Department of Natural Resources
MARYLAND GEOLOGICAL SURVEY
Kenneth N. Weaver, Director

# REPORT OF INVESTIGATIONS NO. 39

# HYDROGEOLOGY OF THE UPPER CHESAPEAKE BAY AREA, MARYLAND, WITH EMPHASIS ON AQUIFERS IN THE POTOMAC GROUP

by
Edmond G. Otton
and
Richard J. Mandle

Prepared in cooperation with the
United States Department of the Interior
Geological Survey
and the
Maryland Energy Administration
Powerplant Siting Program

1984

## CONVERSION OF MEASUREMENT UNITS

The following factors may be used by readers who wish to convert inch-pound units to International System of Units (SI).

| To convert from | Multiply by | To obtain |
|---|---|---|
| inch (in.) | 25.40 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| foot per second (ft/s) | 30.48 | centimeter per second (cm/s) |
| foot squared per day ($ft^2/d$) | 0.0929 | meter squared per day ($m^2/d$) |
| gallon (gal) | 3.785 | liter (L) |
| gallon per day (gal/d) | 0.003785 | cubic meter per day ($m^3/d$) |
| million gallons (Mgal) | 3785 | cubic meter ($m^3$) |
| million gallons per day (Mgal/d) | 3785 | cubic meter per day ($m^3/d$) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| micromhos per centimeter ($\mu$mhos/cm) | 1.000 | microsiemens per centimeter ($\mu$S/cm) |

## NOTE REGARDING VERTICAL DATUM

The National Geodetic Vertical Datum of 1929 (NGVD of 1929), the reference surface to which relief features and altitude data are related, and formerly called mean sea level, is referred to as sea level throughout this report.

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## CONTENTS


| | Page |
|---|---|
| Abstract | 1 |
| Introduction | 3 |
| Geographic setting | 3 |
| Acknowledgments | 3 |
| Method of investigation | 5 |
| Test drilling | 5 |
| Aquifer tests | 7 |
| Hydrogeology | 7 |
| Potomac Group | 7 |
| Hydraulic coefficients | 12 |
| Pumpage from aquifers in the Potomac Group | 18 |
| Water-level trends | 18 |
| Magothy Formation | 19 |
| Hydraulic coefficients | 20 |
| Pumpage from the Magothy aquifer | 20 |
| Formations above the Magothy Formation | 22 |
| Matawan and Monmouth Formations | 22 |
| Pumpage from the Monmouth aquifer | 22 |
| Aquia Formation | 23 |
| Pumpage from the Aquia aquifer | 23 |
| Quaternary deposits | 24 |
| Generalized flow system | 26 |
| Chemical quality | 29 |
| Important chemical constituents | 29 |
| Occurrence of brackish water | 33 |
| Estimating salinity from geophysical logs | 33 |
| Summary and conclusions | 39 |
| Selected references | 40 |


## ILLUSTRATIONS


| | | Page |
|---|---|---|
| Figure 1. | Map showing location of test wells and study area in Maryland | 4 |
| 2. | Map showing altitude of top of crystalline basement rock | 9 |
| 3. | Map showing outcrop area and top of Potomac Group | 10 |
| 4. | Map showing thickness of Potomac Group | 11 |
| 5. | Geologic cross-sections A-A′ and B-B′ | 13 |
| 6. | Map showing percentage thickness of sand and total sand thickness in the Potomac Group | 14 |
| 7. | Map showing location of wells where transmissivity and storage coefficients of Coastal Plain aquifers were determined and location of other wells mentioned in report | 15 |
| 8. | Graph showing water-level fluctuations in well KE-AC 20 and tidal fluctuations at the U.S. Coast Guard Station, Stillpond Neck, Maryland | 17 |
| 9. | Graph showing water-level fluctuations in well KE-BG 33 and barometric fluctuations at Massey in Kent County, Maryland | 18 |

## ILLUSTRATIONS (Continued)


| | | Page |
|---|---|---|
| Figure 10. | Hydrograph showing water levels in observation well CE-CF 49 near Chesapeake City, Maryland | 20 |
| 11. | Map showing the approximate altitude of the prepumping potentiometric surface in the aquifers of the Potomac Group in the upper Chesapeake Bay area | 27 |
| 12. | Geohydrologic section from I-95 in Baltimore County across the Chesapeake Bay to the Delaware line showing regional geology, generalized ground-water flow lines, and occurrence of salty water | 28 |
| 13. | Map showing total iron, pH, dissolved solids and chloride concentration of water from sands of the Potomac Group | 32 |
| 14. | Geologic section A-E′ across the upper Eastern Shore showing a zone of brackish water | 34 |
| 15. | Geologic sections C-C′ and D-D′ across the upper Chesapeake Bay region showing a zone of brackish water | 35 |
| 16. | Graph showing electrically equivalent concentrations of a sodium chloride solution as a function of resistivity or conductivity and temperature | 36 |
| 17. | Segment of electric log of well KE-BG 33 from a depth of 940 to 1,060 ft | 37 |
| 18. | Graph showing relation of dissolved solids to specific conductance in water from sands of the Potomac Group | 39 |
| 19. | Geophysical logs of wells: | |
| | a. CE-EE 29 at Cecilton | 44 |
| | b. KE-AC 20 at Stillpond Neck | 45 |
| | c. KE-BE 43 at Kennedyville | 46 |
| | d. KE-BG 33 at Massey | 47 |
| | e. KE-CB 36 at Fairlee | 48 |
| | f. KE-DB 40 at Rock Hall | 49 |
| | g. QA-BE 15 at Kings Town | 50 |


## TABLES


| | | Page |
|---|---|---|
| Table 1. | Summary of test-hole data | 6 |
| 2. | Generalized description of the geologic units in the upper Chesapeake Bay area | 8 |
| 3. | Transmissivity, hydraulic conductivity and storage coefficients for sand zones of the Potomac Group in the upper Chesapeake Bay area | 16 |
| 4. | Municipal, industrial, and institutional pumpage from aquifers in the Potomac Group in the upper Chesapeake Bay area in 1980 | 19 |
| 5. | Transmissivity and storage coefficients of the Magothy aquifer in the upper Chesapeake Bay area | 21 |
| 6. | Municipal, industrial, and institutional pumpage from the Magothy and/or Monmouth Formations in the upper Chesapeake Bay area in 1980 | 21 |

## TABLES (Continued)


| | | Page |
|---|---|---|
| Table 7. | Transmissivity and storage coefficients of sands in the Monmouth Formation in the upper Chesapeake Bay area | 24 |
| 8. | Municipal, industrial, and institutional pumpage from the Aquia Formation in the upper Chesapeake Bay area in 1980 | 24 |
| 9. | Chemical analyses of ground-water samples from test wells | 30 |
| 10. | Selected formation factors for aquifers in the Potomac Group | 38 |
| 11. | Interpretive geologic logs of wells (based on sample cuttings, drillers' and geophysical logs) | |
| | CE-EE 29 at Cecilton | 51 |
| | KE-AC 20 at Stillpond Neck | 52 |
| | KE-BE 43 at Kennedyville | 54 |
| | KE-BG 33 at Massey | 56 |
| | KE-CB 36 at Fairlee | 57 |
| | KE-DB 40 at Rock Hall | 60 |
| | QA-BE 15 at Kings Town | 61 |

# HYDROGEOLOGY OF THE UPPER CHESAPEAKE BAY AREA, MARYLAND WITH EMPHASIS ON AQUIFERS IN THE POTOMAC GROUP

by Edmond G. Otton[1] and Richard J. Mandle[2]

## ABSTRACT

To gain a better understanding of the ground-water hydrology of aquifers in the Potomac Group on Maryland's Eastern Shore, six test holes were drilled through the Coastal Plain deposits in Cecil and Kent Counties. A similar test hole was drilled in Queen Annes County near Chestertown, Maryland, before the beginning of this study. Data from these holes are included here.

At each test site the Coastal Plain sediments were penetrated to crystalline basement rock, the altitude of which ranges from 1,121 feet below sea level at Stillpond Neck to 2,059 feet below sea level at Massey, Maryland. Thickness of the Potomac Group ranges from 1,038 feet at Stillpond Neck to 1,538 feet at Massey. Geophysical logs were run in each test hole to (1) help evaluate geologists' and drillers' logs, (2) help determine the depth and relative distribution of sand in the Potomac Group, (3) help determine the total dissolved solids of the ground water and (4) to locate appropriate zones in which to screen the observation wells.

Sand-percentage and total sand-thickness maps show that the sand percentage of the Potomac Group decreases with distance from the Fall Line, whereas total sand thickness increases. This is because of the greater increase in total thickness of the Potomac Group. Transmissivity and sand-unit thickness and sand percentage seem to be directly related. Most areas of reported high transmissivity are nearer to the Fall Line, where sand percentages are highest and individual sand units are generally thickest. Also, the sands close to the Fall Line tend to have higher porosities than the more deeply buried sands occurring farther away.

Analyses of multi-point electric logs suggest that brackish water is present in the Potomac Group at the Coast Guard Station on Stillpond Neck and the towns of Fairlee, Kennedyville, and Massey. Subsequent chemical analyses from Stillpond Neck and Fairlee showed chloride and dissolved-solids concentrations of 1,000 and 1,800 milligrams per liter, and 950 and 1,990 milligrams per liter, respectively. The relatively high chloride concentration in the aquifers of the Potomac Group is attributed to sea-water intrusion.

A geohydrologic cross-section shows that water enters the aquifers in the Potomac Group west of Chesapeake Bay and discharges to the Bay and its saline estuaries. There does not seem to be a significiant component of flow under Chesapeake Bay to the Delmarva Peninsula, except perhaps in the deepest aquifers. On the Delmarva Peninsula, water largely recharges the aquifers of the Potomac Group through overlying formations on the upper end of the Peninsula. It then appears to move laterally through the aquifers, then upward through overlying formations and discharges to the Chesapeake Bay and Delaware Bay.

This report presents geohydrologic data which can serve as a basis for modeling studies of aquifers in the Potomac Group. Such data probably will need to be supplemented with additional test drilling, however, because of the variable character of the strata of the Potomac Group.

[1]U.S. Geological Survey (ret.)
[2]U.S. Geological Survey

# INTRODUCTION

In the Coastal Plain region of Maryland and, specifically, in the upper Eastern Shore area with its saline estuaries, the increased demand for water must be met from ground-water sources. In Kent County and the Coastal Plain part of Cecil County, water is obtained from wells in the Quaternary deposits, Aquia Formation, Potomac Group, or Magothy Formation at depths of 25 to 300 ft. Below 300 ft, the geology and ground-water potential of the Coastal Plain deposits, specifically the Potomac Group, are not as well known.

The objective of this study was to collect additional geologic and hydrologic data on the Potomac Group to aid in evaluating the potential of these aquifers. These data will also provide a basis for future modeling of the sand aquifers in the Potomac Group.

Data collected from a test drilling program, together with information from published reports and geophysical logs, were used to refine geologic and hydrologic maps and prepare other geologic maps and cross-sections. This report describes and interprets the data collected at the test sites and presents a preliminary interpretation of the flow system.

## GEOGRAPHIC SETTING

The area of study, a part of the Coastal Plain physiographic province, lies in the northeastern part of Maryland's upper Eastern Shore (fig. 1). Major features of the study area are the upper Delaware Bay, the Chesapeake Bay north of Annapolis, Md., and the area south of the Fall Line (or Fall Line zone) between Baltimore, Md., and the Delaware boundary. The Fall Line is approximately coincident with the northern limit of Coastal Plain deposits shown in figure 1.

Topographic relief is greatest south of the Fall Line at the upper end of Chesapeake Bay along the Elk Neck Peninsula, where elevations range from over 300 ft above sea level to sea level. The general topographic features in this area are short tributary valleys cut into rolling uplands. To the south, in Kent County, the maximum relief is about 90 ft, and the upland areas become level and broad, more typical of the Eastern Shore Coastal Plain. The outstanding features are the several estuarine streams such as the Elk, Sassafras, Bohemia, and Chester Rivers and the numerous small streams draining into them. The economy is largely agricultural, with some fishing and water-related enterprises.

The upper Chesapeake Bay area has a moderately humid climate characterized by warm summers and relatively mild winters. July and August are the warmest months; January and February are normally the coldest. The precipitation is moderately well distributed throughout the year. Data on the climate at Chestertown in the southern part of the area are as follows:

**Climatological Data for Chestertown, Md.[1]**

| *Temperature* | *°F* | *°C* |
|---|---|---|
| Mean annual, 1980 | 55.1 | 12.9 |
| Mean for period 1941–70 | 55.8 | 13.2 |
| *Precipitation* | *Inches* | *Millimeters* |
| Mean annual, 1980 | 34.88 | 894 |
| Mean for period 1941–70 | 42.22 | 1,083 |

[1]Source, National Oceanic and Atmospheric Administration, Annual Summaries—Maryland and Delaware.

## ACKNOWLEDGMENTS

This report is the product of a study by the U.S. Geological Survey in cooperation with the Maryland Geological Survey and the Maryland Energy Administration. R. Page Jett, formerly of the Maryland Geological Survey, and Rene DeLisle and Daniel Phelan of the U.S. Geological Survey assisted in collection of field data.

Descriptions of the crystalline rocks contained in table 11 are based on information provided by Jonathan Edwards, Jr.

The manuscript was typed by Sheryl Protani and illustrations drafted by Cynthia Lang-Bachur and Michael Tompkins.

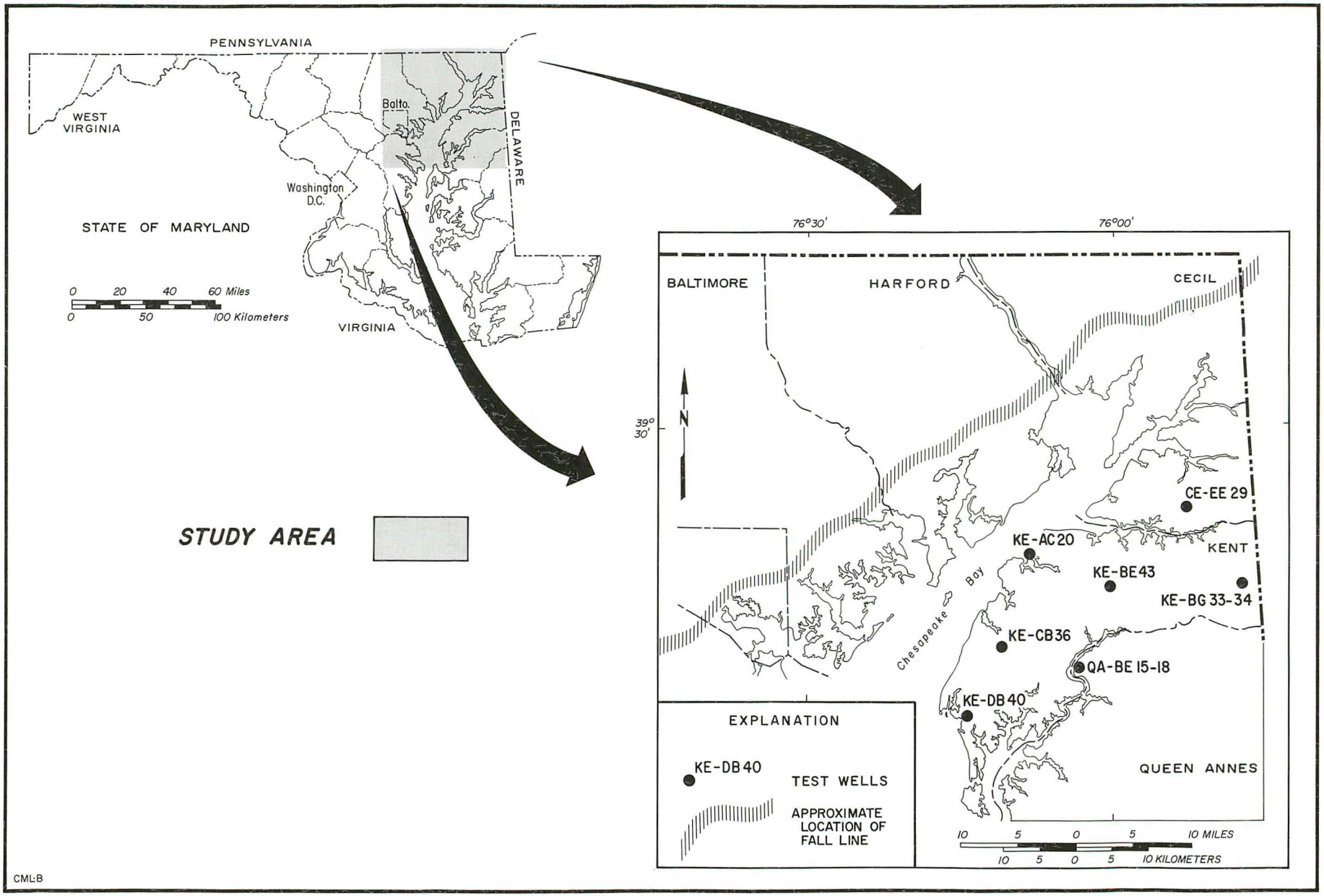


**Figure 1.—Location of test wells and study area in Maryland.**

## METHOD OF INVESTIGATION

### TEST DRILLING

Test holes were drilled at the beginning of the study, because few data on the Coastal Plain sediments below a depth of 300 ft were available. Six sites in Cecil and Kent Counties were selected for exploratory holes to be drilled through the entire wedge of Coastal Plain sediments to bedrock (fig. 1). A seventh site, also described in this report, had previously been drilled in Queen Annes County near Chestertown. These sites were chosen to give broad areal coverage and to tie in with known data points. At each of the sites, a test hole was drilled to a depth ranging from 1,151 to 2,185 ft to collect geologic samples and to run geophysical logs (tab. 1). Each test hole was subsequently completed as an observation well, and water samples were collected for chemical analysis from the screened aquifers.

Drill cuttings were obtained at drill-rod intervals, which were 10, 15, or 20 ft in length. Because of the nature of rotary drilling through Coastal Plain deposits, these drill cuttings were of only limited use in determining the character of the strata penetrated. The samples were commonly contaminated by fine sand and silt, flecks of lignite, and some glauconite recirculated in the drilling mud. Also, parts of the borehole wall above the drill bit sometimes caved in or washed out, further contaminating the downhole samples. However, the drill cuttings were used to indicate the first occurrence of a constituent mineral or an increase in its relative abundance and to better evaluate the subsurface lithology. Interpretive lithologic logs are summarized in table 11 at the back of the report.

Geophysical logs of the test holes drilled during this project are also at the end of the report (figs. 19a–19g). These include multi-point electric, single-point electric, gamma-ray, and caliper logs, and were run by the U.S. Geological Survey. In addition, Birdwell, a division of Seismograph Service Corporation[1], logged the test holes at Stillpond Neck (KE-AC 20) and Massey (KE-BG 34). They obtained induction electric, density borehole compensated, electric, gamma-ray, caliper, and three-dimensional velocity logs at Stillpond Neck. Because of problems with the borehole, Birdwell was able to run only the induction electric and gamma-ray logs at Massey.

The test wells were completed at each site by installing a screen opposite the uppermost permeable sand below the sand used for water supplies at that locality. The presence of these sands was determined from interpretation of the geophysical logs.

The observation and test wells were constructed in each of the holes in the following manner:

1. Approximately 100-200 ft of 8-in. surface casing, emplaced during drilling, was left in the hole.

2. The borehole was backfilled and plugged with a 10-ft-thick grout plug to within about 10 ft of the bottom of the screen.

3. A 10-ft-long, 4-in. diameter tail pipe (with cap on bottom end) was installed at the end of a 10-ft section of stainless steel screen also having a diameter of 4 in. Above the screen, 4-in. diameter casing extended to approximately 3 ft above land surface.

4. To develop the well, water was jetted through the screen to wash out the drilling mud, which had penetrated a short distance into the formation being drilled. Each of the test wells, except KE-BG 33 at Massey and KE-CB 36 at Fairlee, was developed and tested using a 4-in. submersible pump. The wells at Fairlee and Massey were developed with compressed air.

5. A fine gravel pack was installed from the bottom of the tailpipe casing (top of cement plug) to at least 10 ft above the top of the screen.

6. The annulus between the 4-in. casing and the borehole wall was grouted with neat cement from the top of the gravel pack to land surface.

The geologic and geophysical data collected at the test sites, combined with other data, were used to refine previous interpretations of the geology of the Coastal Plain in the study area, such as maps of the top of the crystalline basement rock, and the top and thickness of the Potomac Group. These data aided construction of geologic cross-sections and maps showing sand percentages and total sand thicknesses of the Potomac Group.

[1]Reference to private firms is for identification purposes only and does not constitute endorsement of their services or products.

**Table 1.—Summary of test-hole data.**

| Well No. | State Permit No. | Contractor | Latitude and Longitude | Aquifer | Approximate altitude of land surface (ft) | Depth of borehole (ft below land surface) | Casing diameter (in.) | Length of casing (ft, BLS)[1] | Screen position, in feet below sea level | Screen diameter (in.) | Screen slot size (0.001) in.) | Static water level (ft, ASL)[2] | Date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CE-EE 29 | 73-2266 | Sydnor Hydro-dynamics. | 39°24'03" N., 75°52'18" W. | Potomac | 75 | 1,458 | 4 | 515 | 440- 450 | 4 | 20 | 6 | 8/01/78 |
| KE-AC 20 | 73-0658 | do. | 39°20'07" N., 76°07'55" W. | do. | 7 | 1,151 | 4 | 550 | 543- 553 | 4 | 20 | 5.0 | 12/02/77 |
| KE-BE 43 | 73-0659 | do. | 39°18'23" N., 75°59'47" W. | Magothy(?) | 65 | 1,672 | 4 | 275 | 210- 220 | 4 | 20 | 11.0 | 12/06/78 |
| KE-BG 33 | 73-0670 | Layne-Atlantic | 39°18'15" N., 75°47'21" W. | Potomac(?) | 65 | 2,185 | 4 | 695 | 630- 640 | 4 | 20 | 3.4 | 11/01/78 |
| KE-BG 34[3] | 73-0686 | Middletown Drilling. | 39°18'15" N., 75°47'22" W. | Aquia(?) | 65 | 186 | 6 | 125 | 60- 121 | 4 | 40 | 37.3 | 11/01/78 |
| KE-CB 36 | 73-0660 | Sydnor Hydro-dynamics. | 39°14'00" N., 76°10'14" W. | Potomac | 40+ | 1,540 | 4 | 595 | 555- 565 | 4 | 20 | 4 | 4/25/78 |
| | | | | | | | 4 | 1,050 | 1,010-1,020 | 4 | 20 | .1 | 4/25/78 |
| | | | | | | | 4 | 1,490 | 1,450-1,460 | 4 | 20 | -3(?) | 4/18/78 |
| KE-DB 40 | 73-0805 | A.C. Schultes & Sons | 39°08'37" N., 76°14'04" W. | do. | 15 | 1,832 | 4 | 1,023 | 1,008-1,018 | 4 | 20 | 2.3 | 12/28/78 |
| QA-BE 15 | 70-0130 | Delmarva Drilling | 39°12'03" N. 76°02'43" W. | Patapsco | 25 | 2,009 | 4 | 1,161 | 1,136-1,146 | 4 | 25 | 6 | 8/07/70 |

1/ BLS = below land surface.
2/ ASL = above sea level.
3/ Drilled as a water-supply well for test KE-BG 33.

## AQUIFER TESTS

After completion of each test well, the aquifer was tested to assess the transmissivity of the sands in which the wells were screened. The well at Rock Hall, Md. (KE-DB 40), was tested for 24 hours, and, at the other wells, the aquifer tests lasted from 4 to 8 hours. The quantity of water produced during the tests varied from well to well. Large yields were obtained at some sites but could not be obtained at other sites. The probable reasons for this were high well losses or very low transmissivities in some of the screened sands. The high well losses may have been due to a limitation on the length of time available for well development. No observation wells were available for these tests, so that drawdown and recovery measurements could be made only in the pumped well. For this reason, storage coefficients could not be determined by this method. The transmissivities were determined from data obtained during recovery.

Instead of a conventional pumping test, a packer test was run on well KE-CB 36 at Fairlee because the multi-point electric log indicated a zone of fresh water below a zone of brackish water. Three 10-ft-long, 4-in. diameter screens were inserted into the borehole in the same string of 4-in. casing and positioned opposite the zones of interest. A gravel pack was placed opposite the screens and extended approximately 10 ft above and below the top and bottom of each screen. Cement grout was emplaced between the gravel packs and thence to the land surface to seal off each of these three zones. Each sampled zone was then isolated from the remaining two zones by a pair of packers. Water from the sampled zone was then pumped by airlift until clear water was obtained and remained clear for 8 hours. Water from the lowermost screen took several days to clarify. The slowness was probably due either to extremely low transmissivity or a partly plugged screen. With the packers in place, it was not possible to measure water-level declines in this hole. Consequently, a conventional aquifer test could not be made at the site of KE-CB 36. Because of partial clogging of the screens and inadequate well development, the packer tests provided no reliable data on yields or specific capacities at the tested depths.

At the end of each aquifer test, water samples were collected for analysis of major ions and, in the well at Fairlee (KE-CB 36), for certain trace metals. Here, samples from the two lowermost aquifers were collected after the pumped water cleared; no change in specific conductance was noted after an 8-hour period. At each site, except for well KE-AC 20 at Stillpond Neck, the temperature, pH, and specific conductance of the water were measured in the field.

After the completion of each pumping test, a digital recorder was installed on the well to record water-level fluctuations for 1 year. Also, three observation wells at Chestertown, Md. (fig. 1), each screened in one of the Aquia, Magothy, and Potomac aquifers, were reactivated at this time. The digital recorders were removed from wells that showed no observed water-level declines during 1 year. These sites, however, have continued to be measured on a regular semi-annual basis.

# HYDROGEOLOGY

The Coastal Plain deposits form a wedge-shaped mass of sediments of Cretaceous, Tertiary, and Quaternary age that rests on sloping crystalline basement rock (fig. 2) (Edwards and Hansen, 1979). These deposits consist of unconsolidated beds of clay, silt, sand, and gravel, which thicken west to east from the Fall Line to the ocean. The maximum thickness of these deposits in the report area is about 2,500 ft, from near the mouth of the Chester River to the vicinity of Smyrna, Del.

Table 2 presents a generalized description of the geologic and hydrologic character of the Coastal Plain deposits.

## POTOMAC GROUP

Sediments of Cretaceous age constitute the bulk of the Coastal Plain deposits in Maryland and Delaware. The lowermost unit, the Potomac Group (Lower and Upper Cretaceous), crops out along the Fall Line west of Chesapeake Bay and in parts of Kent and Cecil Counties east of Chesapeake Bay (fig. 3).

The thickness of the Potomac Group ranges from zero at the Fall Line to more than 4,700 ft along the ocean (Hansen, 1984, fig. 1). In the study area, the maximum thickness of the Potomac Group is about 1,800 ft (fig. 4).

