DESCRIPTION AND RESULTS OF TEST-DRILLING PROGRAM AT PICATINNY ARSENAL, NEW JERSEY, 1982-84

By Philip T. Harte, B. Pierre Sargent, and Eric F. Vowinkel

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM UNITS

For those readers who may prefer to use the metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
inch (in.)	25.4	millimeter (mm)

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ABSTRACT

Picatinny Arsenal, located in north-central New Jersey, has a long history of explosives manufacturing. The legacy of past industrial activities and past waste-disposal practices has caused some ground-water-contamination problems. In 1982, the U.S. Geological Survey, in cooperation with the U.S. Army, began a water-resources investigation of the Arsenal. The test-drilling program is a part of this investigation.

The purpose of the test-drilling program is to define the hydrogeology and install observation wells in the glaciated valley southwest of Picatinny Lake where the Arsenal's ground-water supply wells and some water-contamination problems exist. The program included the drilling of 22 boreholes by the hydraulic-rotary method, collecting lithologic samples by solid-tube sampler and core barrel, borehole geophysical logging, grain-size analysis of 62 lithologic samples, installation of 21 observation wells, and measurement of water levels in wells. This report includes data on lithologic and gamma-ray logs, grain-size analyses, well-construction data and some water-levels. An assessment of the hydrogeology and ground-water quality is in progress.

Most of the observation wells are grouped in clusters. The drilling procedure at a cluster site included the drilling of the first borehole through glacial sediments and into 25 to 40 feet of fresh bedrock where a well was then screened. At this site, other wells were then screened in glacial sediments at different depths. Most of these wells are screened in the principal water-bearing zones as interpreted by lithologic- and borehole-geophysical-log analysis of the bedrock well.

The generalized stratigraphic sequence of geologic units penetrated from the test-drilling program are from lower to upper: (1) predominantly dolomitic Leithsville Formation, (2) in the upper part of bedrock--a weathered dolomite zone, (3) a thin discontinous mantle of till, and (4) stratified drift deposit up to 208 feet thick.

INTRODUCTION

Picatinny Arsenal is located in north-central New Jersey (fig. 1). The installation, formally known as the U.S. Army Armament Research and Development Center, employs approximately 6,400 people in research and development of munitions and weapons. The Arsenal covers 6,491 acres and contains more than 1,500 buildings serviced by approximately 85 miles of road.

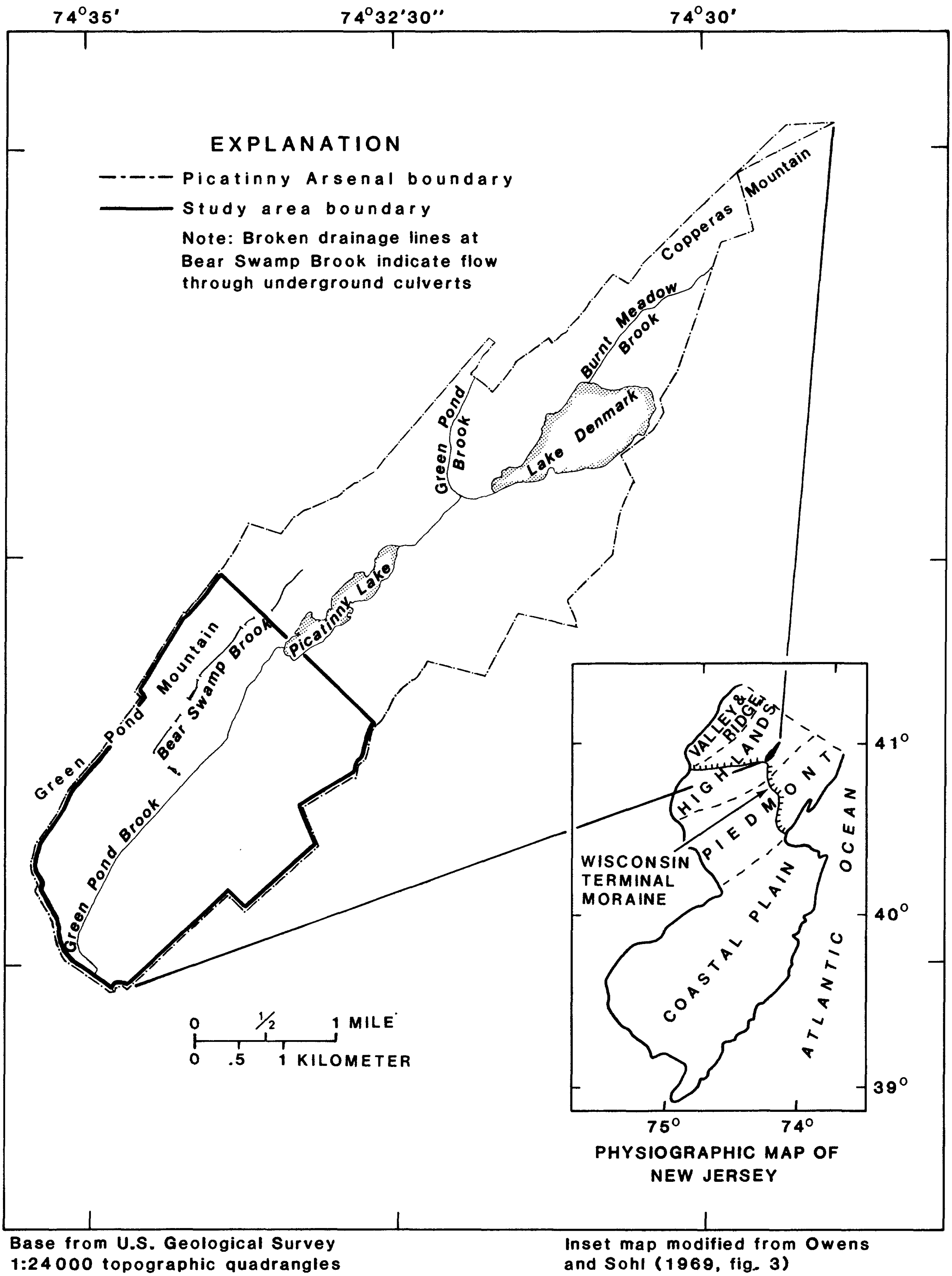


Figure 1.--Picatinny Arsenal, study area, and New Jersey physiography.

The Arsenal has a long history of manufacturing explosives that began in the middle 1800's. In 1908, it was designated a U.S. Army Arsenal. During World War II, 20,000 people were employed to produce artillery, ammunition, bombs, high explosives, pyrotechnics, and other ordnance items. The Arsenal was a major source of munitions for the Korean Conflict and the Vietnam war. The legacy of past industrial activities and past waste-disposal practices has contaminated surface and ground water in parts of the area.

In September 1982, the U.S. Geological Survey began a water-resources investigation of the Arsenal in cooperation with the U.S. Army Armament Research and Development Center. The study area is located southwest of Picatinny Lake where manufacturing activities have caused some ground-water degradation (David Bayha, U.S. Army Environmental Hygiene Agency, written commun., 1982).

The data-collection phase of the investigation has included a regional surface-geophysical survey, construction and maintenance of streamgaging stations, aquifer tests, ground- and surface-water sampling and analysis, and a test-drilling program. The goals of the test-drilling program are to (1) define the number, character and areal extent of the principal aquifers, and (2) install observation wells to collect hydrogeologic and ground-water-quality data. An assessment of the hydrogeology and ground-water quality is in progress.

This report is one phase of a study of the Arsenal. Other phases of the study include the compilation of inorganic and organic water-quality data (Sargent and others, 1986), surface-geophysics reconnaissance (Lacombe and others, 1986), and a geohydrologic and ground-water contamination study (Eric F. Vowinkel, U.S. Geological Survey, written commun., 1986).

Purpose and Scope

The purpose of this report is to describe and to provide geologic and hydrologic information resulting from the 1982-84 test-drilling program.

The test-drilling program included test drilling, lithologic sampling, borehole geophysical logging, grain-size analyses, installing 21 observation wells (16 wells grouped in 5 clusters), and measuring some water levels. All drilling was done in the glaciated valley southwest of Picatinny Lake where the Arsenal's ground-water supply wells are located and where some water-contamination problems have been detected. Emphasis was placed on drilling and installing observation wells in contaminated areas (David Bayha, U.S. Army Environmental Hygiene Agency, written commun., 1982) and in discovering high-yield water-bearing zones. The drilling, which was done by the U.S. Army Corps of Engineers under U.S. Geological Survey supervision, was performed in two phases: the first, September 1982 through November 1983; and the second, November 1983 through February 1984.

Location and Description of the Study Area

Picatinny Arsenal is located in north-central New Jersey (fig. 1). The Arsenal is rectangular in shape, approximately 8.5 miles long by 1.5 miles wide. It is situated in an elongated northeast-southwest trending valley bounded by Green Pond Mountain on the west, Green Pond and Copperas Mountains near the northwestern border, and an unnamed ridge to the southeast. Green Pond and Copperas Mountains are characteristically rugged, rocky, and steeply sloped with a maximum altitude of 1,200 feet above National Geodetic Vertical Datum of 1929 (NGVD of 1929). The southeastern ridge is not as rugged or steeply sloped and has a maximum altitude of 1,100 feet above NGVD of 1929. The valley is drained to the southwest primarily by Green Pond Brook. It has two man made lakes--Lake Denmark and Picatinny Lake.

The study area is located in the glaciated valley southwest of Picatinny Lake (fig. 1 and pl. 1). The area is drained by a number of small brooks and drainage ditches in addition to Green Pond Brook. Topography is flat and generally at an altitude of 700 feet. Some parts of the areas are swampy, prone to flooding, and generally underlain by organic-rich soils (muck). In the developed areas, a stony-fill has been added to give support to structures.

Geologic Setting

The Arsenal is located in the central part of the New Jersey Highlands (fig. 1). The Highlands are characterized by a northeast-southwest trending system of folded and faulted Precambrian to Devonian rocks that form a sequence of valleys and ridges. Wisconsin glacial till occurs in the form of ground, recessional and terminal moraines. The Wisconsin terminal moraine is located across the middle of the Highlands; glacial till of this age occurs north of the moraine. In most places, glacial till is discontinuous on ridges and in the valleys (Salisbury, 1902). In some valley areas, glacial stratified drift directly overlies the till, or in places where till is absent, it overlies the bedrock.

The general stratigraphic relations, lithology and water-bearing characteristics of the geologic units located at the Arsenal are given in table 1. The generalized bedrock geology is shown in figure 2. A brief description of these geologic units follows.

Precambrian gneiss is the oldest bedrock unit, comprised predominantly of three mineralogic rock types (Sims, 1958, Pl. 1) as shown in table 1. In general, the gneiss crops out along the eastern part of the Arsenal and in part of the valley (fig. 2).

Table 1.--Stratigraphic and geohydrologic characteristics of geologic units at Picatinny Arsenal

Geologic time	Time-stratigraphic units		Geologic unit	Maximum thickness (in feet)	Lithology	Geohydrologic characteristics
Era	System	Series	Formation or lithologic unit			
Cenozoic	Quaternary	Holocene	Alluvium	10	Ranges from a sandy loam in the valley to a stony gravel on hillsides.	Too thin to be tapped.
			Swamp Deposits	30	Black, brown and gray organic material.	Permeability rapid along organic layers.
		Pleistocene	Stratified drift	200+	Present in the form of glaciofluvial and glaciolacustrine deposits, mostly sand to clay size sediments, exhibits stratification and in some cases rhythmic laminations (varves).	Yields dependent on degree of sorting and grain size. The well-sorted and coarse-grained deposits are good aquifers with yields up to 2,200 gal/min. Clay and silt deposits are generally unsuitable as aquifers.
			Unstratified drift	100+	Unstratified drift deposits are present in the form of ground, terminal and recessional moraines. Deposits are generally tightly packed and poorly sorted with grain sizes, ranging from boulders to clay.	Yields dependent on degree of sorting and packing. Generally low yields.
					Unconformity	
Paleozoic	Silurian		Green Pond Conglomerate	1500+	Coarse quartz conglomerate interbedded with and grading upward into quartzite and sandstone. Generally massive and red but also may have white and green beds.	Generally yields small amount of water from fracture and joints.
					Unconformity	
	Cambrian	Middle	Leithsville Formation	1000+	Predominantly a light- to medium-gray, microcrystalline, locally stylolitic rock to a fissile, siliceous to dolomitic micrite rock. Often highly weathered into a medium-yellow silty clay.	Contains water bearing fractures and cavities that generally have moderate yields of up to 380 gal/min.
					Gradational	
		Lower	Hardyston Quartzite	200	Orthoquartzite to conglomerate, generally well indurated.	Generally few fractures, yields small amounts of water.
					Unconformity	
Precambrian			Alaskite		Medium- to coarse-grained predominantly granitoid gneiss composed principally of microperthite, quartz, and oligoclase. Includes local bodies of microantiperthite granite and granite pegmatite. Amphibolite inclusions are common.	
			Hornblende granite	Basement	Medium- to coarse-grained predominantly granitoid gneiss, composed principally of microperthite, quartz, oligoclase, and hornblende. Includes local bodies of biotite granite, hornblende granite gneiss, granodiorite, and granite pegmatite. Amphibolite inclusions are common.	All three lithologic units are similar in hydrologic characteristics. Ground water occurs in fractures and joints. Yields are generally low, from 26 to 75 gal/min.
			Biotite-quartz-feldspar gneiss		Medium- to coarse-grained gneiss of widely different composition. The predominant facies is composed of biotite, quartz, and oligoclase; minor facies are characterized by abundant garnet and microperthite, and locally by sillimanite and graphite.	

[1] Modified from Drake, 1969, table 20, Sims, 1958, plate 1, Gill and Vecchioli, 1965, table 3.

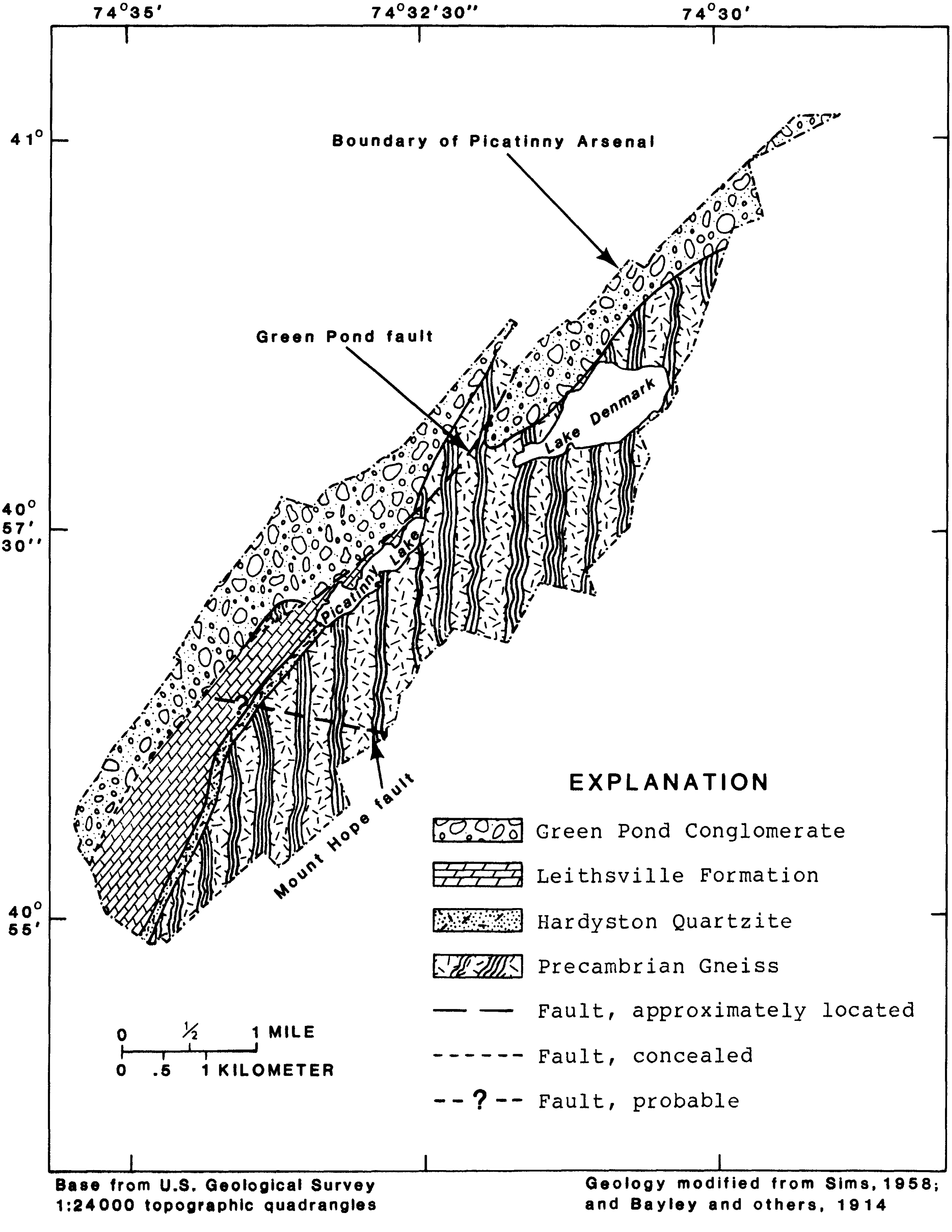


Figure 2.--Generalized bedrock-geology of Picatinny Arsenal, New Jersey.

