

Department of Natural Resources  
MARYLAND GEOLOGICAL SURVEY  
Emery T. Cleaves, Director

OPEN-FILE REPORT NO. 96-02-8

HYDROSTRATIGRAPHIC FRAMEWORK OF THE  
PINEY POINT-NANJEMOY AQUIFER AND AQUIA AQUIFER  
IN CALVERT AND ST. MARY'S COUNTIES,  
MARYLAND

by

Harry J. Hansen



Prepared in cooperation with  
the Boards of Commissioners of  
Calvert County and St. Mary's County

1996

Department of Natural Resources  
MARYLAND GEOLOGICAL SURVEY  
Emery T. Cleaves, Director

OPEN-FILE REPORT NO. 96-02-8

HYDROSTRATIGRAPHIC FRAMEWORK OF THE  
PINEY POINT-NANJEMOY AQUIFER AND AQUIA AQUIFER  
IN CALVERT AND ST. MARY'S COUNTIES,  
MARYLAND

by

Harry J. Hansen



Prepared in cooperation with  
the Boards of Commissioners of  
Calvert County and St. Mary's County

1996

COMMISSION  
OF THE  
MARYLAND GEOLOGICAL SURVEY

M. GORDON WOLMAN, CHAIRMAN  
F. PIERCE LINAWEAVER  
ROBERT W. RIDKY

## CONTENTS

	Page
Abstract . . . . .	1
Introduction . . . . .	3
Acknowledgements . . . . .	5
Regional setting . . . . .	5
Hydrostratigraphy . . . . .	5
Surficial aquifer . . . . .	5
Nomenclature . . . . .	5
Lithology and thickness . . . . .	5
Areal extent . . . . .	7
Hydrogeologic characteristics . . . . .	7
Upper confining bed . . . . .	7
Nomenclature, lithology, and thickness . . . . .	7
Areal extent . . . . .	8
Hydrologic characteristics . . . . .	8
Piney Point-Nanjemoy aquifer . . . . .	9
Nomenclature . . . . .	9
Lithology . . . . .	9
Basal beds of the Chesapeake Group (Calvert Formation) . . . . .	9
Unnamed upper Oligocene (?) beds . . . . .	9
Middle Eocene Piney Point Formation . . . . .	10
Upper part of the lower Eocene Nanjemoy Formation . . . . .	12
Areal extent and thickness . . . . .	13
Hydrogeologic characteristics . . . . .	13
Middle confining bed . . . . .	15
Nomenclature . . . . .	15
Lithology and thickness . . . . .	15
Areal extent . . . . .	15
Hydrogeologic characteristics . . . . .	16
Aquia aquifer . . . . .	16
Nomenclature . . . . .	16
Lithology . . . . .	16
Areal extent and thickness . . . . .	17
Hydrologic characteristics . . . . .	17
Lower confining bed . . . . .	19
Nomenclature . . . . .	19
Lithology and thickness . . . . .	19
Brightseat Formation . . . . .	19
Matawan and Monmouth Formations . . . . .	19
Patapsco Formation . . . . .	21
Areal extent . . . . .	21
Hydrologic characteristics . . . . .	21
Conclusions . . . . .	22
References . . . . .	22

CONTENTS—CONTINUED

	Page
Appendices	
Appendix A. On-site description of Solomons Island core hole (CA-Gd 60) . . . . .	25
Appendix B. Table of wells included in cross-sections A-A' and B-B' . . . . .	40

TABLE

	Page
Table 1. Generalized description of Tertiary hydrogeologic units underlying Calvert and St. Mary's Counties, Md. and their approximate correlation with geologic units . . . . .	6

FIGURES

	Page
Figure 1. Distribution of Lowland and Upland deposits in Calvert County and St. Mary's County, Md. and occurrence of paleochannels beneath Chesapeake Bay and the Potomac River . . . . .	4
2. Hydrogeologic cross-section A-A' extending from near Bristol, Anne Arundel County to near St. James, St. Mary's County . . . . .	Pocket
3. Hydrogeologic cross-section B-B' extending from near La Plata, Charles County, to Point Lookout, St. Mary's County . . . . .	Pocket
4. Isopach map showing approximate thickness of the Piney Point aquifer and cumulative sand thickness of the Nanjemoy Formation . . . . .	11
5. Structure contour map showing approximate depth to the top of the Piney Point-Nanjemoy aquifer . . . . .	14
6. Structure contour map showing approximate depth to the top of the Aquia aquifer . . . . .	18
7. Isopach map showing approximate thickness of the Aquia aquifer . . . . .	20

HYDROSTRATIGRAPHIC FRAMEWORK OF THE  
PINEY POINT-NANJEMOY AQUIFER AND AQUIA AQUIFER  
IN CALVERT AND ST. MARY'S COUNTIES,  
MARYLAND

by

Harry J. Hansen

ABSTRACT

Aquifers and confining beds underlying Calvert and St. Mary's Counties, Maryland were initially identified by correlation with lithostratigraphic units, including the Miocene Chesapeake Group, the Eocene Piney Point and Nanjemoy Formations, the Paleocene Marlboro Clay, and the Paleocene Aquia and Brightseat Formations. Although both formations and aquifers are mappable rock bodies, their boundary discontinuities (contacts) are different. A dual nomenclatural system can be ambiguous because geologically significant, sand-on-sand contacts are not defining boundaries in a hydraulic sense.

The following aquifer-confining bed sequence illustrates the need for stratigraphers and hydrogeologists to define their mapping units carefully in areas where a dual nomenclatural system is used:

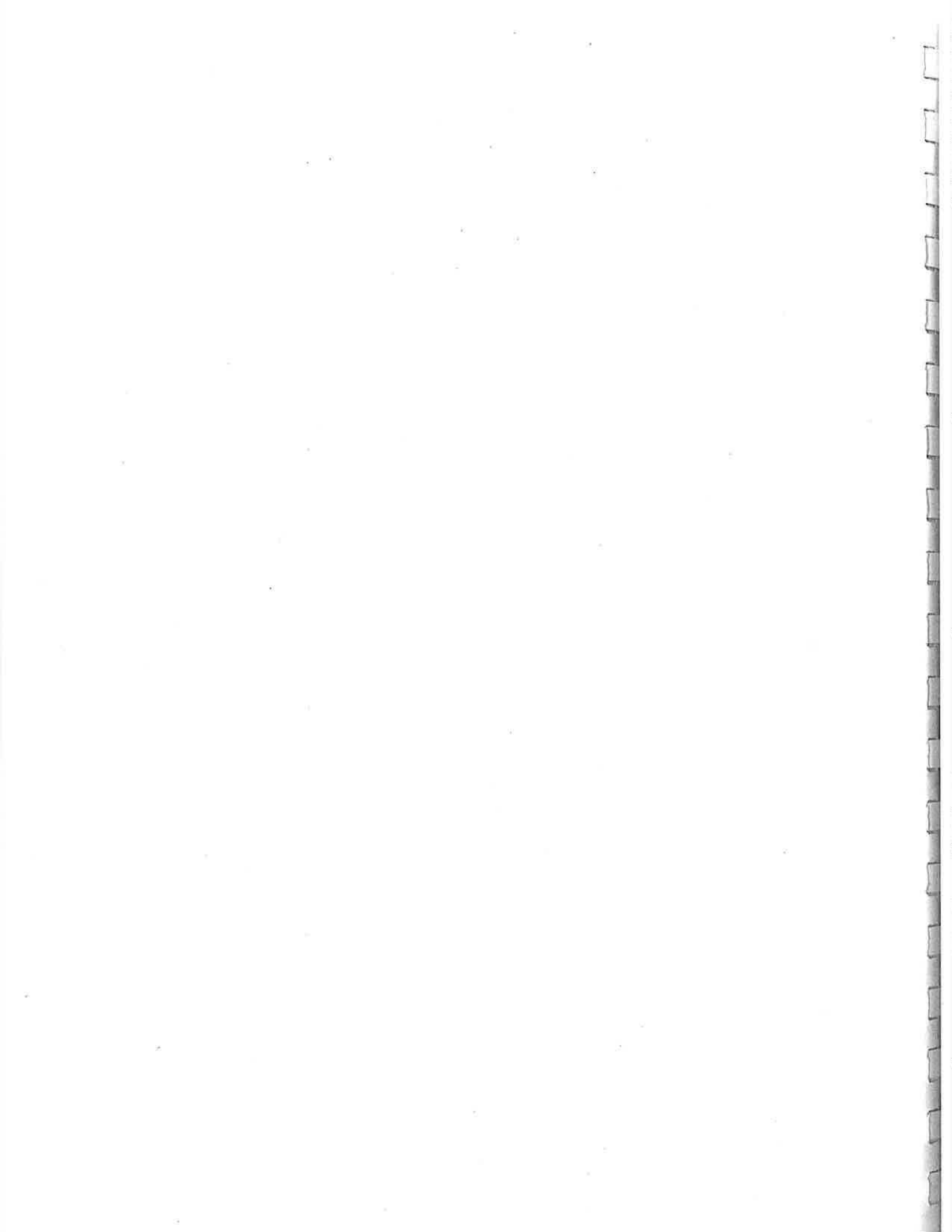
Upper Confining Bed—This unit consists of the undivided Chesapeake Group (St. Mary's, Choptank, and Calvert Formations), except for the basal beds of the Calvert Formation.

Piney Point-Nanjemoy Aquifer—Although the Piney Point aquifer and Nanjemoy aquifer can be differentiated on geophysical logs, they usually function as a single hydrologic unit, consisting of a basal sand of the Calvert Formation; unnamed, thin and patchy sands tentatively assigned to the Oligocene(?); the Piney Point Formation; and the upper, sandy facies of the Nanjemoy Formation.

Middle Confining Bed—This unit consists of fine-grained sediments in the lower part of the Nanjemoy Formation and the Marlboro Clay.

Aquia Aquifer—In Calvert and St. Mary's Counties, Md., the Aquia aquifer correlates with a major sand facies of the Aquia Formation, except for fine-grained sediments at the base of the unit that may be undifferentiated from the underlying confining bed.

Lower Confining Bed—The Paleocene Brightseat Formation overlies the truncated edges of various upper and lower Cretaceous units, creating a locally complex hydrostratigraphic unit that include fine-grained sediments occurring both above and below a regional unconformity.



## INTRODUCTION

Southern Maryland is a rapidly growing coastal plain area located south of Baltimore and west of the Chesapeake Bay. The southern part of this area (consisting of Calvert and St. Mary's Counties) is overwhelmingly dependent on ground water for potable supplies because the surrounding surface-water bodies are brackish and the small freshwater streams originating within the area lack adequate dam sites for reservoirs.

Systematically collected hydrogeologic, water-use, and water-level data are essential to define hydrologic conditions and implement effective ground-water development and management policies. Analysis of the complex interrelationships between these factors has been significantly enhanced by the development of computer-solved models. For example, Chapelle and Drummond (1983) described the hydrogeology of the Aquia and Piney Point aquifer system in Calvert and St. Mary's Counties and developed a digital ground-water flow model, calibrated against historical data collected through 1980. The calibrated model was used to simulate water-level responses to projected rates of future pumpage. During the last 15 years these predictions have provided valuable information to county and State officials involved in water-supply issues and ground-water allocation.

In order to provide comparable information over the next planning period, a project was initiated to recompile the Chapelle and Drummond (1983) ground-water model, verify its predictions against new field data, recalibrate it if necessary; and then make new predictive simulations using revised pumpage forecasts. This type of model validation is called a "postaudit" (Anderson and Woessner, 1992). During the postaudit the hydrogeologic framework of the Aquia and Piney Point-Nanjemoy aquifers was also reviewed in the light of recently published stratigraphic, biostratigraphic, and geophysical log data and modifications were made where warranted. The recalibrated Aquia-Piney Point aquifer model will be used to simulate future water-level trends through 2020 using alternative pumping scenarios (Achmad and Hansen, in preparation). The results of this project will help county water-resources managers plan for future growth and provide a scientifically sound basis for the State's evolving ground-water allocation policy.

Review of the hydrogeologic framework was incorporated into the postaudit in order to resolve ambiguities that have resulted from a nomenclatural system that uses lithostratigraphic names to identify hydrostratigraphic units. A hydrostratigraphic unit is "a mappable body of rock that is defined and identified on the basis of the nature, extent, and magnitude of its hydraulic conductivity and its boundary discontinuities" (Committee on Hydrostratigraphic Units, 1983). Because hydraulic continuity is a defining attribute, aquifers may consist of more than one geologic formation (Laney and Davidson, 1986).

In Maryland aquifers were historically correlated with lithostratigraphic units (formations and groups). These include the Eocene Piney Point-Nanjemoy aquifer and the Paleocene Aquia aquifer. Long-term usage has entrenched these names in the literature and given them legal status through the State's regulation of ground-water pumpage. Although both formations and aquifers are by definition mappable rock bodies, their boundary discontinuities (contacts) are different; the former is defined by lithic contrast and the latter by hydraulic discontinuity. A dual nomenclatural system can be misleading because it implies an exact correlation that often does not exist insofar as contacts of geologic importance may not be defining boundaries in a hydraulic sense (e.g., sand-on-sand contacts). Nomenclatures should be carefully compared to avoid ambiguity, particularly when the scale of investigation covers several counties.

The purpose of the following discussion is to define hydrostratigraphically the aquifers (and associated confining beds) underlying Calvert and St. Mary's Counties and to illustrate the need for hydrogeologists and stratigraphers to define their mapping units carefully so that misunderstandings can be minimized in areas where a dual nomenclatural system is used. Accurate lithostratigraphic analysis is important in ground-water studies to characterize aquifer parameters and to determine boundary conditions for flow modeling.

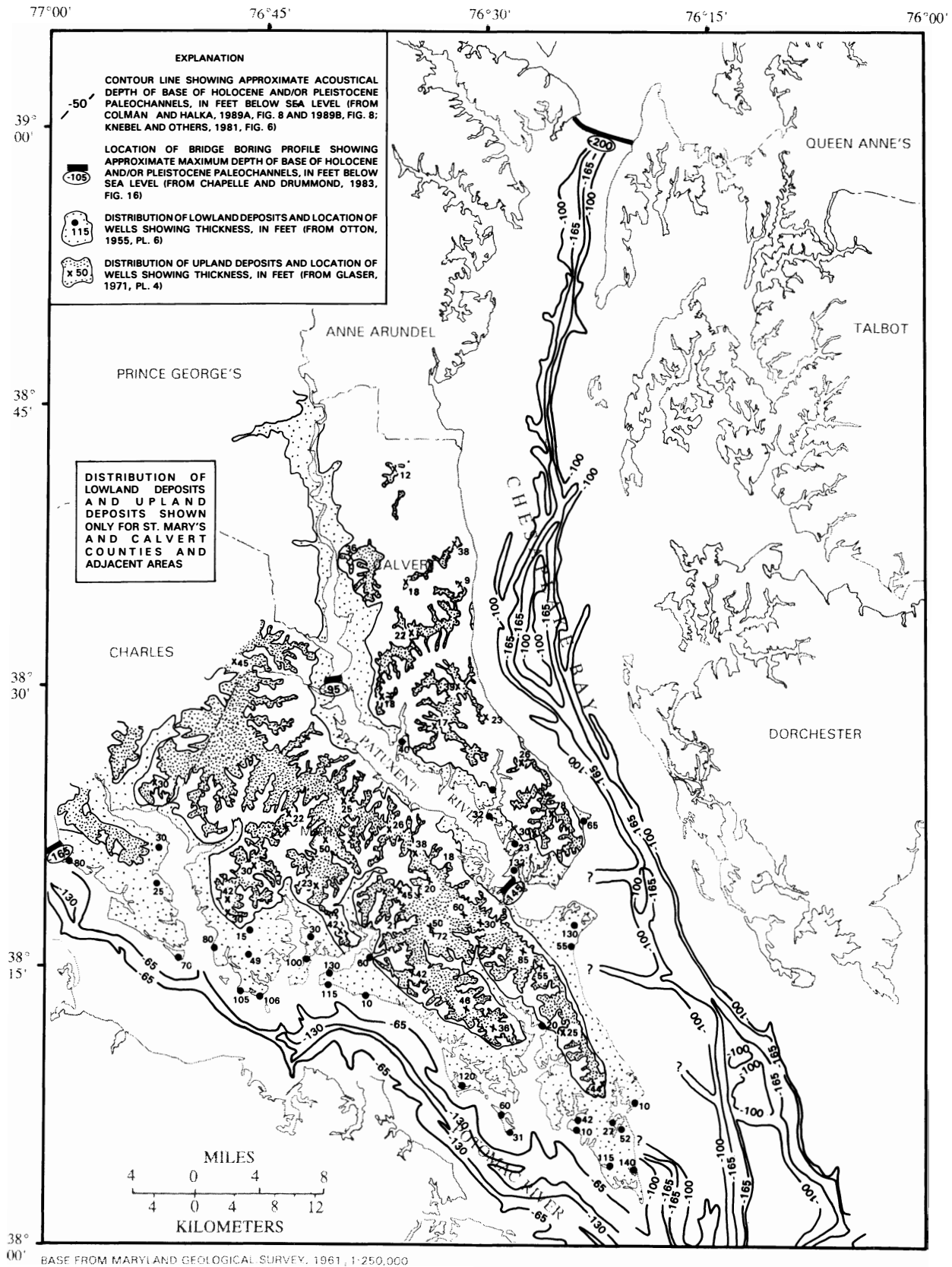


Figure 1. Distribution of Lowland and Upland deposits in Calvert County and St. Mary's County, Md. and occurrence of paleochannels beneath Chesapeake Bay and the Potomac River.

