STATE OF DELAWARE

DELAWARE GEOLOGICAL SURVEY

REPORT OF INVESTIGATIONS NO. 2

HIGH-CAPACITY TEST WELL DEVELOPED AT THE AIR FORCE BASE

Dover, Delaware

by

W. C. RASMUSSEN

J. J. GROOT

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A. J. DEPMAN

Newark, Delaware
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W. C. RASMUSSEN
District Geologist, U. S. Geological Survey

J. J. GROOT
State Geologist of Delaware

and

A. J. DEPMAN
Geologist, Corps of Engineers, U. S. Army

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ABSTRACT

A thick aquifer of Eocene age underlies the Dover area, Delaware at depths ranging from 250 to 400 feet below the land surface. The aquifer is about 250 feet thick beneath the Dover Air Force Base and is composed of fairly uniform medium to fine glauconitic quartz sand. The static water level in a test well at the base was 18 feet below the land surface, or 5.7 feet above sea level, on April 17, 1957. The yield of the test well was about 300 gpm (gallons per minute), and the specific capacity at the end of a 12-hour pumping period was 8.3 gpm per foot of drawdown.

The water is of the sodium bicarbonate type, rather high in dissolved solids, moderately hard, and low in iron. It is suitable for many purposes without treatment. The quality compares not unfavorably with that of the water now being pumped in the area from the Cheswold aquifer of the Miocene series.

Regional correlation indicates that the Eocene aquifer is of great extent. It is correlated with the Piney Point formation of Jackson age (late Eocene), which is identified in southern Maryland and the Maryland Eastern Shore. However, no sands containing late Eocene fossils have been recognized on the surface in Maryland, Delaware, or New Jersey. It is concluded, therefore, that this aquifer does not have an exposed intake area, but receives recharge from adjacent beds.

The aquifer promises to become a valuable source of water in the Dover area.

This report describes the local geology and the construction of a test well drilled to a depth of 1,422 feet at the Dover Air Force Base, Dover, Del., and completed April 17, 1957. The test well was drilled to determine potential water-supply sources at the Air Base to augment or supplant water from the present source, the Cheswold aquifer of Miocene age, which is being depleted. The test well served its purpose in finding a supplemental supply.

Available knowledge indicated that a thick sand of Jackson (late Eocene) age, which is not exposed in Delaware or in adjacent States, might be present beneath the Dover area. This sand, which was named the Piney Point formation in southern Maryland by Otton (1955, p. 85), is a major aquifer in the central Eastern Shore of Maryland (Rasmussen and Slaughter, 1957, p. 3, 61-67, pl. 9). Numerous small-capacity wells are developed in a sand at this stratigraphic position in Delaware (Marine and Rasmussen, 1955, p. 45, 113, and pl. 8).

The water levels in wells penetrating the Cheswold aquifer, the main water-bearing bed now supplying the city of Dover, the Air Force Base, and the environs, have declined steadily in past decades. A summary of the situation as of 1954 (Marine and Rasmussen, 1955, p. 123 and 124) indicated a decline in the center of the cone of depression, at Dover, of 77 feet in the preceding 34 years.

Intermittent water-level measurements at the Air Force Base indicate a decline in piezometric level from 17 feet below the land surface, when the first wells were drilled in 1942 (Marine and Rasmussen, 1955, p. 124), to about 42 feet below the land surface on December 20, 1955. This drawdown trend of about 2 feet a year is not cause for immediate alarm, as the water levels are more than 100 feet above the screens. However, in view of the very rapid recent development of the Dover area, with its resultant increasing water demands, the rate of drawdown probably will increase; thus, intelligent prospecting for other sources is in order, particularly for major installations such as the Dover Air Force Base.

In addition to their primary purpose in regard to water supply for the Air Force Base, the test-well data add to the knowledge of geology and particularly to that of water resources of the deeper formations in an area of Delaware where such information is sparse. Deep-well data were lacking for the general area from Middletown, about 28 miles north of Dover, where an exploratory well 1,478 feet deep was drilled (Miller, 1906, p. 9 and 10), to Bridgeville, about 28 miles south of Dover, where oil tests 3,012, 2,674, and 2,600 feet deep were drilled (Marine and Rasmussen, 1955, p. 143).

The deep exploratory well drilled at the Dover Air Force Base is numbered Je32-4 in accordance with the system of the U.S. Geological Survey for the State of Delaware. The general location is shown in figure 1, a map of the observation wells in Delaware. The letters J and e are shown on the grid on the margin of the map and represent a 5-minute quadrangle: J is the quadrangle row between 39°05' and 39°10' N. Lat. and e is the quadrangle column between 75°25' and 75°30' W. Long. The double digit 32 refers to a specific 1-minute quadrangle within the 5-minute quadrangle, and the digit following the hyphen, -4, indicates the fourth well schedule in this 1-minute quadrangle.

The geologic and hydraulic work was under the direct supervision of the writers; the work of the senior author was under the general supervision of H. C. Barksdale, Branch Area Chief, and A. N. Sayre, Chief of the Ground Water Branch, Water Resources Division, U. S. Geological Survey. The writers were assisted in around-the-clock sampling by Robert M. Germeroth, geologist of the Delaware Geological Survey, Arthur Thomas, geologist of the Corps of Engineers, and Harold E. Gill, geologist, and Durward H. Boggess and O. Jack Coskery, engineering aides, of the U.S. Geological Survey. Mr. Germeroth made the preliminary paleontologic examination. Mrs. C. R. Groot made the sand analyses. The pumping test was run by Messrs. Boggess and Coskery. The drilling contract was let by the Philadelphia District, Corps of Engineers, U. S. Army, under the direct supervision of Joseph B. Trolier, Area Engineer. The drilling contractor was the C. W. Lauman Co., and the drilling was supervised by Herman E. Lauman of that company.

This memorandum is an interim report, and it will be augmented in the future by detailed studies of heavy minerals, grain size, pollen and spores, microfossils, and clay mineralogy, and by regional correlation of the results by members of the staff of the Delaware Geological Survey.

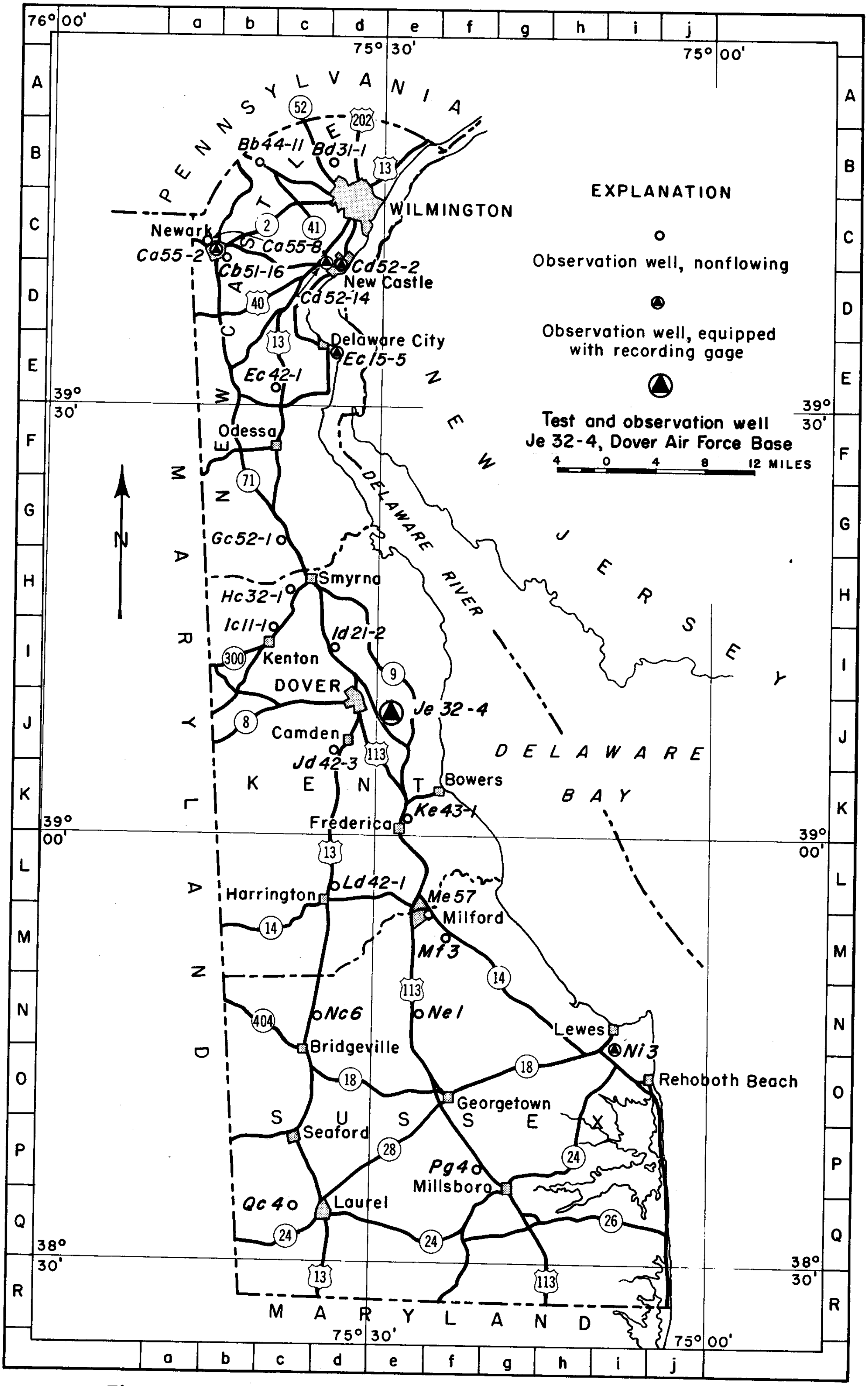

Figure 1. Map of Delaware showing test well and other observation wells

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PROGRAM OF DRILLING

Drilling was let by competitive bidding under invitation No. ENG-36-109-57-46 issued by the District Engineer, Philadelphia District, Corps of Engineers, U. S. Army. The award was made shortly after the bids were opened on February 21, 1957, to C. W. Lauman and Co., for approximately $28,000. Notice to proceed was given March 4, and the driller moved rotary drilling equipment onto the site and set up within the prescribed 5 calendar days.