The Hardyston Quartzite is a Cambrian age orthoquartzite to quartzitic conglomerate, which unconformably overlies the Precambrian gneiss (Drake 1969, p. 77). In New Jersey, the Hardyston Quartzite ranges in thickness from several feet to 200 feet (Drake, 1969, p. 78). At the Arsenal, the Hardyston Quartzite does not crop out and underlies only a small area of the glacial deposits to the southeast (fig. 2) (W. D. Nichols and John Vecchiolli, U.S. Geological Survey, written commun., 1965).

The Leithsville Formation is an Early to Middle Cambrian-age carbonate sequence, consisting predominantly of dolomite with some thin beds of quartzitic or dolomitic sandstone (Drake, 1969, p. 79). The lower contact is gradational with the underlying Hardyston Quartzite (Drake, 1969, p. 78). The Leithsville Formation underlies a large area of the glacial deposits (F. J. Markewicz, N. J. Geological Survey, oral commun., 1983) and crops out on the western shore of Picatinny Lake.

The Green Pond Conglomerate of Silurian age is the youngest bedrock unit and is the principal rock comprising Green Pond Mountain. The lower contact with the Leithsville is not visible but is believed to be separated by the steeply dipping Green Pond fault (Kummel and Weller, 1902, p. 12). The fault is present between Green Pond and Copperas Mountains where the Green Pond Conglomerate is next to an upthrown block of Precambrian gneiss (Sims, 1958, Plate 1). The Green Pond fault extends southwest to Picatinny Lake (Kummel, and Weller, 1902, p. 12).

Wisconsin-age unconsolidated glacial sediments were deposited at the end of the Pleistocene Epoch. The deposits are divided into unstratified drift--deposited directly by the glacier; and stratified drift--deposited by glacial meltwaters.

The unstratified drift (till) is generally poorly sorted and tightly packed; grain sizes range from boulders to clay. The till is present in ground, terminal, and recessional moraines. Till generally forms a thin cover overlying the bedrock on ridges and along the lower part of the valley (Salisbury, 1902. p. 473); however, it is thick between Green Pond and Copperas Mountains (Salisbury, 1902, p. 474). The Wisconsin terminal moraine is located on the southeastern edge of the Arsenal (Sims, 1958, Plate 1). A recessional moraine is located just south of Picatinny Lake (W. D. Nichols, and John Vecchiolli, U.S. Geological Survey, written commun., 1965).

During glacial retreat, meltwater streams deposited sediments in the valley (W. D. Nichols and John Vecchiolli, U.S. Geological Survey, written commun., 1965). These stratified drift deposits are generally well sorted and consist of interbedded gravel, sand, silt and clay. These deposits also can contain gravel-to-boulder-size material. Stratified drift is present predominantly in the valley southwest of Picatinny Lake. Before the test-drilling program, the thickness and distribution of deposits in the valley were not known.

Well-Numbering System

The system used in this report is based on the U.S. Geological Survey (New Jersey District) well-numbering system. The number consists of a two-digit county code and a four-digit sequence number assigned to the well. The Morris County code is 27. A representative well number is 27-242 for the 242nd well inventoried in Morris County. In this report, all wells are in Morris County; therefore, only the sequence number is used. In addition, many wells have been informally identified by the name of the closest building or other man-made feature. These informal names are used in this report, along with the well numbers, so that persons familiar with the Arsenal can more easily identify and locate wells.

Acknowledgments

The authors extend their appreciation to the Environmental Engineering Section of the U.S. Army Armament Research and Development Center for assistance in the test-drilling program and to David Bayha of the U.S. Army Environmental Hygiene Agency.

DESCRIPTION OF TEST-DRILLING PROGRAM

The drilling program occurred in two phases and encompassed drilling 22, 8-inch-diameter boreholes by the hydraulic-rotary method with a total drilling footage of more than 2,900 feet. Twenty-one observation wells were installed in these holes. Five deep wells are screened in bedrock; the other 16 wells are screened in glacial sediments. Sixteen of the 21 wells are located in 5 clusters (pl. 1). Wells are grouped in clusters and screened at different depths to help determine ground-water flow, hydraulic characteristics, and water quality of the different aquifers. Wells located individually are installed for much the same reasons; however, they provide only data for individual aquifers. Table 2 lists pertinent well information. A logistical discussion of drilling procedures follows.

Phase-one drilling, from September 1982 through November 1983, consisted of installing 11 wells grouped in the Cafeteria, Building 65 and Landfill clusters. The cluster wells are:

Cluster	Well
Cafeteria	242
	243
	244
	245
Building 65	246
	247
	248
	249
Landfill	250
	251
	252

Phase-two drilling, from November 1983 through February 1984, consisted of installing 10 wells, including 5 wells in 2 clusters. The cluster wells are:

Cluster	Well
176	277
	278
H	280
	281
	282

Individual wells include 268, 276, 269, 270, and 271.

At each well cluster, the drilling procedure included drilling an exploratory borehole through glacial sediments into underlying bedrock. Drilling continued through 25 to 40 feet of fresh bedrock, where an observation well was then completed. Shallower boreholes were drilled at the same site in a cluster and the wells were screened in the glacial sediments. The selected screened intervals were based on the analysis of lithology and geophysical logs from the first hole in each cluster. Most observation wells are screened in the principal water-bearing zones. An outer 8-inch-diameter metal casing was installed during drilling to prevent hole collapse. The metal casing was pulled after the 4-inch polyvinyl chloride (PVC) well casing was installed.

At individual wells, the drilling procedure included drilling to some predetermined depth or until bedrock was encountered. Screen intervals selected were based on lithologic and geophysical logs.

Core samples were collected from five bedrock wells at cluster sites and from five individual wells. Samples generally were collected continuously or every 10 feet by a 5-foot-long solid-tube sampler in glacial sediments and continuously by diamond-bit-core barrel in bedrock. Drill cuttings were observed if there was poor recovery by the solid-tube sampler or core barrel. This occurred in coarse gravel to boulder layers. In most cases, drill cuttings from weathered bedrock also were observed. In contrast, sampling at well 246 was done solely by core barrel because of the predominance of fine sediments, which permitted retrieval by core barrel.

Well Construction and Development

Observation wells from the test-drilling program are constructed of 4-inch-diameter PVC casings and screens. Screen slot sizes are generally 0.02-inch in coarser-grained sediments and bedrock and 0.01-inch in fine-grained sediments. Well screen lengths are 15 to 30 feet in bedrock and 5 to 10 feet in unconsolidated sediments.

Typical construction of observation wells in bedrock and in unconsolidated sediments from the test-drilling program are shown in figure 3.

After the PVC casing and screen were set in the borehole, the following materials were introduced into the annulus:

1. a fine gravel pack to fill the annular space around the screen,

2. a 1-foot-thick sand layer overlying the gravel,

3. bentonite pellets above the sand to prevent vertical migration of fluid in the annulus, and

4. cement grout or bentonite slurry to fill the remainder of the annulus.

Wells were developed using a submersible pump, the intake of which was set near the screen. Wells were pumped until the water appeared clear. Development time ranged from a minimum of a few hours to a maximum of 36 hours. In some wells, an air compressor was used to assure maximum development by airlifting water out of wells. Static water levels, pumping water-levels and discharges were monitored (table 2).

Lithologic and Geophysical Logs

Borehole/well stratigraphy is based on information from lithologic and borehole geophysical logs. This information was then compared with results of grain-size analyses.

Borehole gamma-ray, caliper and electric (spontaneous-potential and resistance) geophysical logs were run before well installation; gamma-ray logs were run again after well installation. The logs were run in bedrock wells at cluster sites and at individual wells. Most caliper and electric logs were run in weathered and fresh bedrock. Gamma-ray logs were the primary geophysical logs used to help understand well stratigraphy. For this reason, gamma-ray logs were run a number of times to assure reliability of data.

Figures 4 through 11 show generalized lithology, silt and clay content of selected samples, and gamma-ray logs from wells. Table 3 contains more detailed lithologic-log information. Information on caliper and electric logs is not given in this report but is available from the New Jersey District of the U.S. Geological Survey.[1]

[1]U.S. Geological Survey, Water Resources Division, Mountain View Office Park, 810 Bear Tavern Road, Suite 206, West Trenton, N.J. 08628, 609-771-3900, Philip T. Harte.

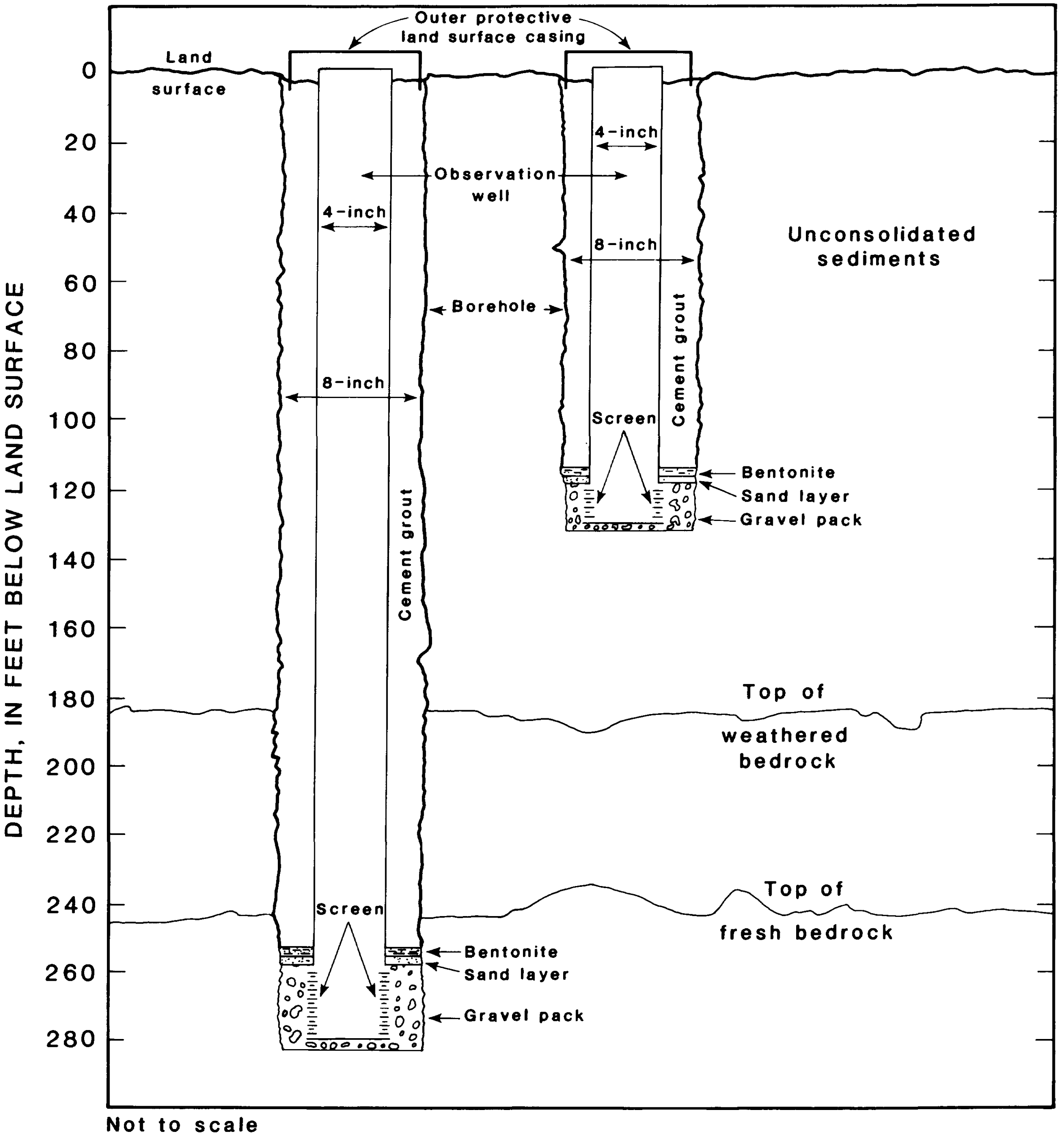


Figure 3.--Generalized diagram showing observation-well construction in bedrock and unconsolidated sediments.

Table 2.--Selected data from observation wells.

[1]Well number	Local identifier	Date completed	Altitude of land surface (feet above NGVD of 1929)	Screen setting (feet below LSD)	Geologic unit	Static water level (feet below LSD)	Date water level measured	Pumping water level (feet below LSD)	Pumping period (hr.)	Yield (GPM)
242	Cafeteria 1	11/12/1982	702.7	253-268	377HRDS	21.4	8/14/1985	38.2	1.6	7.0
243	Cafeteria 2	11/12/1982	702.7	31-36	112SFDF	11.7	8/14/1985	12.2	0.3	4.0
244	Cafeteria 3	11/17/1982	702.8	123-128	112SFDF	25.4	8/15/1985	26.3	0.8	6.0
245	Cafeteria 4	12/10/1982	702.9	168-173	112SFDF	24.6	8/15/1985	----	1.7	4.0
246	Bldg 65-1	12/16/1982	699.9	267-287	374LSVL	18.1	8/21/1985	47.0	0.8	5.5
247	Bldg 65-2	12/09/1982	699.9	201-206	112SFDF	20.8	8/15/1985	26.3	1.5	5.0
248	Bldg 65-3	12/15/1982	700.0	135-140	112SFDF	14.3	8/21/1985	[3]----	1.5	4.0
249	Bldg 65-4	12/15/1982	699.9	30-35	112SFDF	9.2	8/16/1985	12.2	0.3	5.0
250	Landfill 1	11/01/1982	692.8	317-337	374LSVL	19.8	1/06/1983	----	---	1.0
251	Landfill 2	12/07/1982	693.3	60-65	112SFDF	18.8	1/04/1983	56.5	---	8.0
252	Landfill 3	12/14/1982	693.1	152-157	112SFDF	18.4	1/05/1983	144.3	---	5.4
268	151	12/01/1983	694.4	25-30	112SFDF	3.3	1/05/1984	----	---	9.0
269	12D	12/03/1983	694.0	25-30	112SFDF	5.1	8/13/1985	7.2	1.0	7.0
270	12E	12/06/1983	690.0	15-20	112SFDF	1.7	12/9/1983	[3]----	---	2.9
271	320	12/13/1983	696.6	25-30	112SFDF	5.6	1/20/1984	8.7	---	42.8
276	178	01/28/1984	698.9	64-74	112SFDF	10.1	1/30/1984	11.3	---	42.8
277	176 Deep	04/03/1984	689.4	275-305	374LSVL	[2]2.6	3/05/1984	12.5	---	10.0
278	176 Shallow	01/24/1984	689.3	50-60	112SFDF	[2]2.5	3/05/1984	0.9	---	50.0
280	H Deep	04/18/1984	699.2	203-223	374LSVL	14.0	8/14/1985	[3]----	---	5.0
281	H Medium	04/20/1984	699.2	115-125	112SFDF	14.4	8/14/1985	33.5	---	8.0
282	H Shallow	04/23/1984	699.0	15-25	112SFDF	9.5	8/14/1985	10.3	0.5	5.0

Explanation of Codes

LSD is an abbreviation for Land Surface Datum which is a datum plane approximately at the land surface at the well.
NGVD is National Geodetic Vertical Datum of 1929.
GPM is an abbreviation for gallons per minute.

