RESULTS OF TEST DRILLING IN HOWELL TOWNSHIP, MONMOUTH COUNTY, NEW JERSEY

By G. Allan Brown and Otto S. Zapecza

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 90-4062

Prepared in cooperation with the

U.S. ARMY CORPS OF ENGINEERS

U.S. DEPARTMENT OF THE INTERIOR

March 3, 1849

West Trenton, New Jersey

1990

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Mountain View Office Park
Suite 206
810 Bear Tavern Road
West Trenton, NJ 08628

Copies of this report can be
purchased from:

U.S. Geological Survey
Books and Open-File Reports
Box 25425
Federal Center
Denver, CO 80225

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For readers who prefer to use International System (SI) units instead of the inch-pound units used in this report, the following conversion factors are provided:

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
foot per day (ft/d)	0.3048	meter per day (m/day)
gallon per minute (gal/min)	0.06308	liter per second (L/s)

For readers who prefer to use inch-pound units instead of International System (SI) units, the following conversion factor is provided:

Multiply	By	To obtain
millimeter (mm)	0.03937	inch (in.)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

RESULTS OF TEST DRILLING IN HOWELL TOWNSHIP, MONMOUTH COUNTY, NEW JERSEY

by

G. Allan Brown and Otto S. Zapecza

ABSTRACT

A test-drilling program defined hydrologic conditions and water chemistry at a site in Howell Township, south-central Monmouth County, New Jersey. Drilling at the site penetrated 1,500 feet of Coastal Plain sediments consisting of unconsolidated clay, silt, sand, and gravel of Quaternary, Tertiary and Cretaceous age and 162 feet of weathered basement rock. Hard unweathered crystalline basement rock was encountered at a depth of 1,662 feet. Drilling continued through hard rock to a depth of 1,670 feet.

One observation well was installed in each of the five principal Coastal Plain aquifers--from youngest to oldest, the Vincentown aquifer, the Wenonah-Mount Laurel aquifer, the Englishtown aquifer system, the upper aquifer of the Potomac-Raritan-Magothy aquifer system, and the deeper, undifferentiated part of the Potomac-Raritan-Magothy aquifer system. These wells were installed to monitor long-term water-level fluctuations and ground-water quality. The highest water levels measured were in the Vincentown aquifer and ranged from 39 to 56 feet below land surface. The lowest water levels measured were in the Englishtown aquifer system and ranged from 156 to 165 feet below land surface. Dominant ions in water from all five aquifers were calcium and bicarbonate. Specific conductivity ranged from 106 μS/cm (microsiemens per centimeter at 25 degrees Celsius) in the deepest aquifer to 241 μS/cm in the shallowest aquifer.

Laboratory-determined porosities of 13 core samples collected from confining units ranged from 37.9 to 50.4 percent. Laboratory-determined vertical hydraulic conductivities ranged from 5.1×10^{-6} to 1.9×10^{-2} feet per day.

INTRODUCTION

A test-well drilling program was conducted during 1987-88 to determine the lithology, stratigraphy, hydrologic conditions, and water chemistry of the major Coastal Plain aquifers at a site in Howell Township in south-central Monmouth County, New Jersey. Little was known previously about the deep aquifers in this part of Monmouth County. Increasing ground-water withdrawals from the major aquifers in the area have resulted in the formation of large cones of depression for which limited water-level data are available. From April 1987 to February 1988, the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers, drilled a test hole and installed five observation wells near Farmingdale, New Jersey, in an effort to determine the physical, hydrologic, and hydraulic properties of the underlying Coastal Plain aquifers.

Purpose and Scope

This report presents data collected during, and as a result of, the test-well drilling program. Specifically, the report includes information on well construction, methods used to determine subsurface stratigraphy and lithology, hydraulic properties of confining units, water levels, and ground-water quality of the major aquifers underlying the test-drilling site.

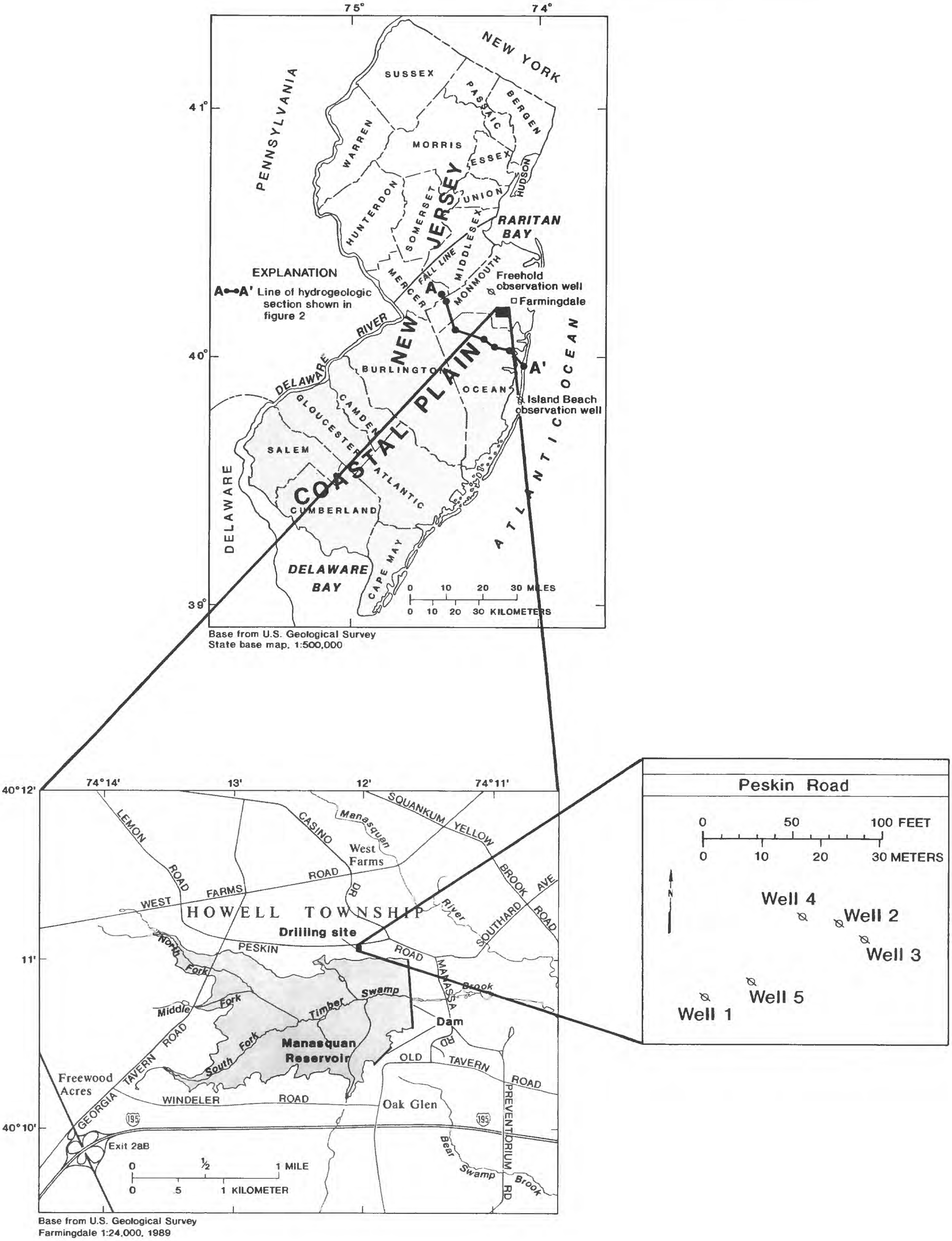
A test hole 1,670 ft (feet) deep was drilled to basement rock. After a suite of geophysical logs was run in the hole, a deep well was constructed in the deeper, undifferentiated part of the Potomac-Raritan-Magothy aquifer system. By using the information gained from the test hole, four shallower holes also were drilled and were finished as wells in the four shallower aquifers. All five wells were developed to be used as observation wells in the major Coastal Plain aquifers. Thirteen core samples were collected from confining units and were analyzed in the laboratory for hydraulic properties. One water sample from each well was analyzed for chemical quality.

Geographic and Hydrogeologic Setting

The drilling site is on the south side of Peskin Road, 2 mi (miles) west-southwest of Farmingdale in Howell Township, Monmouth County, New Jersey (fig. 1). The site is in the drainage area of Timber Swamp Brook, which is a tributary of the Manasquan River. The wells were drilled at latitude 40°11'05" N, longitude 74°12'02" W, about 500 ft north of the Manasquan Reservoir in the headwaters of Timber Swamp Brook. The drilling site was chosen because it was a large open area convenient for drilling several wells. The drilling was unrelated to the reservoir construction that was occurring at the same time. The topography at the drilling site is relatively flat, with an altitude ranging from 111.3 to 112.1 ft above sea level.

The site is in the Coastal Plain physiographic province, about 22 mi east of the Fall Line and about 10 mi from the Atlantic Ocean. The Coastal Plain is underlain by a thick sequence of alternating beds of unconsolidated clay, silt, sand, and gravel. These sediments range in age from Early Cretaceous to Holocene and are classified as continental, coastal, and marine-type deposits (table 1). The marine sediments commonly include glauconite and shell material, locally in significant amounts. In New Jersey, the Coastal Plain sediments form a wedge that thickens and deepens from a featheredge at the Fall Line to a maximum of about 6,500 ft at the southern tip of Cape May County (Zapecza, 1989). The surface sediments of Quaternary age are essentially flat-lying, but the underlying Cretaceous and Tertiary sediments strike generally northeast-southwest and dip from 10 to 60 feet per mile to the southeast.

The ground-water system of the Coastal Plain is directly related to the geology. Water-bearing characteristics are a function of the lithology (grain size), thickness, and lateral extent of the unconsolidated formations. A stratigraphic column of geologic units and associated hydrogeologic units (aquifers and confining units) of the New Jersey Coastal Plain is shown in table 1.



Base from U.S. Geological Survey
State base map, 1:500,000

Base from U.S. Geological Survey
Farmingdale 1:24,000, 1989

Figure 1.--Location of drilling site and observation wells.

Table 1. Geologic and hydrogeologic units in the Coastal Plain of New Jersey

(Modified from Zapecza, 1989, table 2)

SYSTEM	SERIES	GEOLOGIC UNIT	LITHOLOGY	HYDROGEOLOGIC UNIT	HYDROLOGIC CHARACTERISTICS
Quaternary	Holocene	Alluvial deposits	Sand, silt, and black mud.	Undifferentiated	Surficial material, commonly hydraulically connected to underlying aquifers. Locally some units may act as confining units. Thicker sands are capable of yielding large quantities of water.
		Beach sand and gravel	Sand, quartz, light-colored, medium- to coarse-grained, pebbly.		
	Pleistocene	Cape May Formation	Sand, quartz, light-colored, heterogeneous, clayey, pebbly.		
Tertiary	Miocene	Pensauken Formation			
		Bridgeton Formation		Kirkwood-Cohansey aquifer system	A major aquifer system. Ground water occurs generally under water-table conditions. In Cape May County, the Cohansey Sand is under artesian conditions.
		Beacon Hill Gravel	Gravel, quartz, light-colored, sandy.		
		Cohansey Sand	Sand, quartz, light-colored, medium- to coarse-grained, pebbly; local clay beds.		
		Kirkwood Formation	Sand, quartz, gray and tan, very fine to medium-grained, micaceous, and dark-colored diatomaceous clay.		
				Confining unit	Thick diatomaceous clay bed occurs along coast and for a short distance inland. A thin water-bearing sand is present in the middle of this unit.
				Rio Grande water-bearing zone	
				Confining unit	
				Atlantic City 800-foot sand	A major aquifer along the coast.
				Composite confining unit	Poorly permeable sediments.
	Oligocene	Piney Point Formation[1]	Sand, quartz and glauconite, fine- to coarse-grained.	Composite confining unit: Piney Point aquifer	Yields moderate quantities of water.
	Eocene	Shark River Formation			
		Manasquan Formation	Clay, silty and sandy, glauconitic, green, gray, and brown, contains fine-grained quartz sand.	Composite confining unit	Poorly permeable sediments.
	Paleocene	Vincentown Formation	Sand, quartz, gray and green, fine- to coarse-grained, glauconitic, and brown clayey, very fossiliferous, glauconite and quartz calcarenite.	Composite confining unit: Vincentown aquifer	Yields small to moderate quantities of water in and near its outcrop area.
		Hornerstown Sand	Sand, clayey, glauconitic, dark-green, fine- to coarse-grained.	Composite confining unit	Poorly permeable sediments.
Cretaceous	Upper Cretaceous	Tinton Sand	Sand, quartz and glauconite, brown and gray, fine- to coarse-grained, clayey, micaceous.		
		Red Bank Sand		Composite confining unit: Red Bank Sand	Yields small quantities of water in and near its outcrop area.
		Navesink Formation	Sand, clayey, silty, glauconitic, green and black, medium- to coarse-grained.	Composite confining unit	Poorly permeable sediments.
		Mount Laurel Sand	Sand, quartz, brown and gray, fine- to coarse-grained, slightly glauconitic.	Wenonah-Mount Laurel aquifer	A major aquifer.
		Wenonah Formation	Sand, very fine- to fine-grained, gray and brown, silty, slightly glauconitic.	Marshalltown-Wenonah confining unit	A leaky confining unit.
		Marshalltown Formation	Clay, silty, dark-greenish-gray; contains glauconitic quartz sand.		
		Englishtown Formation	Sand, quartz, tan and gray, fine- to medium-grained; local clay beds.	Englishtown aquifer system	A major aquifer. Two sand units in Monmouth and Ocean Counties.
		Woodbury Clay	Clay, gray and black, and micaceous silt.	Merchantville-Woodbury confining unit	A major confining unit. Locally the Merchantville Formation may contain a thin water-bearing sand.
		Merchantville Formation	Clay, glauconitic, micaceous, gray and black; locally very fine grained quartz and glauconitic sand are present.		
		Magothy Formation	Sand, quartz, light-gray, fine- to coarse-grained. Local beds of drak gray lignitic clay. Includes Old Bridge Sand Member.	Potomac-Raritan-Magothy aquifer system: Upper aquifer	A major aquifer system. In the northern Coastal Plain, the upper aquifer is equivalent to the Old Bridge aquifer and the middle aquifer is equivalent to the Farrington aquifer. In the Delaware River Valley, three aquifers are recognized. In the deeper subsurface, units below the upper aquifer are undifferentiated.
		Raritan Formation	Sand, quartz, light-gray, fine- to coarse-grained, pebbly, arkosic; contains red, white, and variegated clay. Includes Farrington Sand Member.	Potomac-Raritan-Magothy aquifer system: Confining unit Middle aquifer	
	Lower Cretaceous	Potomac Group	Alternating clay, silt, sand, and gravel.	Potomac-Raritan-Magothy aquifer system: Confining unit Lower aquifer	
Pre-Cretaceous		Bedrock	Precambrian and lower Paleozic crystalline rocks, metamorphic schist, and gneiss; locally Triassic sandstone and shale and Jurassic diabase are present.	Bedrock confining unit	No wells obtain water from these consolidated rocks, except along Fall Line.