**Table 2.—Generalized description of the geologic units occurring in the upper Chesapeake Bay area.**

| SYSTEM | SERIES | GROUP | FORMATION | THICKNESS (range in feet) | LITHOLOGY | WATER-BEARING PROPERTIES |
|---|---|---|---|---|---|---|
| QUATERNARY | HOLOCENE | | - | 0-10 | Silt and sandy loam soil; tidal marshes and beach sand. | Unimportant as a source of ground water. A few wells in sands near estuaries. |
| | PLEISTO-CENE | | Unconsolidated deposits | 0-90 | Sand and gravel, clay, and sandy clay, lenticular, cross-bedded, and variable. Fluvial and marine in origin. | The water-table aquifer throughout most of upper Eastern Shore. |
| TERTIARY | MIOCENE | Chesapeake | Choptank | Unknown | Sand, silt, and shell layers in counties to the south. Possibly present only in southeastern Queen Annes County. | Only a fair aquifer in Caroline and Talbot Counties. |
| | | | Calvert | 15-165 | Chiefly sandy clay and shell beds. Much blue clay reported in well logs. Marine in origin. | Not an important aquifer in the area. Water-bearing mainly in southeastern Queen Annes County. |
| | EOCENE | Pamunkey | Piney Point | Unknown | Not recognized in wells in the area. May be present in subsurface in southern and southeastern Queen Annes County. | An excellent aquifer in counties to the south and in southern Maryland. |
| | | | Nanjemoy | 0-100 | Chiefly gray and brown clay in wells on Kent Island. At Grasonville, chiefly greensand. Marine in origin. | Leaky confining layer in vicinity of Kent Island, but may be water-bearing at Grasonville and eastward in Queen Annes County. |
| | ? PALEOCENE | | Aquia | 60-230 | Brown, silty greensand in Kent County and northern Queen Annes County. Greensand alternating with thin hard lime-cemented beds in southern Queen Annes County. Marine in origin. | The most important source of ground water in Queen Annes County. Several hundred wells tap it on Kent Island and at Queenstown and Grasonville. Also public-supply wells at Chestertown in Kent County. |
| | | | Hornerstown | Unknown | Subsurface distribution uncertain; chiefly a sand. | Not regarded as a major aquifer. |
| CRETACEOUS | UPPER CRETACEOUS | | Monmouth | 60-100 | Brown, glauconitic sand and sandy clay; iron-stained. Marine in origin. | An important water-bearing formation in Kent County. Water tastes of iron. Probably a leaky confining layer in southern Queen Annes County. |
| | | | Matawan | 50-80 | Dark gray, micaceous, glauconitic sand and silty sand. Marine in origin. | Chiefly a leaky confining layer in parts of Kent and Queen Annes Counties. Where thin sands occur, water may be irony. |
| | | | Magothy | 0-80 | Dark gray, carbonaceous clay and white sand. Contains pyrite and lignite. Estuarine (?) and continental in origin. | An important potential source of water in Kent and Queen Annes Counties. Water tastes of iron in many localities. Used at Cecilton. In places, combines with Patapsco sand to function as one aquifer. |
| | ? LOWER CRETACEOUS | Potomac | Patapsco Arundel Patuxent | 0-1,800 | Unconsolidated sand, clay, and sandy clay. Clays commonly red, brown, light and dark gray, purple, white, and yellow. Contains lignite, pyrite, siderite and hematite, or limonite concretions. | An important source of water in Cecil and parts of Kent County. Water commonly high in iron. Degree of salinity increases with depth. As much as 1,800 mg/L total dissolved solids at Stillpond and Fairlee, Kent County. |

1/ Modified from Overbeck and Slaughter (1958, table 10).

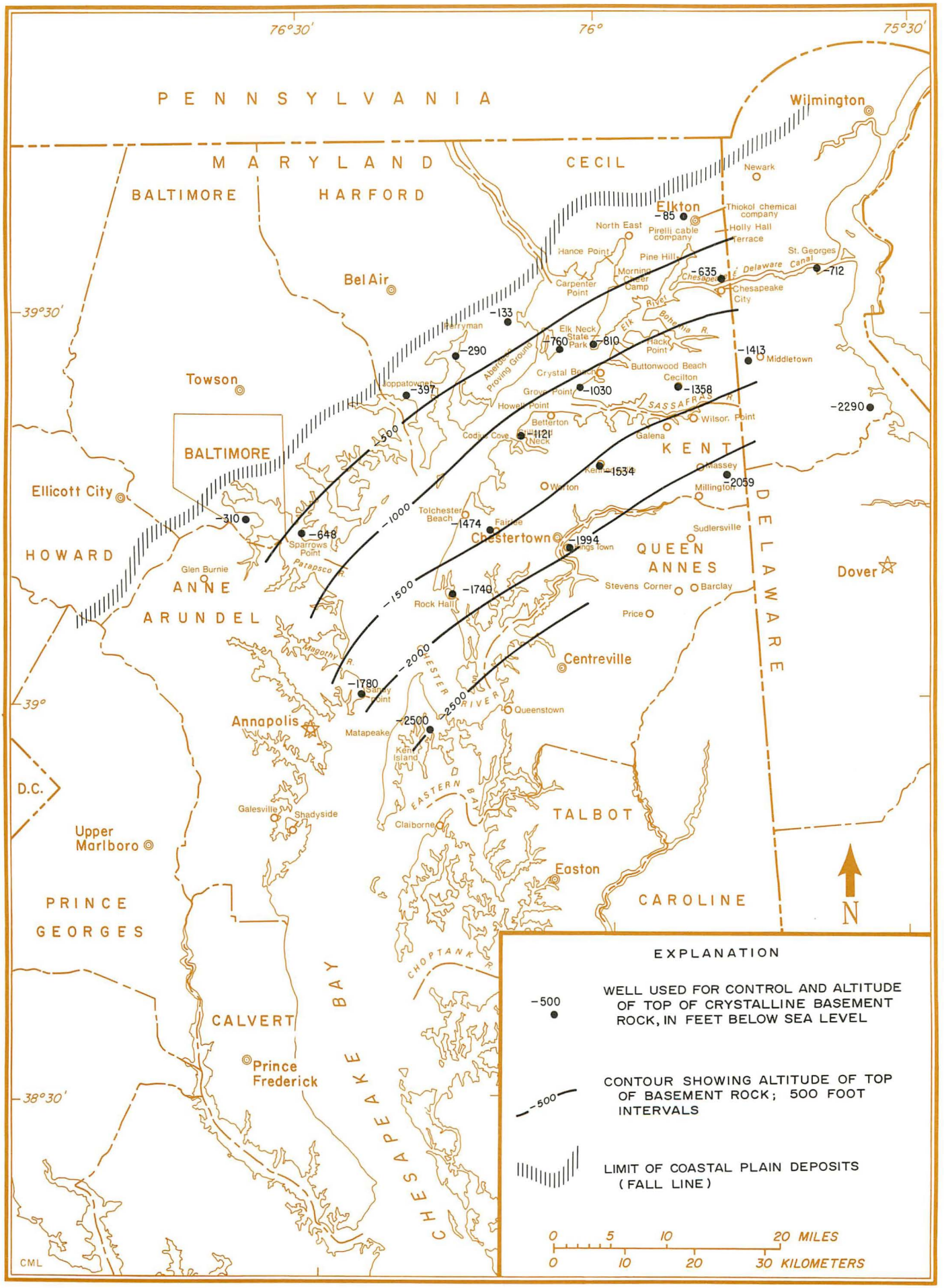


**Figure 2.—Altitude of top of crystalline basement rock.**

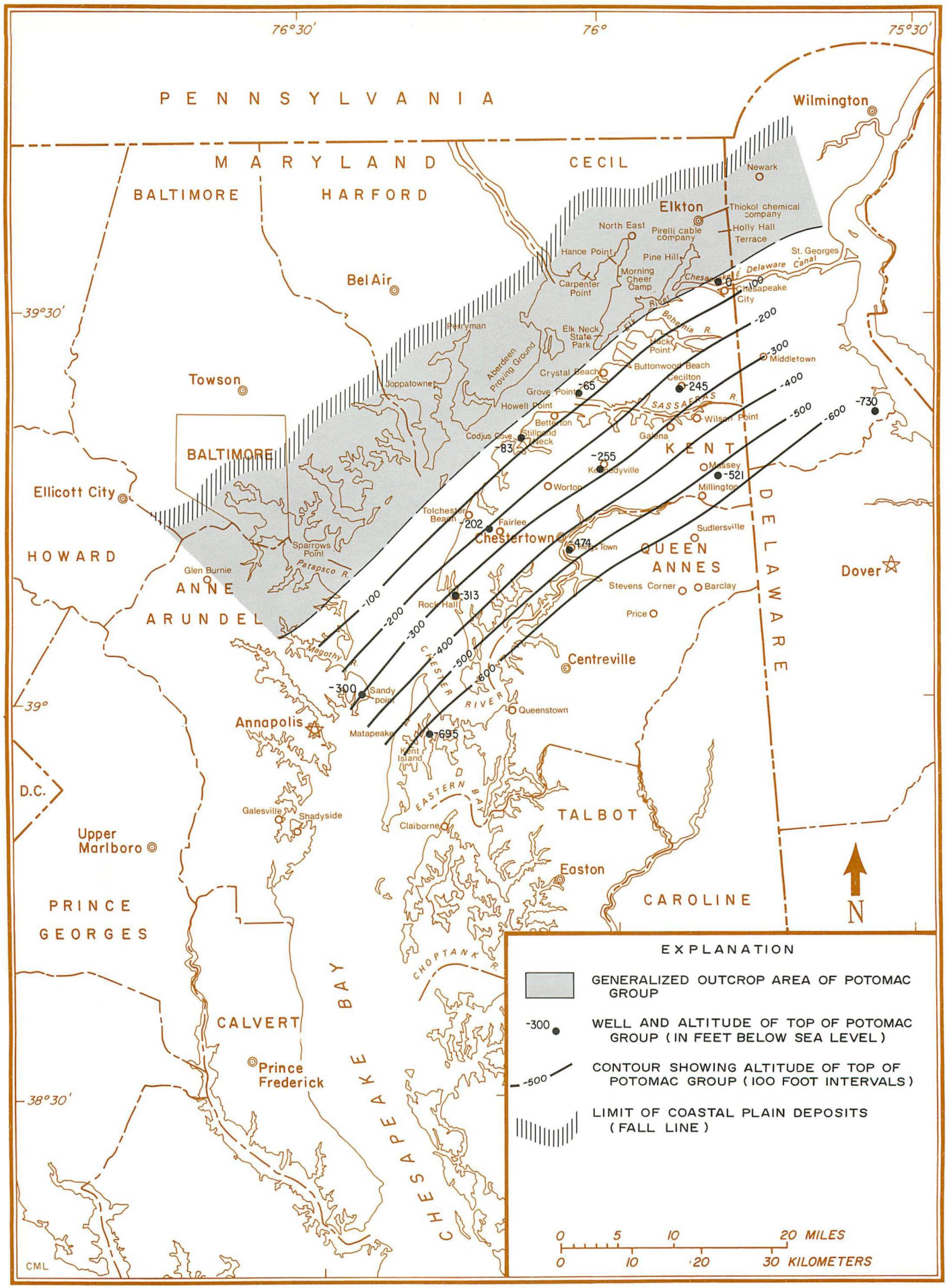


**Figure 3.—Outcrop area and top of Potomac Group.**

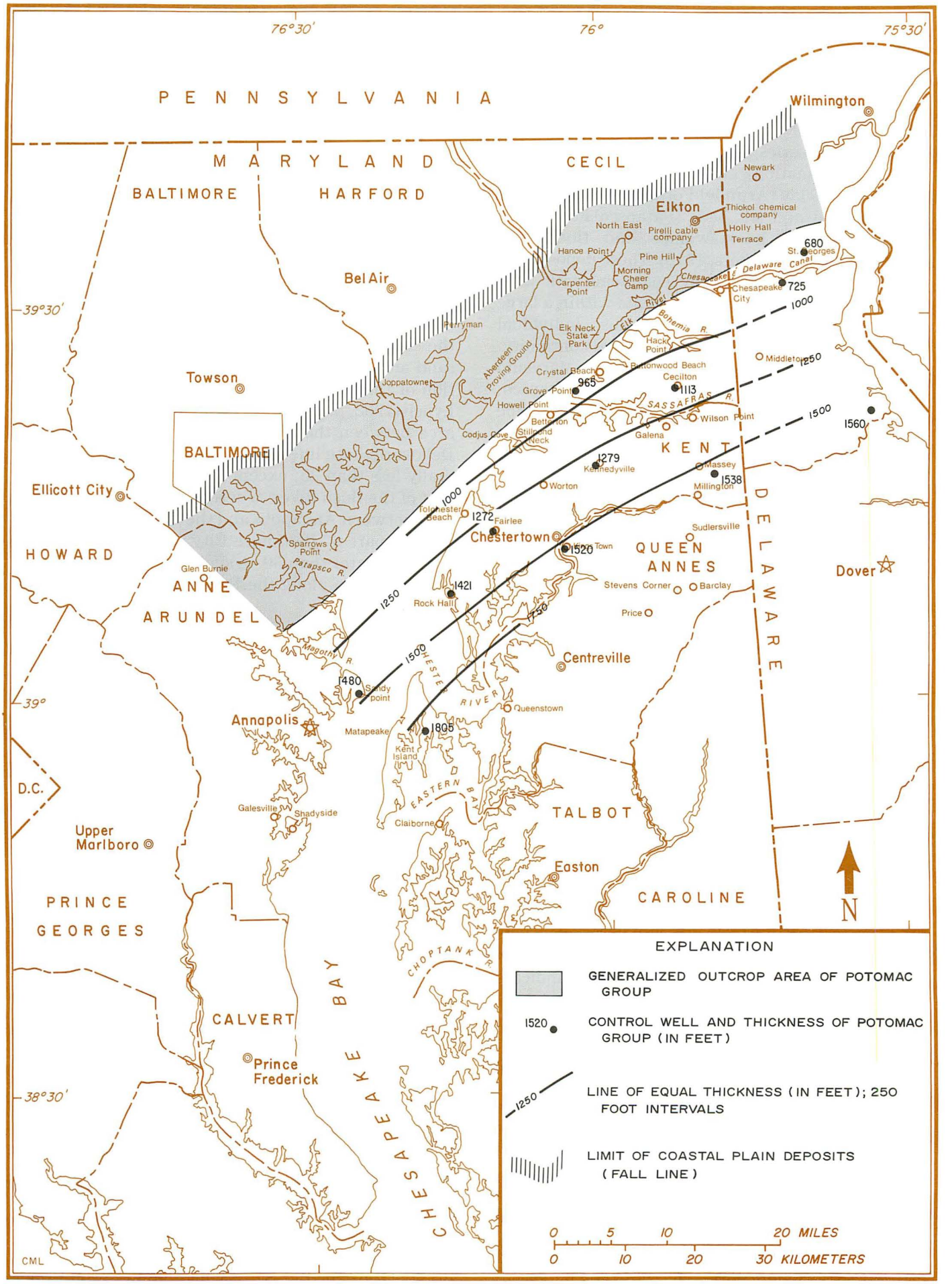


**Figure 4.—Thickness of Potomac Group.**

The sediments of the Potomac Group were deposited in a river-delta environment (Hansen, 1969; Glaser, 1969). The type sediments constitute a transitional series from coarse channel deposits (Patuxent Formation), characteristic of alluvial valleys, to thick clay (Arundel Formation), and fine to medium sand and silt beds (Patapsco Formation) characteristic of back-swamps and flood-plain deposits (Clark and others, 1918). These depositional environments shifted laterally, coalescing with other migrating depositional environments within a large river-delta system. Because of this, individual lithologic units usually have little lateral continuity.

On the Eastern Shore and in southern Maryland the formations of the Potomac Group (Patapsco, Arundel, and Patuxent) are thicker than the type sediments and have more clay. In the absence of fossil pollen and spore data they can be differentiated only with difficulty.

The term "Potomac Group", as used in this report, may include some Magothy sediments that, on the Eastern Shore, are not easily distinguishable from Potomac sediments. In the project area the sediments of the Potomac Group are chiefly composed of interbedded white to gray quartz sand with variegated clay (red, brown, purple, gray, white, and yellow). Some of the sand beds are feldspathic. Also included are medium- to dark-gray clay beds with abundant lignite and pyrite; layers containing concentrations of siderite, hematite or limonite; and quartz pebbles intercalated with light gray micaceous clay overlying weathered basement rock in some places.

Individual lithologic units in the Potomac Group are not readily traceable, even over short distances, because the sediments have little lateral continuity. An example of the complex character of these deposits is geologic cross-section A-A′ (fig. 5). The section is based on interpretation of gamma-ray and multi-point resistivity logs (16- and 64-in. electrode spacing). Deflections to the left on the gamma-ray log and to the right on the resistivity log indicate possible sand beds; conversely, deflections to the right on the gamma-ray log and to the left on the resistivity log indicate clay and silt beds. As can be seen from the logs in figure 5, it is extremely difficult to correlate sand zones from well to well. Note, in particular, that the sand at Sandy Point (well AA-CG 22) at a depth of approximately 250 ft to 750 ft below land surface is not present at Rock Hall (well KE-DB 40), 12 mi to the northeast. Further examination of this cross-section and the other sections shows numerous examples of discontinuous sand zones.

This seemingly random vertical and horizontal distribution of highly permeable sand and impermeable clay makes evaluation of the ground-water potential of the Potomac Group difficult because permeability distribution cannot be mapped directly. However, the distribution of relative permeability can be interpreted in a general way by computing and mapping the percentage of sand and total sand thickness of the Potomac Group. These data were derived from drillers' logs and geologists' logs and from the interpretation of electric logs of wells. Where electric logs were used, sand percentage was determined by calculating the percentage of the area between the spontaneous potential (S.P.) curve and the clay line relative to the total area between the sand and clay lines. This represents the sand fraction of that interval. This procedure is outlined in Lynch (1962, p. 197–199). Figure 6 shows that, in the area between the Little Gunpowder Falls and the Delaware State line, the percentage of sand is generally less than 25, except for one anomalous area east of the Bush River, where it is 60 percent. In the area between Annapolis and the Patapsco River, including part of Baltimore City, the percentage of sand is greater than 50. A similar area occurs south of Wilmington along the Delaware River.

### Hydraulic Coefficients

The transmissivity of the Potomac Group varies widely because of its extremely variable lithology. Hansen (1972) reports that, from 57 aquifer tests in Maryland, transmissivity of sand zones in the Potomac Group ranged from 130 to 6,700 $ft^2/d$. Transmissivities in Delaware are as high as 6,200, as reported by Groot and Rasmussen (1954) for the Newark area. Transmissivity values of 400 to 5,500 $ft^2/d$ were determined from aquifer tests at four of the test sites in Cecil and Kent Counties, Md. Figure 7 shows the location of wells where aquifer tests have been made in the Coastal Plain aquifers—thus, where hydraulic coefficients are available. Values of transmissivity and storage are given in table 3, which also includes a few values from sands in the Potomac Group in Harford County.

The highest transmissivity shown in table 3 (9,200 $ft^2/d$) is based on an extrapolation of a specific capacity test on a highly productive well near Perryman in Harford County (Nutter and Smigaj, 1975, p. 78). A similar high value of 7,000 $ft^2/d$ was reported by Mack (1962, p. 24) from an aquifer test at the U.S. Naval Academy at Annapolis (not included in tab. 3).

Through a method described by Ferris and others (1962, p. 133–134), which makes use of the