Geologic Unit

112SFDF	Stratified drift
374LSVL	Leithsville Formation
377HRDS	Hardyston Quartzite

[1] Well number includes sequence number only, county code is 27.
[2] Water level above land surface.
[3] Well went dry.

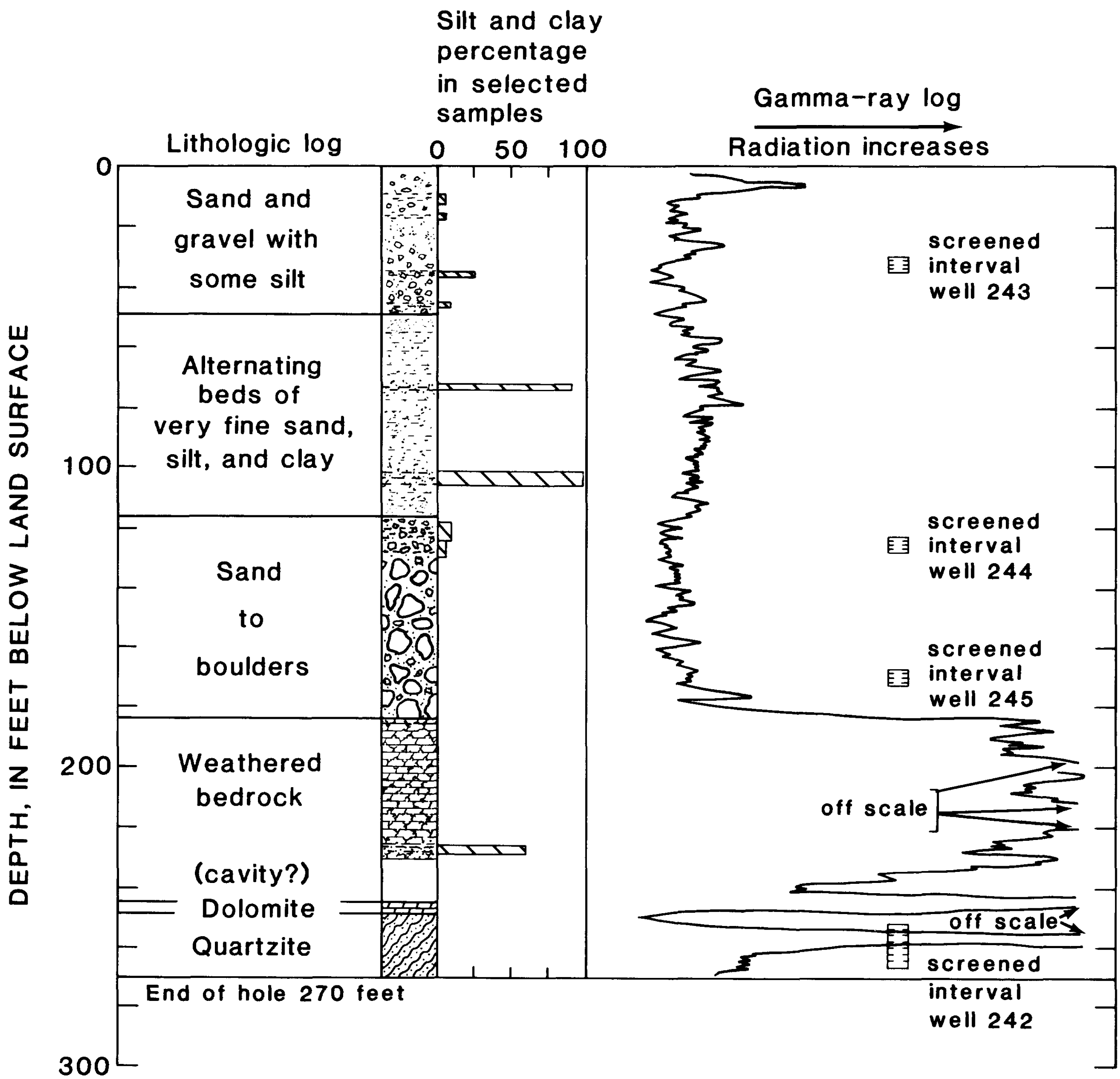


Figure 4.--Lithologic log, grain-size histogram, and gamma-ray log for well 242 (Cafeteria 1); and screened intervals for Cafeteria cluster wells.

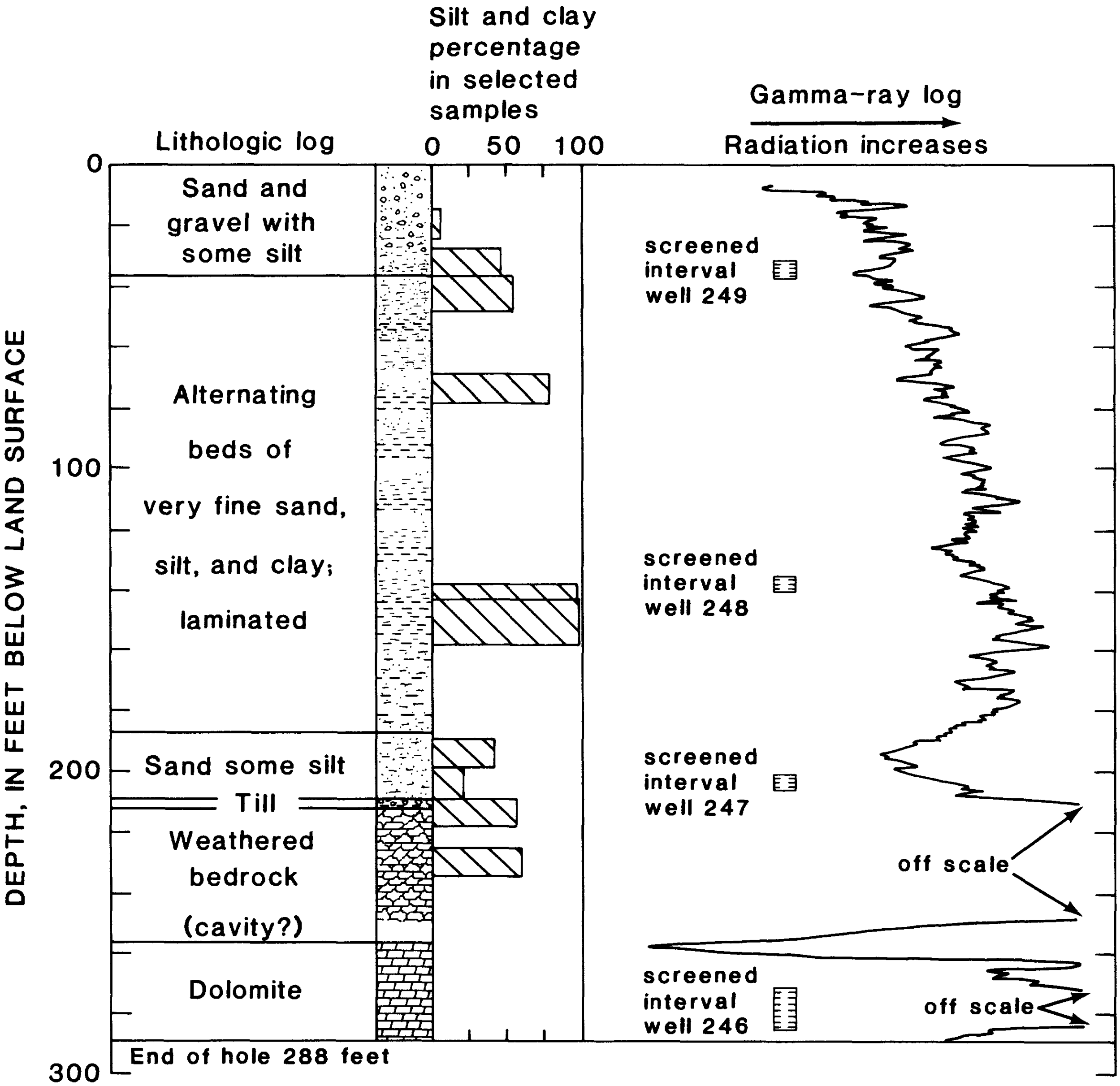


Figure 5.--Lithologic log, grain-size histogram, and gamma-ray log for well 246 (Building 65-1); and screened intervals for Building 65 cluster wells.

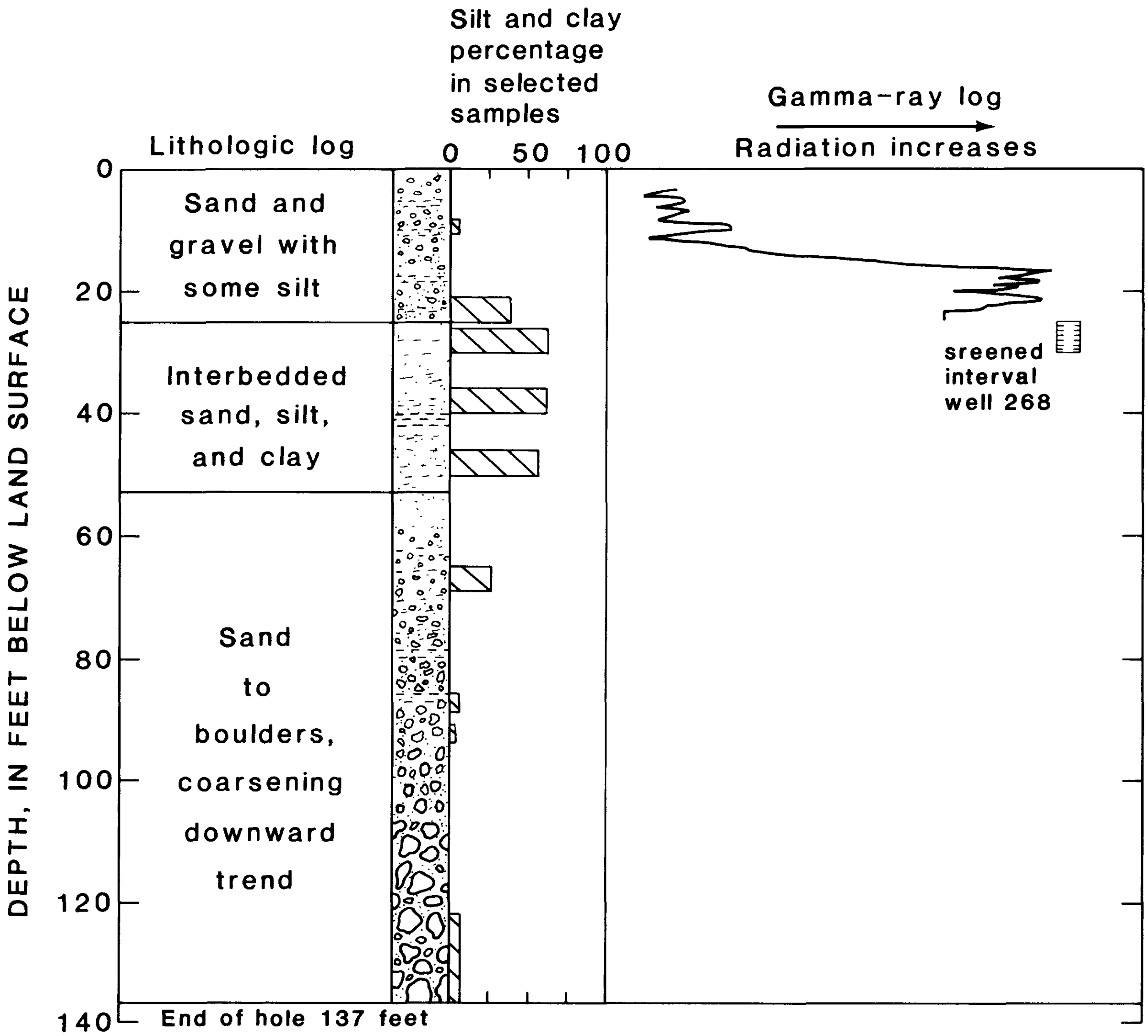


Figure 6.--Lithologic log, grain-size histogram, gamma-ray log, and screened interval for well 268.

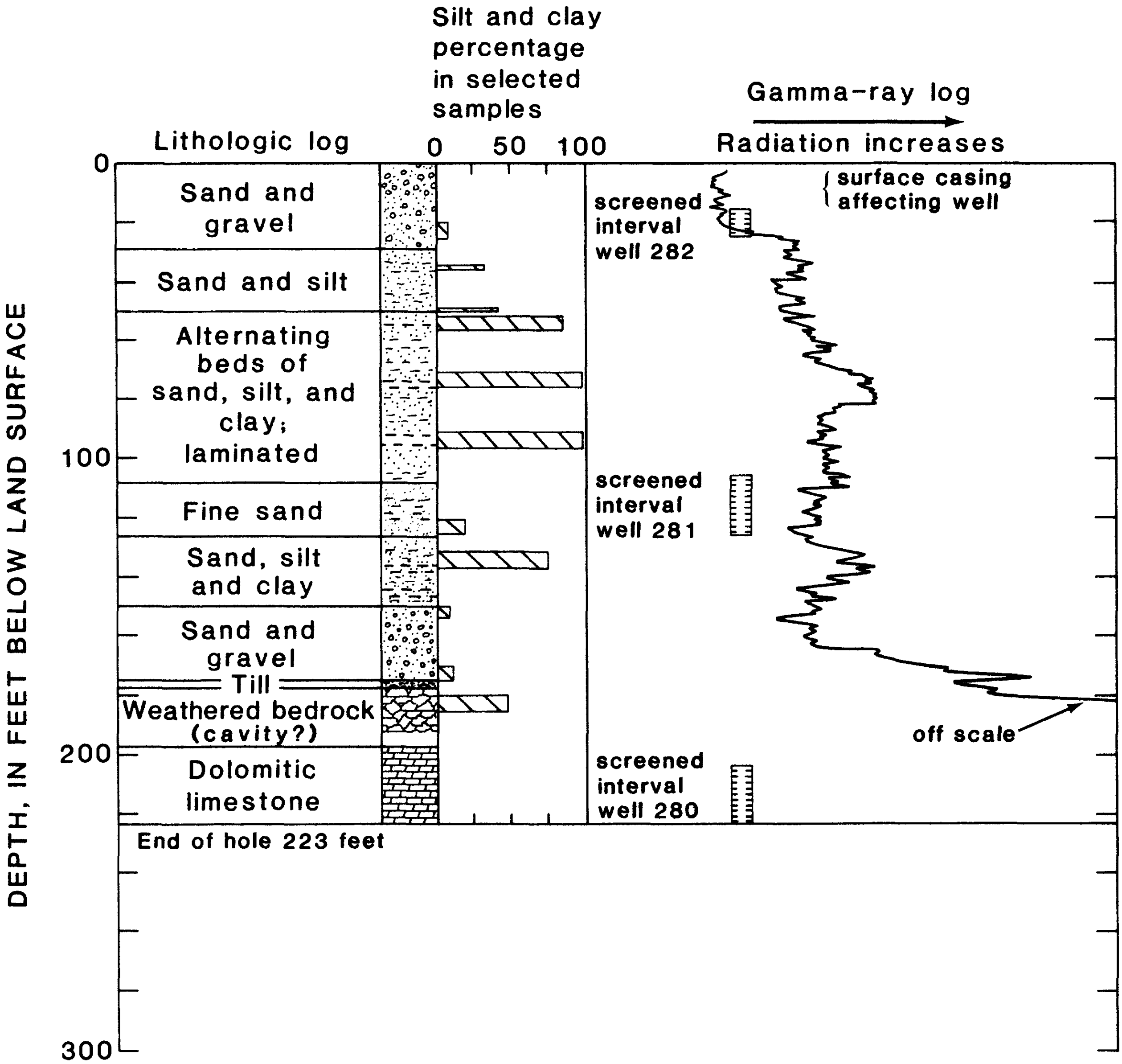


Figure 7.--Lithologic log, grain-size histogram, and gamma-ray log for well 280 (H deep); and screened intervals for H cluster wells.