The hole was spudded March 25, 1957, and a 10-inch hole was drilled to a depth of 1,422 feet, reached late on April 3, 1957. A total of 140 cores were taken, 1 approximately every 10 feet, with an 18-inch wire-line core barrel. Ditch samples were taken from the circulated drilling fluid for the intervals between the cores. The hole was kept open by hydraulic circulation of drilling mud, except for that length of the hole occupied by the surface casing.

On April 4 the hole was logged electrically and radioactively with a Widco logger, by the staff of the Delaware Geological Survey.

A decision was made to set two screens in the Piney Point formation, to span the depth intervals from 361.4 to 391.4 feet and from 555.3 to 565.7 feet. These sands are part of a continuous aquifer about 251 feet thick. The coarser sections of the formation were chosen for screening by grain-size analysis, and H. E. Lauman selected the screen-slot sizes on the basis of this analysis. The dual screen setting was chosen in order that the well would act as a combined piezometer representing heads near the top and bottom of the aquifer. In addition, gravel packing helped to integrate the head of the entire aquifer as shown by the well.

The well construction is summarized in figure 2, which shows also a plot plan of the well location and the site recommended for a production well. According to a survey by D. V. Gray of the Corps of Engineers, the altitude of the land surface at the well site was 23.7 feet, the altitude of the top of the pipe was 25.16 feet, and the altitude of the top of the recorder platform at 26.97 feet above sea level.

The hole below the lowermost screen was filled with a mixture of gravel and clay and then the well was gravel packed to a level 320 feet below the land surface; the pack was certified by the driller as extending from 350 feet to 566 feet after settlement. On April 17, 1957, the pumping test was run, water samples were taken, and shortly thereafter the well was accepted. It was capped, latched, and locked. In early June 1957 an automatic water-stage recorder, with shelter, was installed on the well.

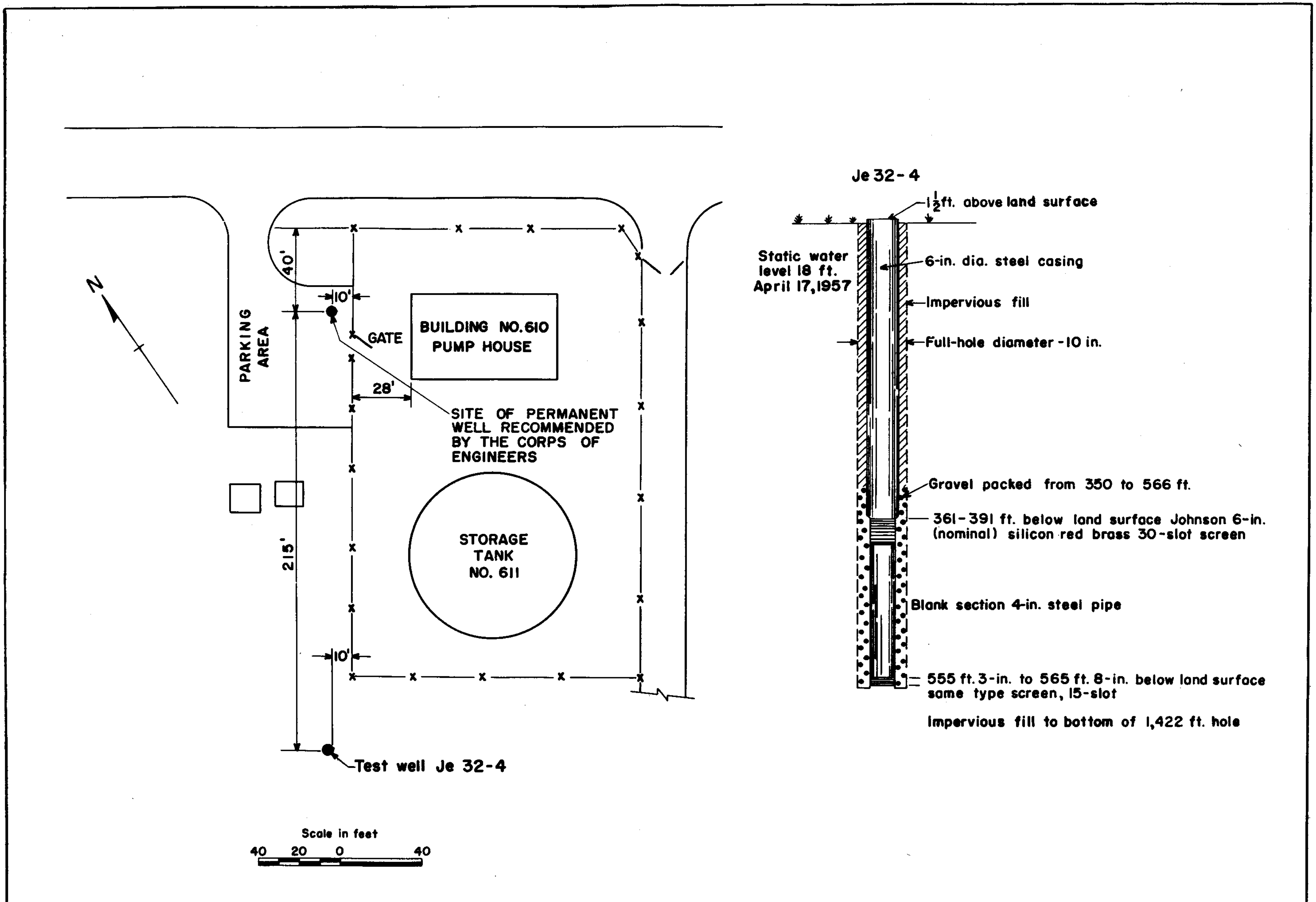


Figure 2.--Plot plan and construction details for test well Je 32-4.

Present knowledge of the geology of Delaware results from studies made by many persons, but until the last 5 years the chief contributors were geologists of Maryland, New Jersey, and the Federal Survey, who carried their investigations over from adjacent States. Thus, Woolman (1892, 1894, 1897, 1899, 1900, and 1902) in the annual reports of the State Geologist of New Jersey, reported on the first correlation of fossils from wells in Delaware. Darton (1896, 1905) of the U. S. Geological Survey considered the artesian-well prospects. Miller (1906; Bascom and Miller, 1920), also of the Federal Survey, did the first surface mapping on the Coastal Plain. From Maryland, Mathews (Clark, Mathews, and Berry, 1918) reported on the water resources of Delaware.

Since 1950, cooperative ground-water investigation of the U. S. Geological Survey and the Delaware Geological Survey have resulted in a review of the geology of the State (Marine and Rasmussen, 1955). Independent geological research by the Delaware Geological Survey has contributed to knowledge of the basic stratigraphy (Groot, Organist, and Richards, 1954; Groot, 1955). This broad foundation is the basis for the correlations and interpretations made in this report.

Local Logs

The log of a well is a personal or mechanical record of observations from various depths in a hole; each log has its specific value, and each its limitations.

Table 1 is the drillers' log, prepared by the two drillers, Audie Reimals and Phillip Bucher, who were in charge of alternate 12-hour work tours. This log is based on their experience with the performance of the hydraulic rotary drill, in various earth materials, gained from years of work on Long Island in similar sediments.

Table 2 is a geologists' log prepared by the writers, and by those mentioned in the Introduction who participated in the around-the-clock sampling. The geologists' tours of duty were 8 hours and the schedule was repeated every two days. This log is based upon hand-lens inspection of the cores and cuttings, and upon reports from the drillers on where they felt a change in the vibration of the drill rod in passing from a clay to a sand or vice versa.

Figure 3 is a graph of the median and quartile sand sizes in the principal water-bearing beds. Table 3 is a compilation of preliminary paleontologic identifications by R. M. Germeroth.

Table 4 is a composite log, derived from all the preceding logs, and given a stratigraphic interpretation. Plate 1, prepared by A. J. Depman and Arthur Thomas, shows this composite log symbolically compared to the electrical logs (self-potential and resistivity) and the gamma-ray log obtained with the Widco logger.

TABLE 1.—Drillers' log

The following information is a faithful copy of the drillers' log recorded by two experienced drillers of the Lauman Co., Audie Reimals and Phillip Bucher. They based their log on the feel of the hydraulic rotary tool, while drilling, on the cuttings that were washed up, and on inspection of each core shortly after it was removed from the core barrel.

Depth (feet)	
0	
	Loam and clay
10	
	Medium gray sand, some clay
20	
	Coarse brown sand, some grit
37	
	Fine brown sand, some clay
44	
	Solid gray clay
55	
	Gray sandy clay, mica
64	
	Fine gray clayey sand, grits
70	
	Fine gray sand, grit, some clay, shell fragments
76	
	Layers of fine gray sand and solid gray clay
85	
	Fine to medium-coarse gray sand, grit
93	
	Solid brownish-gray clay, mica
115	
	Solid gray clay, shell fragments
123	
	Greenish-gray sandy clay, shell fragments
145	
	Solid greenish-gray clay, mica, shell fragments
174	
	Medium-coarse gray sand, shell fragments, streaks of sandy clay
186	
	Solid greenish-gray clay, shell fragments
203	
	Layers of fine gray sand, sandy clay, shell fragments
213	
	Fine gray sand, streaks of sandy clay, shell fragments
225	
	Medium gray sand, some shells, streaks of clay
245	
	Solid brown clay, streaks of sandy clay
279	
	Solid greenish-gray clay
294	
	Fine greenish sandy clay, broken shells
305	
	Solid gray clay, some broken shells
319	
	Solid brown clay, some broken shells
336	
	Fine greenish-gray sandy clay, broken shells

Depth
(feet)

346

Fine green sand, some broken shells

358

Fine green sand, broken shells, some clay, streaks of cemented sand

404

Fine green sand, broken shells, streaks of sandy clay

425

Fine to medium-coarse green sand, some clay, broken shells, streaks of sandy clay

514

Fine green sand, some clay, broken shells, streaks of sandy clay

543

Fine to medium green sand, some clay, broken shells

566

Fine to medium green sand, some clay - very dirty, broken shells

584

Very fine greenish-gray sandy clay, broken shells

633

Solid greenish-gray clay, very hard

664

Greenish-gray clay, black specks

673

Layers of hard and medium-hard greenish clay, pieces and streaks of cemented sand

686

Solid brownish-gray clay

693

Solid greenish-gray clay, pieces of cemented silt

704

Solid greenish-gray clay, streaks of shale

735

Very fine greenish-gray sandy clay

774

Solid greenish-gray clay

784

Solid green clay

805

Solid greenish-gray clay, some small shell fragments

826

Very fine greenish-gray sandy clay, shell fragments

844

Very fine greenish-gray sandy clay, shell fragments at 927 feet, 947, and 977

1,034

Fine gray sandy clay

1,085

Fine greenish-gray sandy clay

1,102

Fine to very fine brownish-gray sand, some clay

1,116

Very fine brownish-gray sand, some clay, mica, streaks of cemented sand

1,132

Very fine brownish-gray sand, some clay, mica

1,143

Very fine greenish-gray sandy clay, mica, pieces of cemented silt

1,163

Very fine greenish-gray sandy clay, mica, pyrite.