## ACKNOWLEDGEMENTS

This open-file report is largely abridged from a Maryland Geological Survey report that describes the hydrogeology and flow-model simulation of the Piney Point-Nanjemoy and Aquia aquifers in Calvert and St. Mary's Counties, Md. (Achmad and Hansen, in preparation). Funding for the project was provided by the Maryland Department of Natural Resources and the Boards of Commissioners of Calvert County and St. Mary's County.

The timely release to open-file status of lithologic and biostratigraphic data from core hole CA-Gd 60 located at Solomons in Calvert County helped to clarify the relationship between geologic and hydrogeologic units in the study area (Appendix A). The efforts of Thomas Gibson of the U.S. Geological Survey and his co-authors are appreciated (Gibson and Andrews, 1994; Gibson and Bybell, 1994).

Donajean Appel compiled Appendix B and prepared the report for printing. The illustrations were drafted by Barbara Cooper.

## REGIONAL SETTING

Calvert and St. Mary's Counties, Md. occur on the western shore of Chesapeake Bay and each form discrete peninsulas separated by the Patuxent River. St. Mary's County is separated from the northern neck of Virginia by the Potomac River (figure 1). The counties occur in a dissected coastal plain setting with upland elevations less than 200 feet above sea level. The formations underlying the Coastal Plain in Calvert and St. Mary's Counties have a total thickness of about 2100 ft and range in age from lower Cretaceous to Quaternary. The strike of the formations changes from northeasterly in northern Calvert County to north-south in southern St. Mary's County, reflecting the structural influence of the Salisbury Embayment, a major mid-Atlantic depocenter (Hansen, 1978). Strata dip to the southeast and east, generally less than 1 degree.

## HYDROSTRATIGRAPHY

### Surficial Aquifer

**Nomenclature:** The Surficial Aquifer (undivided) consists of two informal stratigraphic units, the Lowland Deposits and the Upland Deposits, which were mapped by Cleaves and others (1968) and described by Glaser (1971). More recently McCartan (1989) remapped St. Mary's County and subdivided both the Lowland Deposits and Upland Deposits into several new geologic formations (table 1). According to McCartan (1989), the units comprising the Lowland Deposits are Holocene to Pleistocene in age, while the Upland units are considered largely Pliocene.

**Lithology and Thickness:** Otton (1955, p. 104) states that the Lowland Deposits commonly consist of three lithologic units. The basal 10 to 20 feet are often logged as a cobbly sand and gravel. This unit is overlain by as much as 90 feet of bluish gray to dark brown clay that is silty or sandy in some places (Glaser, 1971, p. 35). The upper unit consists of 10 to 30 feet of pale gray, fairly clean, medium to coarse sand (Glaser, 1971, p. 36; Otton, 1955, p. 104). The Lowland Deposits are of fluvial to estuarine origin.

The Upland Deposits consist of two units of fluvial origin (Glaser, 1971, p. 31). The lower unit may be up to 70 feet thick and consists of interbedded pale yellowish gray to reddish brown, medium to coarse sand, pebbly sand, and sandy gravel; thin irregular beds of mottled red, gray, and purple silt and clay also occur. The

Table 1. Generalized description of Tertiary hydrogeologic units underlying Calvert and St. Mary's Counties, Md. and their approximate correlation with geologic units (modified from Weigle and Webb, 1970; Weigle, Webb, and Gardner, 1970; Chapelle and Drummond, 1983; and Hansen and Wilson, 1984).

Hydrogeologic Unit	Approximate Thickness (ft.)	Water-Bearing Characteristics	Lithologic Description	Geologic Unit	Series	System
SURFICIAL AQUIFER (undivided)	0-140	Yields limited quantities of water to large-diameter wells. Has potential for larger yields along southern shores of St. Mary's County but may be susceptible to salt-water intrusion.	Complexly stratified tan, brown, and gray clay, silt, medium to coarse sand, and gravel. Underlies near-shore areas below 80± feet above sea level.	Lowland Deposits <sup>1</sup>	Holocene to Pleistocene	Quaternary
	0-85	Limited saturated thickness. Yields moderate amounts of water to large-diameter wells. Commonly, streams have cut downward through the deposits permitting the deposits to drain rapidly.	Complexly stratified tan or orange clay, silt, and sand mixture in upper loam member, and sand and gravel in lower gravel member. Underlies dissected southeastward-sloping upland surfaces, between 80± and 200± feet above sea level.	Upland Deposits <sup>2</sup>	Pliocene	
UPPER CONFINING BED	60-270	Yields small amounts of water to wells. Functions as confining bed.	Olive gray, greenish brown, and light gray clays, sandy clays, and fine sands; fossiliferous. Lower beds may be diatomaceous.	Chesapeake Group (undivided)	Miocene	Tertiary
PINEY POINT AQUIFER	0-130	Primary source of water in southern Calvert and St. Mary's Counties where the Piney Point aquifer is hydraulically connected to the upper sandy portion of the Nanjemoy Formation.	Light gray to yellowish green, fine sand. May include phosphatic pebbles and shell clasts at basal contact.			
			Dusky brown to olive green clayey sand. Slightly glauconitic; fossiliferous. (Areal extent uncertain).	Unnamed <sup>3</sup>		
			Light gray to brownish-yellow, slightly glauconitic, medium to coarse sand; interbedded layers of shell and sand, locally cemented.	Piney Point <sup>4</sup> Fm.		
NANJEMOY AQUIFER	0-30	Secondary source of water in northern Calvert and St. Mary's Counties where the Piney Point aquifer is absent.	Sand, silt, and clay; blackish-green to gray; glauconitic; the upper portion of formation is sandy; the lower portion is predominantly silt and clay.	Nanjemoy Fm.	Eocene	
MIDDLE CONFINING BED	70-200	Yields small amounts of water to wells. Functions as a confining bed.	Pink, red, or gray plastic clay.	Marlboro Clay	?	
			Green to yellowish brown, medium grained, clayey, glauconitic sand with locally cemented shell beds	Aquia Fm.	Paleocene	
AQUIA AQUIFER	0-205	Primary source of water in Calvert County and St. Mary's County north of Kitts Point.				
LOWER CONFINING BED	20-105	Yields small amounts of water to wells. Functions as confining bed.	Gray to grayish black, micaceous, slightly glauconitic clay, silt, and fine sand. (Areal extent unknown).	Brightseat Fm.		
			Upper and Lower Cretaceous Units (undifferentiated)			

1. On the St. Mary's County geologic map the Lowland Deposits have been subdivided by McCartan (1989) into several geologic units including Holocene Deposits (undivided), Kent Island Formation (upper Pleistocene), Maryland Point Formation (upper Pleistocene), Omar Formation (upper Pleistocene), and Chicamuxen Church Formation (middle to lower Pleistocene).
2. On the St. Mary's County geologic map the Upland Deposits have been subdivided by McCartan (1989) into several geologic units including Park Hall Formation (upper Pliocene), Upland Gravel 4 (upper Pliocene), and Upland Gravel 3 (lower to upper Pliocene).
3. Ward (1985) has assigned very late Oligocene to very early Miocene (?) beds in Maryland to the Old Church Formation.
4. Olsson, Miller, and Ungrad (1980) have argued that the Piney Point Formation includes Oligocene beds.

upper member consists of yellowish to reddish brown poorly-bedded sandy clay to silty loam (Hack, 1955) and averages about 15 feet in thickness. The base of the Upland Deposits is channeled in places resulting in unusually thick occurrences logged near Lexington Park and in southern Calvert County (figures 1, 2, 3).

**Areal Extent:** The surface distribution of the Lowland Deposits in Calvert and St. Mary's Counties is displayed on the state geologic map (Cleaves, 1968). Otton (1955, pl. 6) had previously published a similar map of the Lowland Deposits, which also included thickness data from well logs. In both Calvert County and St. Mary's County the Lowland Deposits are generally found throughout the Patuxent River valley. Lowland Deposits fringe St. Mary's County along the Potomac River and the Chesapeake Bay, but only occur in a few places along the Calvert Cliffs in Calvert County (Ferguson, 1953; Otton, 1955) (figure 1). The Lowland Deposits extend beneath Chesapeake Bay and the Potomac River, filling deep, ancestral river channels with 200 or more feet of fluvial and estuarine sediments (Hack, 1957; Knebel and others, 1981; Colman and Halka, 1989a; 1989b). Onshore, Otton (1955, pl. 6) has suggested the occurrence of deep channels at the base of the Lowland Deposits in the Solomons area of Calvert County and in areas of St. Mary's County beneath the Patuxent Naval Air Test Center (at Lexington Park) and adjacent to the Potomac River (figure 1).

The Upland Deposits are areally more extensive in St. Mary's County than in Calvert County (Glaser, 1971, pl. 4) (figure 1). The distribution of the Upland Deposits has a distinctly dendritic aspect because the unit caps the higher interfluvial divides in the two-county area. Glaser (1971, p. 31) suggests that the Upland Deposits form a highly dissected sediment sheet whose base slopes southwesterly reaching an elevation of about 80 feet at its southern terminus in St. Mary's County.

**Hydrogeologic Characteristics:** In the past, the Surficial Aquifer was an important source of water in Calvert and St. Mary's Counties when dug or driven wells were widely used for domestic and farm supplies. However, nearly all new wells are drilled into the underlying artesian aquifers. The Upland Deposits are not a reliable source of water because of their relative thinness, limited saturated thickness (particularly during prolonged drought) and dissected topography which causes water to drain from the aquifer as small springs (Otton, 1955, pl. 3). Also the water is naturally irony and is vulnerable to contamination, particularly elevated concentrations of chloride, nitrate, and agricultural chemicals. Likewise the Lowland Deposits are not viewed as an important source of water. Otton (1955, p. 105) reports that the basal sand and gravel unit is commonly less than 20 feet thick; the water often has an irony or "otherwise unpleasant" taste; and the aquifer may be vulnerable to salt-water intrusion from near-by estuaries, if heavily pumped.

In the ground-water flow model of Chapelle and Drummond, (1983, p. 43) the Surficial Aquifer is treated as a constant-head boundary that provides recharge to underlying aquifers by vertical leakage through the Upper Confining Bed (table 1). Chapelle and Drummond (1983, p. 43) observed that hydrographs of water-table wells in southern Maryland indicate that over the long-term, water levels remain relatively constant, although short-term variations occur reflecting cyclical changes in precipitation and evapo-transpiration.

#### Upper Confining Bed

**Nomenclature, Lithology, and Thickness:** With the exception of a relatively thin sandy unit at its base, the Chesapeake Group (undivided) defines the Upper Confining Bed in this report (table 1). In Calvert and St. Mary's Counties the Chesapeake Group consists of three marine formations, from oldest to youngest, the Calvert Formation, Choptank Formation, and St. Mary's Formation. These units were originally established using biostratigraphic data, chiefly molluscan fossils (Shattuck, 1907a; 1907b), and are difficult to recognize in well logs. For this reason the formations of the Chesapeake Group are undifferentiated hydrostratigraphically. Glaser (1971) and Ferguson (1953) described the lithologic character of the three formations as follows:

<u>Formation</u>	<u>Lithologic Character</u>	<u>Approximate Thickness</u>
St. Mary's	Interbedded bluish gray silt-clay and fine argillaceous sand; glauconitic in part; fossiliferous	0 to 50 feet
Choptank	Interbedded bluish gray to grayish green silt-clay and abundantly fossiliferous, fine to medium sand	30 to 100 feet
Calvert	Olive gray to olive brown, fine argillaceous sand, silt, and clay; diatomaceous in lower part. Basal 10 to 20 feet locally consists of fine to medium sand with some gravel and phosphate pebbles, and shell fragments	150 feet

Additional sedimentologic and mineralogic information is reported by McCartan (1989). A lithologic description of the Calvert Formation cored at Solomons (CA-Gd 60) is given by Gibson and Andrews (1994, p. 21-28) (Appendix A).

**Areal Extent:** As shown in cross-section A-A' and B-B' (figures 2, 3), the Upper Confining Bed is present beneath the entire two-county area. In general the unit thickens from northwest to southeast, as younger beds wedge into the top of the section. This angular relationship can be observed by correlating the diatomaceous unit found within the lower part of the Upper Confining Bed. Correlation of the diatomaceous beds in the subsurface is facilitated by an unusual geophysical log aspect that combines a low gamma-radiation trace with low electrical resistivities. This characteristic reflects its fine-grained, siliceous (rather than clayey) lithology. For example, at Prince Frederick (CA-Db 47)<sup>1</sup> in central Calvert County the base of the diatomaceous unit is about 85 feet below sea-level and the thickness of the Upper Confining Bed is about 200 feet (figure 2). In contrast in well CA-Bb 27, located near Dunkirk in the northern part of the county, the upper confining bed has thinned to approximately 115 feet and the base of the diatomaceous unit occurs above sea-level. This general pattern is modified locally because the base of the overlying surficial aquifer may be deeply channeled in places, particularly beneath the Lowland Deposits that underlie the Chesapeake Bay estuaries and contiguous land areas (figure 1).

**Hydrogeologic Characteristics:** Chapelle and Drummond (1983, p. 14) noted that the confining beds in Calvert and St. Mary's Counties are important because they restrain leakage between aquifers and store significant quantities of water. Leakage is controlled by the thickness and vertical hydraulic conductivity of the confining beds. Chapelle and Drummond (1983, tab. 2) compiled from several sources vertical hydraulic conductivities<sup>2</sup> determined by laboratory analysis of core samples. Six values for the Chesapeake Group range from  $6.9 \times 10^{-10}$  ft/sec to  $2.95 \times 10^{-7}$  ft/sec (Hansen, 1977; Kapple and Hansen, 1976; Williams, 1979). The actual values used in Chapelle and Drummond's ground-water flow model were established through calibration procedures and fell within  $10^{-9}$  to  $10^{-10}$  ft/sec, except in channeled areas where higher values were assigned to accommodate infilled deposits of sand and gravel (Chapelle and Drummond, 1983, p. 45). In the absence of laboratory or field data, the specific storage of the Chesapeake Group is usually estimated in modeling studies and then calibrated by trial-and-error reiteration. Chapelle and Drummond (1983) used a specific storage<sup>3</sup> of  $10^{-5}$  ft<sup>-1</sup> and Williams (1979) used a value of  $6.0 \times 10^{-6}$  ft<sup>-1</sup> for the Chesapeake Group.

<sup>1</sup>A table of wells that are included in cross-sections A-A' and B-B' (figures 2 and 3) is contained in Appendix B.

<sup>2</sup>Hydraulic conductivity is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area (Lohman and others, 1972).

<sup>3</sup>Specific storage is the volume of water released from or taken into storage per unit volume of the porous medium per unit change in head (Lohman and others, 1972).

## Piney Point—Nanjemoy Aquifer

**Nomenclature:** The Piney Point-Nanjemoy aquifer is stratigraphically complex, consisting of several geologic units that have stacked, sand-on-sand contacts (table 1). From youngest to oldest the Piney Point-Nanjemoy aquifer includes basal strata of the lower to middle Miocene Chesapeake Group (Calvert Formation); unnamed, upper Oligocene(?) beds that may correlate with Ward's (1985) Old Church Formation; the middle Eocene Piney Point Formation; and the sandy, upper part of the lower Eocene Nanjemoy Formation. Generally speaking, the Piney Point aquifer of Williams (1979) and the Piney Point-Nanjemoy aquifer of Chapelle and Drummond (1983) include all of these units, although not explicitly stated.

Olsson, Miller, and Ungrady (1980) studied microfossil assemblages from several wells in southern Calvert and St. Mary's Counties and identified upper Oligocene strata, which they assigned to the "Piney Point" Formation. However, as Ward (1985, p. 46) pointed out, the upper Oligocene beds described by Olsson, Miller, and Ungrady (1980) appear to overlie the Piney Point Formation (Otton, 1955) at its type locality (well SM-Fe 31, figure 3). For this reason the upper Oligocene beds are left unnamed and the middle Eocene age of the Piney Point Formation is retained. Both units are included in the Piney Point aquifer.

### **Lithology:**

1. *Basal beds of the Chesapeake Group (Calvert Formation):* The Chesapeake Group is assigned to the upper confining bed, except for sandy sediments at the base of the Calvert Formation that are hydraulically connected to the underlying Piney Point-Nanjemoy aquifer. The basal beds are generally 10 to 20 feet thick and consist of yellowish green to greenish light gray, slightly glauconitic fine to medium, quartz sand; in places the basal beds contain shell fragments, phosphate pebbles, and fine gravel (Ferguson, 1953, p. 35; Gibson, 1983, p. 43). The basal beds of the Calvert Formation unconformably overlie older Oligocene and Eocene units and represent a major early Miocene marine transgression. Gibson (1982, p. 10) has observed at some sites two relatively thin, transgressive sands with similar lithologic characteristics. This occurrence may account for the dual gamma-ray log signature found in some well logs (e.g., SM-Fe 31, figure 3), although the presence of underlying upper Oligocene(?) strata of similar lithology may also account for the second spike. Gamma-radiation spikes exceeding background levels are often associated with authigenic minerals, such as phosphate pellets and glauconite that form by chemical processes on the sea-floor during periods of slow detrital sedimentation. Trace amounts of radioactive elements (uranium, thorium, and potassium) are incorporated into these minerals (Miller, 1982, p. 10; Woodruff, 1976, p. 39) producing characteristic gamma-radiation traces that can be used to correlate strata from well to well (figures 2, 3). Thin beds ("condensed sections") containing relatively high percentages of authigenic minerals are significant because of their association with depositional hiatuses, stratal unconformities, and marine transgressions (Loutit and others, 1988, p. 186; Amorosi, 1995, p. 419).

