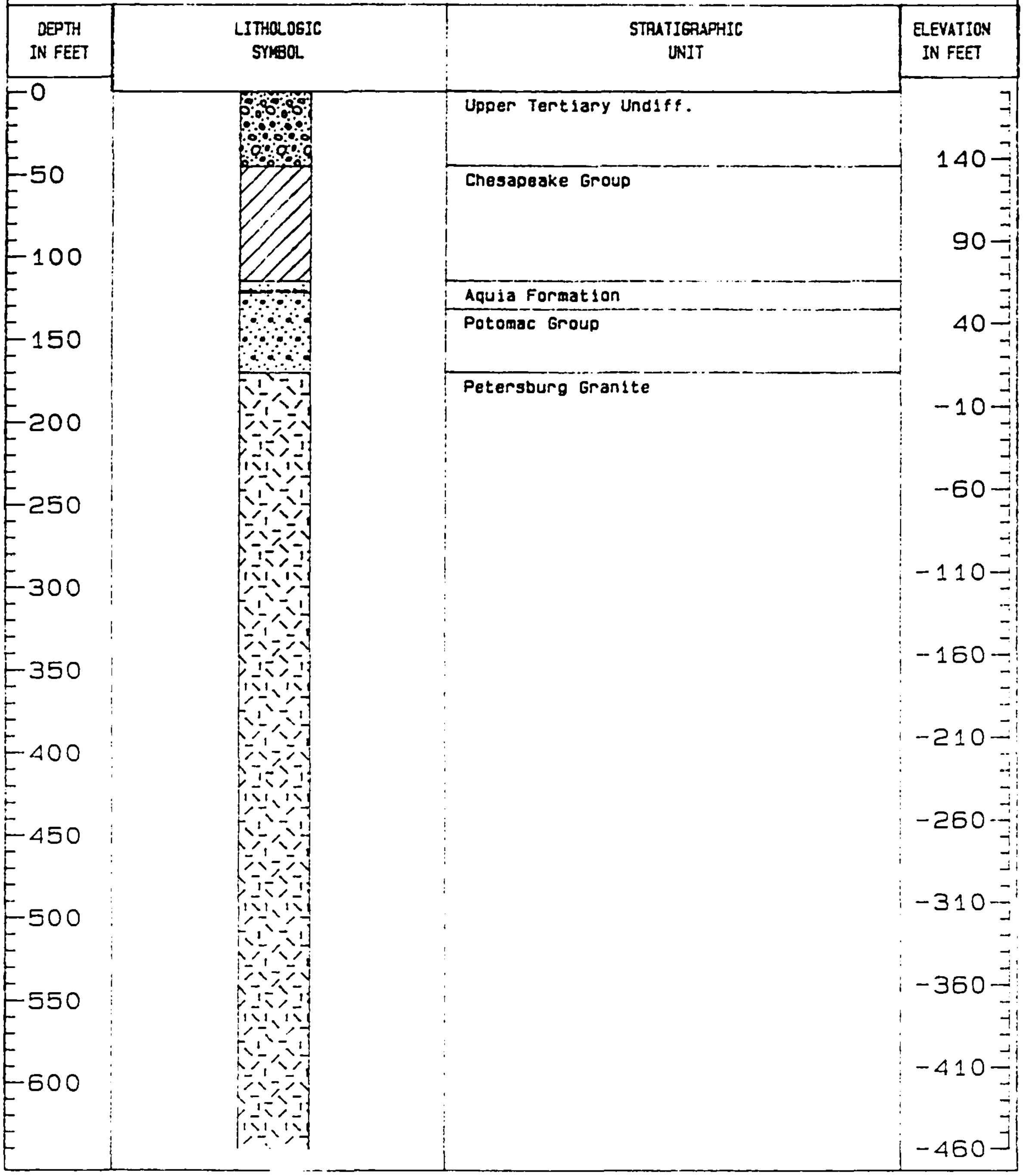
TOTAL DEPTH: 640 feet

COUNTY: HANOVER

DRILLER: SYDNOR HYDRODYNAMICS

AVAILABLE DATA: D & O, HUB

DATE DRILLED: N/A



WELL LOG NUMBER: W3366/C144

QUADRANGLE: YELLOW TAVERN

COUNTY: HANOVER

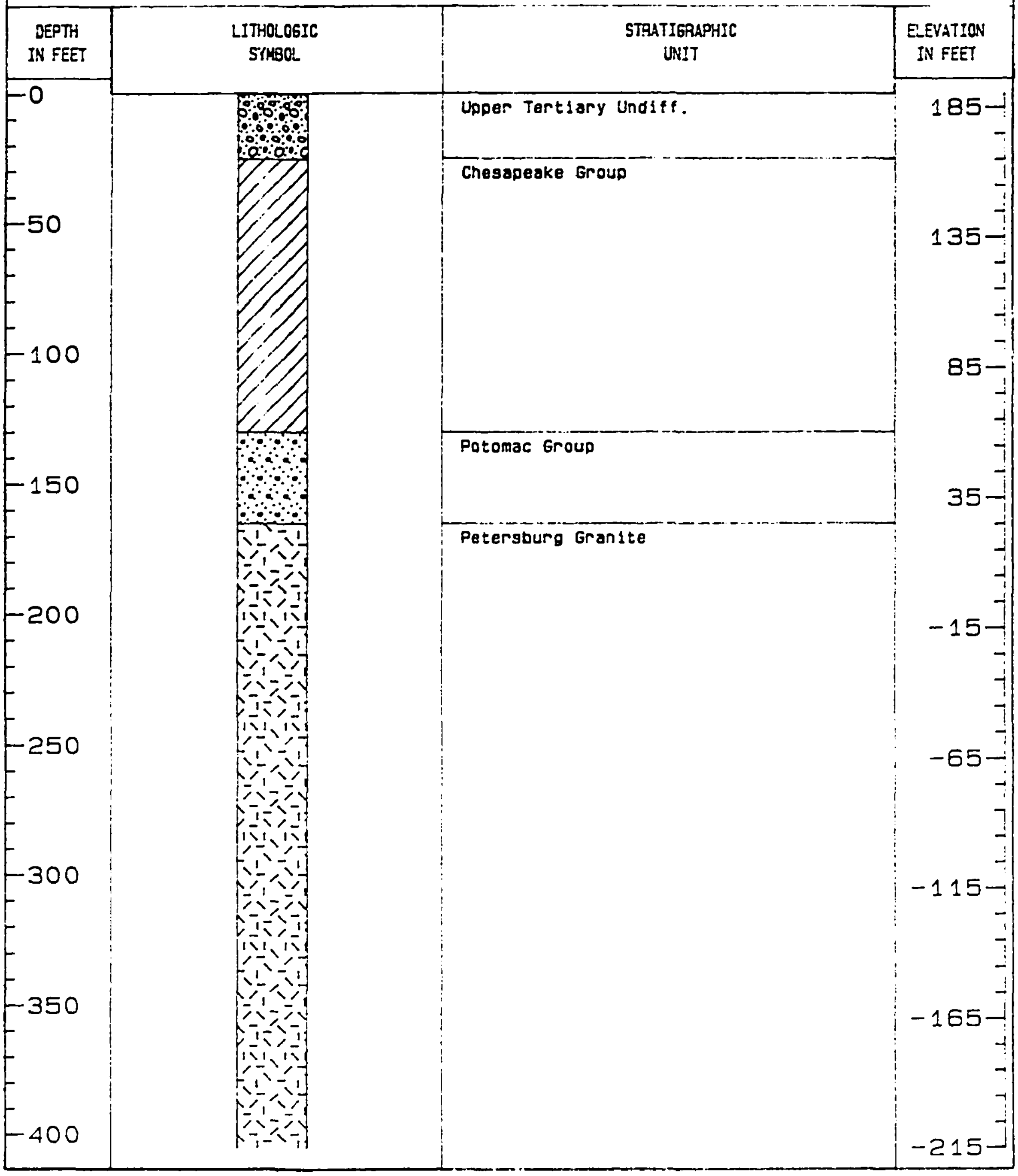
AVAILABLE DATA: D & O, HUB

SURFACE ELEVATION: 190 feet

TOTAL DEPTH: 405 feet

DRILLER: N/A

DATE DRILLED: N/A



WELL LOG NUMBER: 52K2/W199

QUADRANGLE: STUDLEY

COUNTY: HANOVER

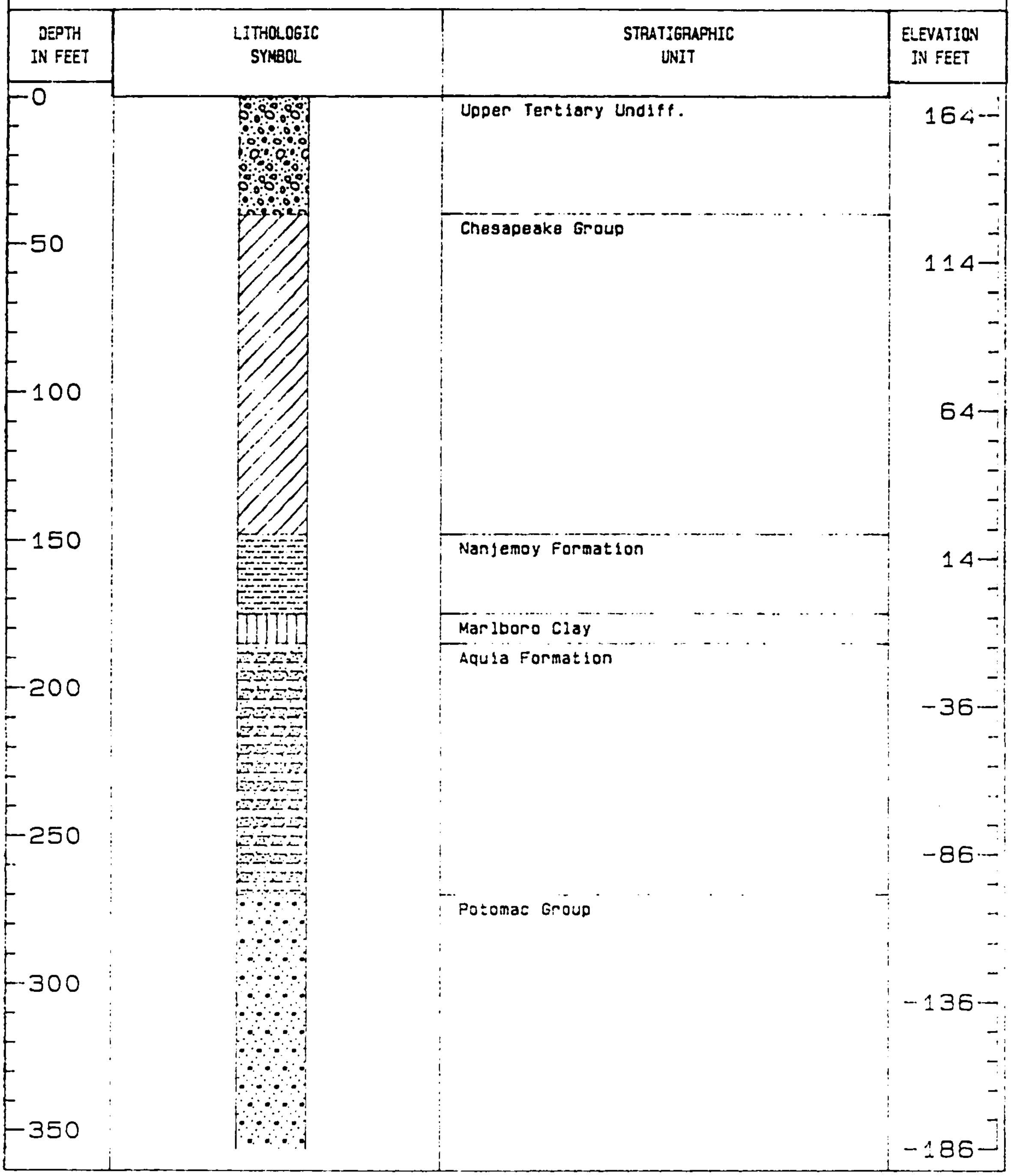
AVAILABLE DATA: D & O

SURFACE ELEVATION: 170 feet

TOTAL DEPTH: 356 feet

DRILLER: MITCHELL WELL & PUMP

DATE DRILLED: 9/1/48



WELL LOG NUMBER: W3900

QUADRANGLE: STUDLEY

COUNTY: HANOVER

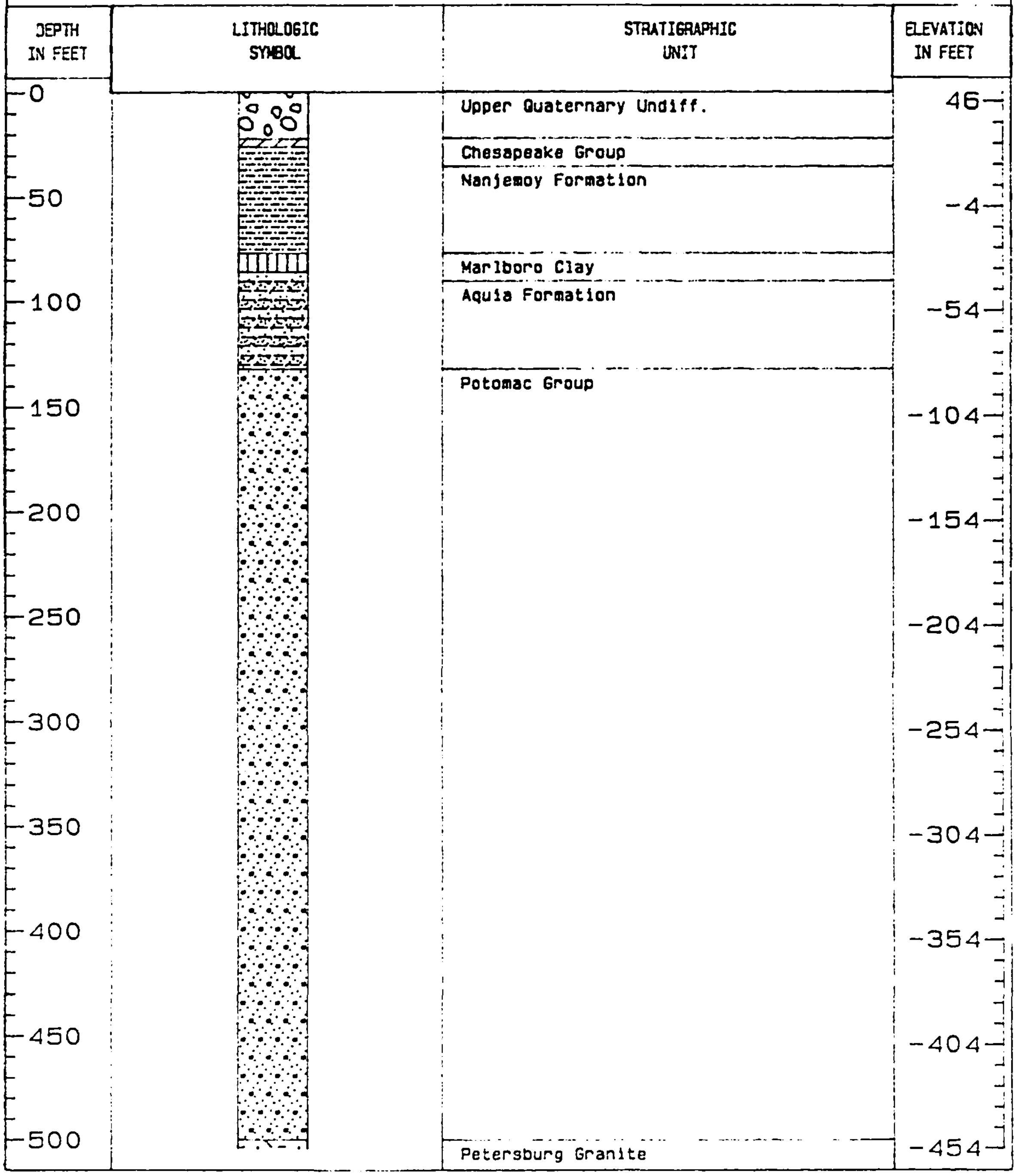
AVAILABLE DATA: D & O, HUB

SURFACE ELEVATION: 50 feet

TOTAL DEPTH: 504 feet

DRILLER: N/A

DATE DRILLED: N/A



WELL LOG NUMBER: W1247

QUADRANGLE: RICHMOND

COUNTY: HENRICO

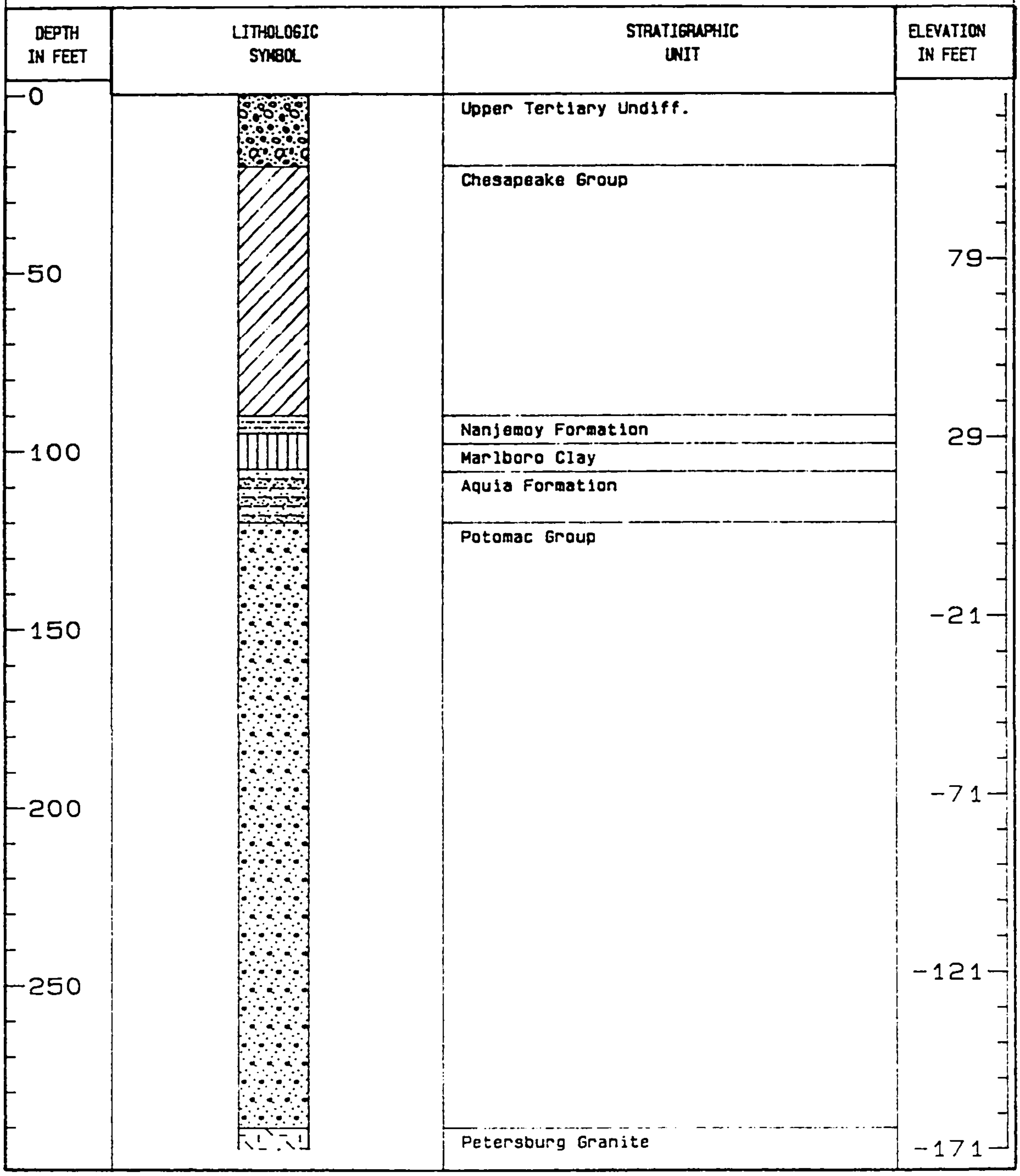
AVAILABLE DATA: D & O

SURFACE ELEVATION: 125 feet

TOTAL DEPTH: 296 feet

DRILLER: SYDNOR HYDRODYNAMICS

DATE DRILLED: 9/4/64



WELL LOG NUMBER: W3902

QUADRANGLE: RICHMOND

COUNTY: HANOVER

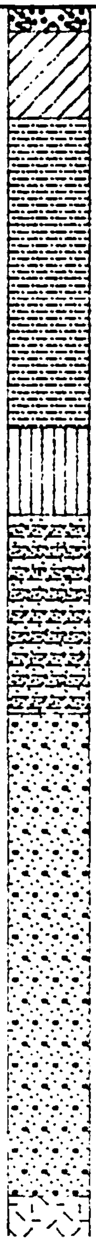
AVAILABLE DATA: D & O, HUB

SURFACE ELEVATION: 90 feet

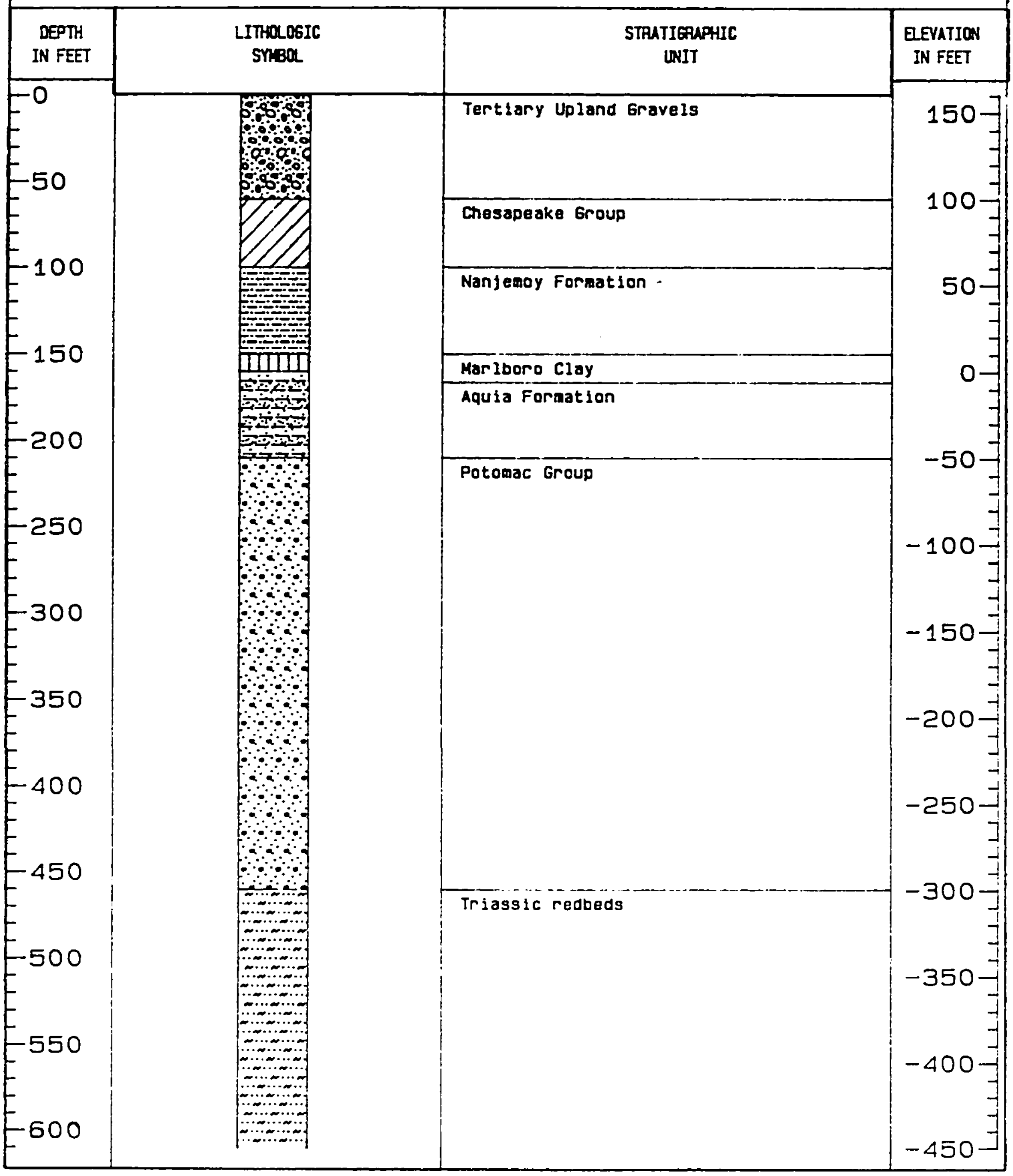
TOTAL DEPTH: 155 feet

DRILLER: N/A

DATE DRILLED: N/A

DEPTH IN FEET	LITHOLOGIC SYMBOL	STRATIGRAPHIC UNIT	ELEVATION IN FEET
0		Upper Quaternary Undiff.	85
		Chesapeake Group	
		Nanjemoy Formation	
50		Marlboro Clay	35
		Aquia Formation	
		Potomac Group	
100			-15
150		Petersburg Granite	-65

WELL LOG NUMBER: 52J12/W3574 C207
SURFACE ELEVATION: 160 feet
QUADRANGLE: SEVEN PINES
TOTAL DEPTH: 610 feet
COUNTY: HENRICO
DRILLER: SYDNOR HYDRODYNAMICS
AVAILABLE DATA: D&O, HUB, SHOMO, E-LOG
DATE DRILLED: 09/17/73



WELL LOG NUMBER: W3904

QUADRANGLE: SEVEN PINES

COUNTY: HENRICO

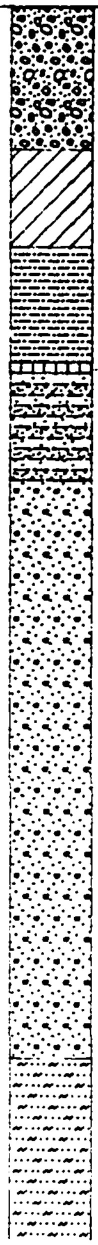
AVAILABLE DATA: D&O, SHOMO, HUB

SURFACE ELEVATION: 170 feet

TOTAL DEPTH: 600 feet

DRILLER: SYDNOR HYDRODYNAMICS

DATE DRILLED: N/A

DEPTH IN FEET	LITHOLOGIC SYMBOL	STRATIGRAPHIC UNIT	ELEVATION IN FEET
0		Tertiary Upland Gravels	170
50			120
		Chesapeake Group	
100			70
		Nanjemoy Formation	
150			20
		Marlboro Clay	
		Aquia Formation	
200			-30
		Potomac Group	
250			-80
300			-130
350			-180
400			-230
450			-280
500			-330
		Triassic redbeds	
550			-380
600			-430

WELL LOG NUMBER: W1297/C148

QUADRANGLE: DREWRYS BLUFF

COUNTY: CHESTERFIELD

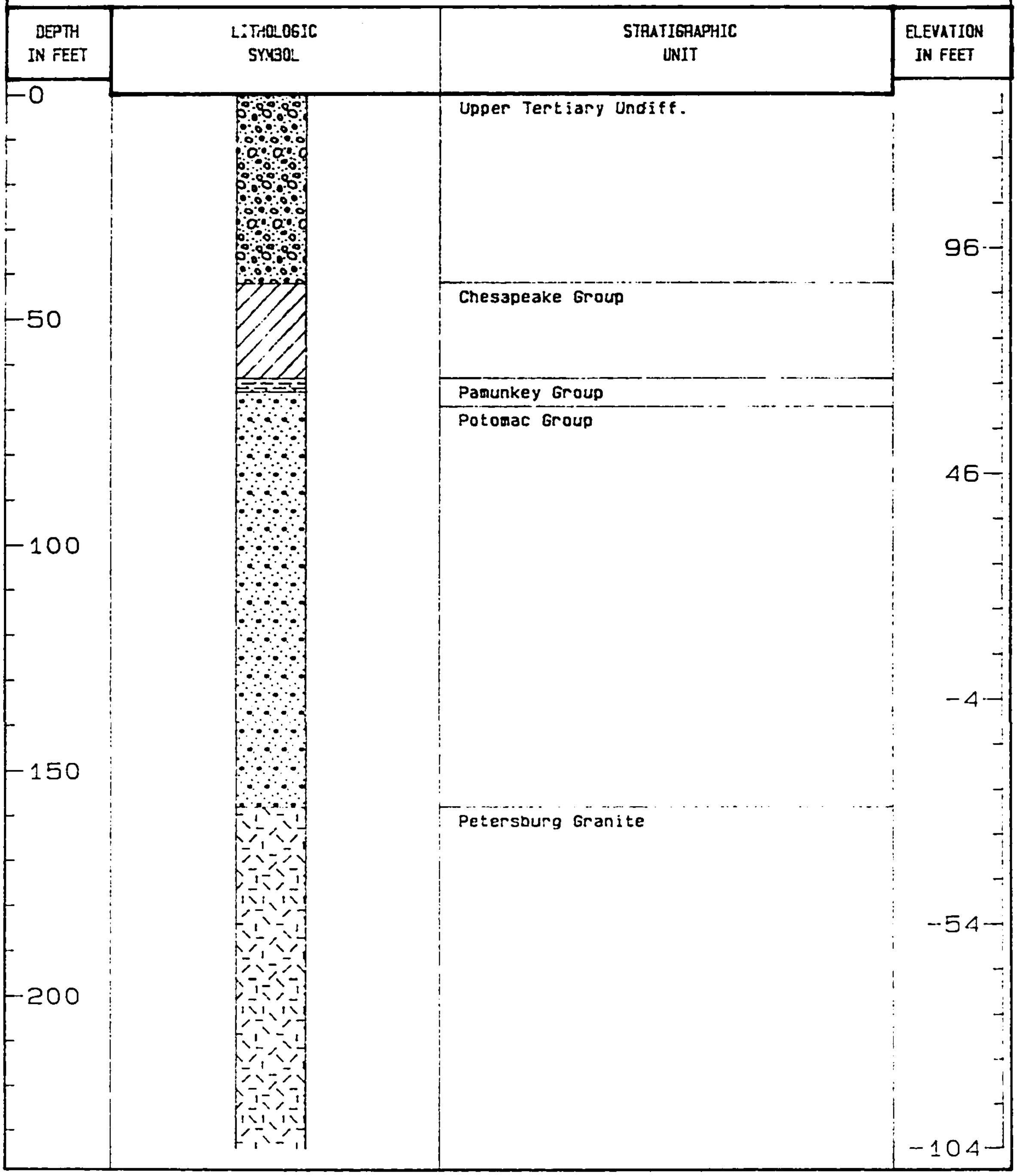
AVAILABLE DATA: HUB.