1,172

Very fine greenish-gray sandy clay, mica, shell fragments

Depth (feet)	
1,232	
	Very fine greenish-gray sandy clay, streaks of lignite and cemented sand
1,246	
	Very fine greenish-gray sandy clay, mica, pyrite
1,277	
	Layers of solid brown clay, fine gray sandy clay, streaks of pyrite
1,285	
	Lignite, streaks of pyrite
1,294	
	Solid gray sandy clay
1,306	
	Very fine gray sand, mica, pyrite
1,334	
	Medium-coarse gray sand, streaks of fine gray sand, lignite
1,345	
	Very fine gray silt
1,356	
	Solid gray clay, streaks of pyrite
1,361	
	Multi-colored solid clay
1,394	
	Medium white sand, streaks of multi-colored clay and pyrite
1,401	
	Fine gray sand, streaks of lignite
1,417	
	Very fine silty gray clay, mica
1,422	

TABLE 2.—Geologists' log

Descriptions by the geologists and engineering aids who collected samples while the drilling was in progress.

Sample number: DS, Ditch sample.

Sample number	Depth interval (feet)	Description
DS-1	0-10	Sand, fine, clayey, buff
DS-2	10-20	Sand, coarse to very coarse, gray-brown
DS-3	20-30	Sand, medium to coarse, reddish-brown, with black fragments
DS-4	30-37	Sand, medium to coarse, with granules and gravel, reddish-brown; lignite
Core 1	37-39	Sand, fine to medium, silty, reddish-brown (recovery 9 in., 50 percent)
DS-5	37-47	Clay, gray, some orange; few gravel fragments
Core 2	47-49	Clay, dark gray, stiff
DS-6	47-57	Clay, gray, some orange, soft
Core 3	57-59	Clay, sandy, medium, gray
DS-7	57-67	Clay, gray, soft, with particles of lignite
Core 4	67-69	Sand, medium to coarse, silty, dark gray, some gravel
DS-8	67-72	Sand, medium to very coarse, quartz, silty and clayey, dark gray, some grit.
Core 5	72-74	Sand, medium to coarse, gray, lots of small shell fragments
DS-9	72-77	Sand medium to coarse, gray, with grit and many small shell fragments.
Core 6	77-79	Sand, medium and coarse, in streaks; sand, medium, silty
DS-10	77-87	Sand, medium to coarse, gray, with shell fragments and clay streaks
Core 7	87-89	Sand, medium to coarse, gray
DS-11	87	At bottom: sand, coarse, gray, with gravel
DS-12	87-97	Sand, medium to coarse, gray, some grit, shell; clay, dark gray, from 93 to 97
Core 8	97-99	Clay, dark gray, dry, small specks of mica

Sample number	Depth interval (feet)	Description
DS-13	97-107	Clay, gray, with some small fragments (shell?)
Core 9	107-109	Clay, dark gray, dry
DS-14	107-117	Clay, gray, with occasional grains of sand
Core 10	117-119	Clay, dark gray, dry, with shell fragments and occasional bits of gravel
DS-15	117-127	Shell fragments with clay (shell layers at 123)
Core 11	127-129	Clay with shell fragments and sand, very fine, gray, with silt
DS-16	127-137	Silt, gray-green, and shells. Fewer shells at bottom of sample.
Core 12	137-139m	Silt, gray-green, and sand, fine, few shells
DS-17	137-147	Silt, sandy, fine, gray-green, some shells
Core 13	147-149	Silt, gray-green, and clay
DS-18	147-157	Silt, gray-green, and clay; shells
Core 14	157-159	Clay, silty, gray-green, few shells
DS-19	157-167	Clay, silty, gray-green
Core 15	167-169	Clay, silty, gray-green, some sand, very fine; shells
DS-20	167-177	Clay, silty, gray-green, shells. Sand encountered at 176 feet (estimated)
Core 16	177-179	Sand, medium to coarse, gray-green, many shells
DS-21	177-186	Shell bed - believe out of it at 186 feet. Drilled to 187 feet.
Core 17	187-189	Clay, gray-green, and silt, shells
DS-22	187-197	Clay, silty, gray-green, some shells
Core 18	197-199	Clay, silty, gray-green
DS-23	197-207	Clay, silty, gray-green, some shells. Sand starting at 205 feet (estimated)
Core 19	207-209	Sand, medium, silty, gray-green, and shells
DS-24	207-217	Sand, gray-green, and shells
Core 20	217-219	Sand, medium, gray (made two trips with core barrel)
DS-25	217-227	Sand, gray-green, (very little in sample). Mainly shells. Driller Reimals says sand encountered at 225 feet.

Sample number	Depth interval (feet)	Description
Core 21	227-228	Sand, gray-green, and shells (made two trips with core barrel to obtain 9-inch core)
DS-26	227-237	Sand and silt, with shell and some lignite
Core 22	237-238.5	Sand, medium fine, slightly silty, greenish-gray (full recovery)
DS-27	237-247	Sand, medium fine, slightly silty, greenish-gray, with clay and streaks of sand estimated by Driller Reimals beginning at 245 feet
Core 23	247-248.5	Clay, brown, interbedded with sand, fine-grained, gray, some mica (full recovery)
DS-28	247-257	Clay, brown, with shell fragments, some mica (muscovite) flakes, and pieces of lignite
Core 24	257-258.5	Clay, brown, with some fine gray sand lenses (50 percent recovery)
DS-29	257-267	Clay, brown, shell fragments
Core 25	267-268.5	Clay, gray, to clay, micaceous, sandy, gray (full recovery)
DS-30	267-277	Clay, gray, with shell fragments
Core 26	277-278.5	Clay, brown, with sand, fine, micaceous, gray, interbedded, some small lignite pieces
DS-31	277-287	Clay, brown, and sand, fine, micaceous, gray, some shell fragments
Core 27	287-288.5	Clay, sandy, gray-green, shell fragments, and aragonite (fibrous structure), full recovery
DS-32	287-297	Clay, sandy, gray-green, shell fragments and aragonite (fibrous structure)
Core 28	297-298.5	Sand, clayey, greenish-gray, to sand, fine-grained, micaceous, much shell material (aragonite)
DS-33	297-307	Clay, sandy, very fine, gray-greenish, micaceous, shell fragments
Core 29	307-308.5	Sand, very fine, clayey, silty, grayish-green; much shell material; very compact
DS-34	307-317	Sand, very fine, clayey, grayish-green; shell fragments
Core 30	317-318.5	Clay, sandy, very fine, silty, grayish-green; shell fragments; very compact
DS-35	317-327	Clay, sandy, very fine, silty, grayish-green; shell fragments; very compact
Core 31	327-328.5	Clay, silty, sandy, very fine, brownish; much fragmented shell; some mica flakes

Sample number	Depth interval (feet)	Description
DS-36	327-337	Clay, silty, sandy, very fine; much fragmented shell; pieces of lignite
Core 32	337-338.5	Sand, very fine, ill-sorted, clayey, grayish-green, compact and dense
DS-37	337-347	Sand, very fine, clayey, grayish-green, some bright green particles
Core 33	347-348.5	Sand, medium-coarse, bright to dark green, loose; glauconite, shell fragments
DS-38	347-357	Sand, medium-coarse, bright to dark green, loose; glauconite; much shell fragments
Core 34	357-358.5	Sand, medium-coarse, glauconitic
DS-39	357-367	Sand, coarse, glauconitic, and shell
Core 35	367-368.5	Sand, medium to coarse, glauconitic, bright green, with some silt and shell fragments; shell at upper end of core
DS-40	367-377	Sand, medium to coarse, glauconitic, clayey, bright green, with shell
Core 36	377-379.5	Sand, medium, glauconitic, clayey, bright green
DS-41	377-387	Clay, sandy, bright green, and shell
Core 37	387-388.5	Sand, fine to coarse, bright green, shell
DS-42	387-397m	Sand, fine to medium, bright green, with shells
Core 38	397-397.5	Sand, fine to medium, bright green, with shells
DS-43	397-407	Do.
Core 39	407-409.5	Sand, fine, bright green
DS-44	407-417	Sand, medium, clayey, bright green, and shell
Core 40	417-418	Sand, medium, bright green, and some clay
DS-45	417-427	Sand, medium to coarse, bright green, and clay with shells
Core 41	427-428.5	Sand, fine to medium, bright green
DS-46	427-437	Sand, fine to medium, bright green, and shells
Core 42	437-438.5	Sand, fine to medium, bright green, and shell fragments
DS-47	437-447	Sand, fine to medium, bright green, and shells
Core 43	447-448.5	Do.
DS-48	447-457	Sand, fine to coarse, glauconitic, green, numerous shell fragments