[1] of Olsson and others, 1980

The principal aquifers of the New Jersey Coastal Plain are, from top to bottom, the Kirkwood-Cohansey aquifer system, the Atlantic City 800-foot sand of the Kirkwood Formation, the Wenonah-Mount Laurel aquifer, the Englishtown aquifer system, and the Potomac-Raritan-Magothy aquifer system. Minor aquifers include the Rio Grande water-bearing zone of the Kirkwood Formation, the Piney Point aquifer, the Vincentown aquifer, and the Red Bank Sand. The lateral extents of the hydrogeologic units in the vicinity of the Howell Township drilling site are shown in hydrogeologic section A-A' (fig. 2). The surficial material at the drilling site is sand of the Kirkwood Formation of Miocene age (Lyttle and Epstein, 1987).

Previous Investigations

The ground-water resources of Monmouth County were described by Jablonski (1968). Brown, Miller, and Swain (1972) presented structure-contour maps, geohydrologic maps, and sections for the Coastal Plain from North Carolina to New York. Nichols (1977) described the geohydrology of the Englishtown Formation in the northern Coastal Plain of New Jersey. Gill and Farlekas (1976) presented structure-contour maps for the pre-Cretaceous basement, the Potomac-Raritan-Magothy aquifer system, and the Merchantville-Woodbury confining unit. The Wenonah-Mount Laurel aquifer in the area was described by Nemickas (1976). Water levels in the aquifers in the New Jersey Coastal Plain were reported by Walker (1983) and Eckel and Walker (1986). Zapecza (1989) used geophysical logs to define the hydrogeologic framework of aquifers and confining units in the New Jersey Coastal Plain.

Acknowledgments

The authors acknowledge the New Jersey Water Supply Authority (NJWSA) for granting permission to install the wells on NJWSA property. Special appreciation is given Ibrahim M. Shaikh of the NJWSA for his help in selecting a suitable site. Roxanne Hawkins, Geologic Division of the U.S. Geological Survey, did X-ray-diffraction analyses of parts of cores collected from confining units to determine clay mineralogy.

The New Jersey Department of Environmental Protection was instrumental in selecting an area in Howell Township for the drilling site. Special thanks are extended to Richard Dalton of the New Jersey Geological Survey for his helpful suggestions throughout the drilling project.

WELL CONSTRUCTION

A test hole was drilled 1,670 ft to basement rock. An observation well was constructed in the test hole. Four additional wells were drilled and were finished as observation wells. During drilling, bottom-hole core samples were collected from confining units for laboratory analysis.

Drilling and Casing Procedures

A private well driller from Graham, Texas, was contracted to drill the test hole and the observation wells by using the direct mud-rotary method. Land surface was the reference datum used for all information collected from the wells. Soft-formation drill bits, including drag bits and tricone roller bits, were used to drill the boreholes. Commercially prepared

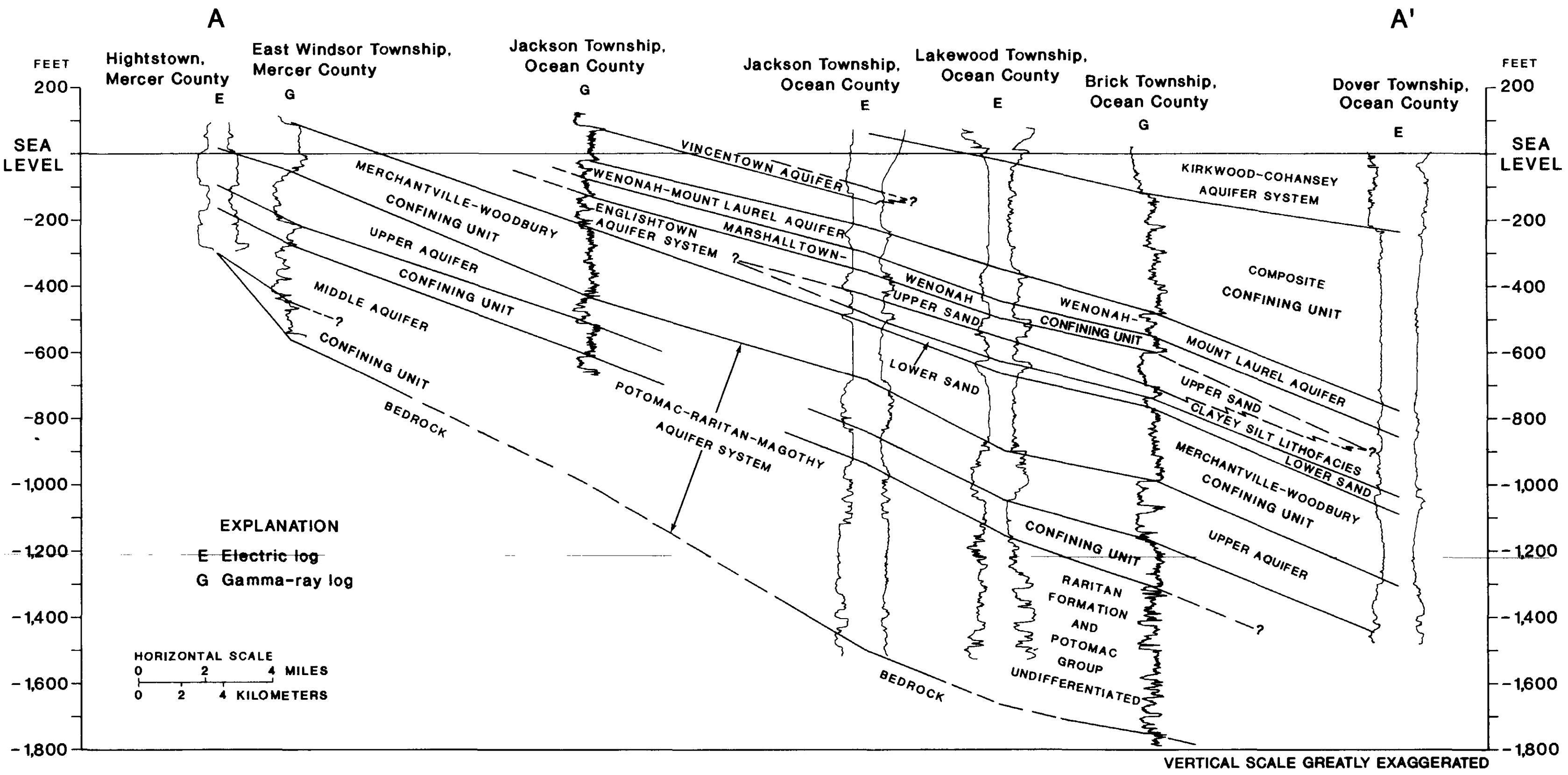


Figure 2.--Hydrogeologic section A-A' from Hightstown, Mercer County, to Dover Township, Ocean County, based on electric and gamma-ray logs. (Modified from Zapecza, 1989, plate 3; line of section shown in figure 1.)

bentonite mud mixed with potable water was used for drilling fluid. Samples of drill cuttings generally were collected at 10-ft intervals and at changes in formation material. A Denison[1] sampler was used to collect undisturbed bottom-hole samples in 2-ft-long by 4-in. (inch) -diameter brass tubes. These cores were taken in confining units in wells 1 and 5 and were saved for later laboratory analysis. Geophysical logs were run in each borehole after completion of drilling and before installation of casing and screen.

Wells 1, 2, 3, 4, and 5 were screened respectively in the undifferentiated part of the Potomac-Raritan-Magothy aquifer system, the Vincentown aquifer, the Wenonah-Mount Laurel aquifer, the Englishtown aquifer system, and the upper aquifer of the Potomac-Raritan-Magothy aquifer system. Well-record information is provided in table 2. Construction details of the wells are shown in figures 3 and 4.

Well 1

A test hole with a diameter of 8-3/4 in. was drilled to a depth of 1,670 ft below land surface. One bottom-hole core was collected with a Denison sampler from the 1,084- to 1,086-ft depth interval in a confining unit. When drilling reached a depth of 1,670 ft, sample cuttings and the slowed drilling rate indicated that hard unweathered crystalline basement rock had been reached. An attempt to collect a core sample of the bedrock with a diamond-bit core barrel failed when the core barrel broke at the bottom of the hole and subsequent attempts to retrieve the core and core barrel were unsuccessful.

A suite of geophysical logs was run in the test hole. The bottom part of the hole was then plugged from the bottom with bentonite grout from 1,670 ft to 1,370 ft. The interval from 1,370 ft to 1,360 ft was plugged with cement grout so that a well could be constructed in the remaining part of the hole above.

A string of 4-in. I.D. (inside diameter) steel casing and screen was then lowered into the hole. However, the casing became stuck at a depth of about 1,200 ft. When attempts to free the casing were unsuccessful, small explosive charges were used to separate the screen from the casing at a 1,200 ft depth and the screen was pushed down to the top of the cement grout at a 1,360 ft depth. The 4-in. I.D. casing was then sealed in place from a depth of 1,200 ft to land surface by using cement, bentonite, and more cement grout as shown in figure 3. A string of 2-in. I.D. steel pipe and stainless-steel wire-wound screen was telescoped below the bottom of the 4-in. I.D. casing and was sealed in place with a K-packer. The well has one 14-ft-long screen and two 10-ft-long screens spaced through the 1,226 ft to 1,330 ft depth interval. The screens have slot openings of 0.010 or 0.012 in. The total depth of the well, including the tailpiece below the lowermost screen, is 1,360 ft. No gravel was added to the well to create a gravel pack. Instead, during subsequent development of the well with

---

[1] The use of brand or firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 2.-- Well-construction information

[LSD, land-surface datum--a datum plane approximately at the land surface at the well. Aquifer codes: 125VNCN, Vincentown aquifer; 211MLRW, Wenonah-Mount Laurel aquifer; 211EGLS, Englishtown aquifer system; 211MRPAU, upper aquifer, Potomac-Raritan-Magothy aquifer system; 211MRPA, Potomac-Raritan-Magothy aquifer system, undifferentiated. USGS NJ-WRD well number, two-digit county code followed by three-digit sequence number.]

Well number	USGS NJ-WRD well number	Date completed	Altitude of land surface (feet above sea level)	Total depth drilled (feet)	Total well depth (feet)	Screened interval (feet below LSD)	Screen slot size (inches)	Aquifer unit	Static water level 03-08-88 (feet below LSD)	Yield during devel-opment (gallons per minute)
1	25-635	12-04-1987	111.3	1,670	1,360	1,226-1,240 1,280-1,290 1,320-1,330	0.012 .010 .010	211MRPA	142.07	45
2	25-636	09-14-1987	111.9	102	100	85-95	.020	125VNCN	54.79	15
3	25-637	09-14-1987	111.9	332	324	307-317	.020	211MLRW	135.42	12
4	25-638	09-25-1987	112.1	512	499	483-493	.020	211EGLS	159.64	23
5	25-639	02-10-1988	111.8	913	907	891-901	.020	211MRPAU	136.67	60

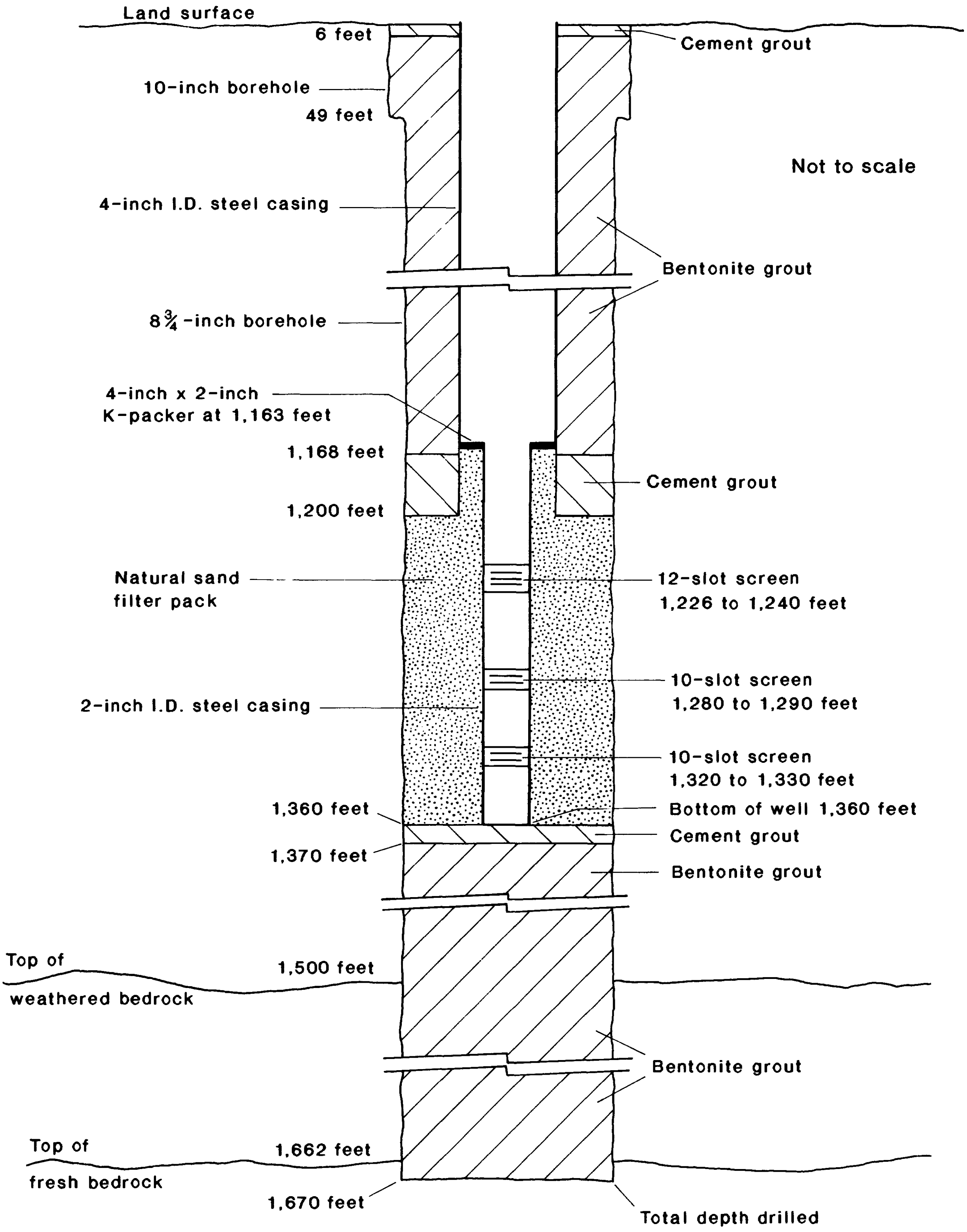


Figure 3.--Construction details of well 1.