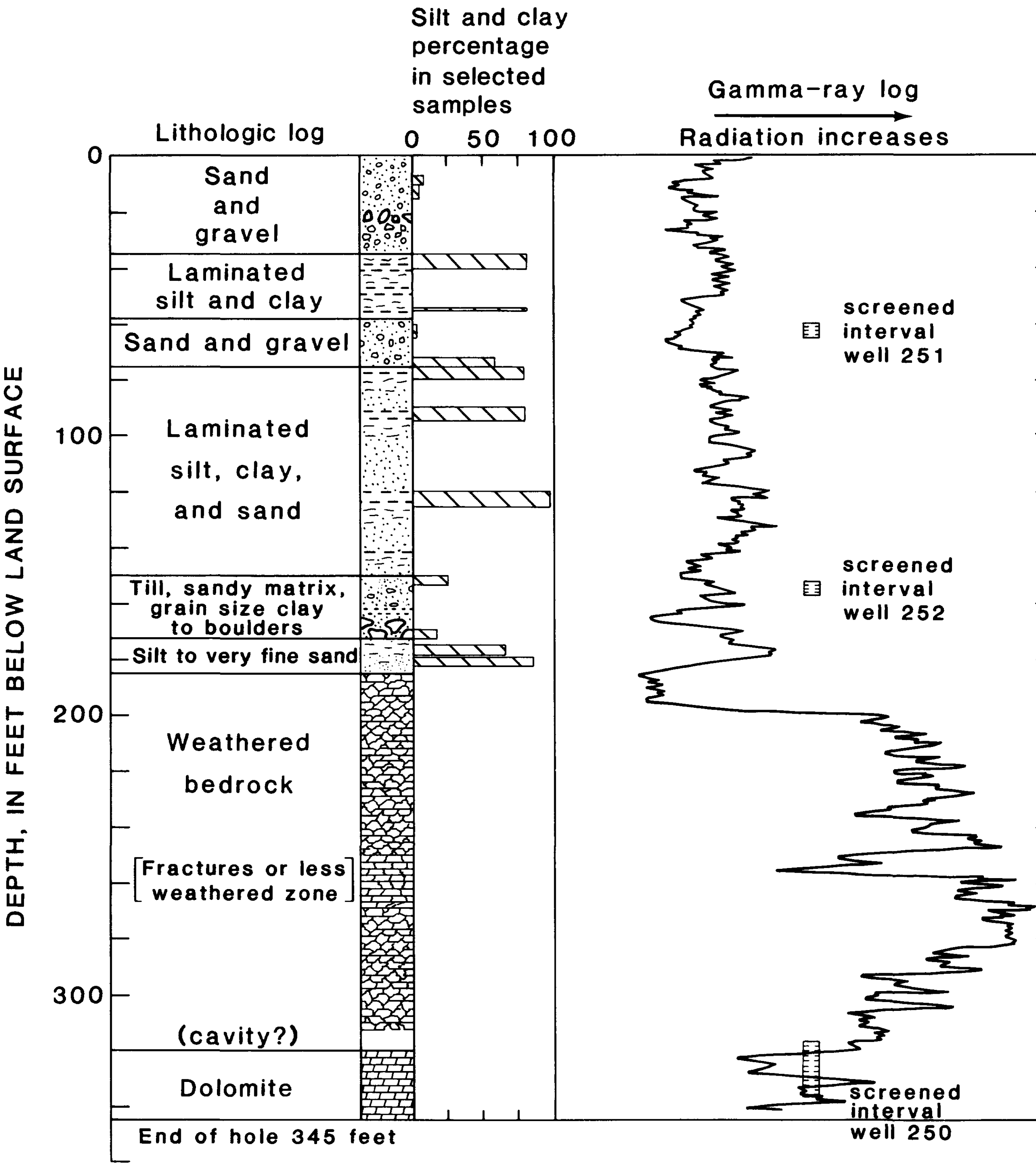


Figure 8.--Lithologic log, grain-size histogram, and gamma-ray log for well 250 (Landfill 1); and screened intervals for landfill cluster wells.

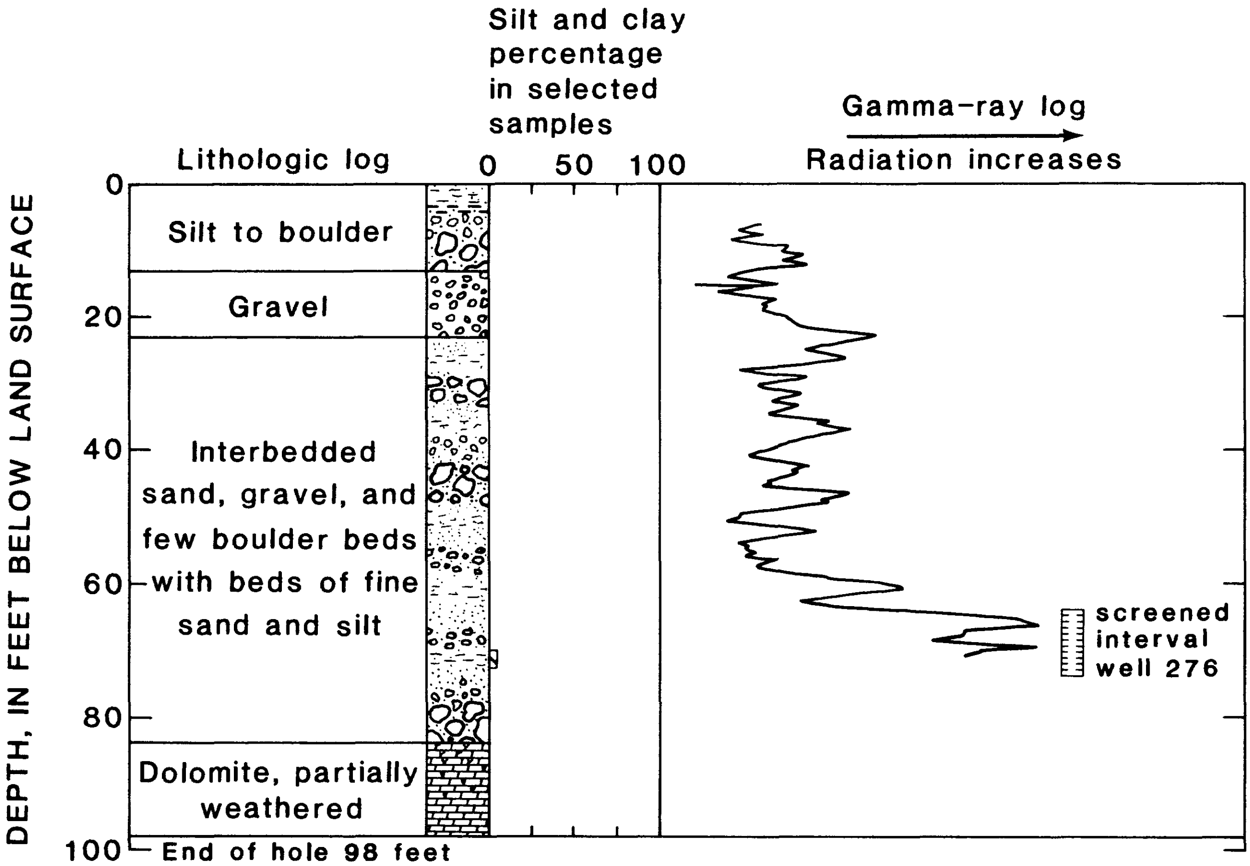


Figure 9.--Lithologic log, grain-size histogram, and gamma-ray log, and screened interval for well 276.

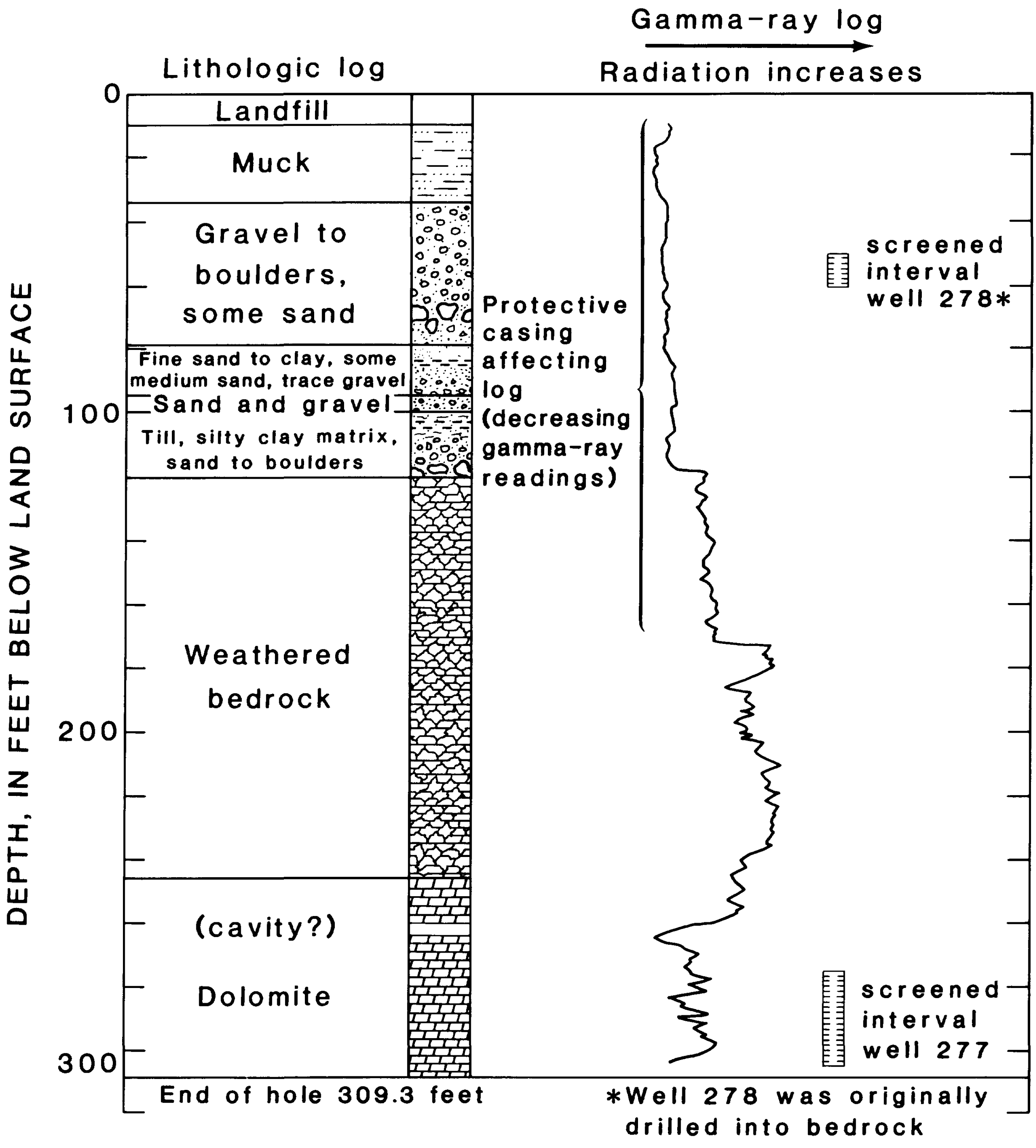


Figure 10.--Lithologic logs, gamma-ray logs, and screened intervals for wells 278 and 277.

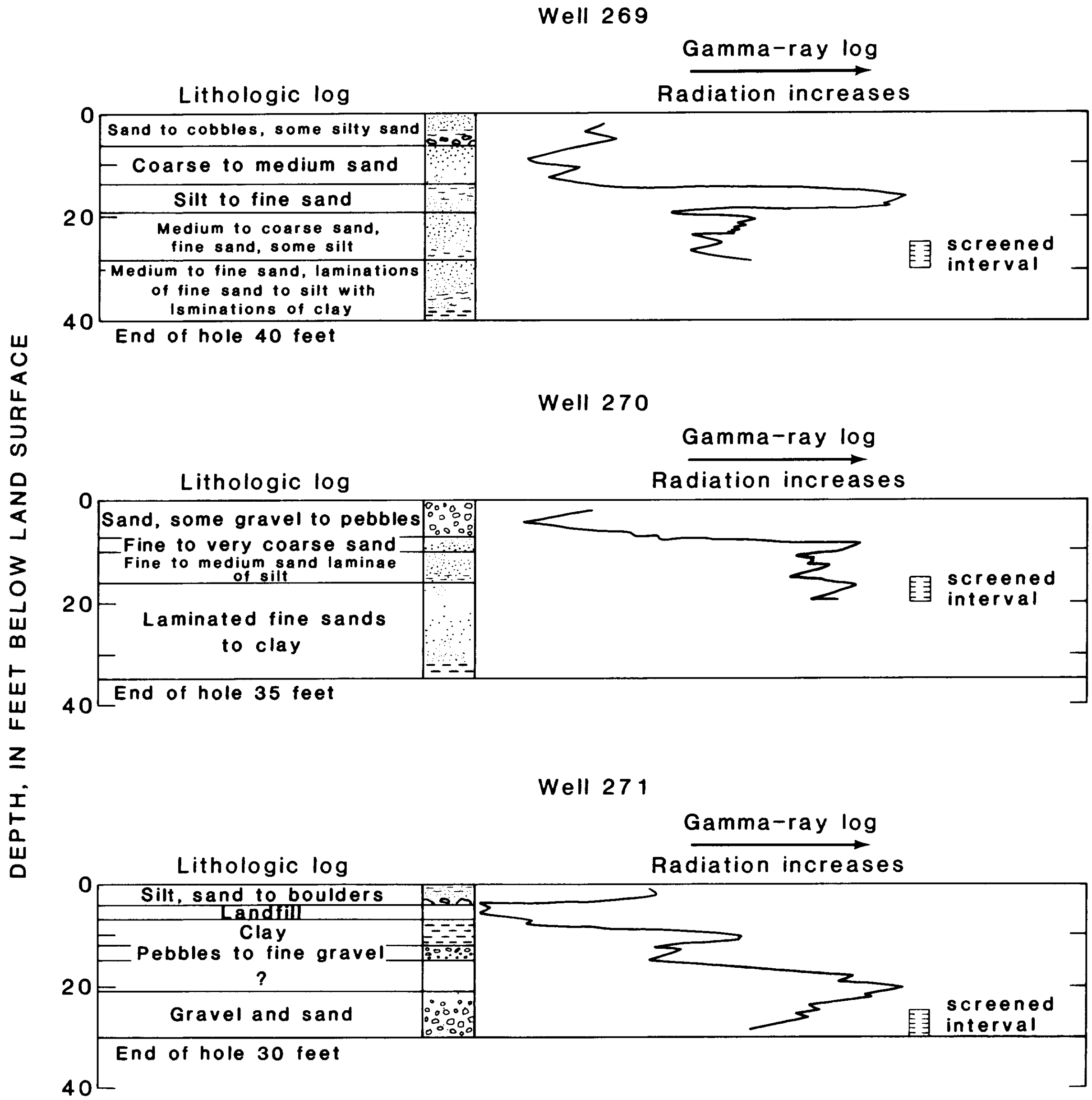


Figure 11.--Lithologic logs, gamma-ray logs, and screen intervals for wells 269, 270, and 271.