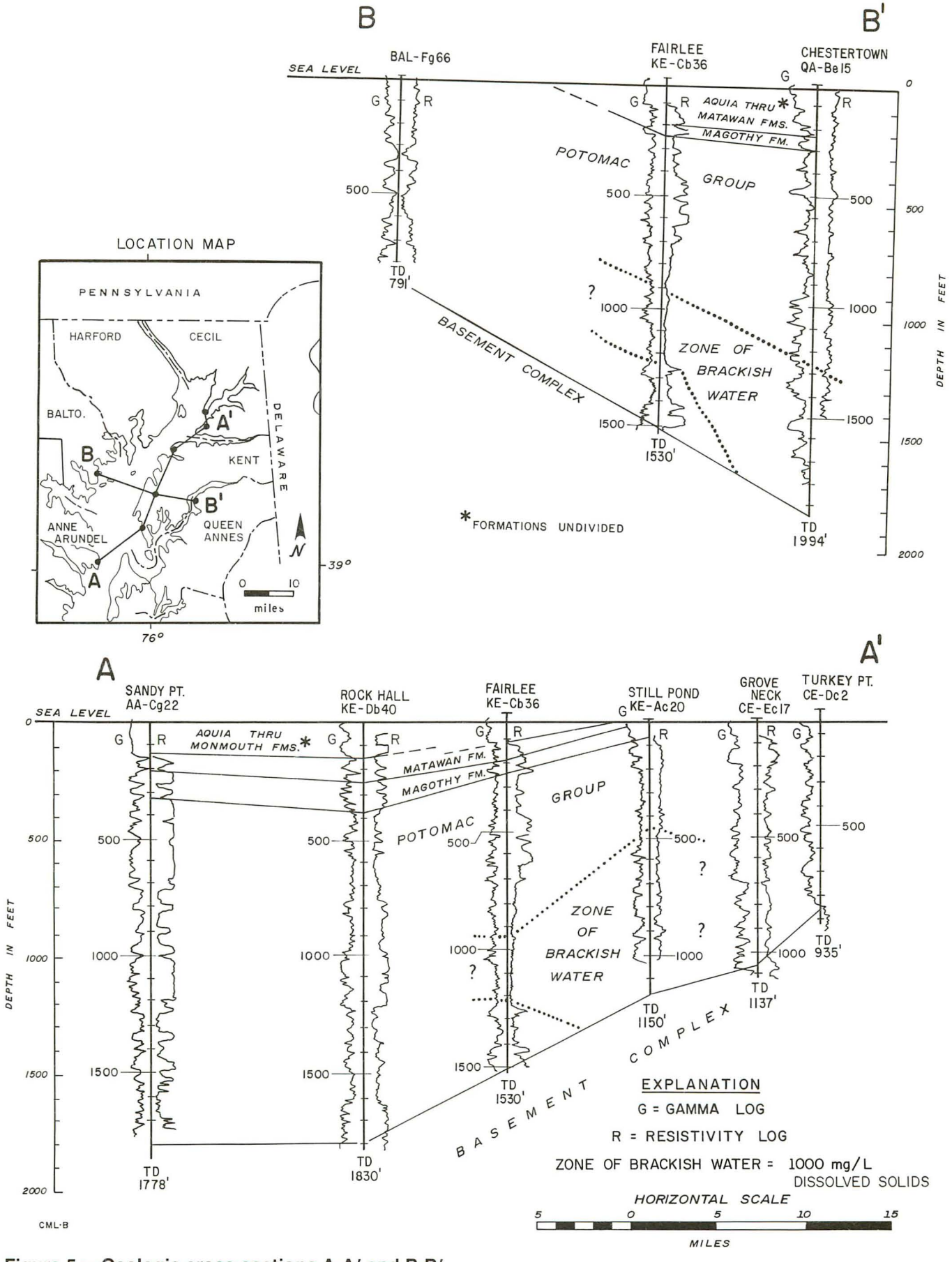


**Figure 5.—Geologic cross-sections A-A′ and B-B′.**

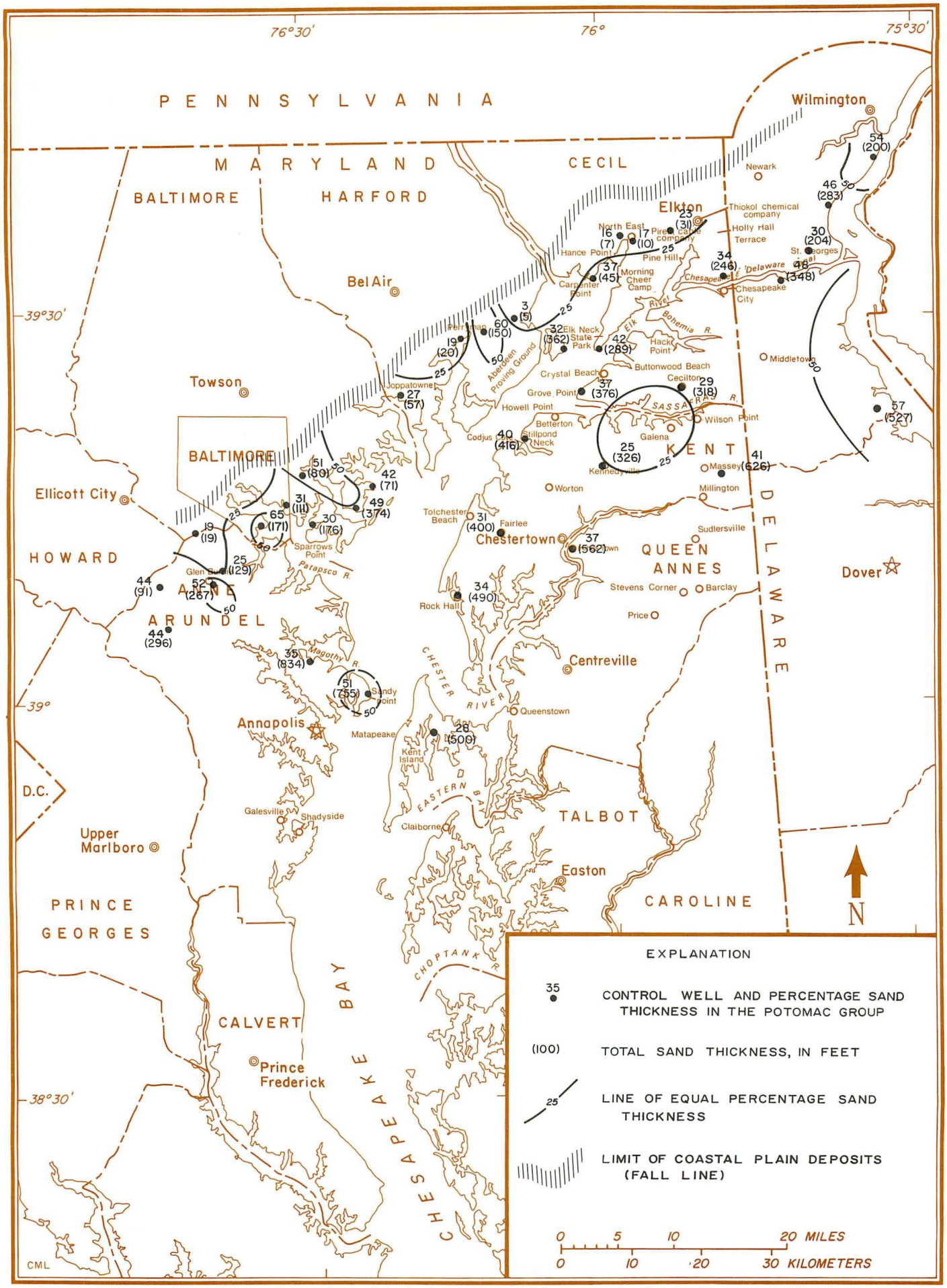


**Figure 6.—Percentage thickness of sand and total sand thickness in the Potomac Group.**

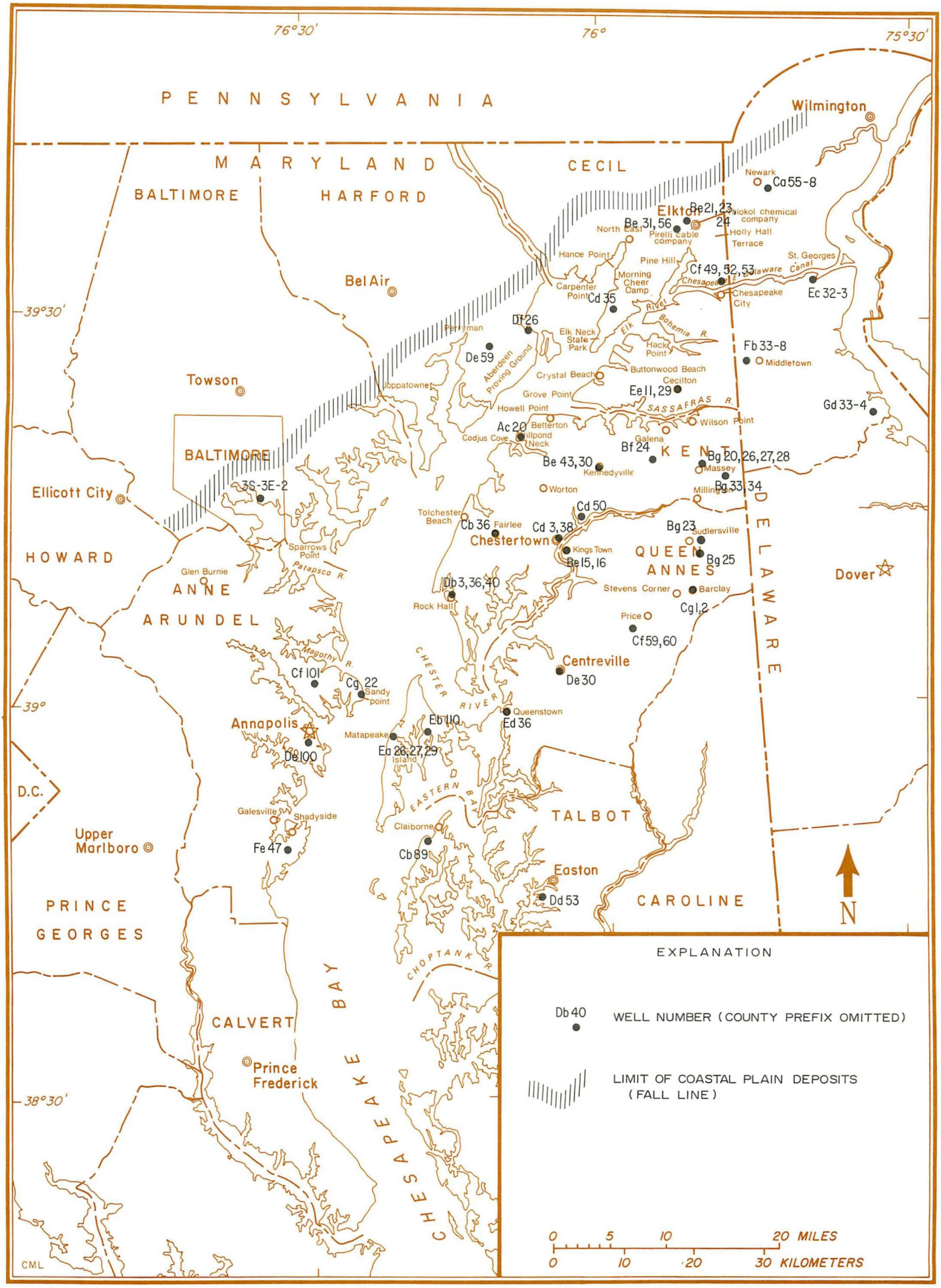


**Figure 7.—Location of wells where transmissivity and storage coefficients of Coastal Plain aquifers were determined and location of other wells mentioned in report.**

**Table 3.—Transmissivity, hydraulic conductivity and storage coefficients for sand zones of the Potomac Group in the upper Chesapeake Bay area.**

| Well No. | Location | Method of determination | Data source or reference | Transmissivity (T) ($ft^2/d$) | Storage coefficient (S) | Depth of screen (ft below land surface) | Effective sand thickness (ft) | Hydraulic conductivity (K) (ft/d) |
|---|---|---|---|---|---|---|---|---|
| CE-BE 31 -BE 56 | Elkton | Aquifer test[1] | Overbeck and Slaughter (1958, p. 47-48) | 740 | 0.0001 | 99-104 | 5 | 150 |
| CE-CD 35 | Elk Neck (Camp Rodney) | do. | do. (p. 49) | 3,200 | - | 165-180 | 15 | 210 |
| CE-CF 49 -CF 52 -CF 53 | Chesapeake City | do. | Sundstrom and others (1967, p. 50) | 2,500 | .0001 | 390-410 | 20 | 125 |
| CE-EE 29 | Cecilton | do. | | 1,500 | - | 515-525 | 10 | 150 |
| -EE 29 | do. | Barometric amplitude | Todd (1959, p. 161-162) | - | .0096 | 515-525 | - | - |
| HA-DE 59 | Perryman | Transmissivity estimated from spec. capacity[2] | Nutter and Smigaj (1975, p. 76) | 9,200 | - | 96-144 | 48 | 190 |
| HA-DF 26 | Aberdeen Proving Ground | do. | do. (p. 76) | 2,500 | - | 79-97 | 18 | 140 |
| KE-DB 40 | Rock Hall | Barometric amplitude | Todd (1959, p. 161-162) | - | .0098 | 1,019-1,031 | 50 | 110 |
| -DB 40 | do. | Aquifer test[1] | - | 5,500 | - | 1,019-1,031 | - | - |
| KE-AC 20 | Stillpond Neck | Tidal time-lag | Ferris and others (1962, p. 134) | 500 | - | 550-560 | 10 | 50 |
| KE-BG 33 | Massey | Barometric amplitude | Todd (1959) | - | .0073 | 695-705 | 10 | 40 |
| -BG 33 | do. | Aquifer test[1] | - | 400 | - | - | - | - |
| QA-BE 16 | Chestertown | do. | Kantrowitz and Webb (1971, p. 13) | 1,000 | - | 478-498 | 20 | 50 |
| CA-55-8 | Newark, Del. | do. | Groot and Rasmussen (1954, p. 82) | 6,200[3] | .07[4] | - | 30 | 200 |
| EC-32-3 | St. Georges, Del. | do. | Geraghty and Miller (1967, p. 10) | 3,600 | .0004 | 318-328 338-348 | 20 | 180 |

1/ Analysis based on Theis non-equilibrium formula (Ferris and others, 1962, p. 101).

2/ Iterative solution based on formula by Lohman (1972, p. 52).

3/ Average of 18 values reported on test of February 1951.

4/ Average of 14 values reported on various tests.

water-level fluctuations in an artesian aquifer due to tidal effects in a coastal region, a transmissivity value of 500 $ft^2/d$ was computed for a water-bearing sand screened at a depth of 550–560 ft in well KE-AC 20. This method uses the time lag between crests of tidal fluctuations in a bay or estuary and tidal fluctuations in an observation well. The formula is:

$$T = 0.08\ t_o\ S \left(\frac{x}{t_1}\right)^2$$

where

$T$ = transmissivity, in feet squared per day;

$t_o$ = period of tidal stage, in days;

$S$ = storage coefficient, in percent;

$x$ = distance, in ft, from tidal-water body to observation well; and

$t_1$ = time lag, in days, between peak of tidal stage and peak of water-level stage in the aquifer.

The input data for well KE-AC 20 are:

$t_o = 0.534$ day;

$t_1 = 0.151$ day;

$x = 200$ ft;

$S = 0.0065$ (from KE-DB 40 at Rock Hall, Md.); and

$T = (0.08)\ (0.534)\ (0.0065) \left(\frac{200}{0.151}\right)^2 = 500\ ft^2/d$ (rounded).

Figure 8 is a graph of the tidal fluctuations during 7 days in June 1978, which were used in the formula for computing the transmissivity of the sand zones tapped by well KE-AC 20.

Six values of the storage coefficient for the aquifers of the Potomac Group were obtained; they range from 0.0001 to 0.0098 (tab. 3). The minimum values of 0.0001 were reported from sands at Elkton and Chesapeake City. These values were computed by means of the Theis nonequilibrium formula applied to aquifer tests where nearby observation wells were available and are in the range commonly reported for artesian aquifers. The three highest storage coefficients in table 3 (0.0098, 0.0096, and 0.0073) were determined by a method described by Todd (1959, p. 161–162), based on a relationship discussed by C. E. Jacob (1940, p. 574). The method requires the simultaneous measurements of barometric atmospheric pressure and static water levels in an artesian aquifer. The formula used by Todd is:

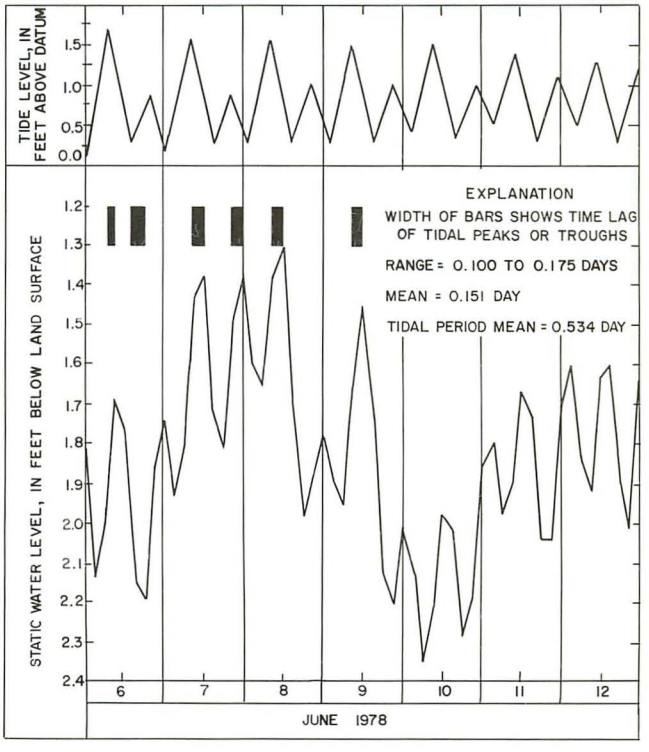


**Figure 8.—Water-level fluctuations in well KE-AC 20 and tidal fluctuations at the U.S. Coast Guard Station, Stillpond Neck, Maryland.**

$$S = \frac{\theta r b}{E_w\ B}$$

where

$S$ = storage coefficient;

$\theta$ = porosity of aquifer, in percent;

$r$ = specific weight of water (62.3 $lb/ft^3$ at 20 °C);

$b$ = aquifer thickness, in feet;

$E_w$ = bulk modulus of compressibility of water (approximately 300,000 $lb/in^2$);

$B$ = barometric efficiency of an aquifer (defined as the ratio of water-level change to atmospheric pressure change).

During June 10–16, 1979, a record of barometric fluctuations was compiled in the vicinity of wells CE-EE 29, KE-BG 33, and KE-DB 40.

These records were analyzed in conjunction with the water levels in the aquifers during the same period and form the basis for the values of storage coefficients in table 3 for the aquifers tapped by the wells. Figure 9 shows the graphic record of barometric fluctuations at Massey and the synoptic water-level fluctuations in well KE-BG 33. This well is screened in a sand at a depth of 695–705 ft below land surface. The aquifer here is 50 ft thick, and the record covers a 7-day period in June 1979. The storage computations are:

$$S = \frac{(0.30)(62.3)(50)}{300{,}000\ (0.428)} = 0.0073$$

where

$\theta =$ 0.30*;

$r =$ 62.3 lb/ft$^3$;

$b =$ 50 ft;

$E_w =$ 300,000; and

$B =$ 0.428.

NOTE: Barometric pressure, in inches of mercury (Hg), must be converted to feet of $H_2O$ to determine (B); 1 inch Hg = 1.13 ft $H_2O$.

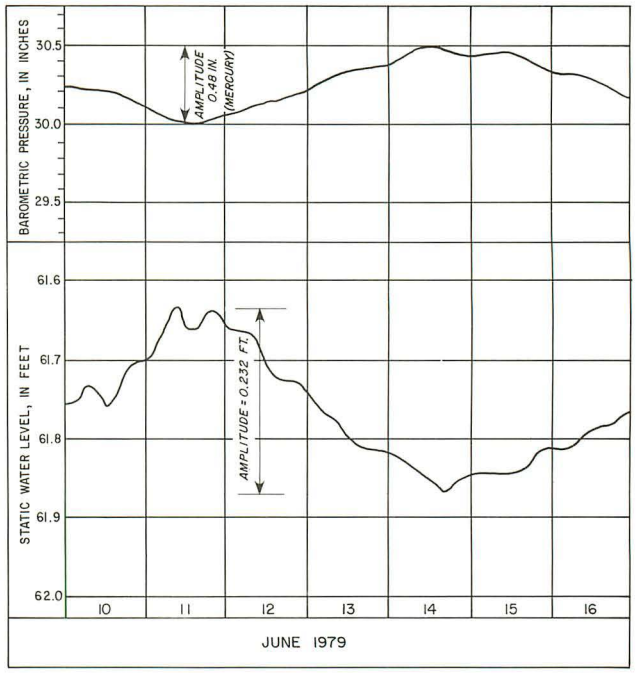


**Figure 9.—Water-level fluctuations in well KE-BG 33 and barometric fluctuations at Massey in Kent County, Maryland.**

### Pumpage from Aquifers in the Potomac Group

Because the upper Chesapeake Bay area is largely rural and the population small, overall ground-water use is low. Combined municipal, industrial, and institutional pumpage from the aquifers of the Potomac Group amounted to only about 0.84 Mgal/d in 1980 (tab. 4). The two largest pumpage centers in 1980 were the community of Holly Hall Terrace near Elkton (213,000 gal/d) and Chesapeake City (168,000 gal/d). Combined self-supplied industrial use by two firms was about 62,000 gal/d, or about 7 percent of the estimated pumpage. At some places, such as Elk Neck State Park, the pumpage is largely seasonal, and the yearly total may be overestimated.

A significant amount of pumpage from these aquifers takes place in the Chesapeake and Delaware Canal (C & D Canal) area of Delaware, 8 to 10 miles east of the town of Chesapeake City in Maryland. Here, pumpage at the Getty Refining Company averaged 4.0 Mgal/d in 1980 (Martin and Denver, 1981, tab. 3). Additional pumping from the Potomac Group occurs at several well fields further northeast in New Castle County, Del.

*Weighted mean value of porosity of three cores from aquifers in the Potomac Group in test well DO-CE 88 near Cambridge, Md. (Trapp and others, 1982).

### Water-Level Trends

Few data are available to indicate water-level trends in aquifers of the Potomac Group, but the record of observation well CE-CF 49 is available from 1967 through 1980. Monthly water-level measurements in the well show a decline of approximately 10 ft during the more than 14 years of record (fig. 10). This decline may be the result of the gradually increasing rate of pumping from the aquifers in both Maryland and Delaware. Much of this increase has been from the Getty Refining Company and a few other industries on the west bank of the Delaware River, about 10 mi east of well CE-CF 49. The annual average rate of pumping increased from 2.13 Mgal/d in 1967 to 4.02 Mgal/d in 1980. The reason that this nearly doubled pumping rate did not cause an even greater decline in water levels is that the outcrop area of the aquifers lies only a few miles north of the center of pumping. In the exposed area, the aquifer receives substantial recharge to replenish the water removed by pumping, thus limiting the rate of growth and extent of the cone of depression.

**Table 4.—Municipal, industrial, and institutional pumpage from aquifers in the Potomac Group in the upper Chesapeake Bay area in 1980[1]**

| Location | Yearly total (Mgal) | Daily average (gal) | Type of use |
|---|---|---|---|
| *CECIL COUNTY* | | | |
| Buttonwood Beach Campground | 4.9 | 13,425 | Municipal |
| Carpenters Point | 3.7 | 10,100 | do. |
| Chesapeake City | 61.3 | 168,000 | do. |
| Crystal Beach | 6.4 | 17,500 | do. |
| Hance Point | 2.0 | 5,480 | do. |
| Holly Hall Terrace (part of Elkton system) | 77.9 | 213,000 | do. |
| Maryland State Forests and Parks (Elk Neck) | 9.1 | 24,930 | Institutional (Seasonal) |
| Meadowview Utilities | 41.4 | 113,400 | Municipal |
| Morning Cheer Camp and Bible Conference Center | 3.2 | 8,770 | Institutional (Seasonal) |
| Pirelli Cable Company | 13.7 | 37,500 | Industrial |
| Pine Hill (Board of County Commissioners) | 7.8 | 21,370 | Municipal |
| Thiokol Chemical Company | 8.8 | 24,100 | Industrial |
| Town and Country Mobile Park | 10.9 | 29,865 | Municipal |
| *KENT COUNTY* | | | |
| Rock Hall | 55.8 | 152,900 | Municipal |
| Total[2] | 306.9 | — | |
| Daily average | — | 840,000 | |

[1]Table 4 does not include dispersed domestic and farm pumpage because of the seasonal population fluctuations along the waterfront areas.
[2]Community of Hack Point pumped about 3.5 Mgal in 1980, but from individual domestic wells, so not included above.

## MAGOTHY FORMATION

The Magothy Formation (Upper Cretaceous), immediately above the Potomac Group, represents a transition from a nonmarine to a marine environment. The association of loose, white, lignitic, "sugary" sand, and gray to dark gray laminated silt and clay, is characteristic of much of the Magothy Formation and serves to distinguish it from contiguous units. The contact between the Magothy and the underlying Potomac Group is characterized in many places by the presence of whitish "sugary" sands overlying red-brown clays or clayey silts marking the top of the Potomac Group. Elsewhere, however, the Magothy may be in direct contact with a sand of the Potomac Group to form a single hydrologic unit, at least locally.

The sand in the Magothy Formation is a major Coastal Plain aquifer and has been traced northeastward from the vicinity of Waldorf in Charles County, Md., across the Chesapeake and Delaware Bays into New Jersey and northeastward to Long Island, N.Y. In the upper Chesapeake Bay region the Magothy crops out only at a few places. One of these is at the mouth of the Sassafras River in low cliffs about 1.5 mi west of Betterton, Md., and another is along the west side of Stillpond Neck, 4 to 5 mi southwest of Betterton (Minard, 1974, p. 6). The Magothy ranges in thickness from 175 ft in Anne Arundel County (Mack and Mandle, 1977, tab. 1) to about 30 ft in the Betterton quadrangle (Minard, 1974, p. 6). In well CE-EE 29, the Magothy Formation occurs at a depth of 240 ft below land surface. In this well, the unit is 80 ft thick according to the geologic log (tab. 11).

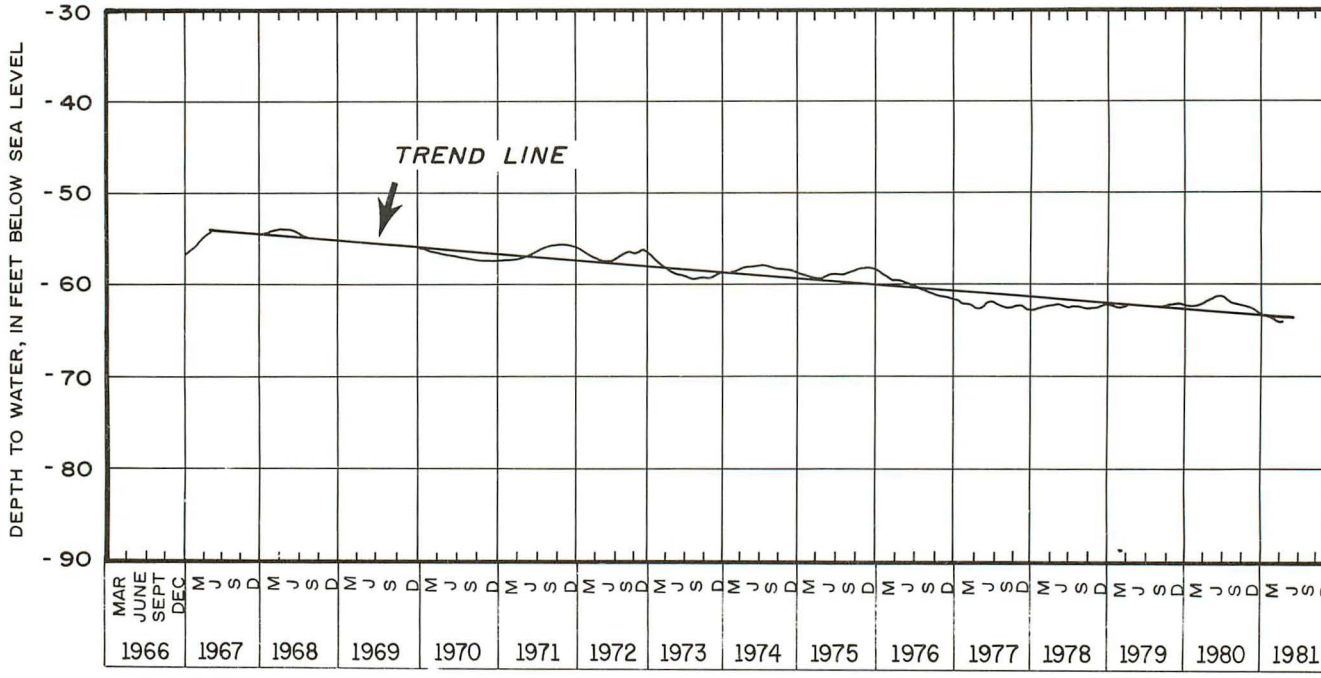


**Figure 10.—Water levels in observation well CE-CF 49 near Chesapeake City, Maryland.**

The following description is from the log of well CE-EE 29 (near Cecilton):

| | Thickness (ft) |
|---|---|
| Magothy Formation | |
| Sand, fine, brown. | 15 |
| Clay, medium to dark gray; abundant lignite and pyrite. | 10 |
| Sand, coarse, white to light gray; quartz with occasional white and pink feldspars; streaks of medium gray clay, lignite and pyrite. | 55 |
| Total | 80 |

### Hydraulic Coefficients

Relatively few data are available on the transmissivity and coefficients of storage of the sands in the Magothy Formation in the upper Bay region. These data are summarized in table 5. The most reliable transmissivity values have been obtained from aquifer tests, three of which range from 3,300 to 10,000 $ft^2/d$. The maximum is from a test well at the U.S. Army Corps of Engineers' Chesapeake Bay Model Laboratory at Matapeake on Kent Island, Md. Transmissivities of 200 and 300 $ft^2/d$ were obtained from averages of specific-capacity tests on domestic wells at Betterton and Grove Point (Overbeck and Slaughter, 1958, p. 57). These low values may be the result of the use of small-diameter screens in the wells and their partial penetration of the aquifer.

Mack and Mandle (1977, tab. 2, p. 18) report that a sample of clay from the Magothy Formation had a hydraulic conductivity of $7.2 \times 10^{-6}$ ft/d. The sample was from well AA-FE 47 near Galesville at a depth of 443 ft. Three values of the storage coefficients range from 0.0001 to 0.00022. The maximum value was from well CE-EE 11 near Cecilton. These values were computed from the Theis nonequilibrium formula and water levels in an observation well.

### Pumpage from the Magothy Aquifer

Pumpage from the Magothy Formation in the upper Chesapeake Bay area in 1980 amounted to only 228,000 gal/d (tab. 6). This pumping was centered around the towns of Cecilton, Betterton, Fairlee-Tolchester Beach, and at the Chesapeake Bay Model Hydraulic Laboratory on Kent Island in Queen Annes County. Total pumpage at the Bay Model facility amounted to 43,000 gal/d. The largest and only significant industrial user of water from the Magothy aquifer was the Tenneco Chemicals Company in Kent County, Md., which pumped 67,000 gal/d in 1980.

**Table 5.—Transmissivity and storage coefficients of the Magothy aquifer in the upper Chesapeake Bay area.**

| Well No. | Location | Method of determination | Reference | Transmissivity ($ft^2/d$) | Coefficient of storage (non-dimensional) | Depth of screen (ft below land surface) |
|---|---|---|---|---|---|---|
| CE-EE 11 | Cecilton | Aquifer test; Theis nonequilibrium formula | Overbeck and Slaughter, 1958, p. 58 | 3,300 | 0.0001 | 262–274 |
| Various wells | Grove Point | Specific capacity (average of 9 wells) | Overbeck and Slaughter, 1958, p. 57 | 200* | — | — |
| Various wells | Betterton | Specific capacity (average of 16 wells) | Overbeck and Slaughter, 1958, p. 57 | 300* | — | — |
| QA-EA 27 | Matapeake | Theis nonequilibrium formula; aquifer test | — | 10,000 | .00022 | 624–663 |
| QA-EA 29 | do. | do. | — | 8,800 | .00022 | 662–682<br>697–699 |

*Relatively low value is due to specific-capacity values from domestic wells that partially penetrate the aquifer.

**Table 6.—Municipal, industrial, and institutional pumpage from the Magothy and/or Monmouth Formations in the upper Chesapeake Bay area in 1980.**

| Location | Yearly total (Mgal) | Daily average (gal) | Type of use | Aquifer |
|---|---|---|---|---|
| *CECIL COUNTY* | | | | |
| Cecilton | 9.2 | 25,200 | Municipal | Magothy |
| *KENT COUNTY* | | | | |
| Betterton | 6.0 | 16,400 | do. | Magothy |
| Fairlee-Tolchester Beach | 14.0 | 38,400 | do. | do. |
| Galena | 13.5 | 37,000 | do. | Magothy[1] |
| Kennedyville | 4.5 | 12,300 | do. | Monmouth |
| Tenneco Chemicals (near Worton) | 24.6 | 67,400 | Industrial | Magothy |
| *QUEEN ANNES COUNTY* | | | | |
| Centreville | 120.0 | 328,800 | Municipal | Monmouth[2] |
| Chesapeake Bay Model Center (Kent Island) | 15.8 | 43,300 | Institutional | Magothy |
| Total | 207.6 | 568,800 | | |

[1]Total includes about 2 percent from the Aquia aquifer.
[2]One well is uncased from 272 to 448 ft; probably yields some water from the Aquia aquifer.