2. *Unnamed upper Oligocene(?) beds:* Based on the work of Olsson, Miller, and Ungrady (1980); Ward (1985); and Mixon and others (1989) it seems apparent that a thin interval of late Oligocene(?) age occurs near the top of the Piney Point-Nanjemoy aquifer at some places in Virginia and adjacent parts of Maryland. Ward (1985) has described 1 to 1.5-foot thick outcrop sections of the Old Church Formation at two sites in Maryland along the Patuxent River. At its type locality in Virginia, Ward (1985, p. 51) describes the Old Church as a 3-foot thick, grayish-olive, clayey, slightly glauconitic, fossiliferous quartz sand. Elsewhere he has noted the occurrence of phosphatic clasts (pebbles, bone, teeth) in the formation. Mixon and others (1989, p. A25) cored the Old Church Formation at a site near Haynesville, Va. about 17 miles southwest of Piney Point, Md<sup>4</sup>. The unit is 4 feet thick and consists of clayey, slightly glauconitic, fossiliferous olive-gray, coarse sand containing fine pebbles

---

<sup>4</sup>The Haynesville core hole is located in Richmond County, Va. 0.65 mile northwest of Haynesville at lat. 37°57'13" N, long. 76°40'26" W (Mixon and others, p. A2; fig. 1).

of phosphate. However, Gibson and Bybell (1994) failed to observe any Oligocene microfossils in the Solomons core hole (CA-Gd 60; figure 2) (Appendix A). Olsson, Miller, and Ungrady (1980, figure 3) believe that the upper Oligocene(?) beds thicken downdip, as suggested on cross-section B-B' (figure 3) between Piney Point (SM-Fe 31) and Point Lookout (SM-Gh 8).

Because the upper Oligocene(?) unit is thin and patchy, it is difficult to map in the subsurface using routinely available sample descriptions and geophysical logs. Consequently, the upper Oligocene(?) beds and the basal Calvert Formation are usually treated as one subsurface mapping unit, defined by a prominent gamma-ray log signature. Although separated from the underlying middle Eocene Piney Point Formation by a significant unconformity, the three formations are hydraulically connected across sand-on-sand contacts, forming a single aquifer (Piney Point aquifer).

3. *Middle Eocene Piney Point Formation*: Otton (1955) first applied the name Piney Point Formation to a sequence of shelly, glauconitic sands underlying the Calvert Formation in southern Calvert County and St. Mary's County. Initially considered late Eocene in age (Overbeck and others, 1951), the Piney Point Formation is now assigned to the middle Eocene (Brown, Miller, and Swain, 1972). It ranges in thickness from 0 feet to about 90 feet at Point Lookout (figure 4); typically, it includes carbonate-cemented interbeds of sand and shelly sand that range up to about 5 feet in thickness. Otton (1955) designated a well at Piney Point, Md. (St. Mary's County) as the formation's type locality. Although the site was not cored, the cuttings described by Otton (1955, p. 305) were bailed from a cable-tool (cased) well (SM-Fe 24) and are considered representative:

<u>Description</u>	<u>Depth Interval (ft.)</u>
Sand, medium-grained, slightly clayey, mottled gray to grayish green; quartz grains fine to coarse, clear, yellow and brown; glauconite light green to brown, medium; pyrite, fine, rare; agglomerates quartz and glauconite grains cemented by calcite ("rock" of drillers)	220-230
Sand, medium-grained, mottled gray to grayish green; quartz grains as above, subrounded to rounded; small pelecypod shells common; glauconite, oblate to botryoidal, green, light green, and brown; pieces indurated rock common	230-240
Sand, medium-grained, mottled gray to yellowish gray; glauconite, fine- to medium-grained, botryoidal to irregular; rock agglomerates common; small pelecypod shells	240-250
Sand, medium- to coarse-grained, mottled gray to grayish green, glauconitic; rock agglomerates common; forams common; small shell fragments common	250-260
Sand, medium- to coarse-grained, as above, glauconitic; quartz grains subrounded to rounded, yellow, clear, and pale brown; glauconite, botryoidal to irregular, green and olive-green; pyrite common; rock agglomerates common; few large forams	260-270

The Piney Point Formation cored at Solomons (CA-Gd 60) is about 45 feet thick and consists of interbedded, fine to medium quartzose sand and calcareous sandstones (Gibson and Bybell, 1994, p. 9) (Appendix A). The beds have a bioturbated aspect and are light olive-gray to dusky yellow-green; glauconite content varies from 5 to 20 percent. Clam shells and molds are abundant. Gibson and Bybell (1994, p. 9) also observed that amber and brown coarse sand and fine gravel occur in the lower beds of the Piney Point Formation (figure 2).

The Piney Point Formation overlies lower Eocene beds of the Nanjemoy Formation. Otton (1955) thought the units were conformable, representing an uninterrupted period of coarsening upward deposition. In the Solomons core hole (CA-Gd 60) neither the upper or lower contacts were recovered. In the absence of core

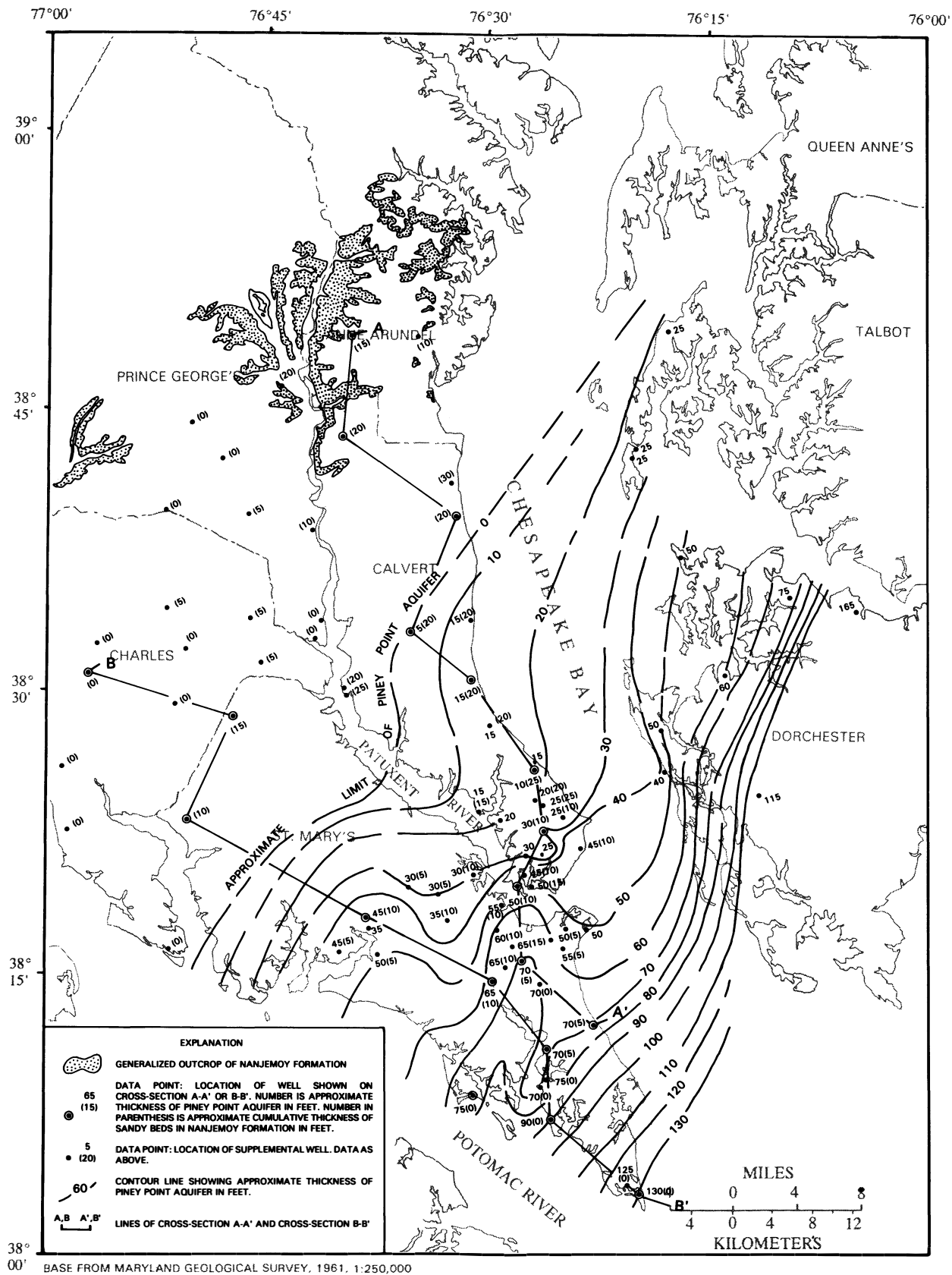


Figure 4. Isopach map showing approximate thickness of the Piney Point aquifer and cumulative sand thickness of the Nanjemoy Formation.

material the nature of the lower contact remains uncertain. On geophysical logs the contact with the Nanjemoy Formation is relatively abrupt, implying a depositional hiatus or unconformity.

4. *Upper Part of the Lower Eocene Nanjemoy Formation:* Although consisting of several depositional cycles separated by disconformities (Gibson and Bybell, 1994), the Nanjemoy Formation coarsens upward overall from dominantly sandy silts and clays to dominantly clayey sands, permitting it to be subdivided into two hydrostratigraphic units. The sandy upper Nanjemoy Formation is hydraulically connected to the overlying Piney Point Formation and following Chapelle and Drummond (1983) is assigned to the Piney Point-Nanjemoy aquifer. The more clayey sediments in the lower part of the Nanjemoy Formation are placed in the Middle Confining Bed. The hydrostratigraphic contact at the base of the Piney Point-Nanjemoy aquifer is somewhat arbitrarily drawn in cross-sections A-A' and B-B' (figures 2, 3) using geophysical log correlations. Gibson and Bybell (1994, p. 5) also subdivide the Nanjemoy Formation into two members, but placed the contact lower using biostratigraphic and sedimentologic criteria.

Otton (1955, p. 305) described the Nanjemoy Formation in the Piney Point type well (SM-Fe 24) as follows:

<u>Description</u>	<u>Depth Interval (ft.)</u>
UPPER PART	
Sand, clayey, grayish olive; quartz grains commonly pale brown and yellow, subrounded; glauconite abundant, oblate to irregular, brown to dark green, shiny; forams scarce; pyrite very scarce	270-280
Sand, clayey, grayish olive; brown to yellow quartz grains very common; brown irregular to botryoidal glauconite very common; small forams, rare	280-290
Sand, clayey, olive gray; brown subrounded to rounded quartz grains common; brown and dark green botryoidal glauconite common; small forams, rare	290-300
LOWER PART	
Clay, sandy, dark greenish gray; quartz, coarse-grained, subrounded, green, clear, and brown, dull to moderate lustre; glauconite, green-black, botryoidal, coarse-grained, abundant; small amount oblate brown glauconite; sponge spicules rare; few forams; pyrite, fine, rare	300-340
Clay, sandy, dark greenish gray; quartz, as above, slightly coarser, pale green, clear, white and yellow; glauconite, green-black; pyrite, fine, rare; sponge spicules rare; few large forams; mica rare	340-360
Clay, sandy, dark greenish gray, and clay, pale yellowish-brown; glauconite, green-black, botryoidal, coarse; pyrite, fine, rare; few pieces pink calcite; forams rare	360-380
Clay, sandy, dark greenish gray, similar to above; few pieces of "rock"; forams rare	380-390

Gibson and Bybell (1994, p. 8) reported that the upper part of the Nanjemoy Formation at Solomons consists of grayish-green clayey, fine to medium sand with relatively thin, sandy clay intervals. Glauconite varies from less than 10 percent to as much as 50 percent. The beds are highly bioturbated, but few shells are present. At Solomons the coarse clastic component of the upper Nanjemoy Formation includes polished, amber to brown, grains (probably iron-stained quartz, phosphate, and/or goethite).

In the Haynesville, Va. core hole, Mixon and others (1989, p. A21) observed that the greenish gray to olive black lower member of the Nanjemoy Formation is a cohesive, very poorly sorted, clayey and silty glauconitic sand and sandy clay-silt. The upper member is mainly dark olive gray, fine to coarse, sparsely shelly, glauconitic quartz sand that is coarser, less glauconitic, and more micaceous than the lower member of the Nanjemoy Formation.

**Areal extent and thickness:** The structure of the Coastal Plain sediments to a large degree controls the areal extent of the Piney Point-Nanjemoy aquifer. The Coastal Plain units dip gently to the southeast and east (figure 5) with the deeper formations generally dipping more steeply than the shallower formations. As a result, the units of the Piney Point-Nanjemoy aquifer are truncated by low-angle unconformities occurring at the base of the Chesapeake Group or upper Oligocene(?) deposits (figures 2, 3).

The Piney Point aquifer is thickest (130 feet) at Point Lookout (figure 4) where undifferentiated basal Miocene to upper Oligocene(?) beds and the Piney Point Formation attain their maximum thickness in southern Maryland. The Piney Point aquifer thins up-dip diminishing to 60 to 70 feet at Lexington Park, 45 to 50 feet at Solomons, 35 to 45 feet at Leonardtown, and about 5 feet at Prince Frederick (figures 2, 3, 4). The approximate limit of the Piney Point aquifer trends southeasterly through central Calvert County and northern St. Mary's County (figure 4). The upper Oligocene(?) and basal Miocene beds at the top of the Piney Point aquifer extend north of this line, but are too thin and patchy to define a primary aquifer in the absence of the Piney Point Formation.

Although most high-capacity wells pumping from the Piney Point-Nanjemoy aquifer are actually screened in the Piney Point Formation, Williams (1979) and Chapelle and Drummond (1983) included the upper part of the Nanjemoy Formation in their ground-water models because the units are viewed as hydraulically connected. Figure 4 shows the approximate cumulative thickness of sands in the Nanjemoy Formation determined by geophysical logs. Like the Piney Point Formation, the Nanjemoy Formation is truncated up-dip by Oligocene(?) and Miocene unconformities. In cross-sections A-A' and B-B' (figures 2, 3), it is evident that most, if not all, of the upper part is absent in northern Calvert (CA-Bb 27) and St. Mary's Counties (SM-Bb 26). In these areas (and adjacent parts of Charles, Prince George's, and Anne Arundel Counties) the cumulative sand thicknesses shown on figure 4 characterize the lower Nanjemoy Formation whereas for the rest of St. Mary's and Calvert Counties the cumulative sand thicknesses for the upper part are shown.

The Nanjemoy Formation in southern Maryland becomes more sandy northeastwardly. For example, at sites along the Potomac River in southern St. Mary's County the upper part has cumulative sand percentages in the range of 0 to 5 feet, but in Calvert County at sites along the Chesapeake Bay sand thicknesses have increased to 20 to 30 feet. Likewise, the lower part, which is nearly devoid of sand beds in Charles County, changes to a more sandy facies in northern Calvert County and southern Anne Arundel County where cumulative thicknesses increase to 10 to 20 feet (figure 4). In Calvert County north of the Piney Point truncation many domestic wells have been completed in the upper part of the Nanjemoy Formation (Drummond, 1984).

**Hydrogeologic Characteristics:** Williams (1979, pl. 5) reported six pumping tests for the Piney Point-Nanjemoy aquifer in Calvert and St. Mary's Counties southeast of the Piney Point truncation. Transmissivity<sup>4</sup> values derived from these tests range between 275 and 690 ft<sup>2</sup>/day. Williams (1979) supplemented these data with about 90 values estimated from specific capacities<sup>5</sup> derived from well completion reports; these values ranged from 125 to 740

---

<sup>4</sup>Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman and others, 1972).

<sup>5</sup>Specific capacity of a well is the rate of discharge of water from the well divided by the drawdown of water level in the well (Lohman and others, 1972). It varies slowly with duration of discharge which should be stated.