Grain-size Analysis

Analyses were made by Woodward-Clyde Consultants of Clifton, New Jersey on 62 lithologic samples: 52 from a solid-tube sampler and 10 from a core barrel. The 62 samples included 58 from glacial sediments and 4 from weathered bedrock. The Unified Soil Classification of the U.S. Bureau of Reclamation of 1974 (U.S. Geological Survey, 1977) was used to classify grain size.

Samples were dry sieved to 0.074 millimeters, which differentiated grain size coarser than silt and clay. Histograms showing percentage of silt and clay for selected samples are shown with lithologic and gamma-ray logs (fig. 4 thru 9). Grain-size-distribution graphs are shown for selected wells (fig. 12 thru 16).

RESULTS OF TEST-DRILLING PROGRAM

Consolidated Rocks (Bedrock)

Two consolidated rock types were encountered during drilling: the Hardyston Quartzite in well 242 and the Leithsville Formation encountered above the Hardyston Quartzite at this well and in the remainder of the bedrock wells. The remaining bedrock wells are 246, 280, 250, 276, 277 and 278. The contact between the Hardyston and Leithsville Formation is gradational in well 242 (table 3). The transition is marked by a dolomite layer with intercalated detrital quartz grains.

The Leithsville Formation is easily eroded and commonly weathered (Markewicz and Dalton, 1980). A weathered dolomite zone was present above the fresh bedrock in all boreholes drilled into bedrock. The zone is characterized by a medium-yellow silty clay and less weathered indurated layers. At well 276 the dolomite was not as decomposed (table 3). The weathered bedrock maximum thickness encountered during drilling is 135 feet at well 250 (Landfill). Below is a list of bedrock wells and the depth to weathered bedrock for each well:

Well Number	Depth to weathered bedrock, in feet
242 (Cafeteria)	184.0
246 (Building 65)	209.4
280 (H)	177.0
250 (Landfill)	185.0
276	84.0
278 (176)	120.0

In many of the above wells, solution cavities are present at the contact of weathered and fresh bedrock.

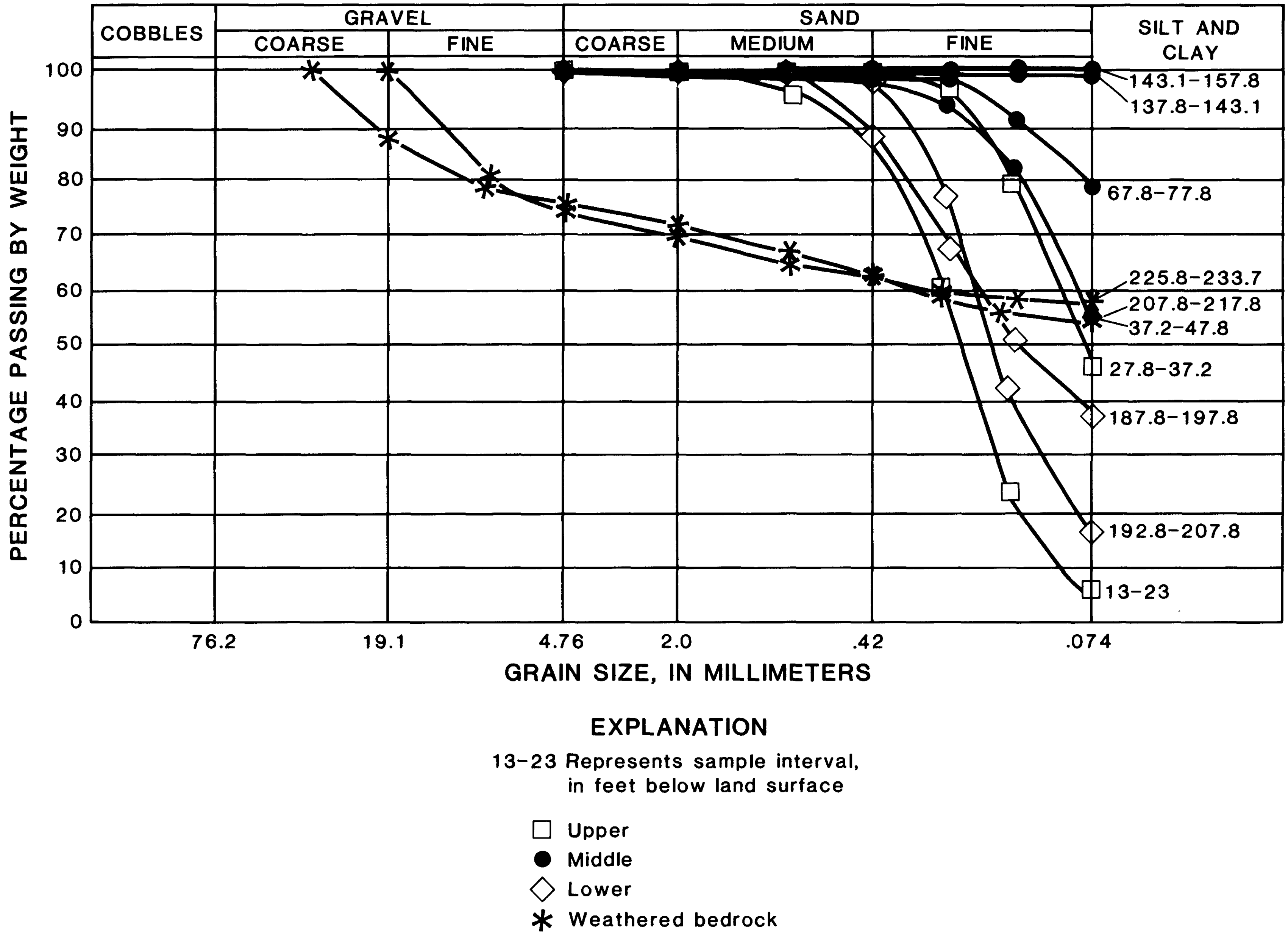


Figure 12.--Grain-size distribution of core samples from well 246 (Building 65).

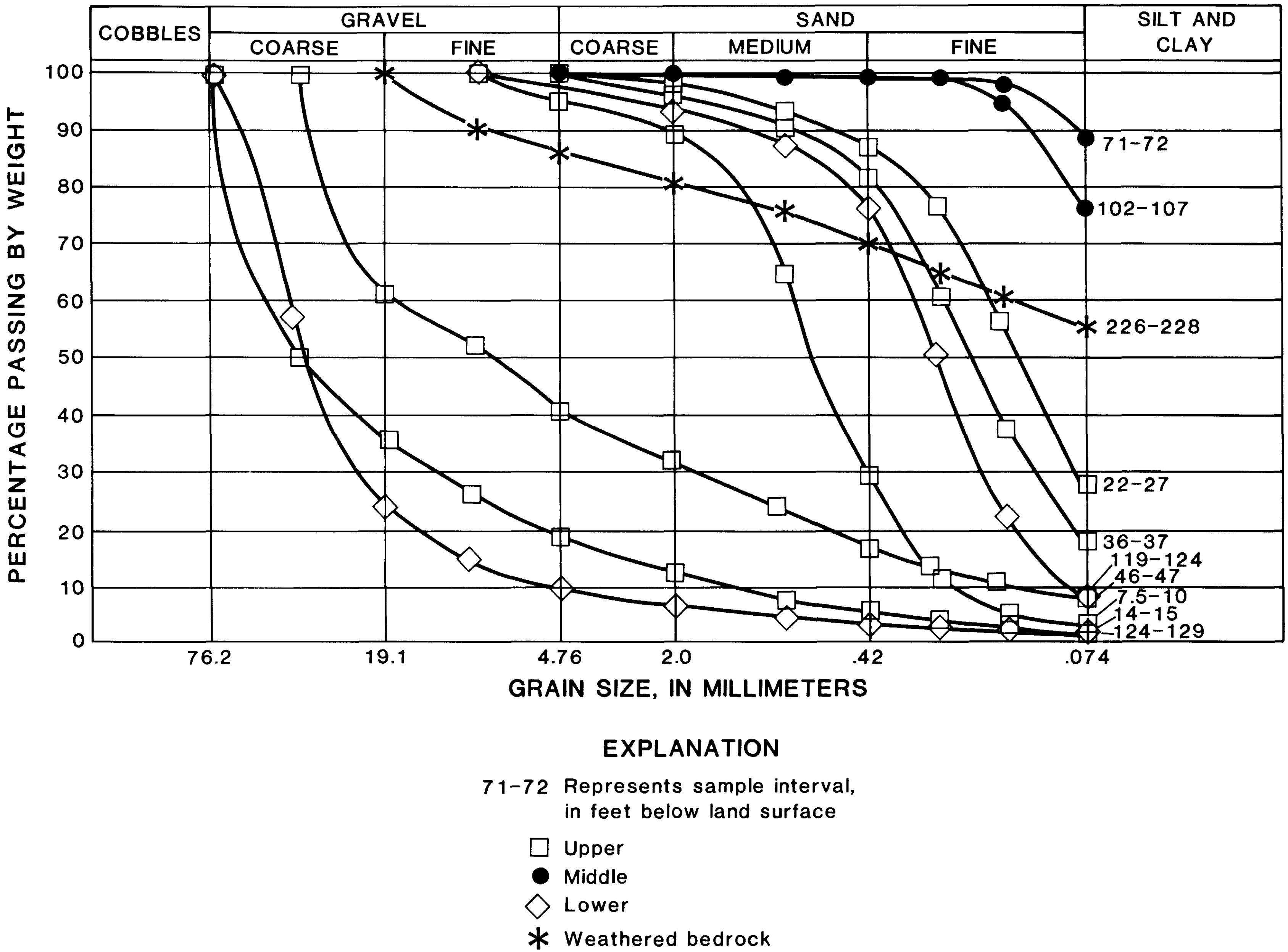


Figure 13.--Grain-size distribution of core samples from well 242 (Cafeteria).

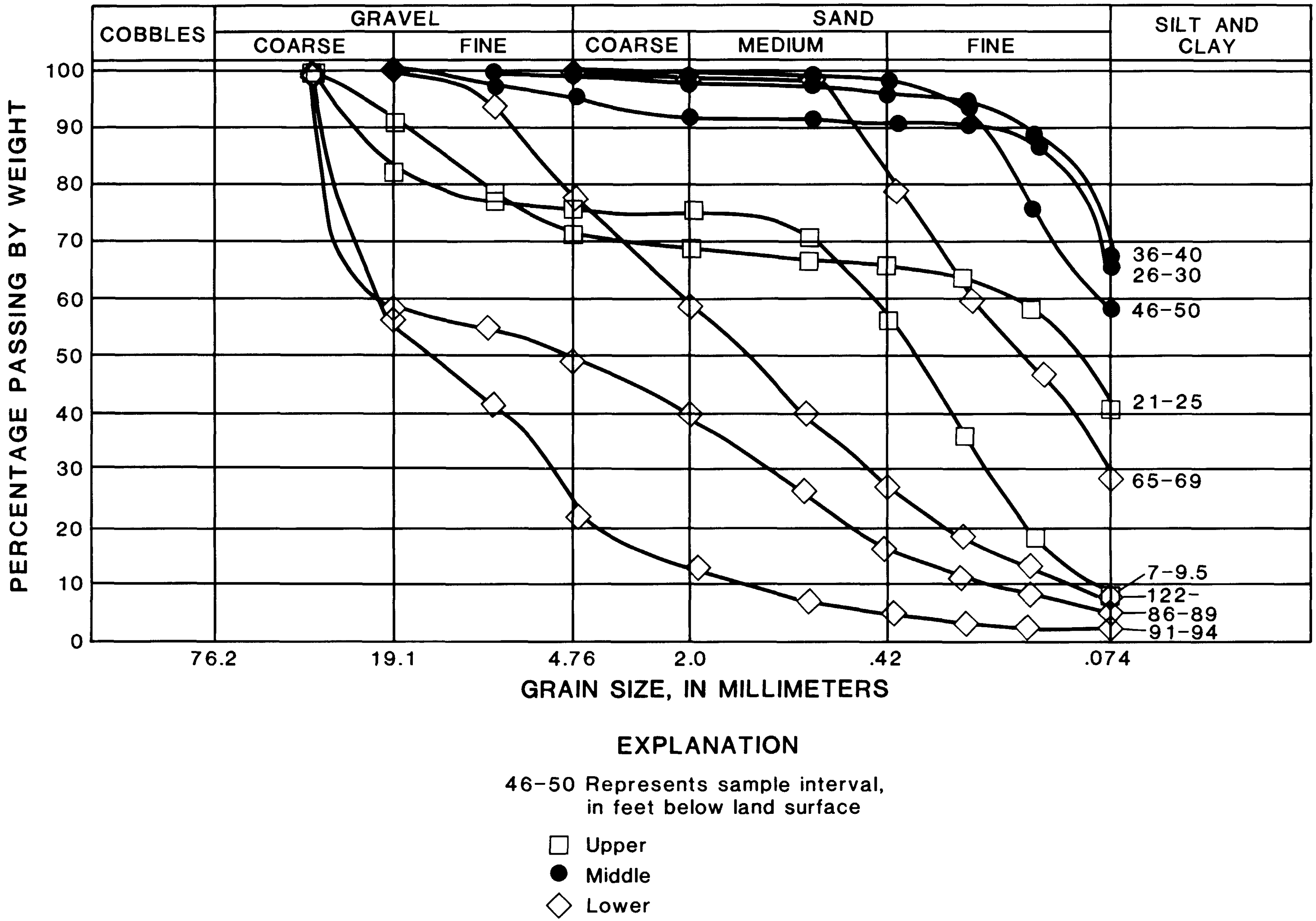


Figure 14.--Grain-size distribution of core samples from well 268.