SURFACE ELEVATION: 130 feet

TOTAL DEPTH: 234 feet

DRILLER: SYDNOR HYDRODYNAMICS

DATE DRILLED: 3/12/65



WELL LOG NUMBER: 51H5/W616 C325

SURFACE ELEVATION: 138 feet

QUADRANGLE: DREWRYS BLUFF

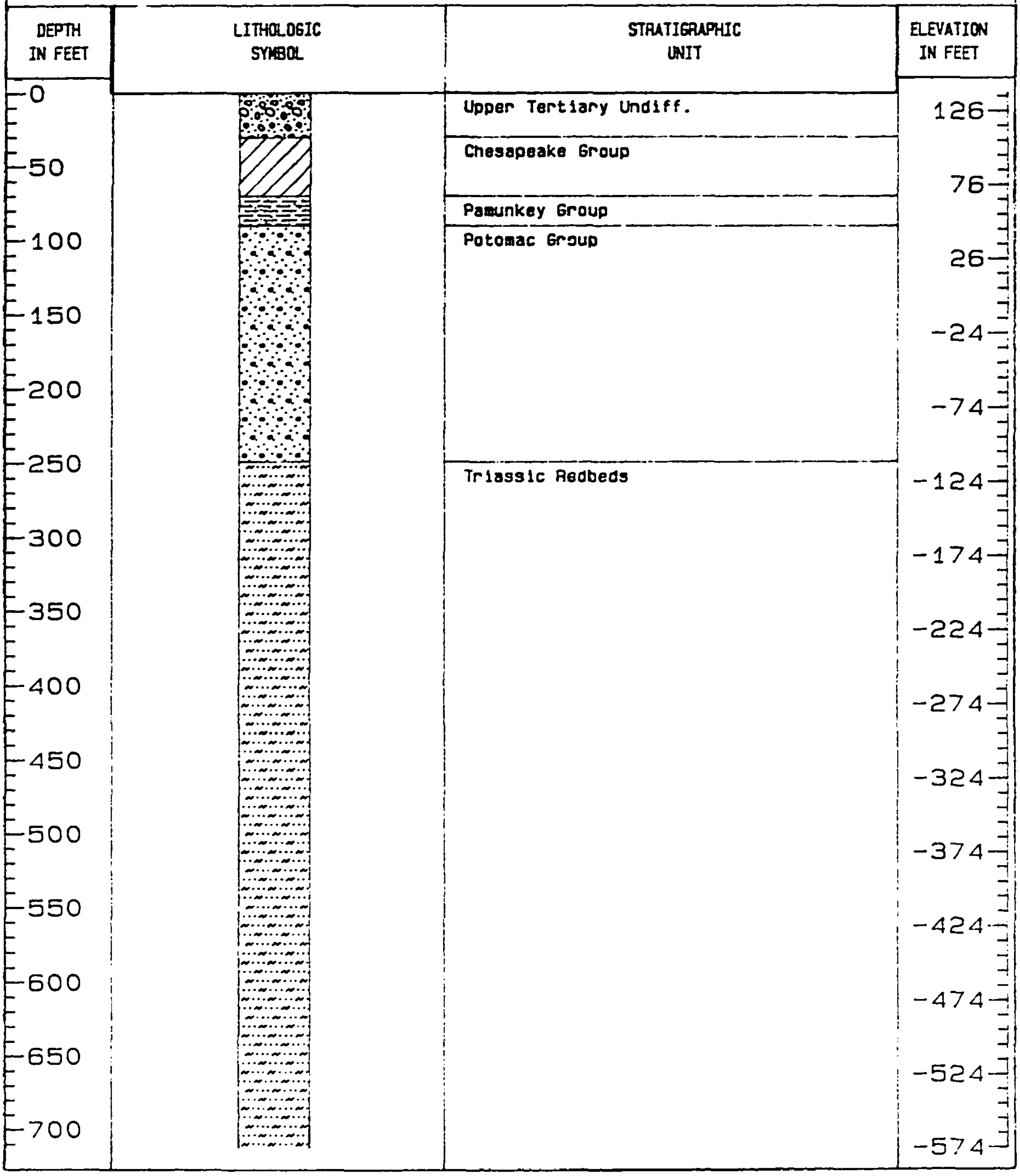
TOTAL DEPTH: 712 feet

COUNTY: HENRICO

DRILLER: SYDNOR HYDRODYNAMICS

AVAILABLE DATA: RESIST. HUB.

DATE DRILLED: 7/10/61



WELL LOG NUMBER: 52H8/C40

QUADRANGLE: DUTCH GAP

COUNTY: HENRICO

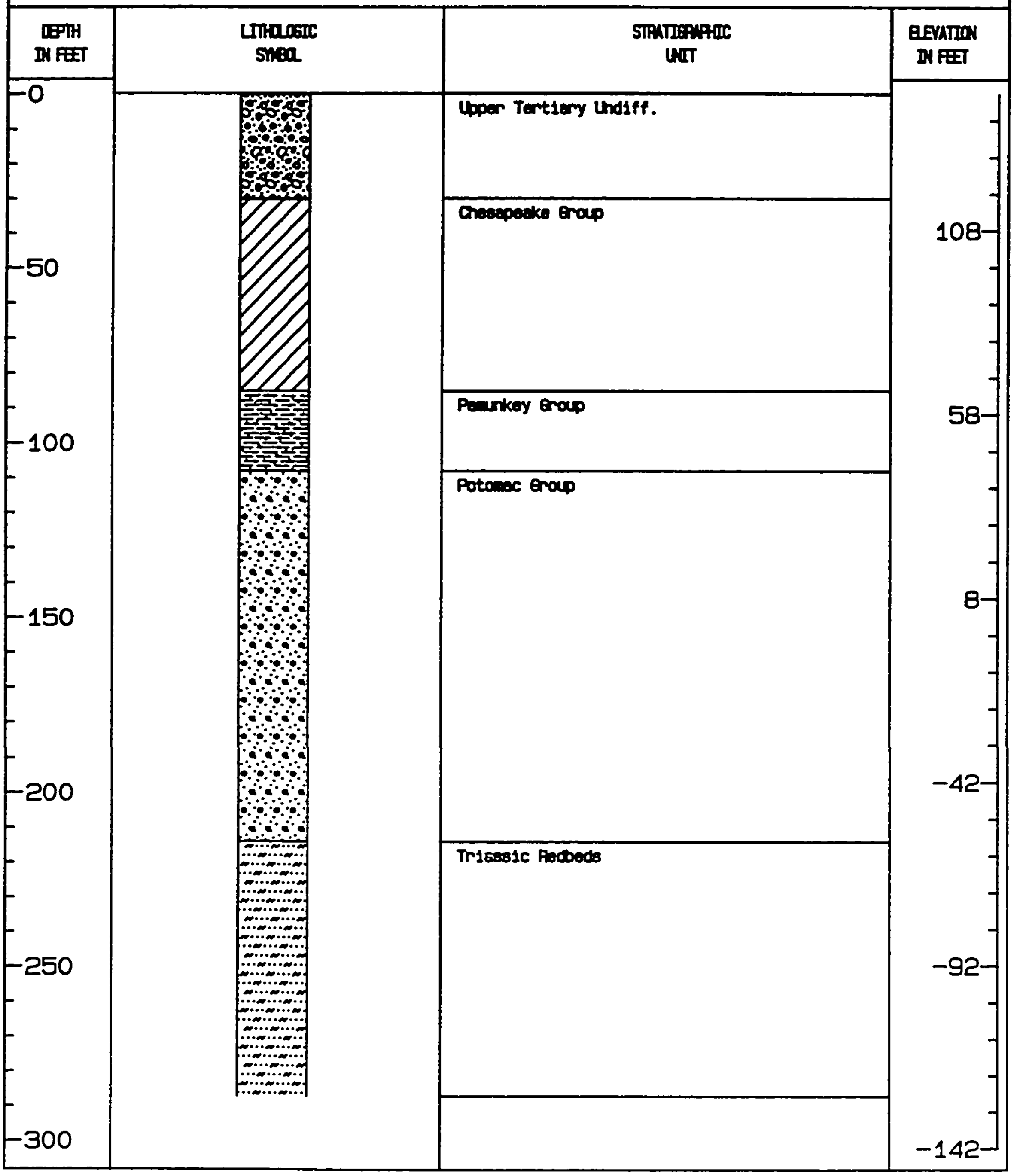
AVAILABLE DATA: E-LOG, M & H

SURFACE ELEVATION: 145 feet

TOTAL DEPTH: 287 feet

DRILLER: SYDNOR HYDRODYNAMICS

DATE DRILLED: 4/18/62



WELL LOG NUMBER: 52H2

SURFACE ELEVATION: 118 feet

QUADRANGLE: DUTCH GAP

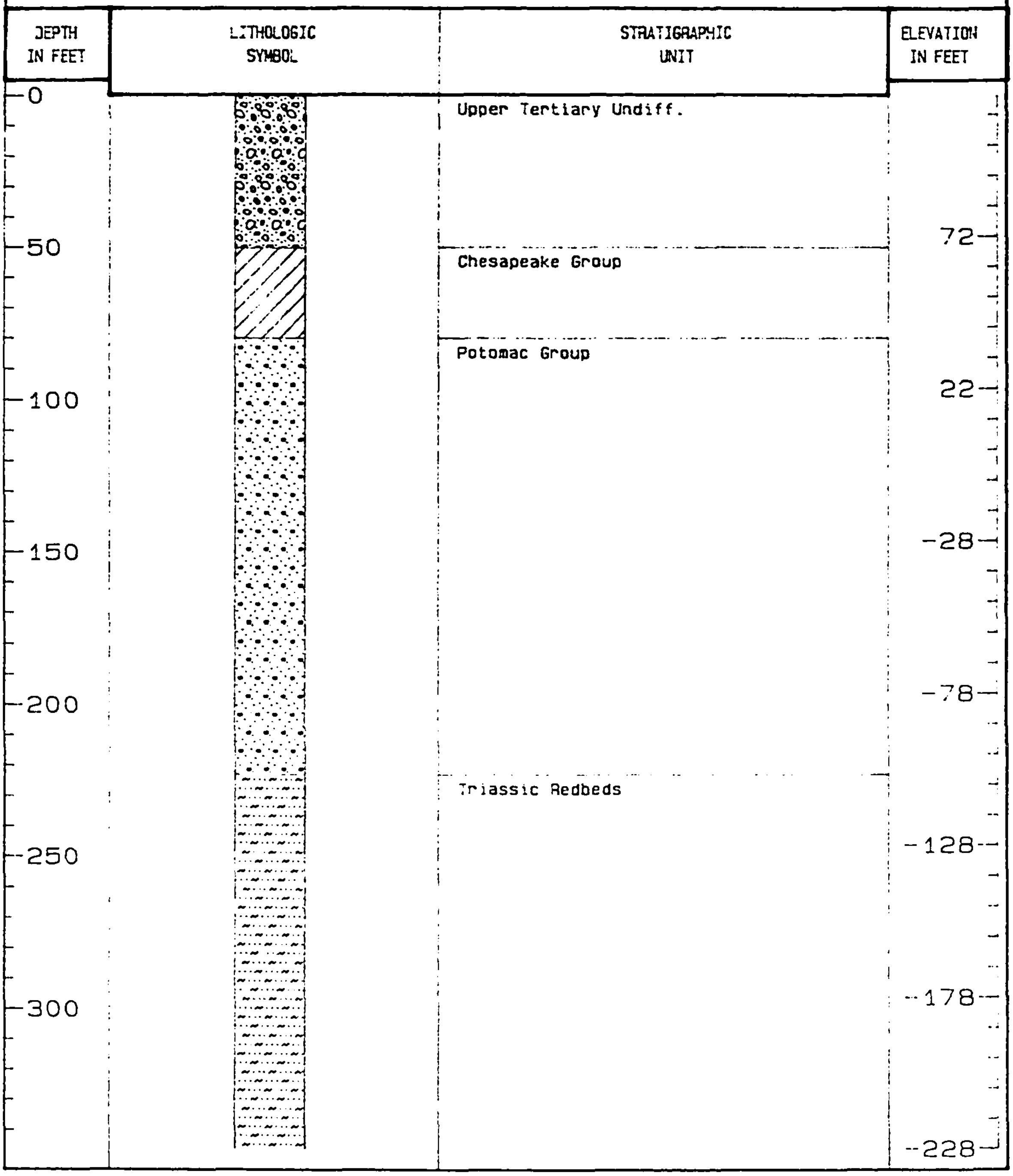
TOTAL DEPTH: 346 feet

COUNTY: HENRICO

DRILLER: SYDNOR HYDRODYNAMICS

AVAILABLE DATA: CEDER57

DATE DRILLED: 1/1/33



WELL LOG NUMBER: 51G3/C221

QUADRANGLE: CHESTER

COUNTY: CHESTERFIELD

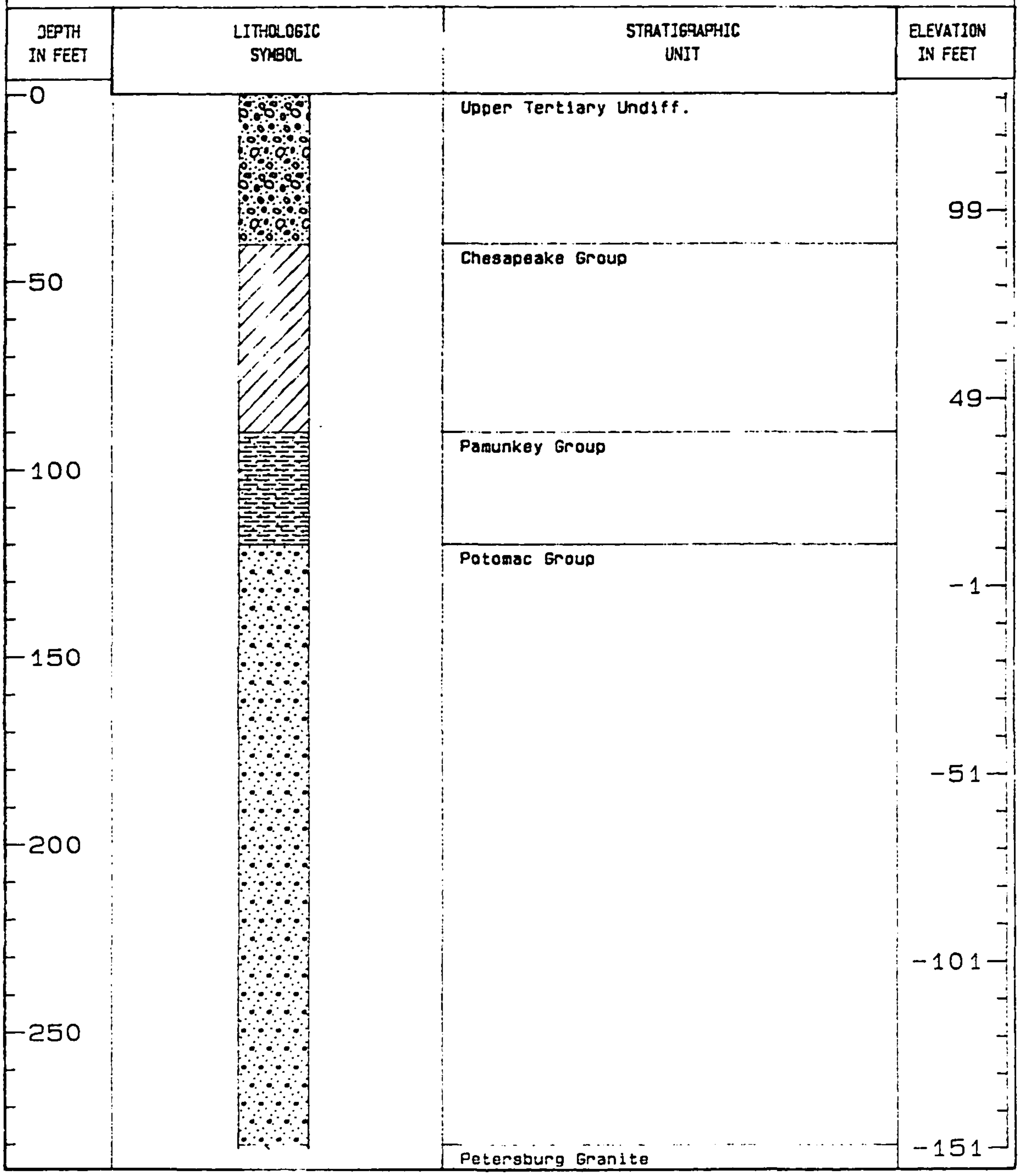
AVAILABLE DATA: RESIST, M & H,

SURFACE ELEVATION: 130 feet

TOTAL DEPTH: 281 feet

DRILLER: SYDNOR HYDRODYNAMICS

DATE DRILLED: 3/7/77



WELL LOG NUMBER: W1908/C171 CH66

SURFACE ELEVATION: 80 feet

QUADRANGLE: CHESTER

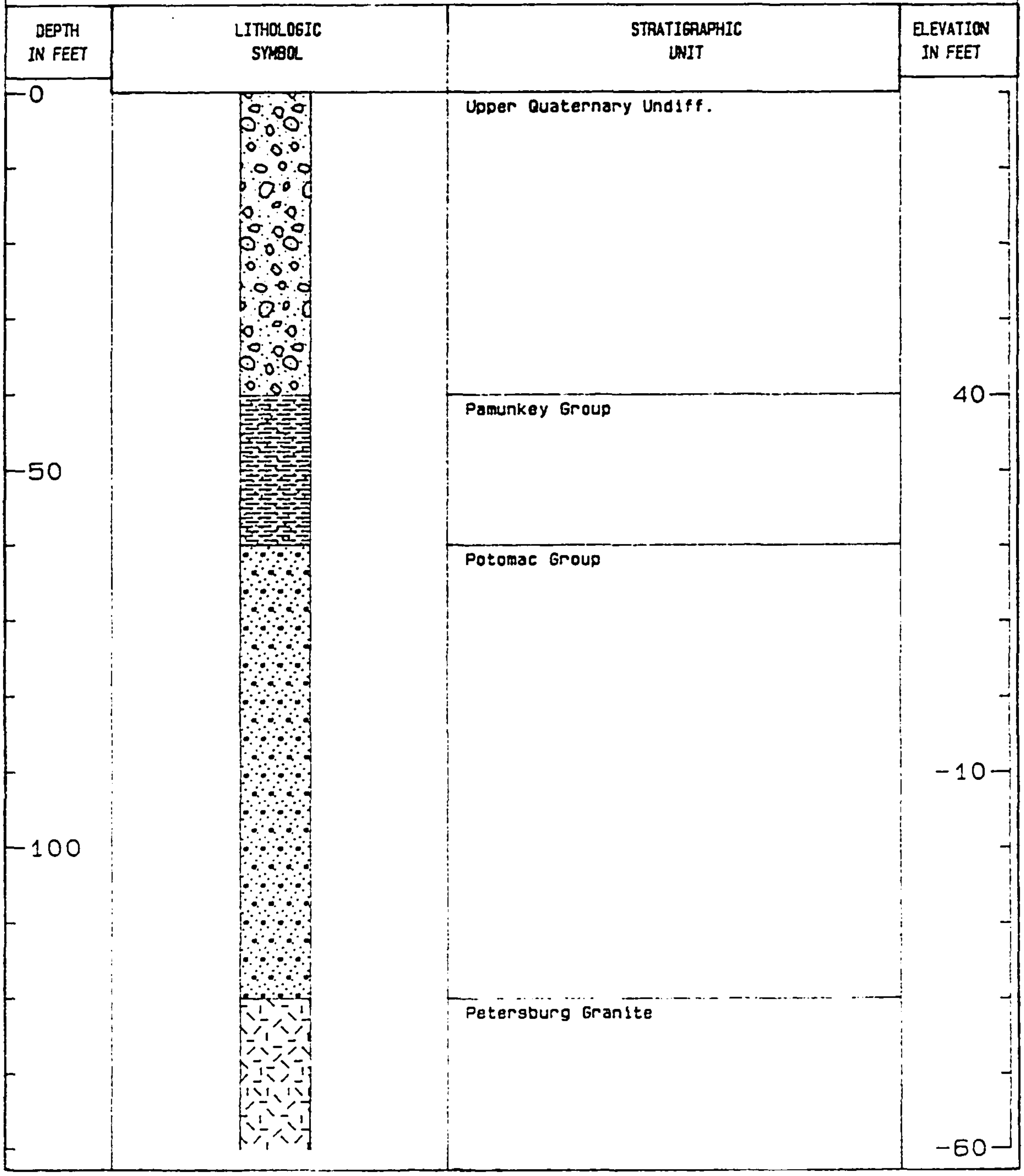
TOTAL DEPTH: 140 feet

COUNTY: CHESTERFIELD

DRILLER: MITCHELL WELL & PUMP

AVAILABLE DATA: OTHER, HUB, SHOMO

DATE DRILLED: 5/1/67



WELL LOG NUMBER: W3411/C198

QUADRANGLE: HOPEWELL

COUNTY: CHESTERFIELD

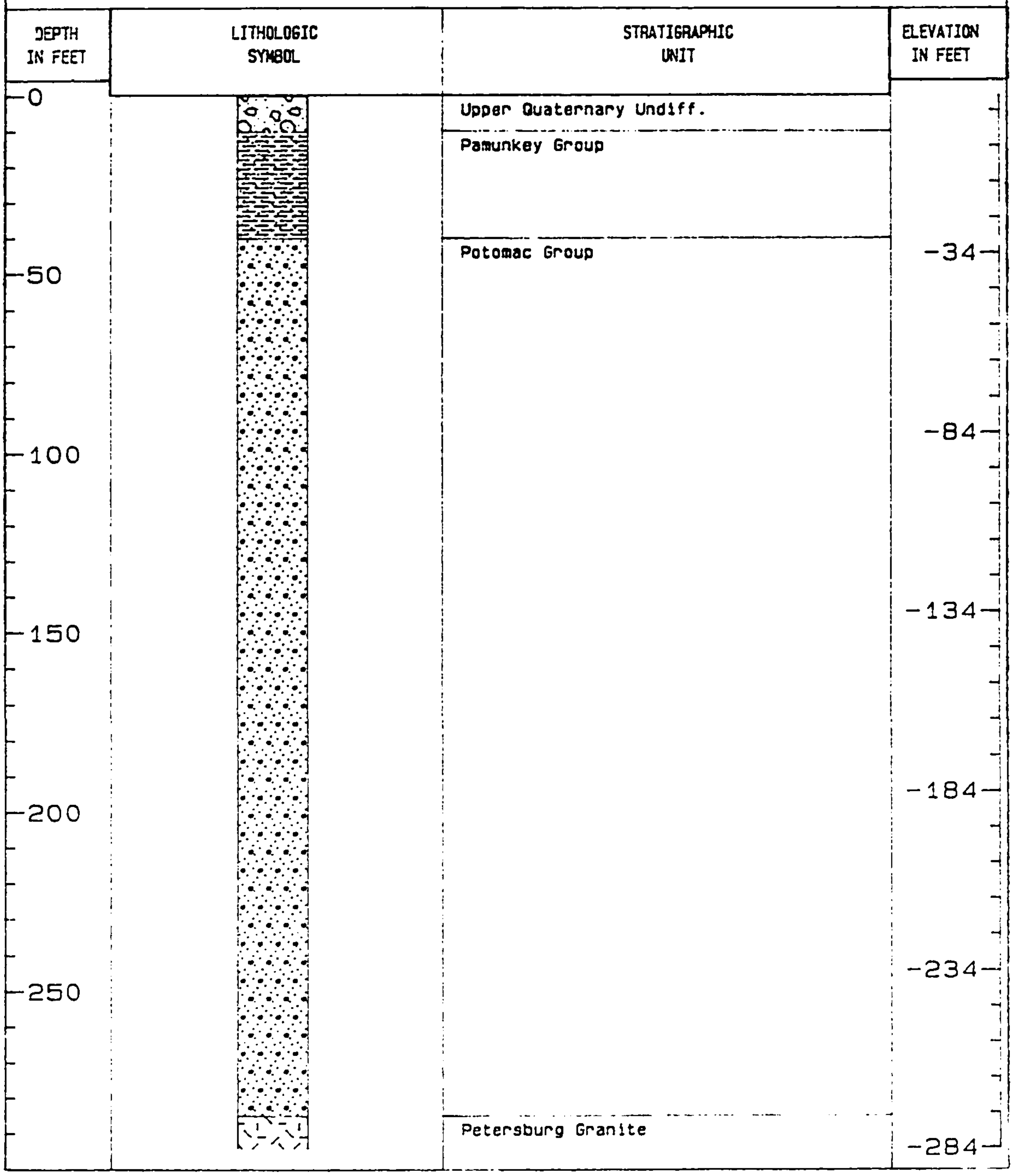
AVAILABLE DATA: RESIST. HUB.