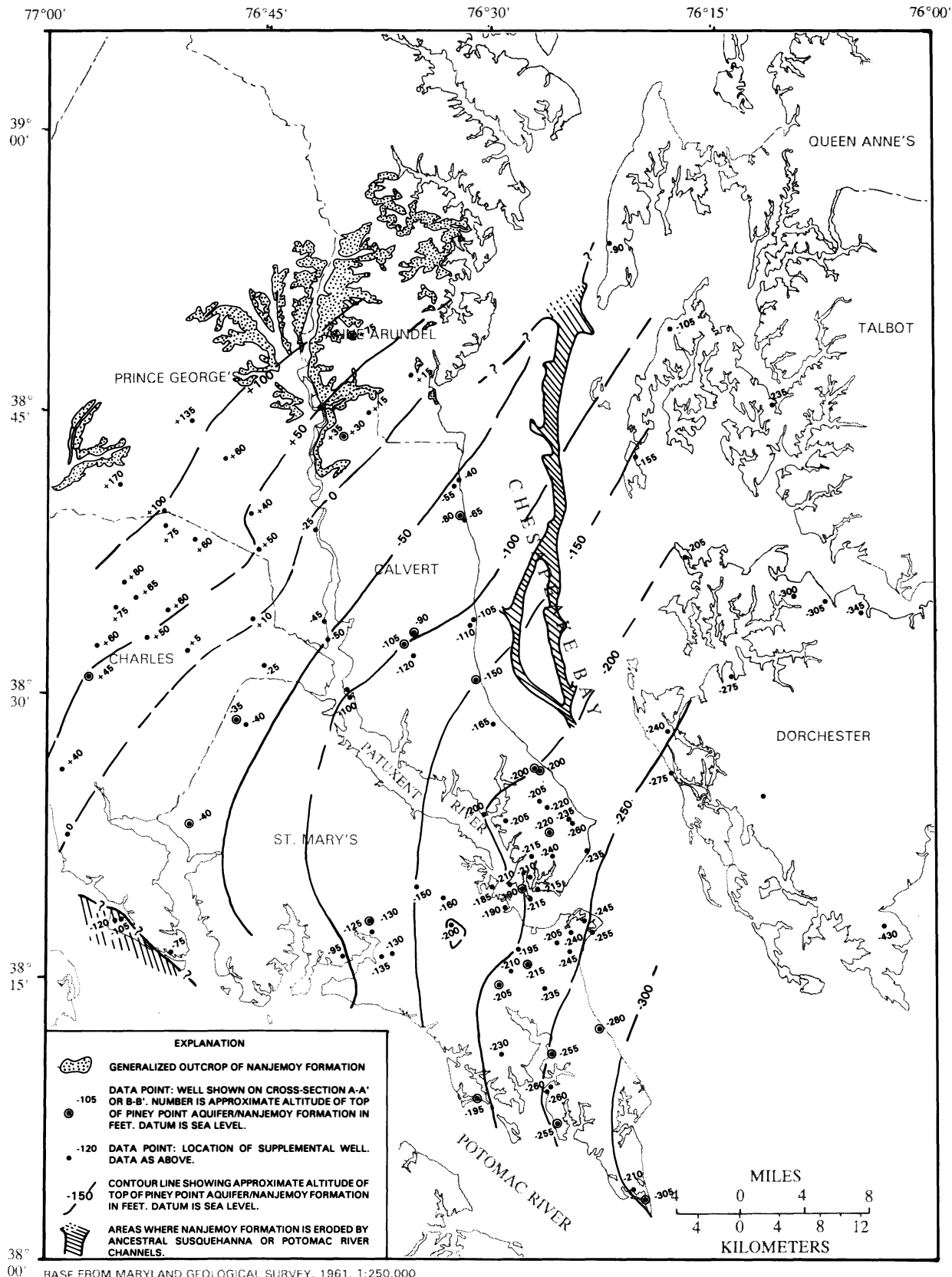


Figure 5. Structure contour map showing approximate depth to the top of the Piney Point-Nanjemoy aquifer.

ft<sup>2</sup>/day. Williams (1979, pl. 5 and figure 5) mapped these data and pointed out that the highest transmissivity values (in south central Calvert County) did not correspond to the thickest part of the aquifer (in southernmost St. Mary's County). Because transmissivity is the product of thickness and hydraulic conductivity (or "permeability"), the incongruence may be explained by differences in aquifer texture that affects the latter characteristic. For example, thicker and more frequent occurrences of cemented strata would significantly reduce transmissivity. Likewise a downdip change to finer sands with more clayey matrix would adversely affect transmissivity even though the aquifer increased in thickness. Chapelle and Drummond (1983, figure 10) modified Williams' map to show that north of the truncation line transmissivities of the Piney Point-Nanjemoy aquifer decrease to less than 100 ft<sup>2</sup>/day. In these areas the aquifer consists solely of basal Miocene and upper Oligocene(?) beds and/or the upper part of the Nanjemoy Formation. Few storage coefficient<sup>6</sup> values for the Piney Point-Nanjemoy Aquifer in southern Maryland have been determined. Hansen (1972) suggested a range of 0.0003 to 0.0004. Williams (1979, p. 13, 28) reported a range of storage coefficient values of 0.00009 to 0.0004, but used a global value of 0.0003 for his ground-water flow model. Chapelle and Drummond (1983, p. 23, 44) calculated a storage coefficient of 0.0004 from a multi-well pumping test near Leonardtown in St. Mary's County and used that value throughout their ground-water flow model.

### Middle Confining Bed

**Nomenclature:** The Middle Confining Bed consists of the lower part of the Nanjemoy Formation (early Eocene) and the underlying Marlboro Clay (late Paleocene) (table 1). Formerly, the Marlboro Clay was thought to be early Eocene in age and was considered a member of the Nanjemoy Formation (Darton, 1948). However, because the pinkish facies of the Marlboro Clay is easily recognizable and widely distributed, Glaser (1971, p. 14) elevated it to formational rank. Ward (1985, p. 25) reviewed the micropaleontologic evidence and assigned the Marlboro Clay to the late Paleocene, although recognizing that the Eocene—Paleocene boundary may occur within the unit (Gibson and others, 1980, p. 24).

**Lithology and Thickness:** The Marlboro Clay occurs at the base of the Middle Confining Bed. The Marlboro varies in thickness from 0 to 30 feet and is described by Glaser (1971, p. 14) as a silvery-gray to pale-red plastic clay interbedded with subordinate yellowish gray to reddish silt; he notes that where the unit is relatively thick the reddish-brown facies typically occurs in the middle portion. The contact between the Marlboro Clay and the underlying Aquia Formation is transitional with greenish glauconitic sand observed in cores to be interlaminated with light brown or silvery gray clay (Glaser, 1971, p. 14; Hansen, 1977, p. 9; Reinhart, Newell, and Mixon, 1980, fig. 5). The upper contact with the Nanjemoy Formation is an erosional unconformity, often disrupted by fossil burrow tubes (Glaser, 1971, p. 14; Gibson and Bybell, 1994, p. 9).

The lower part of the Nanjemoy Formation is predominantly a pale-gray to greenish gray, glauconitic, very fine, muddy sand to sandy clay. It ranges in thickness from about 45 to 170 feet. On geophysical logs it has few recognizable sand beds, except in northern Calvert County and southern Anne Arundel County where cumulative thicknesses increase to as much as 20 feet (figure 4). In the Solomons core hole (CA-Gd 60) the lower beds of the Nanjemoy Formation are dark greenish black to olive black sand to silty clay with occasional, fine sandy intervals. It is highly bioturbated, but no shells were described. Glauconite is abundant and may comprise most of the sand fraction (Gibson and Bybell, 1994, p. 8).

**Areal Extent:** The structure of the Coastal Plain and facies changes in the Nanjemoy Formation and Marlboro Clay control the areal extent of the Middle Confining Bed in Calvert and St. Mary's Counties. In cross-sections

---

<sup>6</sup>Storage coefficient is the volume of water released from or taken into storage per unit surface area of the porous medium per unit change in head (Lohman and others, 1972).

A-A' and B-B' (figures 2, 3), the Middle Confining Bed deepens and thins southeastwardly, reflecting depositional and structural patterns associated with the Salisbury embayment in Maryland (Hansen, 1978). For example, in St. Mary's County the unit is about 200 feet thick at Charlotte Hall and only 70 feet thick at Piney Point; in Calvert County a similar southeastwardly change occurs between Randle Cliff (170 feet) and Solomons (110 feet). Contributing to the increased thickness of the Middle Confining Bed in northern St. Mary's County and adjacent Charles County is a clayey facies change in the upper Nanjemoy beds, which causes these strata to function hydraulically like the lower beds.

At up-dip localities like LaPlata (CH-Ce 51), Dunkirk (CA-Bb 27), and Bristol (AA-Fd 49) the Upper Confining Bed (Chesapeake Group) rests directly on the Middle Confining Bed (lower Nanjemoy Formation) due to erosional truncation of the Piney Point-Nanjemoy aquifer. At these sites the Aquia aquifer is overlain by a composite confining unit (figures 2, 3).

In St. Mary's County south of Lexington Park the reddish-pink facies of the Marlboro Clay thins and is often missing from the stratigraphic section. In its absence the base of the Middle Confining Bed is difficult to map, particularly south of Kitts Point (SM-Ff 36) and St. James (SM-Eg 28) (figures 2, 3) where the Aquia aquifer thins and changes to a clayey facies. At Point Lookout (SM-Gh 8), for example, where the Aquia aquifer is absent, the middle and lower confining units have merged to hydraulically separate the overlying Piney Point-Nanjemoy aquifer from underlying lower Cretaceous sands of the Patapsco Formation (figure 3).

**Hydrogeologic Characteristics:** The Marlboro Clay is usually much "tighter" than the sandy clays and muddy sands of the Nanjemoy Formation, although few laboratory tests for vertical hydraulic conductivity have been performed. Kapple and Hansen (1976, p. 22) reported a range from  $7.9 \times 10^{-7}$  ft/sec to  $7.6 \times 10^{-8}$  ft/sec for the Nanjemoy Formation. On the other hand, laboratory values of vertical hydraulic conductivity for the Marlboro Clay have been consistently lower:  $3.0 \times 10^{-10}$  to  $5.2 \times 10^{-9}$  ft/sec (Kapple and Hansen, 1976, p. 22);  $1.1 \times 10^{-9}$  to  $5.2 \times 10^{-9}$  ft/sec (Hansen, 1977, p. 8); and  $6.7 \times 10^{-10}$  to  $1.1 \times 10^{-9}$  ft/sec (Chapelle and Drummond, 1983, p. 14). Generally, the tightest unit is considered to be the effective factor controlling vertical leakage. Ground-water flow models described by Chapelle and Drummond (1983) and Kapple and Hansen (1976) were calibrated using vertical hydraulic conductivity values of  $10^{-9}$  to  $10^{-10}$  ft/sec, and  $1.6 \times 10^{-10}$  ft/sec, respectively.

Specific storage values assigned to the Middle Confining Bed in the ground-water models described by Chapelle and Drummond (1983) and Kapple and Hansen (1976) are  $10^{-5}$  ft<sup>-1</sup> and  $7.6 \times 10^{-5}$  ft<sup>-1</sup> respectively; Hansen (1977) reported laboratory-derived values for the Marlboro Clay of  $10^{-5}$  to  $1.1 \times 10^{-4}$  ft<sup>-1</sup>.

#### Aquia Aquifer

**Nomenclature:** In southern Maryland the Aquia aquifer correlates with the late Paleocene Aquia Formation (Hansen, 1974), which in earlier reports was named the Aquia greensand because of the near ubiquitous occurrence of the mineral glauconite (Overbeck and others, 1951; Ferguson, 1953; Otton, 1955); early Paleocene beds in the area are thin and consist largely of silty, fine to very fine sandy strata assigned to the Brightseat Formation. In this paper the Brightseat Formation is included in the Lower Confining Bed. Elsewhere in Maryland (for example, on the upper Delmarva Peninsula) the early Paleocene section is thicker and more sandy. Thus in Kent and Queen Anne's Counties (located east of Chesapeake Bay) the Aquia aquifer consists of both the Aquia Formation and the underlying Hornerstown Formation, a possible coeval facies of the Brightseat Formation of southern Maryland (Drummond, 1988; Hansen, 1992).

**Lithology:** Generally speaking, the Aquia Formation is a poorly to well sorted, variably shelly and glauconitic quartz sand, containing thin calcareously cemented sandstone and shell beds (Mixon and others, 1989, p. A7).

The indurated beds ("ledges") are usually 1 to 3 feet thick (Wright and Huffman, 1979). The Aquia Formation was deposited on a shoaling marine shelf, resulting in an overall coarsening upward lithology (Drobnyk, 1965; Glaser, 1971, p. 13). For example, in the Haynesville, Va. core hole (Mixon and others, 1989, p. A9) the lower quarter of the Aquia consists mainly of poorly sorted, light to dark olive gray, clayey, fine to medium glauconitic quartz sand, weakly cemented in part. On the other hand, the upper three-quarters of the Aquia is described by Mixon and others (1989, p. A12) as consisting of moderately to well-sorted, medium to coarse, glauconitic sand. These beds have a "salt and pepper" or speckled appearance due to the mix of light colored quartz grains and greenish to blackish glauconite grains; a yellowish brown aspect is imparted by the relative abundance of iron-stained grains and brownish goethite pellets, which characterizes a sandbank facies in the upper Aquia Formation (Hansen, 1974, p. 44).

In the Solomons core hole the Aquia Formation is about 150 feet thick. Gibson and Bybell (1994, p. 7) noted that the lower part is "commonly clayey, fine grained sand containing some silty, sandy clay intervals. The middle and upper part is somewhat coarser grained, containing fine to medium sand, which is only slightly clayey." They further observe that "thin, shelly sandstone beds are common throughout the formation. Glauconite occurs throughout the formation, varying in abundance from several percent to as much as 50 percent. Goethite grains also are common in the upper part of the formation, where they may comprise 10 to 20 percent of the sand fraction. Quartz grains may be stained green or orange. Shells, particularly thick-shelled clams, are scattered throughout the formation. The Aquia has a burrowed contact with the underlying Brightseat Formation" (Appendix A).

**Areal Extent and Thickness:** The Aquia aquifer underlies all of Calvert County and, except for the Point Lookout area, all of St. Mary's County. It dips southeasterly, increasing in depth from -265 feet at Charlotte Hall to -430 feet below sea level at Lexington Park (figure 6). In southern Maryland the Aquia aquifer is thicker (and more coarsely textured) in a lobate area covering southern Anne Arundel County, northern and central Calvert County, and adjacent parts of St. Mary's County (figure 7). Within this area, which generally defines a sandbank facies (Hansen, 1974, figure 27), the thickness of the Aquia aquifer ranges from about 150 feet to over 200 feet. The Aquia aquifer continues to thicken northeastward where in Talbot and Queen Anne's Counties it approaches 250 feet. In part this is due to the composite nature of the Aquia aquifer in those areas where the Aquia Formation and underlying Hornerstown Formation are hydraulically connected.

South of Piney Point and St. Mary's City in St. Mary's County (and seaward of the sandbank facies), the Aquia aquifer thins as the formation grades into dominantly fine-grained sediments (figures 3, 7). For example, at Kitts Point (SM-Ff 36) the Aquia aquifer is about 40 feet thick, while at Point Lookout (SM-Gh 8) it is unrecognizable on geophysical logs. Apparently seaward of the sandbank facies the Aquia Formation grades into a thin, very clayey facies characteristic of deeper-water deposition. Hydraulically, the Aquia Formation functions as a confining bed in southernmost St. Mary's County.

West of the sandbank facies (e.g., in central Charles County), the Aquia aquifer is also thinner (CH-Ce 51, figure 3), although still exceeding 100 feet in thickness. Here the sands are typically finer grained, more clayey and less well sorted (Hansen, 1974), suggestive of deposition in a protected shelfal environment landward of the sandbank facies. Hydrogeologically, the Aquia functions as an aquifer, but is used only for domestic supplies in most areas of Charles County and adjacent Prince George's County.

**Hydrologic Characteristics:** Kapple and Hansen (1976, figure 9) and Chapelle and Drummond (1983, figure 5) have presented maps showing the distribution in southern Maryland of Aquia transmissivity values derived from pumping tests. Their transmissivity maps show a general conformity to the Aquia thickness map (figure 7) with values highest in areas where the aquifer is thickest. Following the traverse of cross-section A-A' (figure 2), for example, transmissivities diminish southward from 1,330 ft/day near Randle Cliff; 875 to 1,060 ft/day near

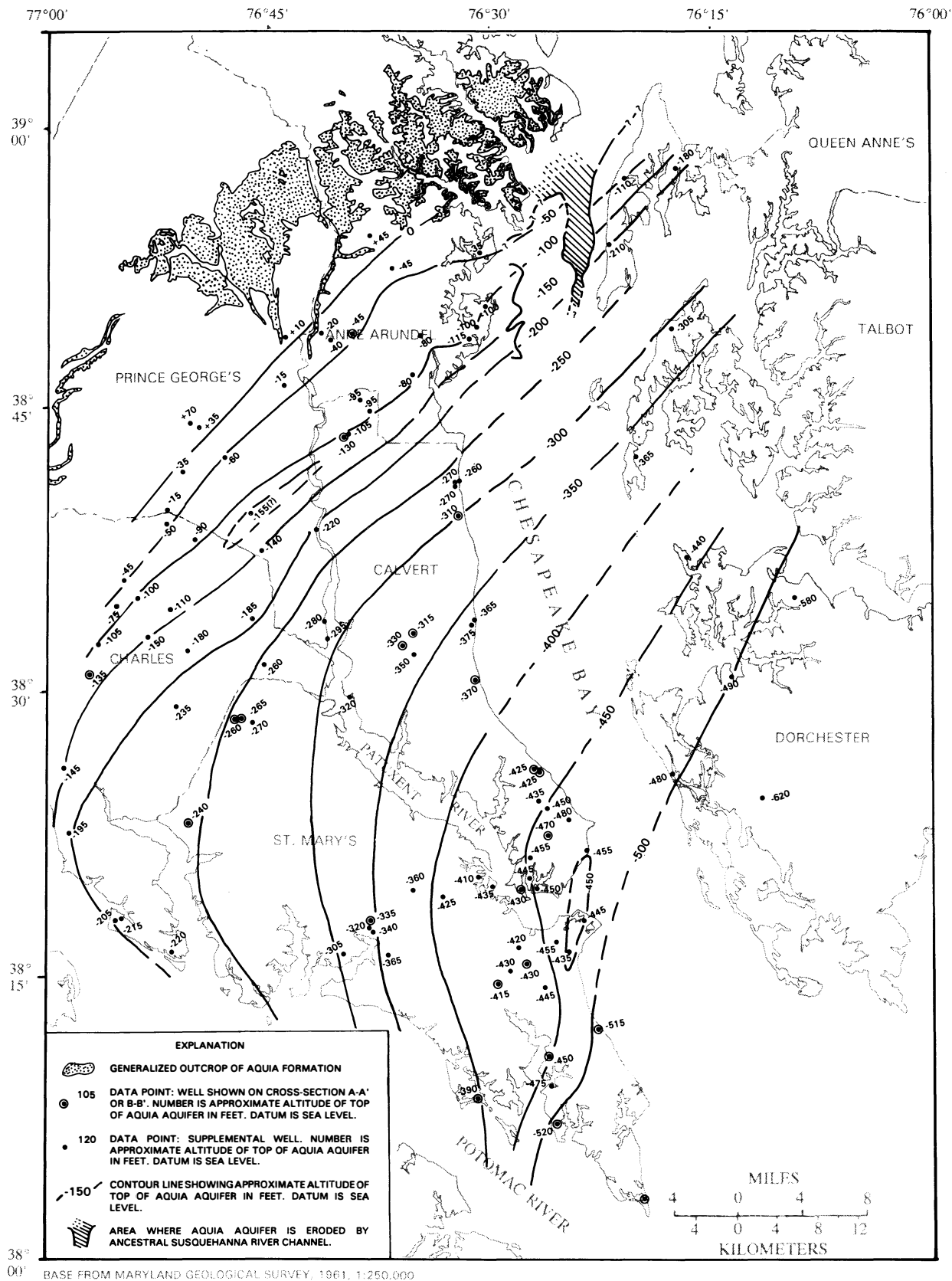


Figure 6. Structure contour map showing approximate depth to the top of the Aquia aquifer.