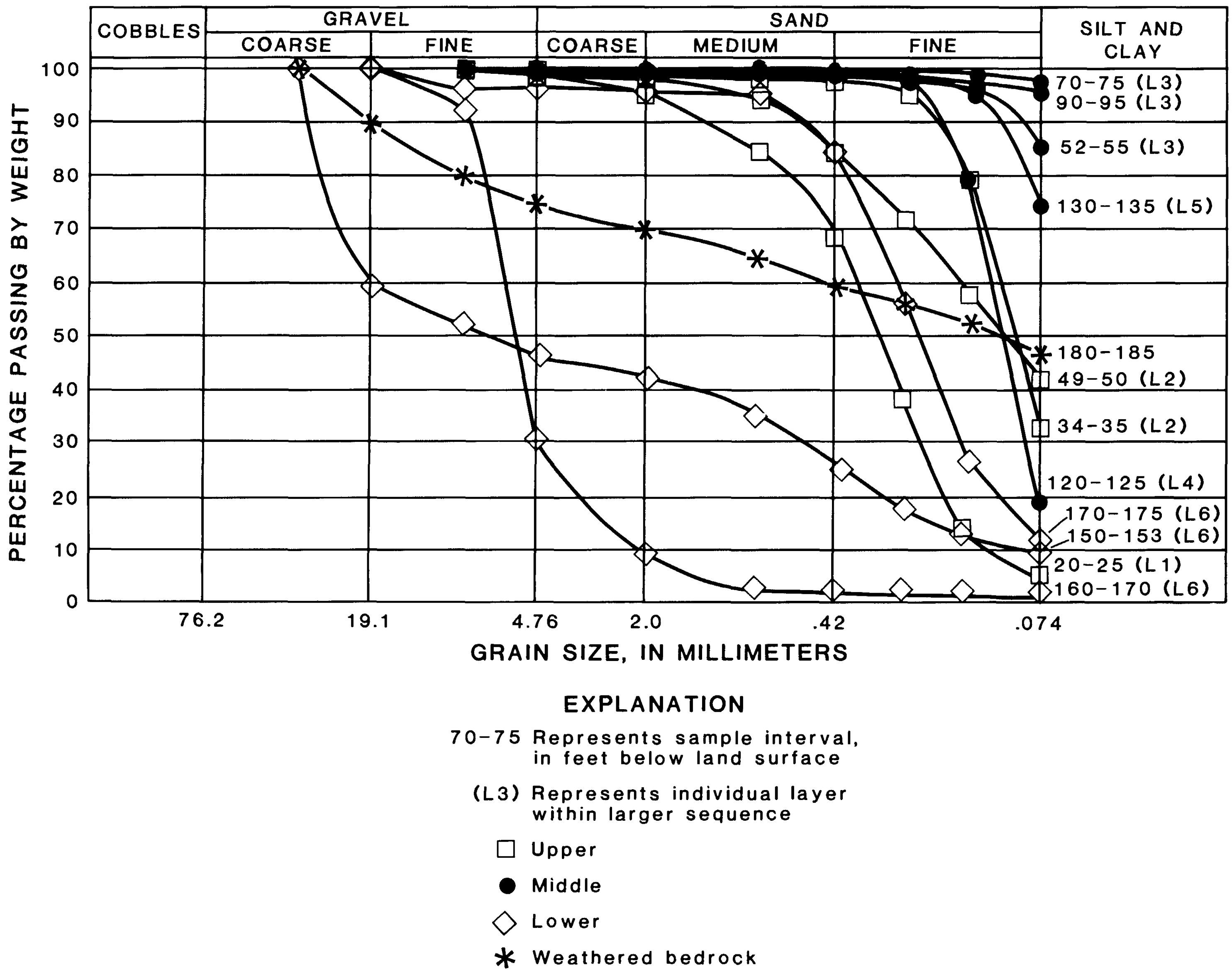
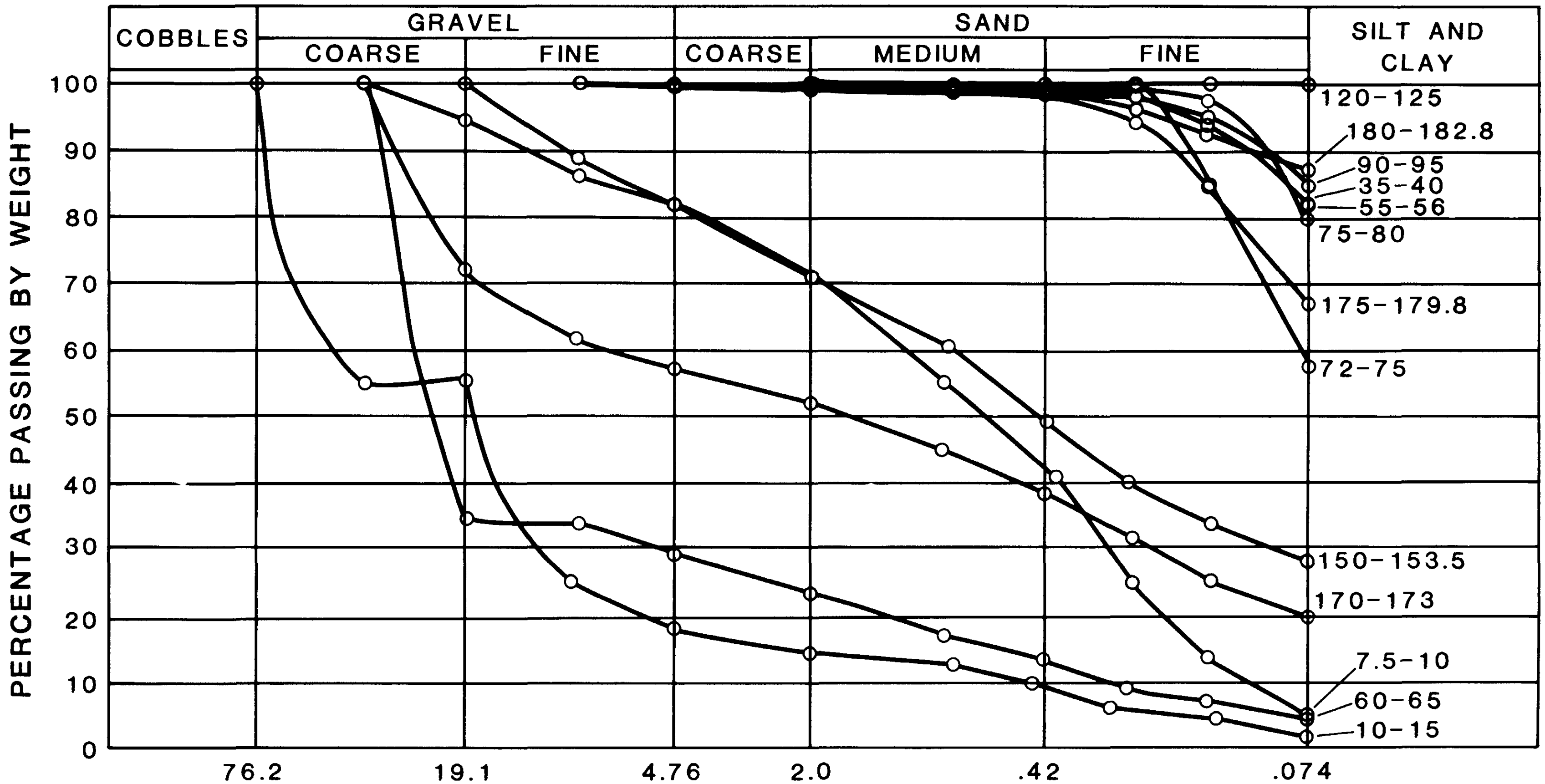


Figure 15.--Grain-size distribution of core samples from well 280 (H).



EXPLANATION

○ 10-15 Represents sample interval, in feet below land surface

Figure 16.--Grain-size distribution of core samples from well 250 (Landfill).

Unconsolidated Sediments

The maximum known thickness of unconsolidated glacial sediments in the Arsenal is 209 feet at well 246 (Building 65). In contrast, the deposits are only 84 feet thick at well 276. In general, the glacial deposits consist of a thin discontinuous mantle of till overlain by a thick deposit of stratified drift. In the following discussion, till deposits are discussed first and the stratified drift deposits last.

A 1- to 15-foot-thick till layer overlies the weathered bedrock at well 246 (Building 65) and at wells 277 and 278 (176). At well 280 (H), before encountering weathered bedrock, rock-bit drilling hit a 2-foot-thick resistant layer thought to be till. The till at the above wells is a poorly sorted, tightly packed, heterogeneous composition of silt to cobbles. At wells 242 and 276, the till was absent. At well 250 (Landfill), a 23-foot-thick layer of sandy till overlies a 10-foot-thick, very-fine sand to silt layer that overlies the weathered bedrock. The sandy till at well 250 contains clay to boulders but is predominantly sandy.

The stratified drift can be subdivided into three distinct layers at wells 242 (Cafeteria), 246 (Building 65), and 268 (figs. 4-6); lower and upper coarse-grained layers are separated by a middle finer-grained layer.

Layer	Lithology
1. Upper	interbedded sand and gravel with some silt.
2. Middle	interbedded, sand, silt, and clay, and
3. Lower	a predominantly medium sand to boulder,

The three stratified drift layers have a maximum combined thickness of approximately 208 feet at well 246 (Building 65). This also represents the maximum known thickness of stratified drift in the valley. In general, grain sizes within the lower and middle layers increase as you go to the northeast, from well 246 to 268. This trend is visible in the grain size graphs (figs. 12-14). The percentage of coarser-grained sediments found in the selected samples is greatest at well 268 and least at well 246. Sediments in the middle layer are generally bedded and rhythmically laminated, especially at wells 246 and 242. The thickness of the lower, middle, and upper layers vary at the three wells. The thickness of the lower coarser-grained layer increases to the northeast; in contrast, the thickness of the middle layer decreases. In the upper layer, no significant lithologic trend was discernible. However, the upper layer is thinner and finer-grained at well 268 as compared to wells 246 and 242. Contacts between the three layers are gradational at wells 246 and 268.

Well 280 is located farther southeast from the center of the northeast-southwest trending valley (pl. 1) than wells 246, 242, and 268. At well 280 (fig. 7), the stratified-drift stratigraphy is similar to that at wells 242, 246, and 268 (figs. 4-6); however, at well 280, some additional layers are discernible. The distribution and depth intervals of lithologies in the stratified drift at well 280 are:

Layers	Lithology	Depth Interval (feet)
Upper	(1) sand and gravel	1 to 29
	(2) sand and silt	29 to 50
Middle	(3) alternating bed of sand, silt and clay	50 to 108
	(4) predominantly fine sand	108 to 126
	(5) silt, fine sand, and clay	126 to 150
Lower	(6) predominantly sand and gravel	150 to 175

At well 280, layer 6 and layers 1 and 2 correspond to the bottom and top layers of wells 242, 246, and 268. At well 280, the middle layer is comprised of three individual layers (3, 4, and 5) as compared to a single, generally continous middle fine-grained layer at wells 242, 246, and 268. Layer 4, predominantly a fine sand, divides the finer-grained layers 3 and 5. Overall, at well 280, the middle layers (3, 4 and 5) are coarser-grained than the middle layers at wells 242 and 246, but generally finer-grained than the middle layer at well 268. At well 280, layer 2 is a gradation between the upper and middle layer. The uppermost layer (1) is finer grained than the upper layer at well 242, but coarser-grained than at well 246.

In contrast to the above wells, wells 250 (Landfill), 276, 277 and 278 lack a three-layer stratigraphy in the stratified drift. The lithologic and gamma-ray logs for these wells are given in figures 8 through 10. A grain-size-distribution graph for well 250 is shown in figure 16.

At well 250, a 12-foot-thick silt to very fine sand layer overlies the weathered bedrock (fig. 8). Overlying the very-fine sand layer is a 23-foot-thick sandy till layer (previously mentioned). Overlying the till is a 75-foot-thick sequence of laminated silt and clay that are commonly rhythmically laminated. Above this, in ascending order, the sequences are: a 16.5-foot-thick layer of predominantly sand-and-gravel, a 23.5-foot-thick layer of laminated silt and clay, and an uppermost 35-foot-thick layer comprised predominantly of sand and gravel.

At well 276 (fig. 9), the stratified drift is 84 feet thick. It consists predominantly of beds of sand, gravel, and some boulders interbedded with beds of fine sand and silt.

At wells 277 and 278 (fig. 10), the stratified drift is 66 feet thick. It is predominantly coarse-grained (sand to boulder) except for a 15-foot-thick layer of mostly fine sand to clay. The stratified drift deposits are overlain by an organic muck layer.

Shallow wells 269, 270, and 271 are all installed in boreholes drilled to a depth of 40 feet or less (fig. 11). In general, sediments are coarser-grained at well 271 than at wells 269 and 270 with well 270 having the most fine-grained sediments. Sediments are bedded and laminated at wells 269 and 270.

SUMMARY

Picatinny Arsenal, located in north-central New Jersey, has a long history of explosives manufacturing. The legacy of past industrial activities and past waste-disposal practices has caused some ground-water-contamination problems. In 1982, the U.S. Geological Survey, in cooperation with the U.S. Army, began a water resources investigation of the Arsenal. The test-drilling program is a part of this investigation.

The purpose of the test-drilling program is to define the hydrogeology and install observation wells in the glaciated valley southwest of Picatinny Lake where the Arsenal's ground-water supply wells and some water-contamination problems exist. The program included drilling 22 boreholes by the hydraulic-rotary method, collection of lithologic samples by solid-tube sampler and core barrel, borehole geophysical logging, grain-size analysis of 62 lithologic samples, installation of 21 observation wells, and measurement of some water levels in wells. This report includes lithologic and gamma-ray logs, grain-size analyses, well-construction data, and some water levels. An assessment of the hydrogeology and ground-water quality is in progress.

Most of the observation wells are grouped in clusters. The drilling procedure at a cluster site included drilling the first borehole through glacial sediments and into 25 to 40 feet of fresh bedrock, where a well was then screened. At the site, other wells were then screened in glacial sediments at different depths. Most of these wells are screened in the principal water-bearing zones as interpreted by lithologic and borehole geophysical log analysis from the bedrock well.

Two bedrock types underlie the glacial sediments in the valley southwest of Picatinny Lake: the Hardyston Quartzite and the predominantly dolomitic Leithsville Formation. Of the seven boreholes drilled into bedrock, all were drilled into the Leithsville Formation, but one also penetrated the underlying Hardyston Quartzite.

A weathered dolomite was found above fresh bedrock in all boreholes drilled into bedrock. The thickest sequence of weathered dolomite was 135 feet, found at well 250 (Landfill). In general, the weathered dolomite is characterized by a medium-yellow silty clay and less weathered, indurated layers.

Glacial deposits overlie the weathered bedrock. In general, the glacial deposits consist of a thin discontinuous mantle of till overlain by a thick deposit (up to 208 feet) of stratified drift. Glacial deposits obtain a maximum known thickness in the Arsenal of 209 feet.

At several wells, the stratified drift has a similar stratigraphic sequence. The stratified drift has a three-layer stratigraphy at wells 242 (Cafeteria), 246 (Building 65) and 268. Lower and upper coarser-grained layers are separated by a middle finer-grained layer. The stratigraphy from lower to upper consists of a layer of predominantly medium sand to boulder; a layer of interbedded sand, silt, and clay; and a layer of interbedded sand and gravel with some silt.

SELECTED REFERENCES

Barnett, S. G., 1976, Geology of the Paleozic rocks of the Green Pond outlier: New Jersey Geological Report Series, no. 11, 9 p.

Bayley, W. S., Salisbury, R. D., and Kummel, H. B., 1914, Raritan [Quadrangle], New Jersey, folio 191 of Geologic atlas of the United States: U.S. Geological Survey, 233 p.

Canace, Robert, Hutchinson, W. R., Saunders, W. R., and Andres, K. G., 1983, Results of the 1980-81 drought emergency ground-water investigation in Morris and Passaic Counties, New Jersey: New Jersey Geological Survey Open-File Report No. 83-3, p. 13-26.

Drake, Avery, 1969, Precambrian and lower Paleozoic geology of the Delaware Valley, New Jersey-Pennsylvania, in Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: Geological Society of America and associated societies, November 1969, Annual Meeting, Atlantic City, New Jersey, New Brunswick, New Jersey, Rutgers University Press, p. 51-132.

Eby, C. F., 1976, Soil survey of Morris County, New Jersey: U.S. Department of Agriculture, Soil Conservation Service, p. 1-111.

Gill, H. E., and Vecchioli, John, 1965, Availability of ground water in Morris County, New Jersey: New Jersey Department of Conservation and Economic Development, Special Report 25, 56 p.

Kummel, H. B., and Weller, Stuart, 1902, The rocks of the Green Pond Mountain region: in Annual Report of the State Geologist for the year 1901, Trenton, New Jersey, p. 1-51.

Lacombe, P. J., Sargent, B. P., Harte, P. T., and, Vowinkel, E. F., 1986, Determination of geohydrologic framework and extent of ground-water contamination using surface geophysical techniques at Picatinny Arsenal, New Jersey: U.S. Geological Survey Water-Resources Investigations Report 86-4051, 33 p.

Markewicz, F. J., and Dalton, Richard, 1980, Field studies of New Jersey geology and guide to field trips: 52nd Annual Meeting of the New York State Geological Association, p. 54-70.

Owens, J. P., and Sohl, N. F., 1969, Shelf and deltaic paleoenvironments in the Cretaceous-Tertiary formations of the New Jersey Coastal Plain, in Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: Geological Society of America and associated societies, November 1969, Annual Meeting, Atlantic City, New Jersey, New Brunswick, New Jersey, Rutgers University Press, p. 236.

Salisbury, R. D., 1902, The glacial geology of New Jersey: New Jersey Geological Survey Final Report, v. 5, p. 449-496.

Sargent, B. P., Green, J. W., Harte, P. T., and Vowinkel, E. F., 1986, Ground-water quality data for Picatinny Arsenal, New Jersey, 1958-85: U.S. Geological Survey Open-file Report 86-58, p. 66.

Sims, P. K., 1953, Geology of the Dover magnetite district, Morris County, New Jersey: U.S. Geological Survey Bulletin 982-G, p. 245-305.

-----, 1958, Geology and magnetite deposits of Dover District, Morris County, New Jersey: U.S. Geological Survey Professional Paper 287, p. 1-59, 1 plate.