SURFACE ELEVATION: 10 feet

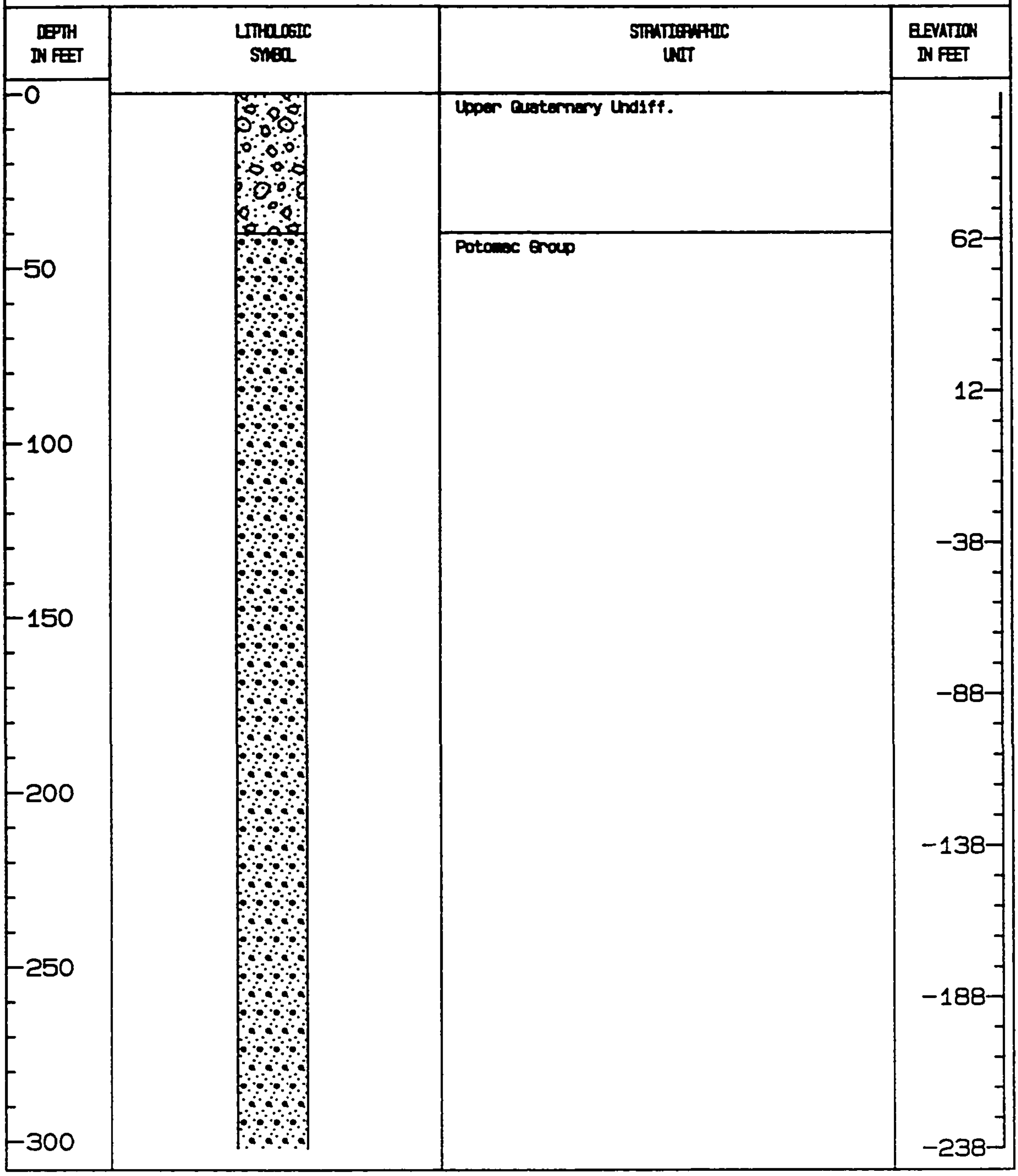
TOTAL DEPTH: 294 feet

DRILLER: SYDNOR HYDRODYNAMICS

DATE DRILLED: 5/7/75



WELL LOG NUMBER: HP1
SURFACE ELEVATION: 110 feet
QUADRANGLE: HOPEWELL
TOTAL DEPTH: 348 feet
COUNTY: PRINCE GEORGE
DRILLER: SYDNOR HYDRODYNAMICS
AVAILABLE DATA: CEDER45
DATE DRILLED: 1/1/30



APPENDIX C

FIELD DOCUMENTED STRUCTURES

FIELD DOCUMENTED STRUCTURES

PHYSIOGRAPHIC SETTING	LOCATION	UNIT(S) ANALYZED	# OF MEASURE-MENTS	DOMINANT TRENDS	COMMENTS
Fall Zone	Lake Chesdin Dam	Petersburg Granite	35	N70E, N20E, N30W	N70E dominant, never vertical slickensides along fracture plane.
	James River Park	Petersburg Granite	45	N70W-E, N20-30E, N50-70W	Biotite foliation (N20-35E), Fault in granite (N20W, 85NE).
	Tidewater Materials Quarry	Petersburg Granite	20	N5E-W, N30-40E, N70-80E, N40W	
	Falling Creek Wayside	Petersburg Granite	29	N25-30E, N40W, E-W	
James River	Varina Farms - Dutch Gap	Potomac Formation	93	N20-40E, E-W, N40-50W, N-S	Fractures observed solely in black clays.
	Daymarker 151 - Dutch Gap	Potomac Formation	34	N40-50E, N40-50W, E-W, N-S	Outcrop parallels N50W trend/ Fractures in black clay.
	Buoy 146 - Jones Neck Cutoff	Potomac Formation	30	N-S, E-W, N20-40W, N20-40E	Rip-up clasts broken into tabular chunks parallel to N30E fracture trend.
Pamunkey River	Wickham Crossing - Ward Stop 1	Potomac Formation	40	E-W, N30-40W, N20-40E, N-S	Fractures observed in Patapsco clay. Basal conglomerate found at base of Aquia Formation.
	Wickham Crossing - Ward Stop 2	Calvert Formation (Chesapeake Gp)	41	N25-30E, N20-40W, E-W, N-S	Fractures solely observed in Calvert Formation.
	Little Page Bridge - Ward Stop 3	Eastover Formation Calvert Formation (Chesapeake Group) Marlboro Clay	5 24 17	N25-30W, N50E N25-50E, N-S N20-30W, N60-70W	Faint fracture ghosts were observed in the fine sand of the Eastover Formation.

NOTE: Field data collection points are located in Figure 11.

TABLE 1
Documented Atlantic Coas
Structures

STRUCTURE	LOCATION	TREND	DIP	TYPE	MAXIMUM DISPLACEMENT	UNITS DISPLACED	BASEMENT TYPE	
Hampton Roads	Hampton Roads, VA	N50-60W	Vertical	Normal	650 ft	Basement to	Crystalline	Borehol
Fault				Down to North		Miocene		Gravity
								Magnet
								Seismic
								Ground
								(Rc
Franklin Monocline	Franklin, VA	N-S		Down to East	40 ft	Basement to	Crystalline	Boreho
						Miocene		Gravity
Brandywine Fault	Cheltenham, MD	N30E	65SE	Reverse	100 ft	Upper	Granitic Gneiss	Geomo
Zone System				Down to West		Cretaceous		Boreho
								Seismic
	Danville, MD	N15E	70SE	Reverse	250 ft	Holocene (?)	Triassic Seds	
				Down to West			(Newark Group)	
Stratford Fault	Dumfries, VA	N35E (Approx)	Steep NW	Reverse	115 ft	Eocene	Biotite Gneiss	Geolog
System	Stafford (Fall Hill)	N39E	78NW	Reverse	115 ft	Late Pliocene -		Driller l
						Pleistocene		Geomo
	Leavells (Hazel Run)	N32E	Steep NW	Reverse	115 ft	Pliocene		
	Brooke, VA	N35E	56NW	Reverse	200 ft	Paleocene		
Graingers Fault	Craven & Lenoir	N30E	Steep	Normal	80 ft	Paleocene	Crystalline	Geolog
Zone	Counties, NC		NW-SE				Triassic (Harris	Driller l
							& Others, 1979)	Geomo
Belair Fault Zone	Augusta, GA	N25-30E	50SE	Reverse	100 ft	Middle Tertiary	Metavolcanic	Geolog
							Phyllites	Driller l
							Gneiss	
Dutch Gap Fault	Hopewell, VA	N5W	75E	Reverse	65 ft	Pliocene	Granite	Geolog
Zone							Triassic Seds	Driller l
								Geomo
								Gravity
								Magne
Cooke Fault Zone	Charleston, SC	N55E	80NW	Reverse	165 ft	Eocene	Crystalline	Seismic
							Triassic Seds	Magne
Helena Banks Fault	Offshore from	N68E	Steep W	Reverse	260 ft	Pliocene	Crystalline	Seismi
	Charleston, SC						Triassic Seds	
Skinkers Neck -	Bowling Green	Approx N30E	Down to NW	Reverse	50 ft	Miocene	Crystalline	Geolog
Port Royal Structures	(Skinkers Neck)						Triassic Seds	Driller l
	Port Royal		Steep	Reverse		Miocene		Geomo
			Down to SE					Gravity
Piankatank River	Piankatank River,	Approx N15E	Steep NW	Normal and	Not Determined	Pliocene	Crystalline	Geolog
Structures	VA			Reverse				Boreho
								Gravity
								Magne
								Remot

TABLE 1
ed Atlantic Coastal Plain
Structures

;	BASEMENT	INVESTIGATIVE	REFERENCES	COMMENTS
ED	TYPE	METHODS		
to	Crystalline	Borehole Samples (Cederstrom, 1945)	Cederstrom (1945b)	• Displacement increases toward Norfolk
		Gravity (Swick, 1940)	Rogers & Spencer	• Abrupt thickening of Eocene sediments north of the
		Magnetic (Woolard, 1940)	-(1971)	James River
		Seismic (Ewing, 1937; Bollard, 1969)		• Fault disapated into folds in Miocene sediments
		Groundwater Quality		
		(Rogers & Spencer, 1971)		
to	Crystalline	Borehole Samples (Cederstrom, 1945b)	Cederstrom (1945b)	• Down to coast monocline
		Gravity (Swick, 1940)		• Extends into North Carolina
	Granitic Gneiss	Geomorphic Structures	Jacobeen (1972)	• Pair of subparrallel drainage alignments delineate
;		Borehole Samples		buried structure
		Seismic Profiles		• Withington (1973) traced Danville faults on ERTS
(?)	Triassic Seds			imagery for 48 km
	(Newark Group)			• Faults disapated into folds in Paleocene to Miocene
				sediments
	Biotite Gneiss	Geologic Mapping	Mixon & Newell	• Alignment of Brandywine & Stafford faults with
ene -		Driller Logs	-(1977, 1978)	Farmville & Richmond Basins border faults
cene		Geomorphic Structures		suggests they are related
	Crystalline	Geologic Mapping	Brown & Others (1977	• May be associated with Triassic basin border fault
	Triassic (Harris	Driller Logs	Harris & Others (1979)	(Harris and Others, 1979)
	& Others, 1979)	Geomorphic Structures		
tiary	Metavolcanic	Geologic Mapping	Prowell & O'Connor	• Belair fauld at contact of Kiokee gneiss and Belair
	Phyllites	Driller Logs	-(1978)	phyllite and may represent reactivation of weakness
	Gneiss		Bramlett & Others	• Fault trend/dip parallels cleavage in the phyllites
			-(1982)	
	Granite	Geologic Mapping	Dischinger (1979)	• May be associated with Triassic basin border faults
	Triassic Seds	Driller Logs	Dischinger (1987)	
		Geomorphic Structures		
		Gravity (Johnson, 1977)		
		Magnetic (Zietz & Others, 1977)		
	Crystalline	Seismic Profiles	Behrendt & Others	• May be associated with Triassic basin border faults
	Triassic Seds	Magnetic (Phillips & Others, 1978)	-(1981)	
			Hamilton & Others	
			-(1983)	
	Crystalline	Seismic Profiles	Behrendt & Others	• May be associated with Triassic rift basin
	Triassic Seds		-(1983)	
	Crystalline	Geologic Mapping	Mixon & Powars	• May be associated with Triassic basin border faults
	Triassic Seds	Driller Logs	-(1984)	
		Geomorphic Structures		
		Gravity (Johnson, 1977)		
	Crystalline	Geologic Mapping	Lane (1984)	• Fault believed to have reversed movement during
		Borehole Data (Brown & Others, 1972)		deposition of Middle Miocene unit
		Gravity (Sabet, 1977)		
		Magnetic (Zietz & Others, 1977)		
		Remote Sensing/Geomorphic		

TABLE 2

Generalized Stratigraphic Column of Co

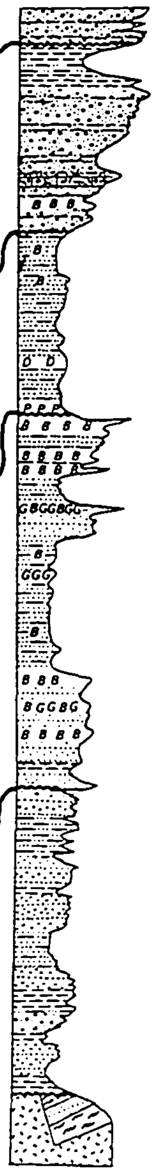
PERIOD	EPOCH	STAGE	PRESENT STUDY	DISCHINGER 1987	JOHNSON AND PEEBLES 1984	WARD 1984	REINHARDT & OTHERS GIBSON & OTHERS 1980
Quater-nary	Holocene	Post-Glacial					
	Pleistocene	Wisconsin to Nebraskan	Quaternary Undifferentiated	Terrace Deposits	Tabb Formation Shirley Formation Chuckatuck Formation Charles City Formation Windsor Formation		Upland Gravels
Tertiary	Pliocene	Placenzian	Upper Tertiary Undifferentiated		Bacons Castle Formation	Chowan River Fm	
		Zanclean		Yorktown Formation	Yorktown Formation	Yorktown Formation: Moorehouse Mbr, Morgarts Beach Mbr, Rushmere Mbr, Sunken Meadow Mbr	
	Miocene	Messinian					
		Tortonian		Virginia St. Marys	Eastover Formation	East-over Fm: Cobham Bay Mbr, Claremont Mbr	
		Serravallian	Chesapeake Group			St. Marys Formation Choptank	Choptank Formation
		Laghian				Calvert	Calvert Formation
		Burdigaun					
		Aqutanian				Old Church	
	Oligocene	Chickasawhayan					
		Vicksburgian					
	Eocene	Jacksonian					
		Claibornian				Piney Point Formation	
	Eocene / Paleocene	Sabinian	Pamunkey Group: Nanjemoy Formation Marlboro Clay Aquia Formation	Nanjemoy Formation Marlboro Clay Aquia Formation		Nanjemoy Formation: Woodstock Formation, Potapaco Member Marlboro Clay Aquia Fm: Paspotansa Mbr, Piscataway Formation	Nanjemoy Formation: Woodstock Member, Potapaco Member Marlboro Clay Aquia Formation: Paspotansa Member
	Paleocene	Midwayan		? ?			Aquia Formation: Piscataway Member
Cretaceous	Late Cretaceous	Maastrichtian					
		Campanian					
		Santonian					
		Coniacian					
		Turonian					
		Cenomanian					Zone IV Zone III
	Early Cretaceous	Albian					Zone II
		Aptian					Zone I
		Barremian					
		Hauterivian					
		Valanginian					
		Berriasian	Potomac Formation	Potomac Formation			Pre Zone I

TABLE 2

raphic Column of Coastal Plain Units

REINHARDT & OTHERS GIBSON & OTHERS 1980	DANIELS & ONUSCHAK 1974	TEIFKE 1973	BROWN, MILLER, & SWAIN 1972	CEDERSTROM 1957	CLARK & MILLER 1912	DARTON 1891
	Alluvium	Columbia Group	Rocks of Post–Miocene Age	Columbia Group	Columbia Group: Talbot Fm; Wilmico Fm; —?——?—; Sunderland Fm	Columbia Formation
Upland Gravels	Sand and Gravel (Regressive seds)					Appomattox Formation
Choptank Formation		Yorktown Formation	Rocks of Late Miocene Age; Rocks of Middle Miocene Age	Chesapeake Group: Yorktown Formation —?——?— St Marys Formation —?——?— Calvert Formation	Chesapeake Group: Yorktown Formation —?——?— St Marys Formation —?——?— Calvert Formation	Chesapeake Formation
Calvert Formation	Clayey Silts (transgressive seds)	Calvert Formation				
			Rocks of Jackson Age	Chickahominy Formation		
Nanjemoy Formation: Woodstock Member; Potapaco Member	Nanjemoy Formation; Marlboro Clay Mbr	Nanjemoy Formation	Rocks of Claiborne Age	Nanjemoy Formation —?——?—	Pamunkey Group: Nanjemoy Formation —?——?— Aquia Formation	Pamunkey Formation
Marlboro Clay						
Aquia Formation: Paspotansa Member; Piscataway Member	Mattaponi Formation	Mattaponi Formation	Rocks of Sabine Age	Aquia Formation		
			Rocks of Midway Age	Mattaponi Formation		
			Rocks of Unit A			
			Rocks of Unit B			
			Rocks of Unit C			
			Rocks of Unit D			
Zone IV		Transitional Beds	Rocks of Unit E	—?——?—		Potomac Formation
Zone III						
Zone II			Rocks of Unit F	Potomac Group	Potomac Group: Potapaco Formation —?——?— Patuxent Formation	
Zone I			Rocks of Unit G			
Pre Zone I	Patuxent Formation	Patuxent Formation	Rocks of Unit H			

FIGURE 9
Generalized Lithologic C
of Study Area



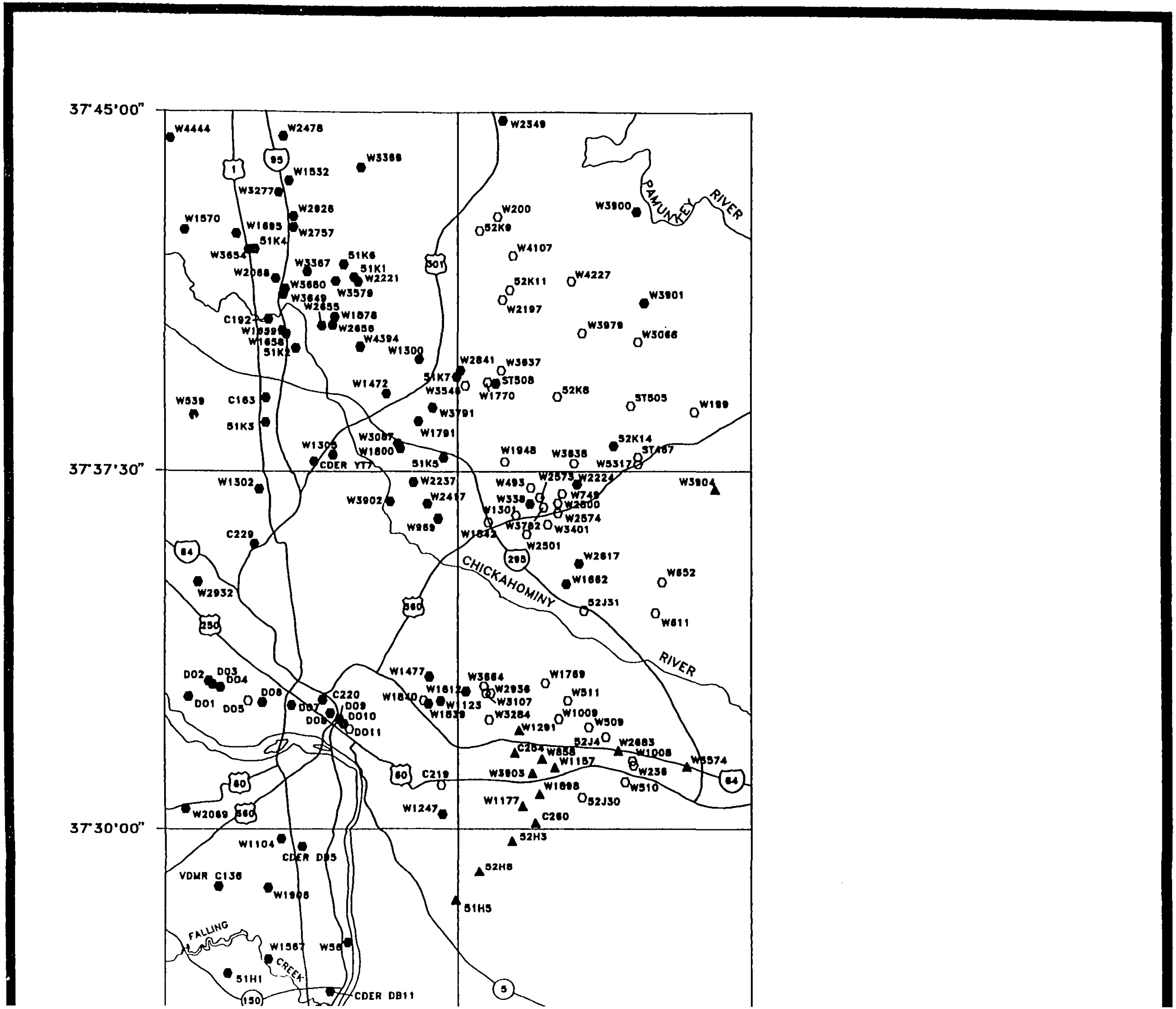
EPOCH	GROUP	FORMATION	LITHO/ RESIST COLUMN (Meng & Harsh, 1984)	LITHOLOGIC DESCRIPTION (Ward, 1984) (Ward & Blackwelder,1980) (Teifke, 1973) (Meng & Harsh, 1984) (Mixon, et al, 1989)	RI
PLEISTOCENE		UNDIFFERENTIATED		Tan, yellow to orange, poorly sorted, fine-coarse quartz sands and gravels interbedded with silty, sandy clays.	Blocky and sp sands and gra
PLIOCENE		BACONS CASTLE FM		Gray, yellowish-orange, reddish-brown sand, gravel, silt, and clay.	Broad U-shape
PLIOCENE	CHESAPEAKE GROUP	YORKTOWN FM		Pliocene sand and gravel: yellowish-orange to reddish-brown gravelly sand, sandy gravel, and fine to coarse sand. Rushmere Mbr: light gray to blue gray ve;, shelly fine quartz sand or bioclastic sand.	Erratic, highly resistance illus correlate with
MIOCENE	CHESAPEAKE GROUP	EASTOVER FM		Claremont Manor Mbr: greenish gray, poorly sorted, silty, clayey, fine-medium quartz sands. Greenish gray diatomaceous clays. Phosphates and quartz pebbles at base. Cobham Bay Mbr: blue gray, well sorted, shelly fine quartz sand.	Erratic, varial interbedded s layers.
MIOCENE	CHESAPEAKE GROUP	ST. MARYS FM		Light gray to blue, silty, shelly sands, silty, clayey sands and silty clays.	Relatively flat p clays, silty, cla silty sands and
MIOCENE	CHESAPEAKE GROUP	CHOPTANK FM		Miocene sand and gravel: gray to light yellowish-gray fine to coarse sand, sandy gravel, silt and clay. Olive-gray sand, fine to very fine, clayey and silty, shelly, and diatomaceous clay-silt.	Relatively flat p clays, silty, cla silty sands and
MIOCENE	CHESAPEAKE GROUP	CALVERT FM		Light gray, olive brown diatomaceous silty clays and interbedded shelly sands. Basal quartz pebbles and phosphate nodules common.	Relatively flat p clay. Occasior sands, pebble signify interbe
EOCENE	PAMUNKEY GROUP	PINEY POINT FM		Light olive gray, clayey, poorly sorted, very glauconitic, highly fossiliferous fine-medium quartz sand. Shell beds common.	Rectangular an high peaks a calcareous ce
EOCENE	PAMUNKEY GROUP	NANJEMOY FM		Potapaco Mbr: dark olive, gray-olive, black, silty, clayey, glauconitic, micaceous, fine sand with concretions, phosphate pebbles. Gray-pink clay studded with glauconite grains, some shells. Woodstock Mbr: Olive, black, well sorted, micaceous, glauconitic, fine quartz sand.	Flat or low resi interbedded s flat profiles).
PALEOCENE	PAMUNKEY GROUP	MARLBORO CLAY		Silvery gray to pale red plastic clay interbedded with yellow gray-reddish silt.	Flat or low res
PALEOCENE	PAMUNKEY GROUP	AQUIA FM		Paspotansa Mbr: Olive gray to dark olive, black, silty to well sorted very fine to fine, micaceous, glauconitic, quartz sand in massive to thick beds with shell beds. Piscataway Mbr: Olive gray, clayey, silty, poorly sorted, glauconitic, very fine to fine quartz sands with shell beds. Olive gray calcareous marl. Occasional basal conglomerate.	Wave shaped waves with sequences of layers (spikes) of high resistiv
EARLY CRETACEOUS		POTOMAC GROUP		Light gray to white massively bedded, light colored, coarse, arkosic, clayey sands with gravels common. Massively bedded clays and finely laminated, carbonaceous clays, light to dark, interbedded with lenticular sands. Bright variable colored (red, green, black, yellow, orange, gray) clays and interbedded sands. Large clay clasts and lignitized coniferous wood fragments common in gravel beds.	Blocky, low massively be lithologic con

FIGURE 9

ized Lithologic Column

of Study Area

ION 980))	RESISTIVITY PATTERN (Meng & Harsh, 1984)	DRILLER REMARKS (Meng & Harsh, 1984)
ands	Blocky and spikey profile of high resistance illustrating massive sands and gravels interbedded with silts and clays.	Yellow, orange clay, sand, and gravel.
and clay.	Broad U-shaped profile indicating uppermost competent clay unit.	Multi-colored to dark gray, fine sandy to silty clays.
own gravelly sand, rtz	Erratic, highly variable resistivity profile of moderately high resistance illustrating interbedded sands, silts, and clays. Spikes correlate with shell layers.	Yellow, orange clay, sand, and gravel. Blue, gray or green clays or marls occasionally containing sand/shell layers.
clayey, fine-medium lays. Phosphates z sand.	Erratic, variable profile of moderate resistance illustrating interbedded sands, silts, and clays. Spikes correlate with shell layers.	Blue, gray or green clays occasionally containing sands or shell layers.
	Relatively flat profile of low resistance illustrating predominantly silty clays, silty, clayey sands. Low amplitude peaks mark interbedded silty sands and shell layers.	Blue or gray silty clays occasionally containing sands or shell layers.
ne to coarse sand, and diatomaceous	Relatively flat profile of low resistance illustrating predominantly silty clays, silty, clayey sands. Low amplitude peaks mark interbedded silty sands and shell layers.	Yellow, orange clay, sand, and gravel. Blue or gray, silty clays, occasionally contains sands or shell layers.
interbedded shelly mon.	Relatively flat profile of low resistance illustrating diatomaceous, silty clay. Occasional sharp break at base marks deposits of coarse qtz sands, pebbles, and phosphate nodules. Low amplitude peaks signify interbedded clayey sands, shells, and diatomaceous layers.	Yellow, blue, gray, or green clays or marls occasionally containing shells or sands.
ghly fossiliferous	Rectangular and spikey moderate resistivity pattern with moderately high peaks attributed to clean sands. Spikes are related to calcareous cemented shell beds.	Light greenish-gray to grayish-green sands with shell rock, limestone, and dark silty clay.
glauconitic, hate pebbles. some shells. uconitic, fine	Flat or low resistivity pattern illustrating massively bedded clays with interbedded sandy clays and sands (erratic anomalies on normally flat profiles). Sharp contact with Aquia Fm.	Dark green or brownish-green silty clays or sandy clays. Commonly with shell and black sand layers.
v gray-reddish silt.	Flat or low resistivity pattern illustrating clay unit.	Slick or sticky pink, gray, or occasionally white clay.
ell sorted very fine massive to thick auconitic, very fine y calcareous marl.	Wave shaped medium resistivity values. Commonly series of 2-3 waves with sharp, spikey peaks indicating massively bedded sequences of glauconitic sands with calcareous cemented shell layers (spikes). Near Fall Line a pronounced U-shaped wave at base of high resistivity marks basal conglomerate.	Soft, running or caving, fine, black sands or green sands that often contain shells and/or hard streaks.
se, arkosic, clayey d finely laminated, ular sands. Bright gray) clays and coniferous wood	Blocky, low to moderately high resistance patterns indicating massively bedded sands, clayey sands, and clays with sharp lithologic contacts. Trends tend no to be gradational.	Hard or tough coarse gray sands that may contain gravels. Tight or hard, light to drab colored clays. Occasionally gray, white, red, green, or brown colored clays present at upper boundary of unit.