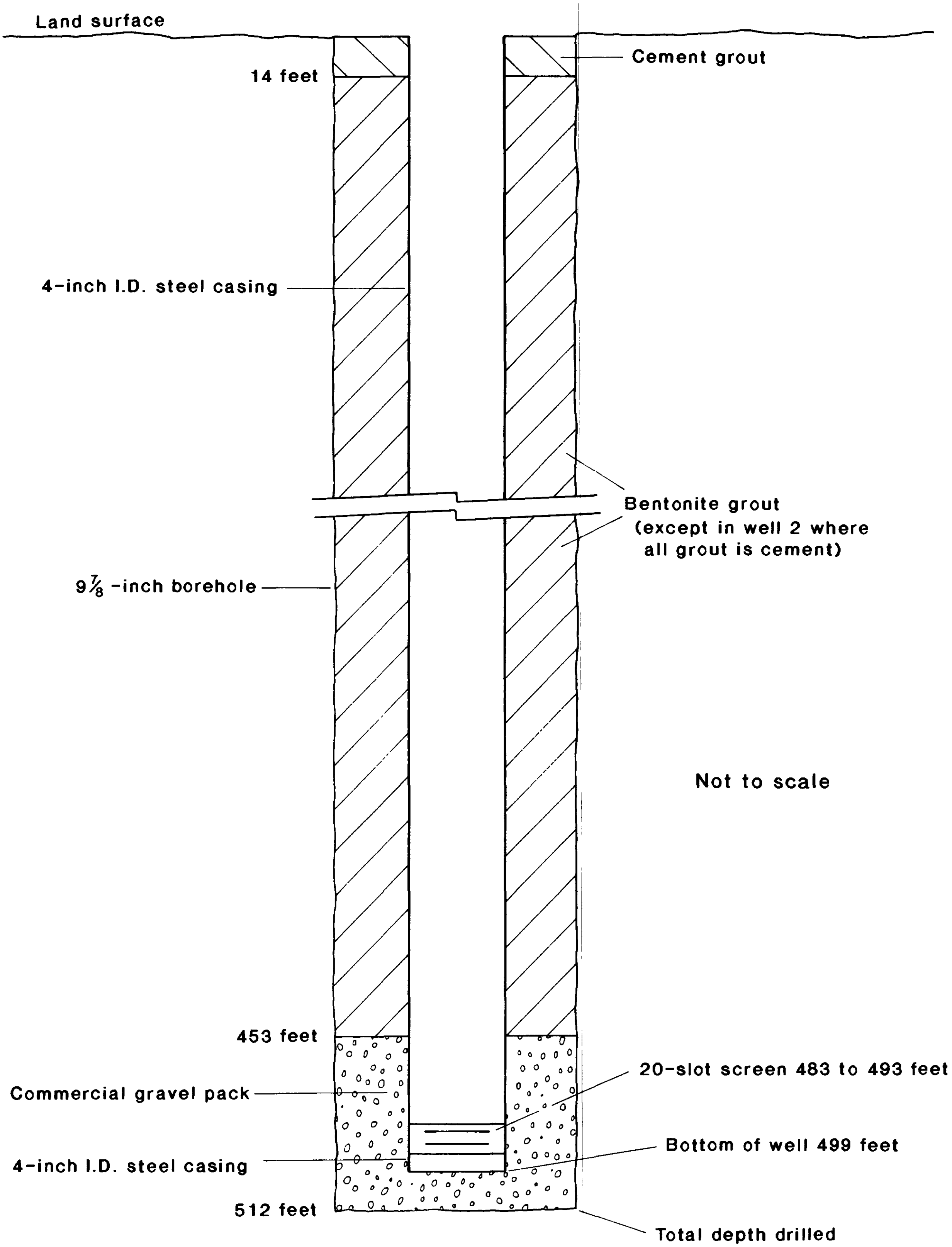


Figure 4.--Construction details of well 4, showing method of installation of wells 2, 3, 4, and 5.

compressed air, the resultant surging action caused formation sand and gravel to cave in around the well to form a natural filter pack around the screens.

Wells 2, 3, 4, and 5

The geophysical logs run in the test hole for well 1 were used to determine the depths to which wells 2, 3, 4, and 5 were drilled. The boreholes for these four wells were drilled to a few feet below the desired depths to allow for cave-in. The boreholes for wells 2 and 5 were drilled to a diameter of 8-3/4 in., and those for wells 3 and 4 were drilled to a diameter of 9-7/8 in. During the drilling for well 5, 12 cores were collected in various confining units. Following drilling, geophysical logs were run in each hole to determine the exact depth at which to set the screen. Four-in. I.D. steel casing and a 10-ft length of 4-in. I.D. stainless steel wire-wound screen with 0.020-in. slot openings were installed in each well. An artificial filter pack was created around each screen by placing commercial size-graded gravel in the annular space between the screen and the borehole, extending up the borehole to a point 20 to 30 ft above the top of the screen. To seal the casing in place in well 2, the remainder of the annular space outside the casing was filled with cement to land surface. In wells 3, 4, and 5, the space was filled with bentonite grout almost to land surface; then the uppermost 6 to 18 ft was filled with cement. Figure 4 is a diagram showing construction details for well 4. This figure also represents the construction of wells 2, 3, and 5, except for the depths shown and the exclusive use of cement grout in well 2.

Development

All wells were developed by using the air-lift method. Compressed air was pumped into the well below the water level, and the water was blown out of the well in a manner that caused water to surge back and forth through the screen, gravel pack, and formation. The surging had the net effect of pulling water and silt and clay particles out of the formation and discharging them from the well. This process created an envelope of coarse-grained, permeable material around the well screen. Wells 2, 3, 4, and 5, with 4-in. I.D. screens, also were developed by washing the insides of the screens with water from a high-pressure side-jetting tool before the air-lift method was used. The side-jetting method could not be used in well 1 because of the small (2-in.) inside diameter of the screen. The wells were developed until the discharge water was clear and sand-free, and the discharge rate was at least 10 gal/min (gallons per minute). Final yields of the wells at the end of development ranged from 12 gal/min in well 3 to 60 gal/min in well 5. These yields are the rates at which water was blown from the wells by the compressed air. Well yields probably would have been larger if a conventional pump were used in these wells.

SUBSURFACE ANALYTICAL METHODS

Drill Cuttings and Lithologic Log

Samples of drill cuttings generally were collected at 10-ft intervals and at depths where the formation material was seen to change. The samples were collected with sieves at the point where the return-drilling fluid flowed from the borehole into the ditch that channeled the fluid back to the mud pit. Drilling fluid was circulated through the borehole after drilling down each length of drill pipe to allow time for all cuttings to reach the land surface. Depth corrections were made to account for the time required for the drill cuttings to travel uphole to the surface.

Drill cuttings were examined with a hand lens and were described by a geologist at the drilling site. Color designations were made by comparing the wet samples with a rock-color chart (Geological Society of America, 1948). Grain sizes were determined by comparing the samples with sand-grain charts size-graded according to the Udden-Wentworth classification (U.S. Geological Survey, 1977, p. 2-85; and Blatt and others, 1980, p. 57).

The lithologic log of well 1 in table 3 (at end of report) was prepared by using the field geologist's sample descriptions as the primary source, aided by laboratory grain-size analysis and hand-lens examination of samples of drill cuttings and Denison cores. Descriptions of samples from wells 2, 3, 4, and 5 were used to supplement this lithologic log in depth intervals where poor drilling samples were retrieved from well 1.

Because a core of the basement rock was not retrieved, interpretation of the rock type was based on drill cuttings. When hard rock was encountered, the rock fragments in the drill cuttings were finely ground and were not retrieved easily. The minerals found in the bottommost cuttings were predominantly biotite and quartz with some feldspar. Cuttings of the weathered rock above contained many pieces of soft quartz-biotite-feldspar gneiss or schist. On the basis of these observations, the basement rock beneath the site is probably a quartz-biotite-feldspar gneiss or schist.

To summarize table 3, well 1 penetrated 1,500 ft of Quaternary, Tertiary, and Cretaceous Coastal Plain sediments. The sediments were unconsolidated to semiconsolidated clay, silt, sand, and gravel. Several thin beds of hard sandstone also were encountered during drilling. Weathered basement rock, or saprolite, was found at a depth of 1,500 ft. After drilling 162 ft through the saprolite, solid unweathered quartz-biotite-feldspar schist or gneiss was encountered at a depth of 1,662 ft. Drilling was stopped at a depth of 1,670 ft.

The basement rock at this site may be similar to that found in a deep corehole near Freehold, N.J., about 5 mi northwest of this site (fig. 1). The basement rock there is a highly weathered, fine-grained, moderately well-foliated, garnet-biotite-quartz-feldspar gneiss (R. Volkert, New Jersey Geological Survey, oral commun., 1989).

About 27 mi south-southeast of the Howell Township site, Southwick (1964) made a detailed study of cores collected during the drilling of a deep test hole at Island Beach State Park (fig. 1). Basement rock at the Island Beach site was described as a strongly foliated garnet-microcline-biotite-quartz-plagioclase veined gneiss. According to Southwick (1964), a potassium-argon radiometric age of 235 million years before present for the biotite in the rock at Island Beach suggests recrystallization during the same late Paleozoic metamorphic event that affected part of southeastern New England.

Southwick (1964) also found in his study of the Island Beach cores that part of the interval above hard basement rock that previously had been called saprolite was, in fact, not saprolite. Saprolite is untransported rock that has been weathered and altered in place. At least the upper 18 ft of the "saprolite" was an epiclastic sand--a mechanically deposited sediment consisting primarily of weathered products of older rocks. Southwick suggested that this type of material found at Island Beach and at other sites may be reworked saprolite rather than original saprolite. At the Howell Township site, a few fragments of siltstone and green rock were found along with decomposed rock in the drill cuttings retrieved from the 1,500- to 1,529-ft depth interval. This fact suggests that the material shown in this interval as "saprolite(?)" in table 3 of this report may actually be reworked saprolite rather than bedrock weathered in place.

Geophysical Logs

After each test hole was drilled and before casing and screen were installed, a suite of geophysical logs was run in the hole. The most extensive suite of logs was run in the test hole for well 1 (fig. 5). The logs run in this hole included natural-gamma-ray, spontaneous-potential, single-point-resistance, short-normal- and long-normal-resistivity, and caliper logs. The logs were used to define lithologic and hydrogeologic units and to decide where to place screens in this well and in the shallower wells. In the boreholes for wells 2, 3, 4, and 5, natural-gamma-ray, spontaneous-potential, and single-point-resistance logs verified the continuity and depths of the hydrogeologic units from well to well.

Borehole geophysical logs--primarily natural-gamma-ray and electric logs--were used to determine the depth and thickness of the aquifers and confining units at the drilling site. Distinctive "signatures" and characteristic patterns on these logs generally mark contacts between aquifers and confining units more reliably than do driller's logs or geological descriptions of drill cuttings. Figure 6 shows the hydrostratigraphic section encountered at the drilling site that was determined primarily by interpretation of natural-gamma-ray and electric logs. The top of saprolite and top of basement rock, however, were determined by inspection of drill cuttings.

Natural-gamma-ray logs are graphical plots of the rate of emission of gamma rays from formations penetrated by the borehole. In general, silt- and clay-bearing sediments (confining units) exhibit much higher natural-gamma activity than do clean quartz sands and carbonates. This activity is partly the result of processes of ion-exchange and adsorption, which concentrate radioactive elements in clays. In addition, feldspars and micas, which decompose readily into clay, contain small amounts of the gamma-emitting radioisotope potassium-40 (Keys and McCary, 1971, p. 65). Gamma radiation increases to the right on the gamma-ray log. Therefore, permeable sediments, such as sand and gravel (aquifers), generally characterized by low radioactivity, cause log deflections toward the left, whereas silt and clay, which generally are slightly more radioactive than sand and gravel, cause log deflections toward the right.