Scientists Cliffs; 935 ft/day at the Calvert Cliffs Power Plant and Chesapeake Ranch Estates; to 755 ft/day at Solomons. Except for the southernmost areas of St. Mary's County where the Aquia aquifer is too clayey to pump, the reported transmissivities (like aquifer thickness) do not vary much. No pumping tests have been reported from northern St. Mary's County, but elsewhere in the county Chappelle and Drummond (1983, figure 5) report transmissivities of 885 ft/day at Hollywood, 665 ft/day at Leonardtown, 800 ft/day at Lexington Park, 850 ft/day at Piney Point, and 670 to 750 ft/day at St. Mary's City; further south at Kitts Point transmissivity is only 365 ft/day and at Point Lookout there is no screenable aquifer material.

Storage coefficient values of the Aquia aquifer in southern Maryland determined by pumping tests range from 0.0001 to 0.0004 (Hansen, 1972). Chappelle and Drummond (1983, p. 44) applied a uniform value of 0.0004 for the confined portion of the Aquia aquifer in their ground-water flow model. Kapple and Hansen (1976, p. 20) used a model-value of 0.0003, which was arbitrarily increased to 0.003 in southernmost St. Mary's County where the Aquia changes to a clayey facies.

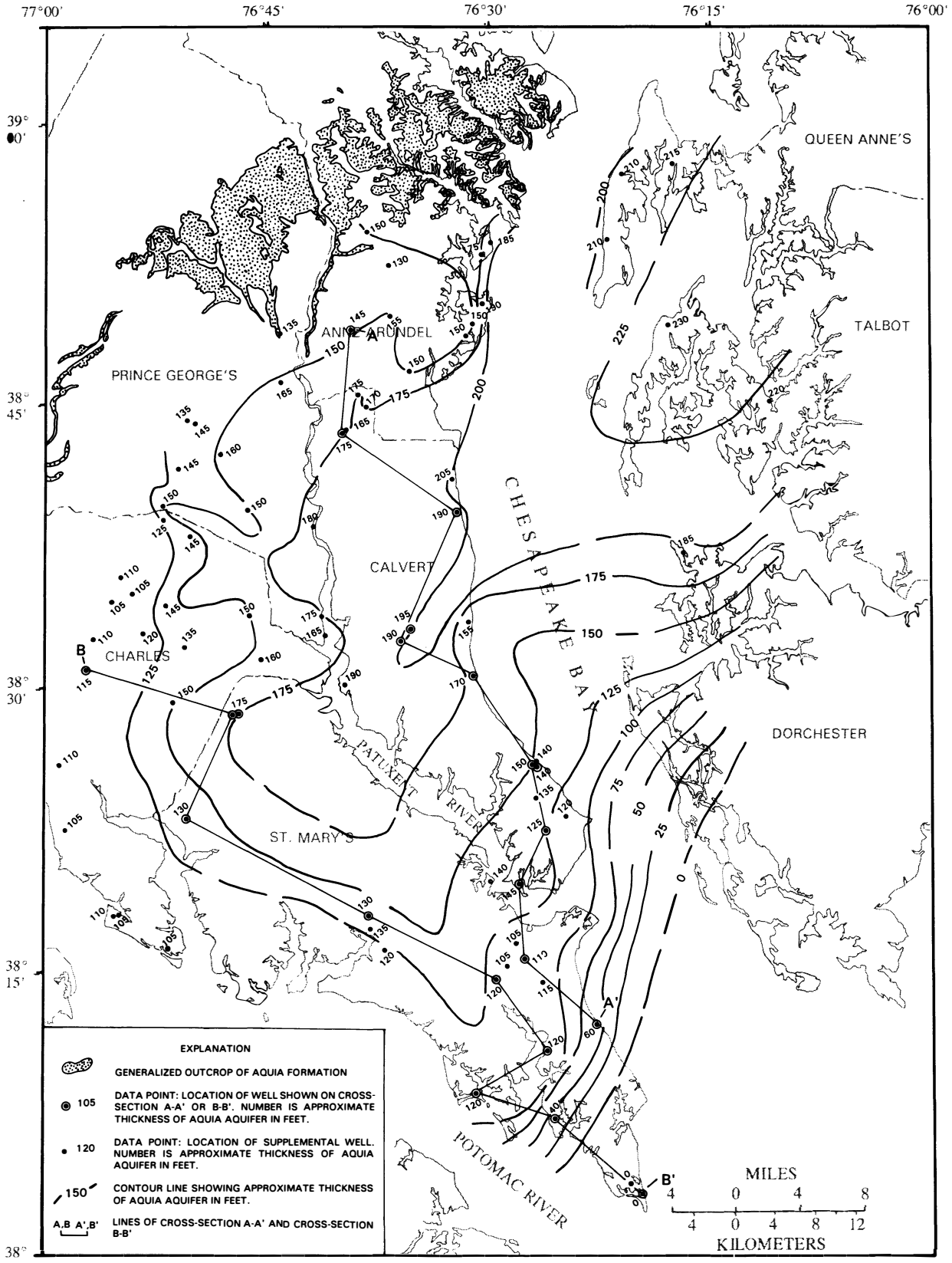
### Lower Confining Bed

**Nomenclature:** The confining bed underlying the Aquia aquifer is composed of several geologic units, which in places may also function as aquifers. These include the lower Paleocene Brightseat Formation and several Cretaceous units that are truncated by a major unconformity at the base of the Paleocene section. The latter include, from youngest to oldest, the upper Cretaceous Monmouth, Matawan, and Magothy Formations; and the lower Cretaceous Patapsco Formation (cross-section A-A', figure 2). In most areas of Calvert and St. Mary's Counties one or more of the Cretaceous units combine with the Brightseat Formation to form a composite confining bed of variable, and sometimes unpredictable, thickness. Adding to the complexity of the Lower Confining Bed is the likelihood that the muddy, fine sands occurring at the base of the Aquia Formation are hydraulically indistinguishable from the underlying Brightseat Formation, although separated stratigraphically by an unconformity.

**Lithology and Thickness:** The Lower Confining Bed consists of several geologic units and has a composite thickness ranging from about 20 feet to 105 feet. The units comprising the Lower Confining Bed are from youngest to oldest:

1. *Brightseat Formation:* Although relatively thin (up to about 25 feet), the Brightseat Formation is widely distributed in Calvert and St. Mary's Counties (Ward, 1985, figure 6). It is generally described as an olive gray to blackish, clayey, very fine to fine sand, commonly micaceous and/or phosphatic (Otton, 1955, p. 70; Glaser, 1968, p. 16; Ward, 1985, p. 6; Gibson and Bybell, 1994, p. 7). It can be differentiated from the overlying Aquia Formation by the absence or sparse occurrence of glauconite. The Aquia—Brightseat contact is a burrowed unconformity where Glaser (1968, p. 6) has observed phosphatic granules and pebbles. Its contact with underlying Cretaceous units is also unconformable and in places includes a basal layer of phosphatic clasts (Glaser, *in* Mack, 1974, p. 62). Because the Brightseat is a thin formation bounded by unconformities (where authigenic minerals such as phosphate concentrate) its gamma-ray log signature has a characteristic peak that is useful for correlation (figures 2, 3). In some wells, such as SM-Ef 56, (figure 3) and CA-Fd 71 (figure 2), primary and secondary peaks are observed, perhaps defining the formations' upper and lower contacts.

2. *Matawan and Monmouth Formations:* The upper Cretaceous Matawan Formation and Monmouth Formation are undifferentiated in this report. The combined thickness of the unit ranges from about 0 to 85 feet in Calvert and St. Mary's Counties. It is chiefly a gray to grayish black micaceous, sandy clay with subordinate clayey, fine sand. Thin (about 1 foot) siderite-cemented layers have been observed in the Matawan Formation, which tends to be less glauconitic than the sandier Monmouth Formation.



BASE FROM MARYLAND GEOLOGICAL SURVEY, 1961, 1:250,000

Figure 7. Isopach map showing approximate thickness of the Aquia aquifer.

3. **Patapsco Formation:** In Calvert and St. Mary's Counties the lower Cretaceous Patapsco Formation of fluvio-deltaic origin (Hansen, 1968) consists of complexly stratified sequences of anastomosing channel sands and fine-grained overbank deposits. The Patapsco sands are mostly fine to medium-grained, with occasional coarse sands logged; grayish in color with some brownish iron-oxide staining; and chiefly quartzose, with lesser occurrences of feldspar and mica. The Patapsco clays are gray and greenish gray, but often are mottled brown, maroon, red, and orange. Thin carbonaceous seams and blebs are common in the more clayey sediments (Hansen and Wilson, 1984, p. 24-25). Only the clayey strata at the top of the Patapsco Formation are included in the Lower Confining Bed of this report; these beds range in thickness from 0 to about 70 feet.

**Areal Extent:** From Anne Arundel County southward the Cretaceous units underlying the Brightseat Formation are progressively truncated (Hansen, 1978, figures 12, 13). In southern Anne Arundel County and northern Calvert County the Aquia aquifer is separated from the underlying Magothy aquifer by a confining bed consisting of 100 or more feet of undifferentiated Brightseat Formation, Monmouth Formation, and Matawan Formation. As shown in cross-section A-A' (figure 2), the Lower Confining Bed thins to less than 50 feet in the vicinity of Prince Frederick. In southern Calvert County the Lower Confining Bed is relatively thin and consists largely of the Brightseat Formation (figure 2). Most of St. Mary's County is south of where the Monmouth, Matawan, and Magothy Formations terminate so that the thickness of the Lower Confining Bed varies depending upon whether the Brightseat Formation overlies a Patapsco clay or sand (figure 3). Because the Magothy aquifer is present only in northernmost St. Mary's County, the Lower Confining Bed separates the Aquia aquifer from Patapsco sands elsewhere in the county.

Based on sparse biostratigraphic data from side-wall cores Hansen and Wilson (1984) suggested that at Lexington Park (SM-Df 84, figure 2) an early Paleocene aquifer occurred between the Brightseat Formation and the Patapsco Formation, possibly a marginal marine facies of the Brightseat or Hornerstown Formations. Meng and Harsh (1988) and Vroblesky and Fleck (1991) assigned these sands to the Brightseat aquifer, which correlates across the Potomac River into the northern neck of Virginia. Later, however, biostratigraphic data from continuous core holes drilled near Haynesville, Va. (Mixon and others, 1989) and Solomons, Md. (CA-Gd 60, figure 2) (Gibson and Bybell, 1994, p. 9) failed to corroborate the early Paleocene age of the aquifer. Both investigators reported finding plant microfossils associated with the Patapsco Formation. Consequently, it is possible that the side-wall cores sampled by Hansen and Wilson (1984) were contaminated by up-hole (Paleocene) material during the coring process; if so, the *in situ* material was barren because no Patapsco floral assemblages were found. In any event the "early Paleocene" aquifer of Hansen and Wilson (1984), Meng and Harsh (1988), and Vroblesky and Fleck (1991) is tentatively reassigned in this report to the upper part of the Patapsco Formation.

**Hydrogeologic Characteristics:** Neither Kapple and Hansen (1976) or Chappelle and Drummond (1983) modeled leakage through the confining bed underlying the Aquia aquifer. Both assumed it was a no-flow boundary. Therefore, although leakage was "calibrated" in both models using pumpage and water-level data neither one actually "verified" the hydrogeologic characteristics of the confining beds. Achmad and Hansen (in preparation) also assign a no-flow boundary to the base of the Aquia aquifer.

A few vertical hydraulic conductivity and specific storage values from consolidation tests of core samples have been reported. A Brightseat core from central Prince George's County yielded hydraulic conductivity and specific storage values of  $1.1 \times 10^{-8}$  ft/sec and  $7.4 \times 10^{-5}$ /ft respectively (Hansen, 1977, p. 12). Mack (1974, tab. 3) reported hydraulic conductivities for the Matawan Formation in the Annapolis area ranging from  $6.6 \times 10^{-10}$  ft/sec to  $3.6 \times 10^{-9}$  ft/sec; a lithified Matawan core sample has a reported value of  $2.9 \times 10^{-10}$  ft/sec. Mack also reported a hydraulic conductivity value of  $1.2 \times 10^{-10}$  ft/sec for a Patapsco clay sample. Mack and Achmad (1986, p. 37, 42) modeled the Magothy—Patapsco aquifer system in Anne Arundel County and calibrated the model using hydraulic conductivities of  $8.3 \times 10^{-11}$  to  $1 \times 10^{-10}$  ft/sec and a specific storage of  $10^{-5}$ /ft for the

Patapsco confining beds. Patapsco confining beds modeled by Wilson and Fleck (1990, p. 50) in Charles County were assigned leakance values (defined as hydraulic conductivity divided by thickness) of  $10^{-11}$  to  $10^{-13}$  (ft<sup>3</sup>/sec)/ft<sup>3</sup>.

## CONCLUSIONS

It would be preferable to have separate nomenclatures for aquifers and formations, but the current names are widely used in Maryland and have legal status in the State's ground-water appropriation regulations. More than likely, dual nomenclatures will continue to exist in Maryland as elsewhere. The areal extent and characteristics of the Eocene Piney Point-Nanjemoy aquifer and Paleocene Aquia aquifer underlying Calvert and St. Mary's Counties, Md. illustrate the need for stratigraphers and hydrogeologists to define carefully their mapping units in order to minimize ambiguities resulting from a dual nomenclatural system. For example, thin, sandy units assigned to the basal Calvert Formation (Miocene) and unnamed beds of Oligocene(?) age overlie the Piney Point Formation unconformably, forming a hydrostratigraphic unit that hydraulically interacts across sand-on-sand contacts. In up-dip areas of Calvert County the Piney Point Formation is truncated, so that for modeling purposes the Piney Point-Nanjemoy aquifer consists of sandy beds of the upper Nanjemoy Formation overlain unconformably by thin and patchy basal Miocene and Oligocene(?) sands.

The Aquia Formation, on the other hand, correlates largely with the Aquia aquifer, except in southern St. Mary's County, where the unit thins and changes to a fine-grained facies. The Aquia Formation in this area forms part of a composite confining bed, which hydraulically separates the Piney Point-Nanjemoy aquifer from underlying lower Cretaceous sands.

## REFERENCES

- Achmad, G. and Hansen, H. J., in preparation, Hydrogeology and model simulation of the Aquia and Piney Point-Nanjemoy aquifers in Calvert and St. Mary's Counties, Maryland: Maryland Geological Survey Report of Investigations.
- Amorosi, A., 1995, Glaucony and sequence stratigraphy: A conceptual framework of distribution in siliciclastic sequences: *Journal of Sedimentary Research*, vol. B65, no. 4, p. 419-425.
- Anderson, M. P. and Woessner, W. W., 1992, The role of the postaudit in model validation: *Advances in Water Resources*, vol. 15, p. 167-173.
- Brown, P. M., Miller, J. A., and Swain, F. M., 1972, Structural and stratigraphic framework and spatial distribution of permeability of the Atlantic Coastal Plain, North Carolina to New York: U.S. Geological Survey Professional Paper 796, 79 p.
- Chapelle, F. H. and Drummond, D. D., 1983, Hydrogeology, digital simulation, and geochemistry of the Aquia and Piney Point-Nanjemoy aquifer system in Southern Maryland: Maryland Geological Survey Report of Investigations No. 38, 100 p.
- Cleaves, E. T. and others, 1968, Geologic map of Maryland: Maryland Geological Survey, (1:250,000 scale).
- Colman, S. M. and Halka, J. P., 1989a, Maps showing Quaternary geology of the northern Maryland part of the Chesapeake Bay: U.S. Geological Survey Map MF-1948-D (1:125,000 scale).
- \_\_\_\_\_, 1989b, Maps showing Quaternary geology of the southern Maryland part of the Chesapeake Bay: U.S. Geological Survey Map MF-1948-C (1:125,000 scale).
- Committee on Hydrostratigraphic Units, 1983, Committee activities *in* The Hydrogeologist—Newsletter of the Hydrogeologic Division of the Geological Society of America, July 1983, p. 3.
- Darton, N. H., 1948, The Marlboro Clay: *Economic Geology*, vol. 43, p. 154-155.
- Drobnyk, J. W., 1965, Petrology of the Paleocene-Eocene Aquia formation of Virginia, Maryland, and Delaware: *Journal of Sedimentary Petrology*, vol. 35, p. 626-642.