37°45'00"
37°37'30"
37°30'00"
PAMUNKEY RIVER
CHICKAHOMINY RIVER
FALLING CREEK

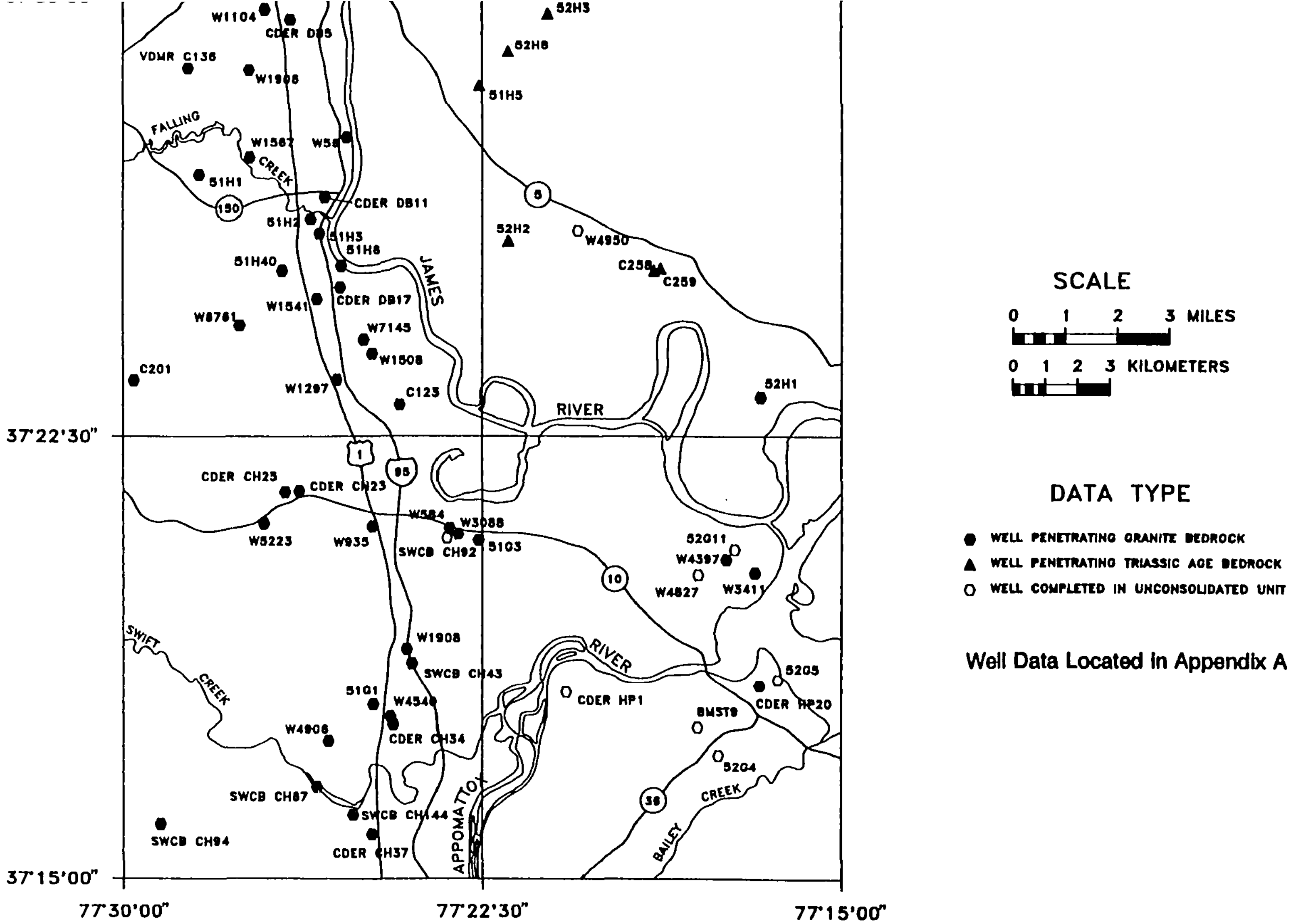
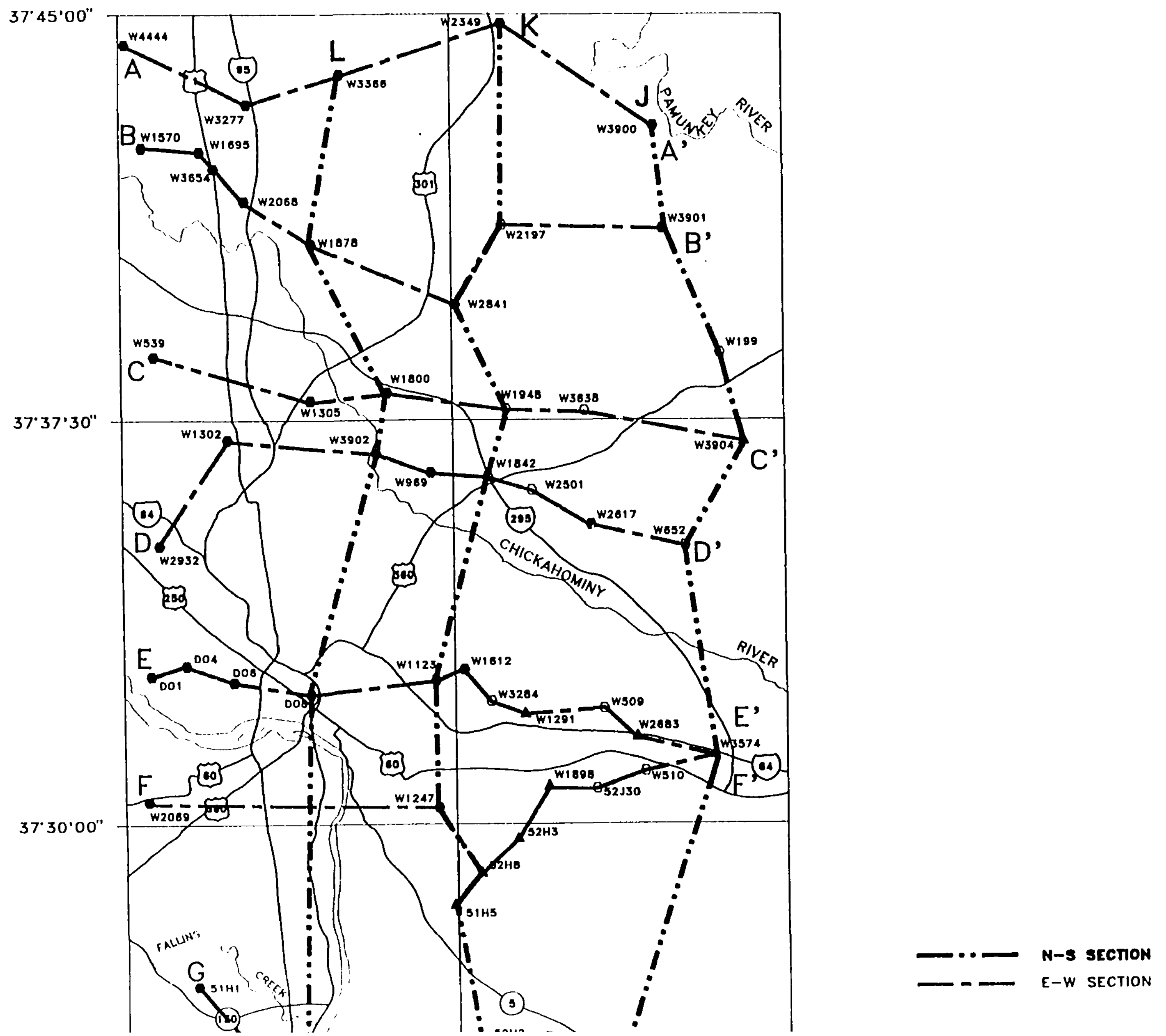


FIGURE 10
Well Data Location Map


37°45'00"
37°37'30"
37°30'00"
A
W4444
W3277
L
W3386
K
W2349
J
W3900
A'
PAMUNKEY RIVER
B
W1570
W1695
W3654
W2068
W1878
W2841
W2197
W3901
B'
W199
C
W539
W1305
W1800
W1948
W3838
W3904
C'
W1302
W3902
W969
W1842
W2501
W2617
W652
D'
D
W2932
CHICKAHOMINY RIVER
E
D01
D04
D06
W1123
W1612
W3284
W1291
W509
W2683
E'
W3574
F'
W1898
52J30
W510
F
W2069
W1247
52H3
52H8
51H5
FALLING CREEK
G
51H1
N-S SECTION
E-W SECTION

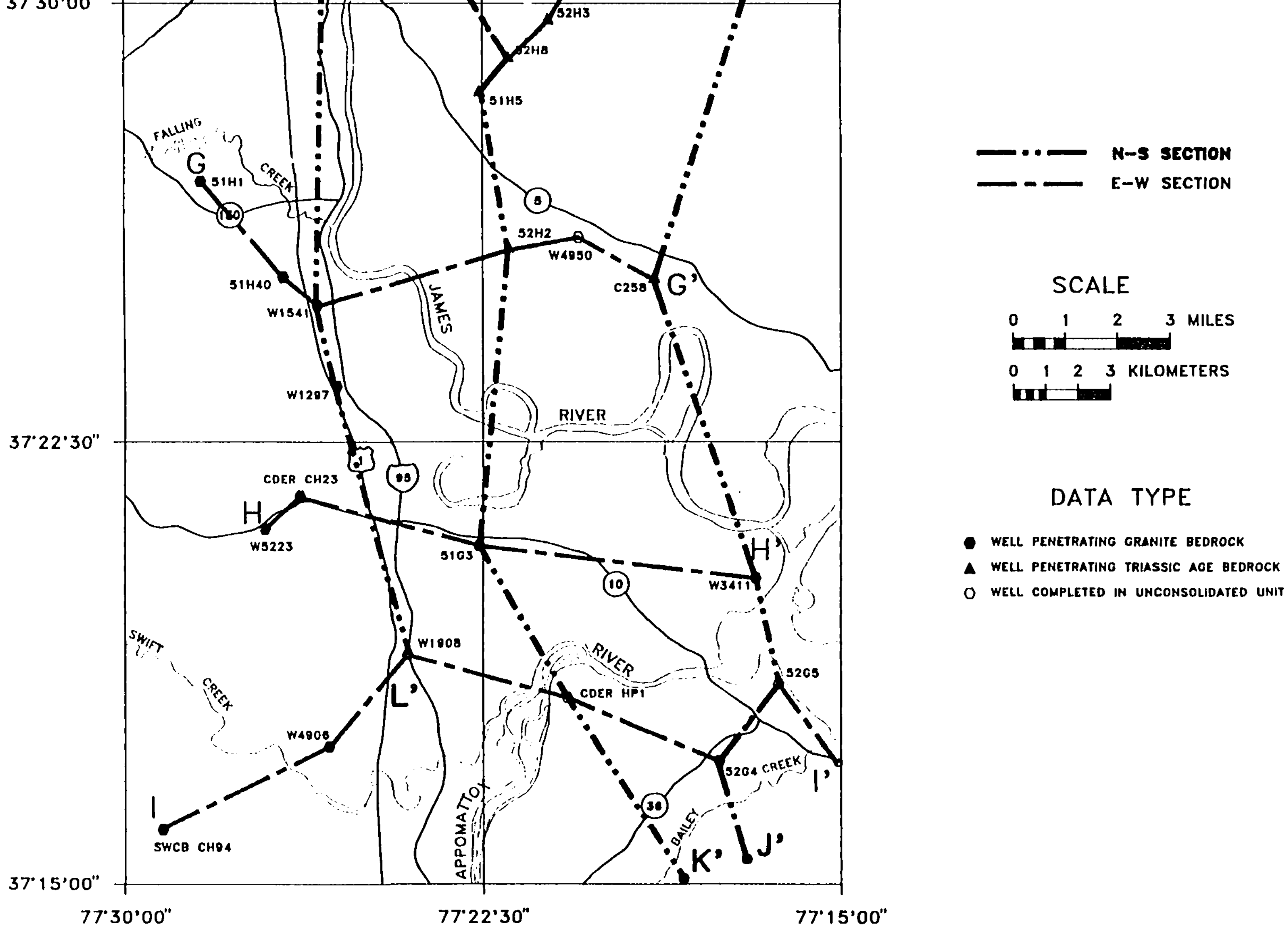
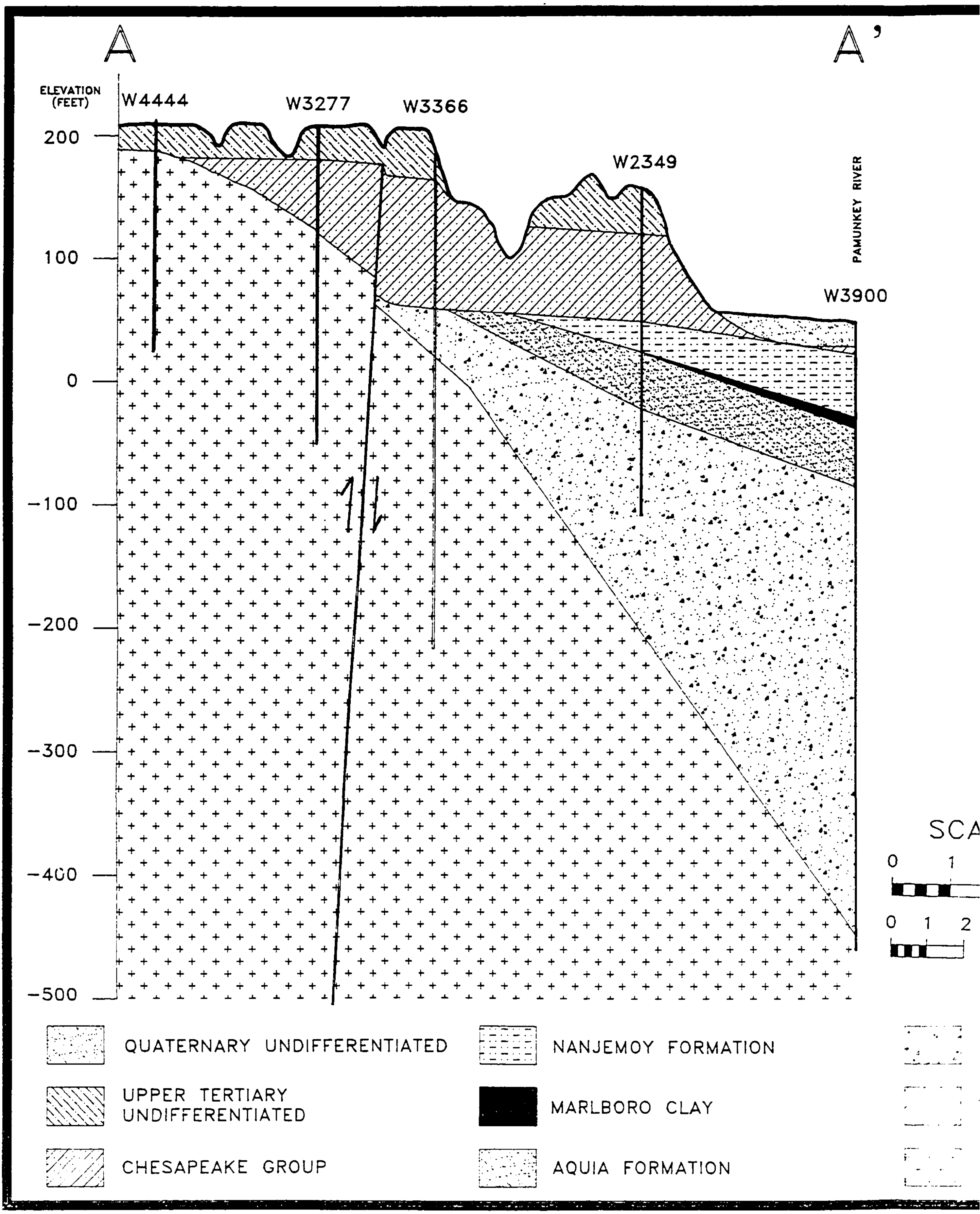
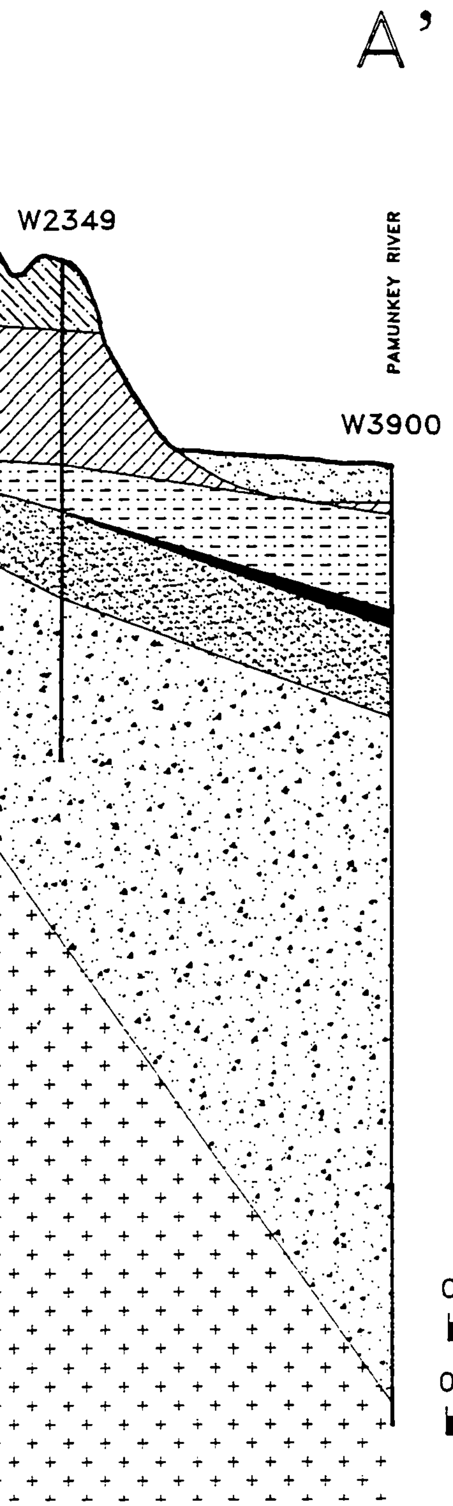
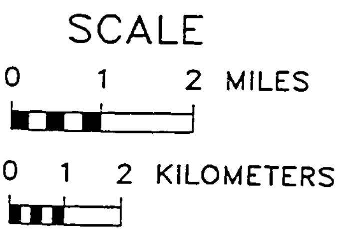
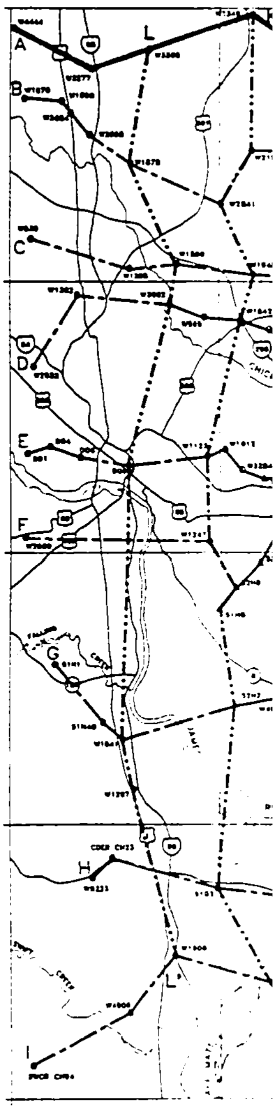


FIGURE 23
Cross Section Location Map


A
A'
ELEVATION (FEET)
200
100
0
−100
−200
−300
−400
−500
W4444
W3277
W3366
W2349
W3900
PAMUNKEY RIVER
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION







EMOY FORMATION

BORO CLAY

A FORMATION

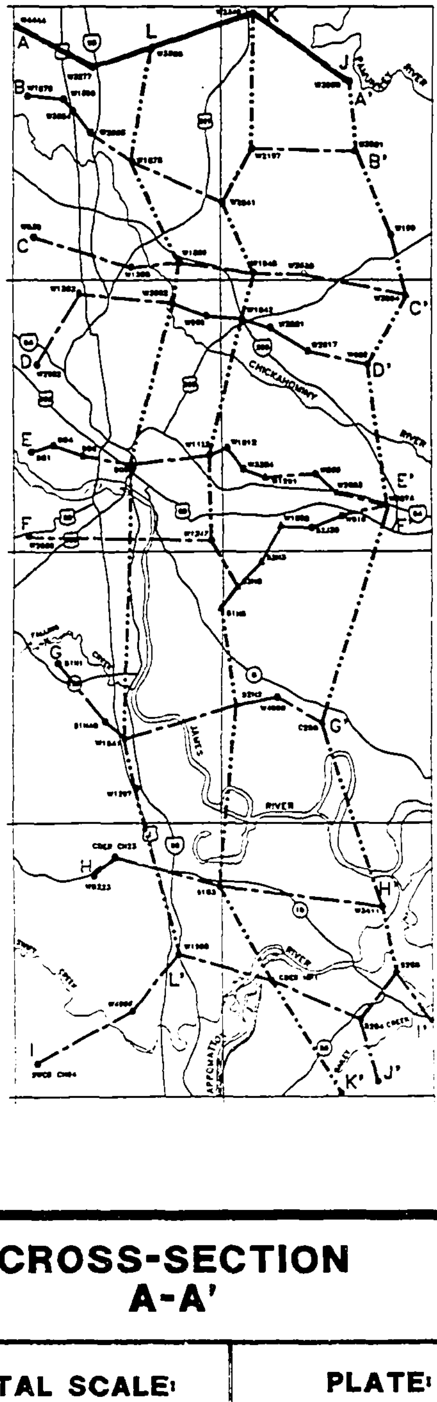
POTOMAC FORMATION

TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

CROSS-SECT
A-A'

HORIZONTAL SCALE:
1 INCH = 2 MILES



CALE

1 2 MILES

2 KILOMETERS

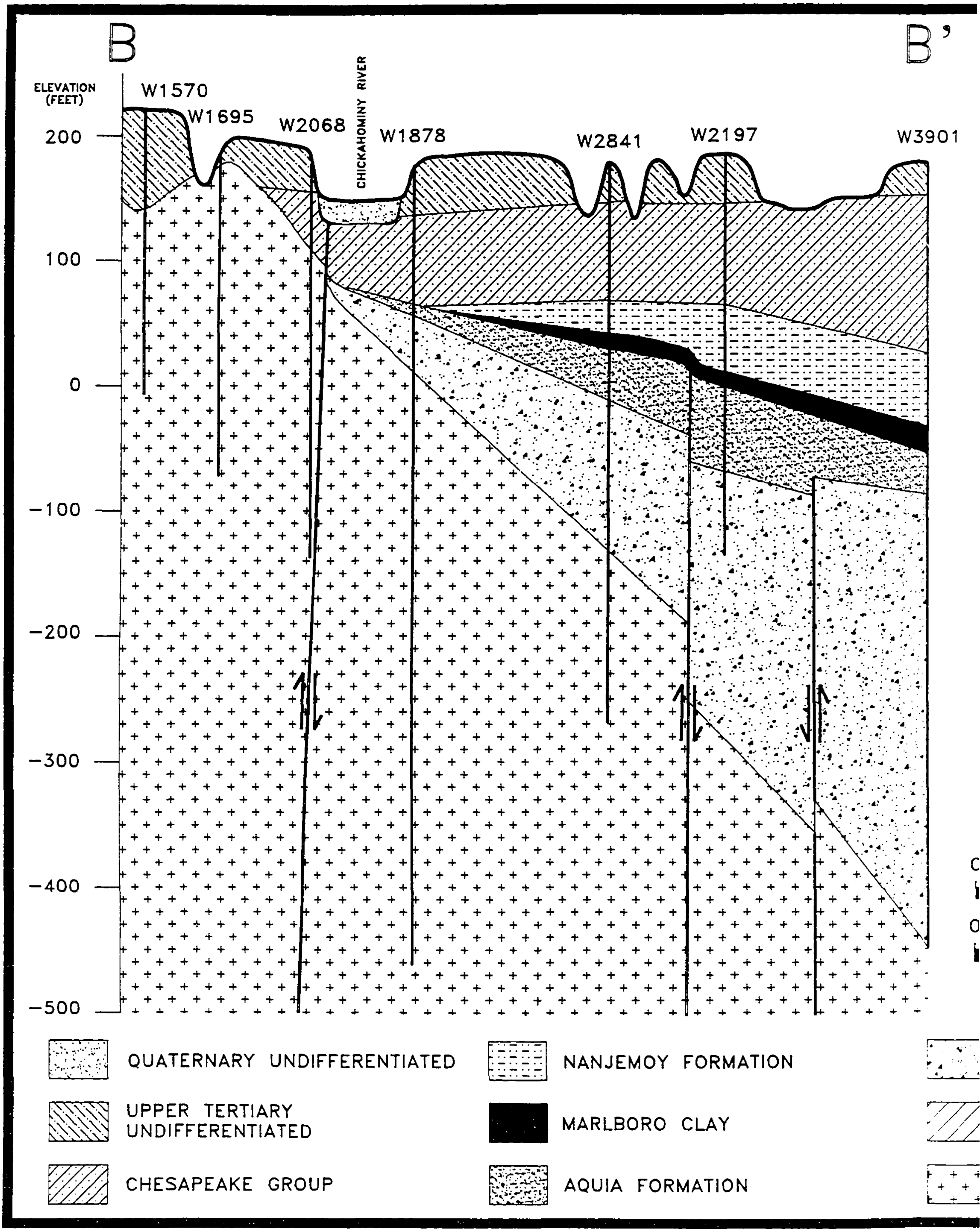
POTOMAC FORMATION

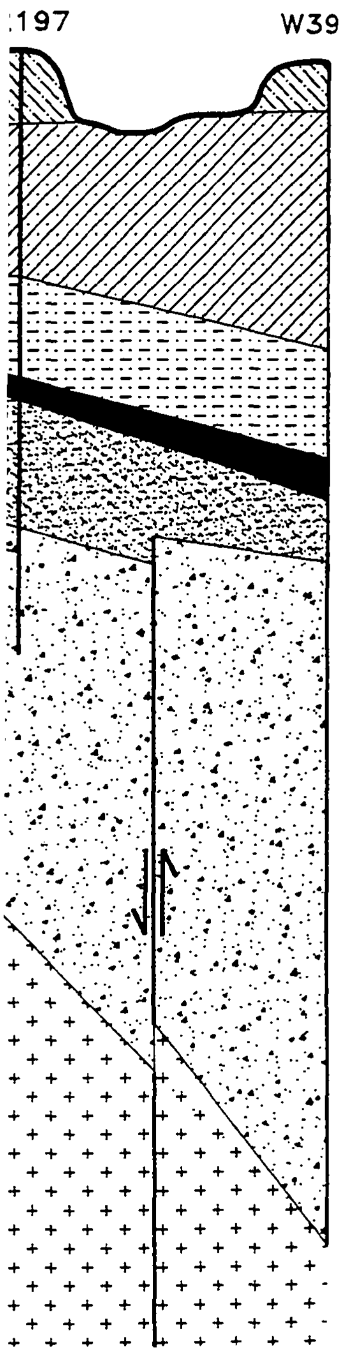
TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

CROSS-SECTION A-A'

HORIZONTAL SCALE:	PLATE:
1 INCH = 2 MILES	1

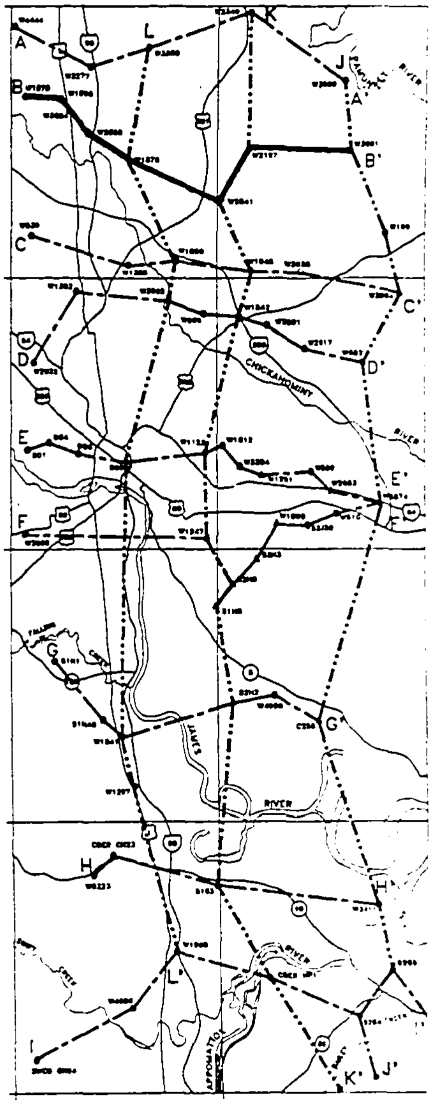

B
B'
ELEVATION (FEET)
200
100
0
-100
-200
-300
-400
-500
W1570
W1695
W2068
CHICKAHOMINY RIVER
W1878
W2841
W2197
W3901
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION