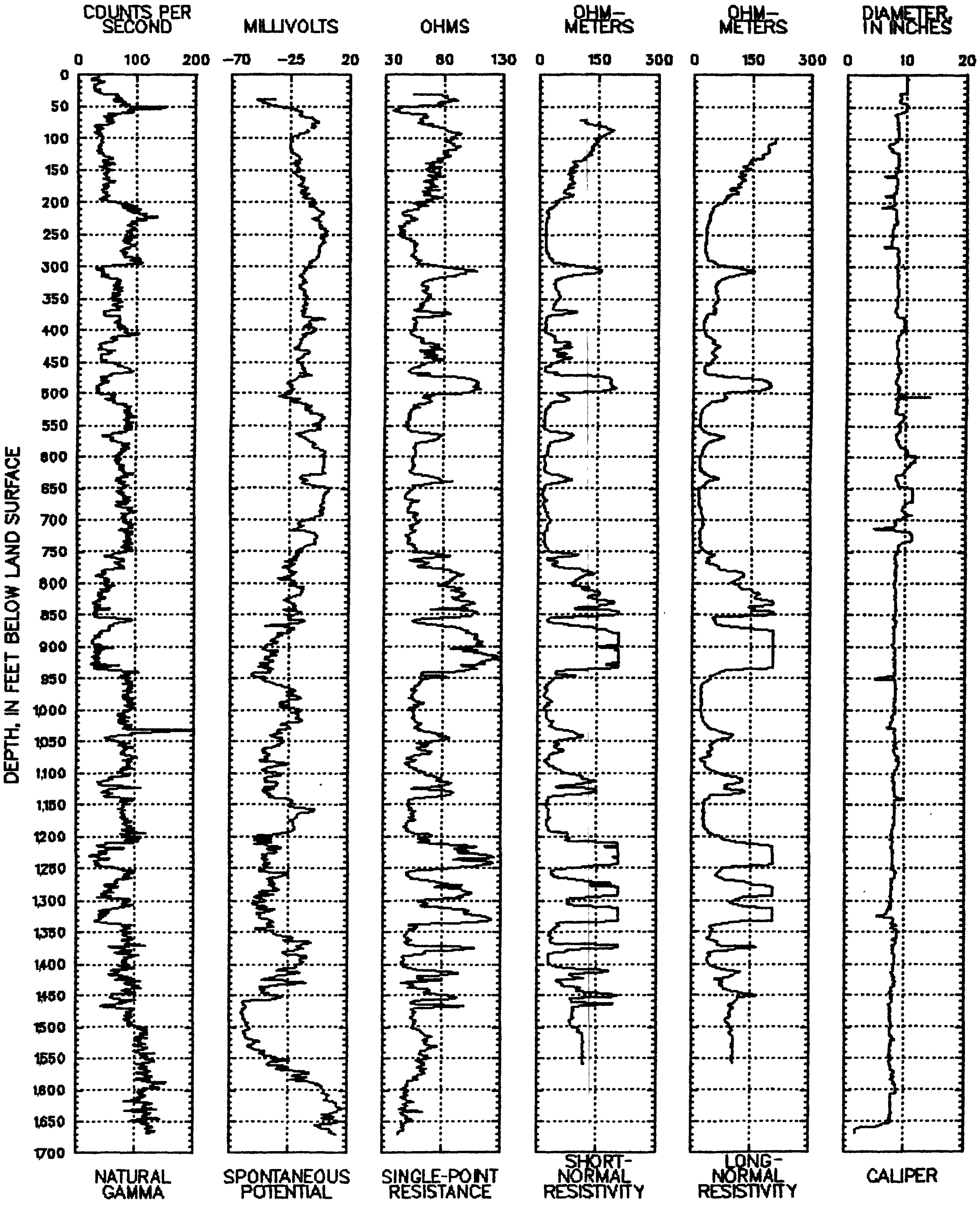


Figure 5.--Borehole geophysical logs run in test hole 1

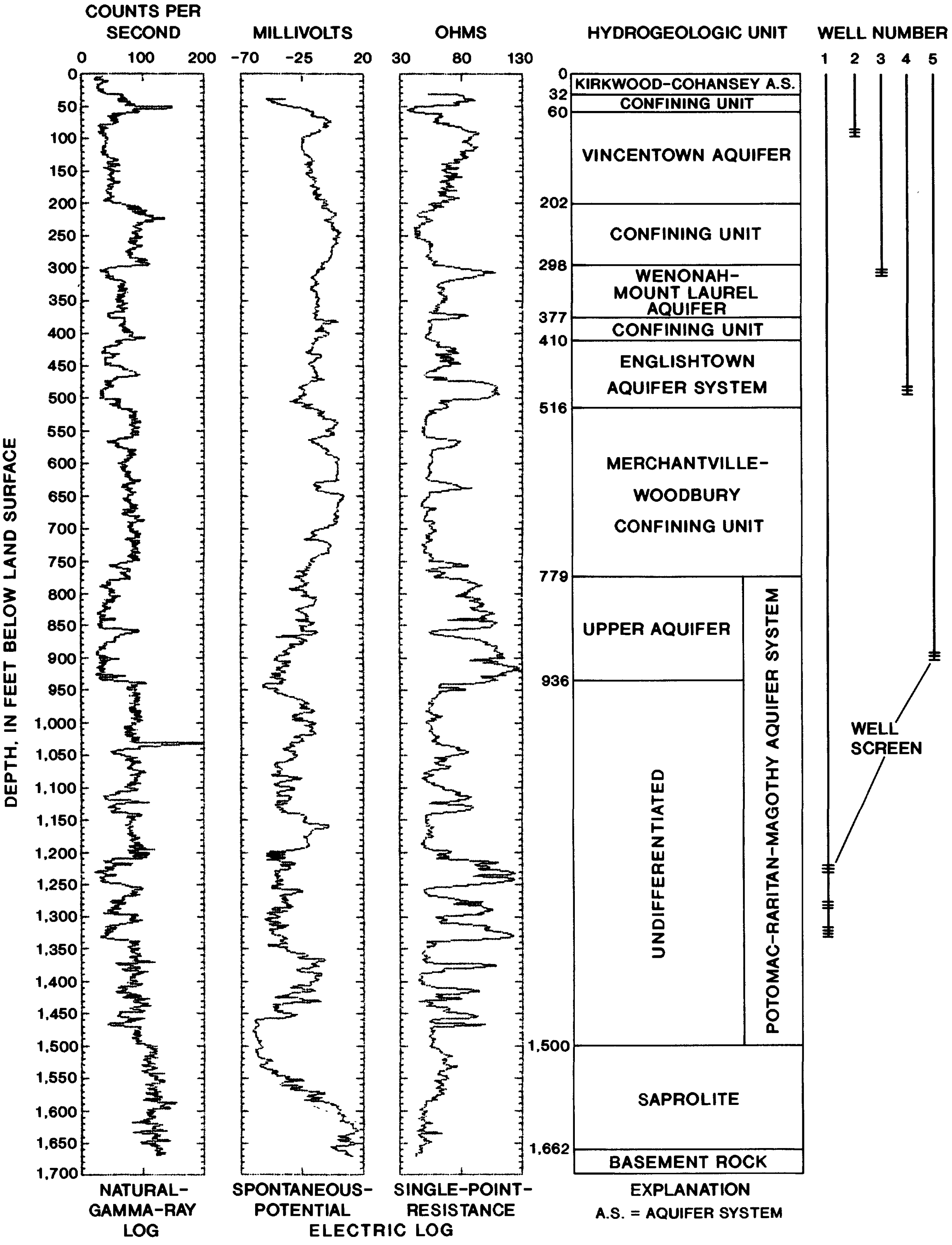


Figure 6.--Hydrostratigraphic section at Howell Township drilling site showing geophysical logs.

The electric log is a dual-track log that includes the spontaneous-potential curve on the left-hand track and a conventional single-point-resistance curve on the right-hand track. The spontaneous-potential curve is a record of small changes in voltage caused by electrochemical reactions between the borehole fluid and the surrounding formation materials. In general, sands saturated with fresh water cause voltage values to deflect to the left, whereas clays cause deflections to the right. The single-point-resistance curve is a record of electrical resistance of formation materials penetrated by the borehole. Sand and gravel generally are more resistant to the flow of electric current than are silt and clay and cause sharp deflections to the right on the resistance log. In contrast, silt and clay are less resistant materials and cause deflections to the left. Simply, the aquifers are identified by the divergence of the two curves from one another, and the confining units are identified by the convergence of the curves.

The short-normal-resistivity and long-normal-resistivity logs (fig. 5), which usually are run simultaneously, are variations of the resistance log described above. They penetrate much further laterally into the formation material and aid in the interpretation of water quality.

The caliper log (fig. 5) is a record of the hole diameter measured by a three-armed tool which expands to fit the borehole size. This information is used to help interpret all the other logs described above because these other measurements are dependent on borehole size.

Core Samples and Analysis

During the drilling for wells 1 and 5, 13 bottom-hole core samples were collected of fine-grained material from the confining units. Only one of these cores was taken in well 1. The depths at which the 12 cores were collected in the hole for well 5 were determined by examining geophysical logs run previously in well 1, which was 27 ft from well 5. The 13 cores were collected for geologic analysis and to determine hydrologic properties of the confining units by laboratory analysis of undisturbed formation material.

When the drilling depth reached 1,670 ft in the test hole for well 1, an attempt was made to cut a bottom-hole core of the basement rock with a diamond-bit rock-coring device. The core barrel broke at the bottom of the hole during the coring procedure. Attempts to retrieve the core and the broken piece of the core barrel were unsuccessful.

Core Recovery

Cores of unconsolidated materials from the confining units were collected with a 2-ft Denison sampler that was attached directly to the bottom of the drill pipe in place of the drill bit. Two trips with the drill rods out and back into the hole were required each time a core was collected. A brass liner was used to enclose the core sample in the core barrel. The brass liners were 4 in. I.D. and 2 ft long. All cores were of silt and clay. Immediately after each core was retrieved and removed from the core barrel, the ends of the brass liner were sealed with tight-fitting metal caps, tape, and melted wax to avoid contamination and drying of the core.

Hydraulic Analysis

The 13 core samples of material from the confining units were analyzed for determination of hydraulic properties at a commercial laboratory. A 4-in.-long section was selected for analysis from the finest grained part of each core. Table 4 shows porosities and vertical hydraulic conductivities of the samples. Porosities ranged from 37.9 percent at a depth of 291.9 ft to 50.4 percent at 51.8 ft. With the exception of these two samples, however, porosities ranged from 40.0 to 46.3 percent. Vertical hydraulic conductivities ranged from 5.1 x 10^{-6} ft/d (feet per day) at 463.1 ft to 1.9 x 10^{-2} ft/d at 213.8 ft, and generally decreased with depth (table 4).

Sieve and Hydrometer Analysis

The commercial laboratory that performed tests of hydraulic properties also made grain-size analyses of the 13 core samples. The analysis was performed on a representative part of the same section of each core that was used for determination of hydraulic properties. The method of analysis used was the sieve-and-hydrometer method described by Lambe (1951). The curves shown in figure 7 show the distribution of grain sizes in the samples.

The grain-size classification shown in these plots is the Unified Soil classification of the U.S. Bureau of Reclamation, and is slightly different from the Udden-Wentworth classification used for the description of the drill cuttings in table 3 of this report. These two classifications are described in a report by the U.S. Geological Survey (1977, p. 2-85). The Unified Soil classification makes no distinction between silt and clay. In this report, clay is sediment having a grain size less than 0.0039 millimeters, according to the Udden-Wentworth classification.

The two deepest samples, both from the Potomac-Raritan-Magothy aquifer system, were silty clays that contained 75 percent or more clay. All other core samples analyzed contained much less clay and were classified as clayey silt, sandy silt, clayey sand, or silty sand.

X-Ray-Diffraction Analysis of Clays

Of the 13 core samples collected during drilling, 12 were selected for analysis for clay content. The part of each core used for clay analysis was from the most clayey part of the core. This was a different piece, however, than that used for laboratory determination of hydraulic properties. The clay fraction from each sample was analyzed by X-ray diffraction. The relative abundance of the clay minerals kaolinite, illite, and mixed-layer illite/smectite was calculated for each sample by measuring the area under the peaks on the X-ray diffractograms. For each sample, the percentage of each clay mineral relative to the combined total of the three minerals is shown in table 5.

In the two deepest samples--those from confining units within the Potomac-Raritan-Magothy aquifer system--kaolinite was the predominant clay type. In all other core samples analyzed--those from the Merchantville Formation up through the Kirkwood Formation--the combination of illite and the mixed-layer illite/smectite predominated over kaolinite. The same composition was noted in the Coastal Plain of Maryland by Trapp and others

Table 4.--Hydraulic analyses of cores from wells 1 and 5

Depth[1] (feet below land surface)	Porosity[2] (percent)	Vertical hydraulic conductivity[3] (feet per day)
51.8	50.4	5.7x10^{-3}
213.8	41.6	1.9x10^{-2}
221.8	46.3	4.0x10^{-3}
253.8	43.5	5.7x10^{-4}
291.9	37.9	9.1x10^{-4}
381.9	45.2	3.7x10^{-4}
407.8	40.0	1.7x10^{-3}
463.1	44.5	5.1x10^{-6}
521.3	45.4	7.4x10^{-5}
620.4	41.3	8.8x10^{-6}
736.8	40.5	8.8x10^{-5}
861.9	42.7	7.9x10^{-6}
[4]1,085.3	43.1	7.4x10^{-6}

[1] Depth represents middle of 4-inch-long sample.

[2] Initial porosity before permeation, calculated by using results of water-content, unit-weight, and specific-gravity determinations.

[3] Hydraulic-conductivity tests performed by using deaired, demineralized water in a constant-volume, falling-head, flexible-walled permeameter (triaxial cell). Results normalized to 20 degrees Celsius.

[4] This core was collected from the test hole for well 1. All other cores were collected from the test hole for well 5.