## FORMATIONS ABOVE THE MAGOTHY FORMATION

The formations above the Magothy have a distinct lithology and may be more readily recognized in sample cuttings and on geophysical logs than the formations below. Briefly, the major formations in Maryland are, in ascending order: the Magothy, Matawan and Monmouth Formations of Late Cretaceous age, and the Hornerstown and Aquia Formations of Paleocene age. Except for the southeastern corner of the area, the Aquia Formation is overlain by irregularly distributed Quaternary deposits. In the southeastern corner, the Miocene Calvert Formation is present in the subsurface above the Aquia. Lithologically, the units above the Magothy consist of stratified clay, clayey silt, glauconitic sand, thin shell and calcite-cemented rock layers, and sand and gravel. The thickness of these deposits ranges from 90 ft at Stillpond Neck to 380 ft at Chestertown, and their thickness increases further to the southeast. The following table gives their thickness in each of the test wells:

| Well No. | Location | Thickness of sediments above the Magothy Formation (ft) |
|---|---|---|
| CE-EE 29 | Cecilton | 240 |
| KE-AC 20 | Stillpond Neck | 90 |
| KE-BE 43 | Kennedyville | 265 |
| KE-BG 33 | Massey | 290 |
| KE-CB 36 | Fairlee | 185 |
| KE-DB 40 | Rock Hall | 248 |
| QA-BE 15 | Chestertown | 380 |

### Matawan and Monmouth Formations

The Matawan Formation is characteristically a dark gray, micaceous, glauconitic silt or clayey sand. The strata may vary from light-colored, iron-stained, silty sand to dark, carbonaceous, silty clay. Hydrologically, the formation functions chiefly as a confining layer.

Mack, in a report describing the geohydrology of the Magothy aquifer in the Annapolis area (1974, p. 16), lists the following values for vertical hydraulic conductivity of the Matawan Formation:

| Well No. | Depth of core (ft) | Values from consolidation tests (ft/d) |
|---|---|---|
| AA-CF 101 | 144 | $3.11 \times 10^{-4}$ |
| AA-CF 101 | 171 | $5.68 \times 10^{-5}$ |
| AA-DE 100 | 214 | $4.83 \times 10^{-4}$ |
| AA-DE 100 | 228 | $2.56 \times 10^{-5}$* |
| AA-DE 100 | 242 | $1.16 \times 10^{-4}$ |

*Based on a constant-flow permeameter test.

The Monmouth Formation is similar in appearance to the underlying Matawan Formation. In outcrops along the C & D Canal, it is characterized by a reddish brown color, a moderately high glauconite content and by argillaceous sand or sandy clay. On the electric logs of drilled wells it cannot readily be distinguished from the underlying Matawan Formation. In some places, however, the Monmouth Formation contains a sand that yields water to wells. The following thicknesses have been reported for the Monmouth Formation in the upper Eastern Shore region:

| Well No. | Location | Reference | Thickness (ft) |
|---|---|---|---|
| KE-BE 30 -BE 43 | Kennedyville | This report. | 76 |
| KE-CD 3 | Chestertown | Overbeck and Slaughter, 1958, p. 62. | 71 |
| KE-DB 3 -DB 36 | Rock Hall | Overbeck and Slaughter, 1958, p. 64. | 29 |
| Not given | Middletown, Del. | Rima and others, 1964, p. 34. | 85 |

Although the sand in the Monmouth Formation is apparently of small areal extent, it is used as a water source at a few places on the upper Eastern Shore, such as Centreville and Rock Hall. For this reason, information on the hydraulic coefficients is given in table 7.

*Pumpage from the Monmouth Aquifer:* Based on records supplied by the Maryland Water Resources Administration, pumping from the Mon-

mouth aquifer was at a rate of 378,000 gal/d in 1980 (tab. 6). Most of this withdrawal was by the town of Centreville, which used an average of 329,000 gal/d. The communities of Galena and Kennedyville in Kent County used 37,000 and 12,000 gal/d, respectively.

### Aquia Formation

The Aquia Formation consists of fine- to coarse-grained green to brown sand interstratified with gray-green silt and clay. In many places, indurated, calcite-cemented sands and fossil beds are present. The greenish color is largely due to glauconite, and the brownish cast is due to goethite. Hansen (1972, p. 63) reports that the minerals glauconite and goethite often form between 20 and 70 percent of the formation. The Aquia Formation crops out in Maryland along a band from the Potomac River in western Charles County to the upper Sassafras River in Cecil County. The Aquia extends into New Castle County, Del., where it is called the Rancocas Formation.

The following description of an outcrop of the Aquia Formation at Wilson Point on the Sassafras River (Kent County) is given by Miller (1926, p. 72):

| | Thickness (ft) |
|---|---|
| Pleistocene deposits: | |
| Sand, coarse, brown, very compact, containing isolated gravel lenses. | 11 |
| Aquia Formation: | |
| Sand, coarse, glauconitic, upper part intensely green, and lower 5 to 8 feet lighter in color, somewhat consolidated. | 27 |
| Total | 38 |

Hansen (1974, fig. 12, p. 20) provides a map which suggests that southeast of Easton, Md., across a belt 8 to 10 mi wide, the Aquia Formation decreases markedly in its sand content. It is apparently not an aquifer southeast of Cambridge, Md., and Dover, Del.

The subsurface thickness of the Aquia ranges from 50 ft at Rock Hall to 240 ft at Claiborne (Talbot County). The thickness of the unit, as determined in seven wells, is given:

| Well No. | Location | Thickness (ft) |
|---|---|---|
| AA-EC 60 | Shadyside (Anne Arundel County) | 190 |
| CE-EE 29 | Cecilton | 51* |
| KE-BE 43 | Kennedyville | 90* |
| KE-BG 33 | Massey | 144 |
| KE-DB 40 | Rock Hall | 50 |
| QA-BE 15 | Kings Town | 122 |
| TA-CB 89 | Claiborne (Talbot County) | 240 |

*Includes the underlying Hornerstown Sand.

The Aquia Formation is an important and productive aquifer at several places in the Maryland Coastal Plain, as in southeastern Anne Arundel County, northern Queen Annes County, and southern Kent County. Coefficients of transmissivity range from 500 $ft^2/d$ at Chestertown to about 5,000 $ft^2/d$ at Queenstown. Storage coefficients based on four aquifer tests range from 0.0002 to 0.0004. Values of transmissivity and storage for the Aquia Formation at six localities are:

| Well No. | Location | Transmissivity ($ft^2/d$) | Storage (percent) |
|---|---|---|---|
| KE-BG 20 | Massey | 800 | .0004 |
| KE-CD 38 | Chestertown | 3,200 | — |
| KE-CD 50 | Chestertown (Campbell Soup Co.) | 500 | 0.0003 |
| QA-DE 30 | Centreville (Queen Annes County) | 3,400 | — |
| QA-ED 36 | Queenstown (Queen Annes County) | 5,000 | .0003 |
| TA-DD 53 | Oxford (Talbot County) | 500 | .0002 |

*Pumpage from the Aquia Aquifer:* Pumpage from the Aquia aquifer in the upper Bay area in 1980 was about 1.3 Mgal/d (tab. 8). Most of this was from the municipal well field at Chestertown and from the extensive well field of the Campbell Soup Company about 2½ mi east of Chestertown. Pumpage at both places in 1980 was 1.08 Mgal/d. The third largest user of ground water from the Aquia aquifer was the Friel

**Table 7.—Transmissivity and storage coefficients of sands in the Monmouth Formation in the upper Chesapeake Bay area.**

| Well No. | Location | Reference | Transmissivity[1] ($ft^2/d$) | Coefficient of storage (percent) | Depth of screen (ft below land surface) | Formation thickness (ft) |
|---|---|---|---|---|---|---|
| KE-BE 30<br>KE-BE 43 | Kennedyville | Overbeck and Slaughter, 1958, p. 65 | 300 | 0.0012 | — | 76 |
| KE-BG 26<br>KE-BG 27<br>KE-BG 28 | Massey | Overbeck and Slaughter, 1958, p. 66 | 730 | .0002 | 177–192 | 44† |
| KE-DB 3<br>KE-DB 36 | Rock Hall | Overbeck and Slaughter, 1958, p. 64 | 670 | .0003 | 107–128 | 29* |
| Not given | Middletown, Del. | Rima and others, 1964, p. 34. | 240 | .00025 | — | 85 |

[1] All values determined from aquifer tests, analyzed by the Theis nonequilibrium formula.
†Sand thickness only.
*Well may not penetrate entire thickness of formation.

**Table 8.—Municipal, industrial, and institutional pumpage from the Aquia Formation in the upper Chesapeake Bay area in 1980.**

| Location | Yearly total (Mgal) | Daily average (gal) | Type of use |
|---|---|---|---|
| *KENT COUNTY* | | | |
| Campbell Soup Co.[1] | 211.7 | 580,000 | Industrial |
| Chestertown[2] | 184.3 | 505,200 | Municipal |
| *QUEEN ANNES COUNTY* | | | |
| Friel Cannery Corp. | 38.4 | 105,200 | Industrial |
| Millington | 4.4 | 12,000 | Municipal |
| Country Pride Foods (Queenstown) | 6.0 | 16,400 | Industrial |
| Queenstown | 16.2 | 44,400 | Municipal |
| Stevensville (Stevens Village) | 11.8 | 32,300 | do. |
| Friel Cannery (second plant at Queenstown) | 11.5 | 32,500 | Industrial |
| Total | 484.3 | 1,327,000 | — |

[1]Total includes unknown amount from Magothy/Patapsco Formations.
[2]Possibly supplied with small amount of water from Magothy/Patapsco Formations.

Cannery Corporation. Its water use amounted to 105,000 Mgal/d. Because the Aquia is relatively shallow and the water generally of good quality throughout most of the area, additional demands on it as a ready source of water supply may be expected.

### Quaternary Deposits

Deposits of Quaternary age (mostly Pleistocene Series) occur as a thin mantle over much of the upper Chesapeake Bay region and along most of the

estuaries and streams. These materials are, in part, of fluviatile origin and, in part, of estuarine or marine origin. They consist of heterogeneous mixtures of sand, gravel, clay, and silt, and have been considered to be of two types: (1) an upland, fluviatile sand, gravel and clayey silt; and (2) an estuarine deposit of clay, silty clay, and sandy gravel containing fossil shells and some woody material. No subdivision of the Quaternary is made in this report. Thickness of the Quaternary sediments ranges from 10 to 100 ft at several localities on the upper Eastern Shore, as listed in the following table:

| Well No. or Designation | Location | County | Thickness (ft) |
|---|---|---|---|
| Outcrop section[1] | Town of Sassafras | Kent | 25 |
| Outcrop section[1] | Tolchester Beach | do. | 25.5 |
| Outcrop section[2] | Betterton | do. | 69 |
| Outcrop section[2] | Howell Point | do. | 32.5 |
| Unnumbered auger hole[3] | 2.5 mi SW of Betterton | do. | 100 |
| Unnumbered auger hole[3] | Stillpond Neck | do. | 90 |
| Unnumbered auger hole[3] | 0.7 mi S. of Stillpond | do. | 10 |
| Unnumbered auger hole[3] | 1 mi N. of Worton | do. | 39 |
| CE-EE 29 | Cecilton | Cecil | 35 |
| KE-AC 20 | Stillpond Neck | Kent | 90 |
| KE-BE 43 | Kennedyville | do. | 20 |
| KE-BG 33 | Massey | do. | 20 |
| KE-CB 36 | Fairlee | do. | 33 |
| KE-DB 40 | Rock Hall | do. | 25 |

[1]Data from Overbeck and Slaughter (1958, p. 94).
[2]Data from Overbeck and Slaughter (1958, p. 89).
[3]Data from Minard (1974, pl. 1).

Only limited information is available on the transmissivity and storage coefficients for these deposits in the upper Bay area, but Overbeck and Slaughter (1958, p. 91–96) report the following results of aquifer tests of permeable sandy gravels at various localities:

| Well No. | Location | Transmissivity ($ft^2/d$) | Storage (percent) | Screened interval (depth below land surface, in ft) |
|---|---|---|---|---|
| CE-BE 21 | Elkton | 100 | — | — |
| CE-BE 23 | do. | 120 | — | — |
| CE-BE 24 | do. | 230 | — | — |
| KE-BF 24 | Galena | 2,000 | — | — |
| QA-BG 25 | Sudlersville | 3,300* | — | — |
| QA-BG 29 | Stevens Corner | 2,100* | — | — |
| QA-CF 59<br>QA-CF 60 | Price | 4,000 | 0.0003 | 29 — 54 |
| QA-CG 1<br>QA-CG 2 | Barclay | 13,000 | — | 50 — 60 |

*Based on method of steady-state uniform recharge described by Ferris and others (1962, p. 131).

The low values of transmissivity reported from the tests at Elkton may be due, in part, to the fact that the tests were run on old hand-dug, brick-lined wells not equipped with screens. Such wells would have low hydraulic efficiencies because of the nature of their construction; therefore, the transmissivity data from them are of limited reliability.

## GENERALIZED FLOW SYSTEM

Generally, ground water flows through the Coastal Plain sediments from areas where the potentiometric surface is high to areas where the potentiometric surface is low. The aquifers in the Potomac Group are made up of numerous sands that do not appear to be physically connected. The intervening clays impede vertical and horizontal flow of ground water between the sands. Over short periods of time, each sand will behave as an individual aquifer; water-level declines due to ground-water withdrawals may spread slowly from one sand to another through intervening clays or silts.

Most of the wells drilled to aquifers in the Potomac Group in the upper Bay region are along the northwestern shore of the Bay. Several wells tap these aquifers immediately south of Wilmington, Del., and north of the Elk River in Cecil County, Md. Because adequate ground-water supplies in overlying aquifers are available, as in the Aquia Formation and the Pleistocene deposits, relatively few wells have penetrated the deep-lying sands in the Potomac Group in Cecil, Kent, and Queen Annes Counties before test wells of this investigation were drilled. As a result, information concerning predevelopment water-level measurements is scarce. However, by using static water levels reported from various wells in the Potomac Group over a period of 75 years, it was possible to develop the information in figure 11. This figure shows, by shading, areas where the prepumping potentiometric surface was probably less than 10 ft above sea level. Where shading is omitted from the map, the water levels were above 10 ft or no data were available. Records of water levels in 51 wells were used to construct figure 11. The shaded area on the figure represents the shore areas of the entire upper Bay northeast of Annapolis, Md. Because two control points near Annapolis and on the central part of Kent Island show water levels of 10 ft or more above sea level, the southern edge of the shaded area was extended across the Bay at the north end of Kent Island.

Figure 12 is a geohydrologic section from I-95 in Baltimore County to the Delaware State line east of Chestertown, Md. It was prepared as an aid to further understand the operation of the ground-water flow system in the Potomac Group and in the overlying deposits. Water levels in both shallow and deep wells are shown in the section. Arrows show the presumed direction of ground-water flow. It is significant that the highest heads occur in the shallow water-table wells in the upland interfluve areas. However, even wells screened in the deepest sands have heads above sea level, except where affected by pumping.

The major source of recharge to the aquifers of the Potomac Group is precipitation in the upland areas. Where the aquifers lie at great depth, recharge must take place very slowly, chiefly by vertical leakage. Of course, direct recharge can and does occur along the outcropping areas of the aquifers, chiefly west of the Bay and north of the C & D Canal. Thus, recharge is both by vertical leakage and movement downdip from outcrop areas.

It should be emphasized, however, that heavy pumpage from wells will modify the natural flow systems in the aquifers. Thus, pumping creates cones of influence and steepens the hydraulic gradients in the aquifers, even reversing their direction. Long-term sustained pumping can significantly affect flow patterns of the ground water and may cause brackish-water intrusion or other undesirable effects.

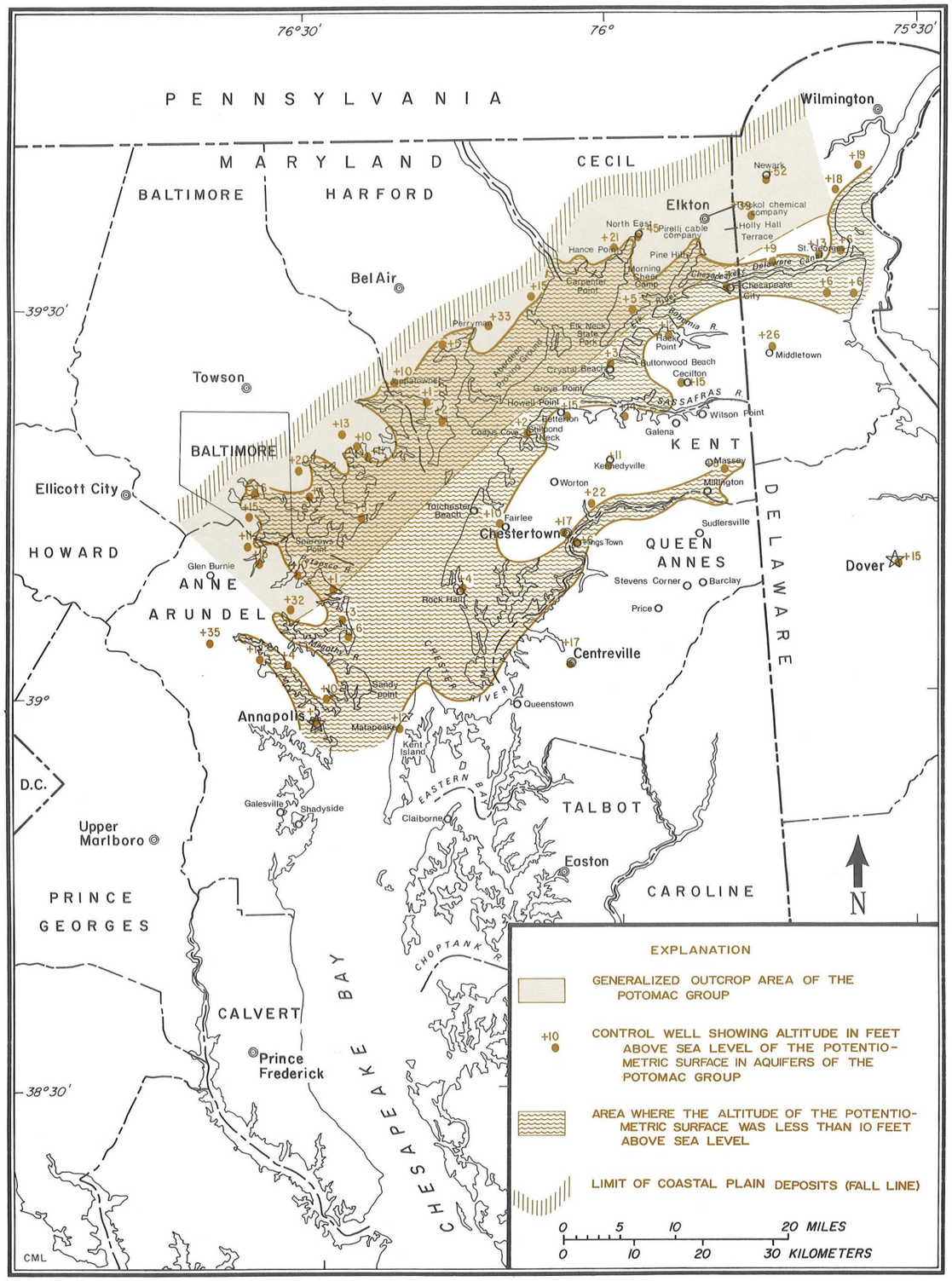


**Figure 11.—Approximate altitude of the prepumping potentiometric surface in the aquifers of the Potomac Group in the upper Chesapeake Bay area.**

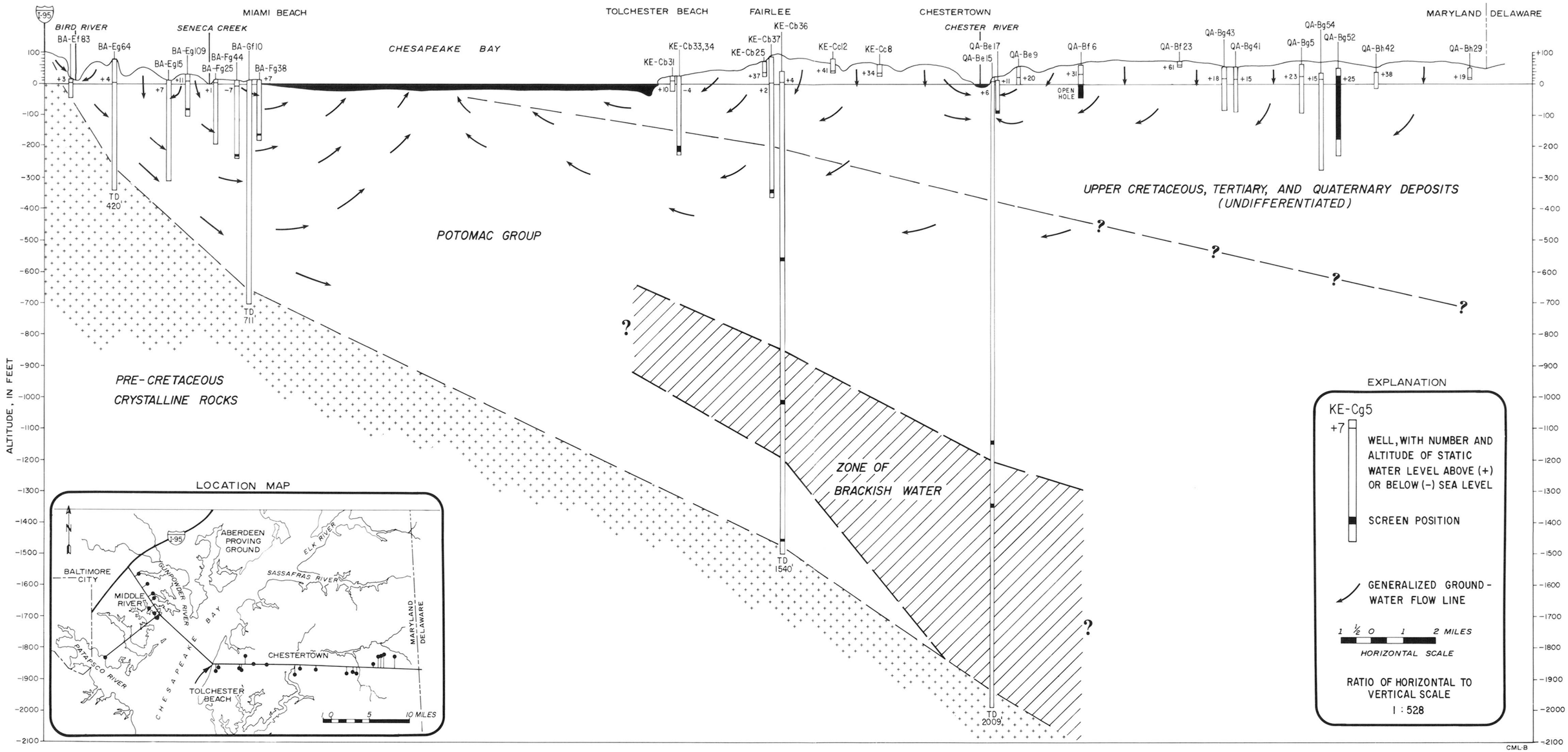


**Figure 12.—Geohydrologic section from I-95 in Baltimore County across the Chesapeake Bay to the Delaware line showing regional geology, generalized ground-water flow lines, and occurrence of salty water.**

# CHEMICAL QUALITY

## IMPORTANT CHEMICAL CONSTITUENTS

Chemical analyses of water samples collected from the test wells are summarized in table 9. These data show that high total iron concentrations are reported from all sites, ranging from 870 μg/L at Massey (well KE-BG 33) to 73,000 μg/L at Stillpond Neck (well KE-AC 20). Ground water from the Potomac Group is generally higher in iron than water in most other aquifers of the Maryland Coastal Plain. The abundant iron-bearing minerals in the sediments (hematite, limonite, and siderite) are a ready source of iron, which will go into solution depending on the oxidation potential (Eh) and the acidity (pH) of the water. Acidic water (pH below 7.0) generally dissolves more iron than does alkaline water (pH above 7.0).

Figure 13 shows the distribution of total iron, pH, dissolved solids, and chloride in ground water from aquifers in the Potomac Group in the upper Bay area. Analyses of water from 23 wells screened in sands of the Potomac Group were used to compile the figure. These data are from previously published water-resources reports and from table 9 of this report. The total iron concentration ranges from 50 μg/L in a well near Elkton in Cecil County to 73,000 μg/L in test well KE-AC 20 on Stillpond Neck in Kent County. The median iron content in 23 analyses is 7,200 μg/L. Iron concentrations in excess of 300 μg/L in water may cause staining of fixtures and will likely cause staining of clothes during laundering. However, several methods of treatment for iron removal are available, and the high iron content of water in public-supply systems may be readily reduced before being supplied to consumers.

The pH of water is a designation of the logarithm (to the base 10) of the reciprocal of the hydrogen-ion concentration. Alkaline water has a pH greater than 7.0 and acidic water has a pH of less than 7.0. The pH of pure water at 25 °C is 7.0. The pH of 22 ground-water samples in figure 13 ranges from 3.5 to 8.1; the median value of 6.2 is in the mildly acidic range. Water having the lowest pH seems to occur in the Magothy-Severn River area of Anne Arundel County on the west side of the Bay. Water from this area has been known to corrode steel casings and well screens within a few years.

Chloride concentrations of water in 21 wells in the upper Bay region are also given in figure 13. Values range from 0.8 mg/L in well QA-EA 26 on Kent Island to 2,580 mg/L in well QA-BE 15 near Chestertown. Chloride concentrations in excess of 250 mg/L may impart a slightly salty taste to the water (U.S. Environmental Protection Agency, 1977b, p. 17,144). Water from four wells had chloride concentrations in excess of 250 mg/L (fig. 13). Information on these wells is summarized below.

| Well No. | Location | Depth to top of screen (ft) | Chloride (mg/L) | Date of analysis |
|---|---|---|---|---|
| 3S-3E 2 | Baltimore City | -150 | 990 | 04/05/44 |
| KE-AC 20 | Stillpond (Kent County) | -550 | 1,000 | 12/02/78 |
| KE-CB 36 | Fairlee (Kent County) | -1,050 | 950 | 04/25/78 |
| QA-BE 15 | Chestertown (Queen Annes County) | -1,160 | 473 | 07/28/70 |
| do. | do. | -1,360 | 2,580 | 08/06/70 |

The high chloride content of the water from well 3S-3E 2 in Baltimore City is due to salt-water intrusion into the aquifers caused by heavy pumpage during World War II (Bennett and Meyer, 1952, p. 130–131). High chloride in the remaining wells tabulated above is probably due to natural causes, such as incomplete flushing of brackish water introduced into the aquifers during higher sea levels in Pleistocene time.