SCALE

0 1 2 MILES

0 1 2 KILOMETERS



ꞱMATION

ꞱY

ION

POTOMAC FORMATION

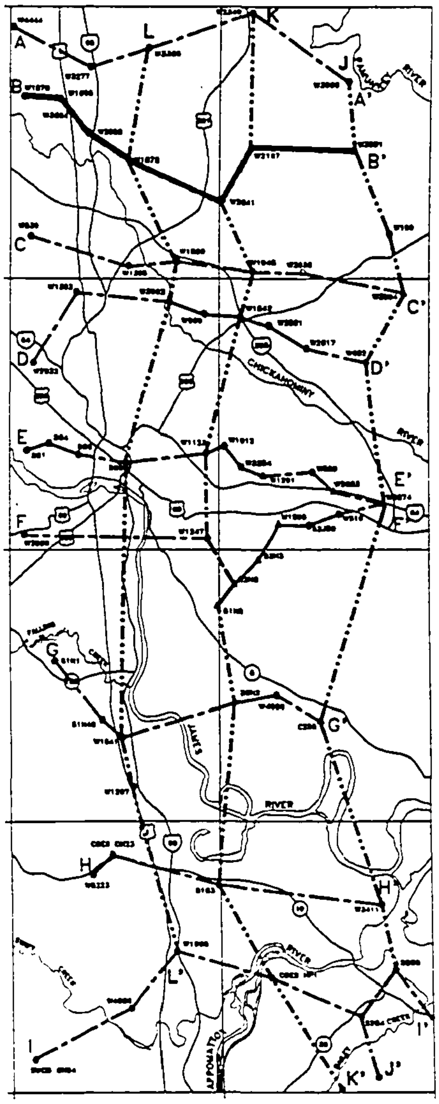
TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

CROSS-SECTION B-B'

HORIZONTAL SCALE: 1 INCH = 2 MILES

PLATE 2



SCALE

1 2 MILES

1 2 KILOMETERS

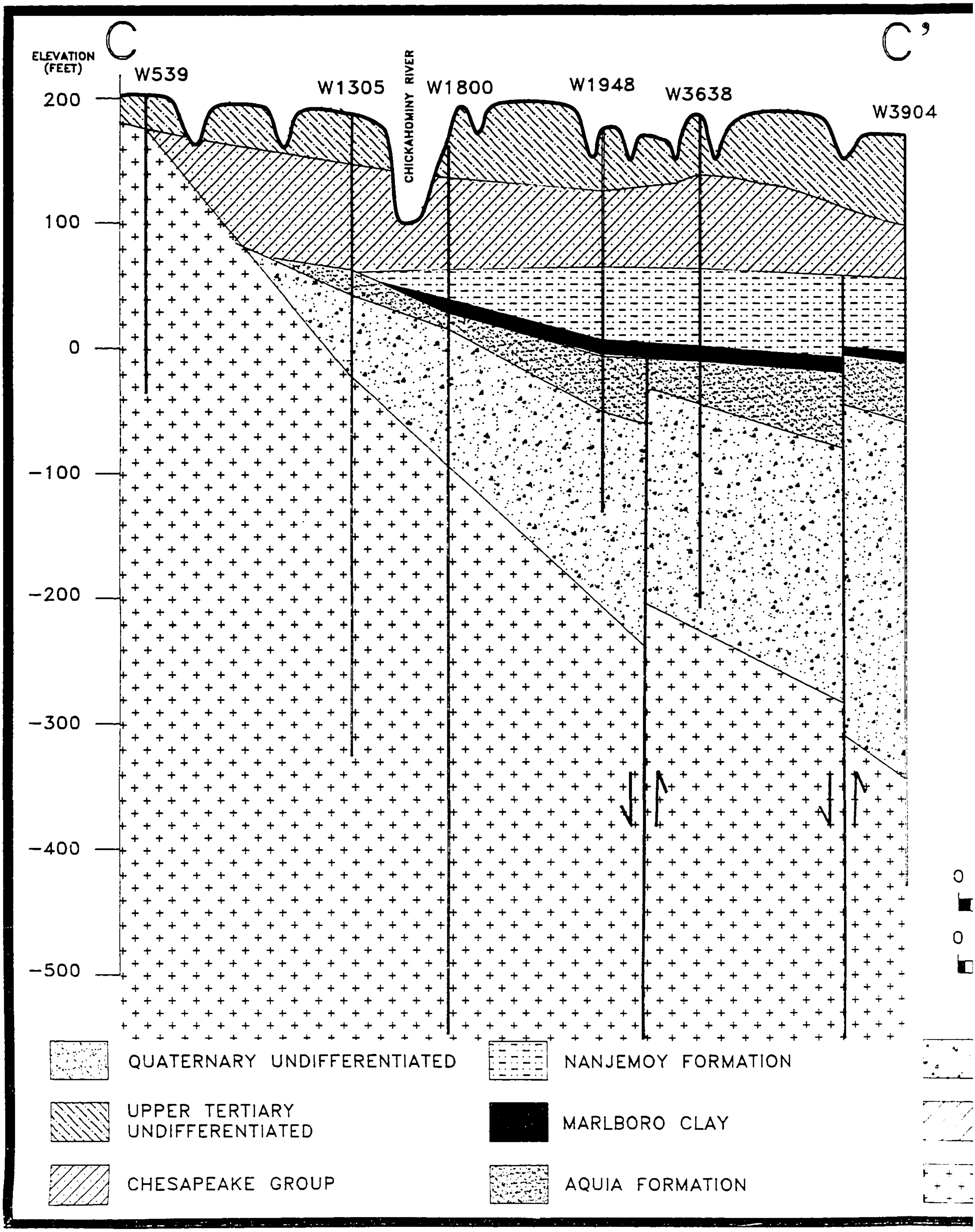
POTOMAC FORMATION

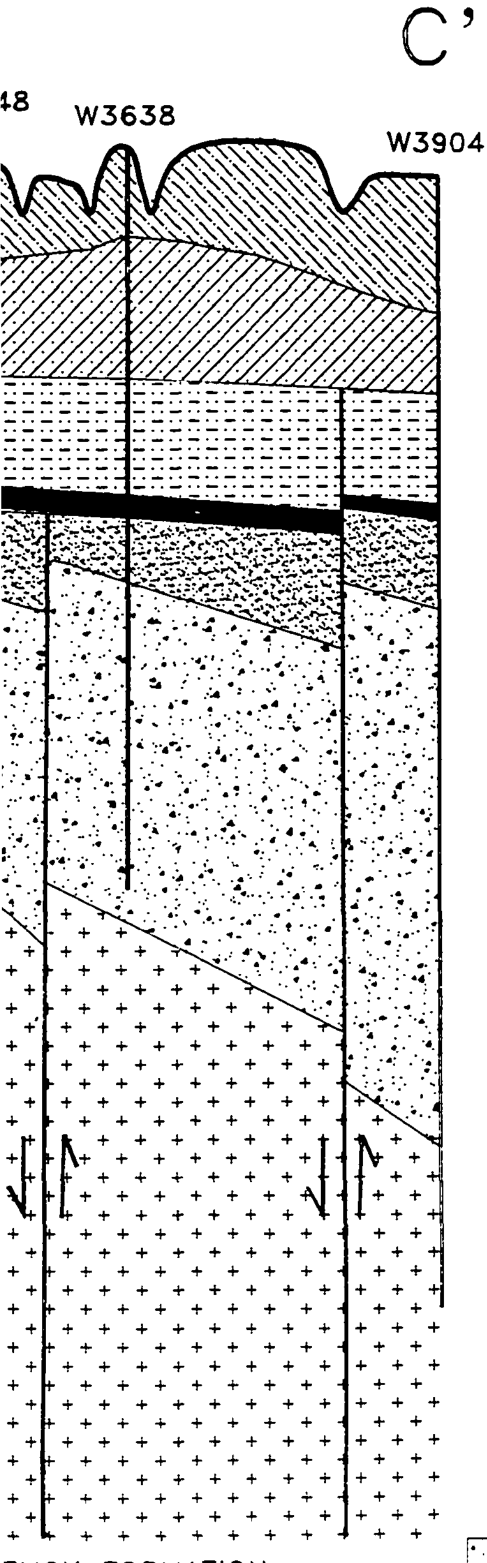
TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

CROSS-SECTION B-B'

HORIZONTAL SCALE: 1 INCH = 2 MILES	PLATE: 2

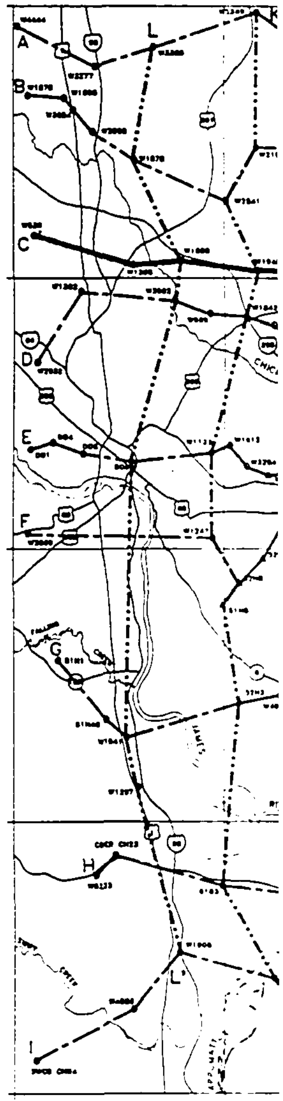

C
C'
ELEVATION (FEET)
W539
W1305
CHICKAHOMINY RIVER
W1800
W1948
W3638
W3904
200
100
0
−100
−200
−300
−400
−500
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION



SCALE

0 1 2 MILES

0 1 2 KILOMETERS



EMOY FORMATION

3ORO CLAY

FORMATION

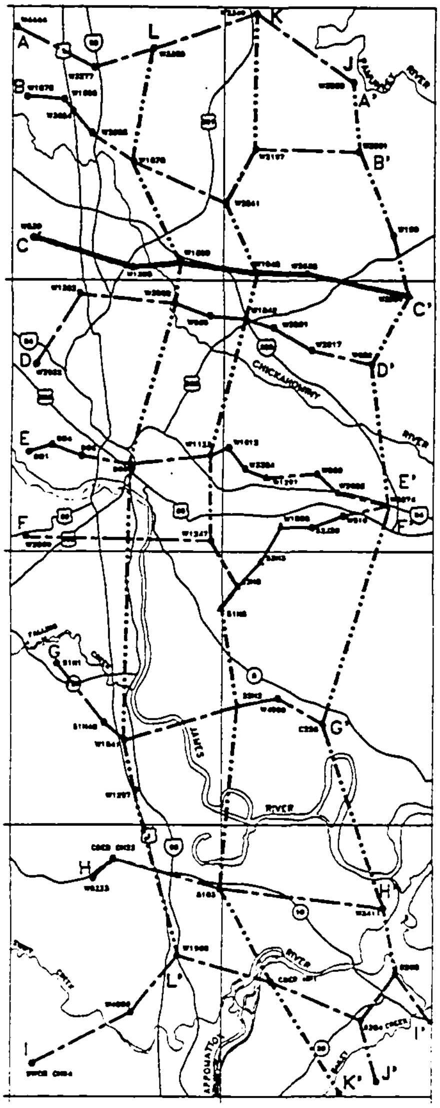
POTOMAC FORMATION

TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

CROSS-SECT
C-C'

HORIZONTAL SCALE:
1 INCH = 2 MILES



SCALE

0 1 2 MILES

0 1 2 KILOMETERS

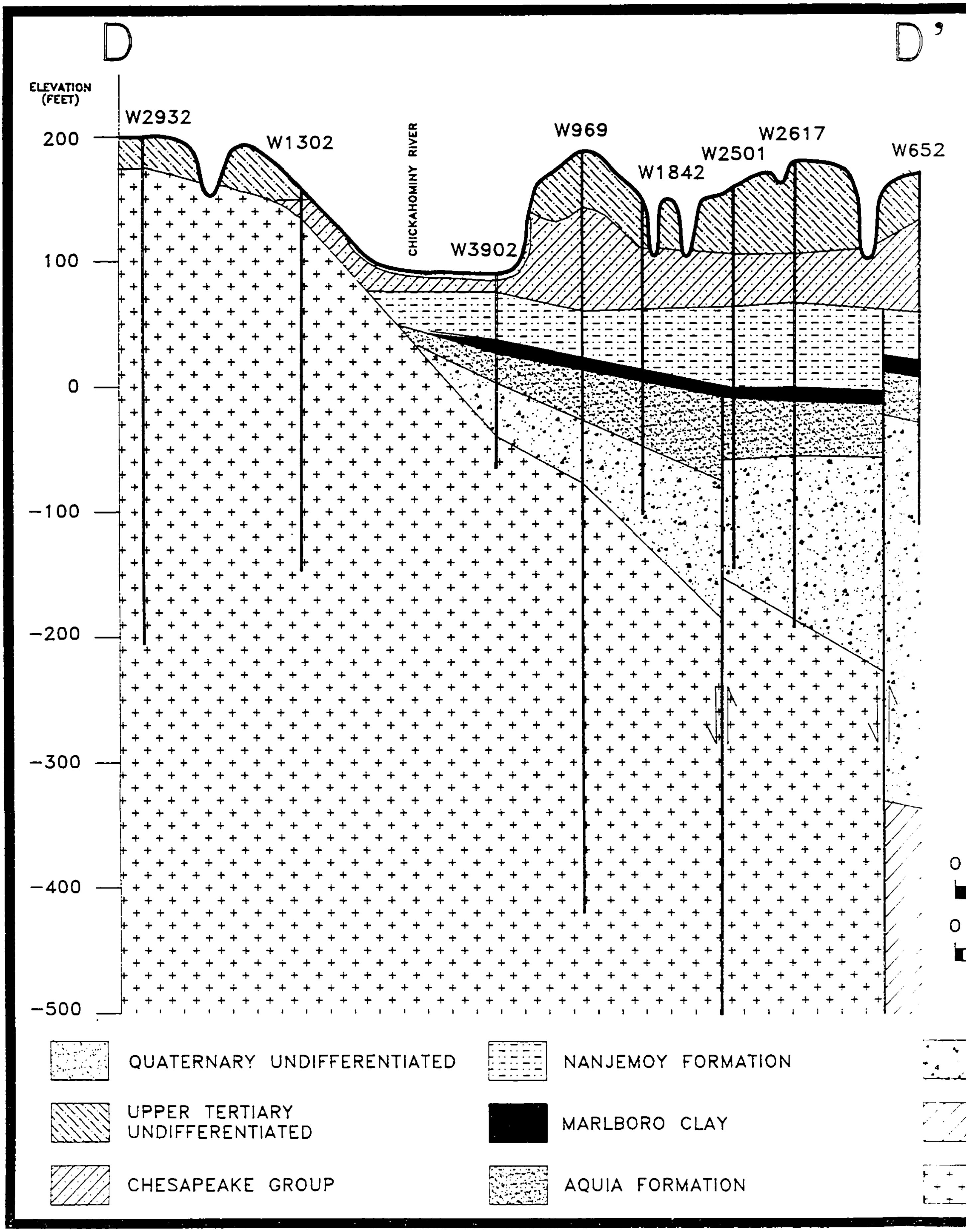
POTOMAC FORMATION

TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

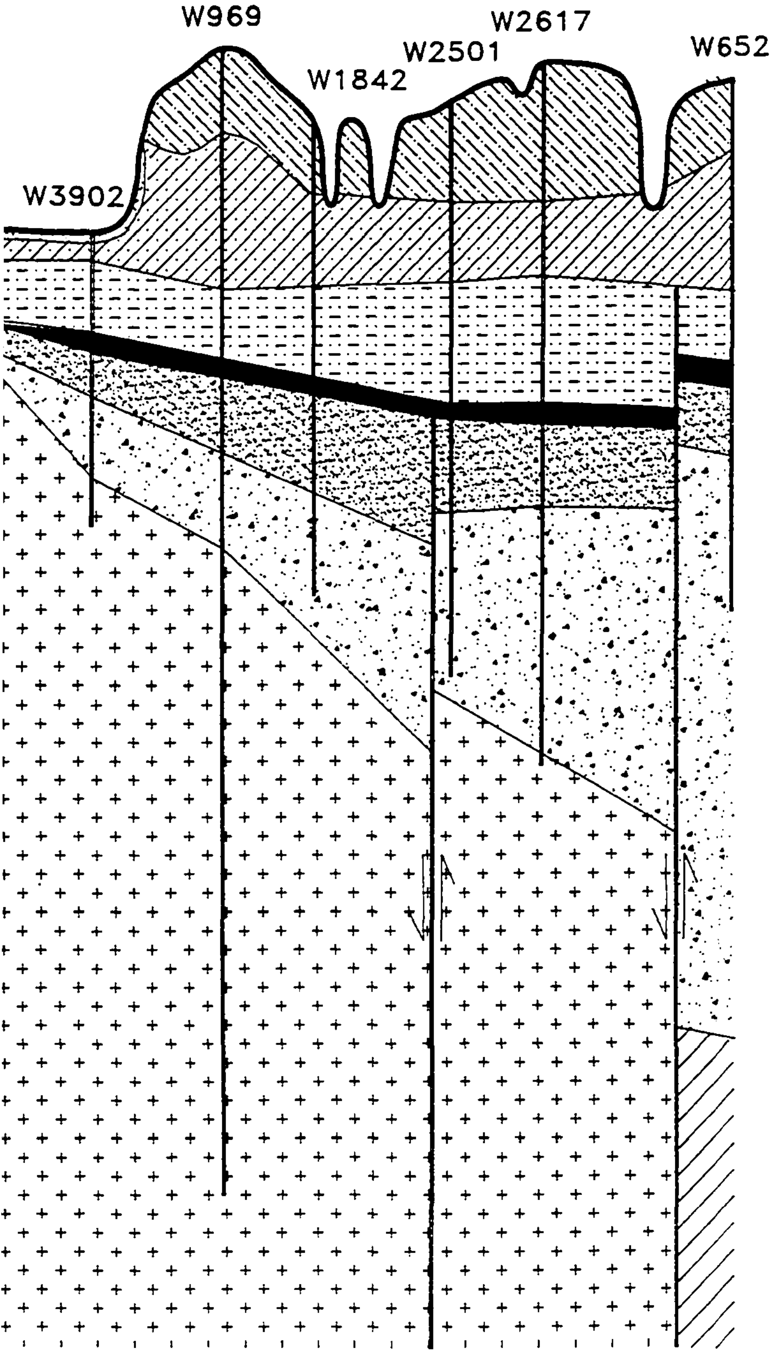
CROSS-SECTION C-C'

HORIZONTAL SCALE:	PLATE:
1 INCH = 2 MILES	3



D
D'
ELEVATION (FEET)
W2932
W1302
CHICKAHOMINY RIVER
W3902
W969
W1842
W2501
W2617
W652
200
100
0
−100
−200
−300
−400
−500
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION

D'



SCALE

0 1 2 MILES

0 1 2 KILOMETERS

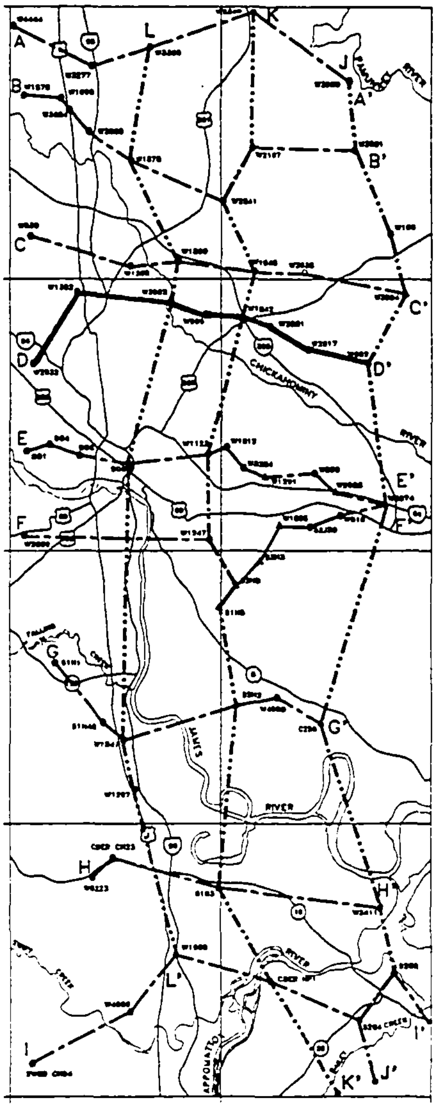
ED — NANJEMOY FORMATION — POTOMAC FORMATION

MARLBORO CLAY — TRIASSIC–JURASSIC REDBEDS

AQUIA FORMATION — PETERSBURG GRANITE

HORIZONT

1 INCH



SCALE

0 1 2 MILES

0 1 2 KILOMETERS

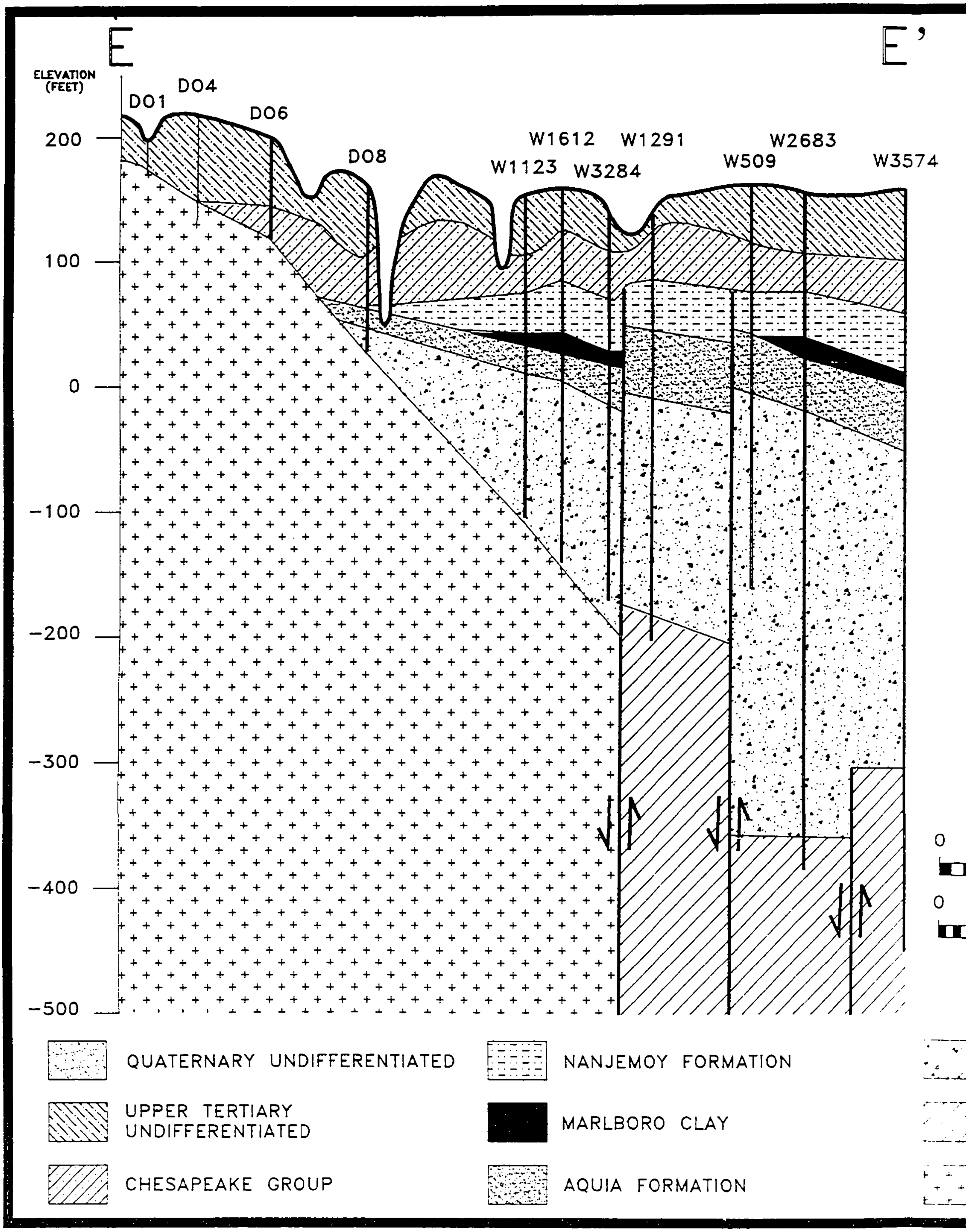
POTOMAC FORMATION

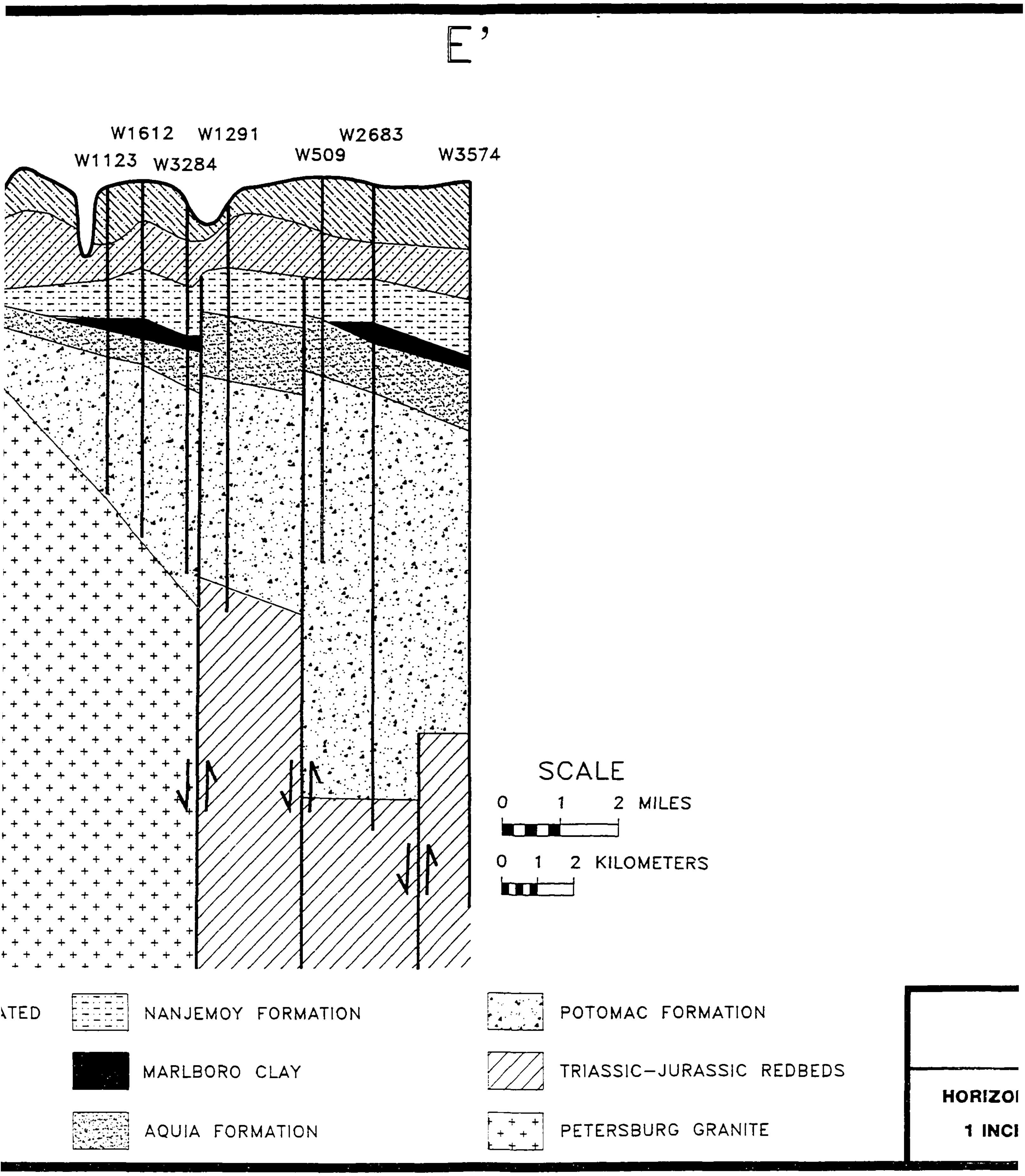
TRIASSIC–JURASSIC REDBEDS

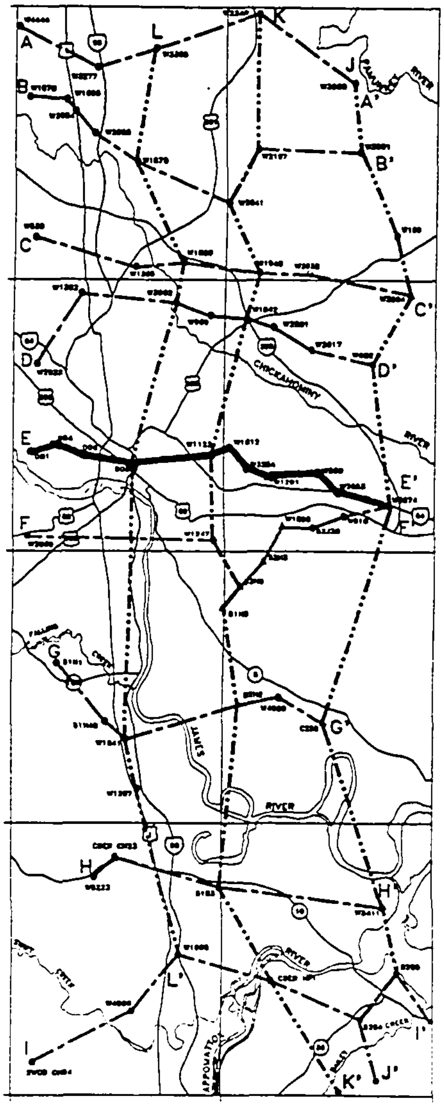
PETERSBURG GRANITE

CROSS-SECTION D-D'