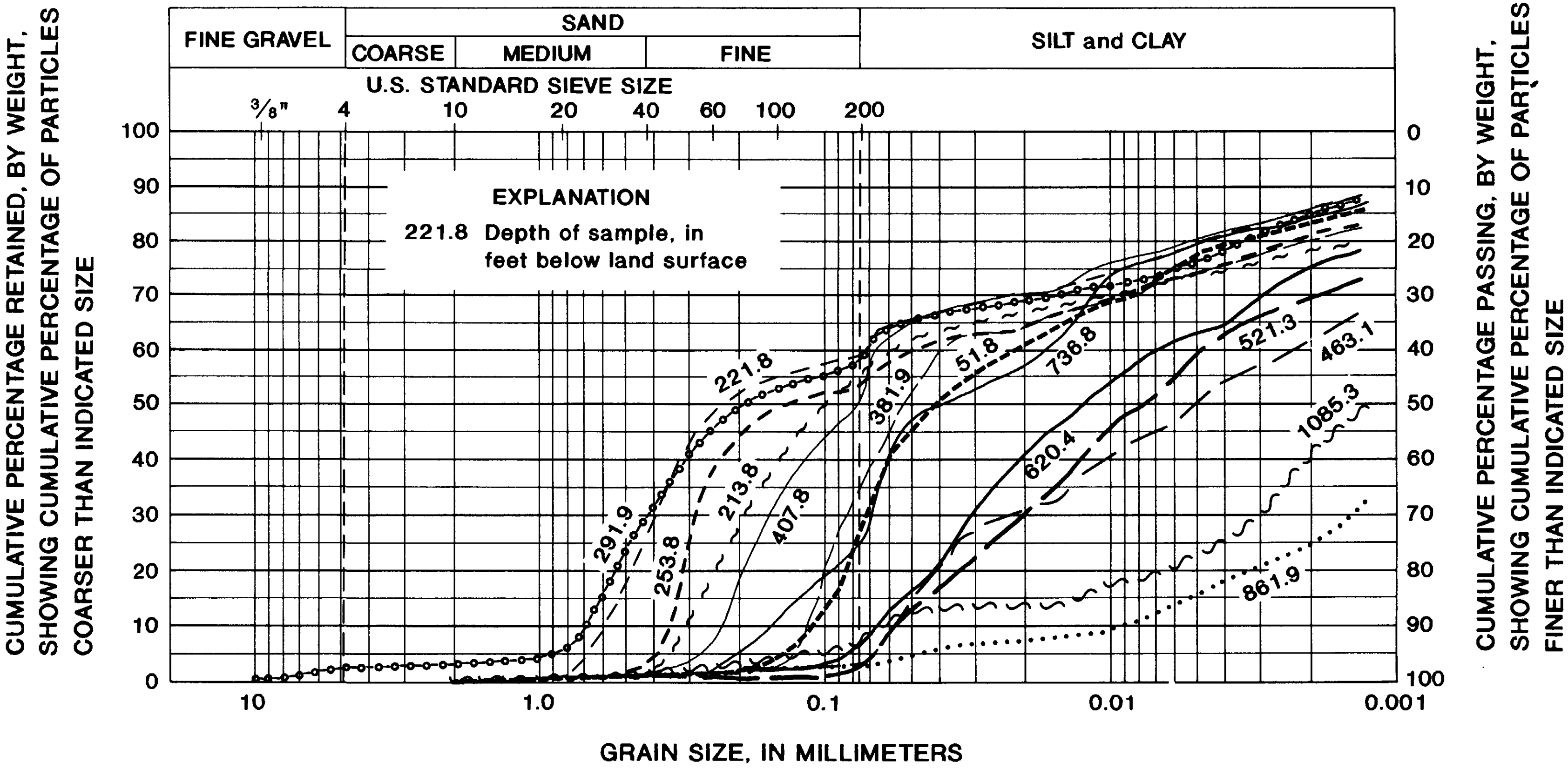


Figure 7.--Grain-size distribution of core samples from confining units.

Table 5.--X-ray analyses of clay fractions of core samples from confining units

[For geologic units, see hydrogeologic section (fig. 2) and table of geologic and hydrogeologic units (table 1)]

Depth interval (feet below land surface)	Geologic unit	Clay, in percent		
		Illite/ Smectite	Illite	Kaolinite
51.3 - 51.5	Kirkwood Formation	31.6	36.3	32.1
214.2 - 214.5	Hornerstown Sand	46.6	[1]44.8	8.6
254.2 - 254.5	Redbank Sand/Tinton Sand	53.8	17.9	28.3
292.2 - 292.6	Navesink Formation	58.8	36.4	4.8
382.2 - 382.5	Marshalltown Formation	72.1	16.8	11.1
408.5 - 408.8	Marshalltown Formation	65.0	14.7	20.3
462.0 - 462.3	Englishtown Formation	52.3	20.9	26.8
520.5 - 520.7	Woodbury Clay	37.9	31.0	31.1
620.6 - 620.7	Woodbury Clay	32.3	23.0	44.7
736.1 - 736.3	Merchantville Formation	5.5	72.1	22.4
862.3 - 862.5	Magothy Formation	36.8	0.0	63.2
[2]1,084.7 - 1,084.9	Potomac Group and Raritan Formation, undifferentiated	30.3	5.2	64.5

---

[1] Some glauconite, which has same diffractogram peak as illite, may be included in this percentage.

[2] This core was collected from the test hole for well 1. All other cores were collected from the test hole for well 5.

(1984, p. 22-23). Pucci and Owens (1989, p. 804) also found similar mineralogy in cores from a continuous corehole near Freehold, N.J., about 5 mi northwest of the present site (fig. 1). Pucci and Owens found that kaolinite was the predominant clay mineral in the Potomac-Raritan-Magothy aquifer system which is composed of fluvial-continental, coastal, and nearshore marine sediments. Pucci and Owens also found that the combination of illite and illite/smectite predominated in the overlying marine sediments, with the exceptions of the Merchantville Formation and Red Bank Sand, in which kaolinite predominated at some depths.

The mineral glauconite has approximately the same peak on the diffractograms as illite and would thus be a component of the illite percentages as shown in table 5. According to J.P. Owens (U.S. Geological Survey, oral commun., 1988), however, glauconite is rare in the clay fraction of sediments in the New Jersey Coastal Plain except in the Hornerstown Sand. Thus, with the possible exception of the core from the Hornerstown Sand (depth of 214.2 to 214.5 ft), the illite percentages shown do not include glauconite.

WATER LEVELS

Continuous water-level recorders were installed on the five completed wells to monitor long-term changes in water levels. The hydrographs in figure 8 show water levels recorded in wells 1 through 5, respectively. The fact that the water levels in the five wells were different confirms that the wells are in different aquifers and that they were constructed properly. All water levels were below sea level except those in the Vincentown aquifer (well 2), which were about 56 to 72 ft above sea level. The lowest water levels were in the Englishtown aquifer system (well 4) and were about 44 to 53 ft below sea level. Gaps in the hydrographs indicate periods when the water-level recorders were not working properly.

The water levels in the shallowest well--in the Vincentown aquifer--showed a strong response to local dewatering operations that began at the end of January 1988 at the nearby Manasquan Reservoir which was under construction at that time. The water levels in all four deeper wells showed seasonal fluctuations caused by regional pumping. All four deeper aquifers are used for ground-water supplies by communities in the area. The minor irregularities in the hydrographs for the four deeper wells are mainly the result of short-term variations in pumpage in the area.

GROUND-WATER QUALITY

After the five wells were developed sufficiently to produce clear, sediment-free water, the water was sampled with a submersible pump. Each well was pumped until a volume of water had been withdrawn equal to three times the casing volume between static water level and the bottom of the well. When water temperature, pH, specific conductance, and the concentration of dissolved oxygen had stabilized, samples were collected for analysis. The sampling procedures used are those described by Wood (1976), Fusillo and Voronin (1981), and Claassen (1982).

The samples were analyzed at the U.S. Geological Survey National Water Quality Laboratory in Arvada, Colorado. Results of the chemical analyses

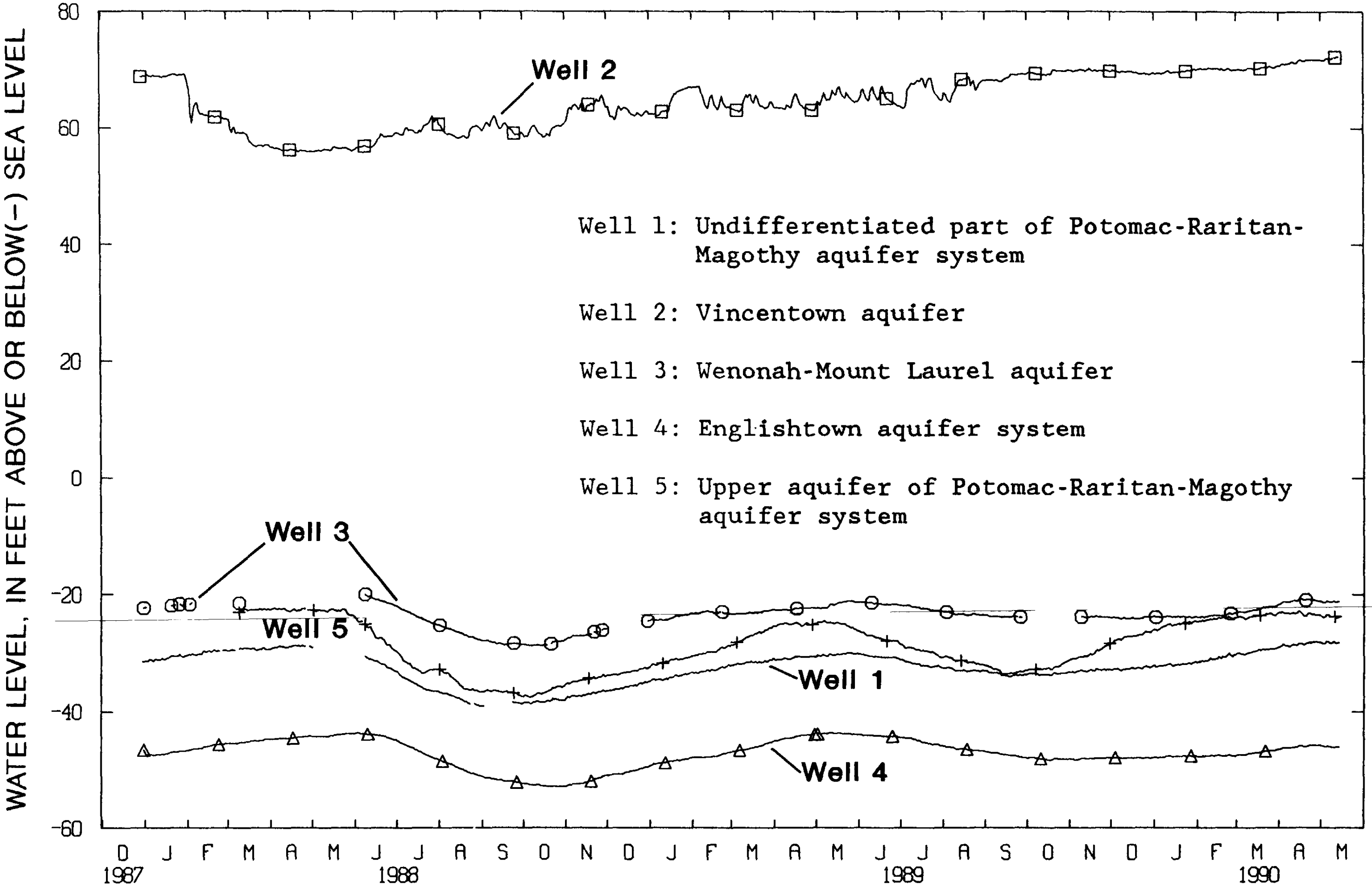


Figure 8.--Hydrographs showing mean daily water levels in wells 1 through 5, December 1987 to May 1990.

are shown in table 6. The graphs in figures 9 and 10 show variations in the major cations and anions among the five wells.

Calcium and bicarbonate were the dominant ions in the water in all five wells. The pH ranged from 6.2 to 8.5, and dissolved oxygen ranged from 0.0 to 3.4 mg/L (milligrams per liter). Specific conductance ranged from 106 μS/cm in the deepest well (well 1) to 241 μS/cm in the shallowest well (well 2). No constituents analyzed for exceeded either New Jersey drinking-water standards or U.S. Environmental Protection Agency (USEPA) primary drinking-water regulations.

SUMMARY

A test-well drilling program in Howell Township, Monmouth County, New Jersey, was conducted during 1987-88 to determine the physical, hydrologic, and hydraulic properties of the underlying Coastal Plain aquifers. Well 1 penetrated 1,500 ft of Quaternary, Tertiary, and Cretaceous Coastal Plain sediments composed of unconsolidated clay, silt, sand and gravel. In addition, 162 ft of weathered basement rock, or saprolite, was penetrated before unweathered quartz-biotite-feldspar schist or gneiss was reached at a depth of 1,662 ft.

Thirteen core samples collected from confining units were analyzed to determine hydraulic properties and clay mineralogy. Porosities of the cores ranged from 37.9 to 50.4 percent, and vertical hydraulic conductivities ranged from 5.1×10^{-6} to 1.9×10^{-2} ft/d. Kaolinite was the predominant clay mineral in the two deepest samples, which were from the Potomac-Raritan-Magothy aquifer system. In all of the samples from shallower depths, illite and illite/smectite predominated over kaolinite.

Five wells were installed with screens at different depths to collect information on water levels and water quality in each of the major aquifers. Water levels measured in the five wells were all different and, with the exception of the shallowest well, showed seasonal fluctuations caused by regional ground-water withdrawals. All water levels were below sea level except those in the Vincentown aquifer (well 2), which were about 56 to 72 ft above sea level. The lowest water levels were in the Englishtown aquifer system (well 4) and were about 44 to 53 ft below sea level.

Analyses of water samples from the completed wells indicate that the dominant ions in each of the five wells were calcium and bicarbonate. Analyses also show that specific conductance ranged from 106 μS/cm in the deepest well (well 1) to 241 μS/cm in the shallowest well (well 2). The pH ranged from 6.2 to 8.5, and dissolved oxygen ranged from 0.0 to 3.4 mg/L. No constituents measured exceeded either New Jersey drinking-water standards or USEPA primary drinking-water regulations.