Sample number	Depth interval (feet)	Description
Core 44	457-459	Sand, fine to medium, bright green
DS-49	457-467	Sand, medium to coarse, bright green, and shell
Core 45	467-468.5	Sand, fine, bright green
DS-50	467-477	Sand, medium to coarse, green, some clay, shell fragments
Core 46	477-479	Sand, medium, glauconitic, green, some clay or silt
DS-51	477-487	Sand, glauconitic, green, with abundant shell fragments
Core 47	487-489	Sand, fine to medium, glauconitic, green; little silt; a few shell fragments. (Driller reports clay streaks in most of this green sand)
DS-52	487-497	Sand, medium, glauconitic, green, shell fragments
Core 48	497-499	Sand, fine to medium, but mostly fine, glauconitic, green, some clay
DS-53	497-507	Same as DS-52
Core 49	507-509	Sand, mostly fine, some medium, green, thin streak of clay, sandy, green
DS-54	507-517	Same as DS-52
Core 50	517-519	Sand, fine, glauconitic, green, thin clay streak
DS-55	517-527	Same as DS-52
Core 51	527-529	Sand, fine, glauconitic, green, some shell fragments, some clay
DS-56	527-537	Same as DS-52
Core 52	537-539	Sand, fine, glauconitic, green
DS-57	537-547	Do.
Core 53	547-549	Sand, fine, some medium, glauconitic, green, little silt
DS-58	547-557	Same as DS-57
Core 54	557-559	Sand, fine to medium, glauconitic, green, shell fragments
DS-59	557-567	Same as DS-57
Core 55	567-569	Sand, fine to medium, green, with shell fragments
DS-60	567-577	Do.
Core 56	577-579	Sand, fine to medium, green, with some small shell fragments, becoming clayey
DS-61	577-587	Same as DS-60

Sample number	Depth interval (feet)	Description
Core 57	587-589	Sand, fine, glauconitic, clayey, green, some shell
DS-62	587-597	Sand, fine, glauconitic, clayey, green, shell fragments
Core 58	597-598	Do.
DS-63	597-607	Sand, fine, glauconitic, very clayey, green, shell fragments
Core 59	607-608	Do.
DS-64	607-617	Do.
Core 60	617-619	Clay, very sandy, fine, glauconitic, shell fragments
DS-65	617-627	Clay, sandy, very fine and silty, glauconitic, shell fragments
Core 61	627-629	Clay, sandy, glauconitic, with shell fragments
	627-637	No sample. Driller says material is clay
Core 62	637-638	Clay, tough, light green (50 percent recovery)
	637-647	No sample. Driller says material is clay. Very slow drilling.
Core 63	647-649	Clay, micaceous, tough, gray-green (100 percent recovery). Drilling about 10 feet an hour.
DS-66	647-657	Clay, gray, more plastic than Core 63 (sample badly contaminated)
Core 64	657-659	Clay, tough, gray-green
DS-67	657-667	Clay, gray-green
Core 65	667-669	Clay, light greenish-gray, with many dark minerals
DS-68	667-677	Clay, light greenish-gray, many dark minerals. Some shell at 676 (?). Hard layers. Drilling easier.
Core 66	677-679	Clay, silty, brown
DS-69	677-687	Clay, silty, brown, with some gray clay
Core 67	687-688.5	Clay, silty, brown
DS-70	687-697	Silt, sandy, brown
Core 68	697-698.5	Silty, sandy, greenish-gray, with glauconitic and other dark grains
DS-71	697-700	Clay, sandy, greenish-gray
DS-72	697-707	Clay, sandy and silty, greenish, with opaque minerals, streaks very hard approaching a shale
Core 69	707-709	Do.
DS-73	707-717	Clay, silty, greenish-gray and brown, and bits of silt and stone

Sample number	Depth interval (feet)	Description
Core 70	717–719	Streaks of clay, silty, greenish-gray, and silt, hard, greenish-gray, approaching siltstone
DS-74	717–727	Clay, silty, few shell fragments
Core 71	727–728	Clay, silty, greenish, with little fine sand and opaque minerals, layers of greenish siltstone
DS-75	727–737	Clay, sandy, greenish, with opaque minerals and shell fragments
Core 72	737–739	Clay, very sandy, glauconitic, greenish
DS-76	737–747	Clay, sandy, glauconitic, greenish-gray, with shell fragments
Core 73	747–749	Clay, greenish-gray, with little very fine sand and silt. No large quantities of glauconite as in Core 72.
DS-77	747–757	Clay, sandy, greenish-gray, hard
Core 74	757–759	Do.
DS-78	757–767	Clay, sandy, glauconitic, greenish-gray
Core 75	767–769	Clay, sandy, greenish-gray, very hard
DS-79	767–777	Clay, sandy, green
Core 76	777–779	Clay, green, hard
DS-80	777–787	Do.
Core 77	787–789	Clay, green, hard. Some very small shell fragments.
DS-81	787–797	Clay, green
Core 78	797–799	Clay, green, very hard, nearly a shale
DS-82	797–807	Clay, green, very hard
Core 79	807–809	Clay, gray-green, hard
DS-83	807–817	Do.
Core 80	817–818	Clay, gray-green, hard, with a few shell fragments
DS-84	817–827	Clay, gray-green, hard
Core 81	827–829	Clay, gray-green, hard, with small shell fragments
DS-85	827–837	Clay, gray-green, hard
Core 82	837–839	Clay, gray-green, hard, with shell fragments
DS-86	837–847	Do.
Core 83	847–849	Sand, very fine, clayey, dark gray-green

Sample number	Depth interval (feet)	Description
DS-87	847-857	Silt, gray-green (badly contaminated with sand)
Core 84	857-859	Clay, dark gray-green; some very fine sand; few shells
DS-88	857-867	Same as DS-87
Core 85	867-869	Same as Core 84
DS-89	867-877	Same as DS-87
Core 86	877-879	Same as Core 84
DS-90	877-887	Same as DS-87
Core 87	887-889	Same as Core 84 except more shell fragments
DS-91	887-897	Very little real sample, identification difficult - drills same as preceding samples
Core 88	897-898	Clay, gray, some shells
DS-92	897-907	Clay, gray
Core 89	907-909	Clay, sandy, dark gray, hard
DS-93	907-917	Clay, gray (drilling mud heavy, difficult to get good sample)
Core 90	917-919	Silt, sandy, dark gray, with clay, many opaque grains
DS-94	917-927	Sand, medium to fine, and clay (sample very poor due to thinning of drilling mud)
Core 91	927-928	Silt, sandy, gray, with large quantities of clay, shell fragments (forams)
DS-95	927-937	Clay, sandy, dark gray
Core 92	937-938	Silt, sandy, dark gray, with large quantities of clay
DS-96	937-947	Same as DS-95
Core 93	947-948	Clay, sandy and silty, dark gray, with numerous dark grains, hard
DS-97	947-957	Clay, sandy, dark gray, with abundant dark grains
Core 94	957-958	Clay, sandy, silty, dark gray, with abundant dark grains
DS-98	957-967	Same as DS-97
Core 95	967-968	Clay, sandy to silty, fine, dark gray, with some small pebbles visible on broken surface
DS-99	967-977	Clay, sandy, fine to medium, dark gray (Driller reports drilling easier indicating more sand in clay)
Core 96	977-978	Clay, silty, dark gray, and shells

Sample number	Depth interval (feet)	Description
DS-100	977-987	Clay, sandy, fine, dark gray (contaminated with small bits of gravel and shell)
Core 97	987-989	Clay, sandy, fine, dark gray, with shell and streaks of glauconite
DS-101	987-997	Clay, sandy, fine, dark gray, with shell fragments, glauconitic
Core 98	997-999	Silt, sandy, fine, glauconitic, dark gray, with clay and shell fragments (forams)
DS-102	997-1007	Clay, sandy, fine, glauconitic, dark gray
Core 99	1007-1009	Silt, sandy, fine, light gray, with some glauconite
DS-103	1007-1017	Clay, sandy, dark gray
Core 100	1017-1019	Silt, sandy, very fine, light greenish-gray; some clay and glauconite
DS-104	1017-1027	Silt, sandy, very fine, light greenish-gray. Some clay and glauconite.
Core 101	1027-1029	Silt, sandy, very fine, gray, some clay
DS-105	1027-1037	Do.
Core 102	1037-1039	Silt, sandy, very fine, gray, some clay and glauconite
DS-106	1037-1047	Silt, sandy, fine, gray, some clay
Core 103	1047-1049	Sand, very fine, silty, light gray
DS-107	1047-1057	Sand, fine, silty, gray
Core 104	1057-1059	Silt, clayey, gray, compact, dry
DS-108	1057-1067	Silt, clayey, light gray, some very fine sand
Core 105	1067-1069	Silt, clayey, gray, compact, dry
DS-109	1067-1077	Clay, sandy, gray
Core 106	1077-1078.5	Clay, sandy, glauconitic, greenish-gray, little quartz (eleven inches recovered)
DS-110	1077-1087	Clay, glauconitic, greenish-gray, little quartz
Core 107	1087-1089	Sand, fine, glauconite, and quartz
DS-111	1087-1097	Sand and clay, glauconitic
Core 108	1097-1098.5	Clay, sandy, very glauconitic, sparsely micaceous
DS-112	1097-1107	Sand, glauconitic, gritty (topped the sand at 1102)
Core 109	1107-1108.5	Sand, fine to very fine, gray-brown, quartz, some glauconite (eight inch recovery, then four inch)

Sample number	Depth interval (feet)	Description
DS-113	1107-1117	Sand, clayey
Core 110	1117-1118.5	Sand, fine, quartz, glauconitic, green-brown
DS-114	1117-1127	Sand, fine to very fine, clayey, gray (hard streaks encountered from 1124 on)
Core 111	1127-1129	Sand, fine, glauconitic, grayish-green-brown, and sandstone
DS-115	1127-1137	Sand, very fine, clayey, gray (drilling easier)
Core 112	1137-1139	Sand, very fine, dark gray-brown, mica
DS-116	1137-1147	Sand, very fine, clayey, gray (this is 20 feet drilled in one hour)
Core 113	1147-1149	Sand, fine, clayey and silty, dark gray-brown, mica and piece of hard brown siltstone
DS-117	1147-1157	Sand, very fine, clayey, gray
Core 114	1157-1159	Sand, fine, clayey, dark gray-brown, with small lumps of brown silt (soft) and mica
DS-118	1157-1167	Same as DS-117
Core 115	1167-1169	Sand, fine, clayey, dark gray, with mica and pyrite
DS-119	1167-1177	Same as DS-117
Core 116	1177-1179	Clay, sandy, micaceous, dark gray (shell fragments?)
DS-120	1177-1187	Clay, sandy, gray
Core 117	1187-1189	Clay, sandy, dark gray, some small shell fragments. Hard.
DS-121	1187-1197	Same as DS-120
Core 118	1197-1199	Clay, sandy, dark gray, with large shell fragments. Hard.
DS-122	1197-1207	Same as DS-120
Core 119	1207-1209	Clay, sandy, gray, some shell fragments
DS-123	1207-1217	Same as DS-120
Core 120	1217-1219	Silt, sandy, glauconitic, dark greenish-gray, with clay and shell
DS-124	1217-1227	Sand, greenish-gray, clay with shell fragments
Core 121	1227-1229	Silt, sandy, fine, glauconitic, greenish-gray, with clay and shell fragments
DS-125	1227-1237	Clay, sandy, greenish-gray, with shell fragments
Core 122	1237-1239	Clay, silty, sandy, fine, greenish-gray. Upper part of core contains yellowish particles which may be broken tests of forams. Bottom of core contains what appears to be a large piece of lignite.