HORIZONTAL SCALE: 1 INCH = 2 MILES	**PLATE:** 4


E
E'
ELEVATION (FEET)
200
100
0
-100
-200
-300
-400
-500
DO1
DO4
DO6
DO8
W1123
W1612
W3284
W1291
W509
W2683
W3574
0
0
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION


E'
W1612
W1291
W2683
W1123
W3284
W509
W3574
SCALE
0 1 2 MILES
0 1 2 KILOMETERS
ATED
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION
POTOMAC FORMATION
TRIASSIC–JURASSIC REDBEDS
PETERSBURG GRANITE
HORIZO
1 INC



:ALE

2 MILES

2 KILOMETERS

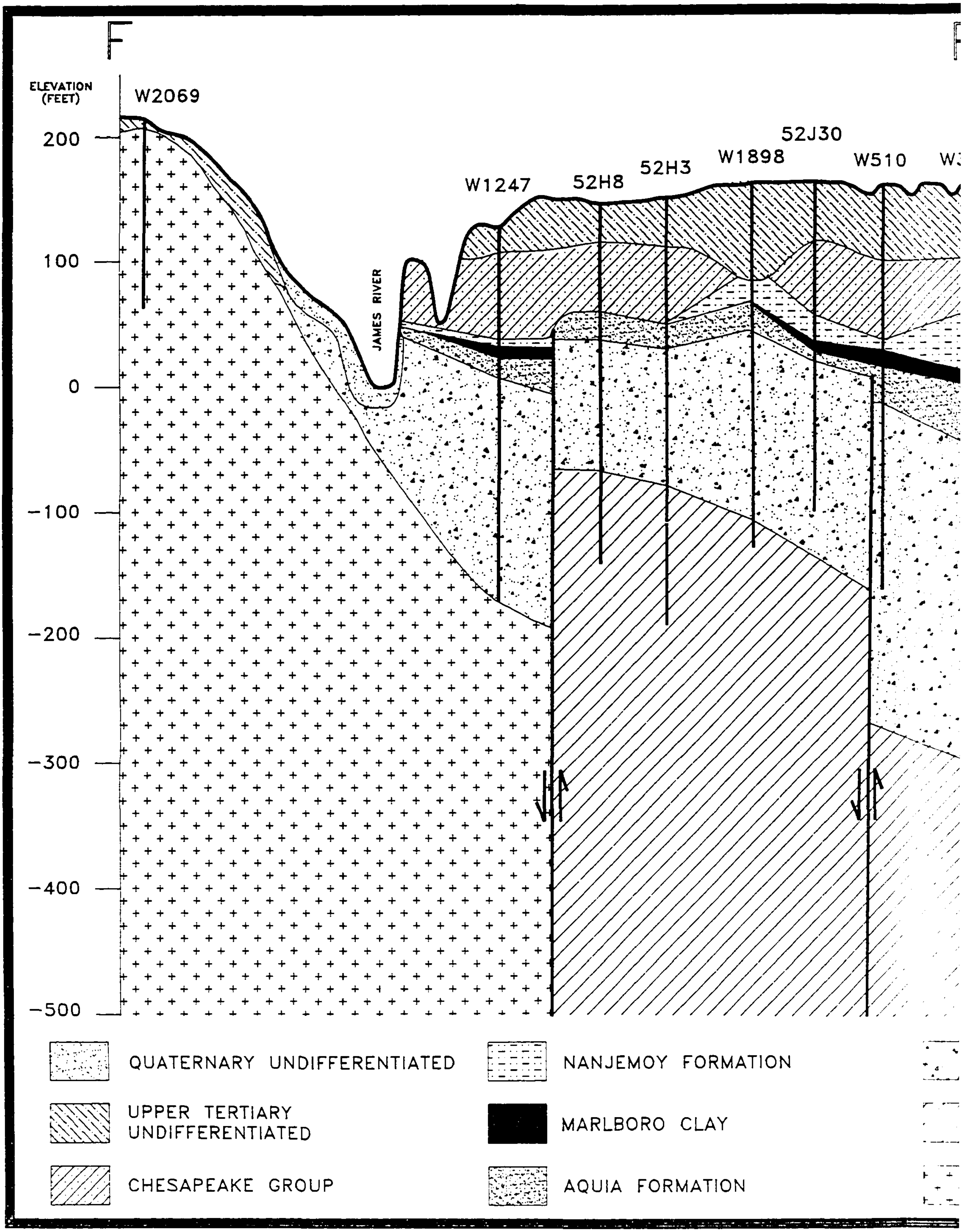
'OTOMAC FORMATION

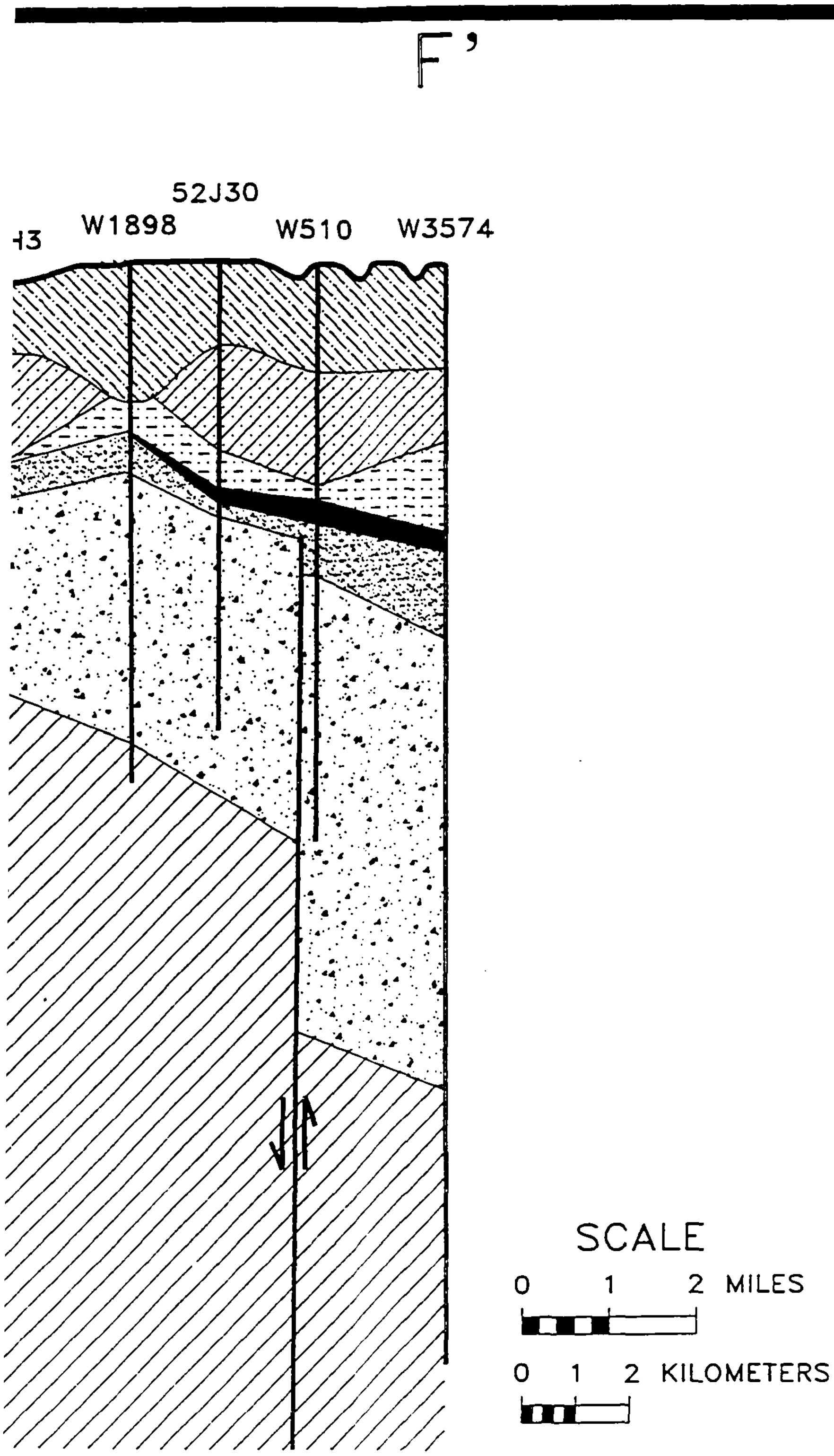
RIASSIC–JURASSIC REDBEDS

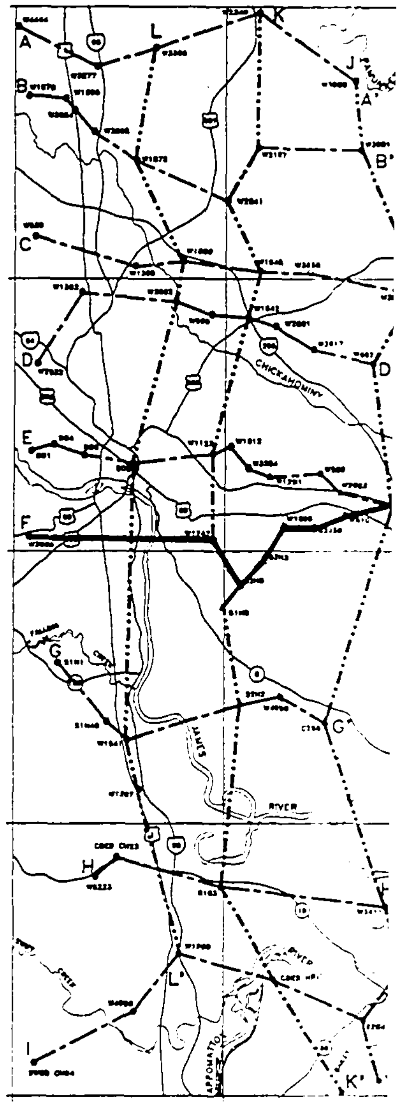
'ETERSBURG GRANITE

CROSS-SECTION E-E'

HORIZONTAL SCALE:	PLATE:
1 INCH = 2 MILES	5


F
ELEVATION (FEET)
W2069
W1247
52H8
52H3
W1898
52J30
W510
JAMES RIVER
200
100
0
−100
−200
−300
−400
−500
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION





' FORMATION

CLAY

RMATION

POTOMAC FORMATION

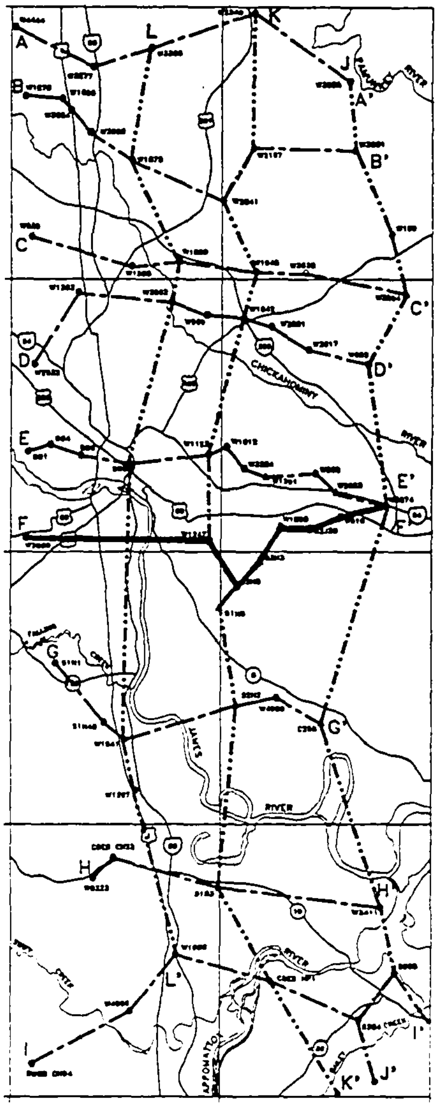
TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

CROSS-SECTION F-F'

HORIZONTAL SCALE: 1 INCH = 2 MILES

PI



SCALE

0 1 2 MILES

0 1 2 KILOMETERS

POTOMAC FORMATION

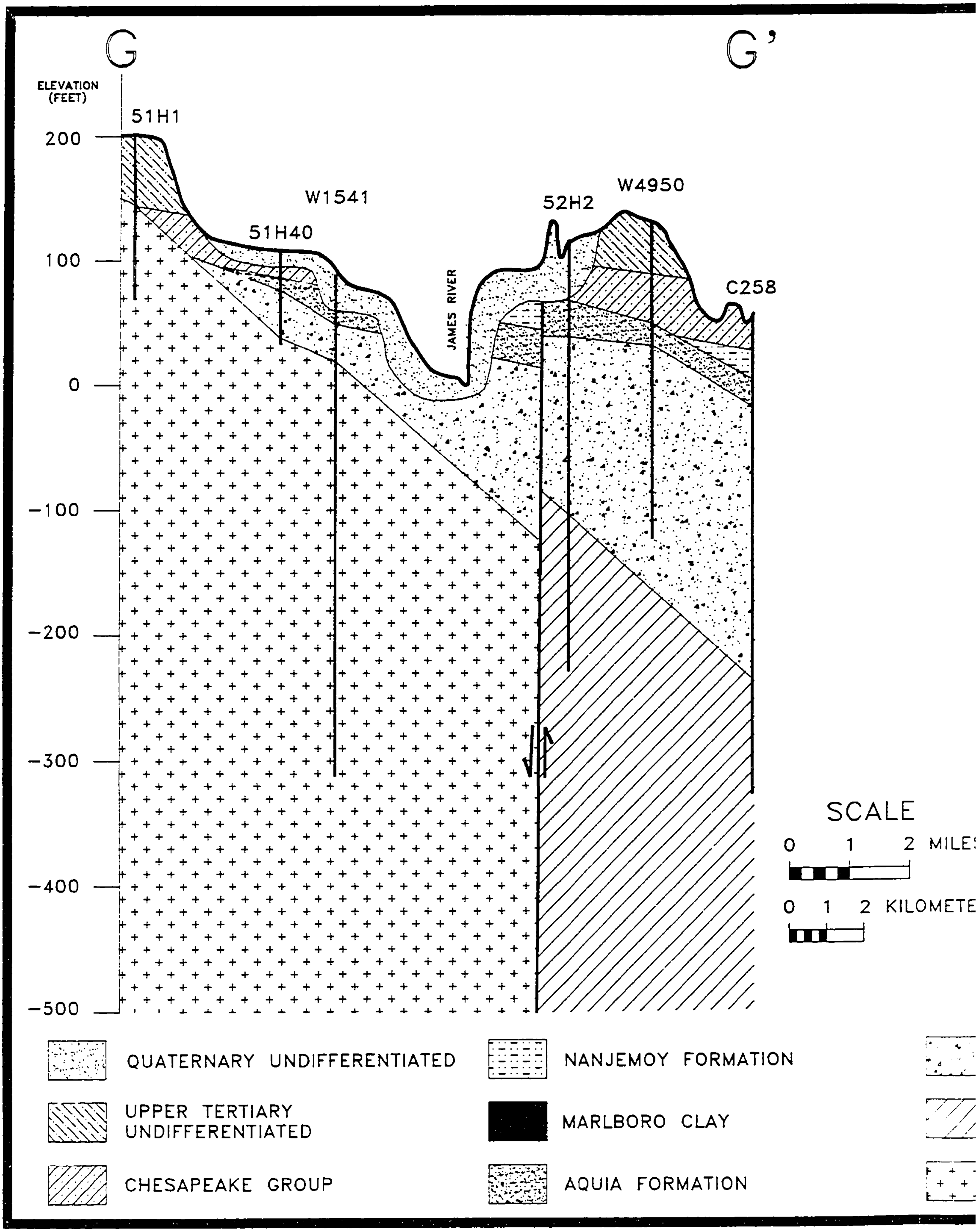
TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

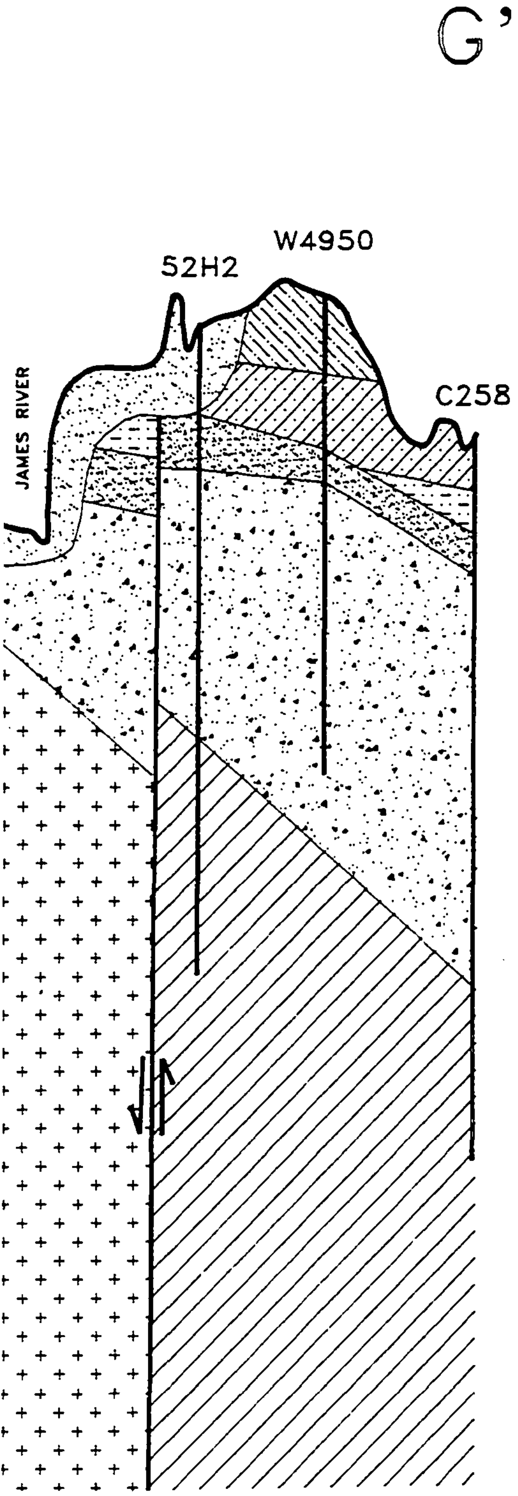
CROSS-SECTION F-F'

HORIZONTAL SCALE: 1 INCH = 2 MILES

PLATE: 6



G
G'
ELEVATION (FEET)
200
100
0
-100
-200
-300
-400
-500
51H1
51H40
W1541
JAMES RIVER
52H2
W4950
C258
SCALE
0 1 2 MILE
0 1 2 KILOMETE
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION



SCALE

0 1 2 MILES

0 1 2 KILOMETERS

:D

NANJEMOY FORMATION

MARLBORO CLAY

AQUIA FORMATION

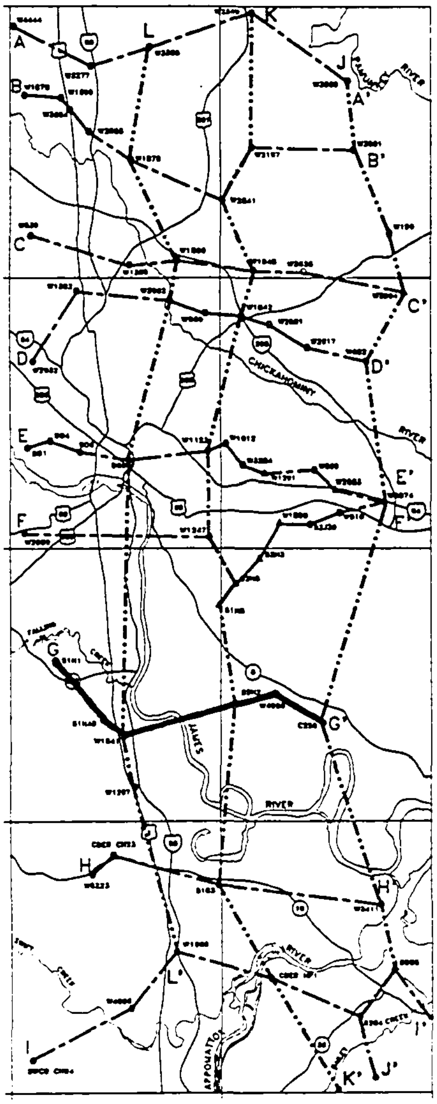
POTOMAC FORMATION

TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

HORIZONT

1 INCH



OTOMAC FORMATION

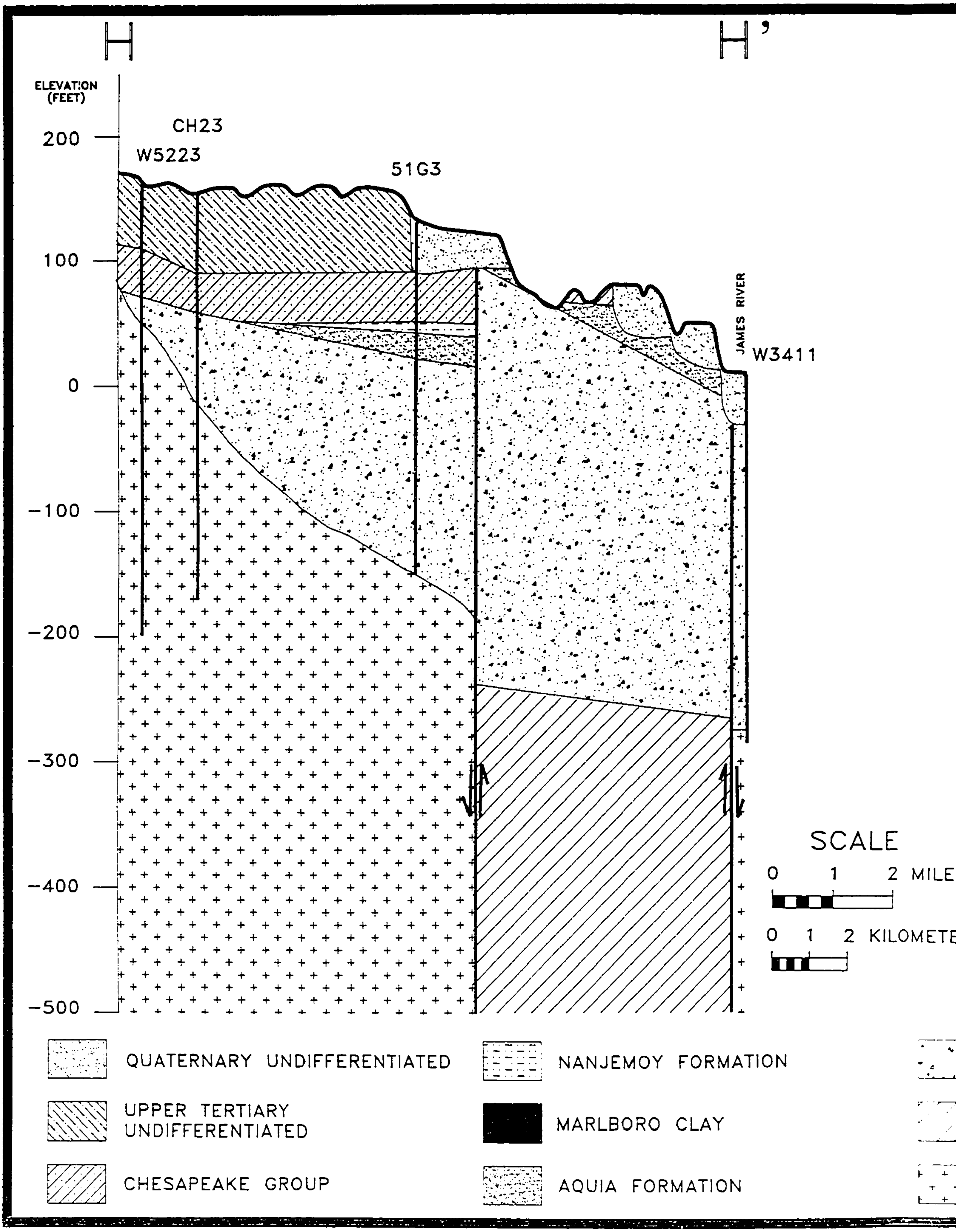
RIASSIC–JURASSIC REDBEDS

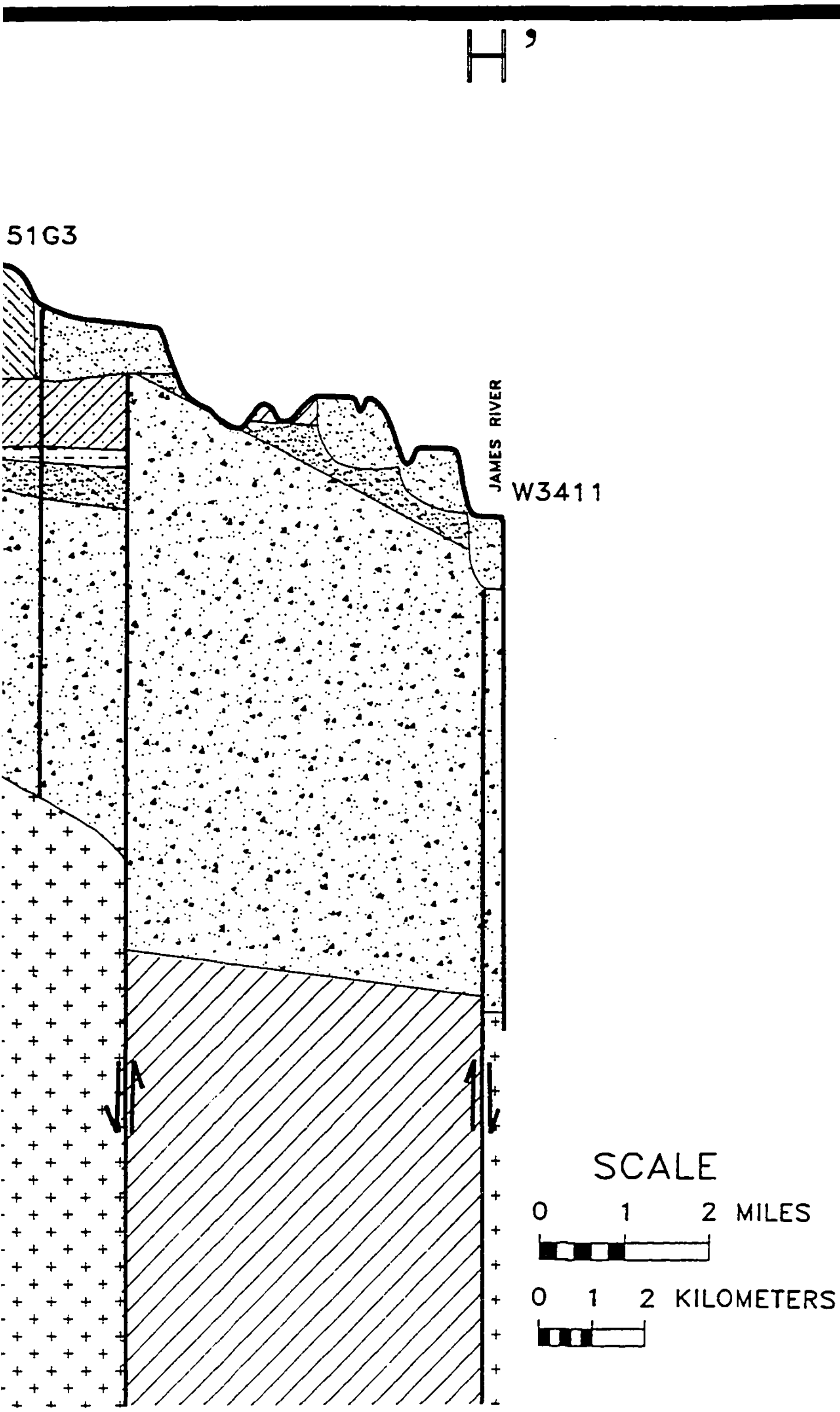
ETERSBURG GRANITE

CROSS-SECTION G-G'