## Table 9.—Chemical analyses of ground-water samples from test wells.

| Well No. | CE-EE 29 | KE-AC 20 | KE-BE 43 | KE-BG 33 | KE-BG 34 |
|---|---|---|---|---|---|
| Geologic unit | Potomac Gp. | Potomac Gp. | Magothy Fm. | Potomac Gp. | Aquia Fm. |
| Date of sample | 78-08-01 | 77-12-02 | 78-12-07 | 78-10-25 | 78-10-26 |
| Depth to top of water-bearing zone (ft) | 515 | 550 | 275 | 695 | 126 |
| Specific conductance (micromhos) | 410 | --- | 290 | 435 | 295 |
| pH field (units) | 7.3 | --- | 7.1 | 8.1 | 7.1 |
| Hardness (mg/l as $CaCO_3$) | 15 | 440 | 130 | 16 | 140 |
| Hardness, noncarbonate (mg/l as $CaCO_3$) | 0 | 390 | 0 | 0 | 0 |
| Calcium, dissolved (mg/l as Ca) | 4.6 | 97 | 44 | 4.7 | 52 |
| Magnesium, dissolved (mg/l as Mg) | .8 | 48 | 4.5 | 1.0 | 1.9 |
| Sodium, dissolved (mg/l as Na) | 70 | 380 | 6.8 | 90 | 3.0 |
| Potassium, dissolved (mg/l as K) | 3.2 | 15 | 3.9 | 4.1 | 1.9 |
| Bicarbonate (mg/l as $HCO_3$) | 190 | 66 | 170 | 180 | 170 |
| Carbonate (mg/l as $CO_3$) | 0 | --- | 0 | 0 | 0 |
| Alkalinity (mg/l as $CaCO_3$) | 160 | 54 | 140 | 150 | 140 |
| Carbon dioxide, dissolved (mg/l as $CO_2$) | 15 | --- | 19 | 2.3 | 22 |
| Sulfate, dissolved (mg/l as $SO_4$) | 13 | 5.9 | 8.8 | 8.6 | 4.3 |
| Chloride, dissolved (mg/l as Cl) | 16 | 1000 | 2.4 | 47 | 2.4 |
| Fluoride, dissolved (mg/l as F) | .9 | .1 | .1 | .6 | .1 |
| Silica, dissolved (mg/l as $SiO_2$) | 8.1 | 9.6 | 11 | 9.1 | 23 |
| Solids, residue at 180 deg. C, dissolved (mg/l) | 439 | 1800 | 168 | 261 | 182 |
| Solids, sum of constituents, dissolved (mg/l) | 212 | 1670 | 168 | 255 | 174 |
| Solids, residue at 105 deg. C, suspended (mg/l) | --- | --- | --- | --- | --- |
| Nitrogen, nitrate dissolved (mg/l as N) | --- | --- | --- | --- | --- |
| Nitrogen, $NO_2$ + $NO_3$, total (mg/l as N) | .03 | .00 | .00 | .00 | .00 |
| Phosphorus, total (mg/l as P) | .260 | .060 | .080 | .070 | .050 |
| Aluminum, total recoverable (µg/l as Al) | --- | --- | --- | --- | --- |
| Boron, total recoverable (µg/l as B) | --- | --- | --- | --- | --- |
| Cadmium, total recoverable (µg/l as Cd) | --- | --- | --- | --- | --- |
| Chromium, total recoverable (µg/l as Cr) | --- | --- | --- | --- | --- |
| Copper, total recoverable (µg/l as Cu) | --- | --- | --- | --- | --- |
| Iron, total recoverable (µg/l as Fe) | 4100 | 73000 | 3100 | 870 | 1100 |
| Iron, dissolved (µg/l as Fe) | 1700 | 80000 | 2700 | 860 | 1100 |
| Lead, total recoverable (µg/l as Pb) | --- | --- | --- | --- | --- |
| Manganese, total recoverable (µg/l as Mn) | 40 | 2800 | 60 | 20 | 80 |
| Manganese, dissolved (µg/l as Mn) | 40 | 3200 | 60 | 20 | 70 |
| Silver, total recoverable (µg/l as Ag) | --- | --- | --- | --- | --- |
| Zinc, total recoverable (µg/l as Zn) | --- | --- | --- | --- | --- |

## Table 9.—Chemical analyses of ground-water samples from test wells—Continued.

| Well No. | KE-CB 36 | KE-CB 36 | KE-CB 36 | KE-DB 40 | KE-DB 40 | QA-BE 15 | QA-BE 15 | QA-BE 16 |
|---|---|---|---|---|---|---|---|---|
| Geologic unit | Potomac Gp. | Potomac Gp. | Potomac Gp. | Potomac Gp. | Potomac Gp. | Potomac Gp. | Potomac Gp. | Potomac Gp. |
| Date of sample | 78-04-18 | 78-04-25 | 78-04-26 | 78-12-04 | 78-12-05 | 70-07-28 | 70-08-06 | 70-09-23 |
| Depth to top of water-bearing zone (ft) | 1490 | 1050 | 595 | 1023 | 1023 | 1160 | 1360 | 478 |
| Specific conductance (micromhos) | 280 | 2850 | 170 | 163 | 153 | 1640 | 7830 | 146 |
| pH field (units) | --- | 6.8 | 6.9 | 5.6 | 6.0 | 6.2 | 6.8 | 7.1 |
| Hardness (mg/l as $CaCO_3$) | --- | --- | --- | 24 | 24 | 140 | 1060 | 36 |
| Hardness, noncarbonate (mg/l as $CaCO_3$) | --- | --- | --- | 0 | 0 | 130 | 1100 | 0 |
| Calcium, dissolved (mg/l as Ca) | 6.0 | 120 | 8.0 | 4.8 | 5.0 | 40 | 272 | 9.1 |
| Magnesium, dissolved (mg/l as Mg) | --- | --- | --- | 2.8 | 2.9 | 10 | 86 | 3.2 |
| Sodium, dissolved (mg/l as Na) | 50 | 310 | 14 | 16 | 15 | 242 | 1160 | 14 |
| Potassium, dissolved (mg/l as K) | 2.9 | 17 | 4.5 | 5.0 | 4.9 | 16 | 39 | 5.6 |
| Bicarbonate (mg/l as $HCO_3$) | 83 | 5 | 50 | 43 | 45 | 10 | 4 | 73 |
| Carbonate (mg/l as $CO_3$) | 0 | 0 | 0 | 0 | 0 | --- | --- | --- |
| Alkalinity (mg/l as $CaCO_3$) | 68 | 4 | 41 | 35 | 37 | 8 | 3 | 60 |
| Carbon dioxide, dissolved (mg/l as $CO_2$) | --- | 1.3 | 10 | 154 | 64 | 10 | 1.0 | 9.3 |
| Sulfate, dissolved (mg/l as $SO_4$) | 19 | 27 | 21 | 14 | 12 | 5.4 | 26 | 10 |
| Chloride, dissolved (mg/l as Cl) | 32 | 950 | 6.4 | 11 | 10 | 473 | 2580 | 2.9 |
| Fluoride, dissolved (mg/l as F) | .2 | .1 | .2 | .2 | .2 | .2 | .2 | .3 |
| Silica, dissolved (mg/l as $SiO_2$) | 7.2 | 8.2 | 7.5 | 10 | 9.8 | 7.5 | 8.1 | 7.4 |
| Solids, residue at 180 deg. C, dissolved (mg/l) | 168 | 1790 | 94 | 112 | 77 | 933 | 5120 | 99 |
| Solids, sum of constituents, dissolved (mg/l) | --- | --- | --- | 93 | 89 | 799 | 4170 | 88 |
| Solids, residue at 105 deg. C, suspended (mg/l) | 57 | 73 | 49 | --- | --- | --- | --- | --- |
| Nitrogen, nitrate dissolved (mg/l as N) | --- | --- | --- | --- | --- | .07 | .25 | --- |
| Nitrogen, $NO_2$ + $NO_3$, total (mg/l as N) | .01 | .00 | .00 | .00 | .00 | --- | --- | --- |
| Phosphorus, total (mg/l as P) | .040 | .010 | .120 | .540 | .210 | --- | --- | --- |
| Aluminum, total recoverable (µg/l as Al) | 270 | 420 | 30 | --- | --- | --- | --- | --- |
| Boron, total recoverable (µg/l as B) | 60 | 60 | 30 | --- | --- | --- | --- | --- |
| Cadmium, total recoverable (µg/l as Cd) | 3 | 0 | 1 | --- | --- | --- | --- | --- |
| Chromium, total recoverable (µg/l as Cr) | 10 | 10 | <10 | --- | --- | --- | --- | --- |
| Copper, total recoverable (µg/l as Cu) | 3 | 7 | 5 | --- | --- | --- | --- | --- |
| Iron, total recoverable (µg/l as Fe) | 1600 | 63000 | 9100 | 7700 | 7200 | 13000 | 30000 | 4500 |
| Iron, dissolved (µg/l as Fe) | --- | --- | --- | 7700 | 7100 | --- | --- | --- |
| Lead, total recoverable (µg/l as Pb) | 18 | 8 | 13 | --- | --- | --- | --- | --- |
| Manganese, total recoverable (µg/l as Mn) | 200 | 2900 | 230 | 230 | 240 | 410 | 1200 | 80 |
| Manganese, dissolved (µg/l as Mn) | 200 | 3200 | 230 | 230 | 240 | --- | --- | --- |
| Silver, total recoverable (µg/l as Ag) | 0 | 0 | 0 | --- | --- | --- | --- | --- |
| Zinc, total recoverable (µg/l as Zn) | 820 | 4800 | 690 | --- | --- | --- | --- | --- |

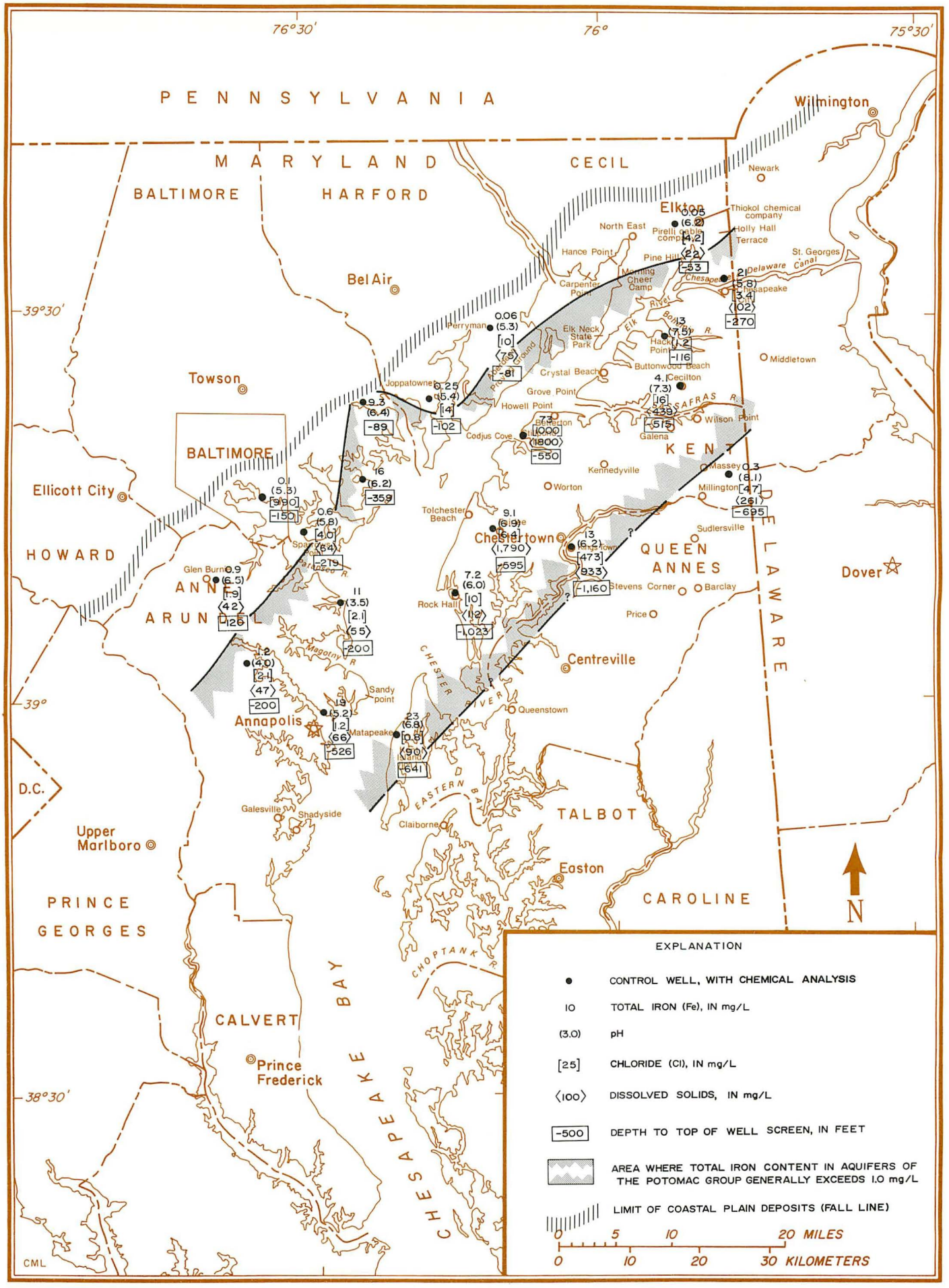


**Figure 13.—Total iron, pH, dissolved solids and chloride concentration of water from sands of the Potomac Group.**

## OCCURRENCE OF BRACKISH WATER

The quality of ground water is a major factor in determining its use and in understanding its occurrence and movement. The amount of dissolved solids (D.S.) in water determines whether it is fresh or saline. Drinking water is recommended to have no more than 500 mg/L of dissolved solids (U.S. Environmental Protection Agency, 1977b, p. 17,146), although water with up to 1,000 mg/L is often used if no other water is available. Water may be classified as follows (Davis and DeWiest, 1966, p. 118):

| Type of water | Concentration of dissolved solids (in mg/L) |
|---|---|
| Fresh | <1,000 |
| Brackish | 1,000 to 10,000 |
| Saline | 10,000 to 100,000 |
| Brine | >100,000 |

Generally, the shallow aquifers in the upper Bay region contain fresh water, and, in places, some of the deeper aquifers contain brackish water. From the classification used above, brackish water is present in the following wells at the depths indicated.

| Well No. | Location | Depth to top of screen (ft) | Dissolved solids (mg/L) |
|---|---|---|---|
| KE-AC 20 | Stillpond Neck | 550 | 1,800 |
| KE-CB 36 | Fairlee | 1,050 | 1,790 |
| QA-BE 15 | Chestertown | 1,160 | 933* |
| QA-BE 15 | do. | 1,360 | 5,120 |

*Slightly below the limiting value of 1,000 mg/L, but included for comparative purposes.

Throughout the Coastal Plain sections of Cecil, Harford, Baltimore, and northern Anne Arundel Counties, the sands in the Potomac Group contain fresh water. However, on the eastern side of the Chesapeake Bay, in an area south of the Sassafras River and northeast of Rock Hall, the deeper sands in the Potomac Group contain brackish water.

It has been speculated that the brackish water in the sands is, in part, connate (original saline water derived from the ocean at the time of deposition of the sediments), but this is subject to question because the sediments almost surely were deposited in a fluviatile, continental environment.

Figures 5, 14, and 15 show the occurrence of brackish water in the sediments of the Potomac Group, based on interpretation of 64-inch normal resistivity logs and available chemical analyses. (See section "Estimating Salinity from Geophysical Logs".) Figure 14, a section along the strike of the aquifers, shows that fresh water is present in the sands both northeast and southwest of the deep test wells at Fairlee and at Kennedyville. In well KE-CB 36 at Fairlee, the interpretation of the resistivity log suggests that at least two fresh-water sands lie below a zone of brackish water 200 to 300 ft thick.

Figure 15 shows two geologic sections extending approximately downdip from the outcrop or subcrop area of the Potomac Group in Harford County to the deep test well at Massey (KE-BG 33) and to a Shell Refining Company test well (GD-33-4) in southeastern New Castle County, Del.

Section C-C′ shows a continuous zone of brackish water extending from a depth of 300 to 350 ft below the surface of the Chesapeake Bay eastward to the Delaware line. The brackish zone at Massey (well KE-BG 33) extends from a depth of 1,000 ft to 2,185 ft, the total depth of the well.

Section D-D′ shows that the zone of brackish water in Delaware (well GD-33-4), from a depth of 1,300 to 2,310 ft, is absent in the 1,460-ft test hole at Cecilton, Md. (well CE-EE 29). The updip edge of this zone cannot be more precisely delineated until additional deep test holes are drilled and logged in southwestern New Castle County, Del.

## ESTIMATING SALINITY FROM GEOPHYSICAL LOGS

In addition to providing information on the lithology of the test wells, the multi-point resistivity log (64-inch long normal) was used to estimate the salinity of water in sands that were penetrated by drilling but not screened for water production. The technique is used to estimate the resistivity of the formation water using a formation factor. Salinity, or dissolved-solids concentration, is then estimated from the resistivity of the water. The use of the formation factor is described by several authors, among whom are Keys and MacCary (1971, p. 39–47), Turcan (1966, p. 3–16), and Whitman (1965, p. 2–11).

All measurements of resistivity or its reciprocal, conductivity (specific conductance), were converted to the same units and adjusted to a standard temperature, 25 °C, so that they could be compared. Diagonal lines in figure 16 show the variation of resistivity or conductivity with temperature for sodium chloride solutions of various concentrations.

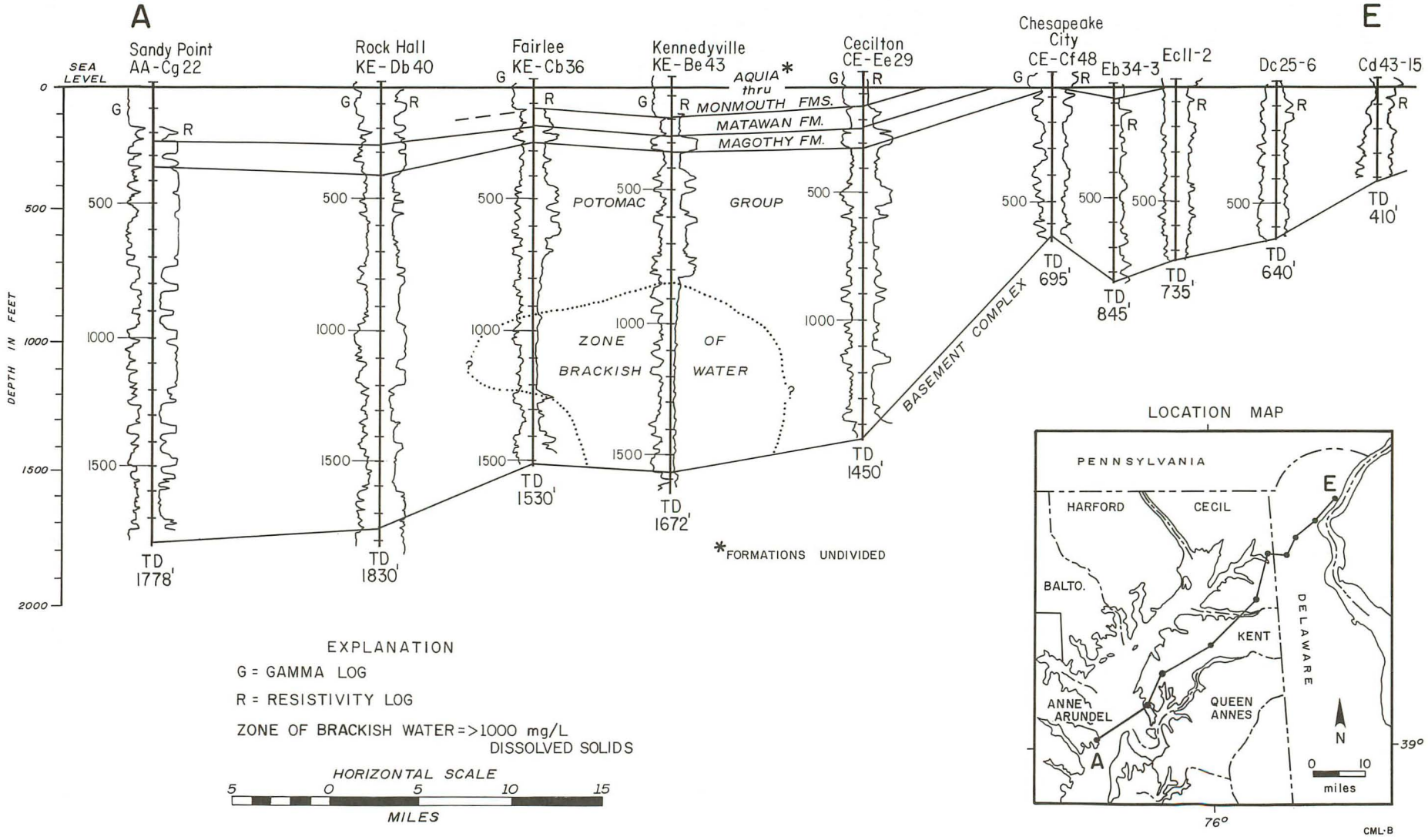


Figure 14.—Geologic section A-E′ across the upper Eastern Shore showing a zone of brackish water.

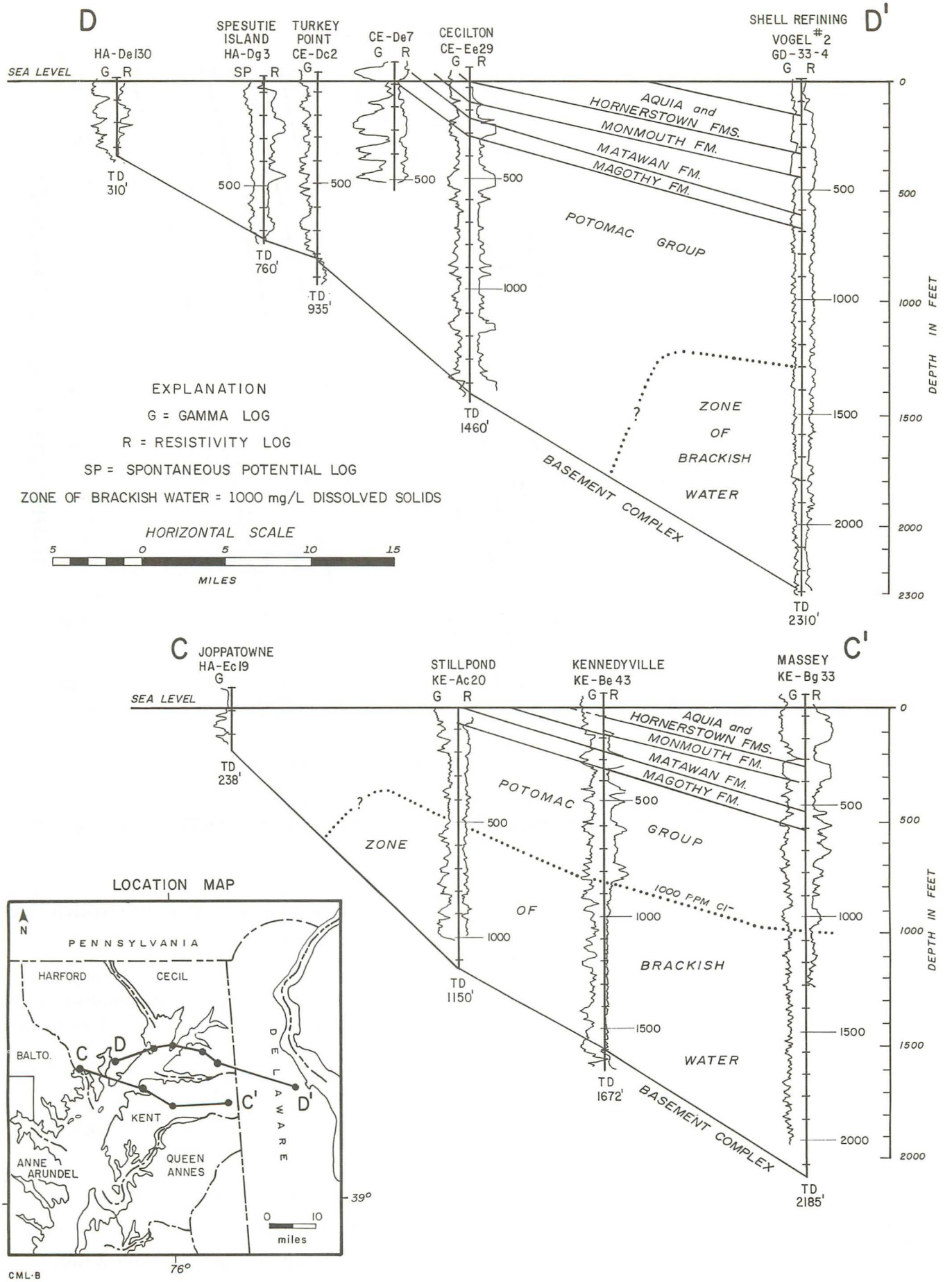


**Figure 15.—Geologic sections C-C′ and D-D′ across the upper Chesapeake Bay region showing a zone of brackish water.**

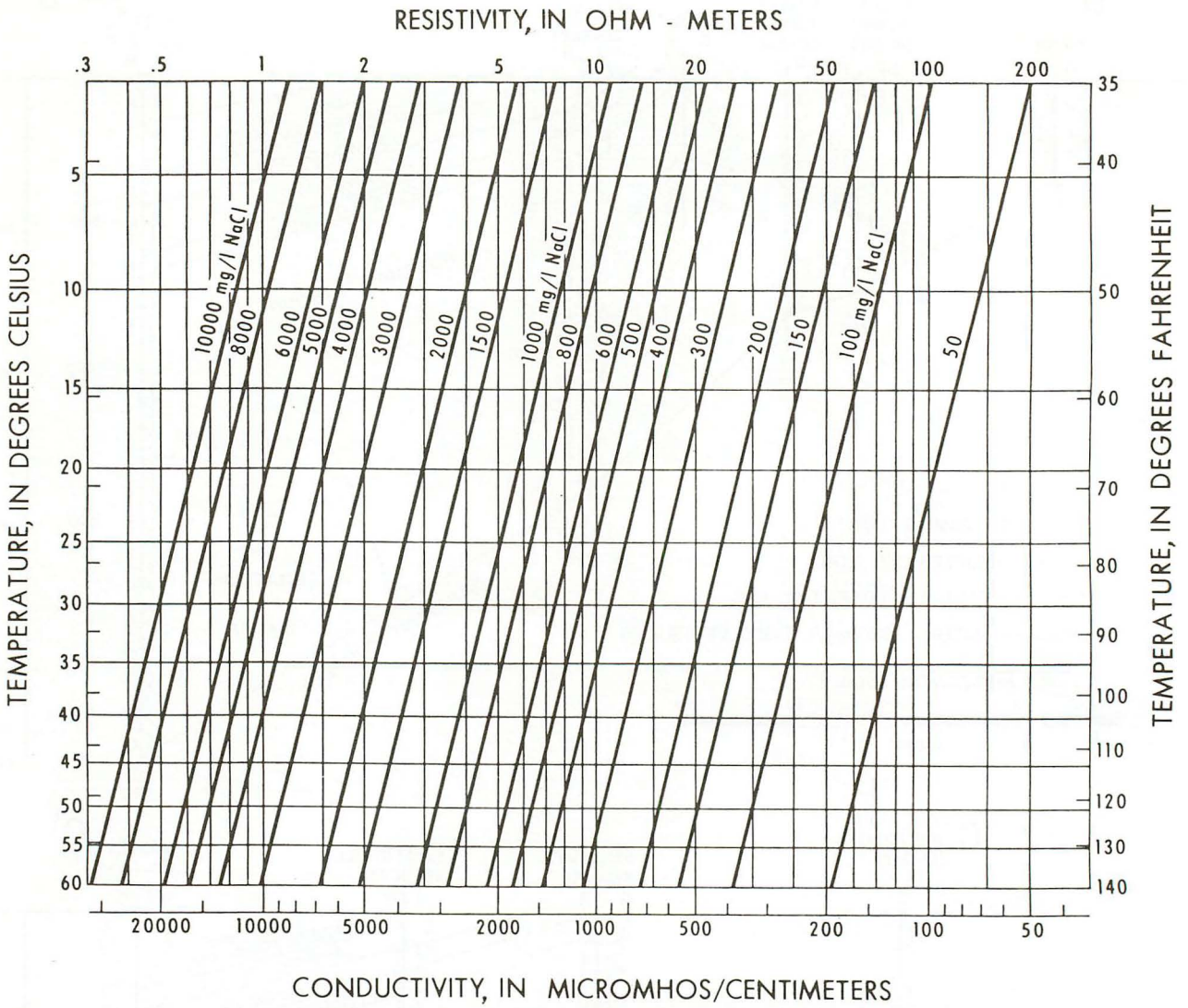


**Figure 16.—Electrically equivalent concentrations of a sodium chloride solution as a function of resistivity or conductivity and temperature (modified from Keys and MacCary, 1971, fig. 2, p. 9).**

For most formation water, the variation of resistivity with temperature is similar to that of a sodium chloride solution; therefore, the graph can be used to adjust resistivity measurements to a standard temperature. Specific conductance can be converted to resistivity by use of this graph or by use of the relation:

$$\text{Resistivity in ohm-meters} = \frac{10{,}000}{\text{Specific conductance, in micromhos per centimeter}}$$

Inversely,

$$\text{Specific conductance, in micromhos per centimeter} = \frac{10{,}000}{\text{Resistivity, in ohm-meters}}$$

Estimation of salinity from the resistivity logs requires several steps:

Step 1. Formation factors are determined where resistivity logs and specific conductance of formation water are available. This uses the relation:

$$F_f = \frac{R_o}{R_w}$$

where

$F_f$ = formation factor;

$R_o$ = resistivity of the saturated sand; and

$R_w$ = resistivity of the formation water.