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

GLOSSARY

Alaskite. A commonly used term for a granitic rock containing only a few percent of dark minerals. A predominantly quartz and alkali-feldspar granite.

Annulus. Space between the well casing and the borehole.

Aquifer. A formation, group of formations, or part of a formation that contains sufficiently saturated permeable material to yield significant quantities of water to wells or springs.

Bed. A deposit marked by a more-or-less well-defined divisional plane from deposits above or below. The term is applied primarily to sedimentary strata.

Caliper log. A graphic record of the diameter of a drill hole or well.

Conglomerate. A cemented clastic rock containing rounded fragments corresponding in their grain sizes to gravel or pebbles. Different types are recognized according to the uniformity or variability of the composition and source of pebbles. The consolidated equivalent of gravel both in size range and in the essential roundness and sorting of its constituent particles.

Contact. A plane or irregular surface between two types or ages of rock.

Detritus (detrital). Any fine particulate debris; material produced by the disintegration and weathering of rocks that has been moved from its site of origin.

Dolomite. A mineral $CaMg(CO_3)^2$ with a hexagonal rhombohedral shape. A term applied to those rocks that approximate the mineral dolomite in composition.

Electric log. Measure of natural potentials and resistances run only in uncased boreholes that are filed with a conducting fluid such as mud or water.

Fresh. Said of a rock or rock surface that has not been subjected to or altered by surface weathering, such as a rock newly exposed by fracturing.

Formation. A body of rock strata, of intermediate rank in the hierarchy of lithostratigraphic units, which is unified with respect to adjacent strata by consisting predominantly of a certain lithologic type or combination of types or by possessing other unifying lithologic features.

Gamma-ray log. Also called natural-gamma log. Records natural gamma radiation emitted by all rocks. Natural gamma-ray logs are graphical plots of the rate of emission of gamma rays emitted by the formations penetrated by the borehole. Unlike the electric log, the gamma-ray log can be obtained in a cased hole, without borehole fluid. In general, silt- and clay-bearing sediments show much higher natural gamma activity than clean quartz sands and carbonates. Additional factors that must be considered in natural gamma-ray log interpretation are related to well construction. These include changes in borehole diameter, type of casing, multiple or single casing, gravel pack, grout along the outside wall of the casing, and well development. All of these factors can cause shifts on natural gamma-ray logs that are not necessarily related to changes in lithology.

Geologic unit. A particular rock, either a formation or part of a formation.

Glacier. A mass of ice formed from the compaction and recrystallization of snow and moving due to the stress of its own weight.

Indurated. Rendered hard. Said of a rock or soil hardened or consolidated by pressure, cementation, or heat.

Intercalated. Occurring between layers of other material.

Interbedded. Occurring between beds.

Lamina. A recognizable layer in sedimentary rocks or sediments less than 1 centimeter thick, differing from other layers in color, composition, or particle size.

Lithology. The physical character of a rock, generally as determined megascopically or with the aid of a low-power magnifier.

Micrite. A carbonate rock with very fine microcrystalline texture.

Moraine. Drift deposited chiefly by direct glacial action, and having topographic features independent of control by the surface on which the drift lies. Accumulation of unsorted, unstratified glacial drift, predominantly till.

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 "Mean Sea Level".

Orthoquartzite. A sedimentary rock composed of silica-cemented quartz sand.

Recessional moraine. A moraine formed during a temporary decrease in the rate of glacial retreat.

Sparry (sparite). A descriptive term for the crystalline transparent or translucent interstitial component of limestone, consisting of clean, relatively coarse-grained calcite or aragonite that either accumulated during deposition or was introduced later as a cement. It is more coarsely crystalline than micrite.

Stratigraphy. That branch of geology which treats the formation, composition, sequence, and correlation of the stratified rocks as parts of the earth's crust.

Stylolite. A straight, vertically grooved column, of the same material as the rock in which it occurs, commonly less than a centimeter in length, fitting into a corresponding socket in a stylolitic seam and being highly inclined or at right angles to the bed.

Terminal moraine. The end moraine, extending across a glacial valley as an arcuate or crescentic ridge, that marks the farthest advance or maximum extent of a glacier; the outermost end moraine of a glacier or ice sheet. It is formed at or near a more-or-less stationary edge, or at a place marking the cessation of an important glacial advance.

Unconsolidated sediments. Sedimentary material in which grains have not been cemented together.

Wisconsin. Last glacial stage in the Pleistocene of North America.

TABLE 3.--Lithologic logs of observation wells
{Altitude in feet above NGVD OF 1929}

WELL NUMBER: 242 (Cafeteria 1)

Altitude of land surface: 702.7

Lithology	Depth Interval (feet)	
Sand, medium-grained, clayey with some pebbles; dark-yellowish-brown	0.0	4.5
Sand, medium- to very coarse-grained; moderate-yellowish-brown	4.5	6.0
Gravel, coarse-grained, pebbles	6.0	6.5
Sand, coarse- to very coarse-grained, brown, clayey, some medium- to fine sand and silt	6.5	10.0
Gravel, fine to coarse, pebbles, rock fragments of conglomerate	10.0	12.0
Sand, medium- to coarse-grained, silty, clayey; light-brown	12.0	15.0
Gravel, coarse- to fine-grained, pebbles, gneiss and quartz rock fragments	15.0	17.0
Sand, very fine-grained	17.0	20.0
Sand, very fine-grained, silt; dusky-yellow	20.0	22.0
Sand, fine- to very fine-grained, silty, brown	22.0	27.0
Sand, medium- to very coarse-grained, some fine sand and fine gravel; moderate-yellowish brown; fine sand contains opaque minerals	27.0	32.0
Sand, medium- to coarse-grained, brown to gray, some fine gravel and gray-brown fine sand	32.0	37.0
Sand, medium- to coarse-grained, yellowish-brown, some fine sand and quartzitic and conglomeratic coarse gravel	37.0	42.0
Sand, fine- to medium-grained, gray to brown, trace silt and fine gravel to coarse sand	42.0	47.0
Sand, very fine-grained, light-olive-gray to brown; a large portion of opaque minerals	47.0	52.0
Sand, very fine-grained, silty, light-olive-gray, exhibits bedding	52.0	57.0
Sand, very fine-grained, light-olive-gray	57.0	62.0
Silt, sandy, medium-dark-gray	62.0	67.0
Silt, grayish-brown, some light-brown-silty-clay, trace fine sand	67.0	72.0
Sand, silty, gray, showing stratification	72.0	77.0
Sand, fine-grained, some silt, medium-dark-gray, black laminations	77.0	82.0

WELL NUMBER: 242 (Cafeteria 1)-Continued

Altitude of land surface: 702.7

Lithology	Depth Interval (feet)	
Silt, clayey, some sand, medium-dark-gray, tightly packed, laminae of fine sand alternating with laminae of clay, some fine gravel	82.0	87.0
Sand, fine-grained, clay, medium-dark-gray, laminae of fine sand alternating with laminae of clay , some fine gravel	87.0	92.0
Sand, fine-grained, clay, medium-dark-gray, laminae of fine sand and laminae of clay; a large portion of opaque minerals	92.0	97.0
Sand, very fine to fine sand, silty, some intercalated gray clay; a large portion of opaques	97.0	102.0
Clay, gray, interbedded with very fine to fine sand, gray-brown	102.0	107.0
Clay, gray, silt, laminae of fine sand	107.0	112.0
Silt, sandy, very fine-grained, laminae of olive-gray clay; a large portion of opaque minerals	112.0	117.0
Gravel, gray-brown, pebbles, rock fragments, some coarse sand, trace silt	117.0	122.0
No sample	122.0	124.0
Gravel, pebbles, coarse sand and conglomerate rock fragments, weathered rock fragments	124.0	129.0
Gravel, fine- to coarse-grained, pebbles and rock fragments; gravel sub-angular to sub-rounded	129.0	139.0
Note: End of solid-tube sampling, corings follow.		
No sample	139.0	144.0
Boulder, granite	144.0	147.0
Pebbles, some gravel and sand	147.0	150.0
Boulders, quartzite, cobbles and various rock fragments	150.0	152.0
Silt	152.0	153.0
Boulders, some pebbles and gravel; sandstone boulders	153.0	155.0
Boulders	155.0	161.0
No sample	161.0	164.0
Sand and gravel	164.0	167.0
Boulders	167.0	169.0
Boulders to fine gravel	169.0	184.0

WELL NUMBER: 242 (Cafeteria 1)-Continued

Altitude of land surface: 702.7

Lithology	Depth Interval (feet)
Weathered rock, silty clay matrix with quartz detrital grains, intervals of less weathered consolidated medium-gray dolomite with intercalated detritus	184.0 245.0
Note: Tube sampled 225 to 228, core 229 to 267.	
Dolomite, medium-gray, intercalated detritus	245.0 247.0
Quartzite, gray to tan, silca cement, some intercalated detrital grains of fine sand and silt, well indurated, some fractures; cavity at 252.5	247.0 270.0

WELL NUMBER: 246 (Building 65-1)

Altitude of land surface: 699.9

Lithology	Depth Interval (feet)	
Sand and gravel, brown, subrounded grain shapes, bedding not pronounced	0.0	13.0
Sand, very fine- to very coarse-grained, predominantly a medium to fine sand; brown, poorly sorted, a large portion of opaque minerals	13.0	23.0
No sample	23.0	24.3
Sand, very fine- to medium-grained, moderate brown, some silt and small amount of coarse sand; poorly sorted, massive bedding, subrounded grains; overall salt and pepper color scheme due to large portion of opaques	24.3	27.8
Sand, very fine- to coarse-grained, mostly fine to very fine sand, some silt; bedded, some beds show graded bedding	27.8	37.2
Sand, medium- to very fine-grained, with silt, mostly a fine to very fine sand; yellowish-brown, generally massive bedding, some dark laminations	37.2	47.8
Clay, silty, sandy, bedded, upper sequence fine sand to silt; toward bottom silt laminations of pale-brown, grayish-brown, pale-yellowish-brown and brownish-gray	47.8	57.8
Sand, very fine with silt, olive-gray, massive	57.8	67.8
Sand, fine-grained to clay, olive-gray, predominantly a fine sand to clay, laminated	67.8	77.8
Silt, clayey, olive-gray to reddish hue, laminated silt to very fine sand and clay	77.8	87.8
Silt, clayey, rhythmic bedding of silt and clay	87.8	97.8
Silt, clayey, olive-gray, some very fine sand; rhythmic bedding, clay laminated	97.8	107.8
Same as above, but with less very fine sand	107.8	117.8
Silt, very fine to medium sand, primarily a fine to very fine sand, clay; laminated	117.8	127.8
Silt, very fine sand and clay, rhythmic laminations of silt and very fine sand with laminations of clay	127.8	137.8
Silt, sandy, clayey, olive-gray, laminae of very fine sand and clay	137.8	143.1

WELL NUMBER: 246 (Building 65-1)-Continued

Altitude of land surface: 699.9

Lithology	Depth Interval (feet)	
Clay, silty, rhythmic laminations of pale-brown, medium-gray and olive-gray	143.1	157.8
Silt, clayey, sandy, dark-yellowish-brown fine sand laminae and olive-gray laminae	157.8	167.8
Sand, silty, clayey, laminated, coarse-grained at top interval	167.8	177.8
Silt, sandy, clayey, dark-yellowish-brown fine sand laminae and olive-gray clay laminae	177.8	187.8
Sand, dark-yellowish-brown, medium-brown silt and clay	187.8	197.8
Sand, very fine- to coarse-grained, primarily a medium to fine sand, trace silt; some bedding, subangular to subrounded grains	197.8	207.8
Till, pebbles, silt and clay; moderate brown, poorly sorted	207.8	209.4
Weathered rock, poorly indurated, grayish-orange silty clay matrix, gravel and sand	209.4	253.0
Cavity	253.0	255.8
Dolomite, gray, microsparry texture, abundant stylolites, some intercalated detrital grains, iron-staining along fractured planes, small voids; fracture zone at 268 ft	255.8	288.0

Note: Retrieved samples by double and triple core barrels.

WELL NUMBER: 250 (Landfill 1)

Altitude of land surface: 692.8

Lithology	Depth Interval (feet)	
Sand, coarse- to very coarse-grained, some gravel and pebbles; subrounded to subangular grains	0.0	5.0
Pebbles, conglomerate and gneiss	5.0	7.0
Sand, coarse-grained, gravel, bedded, some laminations of fine sand	7.0	10.0
Sand, very fine- to very coarse-grained, pre-dominantly coarse sand, medium-gray, gneiss and quartz pebbles and cobbles	10.0	15.0
Sand and gravel, medium-dark-gray, subangular to subrounded grains	15.0	20.0
Boulders	20.0	25.0
Gravel	25.0	30.0
Sand and gravel	30.0	35.0
Silt, coarse-grained, clay; olive-gray, laminated	35.0	40.0
Silt and clay, laminae of clayey silt, olive-gray	40.0	45.0
Silt, clayey, laminated, brownish-olive-gray	45.0	50.0
Silt, fine-grained, clayey, gray laminae	50.0	55.0
Silt, fine- to coarse-grained, some very fine- to fine sand in a coarse silt layer; thin bedded, brownish-gray	55.0	58.5
Sand and gravel, fine to very coarse sand, poorly sorted; dark-gray	58.5	60.0
Sand and gravel, brownish-gray sand; subrounded to subangular grains, disseminated gravel	60.0	70.0
Sand, fine- to very coarse-grained, primarily a coarse sand, gravel, bedded silt and fine sand, brownish-gray sand and gravel	70.0	75.0
Silt, very fine sand, some clay; brownish-gray, thin bedded	75.0	80.0
Silt, coarse-grained, clay, laminated	80.0	85.0
Silt, sandy, clayey, brownish-gray; bedded	85.0	90.0
Silt, sandy, some clay, laminae of silt, sand, and fine sand, trace brownish-gray fine to very fine sand; clay laminae red, other laminae black	90.0	95.0
Silt, with laminated brownish-gray clay and medium -brown, medium sand	95.0	100.0
Clay and silt, laminated, medium-brown	100.0	105.0
No sample	105.0	106.0
Clay and silt, rhythmic laminations	106.0	115.0

WELL NUMBER: 250 (Landfill 1)-Continued

Altitude of land surface: 692.8

Lithology	Depth Interval (feet)	
Silt and clay, laminated, medium-brown	115.0	120.0
Silt and clay, rhythmic laminations, medium-brown	120.0	125.0
Silt and clay, bedded, medium-brown	125.0	130.0
No sample	130.0	131.0
Silt and clay, rhythmic bedding, medium-brown	131.0	140.0
Silt and clay, laminated, wet, dark-yellowish-brown silt laminae, pale-brown and pale-yellowish-brown clay; fining upward sequence, top contact gradational	140.0	145.0
Silt and clay, rhythmic bedding, medium-brown to light-olive gray, some gravel	145.0	150.0
Till, sandy, some clay and pebbles, massive bedding, moderate-yellowish-brown	150.0	155.0
Note: Generally continous tube sampling to 154, core 154 to 165.		
Cobbles and boulders, conglomerate	155.0	165.0
Pebbles	165.0	166.0
Till, very-fine sand to coarse sand matrix, fine gravel to pebbles, sub-angular to sub-rounded, sandstone, gneiss and some dolomite pebbles, some pebbles weathered to white color	166.0	170.0
Till, silty, sandy, clayey, some boulders	170.0	173.0
Silt and sand, very fine to coarse sand, mostly fine to very fine sand; massive bedding	173.0	178.0
Silt, clayey, few pebbles, moderate-brown	178.0	180.0
Sand, silty, clayey, some gravel, poorly sorted, highly weathered pebbles; coarser on top, mostly massive, clay laminae on bottom	180.0	183.0
Note: Tube sample 166 to 188, 188 to 205 drill cuttings.		
No sample	183.0	185.0
Weathered rock, poorly indurated, highly weathered material, disseminated rock in a silty clay matrix, dark-yellowish-orange	185.0	320.0
Note: Tube sample 205 to 211, core 211 to 345.		