HORIZONTAL SCALE: 1 INCH = 2 MILES

PLATE: 7


H
H'
ELEVATION (FEET)
200
100
0
-100
-200
-300
-400
-500
CH23
W5223
51G3
JAMES RIVER
W3411
SCALE
0 1 2 MILE
0 1 2 KILOMETE
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION



TIATED

NANJEMOY FORMATION

MARLBORO CLAY

AQUIA FORMATION

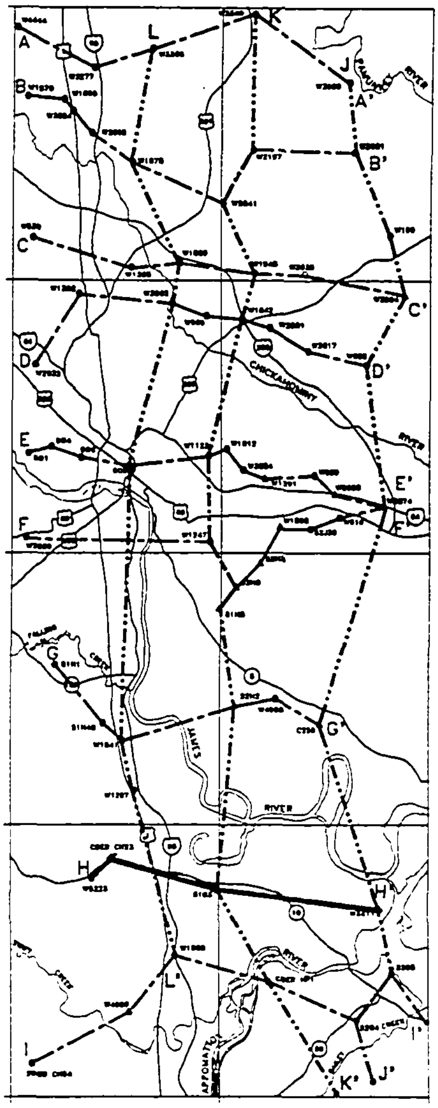
POTOMAC FORMATION

TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

HORIZ
1 IN

RS

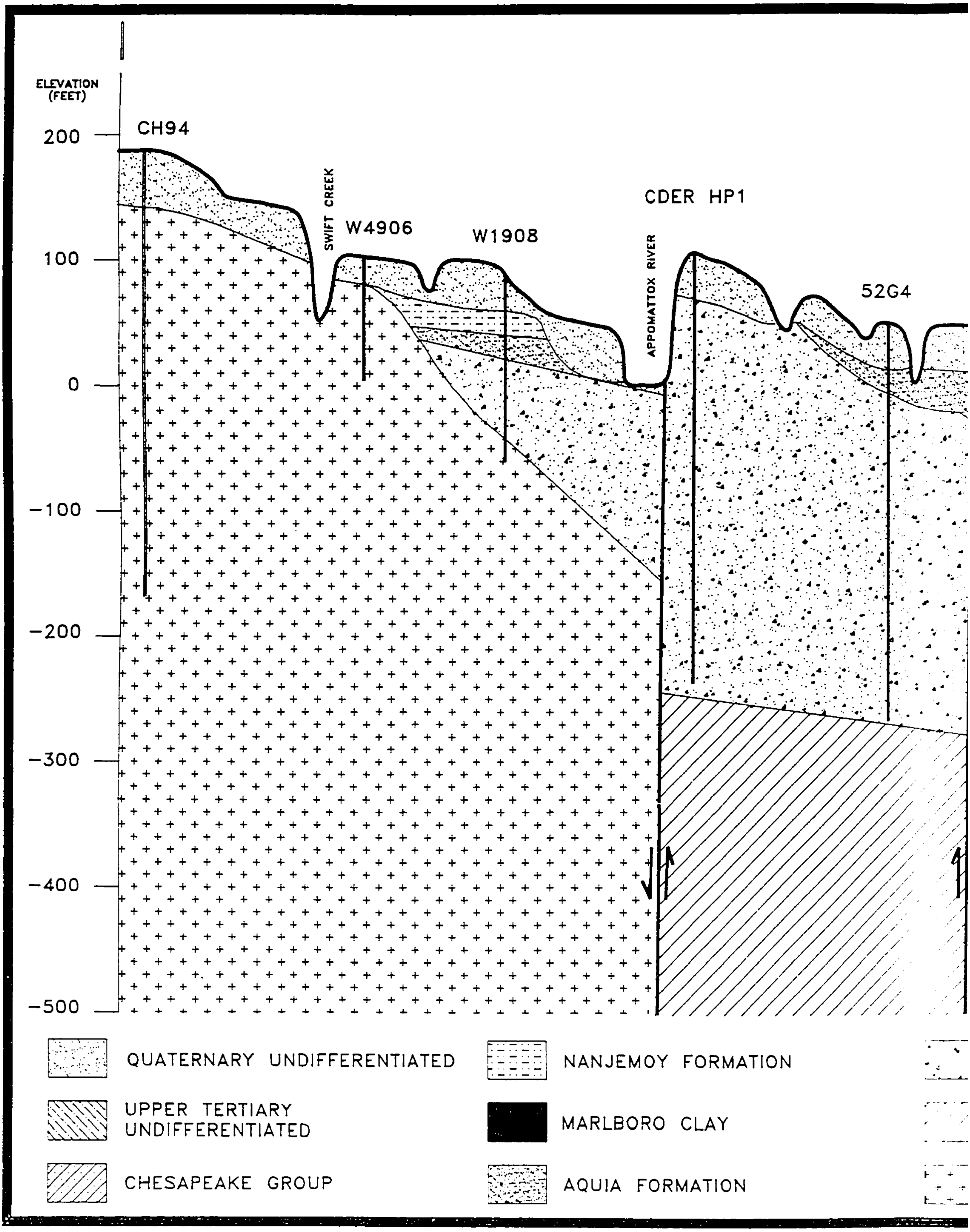


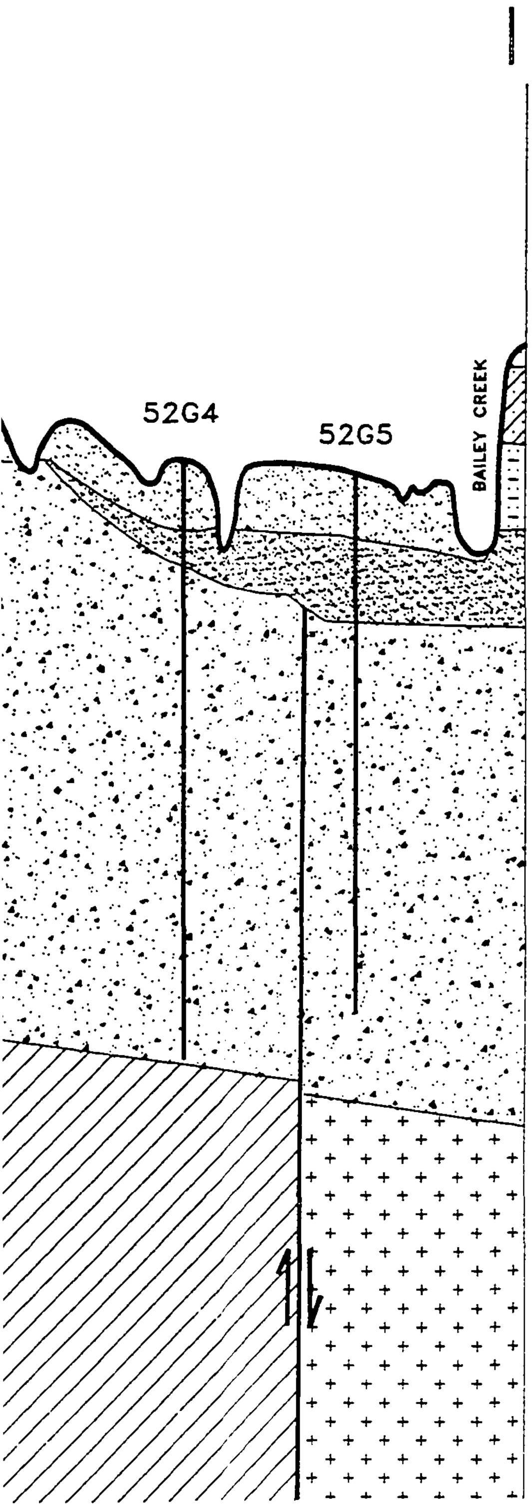
POTOMAC FORMATION

TRIASSIC–JURASSIC REDBEDS

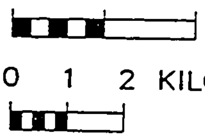
PETERSBURG GRANITE

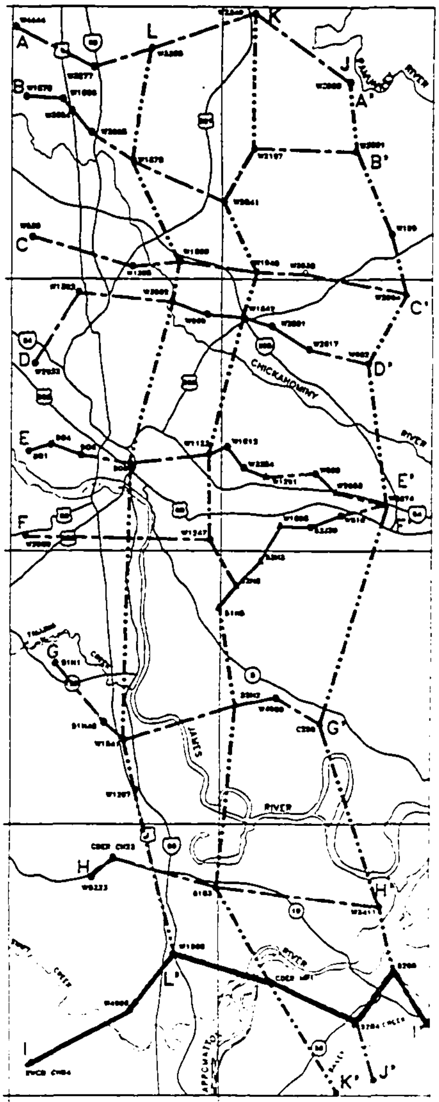
CROSS-SECTION H-H'	
HORIZONTAL SCALE: 1 INCH = 2 MILES	PLATE: 8


ELEVATION (FEET)
200
100
0
-100
-200
-300
-400
-500
CH94
SWIFT CREEK
W4906
W1908
APPOMATTOX RIVER
CDER HP1
52G4
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION



SCALE





ON

POTOMAC FORMATION

TRIASSIC–JURASSIC REDBEDS

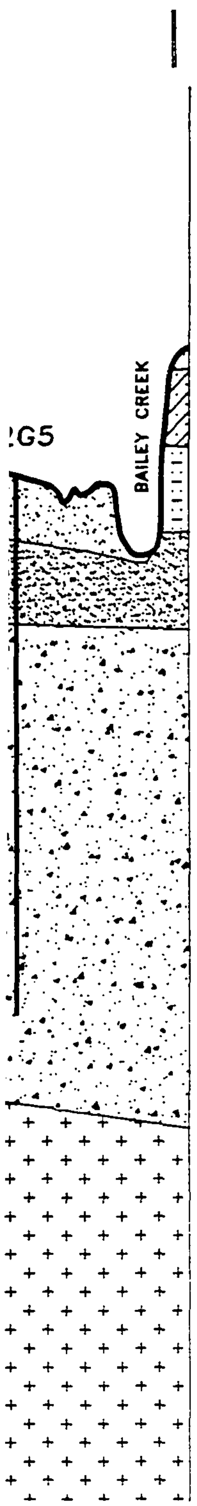
PETERSBURG GRANITE

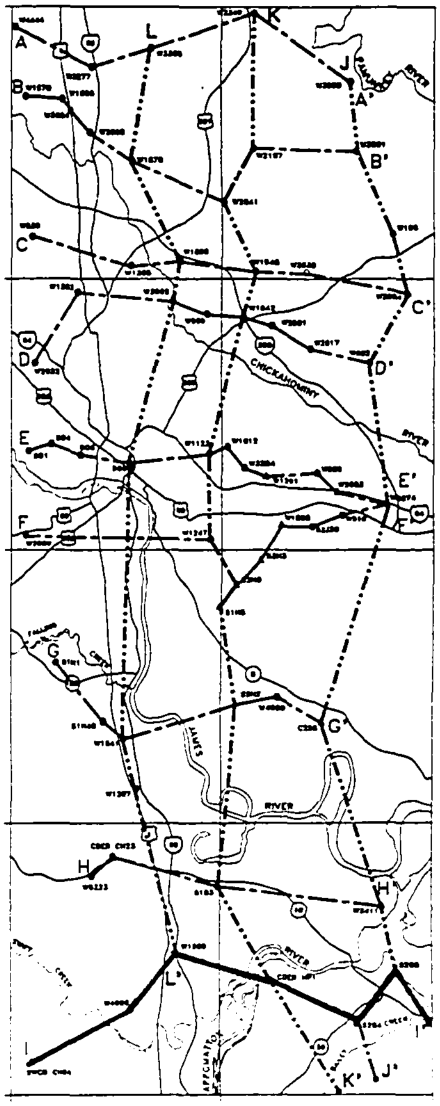
CROSS-SECTION
I-I'

HORIZONTAL SCALE:
1 INCH = 2 MILES

PLATE:
9

I'





SCALE

0 1 2 MILES

0 1 2 KILOMETERS

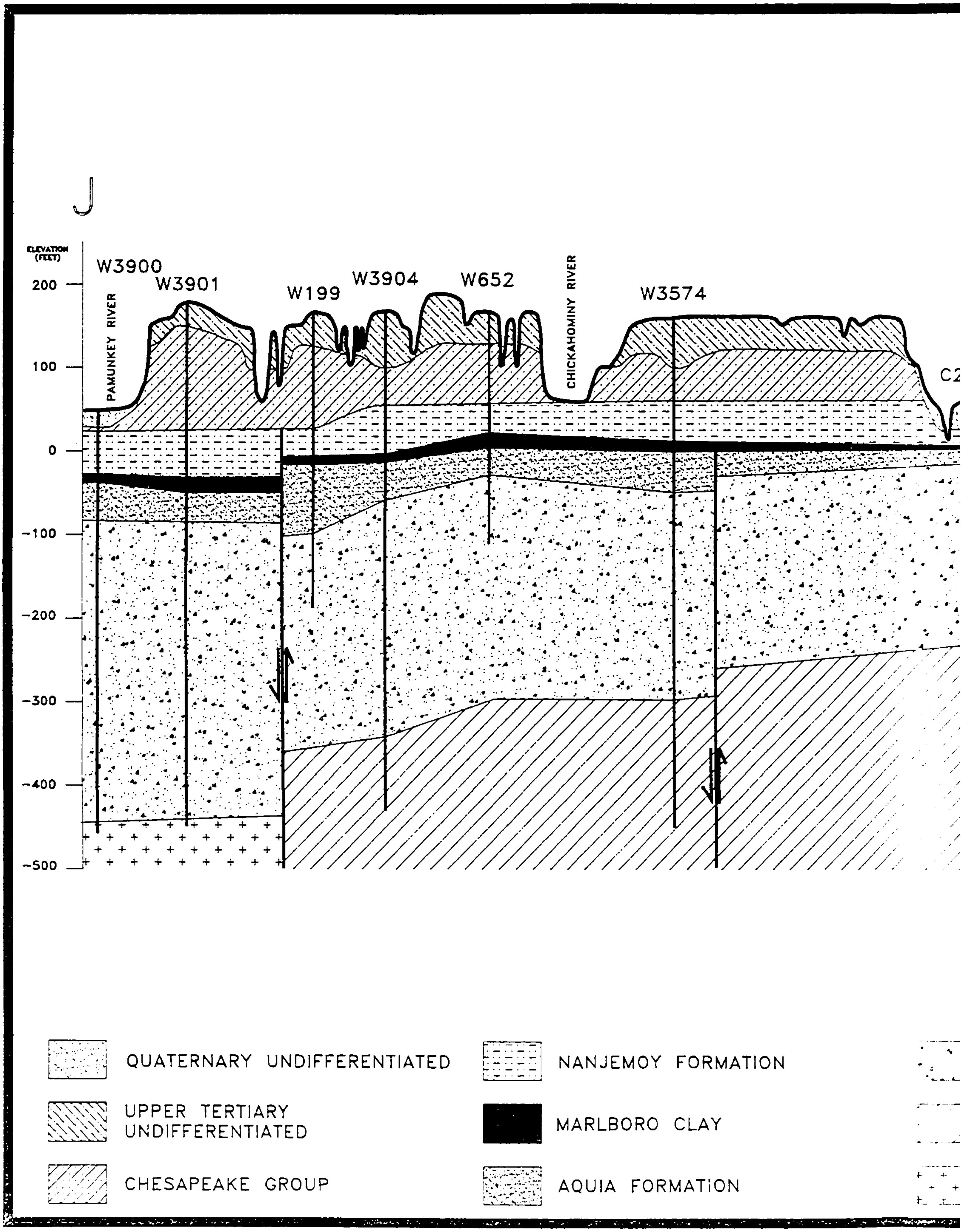
POTOMAC FORMATION

TRIASSIC–JURASSIC REDBEDS

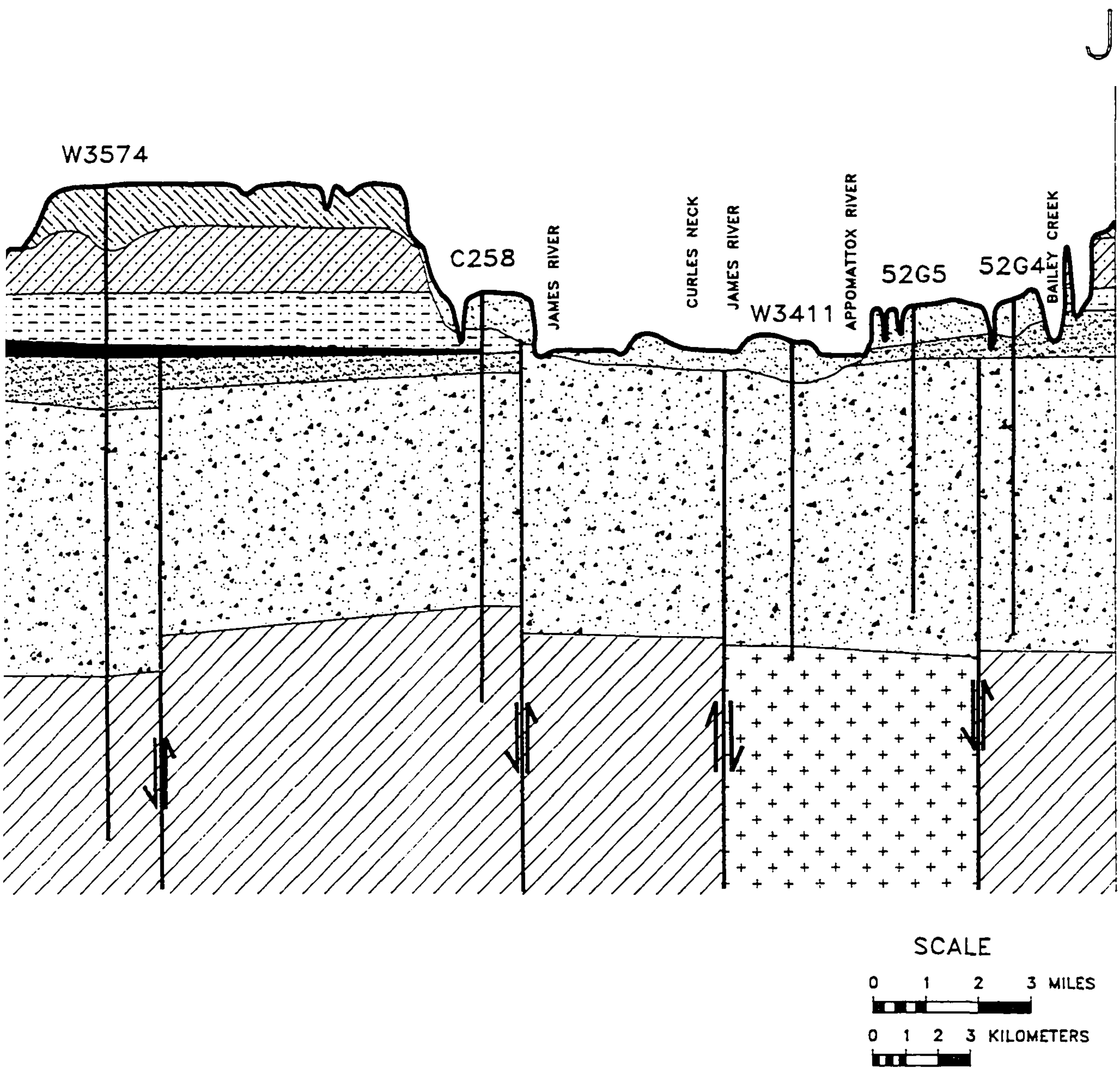
PETERSBURG GRANITE

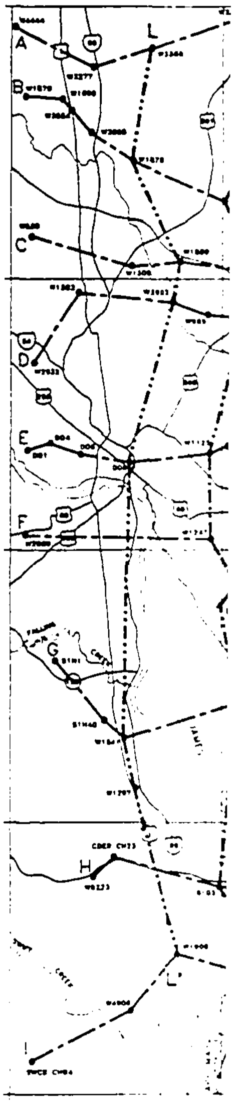
CROSS-SECTION
I-I'

HORIZONTAL SCALE:	**PLATE:**
1 INCH = 2 MILES	**9**



J
ELEVATION (FEET)
200
100
0
-100
-200
-300
-400
-500
W3900
W3901
W199
W3904
W652
W3574
PAMUNKEY RIVER
CHICKAHOMINY RIVER
C2
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION

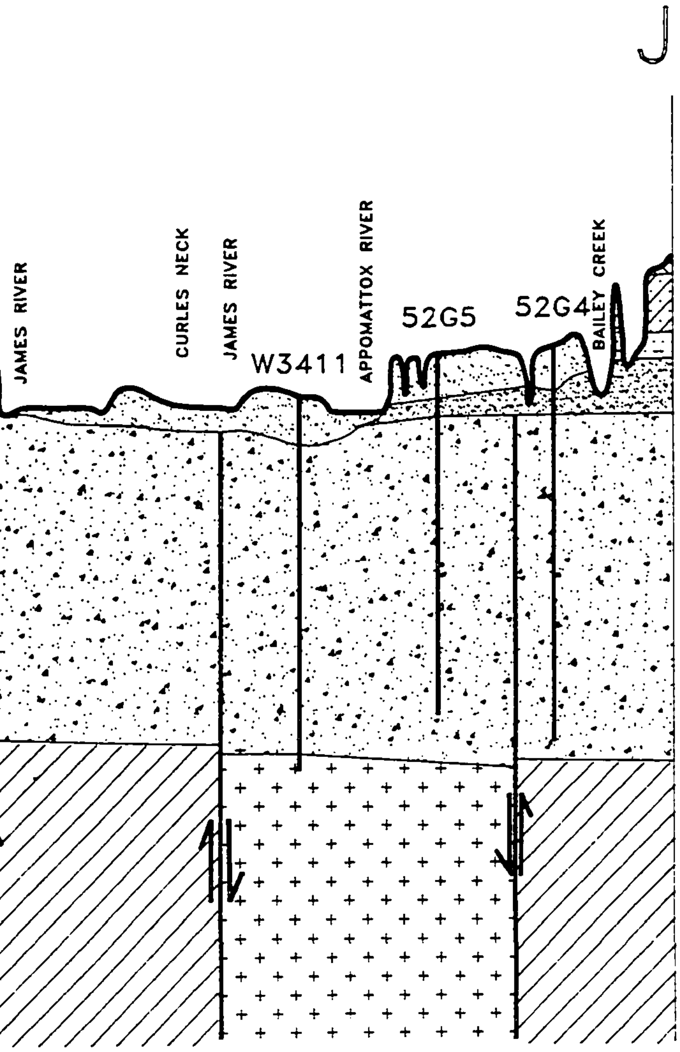


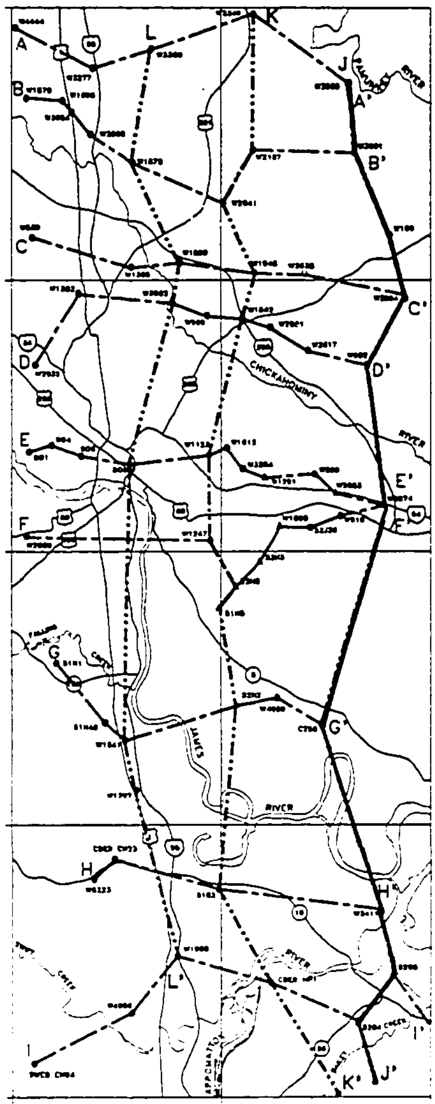


ƗJEMOY FORMATION	POTOMAC FORMATION
꞉LBORO CLAY	TRIASSIC–JURASSIC REDBEDS
JIA FORMATION	PETERSBURG GRANITE

CROSS-SEC
J-J'