For the sand at 1,050–1,060 ft at well KE-CB 36 (tab. 10):

$$F_f = \frac{10 \text{ ohm-meters at } 25\,°C}{3.5 \text{ ohm-meters at } 25\,°C} = 2.9$$

Step 2. The formation factor can then be used to estimate the resistivity of water in comparable sands where 64-inch normal resistivity logs are available. This uses the relation:

$$R_w = \frac{R_o}{F_f}$$

For the sand logged at a depth of 970 to 1,025 ft in well KE-BG 33 at Massey, the resistivity of the saturated sand at an estimated field temperature of 18 °C was 40 ohm-meters. This was determined from the resistivity log as shown in figure 17. Converted to standard temperature, this equals about 33 ohm-meters. Thus:

$$R_w = \frac{33 \text{ ohm-meters at } 25\,°C}{2.9} = 11.4 \text{ ohm-meters at } 25\,°C,$$

which is equal to a specific conductance of 880 μmhos/cm at 25 °C.

Step 3. The specific conductance can then be used to estimate salinity, or dissolved-solids concentration. Figure 18 shows the relation of dissolved solids to specific conductance for water from the Potomac Group sands as given in tables 9 and 10. The relation is approximately:

Dissolved solids (mg/L) = 0.6 × Specific conductance (μmhos/cm at 25 °C)

Thus, the water in the sand at 970 to 1,025 ft in well KE-BG 33, which has an estimated specific conductance of 880 μmhos/cm, has an estimated dissolved-solids concentration of 530 mg/L. Because of the many uncertainties, this estimate should be rounded to 500 mg/L.

Table 10 gives formation factors determined for the test wells used in this study. Aquifer temperatures were estimated using an average shallow

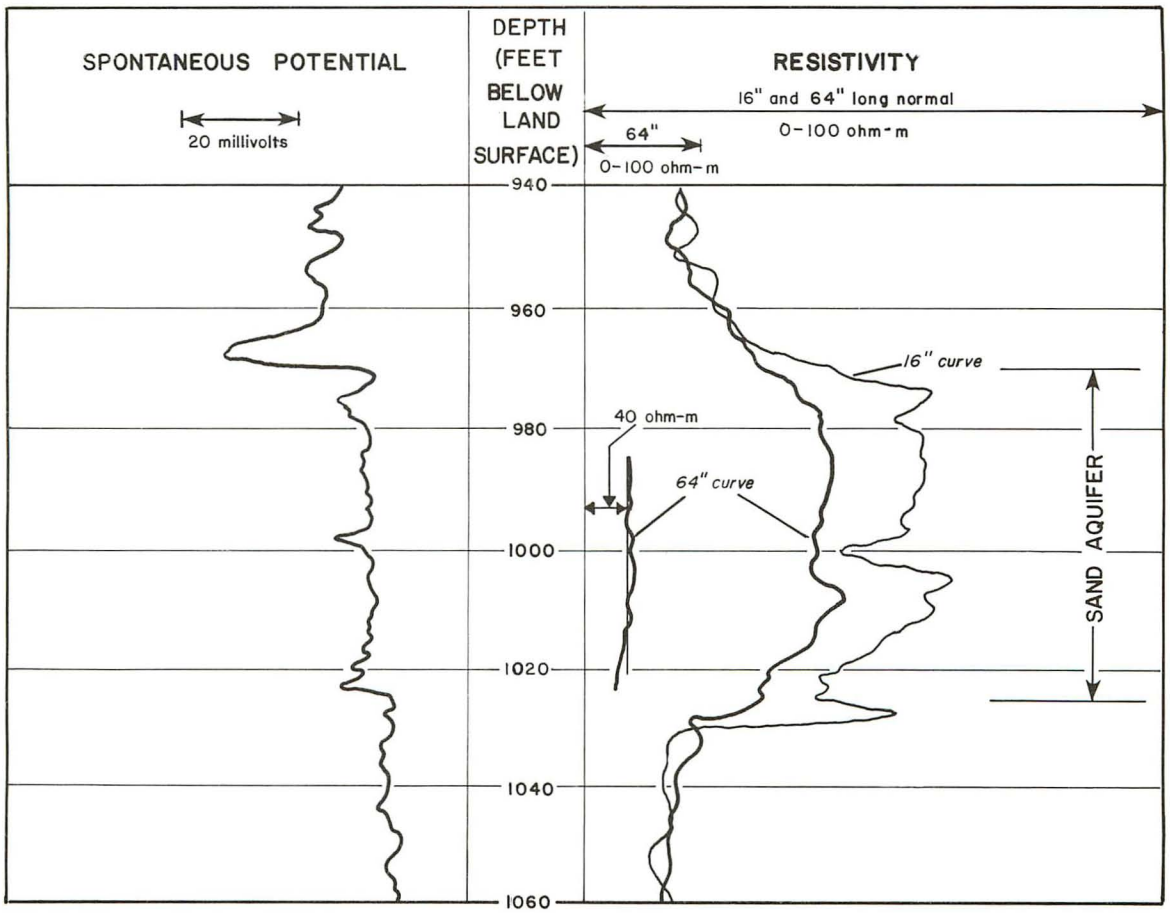


**Figure 17.—Segment of electric log of well KE-BG 33 from a depth of 940 to 1,060 ft.**

## Table 10.—Selected formation factors for aquifers in the Potomac Group.

| Well No. | Aquifer and location | Screen depth (ft below land surface) | Specific conductance (µmhos/cm) at 25°C) | Dissolved solids (mg/L) | Estimated aquifer temperature | | Resistivity on 64-inch long normal curve (ohm-m) | | Formation factor (F) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | °F | °C | at aquifer temperature | at 25°C | |
| CE-EE 29 | Potomac Group at Cecilton | 515-525 | 410 | 439 | 60 | 15.6 | 133 | 110 | 4.5 |
| KE-BG 33 | Potomac (?) Group at Massey | 695-705 | 435 | 261 | 62 | 16.6 | 100 | 80 | 3.5 |
| KE-AC 20 | Potomac Group at Stillpond Neck | 550-560 | 3,390 1/ | 1,800 | 60 | 15.6 | 7 | 5.4 | 1.8 |
| KE-CB 36 | Potomac Group at Fairlee | 1,050-1,060 | 2,850 | 1,790 | 64 | 18 | 12 | 10 | 2.9 |
| QA-BE 15 | Potomac Group at Chestertown | 1,357-1,367 | 7,830 | 5,120 | 68 | 20 | 7 | 6.3 | 4.9 |
| QA-BE 15 | do. | 1,158-1,168 | 1,640 | 933 | 66 | 18.8 | 23 | 19 | 3.1 |

1/ Laboratory, not field measurement.

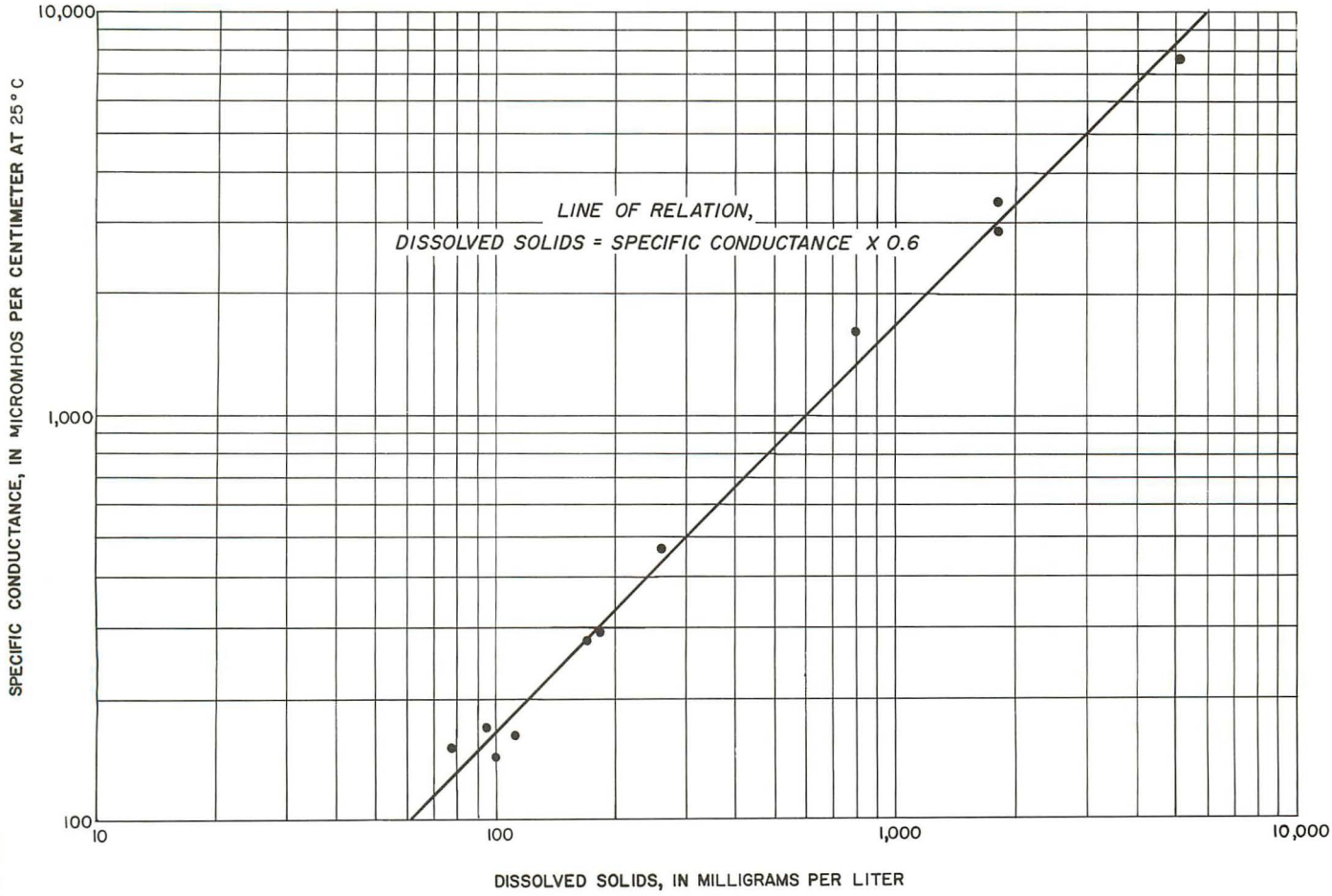


**Figure 18.—Relation of dissolved solids to specific conductance in water from sands of the Potomac Group. (Data from tabs. 9 and 10).**

ground-water temperature of 12.8 °C (55 °F) and an estimated increase in temperature with depth of 0.5 °C for each 100 ft of depth. The range of formation factors was 1.8 to 4.9 and the average was 3.4.

Estimates of salinity based on resistivity logs were used along with available chemical analyses to estimate the occurrence of brackish water as shown in figures 5, 14, and 15. The technique described in this section is empirical and many factors can influence its accuracy. However, it does give a means of estimating salinity that can be useful if used cautiously.

## SUMMARY AND CONCLUSIONS

This report describes the subsurface geology and hydrology of the Potomac Group in the upper Chesapeake Bay region. Much of the information and conclusions in the report were derived from six test and exploratory wells drilled in Cecil and Kent Counties during 1977 and 1978 and from a deep test hole drilled just south of Chestertown in 1970 (Kantrowitz and Webb, 1971). All wells were drilled to obtain information on the thickness and distribution of aquifers and confining beds in the area. Information on the water levels in the aquifers and on their hydraulic coefficients was also obtained.

To evaluate aquifers of the Potomac Group, the wells were drilled to depths ranging from 1,148 to 2,185 ft. The drilling of each well was terminated when it was reasonably certain that crystalline base-

ment rock had been penetrated and that no deeper aquifers would be encountered. Upon completion of the drilling, the wells were screened and aquifer tests of brief duration were conducted. An exception to this was well KE-CB 36 at Fairlee, where the use of three screens in the well made it impractical to measure changes in the water level in each aquifer during pumping; in this case, packer tests were run instead.

Data from these and other test holes show that crystalline basement rock slopes southeastward from the Fall Zone to Chestertown at rates of 75 to 80 ft/mi. These data further reveal that sediments of the Potomac Group range in thickness south of their outcrop belt from 635 ft near Chesapeake City to slightly more than 1,800 ft at Kent Island. Total thickness of water-bearing sands in the Potomac Group south of its outcrop area ranges from 246 ft near Chesapeake City to 626 ft near the Delaware line at Massey, although at Sandy Point, 5 mi east of Annapolis, the total sand thickness is 755 ft.

Transmissivity values for sands in the Potomac Group range widely from 100 $ft^2/d$ south of the town of North East to 9,200 $ft^2/d$ near Perryman (fig. 7). Because transmissivity involves both the thickness and hydraulic conductivity of a sand, the low values in an aquifer may be the result of localized thinning of an otherwise more productive sand. Storage coefficients range from 0.0001 to 0.07.

Total pumpage from the aquifers of the Potomac Group in 1980 amounted to about 307 Mgal, or about 0.84 Mgal/d, exclusive of rural pumping, which is believed to be small.

Pumpage from the Magothy and Monmouth aquifers in the upper Chesapeake Bay area was 569,000 gal/d in 1980. Of this quantity, about 341,000 gal/d (60 percent) was from the Monmouth aquifer at Centreville and at Kennedyville.

The Aquia Formation overlies the Monmouth Formation, but the Aquia is not present in Cecil County. Pumpage from this aquifer in Kent and Queen Annes Counties amounted to about 1.32 Mgal/d in 1980. Most of this was from two well fields near Chestertown.

Pumpage from the overlying Quaternary deposits is chiefly for domestic purposes, and no major withdrawal centers existed in these aquifers in 1980.

Water levels in various wells screened in the Potomac Group suggest that the upper Chesapeake Bay, including the areas along the major tributary streams, is a major locale where ground-water discharge occurs. The upland outcrop areas northwest of the Bay and the interstream upland areas east of the Bay are major sites where ground-water recharge occurs. Such recharge to the deep artesian aquifers must occur very slowly because of the very low permeabilities of the confining clays.

The chemical quality of the water in the aquifers of the Potomac Group in many places in the upper Bay region is such that water treatment may be required for some uses. For example, the iron concentration is in excess of 1,000 $\mu g/L$ throughout a large part of the region. Iron concentration in excess of 300 $\mu g/L$ in water commonly requires treatment for most uses. The water is mostly in the mildly acidic range, but, in places, is very acidic, with a pH as low as 3.5 north of the Magothy River in Anne Arundel County. Brackish water (total dissolved solids in the range of 1,000 to 10,000 mg/L) occurs in the deeper sands of the Potomac Group at various places in the upper Chesapeake Bay area. At Stillpond Neck, water containing 1,800 mg/L of dissolved solids occurs at a depth of 550 ft below the land surface, and, at Chestertown, water containing over 5,000 mg/L of dissolved solids occurs at a depth of 1,360 ft below the land surface. The likely presence of brackish water in many of the deeper sands of the Potomac Group may preclude their use as sources of potable water but may not eliminate their use as a source of geothermal energy or some related purpose.

This report presents geohydrologic data to serve as a basis for future modeling studies of the sands in the Potomac Group. Additional test drilling, however, will be needed to show the physical dimensions of sand layers in the Potomac Group. Such layers and their confining clays could then be modeled as distinct aquifer systems.