Table 6.--Chemical analyses of water from wells in the five aquifers

[Concentrations in milligrams per liter, except as noted; all constituents dissolved, except as noted; <, less than; double dash, data not available; USGS NJ-WRD well number, two-digit county code followed by three-digit sequence number; mm of Hg, millimeters of mercury; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter. Well 1 is in Potomac-Raritan-Magothy aquifer system, undifferentiated; well 2, Vincentown aquifer; well 3, Wenonah-Mount Laurel aquifer; well 4, Englishtown aquifer system; well 5, upper aquifer, Potomac-Raritan-Magothy aquifer system]

Well number	USGS NJ-WRD well number	Date of sample	Water temperature (degrees Celsius)	Barometric pressure (mm of Hg)	Specific conductance, field (µS/cm)	Oxygen	pH, field (standard units)	Total bicarbonate, field (as carbonate)	Ammonia nitrogen (as N)	Nitrite nitrogen (as N)	Nitrate nitrogen (as N)
1	25-635	02-25-88	17.0	759	106	0.0	6.6	57	0.04	<0.01	<0.01
2	25-636	10-15-87	12.0	764	241	3.0	7.8	111	.05	< .01	--
3	25-637	10-15-87	13.0	764	172	3.4	8.5	116	.09	< .01	--
4	25-638	10-06-87	--	--	191	--	7.7	113	.06	< .01	--
5	25-639	02-25-88	16.5	759	116	.2	6.2	67	.02	< .01	< .01

Well number	Ammonia + organic nitrogen (as N)	Nitrite + nitrate nitrogen (as N)	Phosphorus (as P)	Orthophosphate (as P)	Organic carbon (as C)	Total sulfide (as S)	Calcium (as Ca)	Magnesium (as Mg)	Sodium (as Na)	Potassium (as K)	Chloride (as Cl)
1	<0.2	<0.1	0.05	<0.01	0.6	<0.5	9.4	1.1	2.6	1.4	1.8
2	< .2	< .1	.30	.24	.6	< .5	43	1.5	4.2	2.3	9.0
3	< .2	< .1	.07	.07	1.0	< .5	25	2.9	5.9	4.3	2.9
4	< .2	< .1	.08	.07	.6	--	32	3.2	5.3	2.6	2.8
5	< .2	< .1	.06	< .01	.6	< .5	10	1.9	2.4	2.1	2.2

Well number	Sulfate (as SO_4)	Fluoride (as F)	Silica (as SiO_2)	Arsenic (µg/L as As)	Barium (µg/L as Ba)	Beryllium (µg/L as Be)	Cadmium (µg/L as Cd)	Chromium (µg/L as Cr)	Cobalt (µg/L as Co)	Copper (µg/L as Cu)	Iron (µg/L as Fe)	Lead (µg/L as Pb)
1	8.1	0.05	9.4	<1	72	<0.5	<1	<5	<3	<10	9,800	10
2	26	.50	16	<1	43	< .5	1	<5	<3	<10	3,100	<10
3	6.4	.20	12	<1	31	< .5	<1	<5	<3	<10	130	<10
4	7.4	.20	10	<1	100	< .5	3	<5	<3	<10	790	<10
5	11	.06	9.0	<1	92	< .5	<1	<5	<3	<10	10,000	<10

Well number	Manganese (µg/L as Mn)	Molybdenum (µg/L as Mo)	Nickel (µg/L as Ni)	Silver (µg/L as Ag)	Strontium (µg/L as Sr)	Vanadium (µg/L as V)	Zinc (µg/L as Zn)	Aluminum (µg/L as Al)	Lithium (µg/L as Li)	Total phenols (µg/L)	Bromide (as Br)	Mercury (µg/L as Hg)
1	160	<10	<10	1	140	<6	11	10	<4	4	<0.010	<0.1
2	230	<10	<10	<1	75	<6	<3	<10	10	3	.035	< .1
3	17	<10	<10	<1	220	<6	<3	<10	5	--	.014	< .1
4	35	<10	<10	<1	260	<6	7	<10	9	<1	< .010	< .1
5	150	<10	<10	2	110	<6	45	20	9	4	< .010	< .1

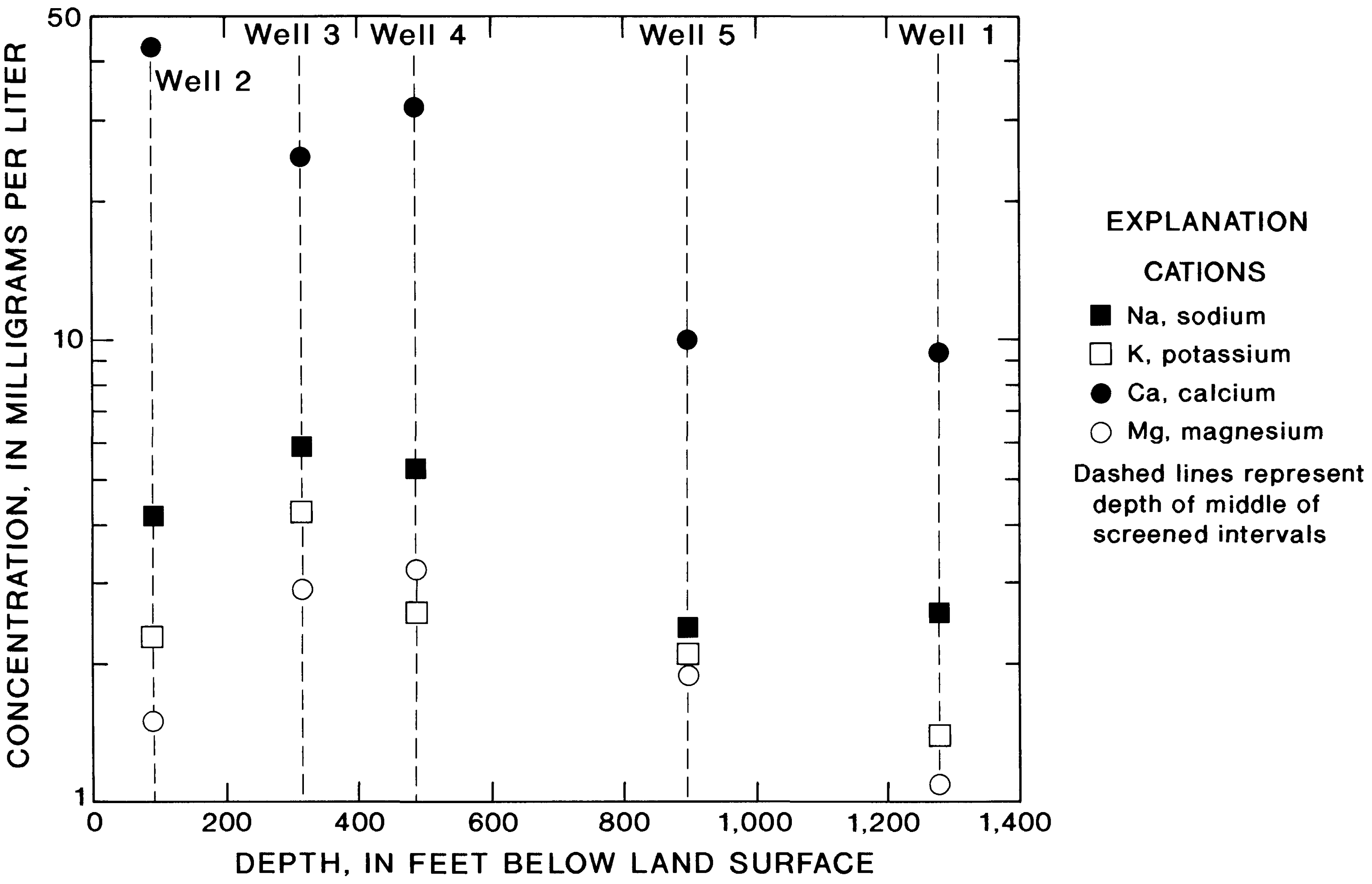


Figure 9.--Variation in concentrations of major cations with depth.

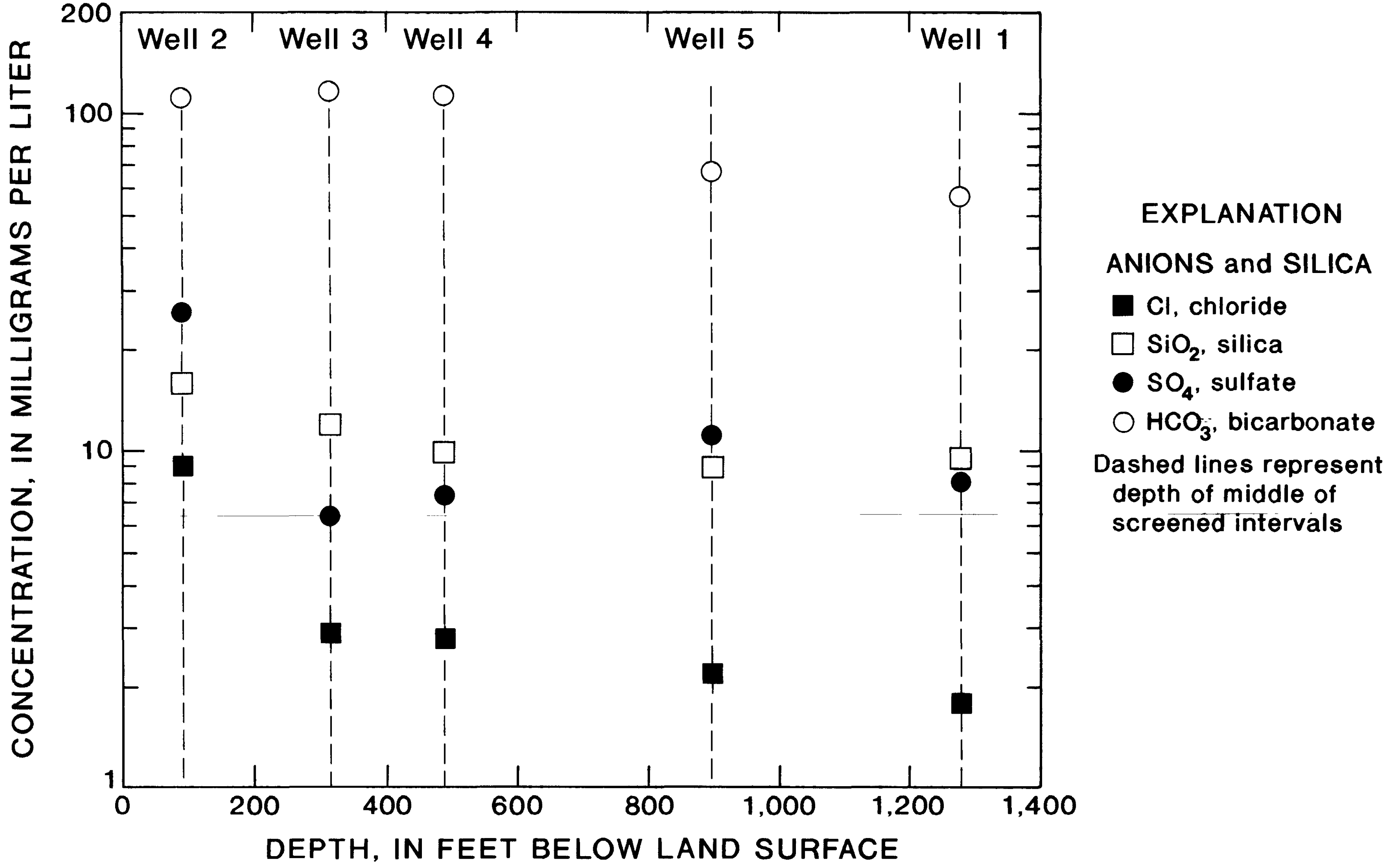


Figure 10.--Variation in concentrations of major anions and silica with depth.

REFERENCES CITED

Blatt, Harvey, Middleton, Gerard, and Murray, Raymond, 1980, Origin of sedimentary rocks (2d ed.): Englewood Cliffs, New Jersey, Prentice-Hall, 782 p.

Brown, P.M., Miller, J.A., and Swain, F.M., 1972, Structural and stratigraphic framework and spatial distribution of permeability of the Atlantic Coastal Plain, North Carolina to New York: U.S. Geological Survey Professional Paper 796, 79 p.

Claassen, H.C., 1982, Guidelines and techniques for obtaining water samples that accurately represent the water chemistry of an aquifer: U.S. Geological Survey Open-File Report 82-1024, 49 p.

Eckel, J.A., and Walker, R.L., 1986, Water levels in major artesian aquifers of the New Jersey Coastal Plain, 1983: U.S. Geological Survey Water-Resources Investigations Report 86-4028, 62 p., 7 pl.

Fusillo, T.V., and Voronin, L.M., 1981, Water-quality data for the Potomac-Raritan-Magothy aquifer system, Trenton to Pennsville, New Jersey, 1980: U.S. Geological Survey Open-File Report 81-814, 38 p., 2 pls.

Geological Society of America, 1948, Rock-color chart: Reprinted 1984, The Netherlands, Huyskes-Enschede.

Gill, H.E., and Farlekas, G.M., 1976, Geohydrologic maps of the Potomac-Raritan-Magothy aquifer system in the New Jersey Coastal Plain: U.S. Geological Survey Hydrologic Investigations Atlas HA-557, scale 1:500,000, 2 sheets.

Jablonski, L.A., 1968, Ground-water resources of Monmouth County, New Jersey: New Jersey Department of Conservation and Economic Development, Division of Water Policy and Supply Special Report 23, 117 p.

Keys, W.S., and McCary, L.M., 1971, Application of borehole geophysics to water-resources investigations: U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 2, Chapter E1, 126 p.

Lambe, T.W., 1951, Soil testing for engineers: New York, John Wiley, 165 p.

Lyttle, P.T., and Epstein, J.B., 1987, Geologic map of the Newark 1° x 2° quadrangle, New Jersey, Pennsylvania, and New York: U.S. Geological Survey Miscellaneous Investigations Series I-1715, scale 1:250,000, 2 sheets.

Nemickas, Bronius, 1976, Digital simulation model of the Wenonah-Mount Laurel aquifer in the Coastal Plain of New Jersey: U.S. Geological Survey Open-File Report 75-672, 42 p.

Nichols, W.D., 1977, Geohydrology of the Englishtown Formation in the northern Coastal Plain of New Jersey: U.S. Geological Survey Water-Resources Investigations 76-123, 62 p.

Olsson, R.K., Miller, K.G., and Ungrady, T.E., 1980, Late Oligocene transgression of the middle Atlantic Coastal Plain: Geology, v. 8, no. 11, p. 548-554.

Pucci, A.A., Jr., and Owens, J.P., 1989, Geochemical variations in a core of hydrogeoloic units near Freehold, New Jersey: Ground Water, v. 27, no. 6, p. 802-812.

Southwick, D.L., 1964, Petrography of the basement gneiss beneath the Coastal Plain sequence, Island Beach State Park, New Jersey, <u>in</u> Geological Survey Research 1964: U.S. Geological Survey Professional Paper 501-C, p. C55-C60.

Trapp, Henry, Jr., and others, 1984, Test well DO-CE 88 at Cambridge, Dorchester County, Maryland: U.S. Geological Survey Water-Supply Paper 2229, 48 p.