HORIZONTAL SCALE:
1 INCH = 3 MILES





SCALE

0 1 2 3 MILES

0 1 2 3 KILOMETERS

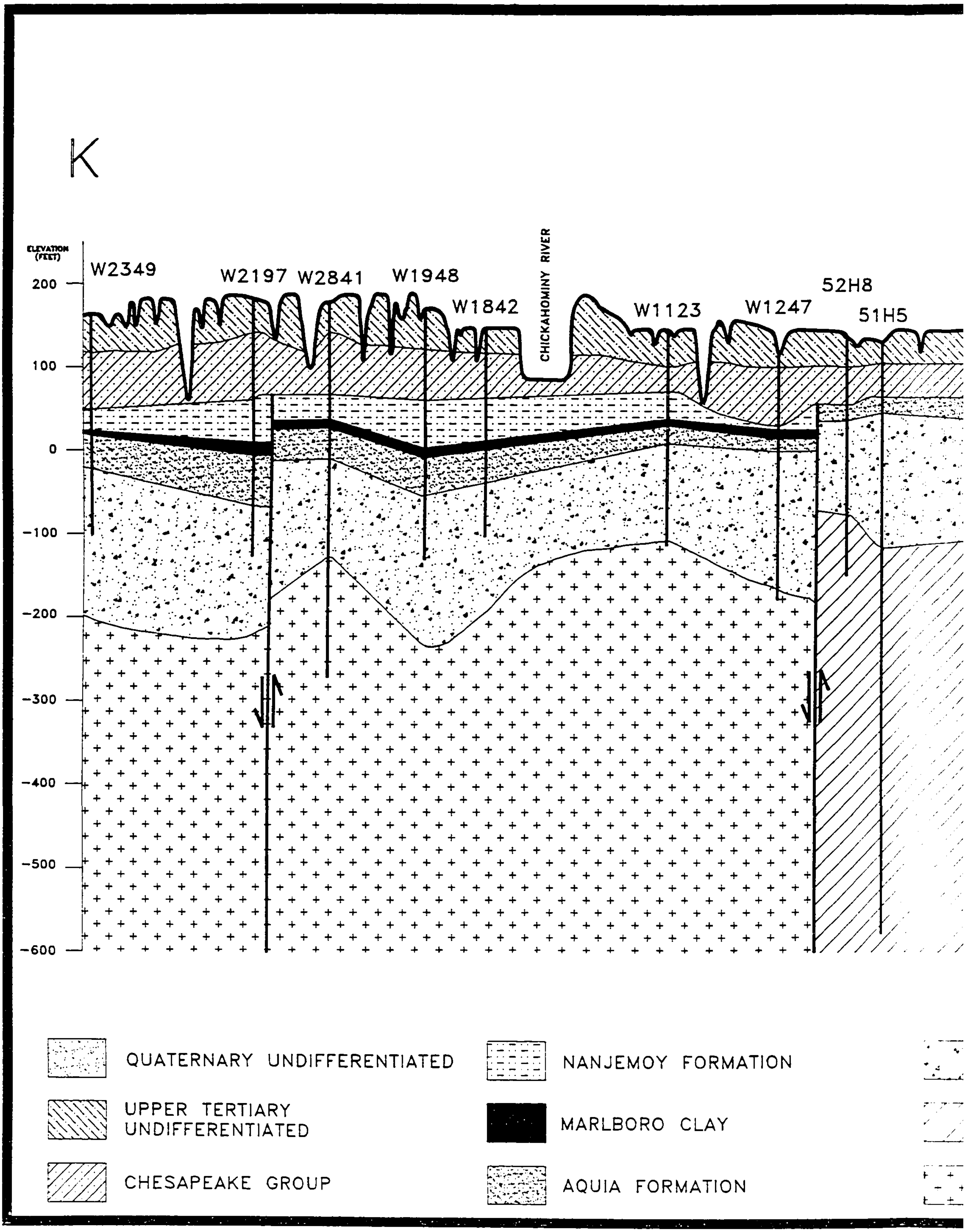
POTOMAC FORMATION

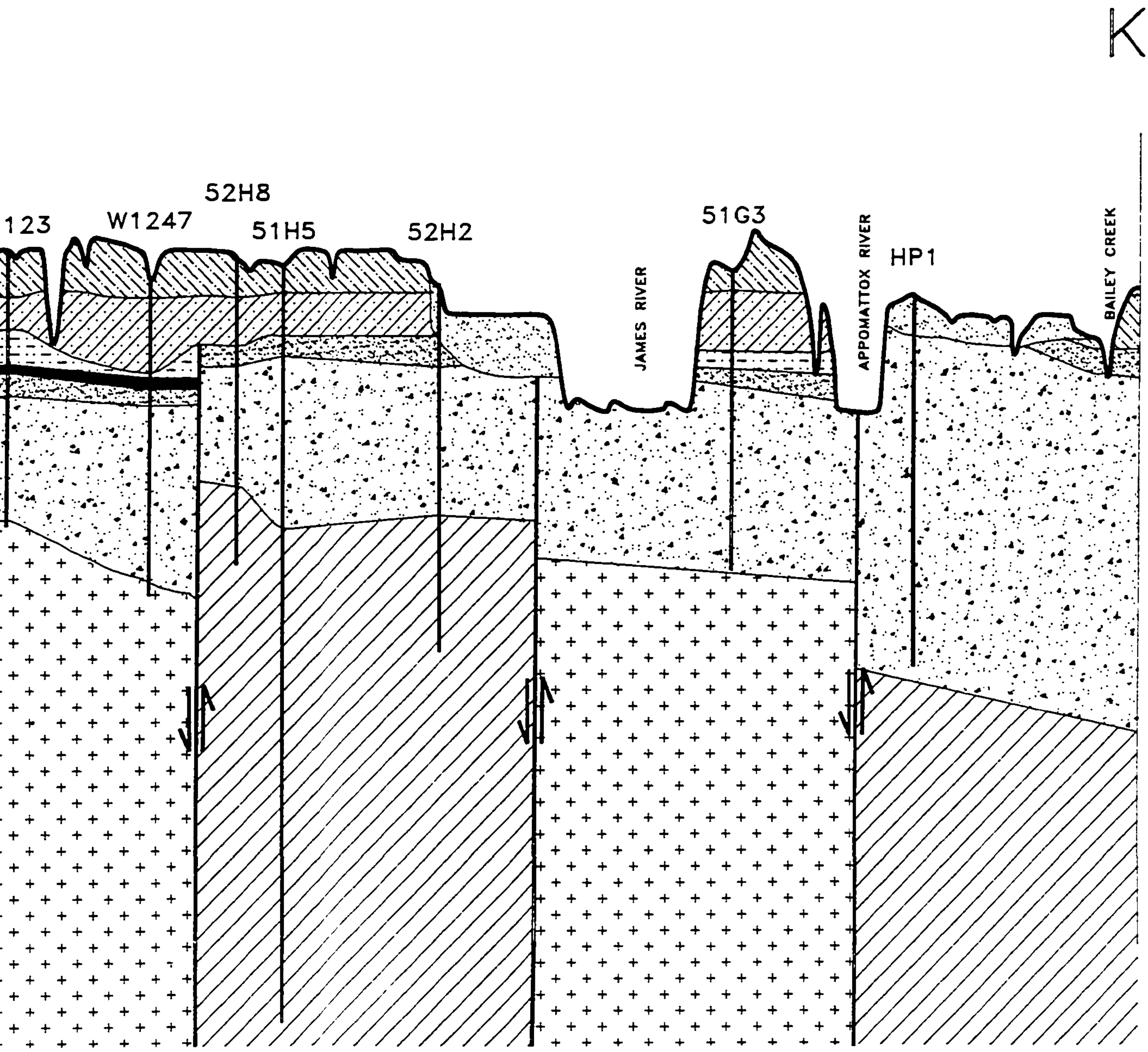
TRIASSIC–JURASSIC REDBEDS

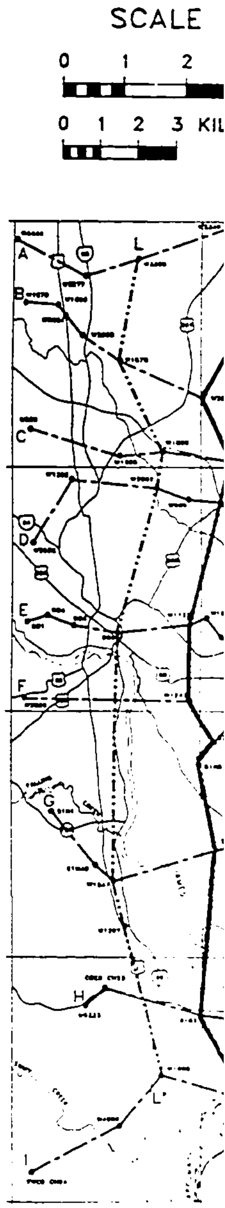
PETERSBURG GRANITE

CROSS-SECTION J-J'

HORIZONTAL SCALE: 1 INCH = 3 MILES	PLATE: 10


K
ELEVATION (FEET)
200
100
0
-100
-200
-300
-400
-500
-600
W2349
W2197
W2841
W1948
W1842
CHICKAHOMINY RIVER
W1123
W1247
52H8
51H5
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION





Y FORMATION

D CLAY

RMATION

POTOMAC FORMATION

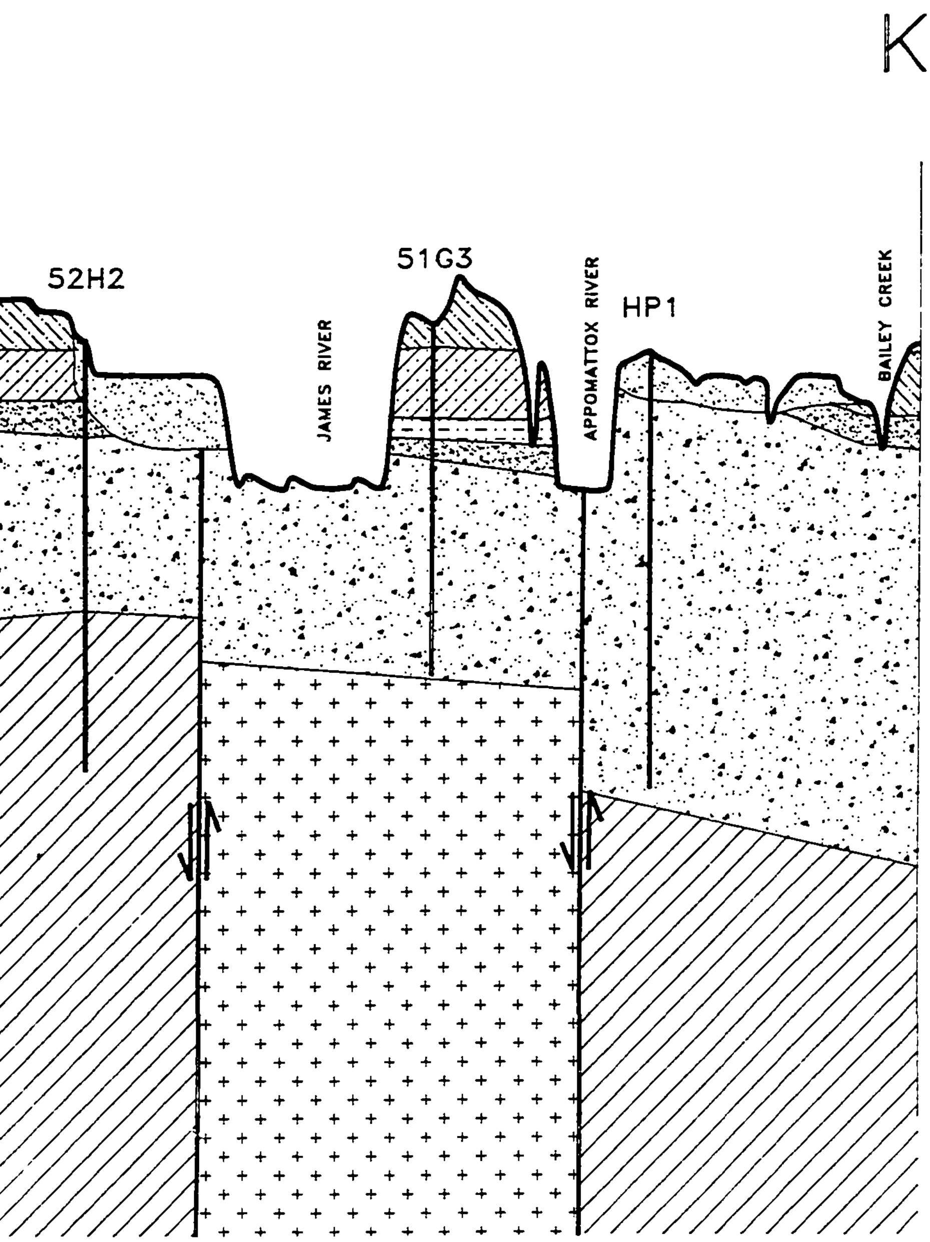
TRIASSIC–JURASSIC REDBEDS

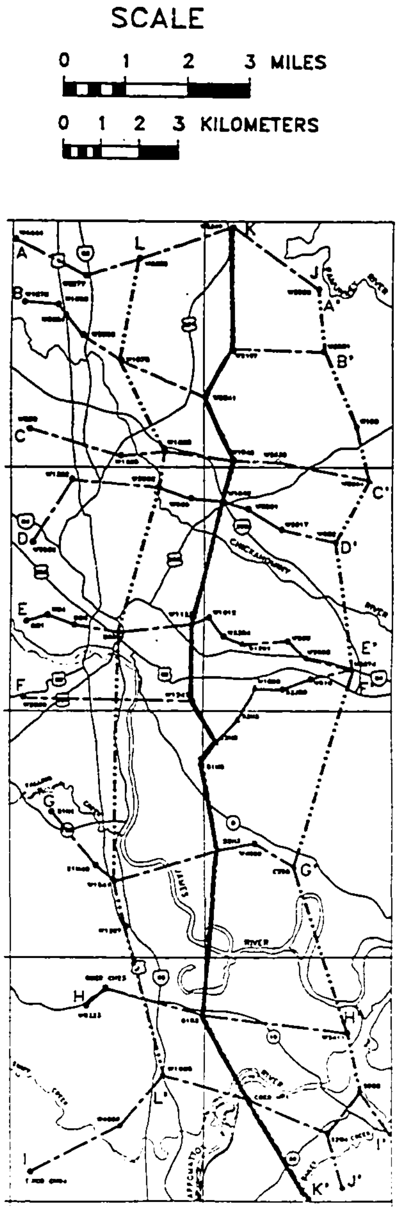
PETERSBURG GRANITE

CROSS-SECTION
K-K'

HORIZONTAL SCALE: 1 INCH = 3 MILES

P





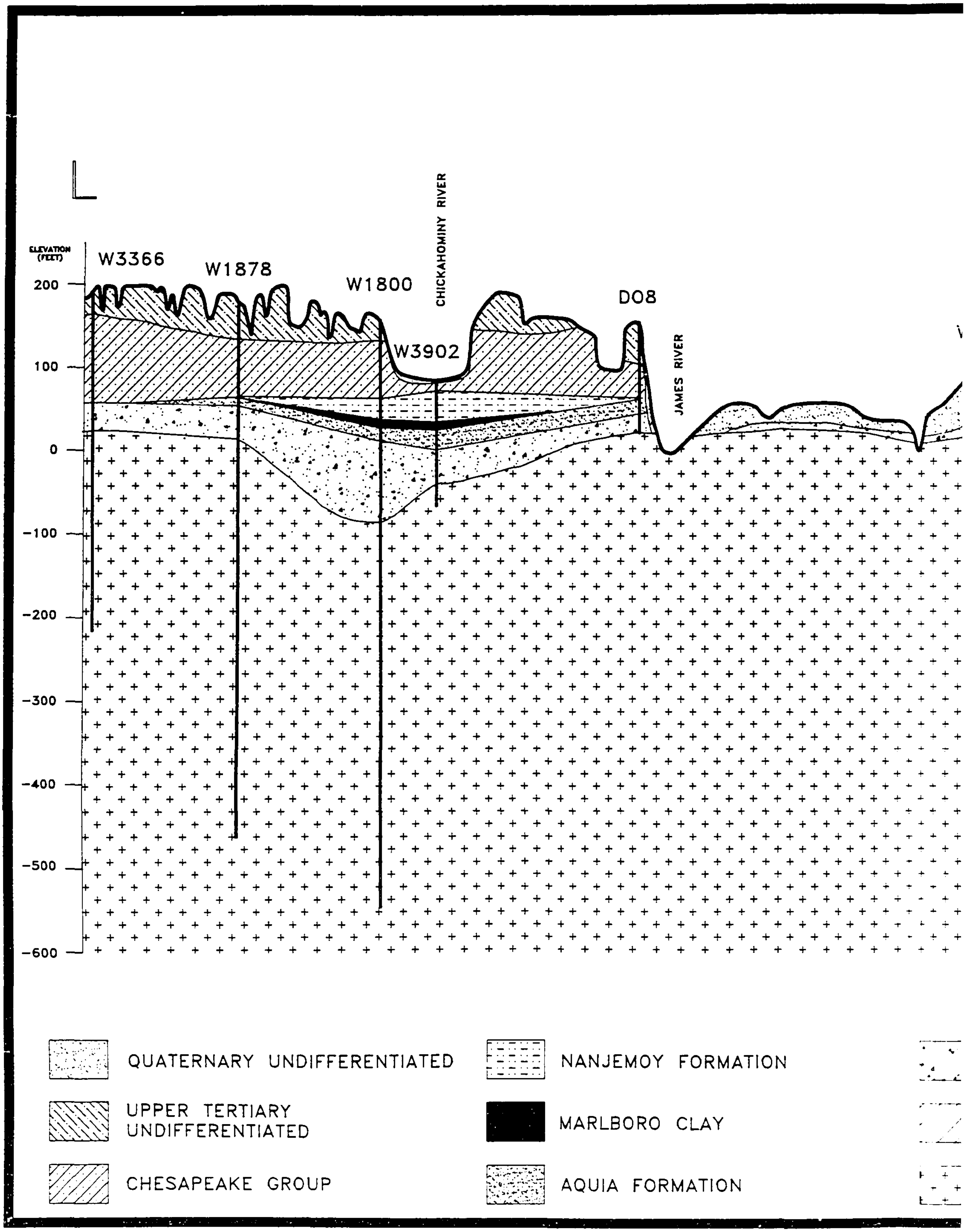
POTOMAC FORMATION

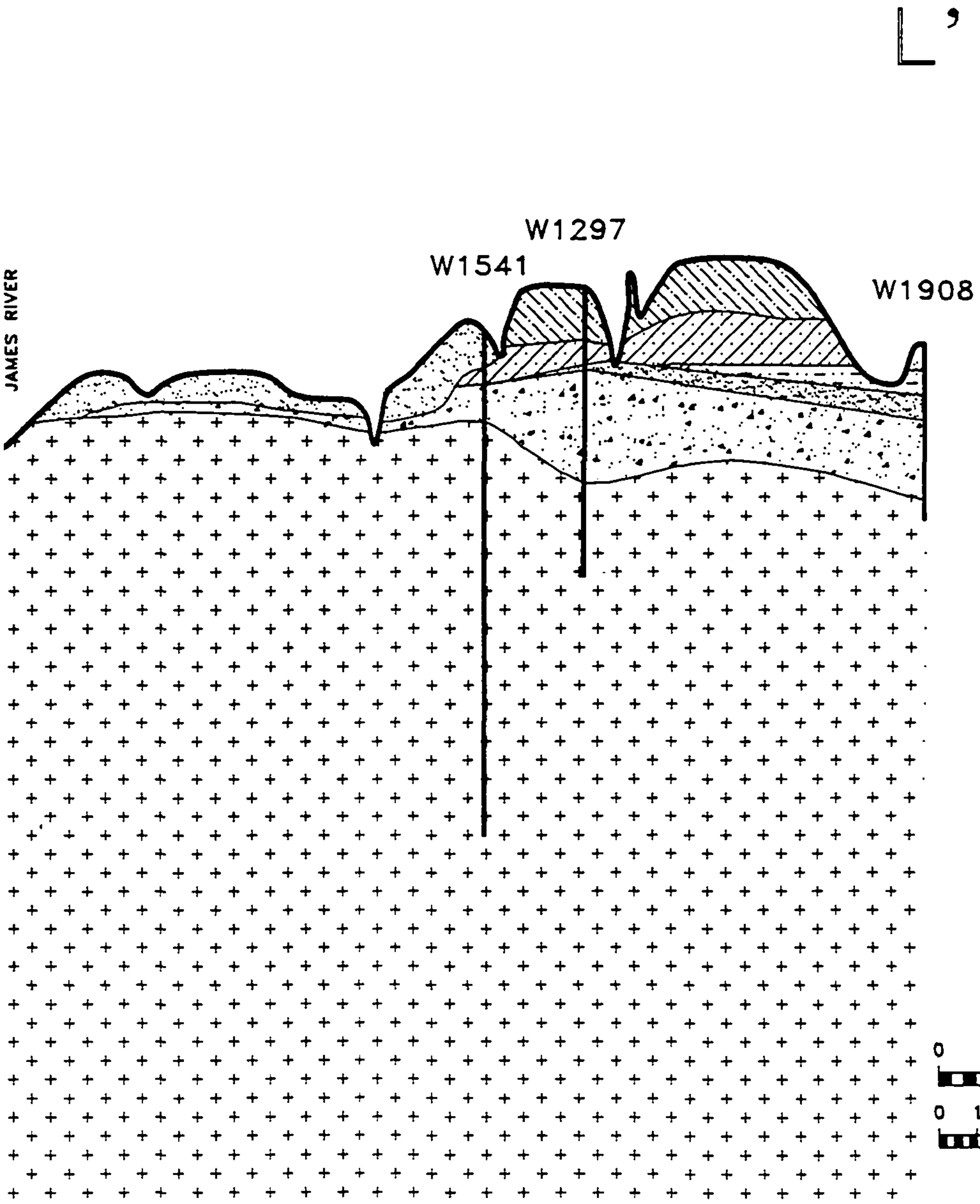
TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

CROSS-SECTION
K-K'

HORIZONTAL SCALE:	PLATE:
1 INCH = 3 MILES	11

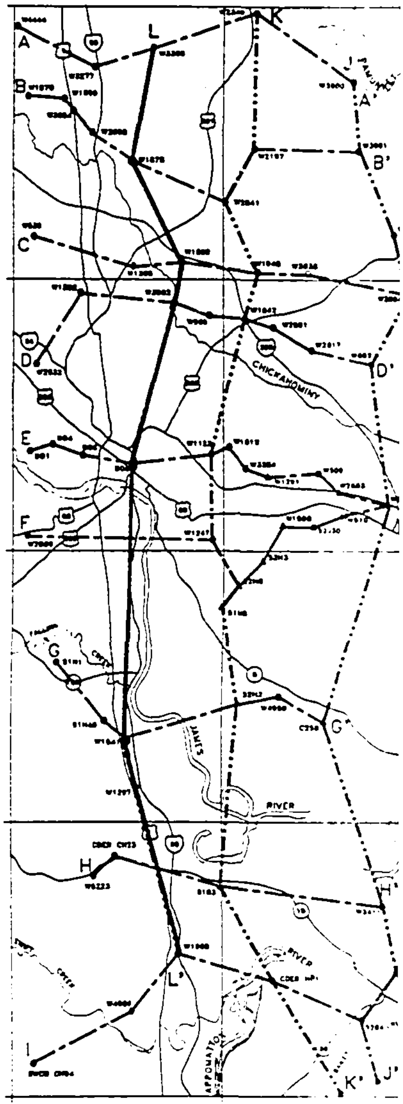

L
ELEVATION (FEET)
200
100
0
-100
-200
-300
-400
-500
-600
W3366
W1878
W1800
W3902
CHICKAHOMINY RIVER
D08
JAMES RIVER
QUATERNARY UNDIFFERENTIATED
UPPER TERTIARY UNDIFFERENTIATED
CHESAPEAKE GROUP
NANJEMOY FORMATION
MARLBORO CLAY
AQUIA FORMATION



SCALE

0 1 2 3 MILES

0 1 2 3 KILOMETERS



FORMATION

CLAY

MATION

POTOMAC FORMATION

TRIASSIC—JURASSIC REDBEDS

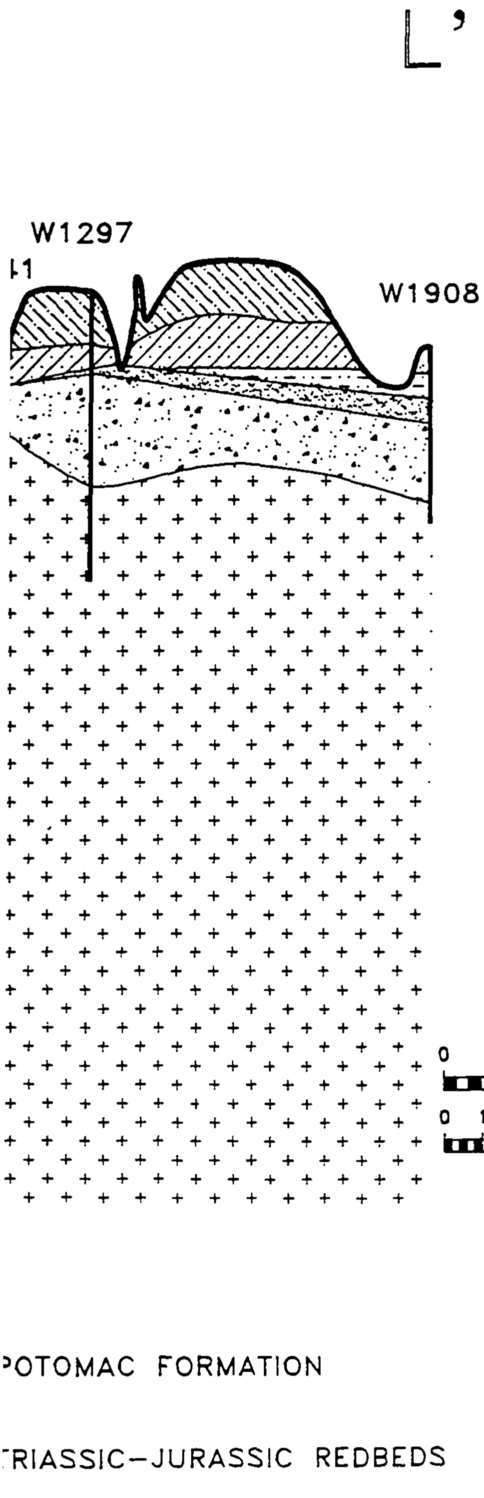
PETERSBURG GRANITE

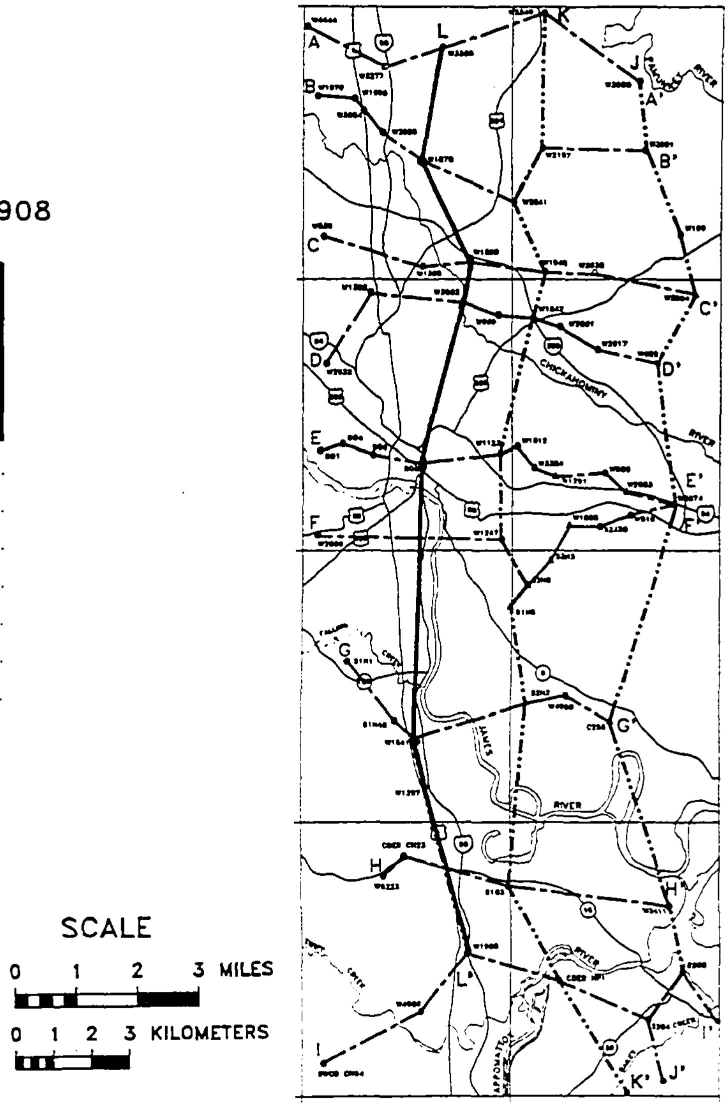
CROSS-SECTION L-L'

HORIZONTAL SCALE:
1 INCH = 3 MILES

PL

1





POTOMAC FORMATION

TRIASSIC–JURASSIC REDBEDS

PETERSBURG GRANITE

CROSS-SECTION L-L'	
HORIZONTAL SCALE: 1 INCH = 3 MILES	PLATE: 12