- Drummond, D. D., 1984, Records of selected wells, Calvert and St. Mary's Counties, Maryland: Maryland Geological Survey Basic Data Report No. 14, 117 p.
- \_\_\_\_\_, 1988, Hydrogeology, brackish-water occurrence, and simulation of flow and brackish-water movement in the Aquia aquifer in the Kent Island area, Maryland: Maryland Geological Survey Report of Investigations No. 51, 131 p.
- Ferguson, H. F. and others, 1953, The water resources of St. Marys County: Maryland Department of Geology, Mines and Water Resources Bulletin 11, 195 p.
- Gibson, T. G., 1982, Depositional framework and paleoenvironments of Miocene strata from North Carolina to Maryland *in* Scott, T. M. and Upchurch, S. B., editors, Miocene of the southeastern United States: Florida Bureau of Geology Special Publication No. 25, p. 1-22.
- \_\_\_\_\_, 1983, Stratigraphy of Miocene through lower Pleistocene strata of the United States Atlantic Coastal Plain *in* Ray, C. E., editor, Geology and paleontology of the Lee Creek Mine, North Carolina, I: Smithsonian Institution Press, Washington, D.C., p. 35-80.
- Gibson, T. G. and others, 1980, Biostratigraphy of the Tertiary strata of the core *in* Geology of the Oak Grove core: Virginia Division of Mineral Resources Publication 20, Part 2, p. 14-30.
- Gibson, T. G. and Andrews, G. W., 1994, Miocene stratigraphy of the Solomons Island, Maryland corehole: U.S. Geological Survey Open-File Report 94-683, 35 p.
- Gibson, T. G. and Bybell, L. M., 1994, Paleogene stratigraphy of the Solomons Island, Maryland corehole: U.S. Geological Survey Open-File Report 94-708, 39 p.
- Glaser, J. D., 1968, Coastal Plain geology of Southern Maryland: Maryland Geological Survey Guide Book No. 1, 56 p.
- \_\_\_\_\_, 1971, Geology and mineral resources of Southern Maryland: Maryland Geological Survey Report of Investigations No. 15, 85 p.
- Hack, J. T., 1955, Geology of the Brandywine area and origin of the upland of Southern Maryland: U.S. Geological Survey Professional Paper 267-A, 41 p.
- \_\_\_\_\_, 1957, Submerged river system of Chesapeake Bay: Geological Society America Bulletin, vol. 68, no. 7, p. 817-830.
- Hansen, H. J., 1968, Depositional environments of subsurface Potomac Group in southern Maryland: American Association of Petroleum Geologists Bulletin, vol. 53, no. 9, p. 1923-1937.
- \_\_\_\_\_, 1972, A user's guide for the artesian aquifers of the Maryland Coastal Plain—Part Two, Aquifer characteristics: Maryland Geological Survey Open-File Report 72-02-1, 123 p.
- \_\_\_\_\_, 1974, Sedimentary facies of the Aquia Formation in the subsurface of the Maryland Coastal Plain: Maryland Geological Survey Report of Investigations No. 21, 47 p.
- \_\_\_\_\_, 1977, Geologic and hydrologic data from two core holes drilled through the Aquia Formation in Prince George's and Queen Anne's Counties, Maryland: Maryland Geological Survey Open-File Report 77-02-1, 77 p.
- \_\_\_\_\_, 1978, Upper Cretaceous (Senonian) and Paleocene (Danian) pinchouts on the south flank of the Salisbury Embayment, Maryland, and their relationship to antecedent basement structures: Maryland Geological Survey Report of Investigations No. 29, 36 p.
- \_\_\_\_\_, 1992, Stratigraphy of upper Cretaceous and Tertiary sediments in a core-hole drilled near Chesterville, Kent County, Maryland: Maryland Geological Survey Open-File Report No. 93-02-7, 38 p.
- Hansen, H. J. and Wilson, J. M., 1984, Summary of hydrogeologic data from a deep (2,678 ft) well at Lexington Park, St. Mary's County, Maryland: Maryland Geological Survey Open-File Report No. 84-02-1, 61 p.
- Kappler, G. W. and Hansen, H. J., 1976, A digital simulation model of the Aquia aquifer in Southern Maryland: Maryland Geological Survey Information Circular No. 20, 34 p.
- Knebel, H. J. and others, 1981, Sedimentary framework of the Potomac River estuary, Maryland: Geological Society America Bulletin, Part I, vol. 92, p. 578-589.
- Laney, R. L. and Davidson, C. B., 1986, Aquifer-nomenclature guidelines: U.S. Geological Survey Open-File Report 86-534, 46 p.

- Lohman, S. W. and others, 1972, Definitions of selected ground-water terms—revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.
- Loutit, T. S. and others, 1988, Condensed sections: The key to age determination and correlation of continental margin sequences, *in* Wilgus, C. K. and others, editors, Sea-level changes—an integrated approach: Society of Economic Paleontologists and Mineralogists Special Publication 42, p. 183-213.
- Mack, F. K., 1974, An evaluation of the Magothy aquifer in the Annapolis area, Maryland: Maryland Geological Survey Report of Investigations No. 22, 75 p.
- Mack, F. K. and Achmad, G., 1986, Evaluation of the water-supply potential of aquifers in the Potomac Group of Anne Arundel County, Maryland: Maryland Geological Survey Report of Investigations No. 46, 111 p.
- McCartan, L., 1989, Geologic map of St. Mary's County: Maryland Geological Survey (1:62,500 scale).
- Meng, A. A., III and Harsh, J. F., 1988, Hydrogeologic framework of the Virginia coastal plain: U.S. Geological Survey Professional Paper 1404-C, C82 p.
- Miller, J. A., 1982, Stratigraphy, structure, and phosphate deposits of the Pungo River Formation of North Carolina: North Carolina Department of Natural Resources—Geologic Survey Section Bulletin 87, 31 p.
- Mixon, R. B. and others, 1989, Lithostratigraphy and molluscan and diatom biostratigraphy of the Haynesville cores—Outer Coastal Plain of Virginia *in* Mixon, R. B., editor, Geology and paleontology of the Haynesville cores—northeastern Virginia coastal plain: U.S. Geological Survey Professional Paper 1489, p. A7-A48.
- Olsson, R. G., Miller, K. G., and Ungrady, T. E., 1980, Late Oligocene transgression of middle Atlantic Coastal Plain: *Geology*, vol. 8, p. 549-554.
- Otton, E. G., 1955, Ground-water resources of the Southern Maryland Coastal Plain: Maryland Department of Geology, Mines and Water Resources Bulletin 15, 347 p.
- Overbeck, R. M. and others, 1951, The water resources of Calvert County: Maryland Department of Geology, Mines and Water Resources Bulletin 8, 100 p.
- Reinhardt, J., Newell, W. L., and Mixon B. B., 1980, Tertiary lithostratigraphy of the core *in* *Geology of the Oak Grove core*, Virginia Division of Mineral Resources Publication 20, Part 1, p. 1-13.
- Shattuck, G. B., 1907a, The Chesapeake Group *in* St. Mary's County report: Maryland Geological Survey, p. 68-80.
- \_\_\_\_\_, 1907b, The Chesapeake Group *in* Calvert County report: Maryland Geological Survey, p. 70-92.
- Vroblecky, D. and Fleck, W. B., 1991, Hydrogeologic framework of the Coastal Plain of Maryland, Delaware, and the District of Columbia: U.S. Geological Survey Professional Paper 1404-E, E45 p.
- Ward, L. W., 1985, Stratigraphy and characteristic mollusks of the Pamunkey Group (lower Tertiary) and Old Church Formation of the Chesapeake Group—Virginia Coastal Plain: U.S. Geological Survey Professional Paper 1346, 78 p.
- Weigle, J. M. and Webb, W. E., 1970, Southern Maryland—records of selected wells, water levels, and chemical analyses of water: Maryland Geological Survey Basic Data Report No. 4, 48 p.
- Weigle, J. M., Webb, W. E., and Gardner, R. A., 1970, Water resources of southern Maryland: U.S. Geological Survey Atlas HA-365 (3 sheets).
- Williams, J. F., III, 1979, Simulated changes in water level in the Piney Point aquifer in Maryland: Maryland Geological Survey Report of Investigations No. 31, 50 p.
- Wilson, J. M. and Fleck, W. B., 1990, Geology and hydrologic assessment of coastal plain aquifers in the Waldorf area, Charles County, Maryland: Maryland Geological Survey Report of Investigations No. 53, 138 p.
- Woodruff, K. D., 1976, Selected logging data and examples of geophysical logs for the coastal plain of Delaware: Delaware Geological Survey Report of Investigations No. 25, 40 p.
- Wright, T. O. and Huffman, A. C., 1979, Correlation of indurated beds in the Paleocene Brightseat and Aquia Formations, Prince George's County, Maryland: *Journal of Sedimentary Petrology*, vol. 49, no. 1, p. 315-320.

## APPENDIX A

### On-site description of Solomons Island core hole (CA-Gd 60) (modified from Gibson and Andrews, 1994; Gibson and Bybell, 1994)

The sediment and rock colors, where used, are from the Geological Society of America's "Rock Color Chart." Depth is in feet below land surface. Altitude of land surface is approximately 15 feet above sea level.

#### LOWLAND DEPOSITS

0-28 ft: No coring. Descriptions from rotary drilled cuttings.

0-1 ft: Gray clay, massive, with about 10 percent fine to coarse quartz sand.

1-8 ft: Brownish-gray clayey sand becoming coarser toward the bottom.

8-16 ft: No description available.

16-26 ft: Becomes more sandy, with gray, very fine sand and gravel.

#### CHESAPEAKE GROUP (CALVERT FORMATION):

26-28 ft: Light-greenish-gray, very fine sand with abundant shell.

Started coring at 28-ft depth.

RUN 1, 28-37 ft:

9-ft core run, 0.2-ft recovery.

28-28.2 ft:

Indurated sand that blocked core barrel.

28.2-37 ft: No recovery.

Drilling bit at end of barrel contained bluish clay suggesting that probably entire run was through Miocene beds.

RUN 2, 37-47 ft:

10-ft core run, 2-ft recovery.

37-39 ft:

SAND, very fine to fine, slightly clayey, massively bedded with abundant shell material; barnacle fragments most abundant, but has clams that look like *Ensis*; several inch-long pieces of wood near bottom; medium-gray-green.

39-47 ft: No recovery.

47-60 ft:

Drillers reamed out hole, mistakenly went 10 ft past targeted depth of 50 ft, no samples over this interval.

RUN 3, 60-66 ft:

6-ft core run, 3-ft recovery.

60-63 ft:

SAND, very fine, clayey, silty, massively bedded, with bioturbated fabric, fairly abundant shell; shells generally in lenses 1/2 to 1 inch thick; some pecten shells that are probably *Chesapecten nefrens* and also some *Turritella*; medium-dark-gray-green.

63-66 ft: No recovery.

RUN 4, 66-76 ft:

10-ft core run, 1-ft recovery.

66-67 ft:

SAND, very fine, clayey, silty, massively bedded; scattered fine shell; medium-dark-gray-green.

67-76 ft: No recovery.

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 5, 76-86 ft:

10-ft core run, 9.3-ft recovery.

76-85.3 ft:

SAND, very fine, silty, clayey; highly bioturbated fabric; very scattered shell in upper 5 ft, more shell in lower 4 ft, both scattered and in layers, including abundant *Turritella*; medium-gray-green.

85.3-86 ft: No recovery.

RUN 6, 86-96 ft:

10-ft core run, 7-ft recovery.

86-89 ft:

SAND, very fine, clayey, silty; some scattered shell; bioturbated fabric; bed appears to be continuation of above unit, has large *Turritella* at top; medium-gray-green; this interval appears to represent a transition to finer grained sediments below that are darker in color and do not have any shell material.

89-93 ft:

CLAY, very fine, sandy and silty, massively bedded; no shells; medium-dark-gray-green; unit is both darker in color and lacks the bioturbated fabric of the above unit.

93-96 ft: No recovery.

RUN 7, 96-106 ft:

10-ft core run, 10-ft recovery.

96-101 ft:

SILT, clayey with some silty clay intervals, massively bedded; common *Turritella* is scattered throughout core, not in layers, and it has some smaller clams; medium-dark-grayish-green; compared to above unit it is both more olive and somewhat lighter in color and it is highly bioturbated and has a fair amount of shell.

101-106 ft:

SAND, silty, clayey, massively bedded; highly bioturbated fabric; common *Turritella* scattered through core; medium-dark-gray-green.

RUN 8, 106-111 ft:

5-ft core run, 5-ft recovery.

106-110 ft:

SAND, very fine, silty, clayey, massively bedded; common *Turritella* scattered through core; carbonaceous debris in lower 2 ft; medium-dark-gray-green.

----- Burrowed surface at 110 ft with underlying more olive unit.

110-111 ft:

CLAY, silty; bioturbated fabric; few shells; possible clay clasts; olive-green.

RUN 9, 111-119 ft:

8-ft core run, 7.6-ft recovery.

111-117.6 ft:

CLAY, silty, massively bedded; highly bioturbated fabric; no shell; clay clasts in upper 3 ft; continuation of unit seen in bottom of above run, which becomes darker and more olive with lighter gray-green bioturbation fabric; olive-green.

117.6-118.6 ft:

SAND, very fine, clayey, massively bedded; sparse poorly preserved shell; carbonaceous debris at 118.3 ft; more gray-green.

118.6-119.0 ft: No recovery.

-----Contact at 119 ft, appears to be burrowed surface.

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 10, 119-126 ft:

7-ft core run, 7-ft recovery.

119-123 ft:

CLAY, sandy, with some highly sandy intervals; highly bioturbated fabric with silty pods in clayey matrix; a few shell fragments in upper part; olive-green mottled in medium-gray-green; appears to have burrows from overlying unit.

123-126 ft:

SAND, fine, clayey, massively bedded; very few shell fragments; medium-dark-gray-green.

RUN 11, 126-136 ft:

10-ft core run, 3.5-ft recovery.

126-129.5 ft:

SAND, fine, clayey, massively bedded; small amount (1-2 percent) of fine- to medium-grained glauconite; small amount of scattered shell with few larger clams of *Astarte?*; bioturbated fabric with lighter colored more silty and sandy areas of dusky-yellow-green (5 GY 5/2) mottled with darker more clayey sand of grayish-olive-green (5 GY 3/2).

129.5-136 ft: No recovery.

RUN 12, 136-146 ft:

10-ft core run, 2.9-ft recovery.

136-138.9 ft:

SAND, very fine to fine, slightly clayey, but with some intervals having considerable clay; massively bedded with bioturbation fabric containing sandy pods; no shell; olive-gray (5 Y 3/2); color considerably different from above run.

138.9-146 ft: No recovery.

RUN 13, 146-156 ft:

10-ft core run, 0.5-ft recovery.

146-146.5 ft:

SAND, very fine to fine, clayey, some more clayey laminae about 1/4 inch thick; parts between laminae are highly bioturbated; no shell; olive-gray (5 Y 3/2); bed is possibly near the base of a cycle as it is much more sandy and more olive in color than the next run.

146.5-156 ft: No recovery.

RUN 14, 156-166 ft:

10-ft core run, 9.5-ft recovery.

156-163.5 ft:

CLAY, silty, very fine, sandy with some intervals grading to clayey silt to very fine sand, massively bedded; bioturbation fabric; few scattered shell fragments; phosphatic brachiopods; fish scales; diatomaceous; dusky-yellow-green (5 GY 5/2); this run is slightly darker in color and slightly less bioturbated than run below.

163.5-165.5 ft:

SAND, very fine, clayey, massively bedded; bioturbation fabric; no shells; diatomaceous; dusky-yellow-green (5 GY 5/2).

165.5-166 ft: No recovery.

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 15, 166-176 ft:

10-ft core run, 9.3-ft recovery.

166-172.3 ft:

SAND, very fine, clayey; heavily bioturbated fabric with lighter colored sand; contains massive bedding; about 1 percent very fine grained glauconite; no calcareous shells but some phosphatic brachiopods; dusky-yellow-green (5 GY 5/2) mottled with lighter grayish-yellow-green (5 GY 7/2).

172.3-175.3 ft:

CLAY, silty, very fine sandy, some intervals with a lot of very fine sand; bioturbated fabric, but also contains some more sandy laminae about 1 inch thick; no shells; grayish-olive-green (5 GY 3/2); possibly a burrowed contact at 172.3 ft or possibly just a lithologic and color change to finer grained sediments with a darker green and less olive color.

175.3-176 ft: No recovery.

RUN 16, 176-186 ft:

10-ft core run, 10-ft recovery.

176-182.7 ft:

CLAY, silty, very fine sandy, massively bedded; bioturbated fabric; 1 percent very fine grained glauconite; slightly diatomaceous; a few small shell fragments; dusky-yellow-green (5 GY 5/2).