WELL NUMBER: 250 (Landfill 1)-Continued

Altitude of land surface: 692.8

Lithology	Depth Interval (feet)	
Dolomite, weathered, dark-yellow to tan, iron-staining; fractured, consists of light-gray microsparry highly stylolitic, massive dolomite, moderately weathered to a tan to brown, brittle, argillaceous dolomite with large dissolution cavities along fracture planes; also has thin beds of black, micrite fissile dolomite severely weathered to a tan, fissile, argillaceous dolomite	320.0	345.0

WELL NUMBER: 268

Altitude of land surface: 694.3

Lithology	Depth Interval (feet)	
Topsoil	0.0	1.0
Sand and gravel in silty matrix	1.0	6.0
Sand, medium- to coarse-grained, brown, some light-brown medium to fine sand, some gravel and trace silt	6.0	10.0
Sand, fine- to medium-grained, some pale-yellowish-brown very fine sand, also some pebbles and gneiss cobbles; a large portion of opaques	10.0	15.0
Sand, fine-grained, gray-brown	15.0	20.0
Sand, silty, light-gray, some gravel and medium to coarse sand	20.0	25.0
Silt, fine sand, gray-brown, few beds of medium to coarse sand	25.0	30.0
Sand, fine-grained, silt, some medium-sand, gray	30.0	35.0
Sand, fine-grained and silt, light-brown, trace fine gravel to medium sand	35.0	40.0
Sand, fine-grained and silt, light-olive-gray, some thin medium-gray clay seams	40.0	42.0
Silt, fine sand, light-olive-gray	42.0	45.0
Silt, brown, laminated, gray fine sand	45.0	53.0
Sand, medium- to coarse-grained, grayish-brown to olive-gray, some fine sand and trace coarse sand; contains a large portion of opaques	53.0	60.0
Sand, medium- to fine-grained, light-olive-gray	60.0	64.0
No sample	64.0	65.0
Sand, coarse-grained, some light-brown medium to fine sand, some silt	65.0	69.0
No sample	69.0	71.0
Sand, medium- to coarse-grained, brownish-gray, some quartzitic and sandstone very coarse sand	71.0	74.0
Sand, coarse-grained	74.0	76.0
Sand, medium- to coarse-grained	76.0	81.0
Sand, medium- to fine-grained, brownish-gray	81.0	82.0
Sand, medium- to coarse-grained, some quartzitic and sandstone pebbles and cobbles	82.0	84.0
Sand, very coarse-grained, fine gravel, gray-brown pebbles and boulders, trace fine sand; loosely packed	84.0	93.0

WELL NUMBER: 268-Continued

Altitude of land surface: 694.3

Lithology	Depth Interval (feet)	
Note: End of solid-tube sampling, 93 to 104 drill cuttings.		
Sand and gravel, loosely packed, some silt	93.0	104.0
Note: Solid-tube sampling 104 to 124.		
Gravel, fine-grained, dark-greenish-gray and grayish-red subangular to subrounded grains, mostly quartz and feldspar, also medium to coarse sand, subangular to subrounded quartz, some feldspar and opaque minerals	104.0	110.0
Gravel,fine- to coarse-grained, pebbles, cobbles and very coarse to medium sand, subangular to subrounded; grayish-green granitoid-gneiss and brownish-red sandstone pebbles	110.0	115.0
Gravel, gneiss, conglomerate and quartzite suban-angular to subrounded pebbles and cobbles in a very coarse sand matrix	115.0	119.0
No sample	119.0	120.0
Sand, very coarse- to medium-grained, brown, angular to subrounded, some fine sand and pebbles; poorly sorted, some opaque minerals of sand size grains	120.0	124.0
Note: End of solid-tube sampling, drill cuttings follow.		
Same as above plus some rock fragments	124.0	128.0
Boulders	128.0	137.0

WELL NUMBER: 269

Altitude of land surface: 693.9

Lithology	Depth Interval (feet)	
Topsoil	0.0	1.0
Sand, coarse-grained, fine gravel, pebbles and cobbles; dark-gray-brown, some silty sand	1.0	5.0
Sand, coarse-grained, fine gravel, some fine to medium sand, light-brown to brownish-black	5.0	10.0
Sand, coarse- to medium-grained, dark-yellowish-brown to olive-gray; contains quartz, feldspar and opaque minerals	10.0	15.0
Silt,fine sand some coarse to medium sand; dark-yellowish-brown to light-gray; contains quartz, feldspar and opaque minerals	15.0	20.0
Sand, medium- to coarse-grained, some fine sand and silt, laminated, fine gravel; contains quartz, feldspars and opaque minerals; grain shapes subrounded to subangular	20.0	25.0
Sand, medium- to coarse-grained, fine sand, some silt and fine gravel, bedded, subrounded to sub-angular grains; olive-gray to gray-brown	25.0	30.0
Sand, medium- to fine-grained, some very fine sand bedded; contains quartz, feldspar and opaque minerals	30.0	35.0
Sand, fine- to medium-grained, alternating laminations of silt to fine sand with laminations of clay	35.0	40.0

Note: Continuous solid-tube sampling.

WELL NUMBER: 270

Altitude of land surface: 690.0

Lithology	Depth Interval (feet)	
Topsoil, black organic muck	0.0	2.0
Sand, coarse- to fine-grained, small pebbles, oxidized; subangular to subrounded grains; light-olive brown	2.0	5.0
Sand, fine-grained, silty, also medium to very coarse sand, gravel, subangular to subrounded grains, contains quartz and opaque minerals, massive bedding; interval exhibits coarsening upward sequence	5.0	10.0
Sand, fine- to medium-grained, some laminae of very fine sand and silt; dark-gray to greenish-gray; coarsening upward sequence	10.0	15.0
Sand, fine-grained, laminae of silt, minor medium sand, quartz and opaque minerals; dark-brown to to light-gray; fining downward sequence	15.0	20.0
Sand, fine- to very fine-grained and silt, trace clay; laminated, dark-yellowish-brown to greenish-gray	20.0	25.0
Silt, fine to very fine sand, trace clay and coarse to medium sand; dark-grayish-brown; rhythmic laminations	25.0	30.0
Silt, laminated, trace very fine sand and clay; dark-grayish-brown	30.0	35.0

Note: Continuous solid-tube sampling.

WELL NUMBER: 271

Altitude of land surface: 696.6

Lithology	Depth Interval (feet)	
Landfill, silt and clay matrix with sand to boulders; dark-yellowish-brown	0.0	4.0
Landfill, black clayey silt with various metal and nonmetal debris	4.0	7.0
Clay, olive-gray, also layer of medium-light-gray clay	7.0	12.0
Pebbles to fine gravel	12.0	15.0
No sample	15.0	21.0
Gravel, fine- to coarse-grained, pebbles, cobbles and rock fragments; varied composition including dark-greenish-gray chlorite-gneiss, quartzites, very dark-red sandstone; subangular to subrounded grains, some well rounded, large amount of opaque minerals	21.0	25.0
Sand, coarse-grained, quartz and opaque minerals, also fine gravel and chlorite pebbles	25.0	30.0

Note: Continuous solid-tube sampling.

WELL NUMBER: 276

Altitude of land surface: 698.9

Lithology	Depth Interval (feet)	
Topsoil, gravel, loamy	0.0	1.5
Sand, silty matrix, assorted pebbles, cobbles and rock fragments, poorly sorted; some well-sorted brownish-red clayey silt beds	1.5	13.0
Gravel, fine-grained, subangular quartz and feldspar, also some medium sand comprised of quartz and opaque minerals, some boulders	13.0	20.0
Note: End of drill cuttings, tube samples follow.		
No sample	20.0	23.0
Sand, coarse- to medium-grained	23.0	25.0
No sample	25.0	30.0
Sand, very coarse-grained, gravel, pebbles, and rock fragments	30.0	35.0
No sample	35.0	45.0
Note: End of tube sampling, drill cuttings follow.		
Sand, coarse-grained, gravel, pebbles	45.0	48.0
Silt	48.0	50.0
Note: Tube sample 50 to 55.		
Sand, coarse- to medium-grained, subrounded to subangular quartz, feldspar and opaque minerals, also subrounded to subangular predominantly quartz gravel, some subrounded to subangular pebbles	50.0	60.0
Sand, fine-grained	60.0	63.0
Sand and gravel	63.0	69.0
Sand, fine-grained	69.0	69.5
Sand and gravel	69.5	70.0
Note: Solid-tube sample 70 to 72.5.		
Sand, very coarse- to medium-grained, subrounded, predominantly quartz, but also opaque minerals, salt and pepper color scheme, mostly quartz granules, some amphibolite-gneiss pebbles and cobbles, quartzite and gneiss rock fragments	70.0	72.5
Sand and gravel	72.5	81.0
Silt	81.0	83.0
Note: Solid-tube sample 83 to 84 and 83 to 86.		
Sand, medium- to coarse-grained, subrounded to subangular quartz and opaque minerals, amphibolite-gneiss, conglomerate and quartzite pebbles	83.0	84.0

TABLE 3.--Lithologic logs of observation wells-Continued

WELL NUMBER: 276-Continued

Altitude of land surface: 698.9

Lithology	Depth Interval (feet)	
Dolomite, fissile, weathering to a silty clay; weathering follows fissile rock structure, weathered rock a yellowish-orange, non-weathered rock, olive gray	84.0	92.0
Dolomite, less weathered than above	92.0	98.0

WELL NUMBER: 278

Altitude of land surface: 689.3

Lithology	Depth Interval (feet)	
Landfill	0.0	10.0
Muck, black, organic	10.0	34.0
Sand, gravel, pebbles	34.0	40.0
Rock fragments, sand and gravel	40.0	50.0
Gravel, fine- to coarse-grained, pebbles, cobbles in a coarse sand matrix; heterogeneous composition, subangular to well-rounded grains	50.0	54.0
No sample	54.0	64.0
Gravel, fine- to coarse-grained, pebbles and cobbles; heterogenous composition	64.0	73.0
No sample	73.0	75.0
Sand, coarse- to medium-grained, dark-yellowish-brown, fine gravel, pebbles, conglomerate and quartzite boulders	75.0	79.0
Sand, medium- to fine-grained, alternating laminae of fine sand, silt, and clay	79.0	83.0
Sand, medium-grained, laminae of dark-gray-black opaque minerals	83.0	85.0
Sand, fine-grained, some very fine sand, silt laminae, also laminae of light-brown sand	85.0	90.0
Sand, fine-grained, some very fine sand, two-inch layer of fine sand and fine gravel	90.0	95.0
Sand, coarse- to medium-grained, fine gravel; subangular grains, predominantly quartz and opaque minerals	95.0	100.0
Till, silty clay matrix with fine to medium sand, light-brown, pebbles, and fine gravel, subrounded to subangular, also chlorite and amphibolite gneiss boulders	100.0	105.0
Till, silty clay, moderate-yellowish-brown, quartzite, conglomerate and felspathic boulders also medium to coarse sand and some fine sand	105.0	110.0
Till, clayey, moderate-yellowish-brown, medium sand, fine gravel, pebbles, some dolomite and conglomerate boulders	110.0	115.0
No sample	115.0	120.0
Note: End of solid-tube sampling, drill cuttings follow.		
Weathered rock, dark-yellowish-orange clay	120.0	161.0

WELL NUMBER: 278-Continued

Altitude of land surface: 689.3

Lithology	Depth Interval (feet)	
Note: Solid-tube sample 130 to 134.		
Weathered rock, alternating clay with non-weathered argillaceous dolomite; weathering pattern follows fissile structure of rock	161.0	172.0
Note: End of drill cuttings, core samples follow.		
Dolomite, argillaceous, fissile	172.0	178.0
Weathered rock, grayish-orange clay, thin seam of black-fibrous-organic silty clay	178.0	180.0
Weathered rock, bands of grayish-orange, moderate-reddish-brown and dark-yellowish-orange clay	180.0	185.0
Rock, iron-rich, well-indurated, blackish-red; comprised of black hematite and goethite; highly fractured zone	185.0	189.0
Weathered rock, silty clay	189.0	200.0
Note: End of core samples, drill cuttings follow.		
Rock, weathered and non-weathered sequences; gray rhombic to microsucrosic texture indicative of less-weathered dolomite and yellowish-brown clay indicative of weathered rock	200.0	246.0
Note: End of drill cuttings, core samples follow.		
Dolomite, gray	246.0	251.0
Dolomite, decomposd	251.0	255.0
Dolomite, calcareous, medium-gray, sparry texture, abundant calcite filled veins and voids (voids filled with euhedral crystals)	255.0	258.0
Cavity containing dolomitic sand grains	258.0	260.5
Same as 255- to 258 ft with a heavily weathered zone at 266- to 267 ft	260.5	269.0
Dolomite, light- to medium-gray, beds of sparry texture, dolomite veins and voids alternating with a dark-gray, fissile, micrite texture beds; less calcareous with depth, highly fractured with iron-staining along fracture planes	269.0	309.3

WELL NUMBER: 280 (H deep)

Altitude of land surface: 699.3

Lithology	Depth Interval (feet)	
Topsoil	0.0	1.0
Topsoil, sand and gravel	1.0	4.0
Gravel, fine-grained, very coarse to coarse sand, brown; heterogeneous composition, increasing sand with depth; grains subangular to subrounded	4.0	10.0
No sample	10.0	15.0
Sand, coarse- to fine-grained, mostly medium sand, well-rounded, fine to coarse gravel, some pebbles and cobbles; light-olive-brown	15.0	20.0
Sand, coarse-grained, fine gravel, some medium to fine sand and pebbles, trace silt; brown	20.0	29.0
Fine sand, silt, greenish-gray; a large amount of opaques	29.0	30.0
Sand, brown, silt	30.0	33.0
Silt, fine sand, light-gray-brown, trace coarse to medium sand	33.0	35.0
No sample	35.0	45.0
Sand, fine-grained, silt, light-brown; some coarse to medium sand, trace fine gravel	45.0	50.0
Sand, very fine-grained, silt, light-gray; some coarse sand	50.0	55.0
No sample	55.0	60.0
Sand, very fine-grained, gray clayey silt with alternating laminae of red silt	60.0	65.0
No sample	65.0	70.0
Sand, very fine-grained, brown; clayey silt with alternating laminae of coarse sand	70.0	75.0
No sample	75.0	80.0
Sand, very fine-grained, light-gray clayey silt with alternating laminae of coarse sand	80.0	85.0
No sample	85.0	90.0
Sand, very fine-grained, light-brown, gray silt and clay laminations	90.0	95.0
No sample	95.0	100.0
Sand, very fine-grained, silt and clay laminations; greenish-gray; large amount of opaques	100.0	105.0

TABLE 3. --Lithologic logs of observation wells-Continued

WELL NUMBER: 280 (H deep)-Continued

Altitude of land surface: 699.3

Lithology	Depth Interval (feet)	
No sample	105.0	110.0
Sand, fine-grained, some silt and medium-gray clay	110.0	115.0
No sample	115.0	120.0
Sand, fine-grained, some silt, trace clay; light-gray-brown	120.0	126.0
No sample	126.0	130.0
Silt, sand, some clay; brown	130.0	135.0
No sample	135.0	140.0
Sand, silt, some clay	140.0	145.0
No sample	145.0	150.0
Sand, fine-grained, coarse sand and fine gravel, trace silt; light-brown, heterogeneous composition	150.0	153.0
Gravel, fine-grained, very coarse sand, some medium to fine sand, micaceous gneiss boulders, quartzite and sandstone pebbles	153.0	165.0
Sand, coarse-grained, fine gravel; light-brown	165.0	175.0
Till	175.0	177.0
Note: End of solid-tube samples at 185, drill cuttings follow.		
Weathered rock, light-olive-brown, silty clayey, fine to coarse sand matrix with some fine gravel and pebbles; some weathered pebbles	177.0	193.0
Note: End of drill cuttings, core samples follow.		
Cavity	193.0	197.0
Limestone, dolomitic, light-gray, generally massive, stylolitic, iron-staining along fracture planes, voids, carbonate clasts, some thin beds of fissile, black, micritic dolomite	197.0	223.0