Hydrogeology, Ground-Water Quality, and Potential for Water-Supply Contamination near an Abandoned Wood-Preserving Plant Site at Jackson, Tennessee

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Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	square hectometer
foot per day (ft/day)	30.48	centimeter per day
gallons per minute (gal/min)	0.06309	liters per second

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

Station and well numbering system: For consistency between reports, the onsite ground-water data collection stations and well numbers in this report are the same as those used for the Remedial Investigation/Feasibility Study (S&ME, Inc., 1988). Onsite wells were numbered 1 through 18, with a few offset wells drilled later at some stations assigned the number of the first well with the letter "X" added as a suffix, for example 10X.

Wells in clusters of three at stations 1, 2, 3, 4, and 5 were assigned a station number followed by a letter indicating the general depth of the well. At station 1, for example, 1S was the designation for the shallow well; 1M for the intermediate depth well; and 1D for the deep well. In addition, several wells installed for the Tennessee Department of Health and Environment *[Tennessee Department of Environment and Conservation as of 1991]* before the Remedial Investigation/Feasibility Study was conducted were numbered AMW-1 through AMW-4.

During this investigation, wells installed in clusters of six at each of the six offsite stations (OSGW1 through OSGW6) were designated by adding hyphens (-) and well-numbers 1 through 6 to the station number for each of the six wells at each station (for example, OSGW1-1). In this report, USGS local well numbers for Tennessee are used to label stratigraphic test holes (fig. 3) and water-level observation wells (figs. 5 and 6) to aid in locating the geophysical logs and water-level data used. USGS local well numbers also are included in tables 2, 3, 5, 9, 10, 11, 12, 13, 14, 15, and 16 for cross reference.

In table 13 of this report, the 50 water-supply wells inventoried within a 2-mile radius of the American Creosote Works abandoned plant site were given map numbers (W1, W2, and so forth) for concise designation of wells on figure 14.

Tennessee District well-numbering system: Wells in Tennessee are identified according to the numbering system that is used by the U.S. Geological Survey, Water Resources Division. The well number consists of three parts:

(1) an abbreviation of the name of the county in which the well is located;
(2) a letter designating the 7 1/2-minute topographic quadrangle on which the well is plotted; quadrangles are lettered from left to right across the county beginning in the southwest corner of the county; and
(3) a number generally indicating the numerical order in which the well was inventoried.

For example, Md:G-326 indicates that the well is located in Madison County on the "G" quadrangle and is identified as well 326 in the numerical sequence.

ACRONYMS

ACW = American Creosote Works, Inc.
BTEX = benzene, toluene, ethylbenzene, xylenes
DPT = Direct Push Technology
GC/PID = gas chromatography with photo-ionization detection
HPLC = high-performance liquid chromatography
JUD = Jackson Utility Division
MCL = maximum contaminant level
NAPL = non-aqueous phase liquids
NWQL = National Water Quality Laboratory
PAH = polynuclear aromatic hydrocarbon
PCP = pentachlorophenol
PVC = polyvinyl chloride
QA/QC = quality assurance/quality control
RI/FS = Remedial Investigation/Feasibility Study
SVC = semi-volatile compounds
TDEC = Tennessee Department of Environment and Conservation
USEPA = U.S. Environmental Protection Agency
USGS = U.S. Geological Survey
VOC = volatile organic compounds

Hydrogeology, Ground-Water Quality, and Potential for Water-Supply Contamination near an Abandoned Wood-Preserving Plant Site at Jackson, Tennessee

By William S. Parks, June E. Mirecki, *and* James A. Kingsbury

Abstract

An investigation was conducted by the U.S. Geological Survey from 1990 to 1993 to collect and interpret hydrogeologic and ground-water-quality data specific to the American Creosote Works (ACW) abandoned plant site at Jackson, Tennessee. The purposes of this investigation were to determine the extent and magnitude of ground-water contamination in offsite areas and to assess the potential for contamination of water-supply wells.

Direct Push Technology was used to collect water samples from the alluvial aquifer at six offsite stations near the ACW site at depths of less than 40 feet below land surface. In addition, 36 wells were installed in clusters of 6 wells at the 6 offsite stations to collect water samples from the alluvial aquifer at depths of less than about 40 feet and from the Fort Pillow aquifer at depths of as much as about 150 feet below land surface.

Ground-water samples collected with Direct Push Technology methods were analyzed for polynuclear aromatic hydrocarbons, phenolic compounds (including pentachlorophenol), and nitrogen-containing heterocyclic compounds using high-performance liquid chromatography. These samples also were analyzed for a selected list of volatile organic compounds using gas chromatography with photo-ionization detection. Water samples pumped from the 36 wells were analyzed for selected volatile and semi-volatile organic compounds and for trace elements and major inorganic constituents.

Most contaminants in offsite areas were in samples from some wells screened in the alluvial aquifer. Naphthalene and volatile organic compounds were detected at concentrations that ranged generally from 0.2 to 20 micrograms per liter. Concentrations of all organic compounds were below State primary maximum contaminant levels for drinking water. Most contaminants are suspected to have been sorbed onto clay-mineral surfaces, or to have been degraded by microbial activity in the alluvial aquifer beneath the ACW site, before reaching the offsite areas.