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**FIGURES 19A TO 19G AND TABLE 11 ARE IN THE FOLLOWING SECTIONS**

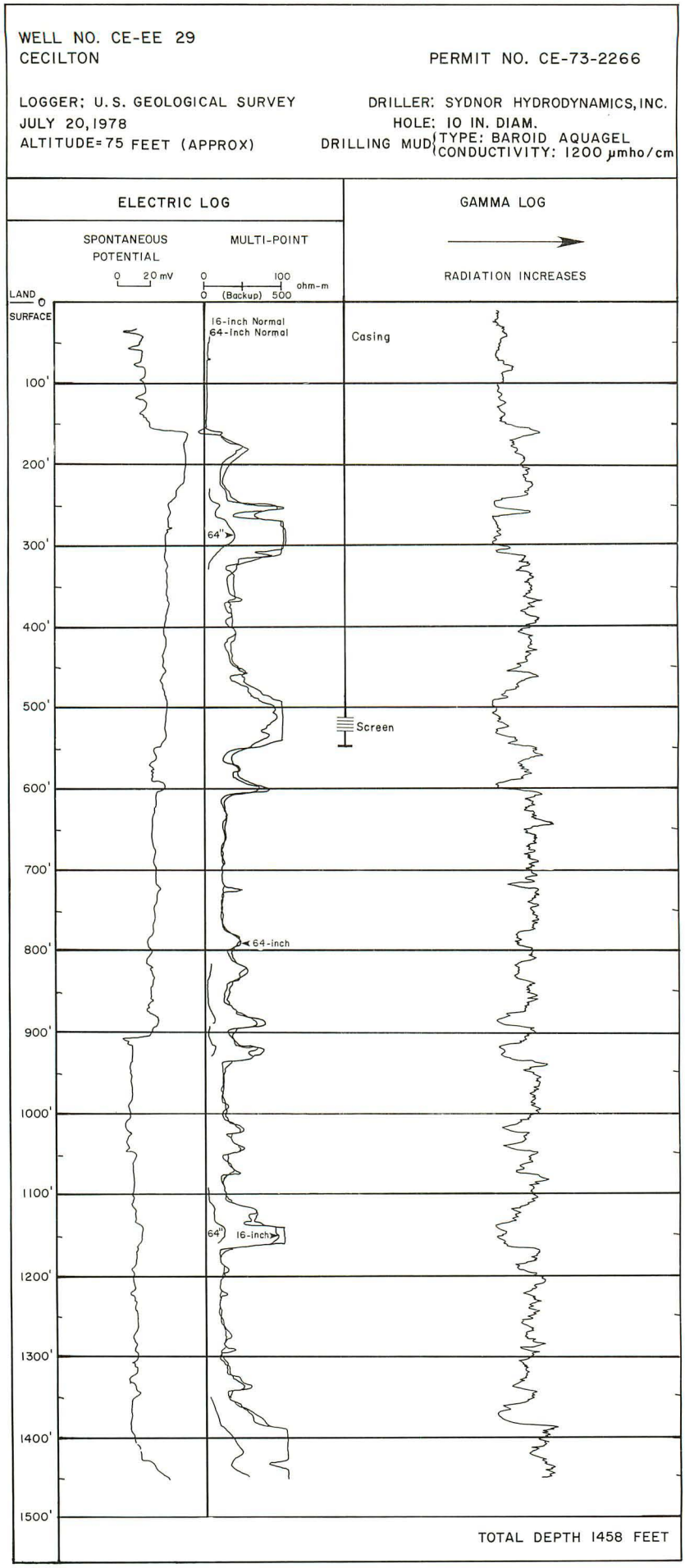


**Figure 19a—Geophysical log of well CE-EE 29 at Cecilton.**

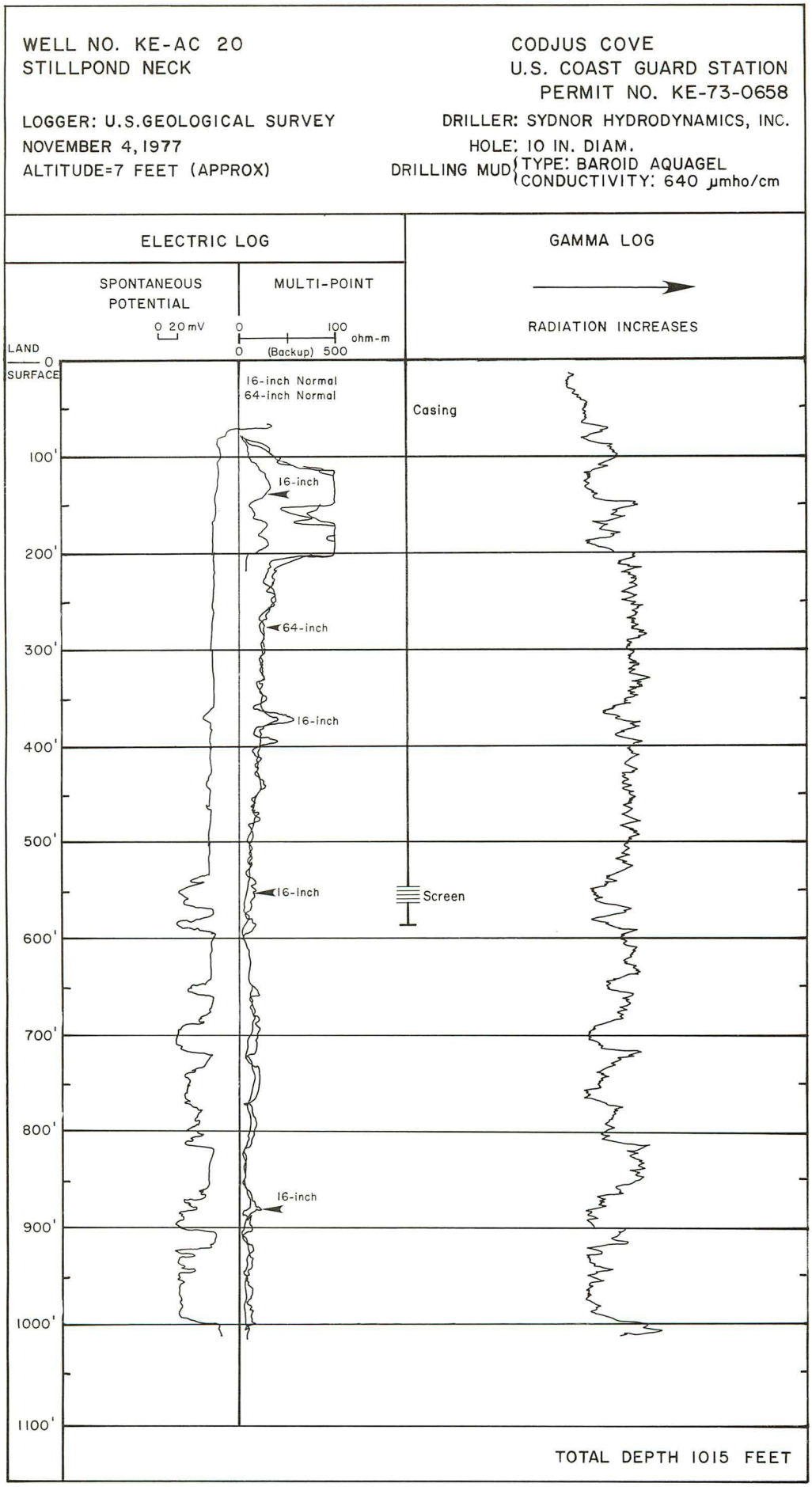


**Figure 19b.—Geophysical log of well KE-AC 20 at Stillpond Neck.**

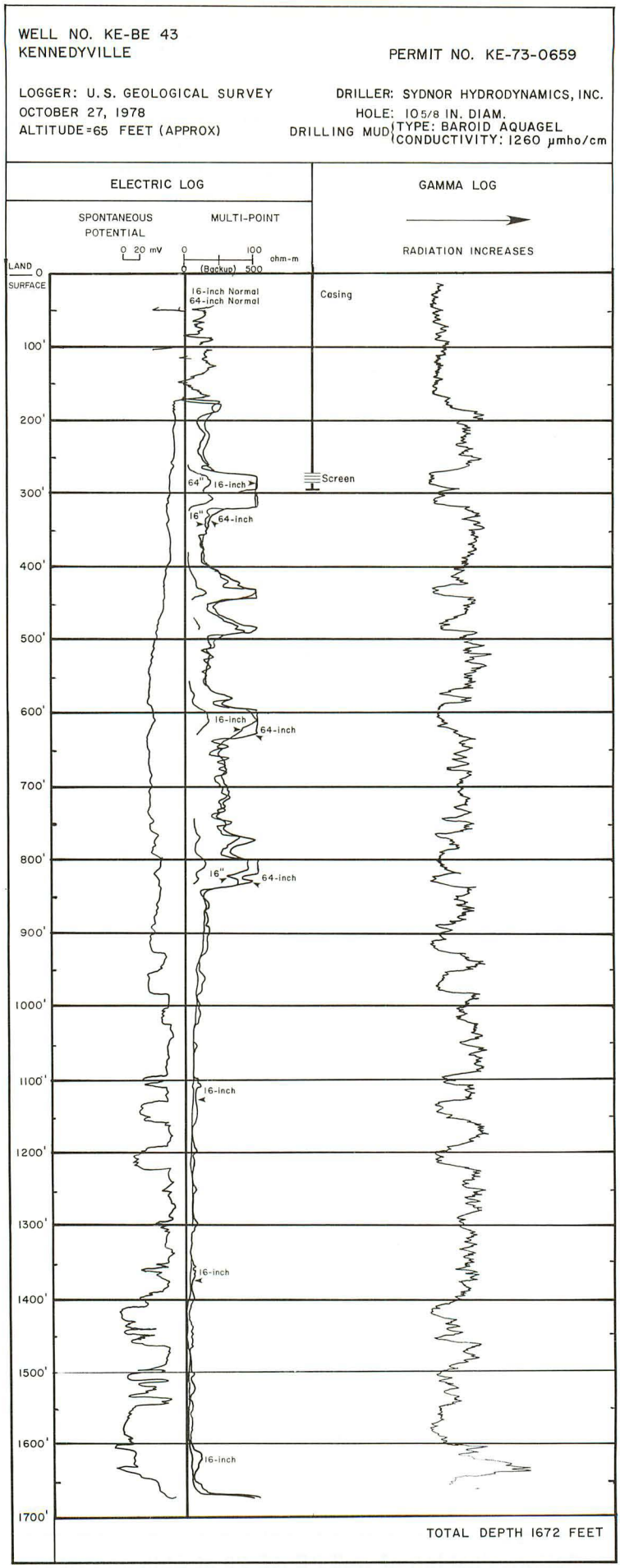


**Figure 19c.—Geophysical log of well KE-BE 43 at Kennedyville.**

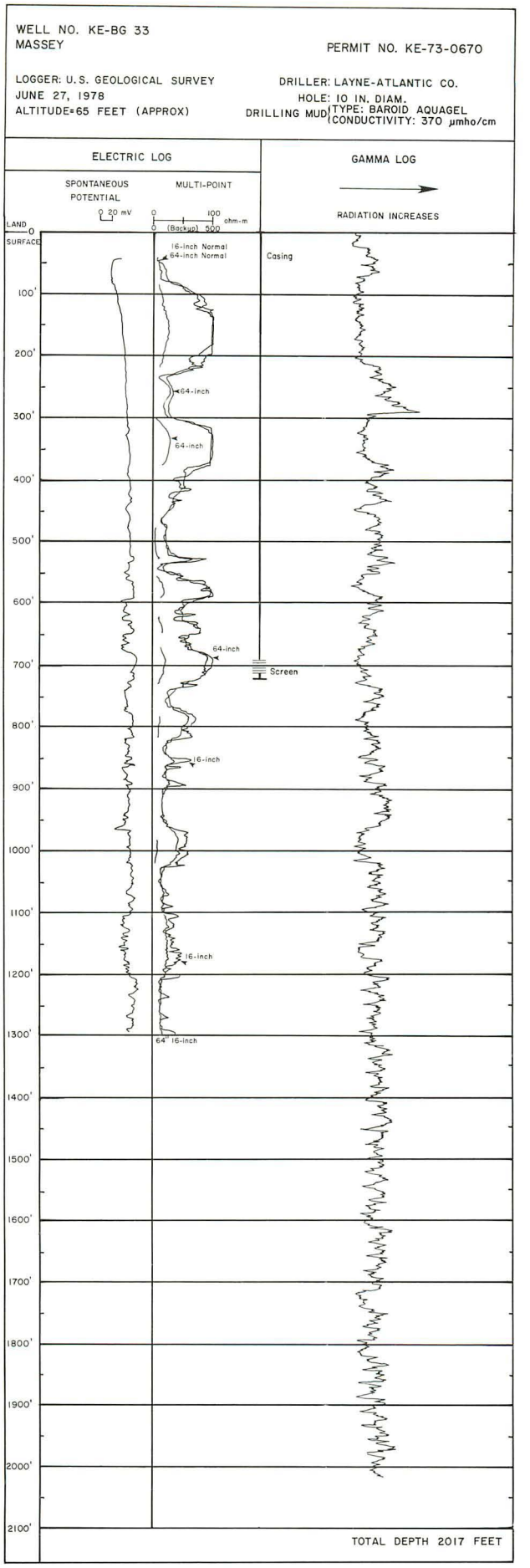


**Figure 19d.—Geophysical log of well KE-BG 33 at Massey.**

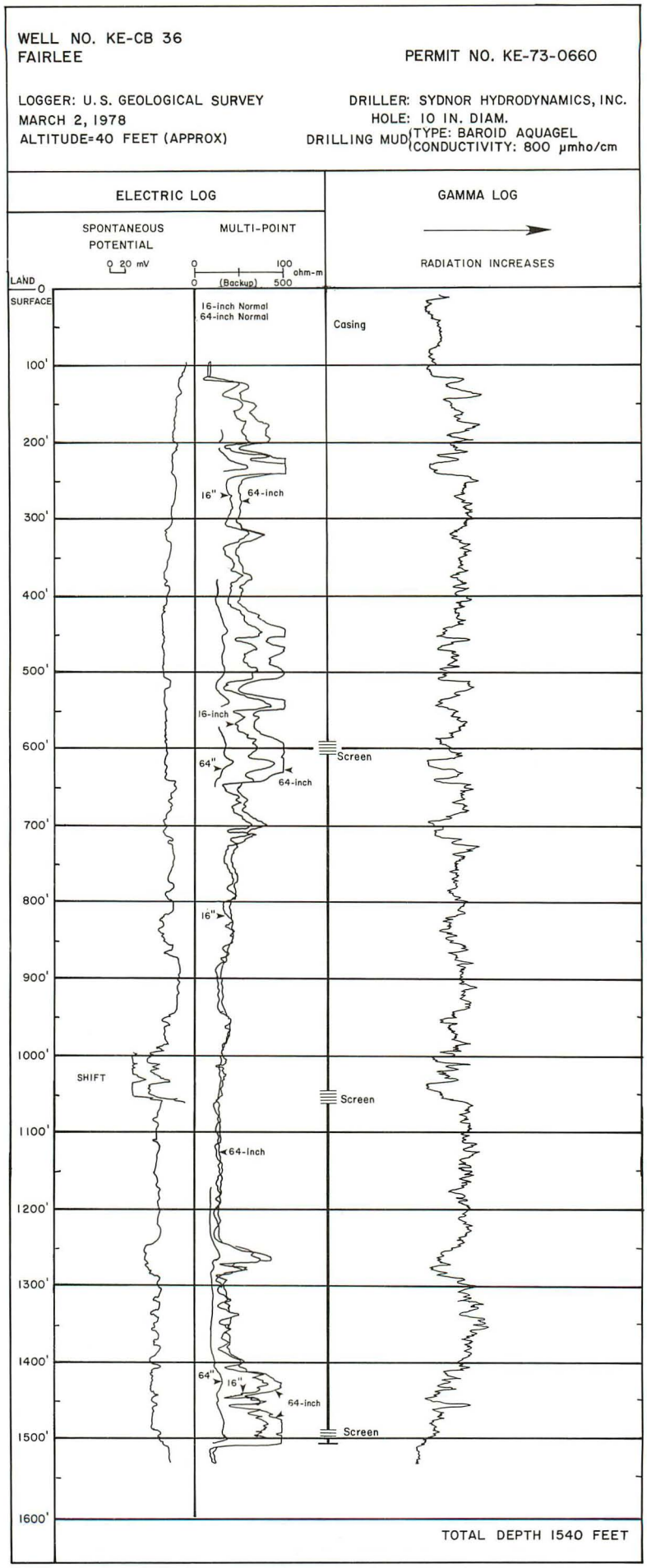


**Figure 19e.—Geophysical log of well KE-CB 36 at Fairlee.**

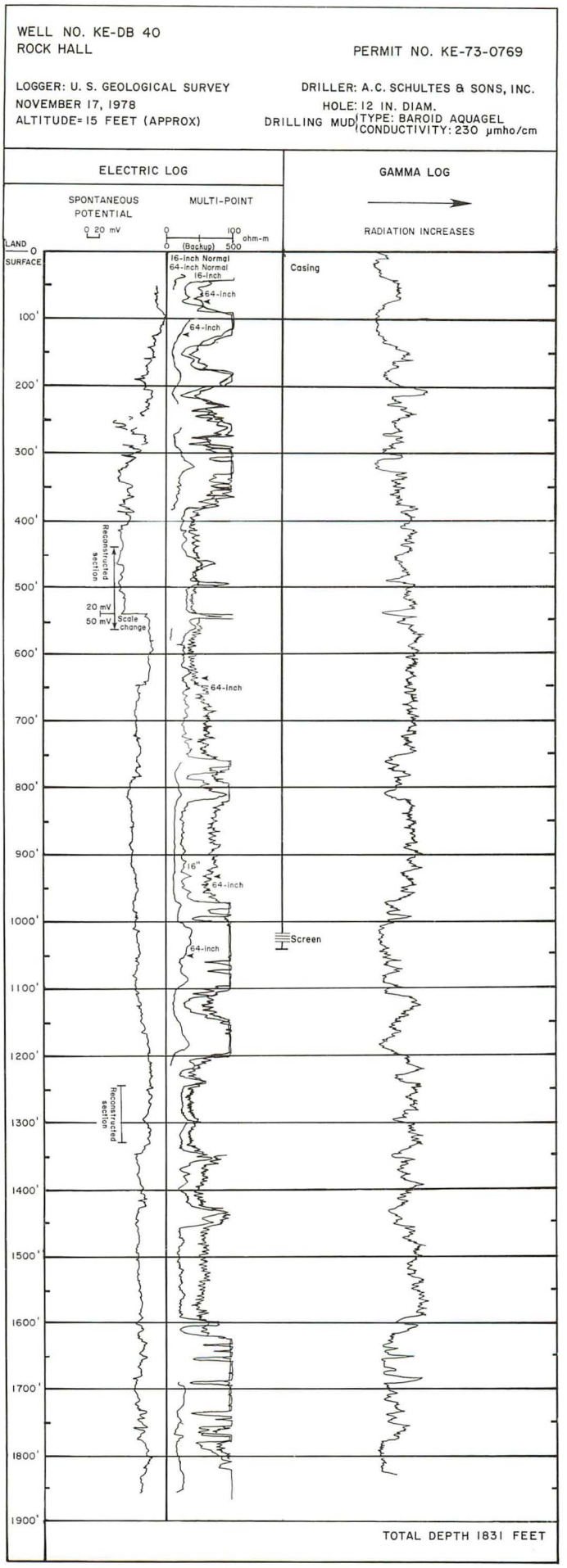


**Figure 19f.—Geophysical log of well KE-DB 40 at Rock Hall.**

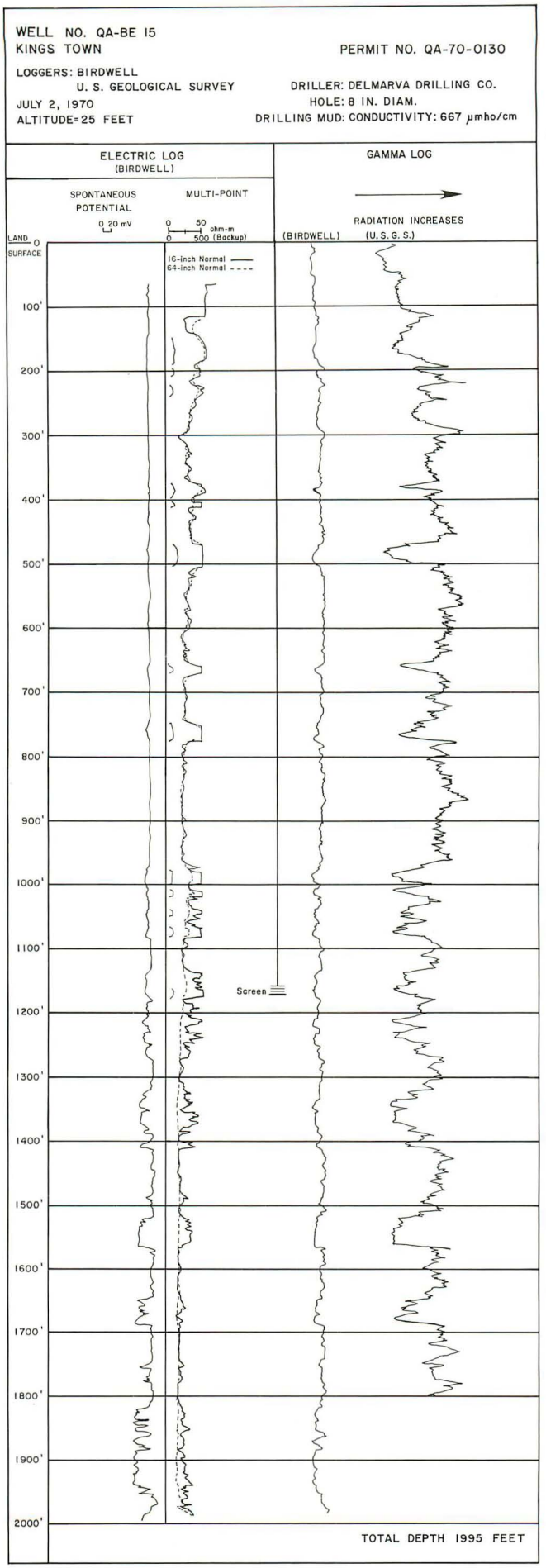


**Figure 19g.—Geophysical log of well QA-BE 15 at Kings Town.**

## Table 11.—Interpretive geologic logs of wells (based on sample cuttings, drillers' and geophysical logs).

Well CE-EE 29 at Cecilton

(Datum is land surface, approximately 75 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Pleistocene deposits, undifferentiated: | | |
| Top soil and yellow clay | 3 | 3 |
| Sand, fine to medium, yellow; some very coarse sand to fine gravel, angular, white to yellow | 27 | 30 |
| Sand, fine to very fine, yellow; some yellow clay; silty | 5 | 35 |
| Aquia and Hornerstown Formations, undivided: | | |
| Sand, fine, white to light green; glauconite; abundant shell fragments; streaks of black-dark green, silty clay | 25 | 60 |
| Sand, fine to very fine, white to light green; glauconite; shell fragments | 12 | 72 |
| Clay, silty, medium gray; some glauconite and shell fragments | 14 | 86 |
| Monmouth Formation: | | |
| Sand, medium to medium coarse, gray-light green; streaks of gray, silty clay | 68 | 154 |
| Matawan Formation: | | |
| Clay, black to dark gray, silty; some shell fragments; streaks of fine gravel | 12 | 166 |
| Clay, black to dark gray; very silty; micaceous; streaks of medium, white to gray sand | 24 | 190 |
| Clay, black; fine lignite (?) fragments | 50 | 240 |
| Magothy Formation: | | |
| Sand, fine, brown | 15 | 255 |
| Clay, medium to dark gray; abundant lignite and pyrite | 10 | 265 |
| Sand, coarse, white to light gray (quartz); some white and pink (feldspars); streak of medium gray clay, lignite and pyrite | 55 | 320 |
| Potomac Group, undivided: | | |
| Clay, white to light gray; streaks of fine, light gray sand | 15 | 335 |
| Clay, red, white, and light gray; some siderite concretions, light gray to tan; streaks of white, silty clay | 15 | 350 |
| Clay, red; siderite and hematite concretions; streaks of white and brown clay | 15 | 365 |
| Clay, brown, tan, and green; some siderite and hematite concretions; some medium gray clay and lignite | 10 | 375 |

Well CE-EE 29 at Cecilton--Continued

(Datum is land surface, approximately 75 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Siltstone, tan; some pyrite | 5 | 380 |
| Clay, red, brown; some siderite and hematite concretions | 45 | 425 |
| Clay, red, brown, tan; some cemented tan sand (noncalcareous); some siltstone | 15 | 440 |
| Clay, dark gray and white, some lignite; streaks of fine white sand | 30 | 470 |
| Clay, red and dark gray, some siderite and hematite concretions; some lignite | 30 | 500 |
| Sand, fine white to light gray; streaks of medium to dark gray clay and lignite | 60 | 560 |
| Clay, light gray; abundant lignite; streaks of light gray cemented sand; some pyrite; streaks of red and white clay | 40 | 600 |
| Sand, fine to medium, white | 15 | 615 |
| Clay, white, some light gray and red | 9 | 624 |
| Clay, red; streaks of white clay; some siderite and hematite concretions | 30 | 654 |
| Clay, medium gray; some lignite; grades to brown and red clay | 30 | 684 |
| Clay, red, brown; streaks of white and medium gray; streaks of fine light gray sand | 95 | 779 |
| Clay, red, medium gray and white; lignite | 11 | 790 |
| Sand, fine, light gray; streaks of medium gray clay and lignite | 50 | 840 |
| Clay, brown and light gray; streaks of fine white-tan sand | 12 | 852 |
| Sand, fine, white to light gray; streaks of medium gray clay | 26 | 878 |
| Clay, red, brown, and medium gray; streaks of light gray sand | 15 | 893 |
| Clay, medium gray and white; streaks of red and olive; streaks of black silty clay; some siderite concretions | 15 | 908 |
| Clay, medium gray, lignite; streaks of fine white to light gray sand | 10 | 918 |
| Sand, fine, white to light gray; streaks of medium gray clay and lignite | 20 | 938 |
| Clay, red | 10 | 948 |
| Clay, medium gray; lignite; some cemented sand | 10 | 958 |
| Sand, fine, white to light gray; streaks of medium gray clay and lignite | 20 | 978 |

Well CE-EE 29 at Cecilton--Continued

(Datum is land surface, approximately 75 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Clay, brown and red, streaks of medium gray and white; streaks of siderite and hematite concretions | 80 | 1,058 |
| Sand, fine, white; some light gray and white clay | 10 | 1,068 |
| Clay, medium to light gray, some brown; some fine, white sand | 14 | 1,082 |
| Sand, fine, white | 8 | 1,090 |
| Clay, red, brown, olive; some medium gray and black, silty clay; some siderite and hematite concretions; some pyrite | 48 | 1,138 |
| Sand, medium, white; streaks of white and light gray clay; lignite; pyrite | 30 | 1,168 |
| Clay, red, brown | 15 | 1,183 |
| Clay, white, light gray; streaks of medium, white sand | 15 | 1,198 |
| Clay, medium to light gray, olive, white and red; streaks of fine, white sand | 40 | 1,238 |
| Clay, white to light gray; streaks of fine, white sand; streaks of red, purple clay and hematite concretions; some loosely cemented, white sand | 45 | 1,283 |
| Clay, red, purple, brown, some olive and white; streaks of siderite and hematite concretions; some medium, cemented sand | 30 | 1,313 |
| Clay, light green to yellow, some red and white; abundant siderite concretions | 15 | 1,328 |
| Clay, medium to dark gray, streaks of red; abundant lignite, pyrite; streaks of siderite | 45 | 1,373 |
| Clay, medium to dark gray, silty; streaks of lignite and pyrite; streaks of fine, white, cemented sand; muscovite | 30 | 1,403 |
| Sand, fine and very coarse, white to light gray; abundant pyrite, lignite, and muscovite; streaks of white to light gray, silty clay; fragmented quartz gravel | 30 | 1,433 |
| Paleozoic and Precambrian crystalline rock: | | |
| Saprolite; dirty white to light gray-green clay; abundant large books of muscovite; fragmented quartz gravel and coarse white sand; some green schist fragments, chloritic | 11 | 1,444 |
| Schist or gneiss, biotite-plagioclase-muscovite-quartz; traces of garnet, chlorite, magnetite, zircon, and possibly sillimanite | 14 | 1,458 |

Well KE-AC 20 at Stillpond Neck

(Datum is land surface, about 7 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Pleistocene deposits, undifferentiated: | | |
| Sand, medium to coarse, orange-brown, some fine gravel | 12 | 12 |
| Sand medium to coarse, brown; fine gravel; wood fragments | 13 | 25 |
| Sand, coarse, brown to light gray; fine gravel; some medium to dark gray clay with shell fragments | 20 | 45 |
| Clay, dark gray to green; streaks of silt | 25 | 70 |
| Clay, medium gray, silty | 10 | 80 |
| Sand, coarse, tan to brown; fine gravel; some medium gray clay | 10 | 90 |
| Potomac Group, undivided: | | |
| Clay, red, white, and light brown-tan; some interbedded fine gravel | 10 | 100 |
| Clay, red, gray, white, and light brown-tan; streaks of sand, medium, white, angular | 10 | 110 |
| Clay, light gray; some hematite (red) and siderite (light gray-tan) concretions, medium to very coarse, spherical pellets | 15 | 125 |
| Clay, light gray, brown; some medium gray sand; traces of hematite and siderite concretions, medium to very coarse spherical pellets | 23 | 148 |
| Siderite concretions, spherical pellets, coarse, light gray-tan, some light green coloring; some light gray clay | 6 | 154 |
| Clay, light to medium gray, red | 6 | 160 |
| Clay, light to medium gray, red; some lignite and fine sand, some red silty clay | 10 | 170 |
| Clay, light to medium gray; lignite; some fine sand | 10 | 180 |
| Clay, light to medium gray; streaks of fine sand | 20 | 200 |
| Siderite concretions, spherical pellets, light gray-tan, medium to coarse, some light green coloring | 5 | 205 |
| Clay, red, some light gray | 75 | 280 |
| Clay, red, brown, light gray, silty | 30 | 310 |
| Clay, red, brown, some light gray-white coloring | 20 | 330 |
| Clay, medium gray, some red, brown and light gray coloring | 10 | 340 |
| Clay, red, brown, some light gray-white coloring | 25 | 365 |

Well KE-AC 20 at Stillpond Neck--Continued

(Datum is land surface, about 7 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Sand, very fine to fine; some brown and light green coloring, some cementation (noncalcareous) | 8 | 373 |
| Clay, medium to dark gray; some lignite | 7 | 380 |
| Clay, red, some light gray-white coloring | 10 | 390 |
| Clay, red, medium gray; streaks of silt or very fine sand | 8 | 398 |
| Clay, red, medium gray; some lignite | 4 | 402 |
| Clay, red, brown, medium to light gray; streaks of silt | 33 | 435 |
| Clay, medium to light gray | 5 | 440 |
| Sand, medium; some hematite concretions, spherical | 5 | 445 |
| Clay, medium to dark gray; abundant lignite | 20 | 465 |
| Clay, medium to light gray; some siderite concretions, light gray-tan, some light green coloring | 5 | 470 |
| Clay, medium to light gray, red; streak of siderite concretions and fine sand | 70 | 540 |
| Sand, fine to medium, clear-gray; layers of light gray clay with abundant lignite | 30 | 570 |
| Clay, medium to light gray; traces of lignite; some siderite concretions | 12 | 582 |
| Sand, very fine to fine, clear to gray; traces of medium to light gray clay | 14 | 596 |
| Clay, medium to dark gray, silty; some lignite | 4 | 600 |
| Clay, light gray, tan, some light green and red coloring, silty | 10 | 610 |
| Clay, tough, red, brown; traces of lignite | 30 | 640 |
| Clay, red, brown; some very fine sand or silt; traces of lignite | 8 | 648 |
| Sand, medium to fine, gray; some light to medium gray clay | 10 | 658 |
| Siderite concretions, light gray-tan, medium to coarse | 2 | 660 |
| Clay, red, brown | 24 | 684 |
| Clay, medium to light gray; streaks of lignite and fine white sand | 9 | 693 |
| Sand, fine, white to light gray; mica | 27 | 720 |
| Clay, red, some light gray | 12 | 732 |
| Clay, tan, light gray; trace of lignite, silt | 8 | 740 |



Well KE-AC 20 at Stillpond Neck--Continued

(Datum is land surface, about 7 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Sand, very fine to fine, light gray to white; some mica and streaks of medium gray, silty clay | 12 | 752 |
| Clay, medium to light gray, trace of red and white, very silty; some mica | 12 | 764 |
| Sand, very fine to fine, light gray to white; streaks of medium to light gray clay and lignite; quartz gravel, white to light gray | 16 | 780 |
| Clay, medium gray, some red, very silty; streaks of lignite and very fine, white sand; thin cemented layers (siltstone (?), very fine sand or silt cemented by silica (?)), light gray to tan | 20 | 800 |
| Sand, clear to white-light yellow, medium to coarse; clay, medium gray, red, purple, white, silty; streaks of siltstone; some pyrite | 20 | 820 |
| Clay, medium and light gray, red, purple, olive-brown | 20 | 840 |
| Sand, medium to coarse, white to light yellow, angular; some siltstone; some siderite concretions; some clay, medium gray, red, olive-brown | 15 | 855 |
| Clay, olive-brown, medium to dark gray, red, purple, some white | 20 | 875 |
| Siltstone, light gray-tan | 7 | 882 |
| Sand, fine to medium, white to light gray; streaks of clay, medium gray, some red; lignite | 28 | 910 |
| Clay, red, purple, medium to light gray | 15 | 925 |
| Clay, red, olive, purple, medium to light gray, silty | 5 | 930 |
| Sand, medium to coarse, white; fine quartz gravel; streaks of dark gray clay with lignite; mica | 70 | 1,000 |
| Clay, light gray, white | 10 | 1,010 |
| Clay, medium to dark gray, some red; some silt or fine sand | 20 | 1,030 |
| Lignite; some medium to light gray clay | 8 | 1,038 |
| Sand, medium, clear to light gray; mica; trace of medium gray, red, clay | 20 | 1,058 |
| Clay, brown-tan, light gray, some red | 14 | 1,072 |

Well KE-AC 20 at Stillpond Neck--Continued

(Datum is land surface, about 7 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Gravel, quartz, white to clear; some medium sand; layers of medium to light gray, red, and brown clay and lignite; mica | 40 | 1,112 |
| Clay, medium to light gray, white; mica | 16 | 1,128 |
| Paleozoic and Precambrian crystalline rocks: | | |
| Clay, white to light gray, light green; mica, thick books (muscovite); quartz fragments, subangular; rock fragments, schistose | 9 | 1,137 |
| Gneiss, muscovite-biotite-quartz and quartzite; traces of zircon and magnetite | 11 | 1,148 |
| No samples available | 3 | 1,151 |