U.S. Geological Survey, 1977, National handbook of recommended methods for water-data acquisition, p. 2-85.

Walker, R.L., 1983, Evaluation of water levels in major aquifers of the New Jersey Coastal Plain, 1978: U.S. Geological Survey Water-Resources Investigations Report 82-4077, 56 p.

Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey, Techniques of Water-Resources Investigations, book 1, chap. D2, 24 p.

Zapecza, O.S., 1989, Hydrogeologic framework of the New Jersey Coastal Plain: U. S. Geological Survey Professional Paper 1404-B, 49 p, 24 pl.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5

[Prepared by G. Allan Brown from hand-lens examination of drill cuttings and cores. Description from 1,140 to 1,500 feet adjusted to lithologic boundaries indicated by geophysical logs. Samples from wells 2, 3, 4, and 5 were used to augment description where necessary. The core sample from 1,084 to 1,085.5 feet was taken from the test hole for well 1; all other core samples were taken from the test hole for well 5, which was 27 feet from and about 1 foot higher than well 1. Colors described from wet samples; color code from Geological Society of America, 1948. Datum is land surface.]

Depth (ft)	Lithology
0-0.3	Soil, sandy, gravel at top.
0.3-5	Sand, dark yellowish-orange (10YR 5/6), fine to medium, slightly silty, subrounded, 3 percent dark minerals.
5-15	Silt, dark yellowish-orange (10YR 5/6), slightly sandy.
15-17	Gravel
17-24	Sand, dark yellowish-orange (10YR 6/6), very fine, silty; streaks of gray clayey sand with some angular sand up to coarse.
24-30	Sand, dark yellowish-orange (10YR 6/6), medium to coarse.
30-38	Clayey sand, dark yellowish-orange (10YR 6/6), fine, and some coarse sand to fine gravel.
38-40	Clayey silt, olive-gray (5Y 3/2).
40-43	Silty sand, dark olive-gray (5Y 3/1) to olive-gray (5Y 3/2), very fine to fine quartz sand; thin interbeds of laminated silt and silty clay; thin laminae of well-sorted very fine, fine, and medium sand; fine-grained muscovite common to abundant. Samples from this interval were collected with a coring device consisting of 4-inch casing adapted to the drill pipe.
43-49	Clayey silt, olive-gray (5Y 3/2), some fine to coarse sand, fine-grained muscovite abundant.
49-54	Clayey silt to silty clay, olive-gray (5Y 3/2) to dark olive-gray (5Y 3/1), muscovite abundant, sticky.
	Core 51-53. Silty clay at top grading downward to glauconitic clayey silty sand, dark olive-gray (5Y 3/1), muscovite common.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
54-57	Clayey sand, olive-gray (5Y 3/2), very fine to medium, and some fine gravel and pale green (10G 6/2) glauconitic clay.
57-62	Clayey sand, grayish-green (10G 4/2), fine-grained quartz and glauconite.
62-72	Clayey sand, olive-gray (5Y 3/2), very fine to medium with some coarse, very glauconitic; sand fraction is part quartz, part glauconite.
72-84	Clayey sand, dusky yellowish-green (10GY 3/2), very fine to medium, very glauconitic.
84-92	Clayey sand, grayish olive-green (5GY 3/2), very fine to medium, glauconite and white shell fragments abundant.
92-114	Silty sand, grayish olive-green (5GY 3/2), very fine to medium with some coarse sand, glauconite and white shell fragments abundant.
114-122	Clayey sandy silt, olive-gray (5Y 3/2), some gravel with grain size up to 5 mm.
122-132	Silty sand to sandy silt, olive-gray (5Y 3/2), soft, glauconite and white shell fragments abundant.
132-137	Silty clayey sand, grayish-olive-green (5GY 3/2), glauconite and white shell fragments common.
137-142	Silty sand to sandy silt, olive-gray (5Y 3/2), glauconite and white shell fragments abundant, one interval with abundant lignite.
142-152	Sand, olive-gray (5Y 3/2), fine to medium, slightly silty; glauconite abundant, white shell fragments common, lignite absent.
152-162	Clayey sand to silty sand, olive-gray (5Y 3/2), glauconite abundant, white shell fragments absent to common in some beds.
162-174	Silty sand, olive-gray (5Y 3/2), some very fine to fine sand and medium to coarse sand, white shell fragments rare.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
174-182	Silty sand, olive-gray (5Y 3/2), very fine to coarse, glauconite abundant, white shell fragments rare to absent; a few cuttings of light gray (N7) very fine to fine sand; hard cemented black glauconite layer 174 to 174 5 ft.
182-187	Clayey sand, grayish-green (10G 4/2), light greenish-gray (5GY 8/1), and grayish olive-green (5GY 3/2), sand fine to coarse, glauconite abundant, shells absent.
187-192	Silty sand, olive-gray (5Y 3/2), glauconite abundant.
192-197	Clayey sand, as above from 182 to 187 ft.
197-202	Clayey silty sand, light olive-gray (5Y 5/1), fine to medium, glauconite abundant; some cuttings are indurated.
202-212	Silty sand, dark greenish-gray (5GY 4/1), very fine to medium, glauconite abundant.
212-222.5	Clayey silt, olive-gray (5Y 3/2); some light gray (N7) very fine sand, light greenish-gray (5GY 8/1) clayey sand, and dusky green (5G 3/2) very glauconitic fine sand; gray shell fragments from 214 to 219 ft.
	Core 213-215. Top is glauconitic clayey silt with abundant shells; some of shells have cemented glauconite inside. Becomes sandier downward. Bottom is glauconitic muscovitic fine-grained olive-black (5Y 2/1) clayey sand; most of sand fraction is glauconite.
	Core 221-222.5. Silty sand, olive-black (5Y 2/1), sand is all medium-grained glauconite, shell fragments abundant; some hard thick shell fragments at bottom; muscovite abundant.
222.5-232	Clayey silt, olive-gray (5Y 3/2), glauconite abundant; some very fine to fine sand; glauconite is about 60 percent of sand fraction.
232-291	Silty sand, olive-gray (5Y 3/2) to olive-black (5Y 2/1), sand is predominantly medium-grained glauconite with minor very fine to fine quartz and muscovite; some olive-gray (5Y 3/2) very glauconitic clayey silt; shell fragments common.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
	Core 253-255. Silty sand, olive-black (5Y 2/1), predominantly medium-grained glauconite with some very fine quartz and muscovite.
291-302	Silty sand, olive-gray (5Y 3/2) and light olive-gray (5Y 5/1), very fine to medium, sand fraction nearly all glauconite; harder than above, but not indurated; bit chattering from 300 to 302 ft.
	Core 291-293. Silty sand, olive gray (5Y 3/2), slightly clayey, all of sand fraction is medium-grained glauconite, shell fragments common, muscovite rare to common.
302-322	Silty sand, olive-gray (5Y 4/1) and light olive-gray (5Y 6/1), soft; glauconite up to 30 percent of sand fraction; some gravel up to 3 mm and shell fragments.
322-342	Sand, olive-gray (5Y 4/1), very fine, quartz predominant; some soft olive-gray (5Y 4/1) very fine to medium glauconitic clayey sand.
342-374	Silty sand, olive-gray (5Y 3/2), fine to medium, quartz predominant, glauconite abundant, trace of pyrite and muscovite, soft, drills easily.
374-380	Sandstone, light gray (N7), fine to medium, quartz predominant, glauconite common, hard.
380-402	Silt to very fine sand, dark olive-gray (5Y 3/1) to olive-black (5Y 2/1), some sand up to fine and medium, glauconite and fine-grained muscovite abundant in some layers.
	Core 381-383. Silty sand, dark olive-gray (5Y 3/1), very fine to fine with a little medium sand, muscovite abundant, biotite common, glauconite absent to rare; tough, nearly dry with shaly fracture.
402-412	Silt, dark olive-gray (5Y 3/1), muscovite common; and dark olive-gray (5Y 2/2) slightly clayey silty sand, very fine to fine, muscovite abundant, glauconite common, very stiff and nearly dry.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
	Core 407-409. Clayey sand, dark olive-gray (5Y 2/2), sand is medium grained and mostly black glauconite with a little quartz and minor green glauconite; inclusions of light olive-gray (5Y 5/1) clayey sand; nearly dry.
412-427	Sand, dark olive-gray (5Y 3/1), very fine.
427-432	Silt: light brownish-gray (5YR 6/1), dark olive-gray (5Y 3/1) and olive-gray (5Y 4/1).
432-442	Silt as above, with some pale yellowish-brown (10YR 6/2) clay.
442-463.5	Silt, clayey silt, and silty very fine sand; olive-black (5Y 2/1) to dark gray (N3); lignite appears at top of interval and becomes abundant below 452 ft; muscovite common.
	Core 461.5-463.5. Silt and clay laminated, dark gray (N3) to grayish black (N2), silt predominant; occasional thin laminations, streaks and lenses of very fine to fine quartz sand with some muscovite; tough but fissile, and essentially dry; lignite absent.
463.5-468	Clayey sand to sandy clay, olive-black (5Y 2/1); a small amount of light red (5R 6/6) clay; lignite common; some pieces of light olive-gray (5Y 6/1) sandstone; slow drilling.
468-482	Sandy silt to silty sand, olive black (5Y 2/1), sand up to very coarse, lignite abundant; a small amount of stiff olive-black (5Y 2/1) silty clay; drilling faster than above.
482-492	Silt to silty sand, dark olive-gray (5Y 3/1), sand fine to medium, lignite abundant, muscovite common in some beds, very soft.
492-502	Silty sand, olive-gray (5Y 4/1), lignite and muscovite common, trace of pyrite; a few pieces of yellowish-gray (5Y 7/2) siltstone and fine-grained sandstone.
502-512	Sand and silty sand, olive-gray (5Y 3/2), very fine to fine, glauconite abundant.
512-522	Silty clay to clayey silt, dark olive-gray (5Y 3/1), lignite common, soft to very stiff; some dark olive-gray (5Y 3/1) silty very fine sand.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
	Core 520-522. Clayey silty sand, olive-black (5Y 2/1), very fine to fine, occasional pebbles up to 2 cm, rare grains of medium to coarse sand, muscovite abundant, thin lenses of silt common, very stiff.
522-532	Silty sand, dark olive-gray (5Y 3/1), very fine alternating with fine to medium, glauconite common; the very fine-grained material is stiff.
532-542	Silt, dark olive-gray (5Y 3/1); some sandy silt with fine to medium sand; very fine-grained muscovite common to abundant, fine-grained glauconite and lignite common.
542-547	Silty sand, dark olive-gray (5Y 3/1), quartz sand is very fine to fine; medium-grained glauconite abundant, lignite common.
547-562	Silt and very fine sand, dark olive-gray (5Y 3/1), muscovite and glauconite common; a thin bed of stiff dark yellowish-orange (10YR 5/6) glauconitic silty sand.
562-582	Silty sand, olive-gray (5Y 4/1), very fine to fine, glauconite and muscovite common, some white shell fragments, soft to stiff; some pieces of silty clay.
582-596	Sandy silt, dark olive-gray (5Y 3/1), very fine to fine, muscovite abundant, glauconite rare to common, slow drilling.
596-626	Silt, olive-gray (5Y 3/2), slightly sandy with very fine to fine sand; fine-grained muscovite abundant, glauconite common.
	Core 620-621. Sandy silt, dark olive-gray (5Y 3/1), slightly clayey, sand very fine, very fine-grained muscovite abundant, shells common, tough, nearly dry.
626-636	Silt as above; some grayish-olive (10Y 4/2) very fine sand; some fragments of sandstone, shells and coral, probably from hard-drilling interval 632 to 636 ft.
636-646	Sand, grayish-olive (10Y 4/2), very fine to fine, silty; thin interbeds of hard sandstone from 643 to 646 ft.
646-656	Silty sand, dark grayish-olive (10Y 3/2), muscovite common; some olive-gray (5Y 3/2) silt, muscovite and glauconite common.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
656-686	Silt, olive-gray (5Y 3/2), slightly sandy with fine to medium sand, muscovite and glauconite common.
686-696	Silt, dark grayish-olive (10Y 3/2), sandy, glauconite common; some olive-gray (5Y 3/2) glauconitic silt.
696-706	Silty clay, dark olive-gray (5Y 2/2); muscovite, glauconite and shell fragments common.
706-723	Sandy silt, olive-gray (5Y 3/2), sand very fine; muscovite, glauconite and shell fragments common.
723-736	Sandy silt, olive-gray (5Y 3/2), sand very fine; muscovite abundant, glauconite and shell fragments common; soft to moderately stiff.
736-744	Clayey silt, olive-black (5Y 2/1), slightly sandy with very fine to fine sand; soft to stiff, mostly soft and gummy, very slow drilling; glauconite abundant.
	Core 736-737. Clayey glauconite sand, dark olive-gray (5Y 2/2), sand is nearly all fine-grained green and black glauconite with a little very fine quartz sand, muscovite abundant, very tough and dense.
744-753	Clayey silt, olive-black (5Y 2/1), stiff to hard and friable, glauconite common, trace of shell fragments and fine-grained pyrite.
753-758	Silty sand, very fine to fine.
758-776	Clayey silt as in 744-753 foot interval.
776-786	Silty sand, brownish-black (5YR 2/1), very fine to fine, muscovite common; some slightly sandy olive-black (5Y 2/1) silt, muscovite and glauconite common.
786-796	Silt and very fine sand, olive-black (5Y 2/1), silt is slightly sandy, fine-grained muscovite common, glauconite rare to common.
796-816	Silty sand, olive-gray (5Y 3/2), very fine to fine, glauconite and muscovite abundant.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
816-836	Silty sand, olive-gray (5Y 4/1), very fine with a little fine sand, soft; lignite, muscovite and glauconite abundant; pyrite common, up to 8 mm; some interbeds of hard, slow-drilling material.
836-856	Silty sand, olive-gray (5Y 3/2), very fine to fine alternating with fine to medium, a little coarse sand to pea gravel; lignite and muscovite common.
856-866	Sandy silt, dark greenish-gray (5GY 4/1), glauconite abundant, trace of pyrite. Also some: olive-gray (5Y 3/2), gummy, glauconitic, slightly clayey sandy silt, with very fine to fine sand; dusky yellow (5Y 6/4), partially indurated very fine to medium silty sand; light gray (N7), very soft, slightly sandy, slightly glauconitic clay; and olive-gray (5Y 3/2) silty sand, with very fine to medium sand. **Core 861-863**. Clay, light olive-gray (5Y 5/1) mottled locally to yellowish-gray (5Y 7/2), abundant small pieces (up to 1 cm) of black organic material, hard and dense.
866-870	Clay, light gray (N7), slightly sandy, fine-grained glauconite common, very soft and sticky; some olive-gray (5Y 3/2) sandy silt, with sand very fine to fine; very slow drilling.
870-876	Silty sand, olive-gray (5Y 4/2), very fine to fine, soft, drills easily.
876-891	Silty sand, olive-black (5Y 2/1); muscovite, glauconite and lignite common; trace of pyrite; tough and friable to soft; some cuttings of white (N9) silty very fine sand.
891-895	Silt and sandy silt, olive-gray (5Y 3/2), sand very fine to fine, soft.
895-911	Silty sand, olive-gray (5Y 3/2), predominantly very fine to fine with some medium to coarse sand, glauconite abundant; some olive-gray (5Y 3/2) clayey silt; more sandy and faster drilling than above.
911-921	Sandy silt, olive-gray (5Y 3/2), muscovite and glauconite common; small amounts of sand up to very coarse-grained.
921-931	Sand, fine to very coarse with a little very fine gravel, white and gray quartz, slightly silty, lignite common.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
931-952	Silty sand, medium light gray (N6) to light gray (N7), predominantly fine to coarse with some very coarse sand and gravel up to 3 mm, glauconite common, soft; a small amount of grayish-olive-green (5GY 3/2) sandy silt; a little medium gray (N5) silt at bottom of interval.
952-962	Silty sand, olive-gray (5Y 3/2), very stiff; some soft olive-gray (5Y 3/2) sandy silt; slow drilling.
962-971	Sand and gravel, white and gray quartz up to 1 cm; some olive-gray (5Y 4/1) clayey silt.
971-981	Silt, olive-gray (5Y 3/2); some light olive-gray (5Y 6/1) silt and olive-gray (5Y 4/1) silty sand. Drilling very slow 971 to 972.5 ft.
981-986	Silt and sandy silt, olive-gray (5Y 4/2), stiff.
986-991	Sand, olive-gray (5Y 3/2), fine to medium with a little coarse sand, silty, slightly clayey, drills easily.
991-1001	Silt and fine sand; some coarse sand to fine gravel in top part of interval; small amounts of white (N9) and olive-gray (5Y 3/2) clay in bottom part of interval.
1001-1011	Silty clay, medium gray (N5), some fine sand.
1011-1031	Sand, olive-gray (5Y 3/2), fine to medium, fine black heavy minerals abundant.
1031-1032	Clay, hard drilling.
1032-1037	Silty sand, dark greenish-gray (5GY 4/1), medium; some light olive-gray (5Y 5/1) silty sand to very fine sand and olive-gray (5Y 4/2) clayey silt.
1037-1042	Sandy silt, olive-gray (5Y 3/2), sand very fine, stiff; some soft olive-gray (5Y 3/2) clayey silty sand.
1042-1062	Silty sand, light olive-gray (5Y 5/1), very fine, muscovite common, soft; some soft olive-gray (5Y 3/2) very fine to fine silty sand, and stiff olive-gray (5Y 3/2) muscovitic, slightly glauconitic fine silty sand.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
1062-1083	Sandy silt, dark olive-gray (5Y 3/1), sand very fine, stiff; some soft to stiff dark olive-gray (5Y 3/1) silty sand.
1083-1083.5	Sandstone and siltstone, light olive-gray (5Y 5/2), sandstone fine to medium, glauconite common, hard, some fragments iron-stained.
1083.5-1084	Clayey silt, olive-gray (5Y 3/2), muscovite common, stiff to gummy.
	Core 1084-1085.5. Clayey silt to silty clay, dark gray (N3), hard and dense, nearly dry, small pockets of fine-grained pyrite.
1085.5-1100	Clayey silty sand, olive-gray (5Y 3/2); glauconite, pyrite and muscovite common; soft and sticky to stiff.
1100-1107	Sand and gravel, sand medium to very coarse, gravel up to 1 cm, subrounded, white and gray quartz, much iron-staining of grains.
1107-1125	Silty sand, olive-gray (5Y 4/1 to 5Y 4/2), fine to medium. Also some dark olive-gray (5Y 3/1) very fine sand with abundant dark minerals; light gray (N7) very fine to fine sand; and medium to very coarse sand with some fine gravel. Hard layer 1123 to 1123.5 ft.
1125-1140	Silt to very fine sand, light gray (N7), very soft to slightly stiff, a little fine to medium sand; some olive-gray (5Y 4/1) very fine to medium clayey sand, and dark gray (N3) stiff clayey sand.
1140-1150	Silty sand, pale olive-gray (5Y 7/1), fine streaks of fine-grained black minerals; some light brownish-gray (5YR 5/1) clayey silt, stiff olive-gray (5Y 4/1) sandy silt, cemented glauconite grains, and a few pieces of hard but friable sandstone.
1150-1154	Clayey sandy silt, mottled pale red (5R 6/2) and very light gray (N8), glauconite common, very soft. Also some soft, pale red (5R 6/2) silty clay; soft mottled reddish orange (10R 5/6) and light gray (N7) sandy clay; soft light red (5R 5/6) silty clay; soft yellowish-gray (5Y 7/1) clayey silt; light olive-gray (5Y 5/1) muscovitic silt to very fine sand; hard light gray (N7) silt; and hard mottled light dusky red (5R 4/4) and white (N9) silt.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
1154-1156	Clayey silt, very light gray (N8) soft; some stiff light grayish-red (10R 5/2) and light gray (N7) clayey silt and soft moderate olive-brown (5Y 4/4) silty sand.
1156-1159	Clay, light grayish-red (10R 5/2), mottled white (N9) locally. Also some hard black (N1) shale with fine-grained disseminated pyrite; soft grayish-black (N2) sandy silt; soft grayish-red (10R 4/2) sandy clay; and light reddish-orange (10R 7/6) sandy silty clay.
1159-1161	Sandy clay, light olive-gray (5Y 6/1), sand very fine to fine, soft.
1161-1174	Silty sandy clay to clay, moderate reddish-brown (10R 4/6) to light reddish-brown (10R 5/6), mottled locally white (N9). Also lesser amounts of light gray (N7) clayey silt; soft white (N9), light gray (N8), and grayish-pink (5R 8/2) silt; soft pale red (10R 6/2) slightly sandy silty clay; and soft mottled white (N9) and moderate red (5R 4/6) clayey silt.
1174-1183	Clay, brilliant reddish-orange (10R 5/8) and pale yellowish-orange (10YR 8/6), mottled white (N9) to very light gray (N8), soft to stiff. Also some very stiff dusky red (5R 3/4) silt with very light gray (N8) mottling; mottled pale brown (5YR 5/2) and light red (5R 6/6) sandy clay; stiff banded light grayish-red (5R 5/2) and pinkish-gray (5YR 8/1) clayey silt; soft light brown (5YR 6/4) silty clay; soft very light gray (N8) silt to very fine sand; stiff very light gray (N8) slightly sandy clayey silt; soft moderate olive-brown (5Y 4/4) clayey sand; stiff muscovitic very fine to fine olive-black (5Y 2/1) silty sand; and soft pale reddish-orange (10R 6/4) sandy silty clay.
1183-1195	Sandy clay, light reddish-brown (10R 5/6), soft and sticky. Also lesser amounts of soft dark yellowish-orange (10YR 5/6 and 10YR 6/6) clayey sand to sandy clay, and stiff very light gray (N8) clayey silt.
1195-1210	Sandy silt, silt and very fine sand, very light gray (N8) to light gray (N7), slightly clayey to clayey, soft, drills much faster than material above. Small amounts of light reddish-brown (10R 5/6) sandy clay.
1210-1253	Silty sand, medium gray (N5) to very light gray (N7), slightly clayey in some beds, sand up to very coarse.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
1253-1263	Sandy silt, dark yellowish-orange (10YR 5/6), soft. Also lesser amounts of stiff light gray (N7) silty clay, soft moderate reddish-orange (10R 6/6) sandy clayey silt, and soft moderate reddish-brown (10R 4/6) silty clay.
1263-1268	Clayey sandy silt, medium light gray (N6), stiff.
1268-1296	Silty sand, olive-gray (5Y 4/1), very fine to medium with some coarse sand, dark minerals 5 to 10 percent of sample, becoming more silty in lower part of interval.
1296-1313	Sandy clayey silt and silty clay, medium light gray (N6) to very light gray (N8), sticky, lignitic in one bed. Also a little soft mottled light reddish-brown (10R 5/6) and medium gray (N5)sandy clay. Very hard layer at 1311 ft.
1313-1336	Silty sand, medium gray (N5), very fine to very coarse, poorly sorted, pyrite and glauconite common; a small amount of stiff glauconitic olive-gray (5Y 3/2) sandy clay.
1336-1348	Silty clay, very light gray (N8) and medium gray (N5), sandy, soft and sticky; some stiff glauconitic olive-gray (5Y 3/2) sandy clayey silt to sandy silt, and stiff sticky dusky yellow (5Y 6/4) clayey sand.
1348-1356	Clayey silt to clayey sand, light reddish-brown (10R 5/6), soft; some stiff olive-gray (5Y 3/2) clayey silt, and soft sticky moderate yellowish-brown (10YR 5/4) clayey silt; some muscovite flakes up to 3 mm.
1356-1365	Clayey sandy silt, yellowish-brown (10YR 4/4), stiff; some mottled yellowish-brown (10YR 4/6) and light reddish-brown (10R 5/6) clayey silt, and soft very light gray (N8) silty clay.
1365-1370	Clayey silt, light reddish-brown (10R 5/6), stiff; some mottled light brown (5YR 5/6) very light gray (N8) clayey silt.
1370-1379	Sand, olive-gray (5Y 4/1 to 5Y 4/2), fine to coarse with a little very coarse, slightly silty to silty, lignite abundant.
1379-1389	Sandy clay, very light gray (N8) to white (N9), very soft.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
1389-1395	Sandy clay, light reddish-brown (10R 5/6), soft, rounded black mineral (glauconite?) common; some stiff muscovitic glauconitic (?) olive-black (5Y 2/1) silty sand.
1395-1409	Silty clay, deep reddish-brown (10R 4/7), slightly sandy in some layers, very soft. Also some hard light dusky red (5R 4/4) and dark reddish-brown (10R 3/6) silty clay; mottled white (N9) and moderate red (5R 4/6) to deep red (5R 4/7) silty clay; soft moderate reddish-orange (10R 6/6) clayey sandy silt; stiff slightly sandy moderate reddish-brown (10R 4/6) clayey silt; and stiff slightly sandy very light gray (N8) silty clay. Drilling mud turned from olive-gray to red.
1409-1418	Clayey sand, very light gray (N8), soft, lignite abundant in some layers, some large flakes of muscovite.
1418-1436	Clayey sand, very light gray (N8), fine to medium, soft to moderately stiff, large flakes of muscovite common. Also some soft pinkish-gray (5YR 7/1) clayey sand; soft slightly sandy deep reddish-brown (10R 4/7) and light reddish brown (10R 5/6) silty clay; soft light gray (N7) silty clay; soft white (N9) sandy clay; and minor grayish yellow (5Y 8/4) silt.
1436-1448	Silt and clay, light gray (N7), soft; some soft slightly sandy deep reddish-brown (10R 4/7) clay and moderately stiff dark brown (5YR 4/6) clayey silt.
1448-1451	Silt, light gray (N7), a little very fine sand, soft, fine-grained muscovite common.
1451-1456	Sand, very fine to medium with some coarse, slightly silty, black minerals abundant.
1456-1463	Silty clay, very light gray (N8), sticky. Also minor amounts of moderate reddish-brown (10R 4/6) clay with some very light gray (N8) variegations, and very hard deep reddish-brown (10R 3/6) clayey silt.
1463-1469	Sand, white (N9) to very light gray (N8), very fine to medium, clayey, soft, pink feldspar abundant, sandstone fragments rare to common.
1469-1489	Silty clay, very light gray (N8), slightly sandy, dark minerals common in some beds; some dusky red (5R 3/4) clayey silt and medium to coarse-grained very light gray (N8) clayey sand.