Low concentrations of a few volatile organic compounds also were detected in samples from some offsite wells screened in the deeper Fort Pillow aquifer. Benzene and xylene were detected at concentrations ranging from 0.2 to 0.9 micrograms per liter, at depths of as much as 135 feet below land surface. However, semi-volatile organic compounds that commonly characterize contamination from wood-preserving processes were not detected in the Fort Pillow aquifer.

Two wells in the Jackson Utility Division South Well Field and an industrial well screened in the Fort Pillow aquifer east (upgradient) of the ACW site were sampled. The samples were analyzed for the same organic compounds and inorganic constituents as the 36 offsite wells near the ACW site.

Tetrachloroethylene, trichloroethylene, chloroform, and other volatile organic compounds were detected at low concentrations in water from these three wells. The detection of these contaminants, which are not commonly associated with woodpreserving processes, in the well-field wells is problematic inasmuch as many possible sources for these contaminants exist in the well-field area.

In addition to sampling the three wells in the Fort Pillow aquifer east of the ACW site, a domestic well, an industrial well, and an agricultural well screened in this aquifer west (downgradient) of the site were sampled. No contaminants from the ACW site were detected in the samples from these wells.

INTRODUCTION

American Creosote Works, Inc. (ACW) operated a wood-preserving plant at Jackson, Tennessee, for about 50 years (1930's until December 1981). Both creosote and pentachlorophenol (PCP) were used in the wood-preserving processes. Operations at this facility caused significant soil, surface-water, and ground-water contamination, and in 1984, the abandoned plant site was placed on the U.S. Environmental Protection Agency (USEPA) Superfund National Priorities List. Although a Remedial Investigation/Feasibility Study (RI/FS) was conducted at the ACW site for the USEPA (S&ME, Inc., 1988), available data were inadequate to assess the associated effects on nearby surface water or to delineate and characterize any offsite groundwater contamination. Subsequently, the U.S. Geological Survey (USGS) in cooperation with the North Superfund Remedial Branch, Waste Management Division, of the USEPA, Region IV, conducted investigations from 1990 to 1993 to determine and document toxicological effects on nearby surface waters, to delineate and characterize any ground-water contamination in offsite areas, and to assess the potential for contamination of water-supply wells.

Purpose and Scope

This report summarizes the results of the USGS investigation of ground-water contamination in areas near the ACW site and presents the hydrogeologic, water-level, and water-quality data collected. The report also summarizes the field work conducted and procedures followed during the investigation (Appendix 1) and presents geologic information from stratigraphic test holes and construction details for wells installed (Appendix 2).

The specific objectives of the ground-water investigation were to determine the areal extent and magnitude of contaminants in ground water in areas near the ACW site and to assess the potential for water-supply contamination from the site with emphasis on the municipal wells in the Jackson Utility Division (JUD) South Well Field. The offsite ground-water investigation was limited to areas within about 500 feet to the south and west of the ACW site. The assessment of the potential for water-supply contamination was limited to an area within a 2-mile radius of the site.

Approach

Because areas where the offsite ground-water investigation was to be conducted were located in low-lying, swampy terrain, and because depths of possible contaminant migration determined during the work conducted for the onsite RI/FS (S&ME, Inc., 1988) exceeded the capabilities of most small, lightweight drilling rigs, much consideration was given to the selection of subsurface exploration and ground-water sampling methods before the offsite investigation was begun. Direct Push Technology (DPT) of In-Situ Technology, Orlando, Florida, and a modified-auger method of subsurface exploration and ground-water sampling were evaluated at two onsite ground-water data-collection stations at the ACW site to determine the suitability of these methods for use during the offsite investigation (Parks and others, 1993). In addition, gas chromatography with photo-ionization detection (GC/PID), high-performance liquid chromatography (HPLC), CHEMetrix phenol analysis, and Microtox bioassay methods for water-quality analysis also were evaluated.

Results from this evaluation showed that DPT methods were useful for lithologic data and ground-water-sample collection to depths less than about 35 feet below land surface, which was the approximate depth limit of penetration refusal of the DPT piezocone and Hydrocone tools. Ground-water samples collected with the modified-auger method proved to be susceptible to downhole contamination once contaminated zones were penetrated. Of the four water-quality-analysis methods evaluated, the GC/PID and HPLC proved to be the most effective in detecting contaminants in ground water (Parks and others, 1993).

On the basis of the onsite evaluation of methods, DPT was used for collecting lithologic data and ground-water samples to depths of about 40 feet below land surface (depth of penetration refusal) at six offsite stations and GC/PID and HPLC were used for analysis of the ground-water samples collected. In addition, six wells were installed at each of the six offsite stations. Three at each station were screened at depths less than about 35 feet below land surface (depths determined from the DPT work and GC/PID and HPLC analyses), and three wells were screened from about 40 to 150 feet below land surface (depths determined from stratigraphic test holes drilled at each station).