Well KE-BE 43 at Kennedyville

(Datum is land surface, approximately 70 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Pleistocene deposits, undifferentiated: | | |
| Top soil | 1 | 1 |
| Clay, yellow, brown; large gravel and small boulders (approximately 1 ft in diameter) | 19 | 20 |
| Aquia and Hornerstown (?) Formations: | | |
| Sand, light green, brown, yellow, medium; streaks of green clay; streaks of fine, white gravel | 48 | 68 |
| Clay, medium to dark green; glauconite; streaks of medium, green, sand and fine, white gravel | 42 | 110 |
| Monmouth Formation: | | |
| Sand, light green, medium; glauconite; streaks of dark green clay and shells | 56 | 166 |
| Clay, dark green, dark gray; sand, light green, medium | 20 | 186 |
| Matawan Formation: | | |
| Clay, dark green, black; some fine sand | 14 | 200 |
| Clay, dark gray, black; sand, white to clear | 20 | 220 |
| Clay, dark gray, black; sand, white to clear, fine; streaks of black, cemented sand | 20 | 240 |
| Clay, dark gray, black; lignite; streaks of fine to coarse, white sand | 25 | 265 |
| Magothy Formation: | | |
| Sand, fine, white to tan; streaks of light gray clay | 30 | 295 |
| Clay, light to medium gray; lignite | 5 | 300 |
| Sand, medium to coarse, white; lignite; clay, medium gray; some white gravel | 20 | 320 |
| Potomac Group, undivided: | | |
| Clay, red, brown, some white; streaks of medium, white sand | 50 | 370 |
| Clay, red, some white and light gray; some silt or very fine sand | 15 | 385 |
| Clay, red; silt or very fine sand | 15 | 400 |
| Clay, medium to light gray, white, some red; lignite; very fine sand | 26 | 426 |
| Sand, fine, white | 19 | 445 |

Well KE-BE 43 at Kennedyville--Continued

(Datum is land surface, approximately 70 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Clay, red, light gray and white, silty | 15 | 460 |
| Clay, red, silty | 15 | 475 |
| Sand, white, medium, some cementation (sideritic?); clay, light gray; lignite | 20 | 495 |
| Clay, red, some dark gray streaks, tough; streaks of siderite and hematite or limonite nodules | 80 | 575 |
| Sand, white, fine, some cementation (sideritic?); streaks of siderite nodules; streaks of dark to medium gray clay with lignite | 50 | 625 |
| Clay, medium to dark gray, silty; lignite; streaks of fine white sand, some cementation | 55 | 680 |
| Clay, medium to dark gray, tan, brown, silty | 20 | 700 |
| Clay, medium to dark gray; lignite; streaks of black cemented sand; some fine white sand | 60 | 760 |
| Sand, fine, white; streaks of black cemented sand; streaks of medium to dark gray clay; lignite | 54 | 814 |
| Clay, red, tough | 4 | 818 |
| Sand, medium white; some red clay | 17 | 835 |
| Clay, red, some white and medium gray; streaks of fine sand | 19 | 854 |
| Clay, light and dark gray, silty; some very fine sand | 26 | 880 |
| Sand, medium to coarse, white; some fine white gravel; lignite; streaks of light and medium gray clay | 47 | 927 |
| Clay, red, brown; some hematite or limonite nodules; some medium sand | 25 | 952 |
| Sand, fine, white; streaks of dark gray silty clay | 30 | 982 |
| Clay, red, brown, light green, gray-white; some siderite nodules; some lignite | 40 | 1,022 |
| Clay, red, purple; some light green and white; hematite or limonite nodules | 70 | 1,092 |
| Sand, fine, white to clear; some white to light gray clay with siderite nodules; some lignite | 14 | 1,106 |
| Clay, red, brown, silty | 21 | 1,127 |

Well KE-BE 43 at Kennedyville--Continued

(Datum is land surface, approximately 70 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Sand, medium to coarse, white to light gray; some dark gray silty clay | 27 | 1,154 |
| Clay, dark and light gray; some lignite; some fine white sand | 36 | 1,190 |
| Sand, fine to medium, white; some white fine gravel; streaks of dark and medium gray clay and lignite | 30 | 1,220 |
| Clay, red, dark and light gray, white, purple, brown and green; some hematite or limonite nodules | 62 | 1,282 |
| Clay, red, pale yellow and light gray; siderite nodules; some fine white sand | 26 | 1,308 |
| Clay, brown, streaks of yellow and red, silty | 27 | 1,335 |
| Clay, red, green, and medium gray, silty | 23 | 1,358 |
| Clay, medium gray, white, some brown and light green; streaks of brown-white sand | 25 | 1,383 |
| Clay, medium gray, brown, red, purple, white; some very fine sand | 13 | 1,396 |
| Clay, medium gray; lignite | 10 | 1,406 |
| Sand, white to light gray; medium to dark gray clay; lignite | 54 | 1,460 |
| Clay, red, brown, purple, tough | 28 | 1,488 |
| Clay, light gray, some light-medium green; muscovite; pyrite; lignite; sand, white to clear, medium to coarse | 57 | 1,545 |
| Sand, medium to coarse, white to clear; muscovite; lignite; streaks of light gray-light green clay | 23 | 1,568 |
| Gravel, white; lignite; muscovite; dirty white-light green clay | 36 | 1,604 |
| Paleozoic and Precambrian crystalline rocks: | | |
| Clay, dirty light gray-light green; medium, white to clear quartz fragments; abundant mica | 20 | 1,624 |
| Weathered schist (?); medium green clay; abundant mica; white to clear quartz fragments | 36 | 1,660 |
| Gneiss, muscovite-biotite-plagioclase-quartz; strongly strained and altered. Also contains epidote, chlorite and traces of hematite, magnetite, leucoxene, zircon, apatite, and pyrite | 12 | 1,672 |

Well KE-BG 33 at Massey

(Datum is land surface, approximately 65 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Pleistocene deposits, undifferentiated: | | |
| Top soil | 5 | 5 |
| Clay, white, yellow | 7 | 12 |
| Sand, brown, yellow, coarse; gravel, medium, brown, yellow | 8 | 20 |
| Calvert (?) Formation: | | |
| Clay, medium blue gray; streaks of medium to fine, white sand | 32 | 52 |
| Clay, dark gray; streaks of fine, white sand | 16 | 68 |
| Aquia Formation: | | |
| Sand, green, light gray, fine; glauconite; streaks of dark green-gray clay | 52 | 120 |
| Sand, green, light gray, coarse; streaks of shells; streaks of dark green-gray clay; some glauconite | 22 | 142 |
| Sand, green, light gray, medium fine to coarse; abundant shells; streaks of dark green-gray clay; some glauconite | 38 | 180 |
| Sand, green, light gray, medium fine; streaks of dark green-gray clay; some glauconite | 32 | 212 |
| Hornerstown Formation (?): | | |
| Clay, medium gray to black; streaks of medium to fine sand, tan-light gray; some glauconite; a few shell fragments | 28 | 240 |
| Clay, dark gray to black; streaks of medium to coarse, light-gray sand; some glauconite | 50 | 290 |
| Monmouth (?) Formation: | | |
| Sand, medium, white to light gray; traces of light gray clay | 72 | 362 |
| Matawan and Magothy Formations, undivided: | | |
| Clay, medium to dark gray; streaks of medium to fine, white to light gray sand; lignite (?) | 76 | 438 |
| Sand, white to light gray, medium | 16 | 454 |
| Clay, medium to dark gray, tough; streaks of fine, light-gray sand; traces of lignite (?) | 99 | 553 |

Well KE-BG 33 at Massey--Continued

(Datum is land surface, approximately 65 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Sand, fine to very fine, "salt and pepper"; streaks of light gray clay | 33 | 586 |
| Potomac Group, undivided: | | |
| Clay, light gray, red, tough; streaks of fine to medium, light gray sand | 82 | 668 |
| Sand, medium, white to light gray; some white gravel; streaks of red, white, and medium gray clay | 60 | 728 |
| Clay, red, medium gray, tough | 42 | 770 |
| Sand, fine to medium, white to light gray; streaks of medium gray clay | 42 | 812 |
| Clay, red, some medium and light gray; streaks of fine, white sand | 30 | 842 |
| Clay, red, medium and light gray; alternating layers of medium light gray-white sand | 68 | 910 |
| Clay, red, very hard | 50 | 960 |
| Sand, medium to coarse, white to light gray, some brown-tan | 60 | 1,020 |
| Clay, red, white, brown, medium gray; some hematite or limonite nodules; some siltstone, tan; some siderite nodules, coarse | 130 | 1,150 |
| Sand, medium to coarse, white; trace of red, gray clay | 30 | 1,180 |
| Clay, red, medium gray, brown, very tough; streaks of medium, white sand | 220 | 1,400 |
| Clay, red, medium gray, white, brown; streaks of siltstone (?) or siderite (?) concretions | 40 | 1,440 |
| Clay, blue, light gray (marine?) | 17 | 1,457 |
| Clay, red, white, some light gray; streaks of fine to medium, white sand, cemented (siderite?) at 1,530-1,537) | 113 | 1,570 |
| Sand, medium to coarse, white; traces of lignite; streaks of red, white, clay; streaks of blue (marine?) clay; shell fragments | 44 | 1,614 |
| Clay, red, medium gray, tan-brown; streaks of siltstone; some coarse white sand | 43 | 1,657 |
| Clay, blue-light gray (marine?), very tough | 58 | 1,715 |

Well KE-BG 33 at Massey--Continued

(Datum is land surface, approximately 65 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Sand, medium to coarse, white; clay, medium gray; streaks of lignite; some mica | 124 | 1,839 |
| Clay, red, purple, tan, medium gray; streaks of lignite; streaks of cemented sand (siderite?); streaks of hematite or limonite nodules | 84 | 1,923 |
| Clay, black; mica, lignite | 52 | 1,975 |
| Clay, black; micaceous; some blue (marine?) clay; some shell fragments | 25 | 2,000 |
| Sand, medium, white-tan, cemented (siderite?); streaks of red and green, micaceous clay; some lignite | 4 | 2,004 |
| Sand, medium, black, cemented; siltstone streaks; some lignite; streaks of red and green clay | 20 | 2,024 |
| Clay, red, green, streaks of black; black cemented sand; some lignite; some siderite nodules | 40 | 2,064 |
| Sand, coarse, white, very angular (gravel fragments?); streaks of red and green, micaceous clay | 60 | 2,124 |
| Paleozoic and Precambrian crystalline rocks: | | |
| Clay, light gray, green, micaceous | 20 | 2,144 |
| Rock fragments, deep red and dark green; shaly or schistose; intermixed with subangular quartz fragments | 5 | 2,149 |
| Gneiss, biotite-quartz-plagioclase or schist. Severely altered to chlorite and sericite. Also contains calcite. | 36 | 2,185 |

Well KE-CB 36 at Fairlee

(Datum is land surface, approximately 40 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Pleistocene deposits, undivided: | | |
| Top soil | 1 | 1 |
| Clay, yellow-brown, dark gray and white | 12 | 13 |
| Gravel; streaks of white and light yellow-brown clay; some shell and rock fragments | 20 | 33 |
| Monmouth Formation: | | |
| Clay, dark green, glauconitic; streaks of silt or very fine sand | 42 | 75 |
| Sand, very fine to fine, green; glauconite; some silt; streaks of dark-green-black, silty clay | 40 | 115 |
| Matawan Formation: | | |
| Clay, dark green-black, silty; some glauconite; streaks of fine sand, white to clear | 27 | 142 |
| Sand, medium, white to light gray, subangular; some silt, glauconite, and mica; streaks of dark green-black, silty clay | 33 | 175 |
| Clay, dark gray, silty; some very fine sand; traces of glauconite | 10 | 185 |
| Magothy Formation: | | |
| Clay, medium to dark gray, silty, micaceous; streaks of lignite; some pyrite; streaks of fine sand, white to light gray | 35 | 220 |
| Clay, light gray, some red, silty, and sand, very fine to medium, light gray to white, angular; with streaks of cemented sand, light gray to light green in coloring, some bright olive green coloring | 22 | 242 |
| Potomac Group, undivided: | | |
| Clay, bright red, dark and medium gray, some white; red iron nodules (hematite or limonite concretions | 8 | 250 |
| Clay, red, white, medium gray and brown | 10 | 260 |
| Clay, red, some white, medium gray and brown; red iron nodules, coarse (hematite or limonite concretions); streaks of light gray to tan siderite concretions, spherical; rock fragments, medium, angular, tan to light gray | 40 | 300 |

Well KE-CB 36 at Fairlee--Continued

(Datum is land surface, approximately 40 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Clay, red, brown, traces of white and medium gray; streaks of medium sand, white to light gray | 12 | 312 |
| Sand, very fine to fine, clear to light yellow; streaks of red, brown, white, light gray clay | 18 | 330 |
| Clay, red, brown, some irony streaks; streaks of very fine sand, clear to light yellow | 35 | 365 |
| Sand, fine, light gray | 13 | 378 |
| Clay, medium gray, some fine sand; streak of lignite | 10 | 388 |
| Clay, red, white | 12 | 400 |
| Clay, red | 10 | 410 |
| Clay, medium gray; some silt or very fine sand | 5 | 415 |
| Sand, very fine, clear to tan; streaks of dark gray, red clay | 9 | 424 |
| Sand, medium, brown to clear | 28 | 452 |
| Clay, dark gray, silty; some very fine brown sand; some lignite | 10 | 462 |
| Sand, fine to medium, brown; some dark gray, red silty clay and lignite; some iron nodules (hematite or limonite concretions) | 48 | 510 |
| Clay, dark gray, red, brown, olive, some white; some lignite and iron nodules (hematite or limonite concretions) | 15 | 525 |
| Sand, very fine to medium, brown, some light gray; siltstone streaks, light gray to tan | 22 | 547 |
| Clay, dark to medium gray, some red, white and brown streaks of lignite and light gray to tan siltstone | 28 | 575 |
| Clay, dark gray, silt or very fine sand; streaks of sand, medium, light gray to white; streaks of lignite and siltstone; some pyrite | 30 | 605 |
| Clay, tan, some medium gray, red, and brown; sandy streaks | 7 | 612 |
| Sand, medium to fine, light gray to white | 13 | 625 |
| Sand, medium, light gray-white; streaks of light to medium gray clay, some red, brown and tan | 17 | 642 |
| Clay, red | 15 | 657 |
| Clay, red, white; some medium to fine sand, white to light gray | 8 | 665 |

Well KE-CB 36 at Fairlee--Continued

(Datum is land surface, approximately 40 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Clay, medium gray, some red and white; lignite; some medium to fine sand, white to light gray; some iron nodules (hematite or limonite concretions) and siderite concretions | 20 | 685 |
| Sand, medium to fine, tan-light brown; siltstone streaks, tan to light gray; pyrite; some iron nodules (hematite or limonite concretions) and siderite concretions | 17 | 702 |
| Clay, medium gray; lignite; some medium to fine sand, light gray to white | 11 | 713 |
| Clay, red, brown, and white | 10 | 723 |
| Clay, red, brown | 27 | 750 |
| Clay, red, brown, and white; some medium to fine sand | 10 | 760 |
| Clay, red, brown, medium gray; some lignite; some medium to fine sand | 15 | 775 |
| Clay, red, white, brown | 11 | 786 |
| Sand, medium, light gray to tan; some light gray to tan siderite concretions | 12 | 798 |
| Clay, red, brown, white | 18 | 816 |
| Sand, medium, white to light gray; thick lignite streaks; streaks of red, brown, and medium gray clay | 54 | 870 |
| Clay, red, brown, white | 70 | 940 |
| Clay, red, brown, medium gray | 8 | 948 |
| Sand, medium, tan to white; streaks of clay, light green and white, some red and brown; siderite concretions | 12 | 960 |
| Clay, light green, white, some red and brown; siderite concretions | 5 | 965 |
| Clay, red, brown, white | 19 | 984 |
| Clay, red, brown, medium gray; streaks of dark gray silty clay; streaks of fine sand; some lignite | 14 | 998 |
| Sand, medium to fine, white to light gray; siderite concretions, light gray to tan; thick lignite streaks; some medium gray clay | 28 | 1,026 |
| Clay, medium gray, white, some red; some medium to fine, white to light gray sand | 12 | 1,038 |
| Sand, medium to fine, white; some mica; streaks of red, white, and medium gray clay | 22 | 1,060 |

Well KE-CB 36 at Fairlee--Continued

(Datum is land surface, approximately 40 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Clay, red, brown, purple, white | 50 | 1,110 |
| Clay, black, sandy; streaks of brown clay; mica; small quartz gravel | 5 | 1,115 |
| Clay, red, brown, purple, some light green and white; streaks of black silty clay; streaks of fine white sand | 135 | 1,250 |
| Sand, medium to fine, white to light gray; streaks of white and gray clay; streaks of lignite; streaks of very coarse sand, white to light gray; some pyrite | 40 | 1,290 |
| Clay, medium to dark gray | 5 | 1,295 |
| Clay, red, brown, white, some medium gray, some silty yellow | 21 | 1,316 |
| Sand, very fine, white to light gray | 10 | 1,326 |
| Clay, white, light to medium gray, some red, silty; some medium sand, white to light gray; some siderite concretions | 12 | 1,338 |
| Sand, medium, white to light gray; some coarse quartz sand, white to light gray | 10 | 1,348 |
| Clay, gray, some red, brown, light green and white; some lignite | 8 | 1,356 |
| Sand, medium to fine, white to light gray; streaks of medium gray clay; some lignite and pyrite | 12 | 1,368 |
| Clay, medium gray, white, olive, some red and brown | 8 | 1,376 |
| Sand, medium to fine, white to light gray | 10 | 1,386 |
| Clay, medium gray, white, streaks of lignite; some medium, white to light gray sand; some pyrite | 10 | 1,396 |
| Sand, fine, white to light gray; some medium and light gray, yellow clay | 17 | 1,413 |
| Clay, light to medium gray, some white | 4 | 1,417 |
| Sand, fine, white; mica; some pyrite; some light to medium gray clay | 28 | 1,445 |
| Clay, red, light to medium gray, white, some lignite and pyrite; streaks of fine white sand; some white quartz gravel | 21 | 1,466 |
| Quartz gravel, white; medium gray clay matrix with fine white sand; mica; lignite | 48 | 1,514 |



Well KE-CB 36 at Fairlee--Continued

(Datum is land surface, approximately 40 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Paleozoic and Precambrian crystalline rocks: | | |
| Clay, light gray, green; some rock fragments | 11 | 1,525 |
| Rock, weathered, green, some quartz | 10 | 1,535 |
| Rock, serpentinite and epidote-actinolite-schist; also contains some biotite and hornblende | 5 | 1,540 |

Well KE-DB 40 at Rock Hall

(Datum is land surface, approximately 15 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Pleistocene deposits, undifferentiated: | | |
| Top soil | 1 | 1 |
| Clay, orange and light gray, sandy, some wood | 9 | 10 |
| Sand, fine, white to yellow | 15 | 25 |
| Aquia (?) and Hornerstown (?) Formations, undivided: | | |
| Clay, dark green, silty; some medium gravel, white to light green; streaks of very fine, white to light green, glauconitic sand with some muscovite | 19 | 44 |
| Clay, green, some brown and red; glauconite; streaks of fine white to light green sand | 13 | 57 |
| Clay, green; glauconite; streaks of fine and coarse, white to light green sand; muscovite | 18 | 75 |
| Monmouth, Matawan, and Magothy (?) Formations, undivided: | | |
| Sand, fine, gray to green; glauconite; streaks of coarse, white, gray to green, silty clay | 40 | 115 |
| Sand, medium coarse, gray to green; abundant shells; some fine, gray-green sand; some gray clay | 27 | 142 |
| Clay, tan to brown, sticky | 5 | 147 |
| Clay, black, silty, micaceous, very tough | 27 | 174 |
| Sand, dark gray to green; some black to dark green, silty clay | 26 | 200 |
| Clay, dark green-black, silty; some glauconite | 14 | 214 |
| Sand, fine, white to light gray; streaks of black to dark green clay; some glauconite | 18 | 232 |
| Clay, dark green to black; silty; streaks of fine, white to light gray sand | 16 | 248 |
| Magothy Formation: | | |
| Sand, coarse, white to light gray; streaks of medium to dark gray clay; streaks of lignite; streaks of fine, white gravel | 80 | 328 |
| Potomac Group, undivided: | | |
| Clay, dark gray, dark brown mixed, some red and white clay | 18 | 346 |
| Clay, red, white, some silt; abundant red iron nodules, coarse (hematite or limonite concretions) | 10 | 356 |

Well KE-DB 40 at Rock Hall--Continued

(Datum is land surface, approximately 15 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Clay, white, no silt | 15 | 371 |
| Clay, red and light gray, hard; lignite; siderite and hematite or limonite concretions | 13 | 384 |
| Clay, red, some light gray, hard | 28 | 412 |
| Clay, red, medium gray, light gray; lignite | 30 | 442 |
| Clay, red, medium gray; streaks of fine white sand | 44 | 486 |
| Sand, very fine to fine, white to clear; some small white gravel; some siderite concretions | 10 | 496 |
| Clay, dark gray; streaks of lignite | 38 | 534 |
| Sand, fine, white to clear, trace of white clay | 11 | 545 |
| Clay, light gray, white | 8 | 553 |
| Clay, red, light gray, some white; some lignite; streaks of fine white sand | 19 | 572 |
| Clay, red, light gray, tan, white, tough; streaks of fine white sand | 178 | 750 |
| Sand, fine, white; clay, light gray, white | 66 | 816 |
| Clay, red, light gray, white, very tough | 69 | 885 |
| Clay, red, dark gray, white, silty; streaks of fine white sand; some hematite or limonite concretions | 79 | 964 |
| Sand, fine (top) to coarse (bottom), white to clear; streaks of light gray, white clay, with some lignite and pyrite; some siderite concretions | 148 | 1,112 |
| Clay, red, medium gray, tan, brown | 32 | 1,144 |
| Sand, fine, white to clear; streaks of red, white, and medium gray clay | 56 | 1,200 |
| Clay, medium to light gray, white | 26 | 1,226 |
| Sand, fine, white to clear | 16 | 1,242 |
| Clay, red, purple, dark and light gray, brown; some lignite | 40 | 1,282 |
| Sand, fine, white to clear; some light gray, white, red, silty clay | 18 | 1,300 |
| Clay, medium gray, red, some white, some lignite; some cemented silts (sideritic?) | 40 | 1,340 |
| Sand, fine, white to clear | 18 | 1,358 |

Table 11.--Interpretive geologic logs of wells (based on sample cuttings, drillers' and geophysical logs)--Continued.

Well KE-DB 40 at Rock Hall--Continued

(Datum is land surface, approximately 15 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Clay, medium gray, some red and white; streaks of fine white sand; some lignite | 70 | 1,428 |
| Sand, medium, white to tan; streaks of red, tan and white, silty clay | 25 | 1,453 |
| Clay, red, brown, tan, gray, silty | 15 | 1,468 |
| Sand, medium to coarse, white; muscovite; some lignite | 9 | 1,477 |
| Clay, brown, tan, light and medium gray; some dark red-purplish; streaks of silt or very fine sand | 31 | 1,508 |
| Clay, red, white, light gray; streaks of siderite and hematite or limonite nodules | 24 | 1,532 |
| Clay, red, light and medium gray, white; streaks of fine to very fine, white sand | 58 | 1,590 |
| Sand, fine, white; streaks of red and medium gray clay; some lignite | 60 | 1,650 |
| Sand, medium to coarse, white, very angular; muscovite; streaks of medium and dark gray clay; lignite | 105 | 1,755 |
| Paleozoic and Precambrian crystalline rocks: | | |
| Clay, light gray, light green, dirty white; abundant mica | 23 | 1,778 |
| Gneiss, quartz-plagioclase and quartzite. Also a few percent to traces of chlorite, magnetite, and apatite | 44 | 1,822 |

Table 11.--Interpretive geologic logs of wells (based on sample cuttings, drillers' and geophysical logs)--Continued.

Well QA-BE 15 at Kings Town

(Datum is rotary table, 3 ft above land surface and 25 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Holocene and Pleistocene deposits, undifferentiated: | | |
| Soil | 4 | 4 |
| Sand, medium to coarse, brown; some very coarse sand and fine gravel | 12 | 16 |
| Aquia Formation: | | |
| Sand, fine to medium, reddish-brown; some coarse sand | 23 | 39 |
| Sand, fine, reddish-brown, silty; some medium sand | 28 | 67 |
| Sand, fine to medium, reddish-brown; some coarse sand | 21 | 88 |
| Sand, fine, greenish-gray; shell fragments; some medium sand | 29 | 117 |
| Hornerstown Formation: | | |
| Sand, fine, greenish-gray; shell fragments; some clay and very fine sand | 21 | 138 |
| Monmouth, Matawan, and Magothy Formations, undivided: | | |
| Sand, fine to medium, greenish-gray; shell fragments | 23 | 161 |
| Sand, fine, dark-gray; some medium sand | 23 | 184 |
| Sand, very fine to fine, silty, dark-gray | 106 | 290 |
| Sand, very fine, silty, dark gray; some clay | 90 | 380 |
| Sand, very fine to fine, light gray | 14 | 394 |
| Potomac Group, undivided: | | |
| Clay, light gray; some brown mottling | 74 | 468 |
| Sand, very fine, light gray; some silt and lignite | 10 | 478 |
| Sand, medium, light gray; some lignite | 26 | 504 |
| Clay, variegated, light gray, purple, red, brown, and some yellow | 154 | 658 |
| Sand, very fine, light gray; some fine and medium sand | 12 | 670 |
| Clay, red; some light gray mottling | 75 | 745 |
| Sand, very fine to fine, light gray | 33 | 778 |
| Clay, red and light gray, mottled; some silty clay layers | 197 | 975 |
| Sand, fine, light gray | 26 | 1,001 |

Table 11.--Interpretive geologic logs of wells (based on sample cuttings, drillers' and geophysical logs)--Continued.

Well QA-BE 15 at Kings Town--Continued

(Datum is rotary table, 3 ft above land surface and 25 ft above sea level)

| | Thickness (ft) | Depth (ft) |
|---|---|---|
| Clay, light gray | 8 | 1,009 |
| Sand, fine, light gray, lignitic | 11 | 1,020 |
| Clay, light gray | 18 | 1,038 |
| Sand, very fine to fine, light gray, with light gray clay layers | 47 | 1,085 |
| Clay, red and light gray, mottled | 53 | 1,138 |
| Sand, fine to medium, light gray; some clayey sand | 40 | 1,178 |
| Sand, fine to medium, light gray; some layers of gray clay | 94 | 1,272 |
| Clay, red | 38 | 1,310 |
| Sand, very fine to fine, light gray, very clayey | 100 | 1,410 |
| Clay, variegated, brown, light gray, and some yellow | 110 | 1,520 |
| Sand, very fine, light gray, silty; some clay | 46 | 1,566 |
| Clay, light gray, some yellow mottling | 79 | 1,645 |
| Sand, very fine, light gray, silty and clayey | 41 | 1,686 |
| Clay, light gray; some silt | 61 | 1,747 |
| Silt, light gray; clayey | 30 | 1,777 |
| Clay, light gray, some red mottling | 39 | 1,816 |
| Sand, very fine, silty, light gray | 137 | 1,953 |
| Paleozoic and Precambrian crystalline rocks: | | |
| Rock, weathered | 16 | 1,969 |
| Rock, progressively harder with increasing depth | 40 | 2,009 |
| Biotite-quartz-plagioclase gneiss. Also contains traces of chlorite, sphene, magnetite, zircon, and apatite. | | |

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