Sample number	Depth interval (feet)	Description
DS-126	1237-1247	Same as DS-125
Core 123	1247-1249	Clay, silty, green-gray, with shells
DS-127	1247-1257	Clay, sandy, green-gray, with shell fragments
Core 124	1257-1259	Clay, silty, micaceous, greenish-gray, with shell fragments. Piece of pyrite found in bottom of core.
DS-128	1257-1267	Clay, dark gray
Core 125	1267-1269	Silt, clayey, dark gray, some very fine sand, shell fragments, and some mica
DS-129	1267-1277	Clay, some sand, very fine
Core 126	1277-1279	Silt, clayey, micaceous, very dark gray - almost black, containing much lignite, some very fine sand, heavy nodules pyrite (?), one 3/4 in. pebble
DS-130	1277-1287	Clay
Core 127	1287-1289	Lignite, black, nodules of pyrite
DS-131	1287-1297	Lignite contaminated with gray clay
Core 128	1297-1299	Clay, very silty, brownish-gray, with small spots of very fine white sand; some pyrite
DS-132	1297-1307	Clay, very silty, and fine sand (contaminated with lignite)
Core 129	1307-1309	Sand, fine, black, at top of core; at middle and bottom of core: sand, very fine, white and gray, with some lignitic material
DS-133	1307-1317	Clay, very silty, and fine sand
Core 130	1317-1319	Sand, very fine, white
DS-134	1317-1327	Clay and sand, fine
Core 131	1327-1329	Sand, fine, white
DS-135	1327-1337	Clay, gray, and sand
Core 132	1337-1338	Sand, medium to coarse, light gray (9 in. recovery)
DS-136	1337-1347	Same as DS-135
Core 133	1347-1349	Sand, very fine, silty, light gray
DS-137	1347-1357	Same as DS-135
Core 134	1357-1359	Same as Core 133
DS-138	1357-1367	Clay, sandy, gray, with lignite
Core 135	1367-1369	Clay, silty, very fine, light gray, hard, dry, soapy, nodules of pyrite

Sample number	Depth interval (feet)	Description
DS-139	1367-1377	Clay, light gray
Core 136	1377-1379	Clay, silty, very fine, varicolored (light gray, reddish-brown), hard
DS-140	1377-1387	Clay, silty, varicolored (reddish-brown and light gray); 80 percent of sample contamination of material from above
Core 137	1387-1389	Clay, varicolored, reddish-brown and light gray, hard
DS-141	1387-1397	Clay, varicolored, reddish-brown and light gray, contamination now only about 20 percent
Core 138	1397-1399	Alternating lenses of clay, varicolored reddish-brown, dark green, tan, with sand, medium, white, sand predominates; nodule of pyrite in center of core in green clay lens.
DS-142	1397-1402	Sand, fine to medium
Core 139	1402-1404	Sand, fine to medium, white
	1402-1410	No ditch sample obtained. Attempted to take core sample at 1407 feet but was unable to recover a core after 200 blows.
Core 140	1410-1412	Sand, fine to medium, white
DS-143	1410-1420	Sand, medium to coarse, white, with lignite
Core 141	1420-1422	Clay, sandy, light gray

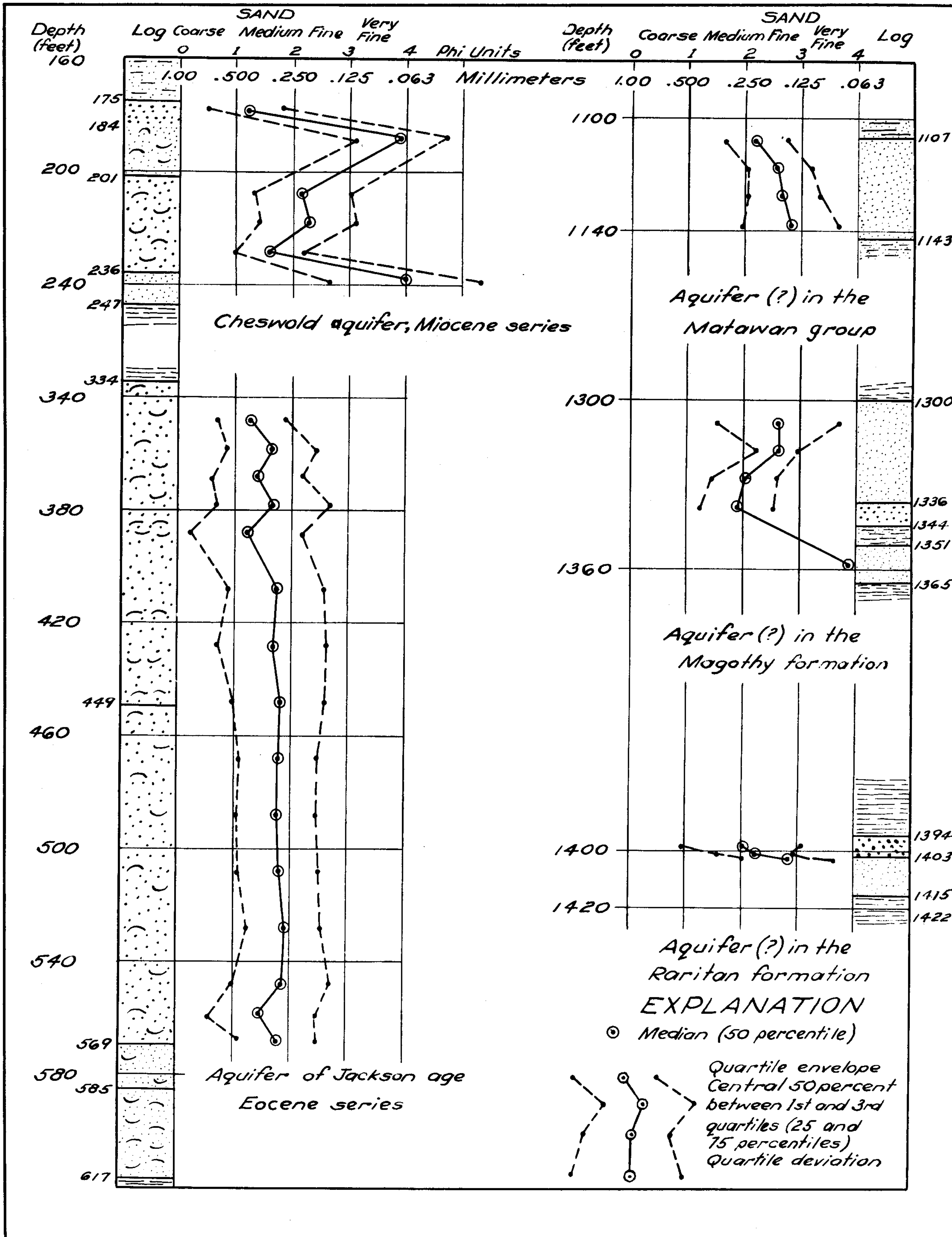


Figure 3. Graph of sand analyses of the principal water-bearing beds

TABLE 3.—Preliminary description of the paleontology of the Dover Air Force Base test well

By R. M. Germeroth

Core number	Depth interval (feet)	Geologic unit	Description of fossils
8	97–99	Miocene series, Calvert formation	Diatoms abundant. According to Shattuck, diatoms are restricted to the Calvert formation of Maryland.
10	117–119	Do	Diatoms and radiolarians very abundant.
32	337–338.5	Miocene series, undifferentiated	The fauna is composed of *Nonion*, *Bulimina*, and *Uvigerina*.
43	447–448.5	Eocene series, Jackson equivalent	*Cibicides cocoaensis* (Cushman) Bandy, *Robulus alato-limbatus* (Gümbel) Cole.
51	527–529	Do	*Cibicides cocoaensis* (Cushman). One Cibicides seems to be referable to C. *pseudoungerianus* (Cushman) Cushman.
55	567–569	Do	*Textularia ocalana* Cushman, *Virgulina dibollensis* Cushman and Applin.
56	577–579	Paleocene series, undifferentiated	*Robulus midwayensis* (Plummer) Cole and Gillespie. Index of the Midway of the Gulf Coast.
58	597–598	Do	*Robulus midwayensis* (Plummer) Cole and Gillespie.
76	777–779	Upper Cretaceous series, undifferentiated	One foram is referable to *Epistomina caracolla* (Roemer) Franke, which ranges through the Upper Cretaceous.
95	967–968	Upper Cretaceous series, Taylor (?) equivalent	*Robulus pseudo-secans* Cushman. This form is recorded from the Selma chalk, of Taylor age, in Tennessee and also from the basal Navarro.

TABLE 4.--Composite geologic and lithologic log.

Based on geologists' field log, drillers' log, sand log, sample and core description, electrical log, radioactive log, and preliminary microfossil investigation.