----Sharply burrowed contact at 182.7 ft with 0.7 ft relief.

182.7-186 ft:

CLAY, silty, massively bedded; bioturbation fabric; diatomaceous; no shell; grayish-olive-green (5 GY 3/2).

RUN 17, 186-190 ft:

4-ft core run, 4-ft recovery.

186-190 ft:

CLAY, silty, massively bedded; bioturbation fabric of light-olive-gray (5 Y 5/2) with yellowish-gray (5 Y 7/2); diatomaceous; no shell; echinoid spines abundant.

RUN 18, 190-196.5 ft:

6.5-ft core run, 6.5-ft recovery.

190-196.5 ft:

CLAY, silty, mostly massively bedded but has some thin, 1-mm-thick silty laminae; otherwise has bioturbated fabric; very diatomaceous; no shell; light-olive-gray (5 Y 5/2).

RUN 19, 196.5-206 ft:

9.5-ft core run, 9.5-ft recovery.

196.5-204.9 ft:

CLAY, silty, massively bedded; faint bioturbation fabric; very diatomaceous; no shell; continuation of above unit; light-olive-gray (5 Y 5/2).

----GRADATIONAL CHANGE across 0.5 ft from 204.4 to 204.9.

204.9-206 ft:

SAND, medium to coarse with some angular phosphate; abundant shells, some look like large oysters; at base is coarse sand with no shell; grayish-olive-green (5 GY 3/2).

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 20, 206-216 ft:

10-ft core run, 3.3-ft recovery.

206-208.3 ft:

SAND, fine to medium, clayey with some phosphatic fine gravel, massively bedded; contains bioturbated fabric; micaceous; abundant thick oyster and clam shells; dusky-yellow-green (5 GY 5/2).

----GRADATIONAL CHANGE across 0.2 ft from 208.1 to 208.3 ft.

208.3-209.3 ft:

SAND, slightly clayey, massively bedded with a few fine glauconite grains; few shells; this interval has less clay and shell than immediately above; grayish-olive-green (5 GY 3/2).

209.3-216 ft: No recovery.

RUN 21, 216-226 ft:

10-ft core run, 3-ft recovery.

216-217.5 ft:

SAND, bimodal sediment distribution with abundant medium to coarse sand and fine quartz gravel mixed with some clay, massively bedded; contains less than 1 percent glauconite; some shell; dusky-yellow-green (5 GY 5/2); is basal part of Calvert Formation.

217.5-221 ft: No recovery.

----MAJOR LITHOLOGIC CHANGE at 221 ft.

**PINEY POINT FORMATION:**

221-222.5 ft:

SANDSTONE, fine- to medium-grained quartzose; 10-20 percent glauconite; abundant clam shell molds; light-olive-gray (5 Y 6/1); hard bed is top of Piney Point Formation.

222.5-226 ft: No recovery.

RUN 22, 226-236 ft:

10-ft core run, 0.3-ft recovery.

226-226.3 ft:

SANDSTONE, fine- to medium-grained quartzose; contains 5-10 percent glauconite, phosphate grains, abundant clam shells and molds; appears to have dolomitic cement, bioturbated fabric with some more clayey areas; greenish-gray (5 GY 6/1).

226.3-236 ft: No recovery. Appears to be an interval of alternating indurated beds and very loose sands.

RUN 23, 236-246 ft:

10-ft core run, 0.5-ft recovery.

236-236.5 ft:

SANDSTONE and SAND; sandstone is fine grained, massively bedded with 5 percent glauconite, grayish yellow green (5 GY 7/2); sand is fine to medium, very slightly clayey with 5-10 percent glauconite, fairly abundant fine shell hash; dusky yellow green (5 GY 5/2).

236.5-246 ft: No recovery. Appears to be interval of alternating indurated beds and very loose sands.

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 24, 246-256 ft:

10-ft core run, 1.9-ft recovery.

246-247.9 ft:

SAND and SANDSTONE; sand is mostly fine with some medium grains, slightly clayey, massively bedded; contains 5-10 percent glauconite, fairly abundant fragmental shells, and some large oysters; grayish olive-green (5 GY 3/2); several 0.2-ft-thick sandstone beds in this interval.

247.9-256 ft: No recovery. Appears to be interval of alternating indurated beds and very loose sands.

RUN 25, 256-266 ft:

10-ft core run, 1-ft recovery.

256-257 ft:

SANDSTONE, fine-grained, clayey in places; contains some coarse sand and gravel of which some grains are amber coated and others are brown like goethite; massively bedded with bioturbated texture; 5 percent glauconite; pale-olive (10 Y 6/2); is near or at base of the Piney Point Formation.

257-266 ft: No recovery.

----MAJOR LITHOLOGIC CHANGE.

**NANJEMOY FORMATION:**

RUN 26, 266-276 ft:

10-ft run, 6.7-ft recovery

266-272.7 ft:

SAND, fine to medium, clayey with abundant medium to coarse sand and some fine gravel of which many grains have a yellow-stained surface; medium to coarse quartz grains are highly polished; contains dark-gray clay layers that are 1-3 inches thick and thinner discontinuous clay lenses that have many burrows filled with light-gray-green sand; contains 5-20 percent glauconite, 10-20 percent polished brown phosphate; is highly bioturbated with no visible shell; dark-grayish-green; is near or at top of Nanjemoy Formation.

272.7-276 ft: No recovery.

RUN 27, 276-286 ft:

10-ft core run, 6-ft recovery.

276-280 ft:

SAND, fine to medium, clayey; is interspersed with sandy clay intervals and highly burrowed, more olive clay laminae about 1/2 inch thick; contains abundant medium to coarse sand and fine gravel clasts that are polished and subrounded to rounded, commonly with amber to brown coating, 10 percent glauconite, 5 percent phosphate, several pieces of lignitized wood, no visible shell; is highly bioturbated; dark-grayish-green.

280-282 ft:

CLAY, sandy; is interspersed with highly burrowed clay laminae; amber to brown-stained quartz gravel are more abundant than in above interval; gravel is polished and subrounded to rounded; contains 5-10 percent glauconite, 5-10 percent phosphate, no visible shell; dark-grayish-green.

RUN 28, 286-296 ft:

10-ft core run, 0.3-ft recovery.

286-286.3 ft:

SAND, fine to coarse, clayey with some fine gravel, no visible shell; dark-grayish-green.

286.3-296 ft: No recovery.

## Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 29, 296-301 ft:

5-ft core run, 0.2-ft recovery.

296-296.2 ft:

SAND and SANDSTONE, fine to medium, clayey with 5-10 percent glauconite; highly bioturbated; dark-grayish-green.

296.2-301 ft: No recovery.

RUN 30, 301-309 ft:

8-ft core run, no recovery.

RUN 31, 309-316 ft:

7-ft core run, 3-ft recovery.

309-312 ft:

SAND, fine to medium with some coarse, clayey sand, mostly massively bedded, but contains some 1/2-inch-thick clay laminae that are burrowed; medium to coarse quartz sand is polished and has yellow to yellow-brown coating; contains 10-15 percent glauconite, no visible shell; medium-dark-grayish-green.

312-316 ft: No recovery.

RUN 32, 316-322 ft:

6-ft core run, 4.5-ft recovery.

316-320.5 ft:

SAND, fine to medium, clayey with some coarse sand and fine gravel, massively bedded with some 1/2-inch-thick burrowed clay lenses, 10-20 percent glauconite, no visible shell; dark-grayish-green.

320.5-322 ft: No recovery.

RUN 33, 322-326 ft:

4-ft core run, 2-ft recovery.

322-324 ft:

SAND, fine to medium, clayey with some quartzose coarse sand and fine gravel that is yellow to brown coated, some 1/2-inch-thick burrowed clay lenses, 10-20 percent glauconite, no visible shell; dark-grayish-green.

324-326 ft: No recovery.

RUN 34, 326-331 ft:

5-ft core run, 4.5-ft recovery.

326-327.5 ft:

SAND, clayey; same as that in above run with no visible shell.

327.5-330.5 ft:

SAND, fine to medium, clayey with some burrowed thin clay laminae, polished coarse sand and fine gravel, 5 percent glauconite, some glauconite staining of particles, no visible shell; this run is a coarser sand with less clay than in above run; dark-grayish-green.

330.5-331 ft: No recovery.

RUN 35, 331-336 ft:

5-ft core run, 3-ft recovery.

331-334 ft:

SAND, fine, clayey with some coarse sand and fine gravel; contains common burrowed clay laminae, 10-20 percent glauconite with glauconite more abundant in lower 0.3 ft where it is associated with glauconitic staining of burrows and sediment; dark-grayish-green; this run is a finer sand with more clay and less coarse sand and gravel than above run.

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

334-336 ft: No recovery.

RUN 36, 336-341 ft:

5-ft core run, 4-ft recovery.

336-340 ft:

SAND, clayey with some coarse sand and a little fine gravel; contains abundant burrowed clay laminae, 20-30 percent glauconite; quartz grains stained green (not yellow), no visible shell; more abundant clay laminae, more glauconitic, and less coarse-grained material than in above runs; dark-green with more olive clay intervals than above.

340-341 ft: No recovery.

RUN 37, 341-346.5 ft:

5.5-ft run, 5.5-ft recovery.

341-346.5 ft:

SAND, clayey with small amount of coarse sand; contains abundantly burrowed silty clay laminae, highly bioturbated fabric with medium-olive-grayish-green clay and dark-greenish-black glauconitic sands that may contain 50 percent glauconite; no visible shell.

RUN 38, 346.5-356 ft:

9.5-ft run, 2.7-ft recovery.

346.5-349.2 ft:

SAND, fine, clayey with a few coarse sand grains; contains abundant burrowed clay laminae, of which some are discontinuous; has highly bioturbated fabric with glauconite more than 50 percent in sandier portions, glauconitic staining of quartz grains; few scattered shell fragments; dark-greenish-black.

349.2-356 ft: No recovery.

RUN 39, 356-359 ft:

3-ft core run, 1-ft recovery.

356-357 ft:

SAND, fine to medium, clayey with some coarse sand; contains discontinuous clay laminae, bioturbated fabric with dark-greenish-black glauconitic sand and medium-olive-green clay; glauconite exceeds 50 percent in sand; glauconite comprises fine sand and quartz comprises the medium sand; very few scattered shell fragments.

357-359 ft: No recovery.

RUN 40, 359-366 ft:

7-ft core run, 6-ft recovery.

359-362 ft:

SAND, fine, clayey with some medium to coarse sand, discontinuous clay lenses, bioturbated fabric of dark-greenish-black, highly glauconitic sand and medium-olive-grayish-green clay; glauconite may be greater than 50 percent in sands; very few shell fragments.

362-365 ft:

SAND, fine to medium, quite clayey with few medium to coarse sand grains and fine gravel, bioturbated fabric of dark-greenish-black sand and medium-olive-grayish-green clay; very few shell fragments.

365-366 ft: No recovery.

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 41, 366-373 ft:

7-ft core run, 7-ft recovery.

366-373 ft:

SAND, fine to medium, quite clayey with some medium to coarse sand and fine gravel, bioturbated fabric of dark-greenish-black sand and medium-olive-grayish-green clay; glauconite may be more than 50 percent in sands; very few shell fragments.

----RAPID GRADATIONAL CHANGE to more clayey and less glauconitic beds.

RUN 42, 373-376 ft:

3-ft core run, 3-ft recovery.

373-374.5 ft:

CLAY, fine, sandy with bioturbated fabric, 2 percent glauconite, very little shell; medium-grayish-green.

374.5-376 ft:

SAND, fine, silty, very clayey with bioturbated fabric of medium-grayish-green sand and darker olive-grayish-green clay; contains 5-10 percent glauconite, no visible shell.

RUN 43, 376-386 ft:

10-ft core run, 9-ft recovery.

376-379 ft:

CLAY, very fine, sandy, silty, and SAND, very fine, silty, very clayey; olive-gray (5 Y 3/2); clayey intervals are dominant; contains discontinuous clay laminae, bioturbated fabric, 5-10 percent glauconite, scattered carbonaceous debris, few small shells.

379-385 ft:

CLAY, silty with discontinuous clay and glauconitic sand laminae in some intervals; remainder has bioturbated fabric of clay and sand, 5 percent medium to coarse glauconite, scattered small clam shells; grayish-olive-green (5 GY 3/2).

385-386 ft: No recovery.

----GRADATIONAL CHANGE to much more glauconitic beds.

RUN 44, 386-396 ft:

10-ft core run, 10-ft recovery.

386-396 ft:

CLAY, sandy, silty with some medium to coarse quartz grains that are highly polished; contains few discontinuous laminae; bioturbated fabric dominates with grayish-olive-green (5 GY 3/2) clayey areas and greenish-black (5 G 2/1) glauconitic sandy clay areas; up to 30 percent fine to coarse glauconite.

RUN 45, 396-406 ft:

10-ft core run, 10-ft recovery.

396-406 ft:

CLAY, sandy; most of sand component is glauconite; contains some polished, green-stained, fine to medium quartz, bioturbated fabric, 30-50 percent glauconite or more in some places, no visible shell; grayish-olive-green (5 GY 3/2).

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 46, 406-416 ft:

10-ft core run, 0.5-ft recovery.

406-406.5 ft:

SAND, fine to medium with a few coarse grains, clayey with bioturbated fabric; contains 50 percent glauconite, green-stained quartz grains, no visible shell; dark-greenish-black (5 G 2/1).

406.5-416 ft: No recovery.

RUN 47, 416-419 ft:

3-ft core run, 3-ft recovery.

416-419 ft:

SAND, fine with some medium sand, clayey with bioturbated fabric, 50 percent glauconite, no visible shell; olive-black (5 Y 2/1).

RUN 48, 419-426 ft:

7-ft core run, 7-ft recovery.

419-426 ft:

CLAY, fine, sandy with few medium to coarse sand grains and thin, discontinuous clay laminae; becomes more clayey in lower 2 ft; contains bioturbated fabric, 50 percent glauconite, green-stained quartz grains, no visible shell; olive-black (5 Y 2/1).

RUN 49, 426-436 ft:

10-ft core run, 10-ft recovery.

426-427 ft:

CLAY, fine to very fine, sandy with 5-10 percent glauconite, 1/2-inch clay clasts in lower 0.5 ft; no visible shell; dark-greenish-gray (5 GY 4/1).

----MAJOR LITHOLOGIC CHANGE, burrowed surface with 1-inch-diameter burrows of lowermost Nanjemoy Formation extending as much as 1.8 ft into underlying Marlboro Clay.

**MARLBORO CLAY:**

427-436 ft:

CLAY, silty, massively bedded with very faint mottling in upper 2 ft; has some very thin (1/16 inch) more silty laminae in otherwise mottled beds; olive-gray (5 Y 4/1) in upper part, becoming somewhat pinkish near the bottom.

RUN 50, 436-446 ft:

10-ft core run, 1.7-ft recovery.

436-437.6 ft:

CLAY, silty with some glauconite sand floating in clay in upper part; contains differing colored indistinct laminae 1 to 2 inches thick in bottom 1 ft; lenticular pods 1/2 inch wide by 1 inch high in lower 1 ft have 10 percent glauconite and yellow-stained coarse sand and fine gravel; bottom 0.1 ft has interlaminated clay and glauconitic clay with 10-15 percent glauconite; brownish-gray (5 YR 4/1) at top, grading to pale-yellowish-brown (10 YR 6/2) at bottom; bottom is base of Marlboro.

----MAJOR LITHOLOGIC CHANGE.

**AQUIA FORMATION:**

437.6-437.7 ft:

SAND, fine to medium, massively bedded, glauconitic; "pistachio" green.

437.7-446 ft: No recovery.

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 51, 446-452 ft:

6-ft core run, 3-ft recovery.

446-449 ft:

SAND, fine to medium, slightly clayey, massively bedded; contains 20-40 percent glauconite, 10-20 percent goethite, abundant clam shell fragments; grayish-olive (10 Y 4/2).

449-452 ft: No recovery.

RUN 52, 452-456 ft:

4-ft core run, 0-ft recovery.

452-456 ft: No recovery; appears to be loose sands.

RUN 53, 456-462 ft:

6-ft core run, 0-ft recovery.

456-462 ft: No recovery; appears to be loose sands.

RUN 54, 462-466 ft:

4-ft core run, 4-ft recovery.

462-466 ft:

SAND, fine to medium, slightly clayey, massively bedded with 10-20 percent glauconite with some colored orange-brown; many quartz grains are orange or green stained; contains scattered, small to medium clam shells; grayish-olive (10 Y 4/2).

RUN 55, 466-476 ft:

10-ft core run, 0.7-ft recovery.

466-466.7 ft:

SAND, fine to medium, slightly clayey, massively bedded; contains 10-20 percent glauconite with some colored orange-brown, scattered small clam shells; grayish-olive (10 Y 4/2).

466.7-476 ft: No recovery.

RUN 56, 476-486 ft:

10-ft core run, 0.2-ft recovery.

476-476.2 ft:

SANDSTONE, fine- to medium-grained, massively bedded with some coarse quartz and goethite grains, 20 percent glauconite, green-stained quartz, abundant clam shells; very light gray (N 8).

476.2-486 ft: No recovery.

RUN 57, 486-496 ft:

10-ft core run, 0.2-ft recovery.

486-486.2-ft:

SANDSTONE, fine- to medium-grained, massively bedded with some coarse quartz and goethite grains, 15 percent glauconite, abundant clam shells; very light gray (N 8).