Table 3.--Lithologic description of drill cuttings and core samples from wells 1 and 5--Continued

Depth (ft)	Lithology
1489-1500	Clayey sand, very light gray (N8), fine to very coarse, subangular to subrounded, lignite abundant, pink feldspar common, fine black minerals common; minor amounts of soft, sticky, very light gray (N8) silt.
1500-1509	Saprolite (?), clayey sand, very light gray (N8) to light gray (N7), fine to very coarse, subangular, fine black mineral common, pink feldspar rare to common, muscovite flakes rare, dark green rock fragments rare; also some medium dark gray (N4) sandy clay with biotite and dark minerals common.
1509-1512	Saprolite (?), clayey sand, medium gray (N5), fine black minerals abundant; fragments of fresh angular qtz common; fragments of biotite-quartz-feldspar-garnet schist rare, with altered feldspar.
1512-1529	Saprolite (?), very weathered; angular quartz fragments; biotite books, with biotite increasing towards bottom of interval; weathered white feldspar; siltstone fragments.
1529-1589	Gneiss or schist, grayish-black, very weathered and friable, primarily biotite and white to very light gray clay which is altered feldspar; angular quartz fragments.
1589-1599	Gneiss or schist, same as above, but getting some pieces of weathered schist which are pale green and pale red; trace of pyrite; alternating hard and soft layers.
1599-1652	Gneiss or schist, grayish-black, very weathered, soft; biotite, angular quartz, and white to light gray clay which is altered feldspar; hard-drilling layers are probably quartz lenses.
1652-1662	Gneiss or schist, grayish-black, less weathered than above; biotite, quartz and feldspar; feldspar less altered than above; biotite pieces larger than above, up to 3 mm.
1662-1667	Gneiss or schist, grayish-black, much harder and less weathered than above, predominantly biotite and quartz with some feldspar; very slow drilling.
1667-1670	Gneiss or schist, grayish-black, not weathered, very hard, very few good cuttings.