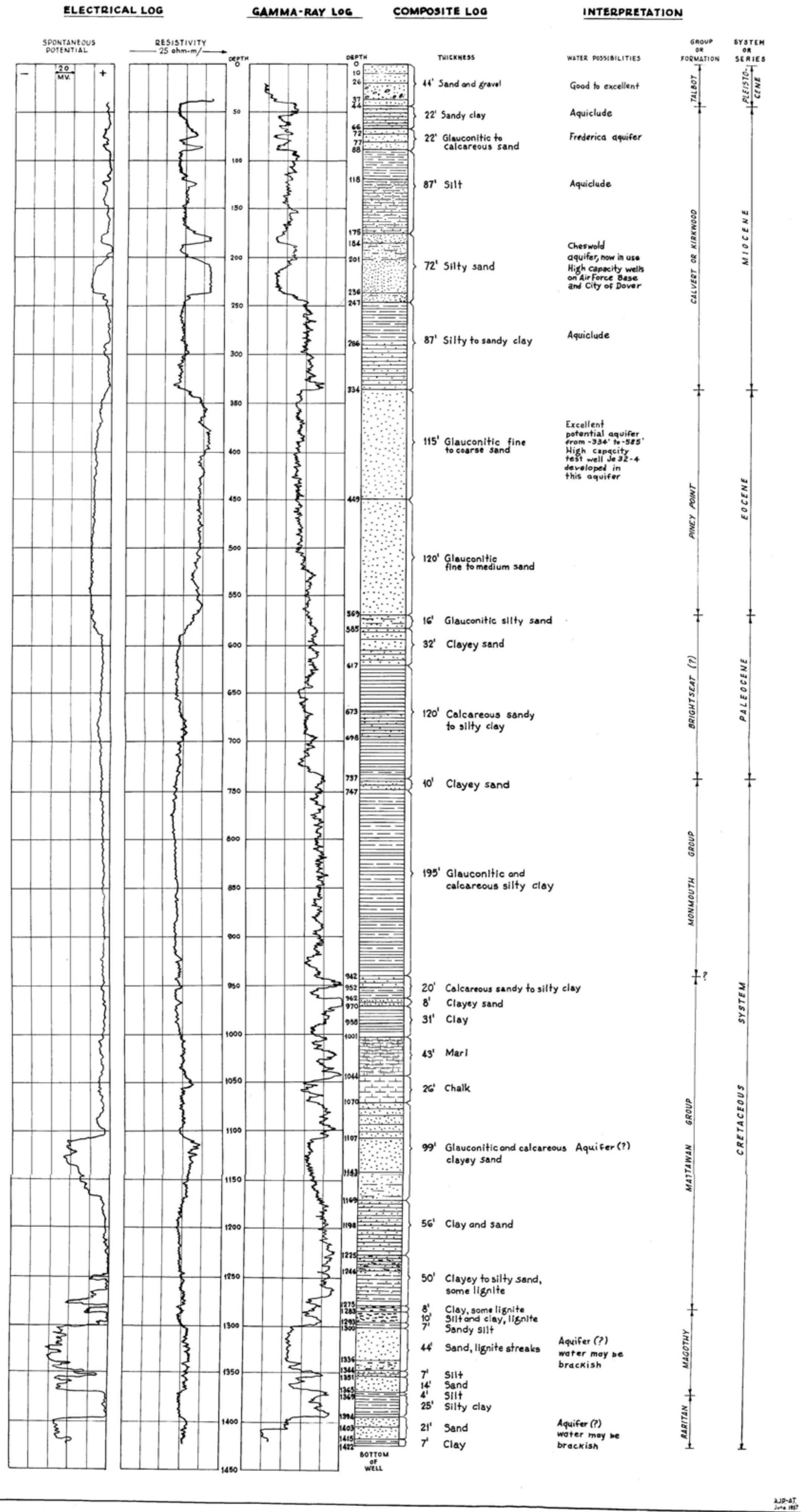
Boundary between the Monmouth and Matawan groups is questionable.

Description	Thickness (feet)	Depth (feet)
Pleistocene series		
Sand, fine and loam, buff	10	10
Sand, coarse to medium, gray	10	20
Sand, coarse, with some grit and fine gravel, reddish-brown	17	37
Sand, fine, brown	7	44
Miocene series		
Calvert formation or Kirkwood formation		
Aquiclude		
Clay, sandy, gray, noncalcareous	22	66
Frederica aquifer		
Sand, medium to coarse, glauconite, and quartz, noncalcareous, greenish	6	72
Sand, medium to coarse, calcareous, abundant shell fragments, gray	5	77
Sand, fine to coarse, noncalcareous, gray	11	88
Aquiclude		
Silt, noncalcareous, gray	30	118
Sand, very fine and silt, gray, calcareous, with shell fragments in places	57	175
Cheswold aquifer		
Shells and sand, coarse to medium, gray-green	9	184
Sand, very fine, and silt, some shells	17	201
Sand, medium to fine, gray, abundant shells	35	236
Sand, very fine, gray, slightly micaceous, noncalcareous	11	247

Description	Thickness (feet)	Depth (feet)
Aquiclude		
Clay and silt, gray-brown, noncalcareous	39	286
Clay, sandy, greenish-gray, slightly glauconitic, scattered shell fragments and seams of aragonite, calcareous, compact	48	334
Eocene series		
Piney Point formation		
Sand, fine to coarse, green, about 20 percent glauconite, about 10 percent shells, remainder quartz, calcareous cement	115	449
Sand, fine to medium, green, glauconitic, calcareous, some shells, compact	120	569
Paleocene series		
Brightseat (?) formation		
Sand, fine, silty, glauconitic, compact, some shells, green	16	585
Sand, very fine, clayey, glauconitic, gray-green, shells	32	617
Clay, calcareous, compact, light greenish-gray	56	673
Clay, sandy, calcareous, brownish-gray	25	698
Clay, silty, calcareous, hard, light gray	39	737
Upper Cretaceous series		
Monmouth group		
Sand, glauconite, clayey, calcareous, greenish-blue	10	747
Clay, silty, very finely glauconitic, sparsely micaceous, fossiliferous, calcareous, greenish-gray	195	942
Matawan group		
Clay, sandy, glauconitic, calcareous, dark gray	10	952
Clay, silty, micaceous, calcareous, dark gray	10	962
Sand, fine, glauconitic, clayey, green-gray	8	970
Clay, very glauconitic, calcareous, dark gray	18	988
Clay, glauconitic, calcareous, shell fragments, dark gray	13	1001

Description	Thickness (feet)	Depth (feet)
Marl, slightly glauconitic, light gray	43	1044
Chalk, slightly glauconitic, impure, grayish-white	26	1070
Sand, fine, glauconitic, and clay, green-gray	35	1107
Sand, medium to fine, dirty, quartz and mica, calcareous, gray-brown; some cemented streaks	36	1143
Sand, very fine, glauconitic and micaceous, and silt, gray, with pyrite	26	1169
Clay, sand, gray, with fine shell fragments	29	1198
Clay and glauconitic sand, greenish-gray	27	1225
Sand, clayey, yellow-green and gray altered glauconite with streaks of lignite	21	1246
Silt and very fine sand, clayey, slightly micaceous, pyritic, calcareous, and glauconitic, greenish-gray	29	1275
Magothy formation		
Clay, lignitic, dark gray with nodules of pyrite	8	1283
Lignite, black, with rare pieces of pyrite	10	1293
Silt, sandy, ash-gray	7	1300
Sand, fine, quartz, slightly calcareous, white to light gray	36	1336
Sand, medium to coarse, quartz, slightly calcareous, gray, with lignite streaks	8	1344
Silt, coarse, and sand, very fine, slightly calcareous, light gray	7	1351
Sand, fine, lignitic, gray, quartz and mica, slightly calcareous	14	1365
Raritan formation		
Silt, pulverulent, white	4	1369
Clay, silty, varicolored, red, orange, white, dark green, hard nodules of pyrite	25	1394
Sand, medium, white and brown, with nodules of pyrite	9	1403
Sand, fine to medium, white, with thin layer of black lignite	12	1415
Clay, soapy feel, silty, slightly micaceous, non-calcareous	7	1422

Logs of Je 32-4 , Dover Air Force Base, Delaware



1.--Electrical, radioactivity, and composite log of Je 32-4.

The composite log represents an effort to synthesize the best elements of all the other logs--electrical, gamma-ray, paleontologic, descriptive, drillers', and geologists'--into one authoritative log. Each of the logs differs by a few feet from the others in recording lithologic, paleontologic, or stratigraphic breaks. The electrical and radioactive logs have a systematic difference of 2½ feet because those logs were taken from the rotary table, 2½ feet above the land surface, whereas the drillers' and geologists' logs were taken from the land surface. In general, the inflection points of the self-potential and resistivity curves, corrected by subtracting 2½ feet, were taken as the boundaries of sands and clays. The machine-made logs are reproducible on repetition of the recording process, and are not subject to the human error which may occur in geologists' or drillers' logs.

Regional Correlation

A regional geologic correlation is presented in the cross section of Delaware, plate 2. As the accuracy of the cross section depends on the quantity and quality of the information on which it is based, the pertinent sources of data are summarized on the plate. Although paleontologic information is still meager, the electric and gamma-ray logs and the available lithologic data are considered sufficient for the tentative correlations shown on the plate.