486.2-496 ft: No recovery.

RUN 58, 496-506 ft:

10-ft core run, 0-ft recovery.

496-506 ft: No recovery, except loose slurry of fine to medium glauconitic sand.

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 59, 506-516 ft:

10-ft core run, 0.9-ft recovery.

506-506.5 ft:

SANDSTONE, fine- to primarily medium-grained, massively bedded with 10-20 percent glauconite, orange-colored grains, some shell fragments; light-gray (N 7).

506.5-506.9 ft:

SANDSTONE, mostly fine- to some medium-grained, massively bedded with 20-30 percent glauconite; olive-gray (5 Y 4/1).

506.9-516 ft: No recovery.

RUN 60, 516-526 ft:

10-ft core run, 3-ft recovery.

516-517.5 ft:

SANDSTONE, fine- to medium-grained, massively bedded with 10-20 percent glauconite, about 10 percent yellow and orange grains; contains green-stained quartz, some scattered shell; olive-gray (5 Y 4/1).

517.5-518 ft:

SAND, mostly fine to medium, moderately clayey, massively bedded with 10-15 percent glauconite; olive-gray (5 Y 4/1).

518-519 ft:

SANDSTONE, fine-grained with some medium-grained, massively bedded with 10-15 percent glauconite; light-gray (N 7).

519-526 ft: No recovery.

RUN 61, 526-536 ft:

10-ft core run, 8.5-ft recovery.

526-527.3 ft:

SAND, fine to medium, clayey, massively bedded with 10-15 percent glauconite, abundant large clams, large bryozoan colonies; grayish-olive-green (5 GY 3/2).

527.3-531.6 ft:

SAND, fine, clayey, massively bedded with 2-3 percent glauconite, some shell, 0.3-ft-thick indurated zone; light-olive-gray (5 Y 5/2).

-----GRADATION CHANGE over 530.6-531.6 ft to more glauconitic and darker colored beds.

531.6-533.1 ft:

SAND, fine with some medium sand and small amounts of coarse, clayey, massively bedded sand with 10-20 percent glauconite, scattered shells; olive-gray (5 Y 3/2).

533.1-534.5 ft:

SANDSTONE, fine, massively bedded with bioturbated fabric, 10-40 percent glauconite; light-gray (N 7).

534.5-536 ft: No recovery.

RUN 62, 536-546 ft:

10-ft core run, 7-ft recovery.

536-541 ft:

SAND, grayish-olive-green (5 GY 3/2), fine, clayey with moderate amount of medium to coarse sand; is massively bedded with 20 percent glauconite, scattered shell; light-gray (N 7).

541-543 ft:

SAND, fine, some coarse, fairly clayey, massively bedded with 10-15 percent glauconite, some shell; olive-gray (5 Y 4/1).

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

543-546 ft: No recovery.

RUN 63, 546-556 ft:

10-ft core run, 6-ft recovery.

546-546.9 ft:

SANDSTONE, fine-grained, clayey, massively bedded with 2 percent glauconite; light-gray (N 7).

546.9-549.5 ft:

SAND, fine, clayey, massively bedded with 3 percent glauconite, common scattered shell; olive-gray (5 Y 4/1).

549.5-550.2 ft:

SAND, fine, clayey, massively bedded with 2 percent glauconite; light-gray (N 7).

550.2-552 ft:

SAND, very fine, silty, clayey, massively bedded with bioturbated fabric, 1 percent glauconite, moderate amounts of scattered shell; olive-gray (5 Y 4/1).

552-556 ft: No recovery.

RUN 64, 556-566 ft:

10-ft core run, 10-ft recovery.

556-561 ft:

CLAY, silty, very fine, sandy, massively bedded with bioturbated fabric, 1 percent glauconite, moderate scattered shell, some scattered carbonaceous debris; gradational change to underlying unit; olive-gray (5 Y 4/1).

561-565 ft:

CLAY, silty, very fine sandy, massively bedded with 3- 5 percent glauconite, some phosphate grains, moderate amounts of scattered shell; gradational change to underlying unit; olive-gray (5 Y 4/1).

565-566 ft:

SAND, fine to some medium, clayey, massively bedded with 20 percent glauconite at top of interval to 50 percent at bottom; moderate amount of scattered shell; olive-gray (5 Y 4/1).

RUN 65, 566-576 ft:

10-ft core run, 0-ft recovery.

566-576 ft: No recovery.

RUN 66, 576-586 ft:

10-ft core run, 6-ft recovery.

576-582 ft:

SAND, fine with some medium sand, clayey, massively bedded with 20-50 percent glauconite, abundant thick-shelled clams and probable *Oleneothyris*; dark-greenish-gray (5 GY 4/1).

582-586 ft: No recovery.

RUN 67, 586-596 ft:

10-ft core run, 10-ft recovery.

586-587 ft:

SANDSTONE, fine-grained with some medium- and coarse-grained, massively bedded with 10-15 percent glauconite, many thick-shelled clams in random orientations; olive-gray (5 Y 3/2); base of Aquia Formation.

----MAJOR LITHOLOGIC CHANGE AND FORMATIONAL CHANGE, burrowed contact with burrows filled from overlying unit, extending 0.1- 0.2 ft into underlying unit.

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

**BRIGHTSEAT FORMATION:**

587-596 ft:

SAND, very fine, silty, clayey, massively bedded; contains bioturbated fabric with burrow fills of more shelly, silty, clayey, very fine sand mixed with more clayey areas; 2 percent fine-grained glauconite; is slightly micaceous; lower 2 ft become increasingly rich in pyrite; contains some small to medium mollusk shells; olive-black (5 Y 2/1).

RUN 68, 596-606 ft:

10-ft core run, 5.6-ft recovery.

596-596.2 ft:

SAND, very fine with some fine and medium sand, silty, clayey, massively bedded with a little glauconite, no visible shells; base of Brightseat Formation; olive-black (5 Y 2/1).

---MAJOR LITHOLOGIC CHANGE AND FORMATIONAL CHANGE, undulating contact with relief of 0.1 ft.

**POTOMAC GROUP (PATAPSCO FORMATION)**

596.2-596.4 ft:

CLAY, sandy, massively bedded; light-olive-gray (5 Y 6/1).

596.4-597.9 ft:

SAND, fine, clayey, cross-bedded; pale-yellowish-brown (10 YR 6/2).

597.9-598.4 ft:

CLAY, massively bedded; pale-brown (5 YR 5/2).

598.4-600.4 ft:

SAND, fine to medium, crossbedded; pale-yellowish-brown (10 YR 6/2).

600.4-601.1 ft:

CLAY, pale-brown (5 YR 5/2) with green wavy mottling.

601.1-601.3 ft:

SAND, fine, crossbedded; pale-yellowish-brown (10 YR 6/2).

601.3-601.6 ft:

CLAY, pale-brown (5 YR 5/2) with green wavy mottling.

601.6-606 ft: No recovery.

RUN 69, 606-616 ft:

10-ft core run, 5.2-ft recovery.

606-607.3 ft:

CLAY, silty, massively bedded, slightly micaceous; purplish-olive-gray.

607.3-608.2 ft:

CLAY, silty; red and greenish-gray mottled.

608.2-611.2 ft:

SAND, fine, crossbedded; light-olive (5 Y 6/1).

611.2-616 ft: No recovery.

RUN 70, 616-626 ft:

10-ft core run, 0-ft recovery.

616-626 ft: No recovery, but appears to be a fine, well-sorted sand from drill cuttings.

Appendix A. On-site description of Solomons Island core hole (CA-Gd 60)—Continued

RUN 71, 626-636 ft:

10-ft core run, 0-ft recovery.

626-636 ft: No recovery, but appears to be a fine, well-sorted sand from drill cuttings.

-----TOTAL DEPTH OF HOLE -636 FT; bottomed in Patapsco Formation

## Appendix B. Wells in cross-sections A-A' and B-B'

[Depths stated in feet below land surface; + = water level above land surface datum (lsd); M = measured]

Well number	State permit number	Owner	Driller	Approximate altitude of land surface (ft)	Date well reported completed	Depth hole (ft)	Depth well (ft)	Diameter of well screen (inches)
AA Fd 49	AA-88-2900	Old South County Country Club	Wolford's Well & Pump Service, Inc.	120	08-24-89	800	-	-
CA Bb 27	CA-73-3303	U.S. Geological Survey	Calvert Well Drilling Co.	137.9	08-01-79	440	320	2
CA Cc 55	None	U.S. Naval Research Laboratory	Delmarva Drilling	96	1973	1,020	868	4
CA Db 36	CA-67-0037	U.S. Geological Survey	East Coast Well & Pump, Inc.	130	10-10-66	1,515	-	-
CA Db 47	CA-73-3304	U.S. Geological Survey	Calvert Well Drilling Co.	140	07-23-79	680	570	2
CA Dc 35	CA-73-0718	U.S. Geological Survey	Delmarva Drilling	91.6	10-02-74	1,000	760	2
CA Ed 22	CA-69-0039	Baltimore Gas & Electric Co.	Shannahan Artesian Well Co.	120	11-22-68	789	758	6
CA Ed 45	CA-73-4435	Baltimore Gas & Electric Co.	Shannahan Artesian Well Co.	60	11-18-82	621	608	5
CA Fd 71 (test well and redrill)	CA-88-3340	Chesapeake Ranch Water Co.	A.C. Schultes of Maryland, Inc.	110	06-21-93 05-11-93	- 1,296	687 934	8 4
CA Gd 60	-	U.S. Geological Survey	U.S. Geological Survey	15	11-22-86	636	-	-
CH Ce 51	CH-81-0828	La Plata, Town of	Layne-Atlantic Co.	150	11-02-84	1,509	1,340	12
SM Bb 26	SM-81-0091	Charlotte Hall Veterans' Home	Shannahan Artesian Well Co.	170	05-20-83	559	559	5

Appendix B. Continued

Screen settings (ft)	Aquifer	Pumping test data						Remarks	Well number
		Depth to static water level (ft)	Date reported	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm/ft)	Duration of test (hours)		
-	Patapsco	-	-	-	-	-	-	Hole abandoned and plugged. See cross-section A-A'.	AA Fd 49
310-320	Aquia	120 136.13M 138.95M	08-01-79 08-30-79 05-01-81	12 12	21 21	0.6 0.6	3	Observation well. Highest water level measured, 133.82 ft below land surface datum, 05-06-80; lowest measured, 164.84 ft below land surface datum, 08-02-93. Period of record: 08-79 to 09-93. See cross-section A-A'.	CA Bb 27
858-868	Lower Magothy	84	01-28-74	130	112	1.2	Not reported	Observation well at Chesapeake Bay Annex. See cross-section A-A'.	CA Cc 55
-	-	-	-	-	-	-	-	U.S. Geological Survey test hole. No casing; hole filled in. See cross-section A-A'.	CA Db 36
560-570	Aquia	150 141.24M 152.90M	07-23-79 08-31-79 05-01-81	40	24	1.7	3	Observation well. Highest water level measured, 141.24 ft below land surface datum, 08-31-79; lowest measured, 178.44 ft below land surface datum, 09-09-93. Period of record: 07-79 to 09-93. See cross-section A-A'.	CA Db 47
750-760	Magothy	82	10-02-74	12	98	0.1	12	Test well. See cross-section A-A'. Gravel pack 700-760 ft.	CA Dc 35
725-758	Magothy	113	11-22-68	30	187	0.2	10	Test well #2. See cross-section A-A'.	CA Ed 22
520-608	Aquia	86	11-18-82	230	91	2.5	8.5	See cross-section A-A'. Gravel pack 420-608 ft.	CA Ed 45
604-684 810-815 870-875 909-929	Aquia Upper Patapsco	189 128	06-21-93 05-10-93	351 70	159 55	2.2 1.3	24 24	Chesapeake Ranch Estates. See cross-section A-A'. Gravel pack 550-687 ft. Deep test well plugged.	CA Fd 71
-	-	-	-	-	-	-	-	U.S. Geological Survey core hole. See cross-section A-A'.	CA Gd 60
1,250-1,340	Lower Patapsco	182	11-02-84	450	188	2.4	24	Owner's well #9. Production well at Clark's Run. See cross-section B-B'.	CH Ce 51
435-559	Aquia	171	05-20-83	240	79	3.0	24	Owner's well #1. See cross-section B-B'.	SM Bb 26

Appendix B. Wells in cross-sections A-A' and B-B'—Continued

Well number	State permit number	Owner	Driller	Approximate altitude of land surface (ft)	Date well reported completed	Depth hole (ft)	Depth well (ft)	Diameter of well screen (inches)
SM Bb 27	SM-81-0295	Charlotte Hall Veteran's Home	East Coast Well & Pump, Inc.	165	10-12-85	1,001.5	-	-
SM Ca 5	SM-73-0438	Wicomico Shores Yacht & County Club	Sydnor Hydrodynamics, Inc.	140	07-23-73	908	650	6
SM Dd 50	SM-73-3082	U.S. Geological Survey	Shannahan Artesian Well Co.	99.4	10-26-78	579	515	3
SM Df 84	SM-81-0119	Maryland Geological Survey	A.C. Schultes & Sons, Inc.	108.4	01-05-83	2,679	920	4
SM Ef 56/ Ef 57	SM-67-0089	U.S. Geological Survey	East Coast Well & Pump, Inc.	108	12-05-66	1,509	322	4
SM Ef 79	SM-81-0362	St. Mary's City Commission	Branham Contractors, Inc.	40	09-23-83	685	685	6
SM Ef 81	SM-81-3371	St. Mary's College of Maryland	Sydnor Hydrodynamics, Inc.	44	08-30-88	740	590	10
SM Eg 28	SM-73-1991	U.S. Geological Survey	Patuxent Pump & Well, Inc.	10	07-22-76	601	545	2

Appendix B. Continued

Screen settings (ft)	Aquifer	Pumping test data						Remarks	Well number
		Depth to static water level (ft)	Date reported	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm/ft)	Duration of test (hours)		
-	-	-	-	-	-	-	-	Hole abandoned and plugged. See cross-section B-B'.	SM Bb 27
578-588 608-628 636-642 646-650	Upper Patapsco	134 143.56M	07-23-73 08-29-78	200	45	4.4	24	See cross-section B-B'. Gravel pack 100-655 ft.	SM Ca 5
505-515	Aquia	124 124.36M	10-26-78 05-01-81	12	36	0.3	4	St. Mary's Technical Center. Observation well. See cross-section B-B'. Highest water level measured, 119.05 ft below land surface, 02-02-79; lowest measured, 158.49 ft below land surface, 09-10-93. Period of record: 12-78 to current year (1993). Gravel pack 490-579 ft.	SM Dd 50
829-854 860-865 895-910	Upper Patapsco (?)	115.7	01-04-83	193	45.7	4.2	24	Test well. Well data published in Maryland Geological Survey Open-File Report No. 84-02-1 (Hansen and Wilson, 1984). See cross-section A-A'.	SM Df 84
317-322	Piney Point-Nanjemoy	115 114.46M	12-05-66 12-15-66	45	185	0.2	4	Well Ef 56 assigned to 1,509 ft hole; Ef 57 assigned to 322 ft hole; U.S. Geological Survey observation well. Highest water level measured, 114.46 ft below land surface datum, 12-15-66; lowest measured, 137.99 ft below land surface datum, 08-06-86. Period of record: 12-66, 06-67, 02-69 to 12-88. See cross-section B-B'.	SM Ef 56/ Ef 57
665-685	Upper Patapsco(?)	45	09-23-83	50	75	0.7	10	Visitors Center. Screened below Aquia aquifer, may be in Patapsco Formation. See cross-section B-B'.	SM Ef 79
505-570	Aquia	103	08-30-88	400	104	3.8	12	Owner's well #4. See cross-section B-B'. Gravel pack 400-740 ft.	SM Ef 81
535-545	Aquia	20	07-22-76	1	205	0.005	3	U.S. Geological Survey test hole. See cross-section A-A'.	SM Eg 28

Appendix B. Wells in cross-sections A-A' and B-B'—Continued

Well number	State permit number	Owner	Driller	Approximate altitude of land surface (ft)	Date well reported completed	Depth hole (ft)	Depth well (ft)	Diameter of well screen (inches)
SM Fe 31	SM-73-3088	U.S. Geological Survey	Shannahan Artesian Well Co.	8	10-18-78	639	461	3
SM Ff 36	SM-73-1478	Kitts Point Utility Corp.	Patuxent Pump & Well, Inc.	5	10-29-75	940	618	8
SM Gh 8	SM-71-0339	Point Lookout State Park	Patuxent Pump & Well, Inc.	5	08-23-71	720	716	6

Appendix B. Continued

Screen settings (ft)	Aquifer	Pumping test data						Remarks	Well number
		Depth to static water level (ft)	Date reported	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm/ft)	Duration of test (hours)		
451-461	Aquia	33	10-18-78	12	27	0.4	4	Observation well. Highest water level measured, 29.77 ft below land surface, 12-05-78; lowest measured, 64.95 ft below land surface, 03-03-93. Period of record: 10-78 to 09-93. See cross-section B-B'. Gravel pack 430-639 ft.	SM Fe 31
594-618	Upper Patapsco(?)	5 6.80M	10-29-75 11-14-78	300	90	3.3	24	Test well. See cross-section B-B'.	SM Ff 36
677-694 698-716	Upper Patapsco(?)	Flowing 2 gpm at +1	08-23-71	250	187	1.4	30	Public supply well. See cross-section B-B'.	SM Gh 8