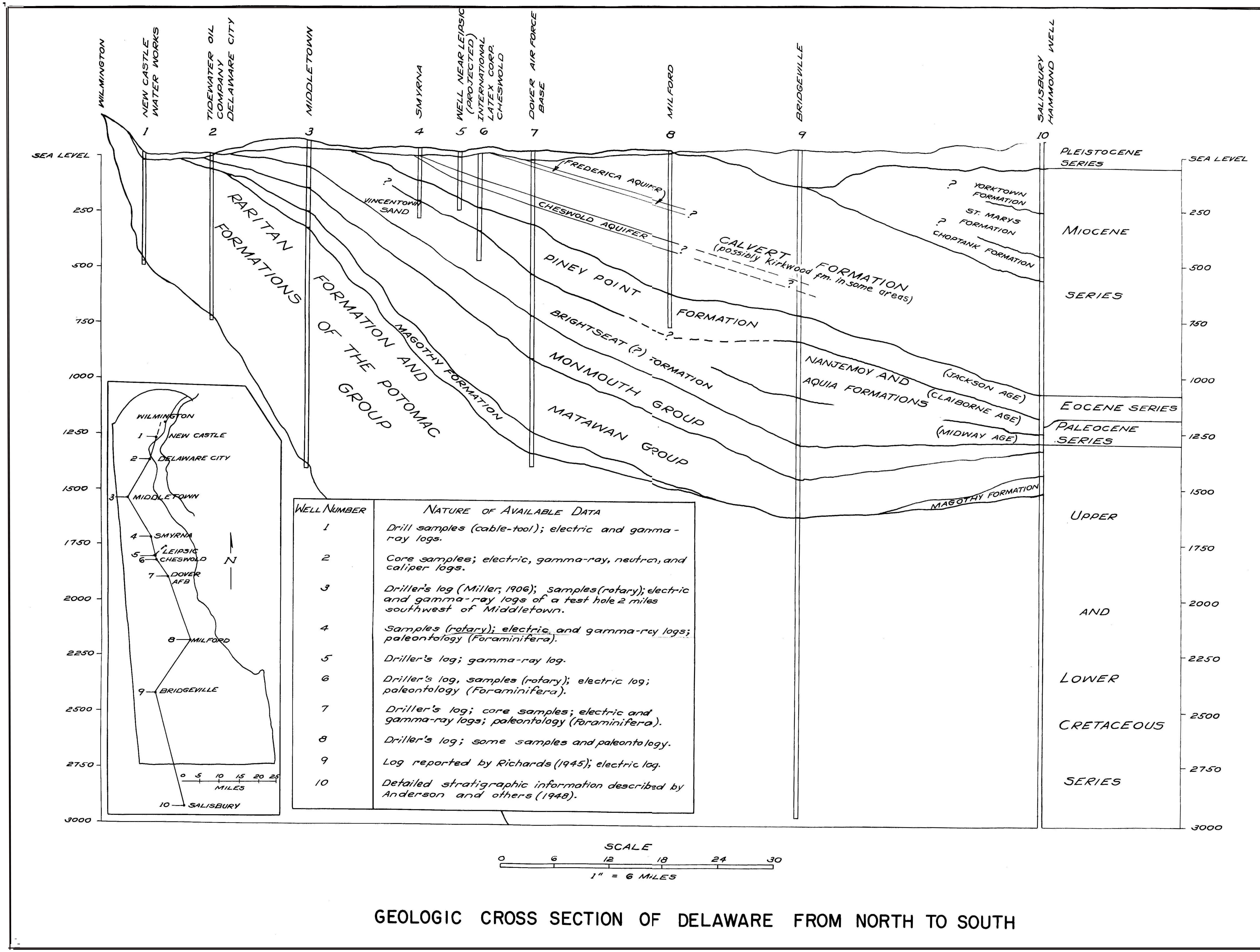
The Raritan formation and the formations of the Potomac group are not differentiated because they are lithologically similar and generally are unfossiliferous. Anderson (Anderson and others, 1948) divided these sediments into three units--the Patuxent, the Arundel and Patapsco, and the Raritan formations--primarily on the basis of heavy minerals, the top of the Patuxent formation coinciding with a decrease in staurolite content and the appearance of abundant epidote. In the outcrop, and in well 2 (Delaware City), staurolite-rich sediments also are encountered, and these may be equivalent to deposits of Patuxent age in the Salisbury well (number 10). However, because no heavy-mineral data are yet available for the area between wells 2 and 10, no attempt has been made to correlate them.

The Raritan formation and the Potomac group contain important aquifers. South of Smyrna, however, they occur at such great depths that their development is not practical at the present time.

The Magothy formation underlies most of Delaware, but it is absent in the Delaware City and Bridgeville areas. It overlies the Raritan formation unconformably and is in turn unconformably overlain by the sediments of the Matawan group. In northern New Castle County sands of the Magothy formation form an aquifer of minor importance, but in the Middletown area large quantities of water are produced from it. A sand of the Magothy formation is present also in the Dover test hole (see table 4), but its capability is unknown; the electric log indicates a relatively low resistivity, suggesting that the sand may contain brackish water.

The Matawan and Monmouth groups can be subdivided into formations in the outcrop in northern New Castle County (Groot and others, 1954), but downdip the facies change. The two groups may be separated on the basis of megafossils, the Matawan being characterized by *Exogyra ponderosa* and the Monmouth by *Exogyra cancellata and E. costata*. In the subsurface, recognizable megafossils are seldom found, and the separation must be done on the basis of the microfauna, the Matawan containing a fauna similar to that of the Taylor marl and the Monmouth a fauna similar to that of the Navarro group of the Gulf Coastal Plain. In the Dover test hole, the separation was tentatively made on the basis of lithology and geophysical logs.

In northern New Castle County, the Matawan and Monmouth groups contain aquifers of relatively minor significance (Marine and Rasmussen, 1955). A sand of the Matawan group, the Wenonah sand, yields water to wells in the Middletown-Odessa area in southern New Castle County. According to Spangler and Peterson (1950, fig. 23) the Monmouth is absent in a large area in central Delaware, but no evidence in support of this view is presented.



WELL NUMBER	NATURE OF AVAILABLE DATA
1	Drill samples (cable-tool); electric and gamma-ray logs.
2	Core samples; electric, gamma-ray, neutron, and caliper logs.
3	Driller's log (Miller, 1906); samples (rotary); electric and gamma-ray logs of a test hole 2 miles southwest of Middletown.
4	Samples (rotary); electric and gamma-ray logs; paleontology (Foraminifera).
5	Driller's log; gamma-ray log.
6	Driller's log, samples (rotary); electric log; paleontology (Foraminifera).
7	Driller's log; core samples; electric and gamma-ray logs; paleontology (Foraminifera).
8	Driller's log; some samples and paleontology.
9	Log reported by Richards (1945); electric log.
10	Detailed stratigraphic information described by Anderson and others (1948).

Plate 2. Regional Cross section of Delaware.

The Paleocene and Eocene series have been separated in the cross section (pl. 2), but the boundary between them is questionable. The Vincentown sand and Aquia greensand have been regarded as early Eocene, but recently McLean (1952) suggested that the Vincentown sand is correlative with the Midway of the Gulf Coast and the Danian of Europe, and therefore he considers it to be of Paleocene age. A. R. Loeblich (personal communication to R. M. Germeroth) also assigned a Paleocene age to the Vincentown sand and its equivalent, the Aquia greensand. Fox and Olsson (1955), however, believe the Vincentown to be of early Eocene age. Richards (1956), summarized the discussion on the age of the Vincentown sand as follows:

SUMMARY: The bulk of the evidence favored a Paleocene age for the Vincentown formation and a correlation with the Danian. This would make the Hornerstown still lower Paleocene. Since the Manasquan-Shark River formations are Claiborne—as shown by both macro-and micro-fossils, this leaves a gap for the Wilcox. Possibly it is missing in New Jersey, or possibly the Vincentown may represent both Midway and at least part of the Wilcox. Possibly the same ecological conditions continued from Paleocene into Wilcox times allowing for the mingling of the old Paleocene fauna with new elements of Wilcox age. Detailed studies on the Vincentown formation in outcrop and well samples will be needed before a positive answer can be obtained.

In the central part of Delaware deposits of late Eocene (Jackson) age rest directly on sediments of early Eocene or Paleocene age; for instance, in well 4 at Smyrna, deposits believed to be of Jackson age overlie the Vincentown sand; in well 7 at the Dover Air Force Base, a sand of Jackson age immediately overlies the Paleocene sediments. In test well Je32-4 no deposits of Claiborne (middle Eocene) age have been recognized, although further paleontologic study is needed on this point. In southern Delaware and the Eastern Shore of Maryland, however, sediments of Claiborne age are found, (for example, the Nanjemoy formation in well 9 at Bridgeville).

In central Delaware the sediments of Jackson age consist mostly of fine to medium glauconitic sand and thin interbedded clay lenses. On the basis of lithology, microfossils, and semicontinuous tracing in wells, this sand is correlated with the Piney Point formation of southern Maryland (Otton, 1955, p. 85) and the Eastern Shore (Rasmussen and Slaughter, 1957, p. 3, 61-67, pl. 9). South of Bridgeville the character of the sediments of Jackson age changes; clay begins to dominate, and the sand becomes fine and clayey. Consequently, it is expected that large quantities of ground water can be developed from the Piney Point formation only in the area between Dover and Bridgeville.

The Miocene series unconformably overlies the Eocene and Paleocene series. In Delaware the Miocene series is represented mainly by the Calvert formation, although equivalent materials in test well Je32-4 may represent the Kirkwood formation; in southern Sussex County the Choptank and St. Marys formations, which were reported by Anderson (1948) in the Salisbury oil test (well 10, pl. 2), may be present. In addition, some sediments now included in the Pleistocene series may be late Miocene in age, and may belong to the Cohansey sand.

The Calvert formation (or Kirkwood formation where present) contains two important aquifers; the Cheswold aquifer, which yields large quantities of water to wells in the Dover area, and the Frederica aquifer, which is productive in the area between Wyoming and Milford. A thick sand of Calvert age also occurs in the Bridgeville oil test (well 9, pl. 2) at a depth of about 500 to 600 feet, but it is not known whether it is continuous with the Cheswold aquifer in the Dover area. This report is the first to assign the Cheswold and Frederica aquifers to the Calvert formation or equivalent. Previously they have simply been indicated as "of Miocene age."

The Pleistocene series overlies the Miocene deposits unconformably. It forms one of the most important aquifers in Delaware, and it supplies nearly all the ground water now used in Sussex County.

PUMPING TEST

On April 17, 1957, the developed observation well was given a final pumping test for 12 hours at an average rate of 211 gpm. The water level was drawn down 25.5 feet, from a static water level 18.0 feet below the land surface (5.7 feet above sea level) to 43.5 feet below the land surface (19.8 feet below sea level). The specific capacity, 8.3 gpm per foot of drawdown, indicates a well of moderate capacity.

The most impressive characteristic of this aquifer beneath the Air Force Base is the extensive drawdown available between the static water level and the top of the producing sand, approximately 315 feet. Applying, as a rule of thumb, the 12-hour specific capacity of 8 gpm per foot, it is apparent that a 1,200 gpm well would have a drawdown of about 150 feet, 165 feet of drawdown being left to allow for gradual decline. This gradual decline would occur if the 1,200-gpm rate were continued beyond 12 hours and if other wells were installed that would cause mutual interference.

The rate of pumping was measured by means of an orifice and piezometer placed at the end of the discharge line. Although the turbine pump was gasoline powered, a remarkably steady discharge was maintained throughout the 12-hour pumping period. Eighteen measurements of flow showed a fluctuation from 214 to 210 gpm and a weighted average of 211 gpm.

The water levels were measured by air line and are accurate only to the nearest half foot. Thirty-two readings of drawdown and 20 readings of recovery were made. Figure 4 is an arithmetic graph of water-level drawdown and recovery, with an inserted table giving selected water levels measured during the 720-minute pumping period and the succeeding 140-minute recovery period.

The initial drawdown was very rapid, and near stability was reached at the end of 2 hours, no further decline being noticeable by air-line measurements in the final 10 hours of pumping. The drawdown trend shown on the graph is interpreted within the limits imposed by the accuracy of the measurements. It is possible that essential equilibrium had been attained, but it is more probable that the water level was declining slowly. This slow decline would become manifest if the test were longer, or if measurements could have been made with a steel tape or an electric tape to the nearest hundredth of a foot.

Logarithmic and semilogarithmic plots of the data were made, in which drawdown or recovery was plotted against time. Attempts were made to analyze the plotted data by means of the Theis type curve (Theis 1935; Brown, 1953, p. 852); the methods developed by Cooper and Jacob (1946); and other modified methods (Ferris, 1948; Stallman, 1952). No reliable values for the coefficients of transmissibility and storage could be derived. The data suggested the presence of a nearby recharge boundary, but its distance and direction from the pumped well cannot be determined without additional data.

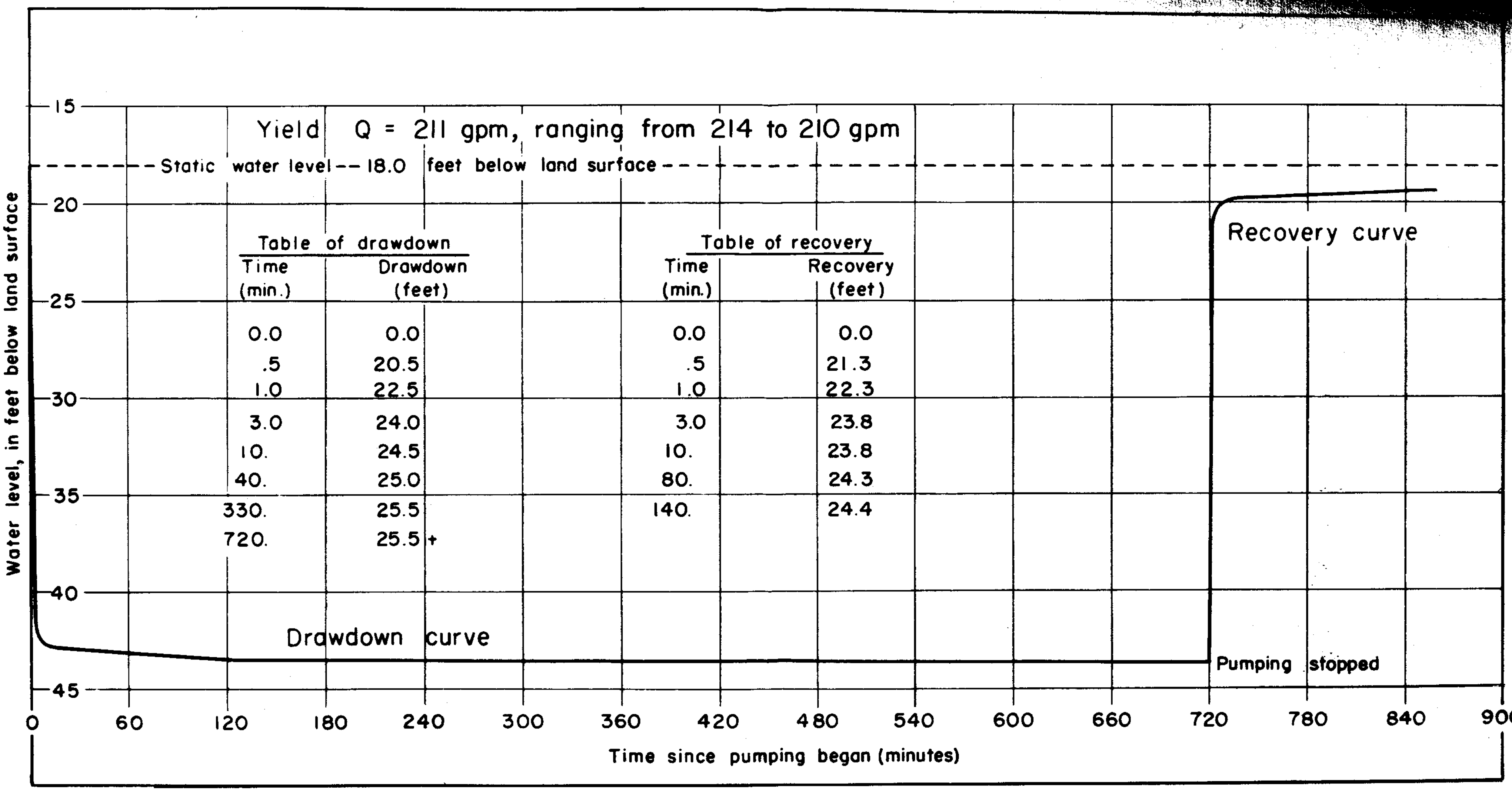


Figure 4.--Graph of water-level drawdown and recovery in test well Je 32-4.

An analysis of water levels observed in a pumped well may be subject to considerable error because of the head losses attributable to such factors as turbulent flow in and near the well screen; size, shape, and arrangement of screen slots; and method and degree of well development. The transmissibility coefficient obtained by observing a pumped well thus may represent only an approximation of the true transmissibility; that is, only if well conditions satisfied the ideal conditions required for the analytical equations would the true aquifer transmissibility be ascertained. By using one or more observation wells, some distance from the pumped well, to avoid turbulence and any distortions in the flow field, more reliable and representative values for the coefficients of transmissibility and storage could be obtained.

An automatic water-stage recorder was installed on well Je32-4 late in June 1957. Records obtained on weekly charts for the period July 2 to September 4, 1957, showed a daily response of this well to the pumping of well Je32-3, about 630 feet southeast of the observation well, and well Je31-1, about 960 feet northeast of the observation well. Both pumped wells are screened in the Cheswold aquifer at depths ranging from 185 to 238 feet below the land surface.

The magnitude of water-level changes is only 0.05 to 0.21 foot in any single drawdown period, and the maximum change occurs only when both wells are being pumped. Two to four drawdown-recovery cycles are recorded each day, the shape of the curves indicating sensitive response. According to the log for well Je32-4 (table 4), the Cheswold aquifer is separated from the Piney Point formation by clay, silt, and sandy clay. The fluctuations indicate that there is upward leakage through this aquiclude.

QUALITY OF WATER

The analysis of water from well Je32-4 is given in table 5 in comparison with the analysis of water from well Je31-2, which is in the same well field but taps a different aquifer. The water from the test well is of the sodium bicarbonate type--that is, the principal cation is sodium and the principal anion is bicarbonate. It is relatively high in dissolved solids (331 ppm), of moderate hardness (82 ppm), and has an iron content (0.24 ppm) that is less than the maximum concentration limit recommended by the U. S. Public Health Service (1946) for municipal water supplies. The fluoride content at 0.5 ppm is within the limit established by the U. S. Public Health Service for drinking water. The water is suitable for most purposes with little or no treatment. It would not be suitable for boiler feed without treatment.

The water from the new source in the Eocene series is higher by more than 50 percent in dissolved solids, about the same in iron content and slightly softer than the water from the Miocene series now being used. The waters from both sources are suitable for most purposes.

TABLE 5.—Water Analyses

Quality of Water Laboratory, U. S. Geological Survey,

Philadelphia, Pa.

	Je31-2 Operating well	Je32-4 New test well
Depth, in feet	233	566
Aquifer	Cheswold aquifer	Piney Point formation
Geologic series	Miocene	Eocene
Date sampled	March 11, 1957	April 17, 1957
Sampled by	Sgt. Salters	D. H. Boggess
Altitude (ft. above msl)	25	24
Static water level (ft. below lsd on sample date)	64	18.0
Chemical components	Parts per million	
Silica (SiO_2)	48	25
Iron (Fe) in solution	.03	.10
Iron (Fe) total	.23	.24
Manganese (Mn) in solution	.02	.00
Calcium (Ca)	27	17
Magnesium (Mg)	4.2	9.4
Sodium (Na))	32	94
Potassium (K))		9.1
Carbonate (CO_3)	7.0	—
Bicarbonate (HCO_3)	161	342
Sulfate (SO_4)	6.7	5.8
Chloride (Cl)	2.3	6.2
Fluoride (F)	.1	.5
Nitrate (NO_3)	.5	1.2
Carbon dioxide (CO_2) calculated	1.0	4.4
Dissolved solids	211	331
Hardness as $CaCO_3$	85	82
Specific conductance (micromhos at 25°C)	278	536
pH	8.3	8.1
Color	3	4

CONCLUSIONS

In summary, it may be observed that the yield of well Je32-4 (307 gpm for a short period) is good despite its small diameter (6 inches), its limited screen length (40 feet), its thin gravel packing (2 inches), and relatively brief development (2 days). The results of a 12-hour period of pumping at 211 gpm indicate that at least one relatively high-yield production well can be constructed here.

The drilling contractor, Herman E. Lauman, has offered the opinion that such a production well, 18 inches or more in diameter, suitably gravel packed and developed, would produce more than 1,000 gpm. However, practically no reliable information has been obtained on the hydraulic characteristics of the aquifer. This knowledge remains to be determined, by means of a carefully controlled aquifer test, after an adequate production well has been developed. Only when reliable coefficients of transmissibility and storage and the positions of impermeable barriers and recharge boundaries are thus ascertained can a reasonable prediction of the performance of this aquifer be made.

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