Major work tasks performed for the offsite ground-water investigation and the assessment of the potential for water-supply contamination were:

(1) inventorying water-supply wells within a 2-mile radius of the ACW site;
(2) recording water levels continuously in 1 shallow well and 1 deep well onsite;
(3) drilling stratigraphic test holes at 3 onsite and 6 offsite stations;
(4) conducting DPT work to collect lithologic data and ground-water samples at the 6 offsite stations;
(5) analyzing these ground-water samples using field GC/PID and laboratory HPLC methods;
(6) installing and developing 36 wells for ground-water sample collection at the 6 offsite stations;
(7) measuring water levels in 33 onsite and 36 offsite wells, during seasonal high and low water levels;
(8) sampling the 36 wells installed at the 6 offsite stations;
(9) sampling 6 water-supply wells screened in the Fort Pillow aquifer and 1 screened in the alluvial aquifer within a 2-mile radius of the site;
(10) analyzing the water samples collected from the 36 offsite wells and 7 water-supply wells;
(11) compiling and interpreting hydrogeologic, water-level, and water-quality data; and
(12) preparing this report for publication.

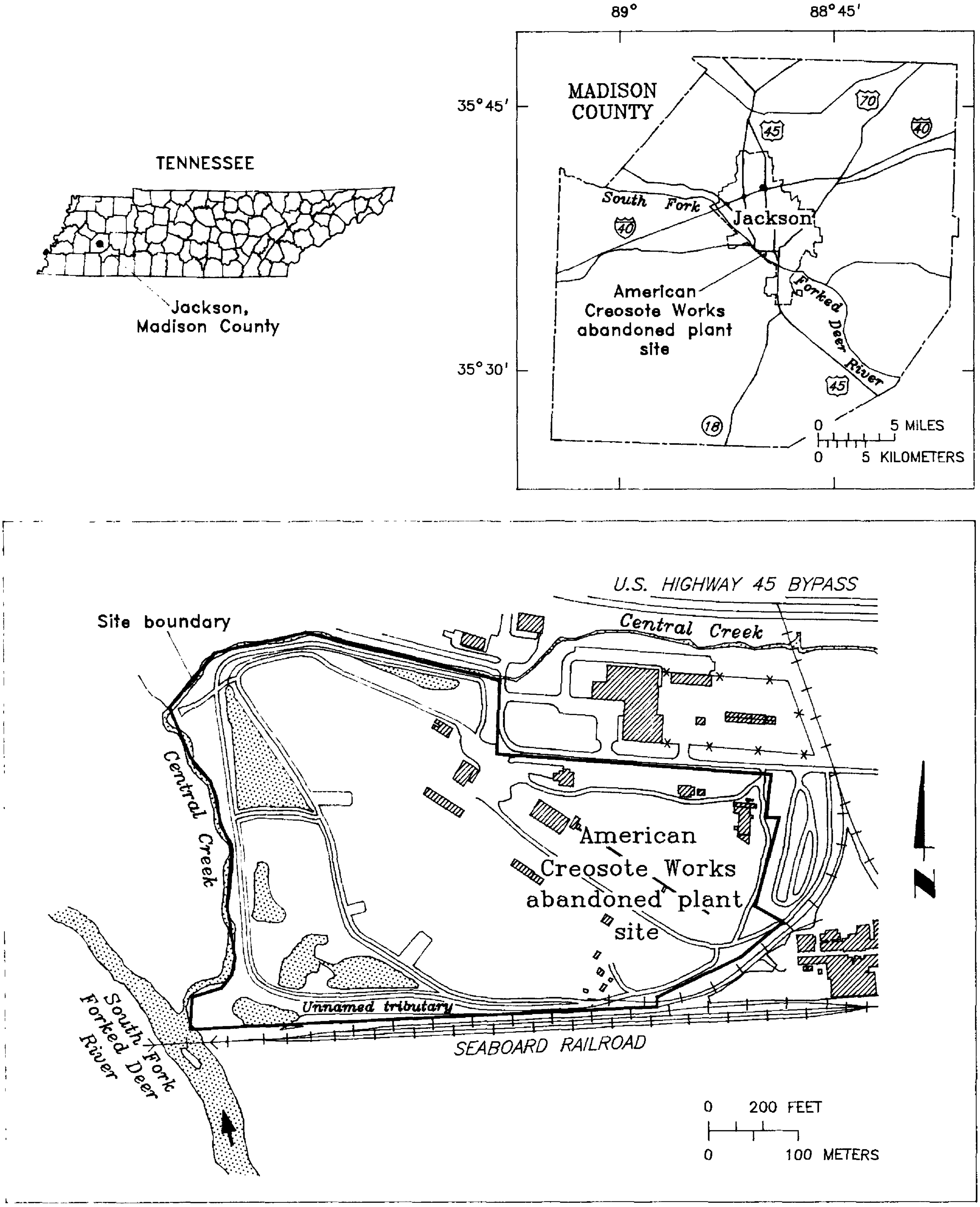
SITE DESCRIPTION

The ACW abandoned plant site (fig. 1) is located in the southwestern part of the city of Jackson, Madison County, Tennessee. The site, which is approximately 60 acres in size, is bounded on the north by Central Creek, on the east by industrial properties, on the south by the Seaboard Railroad and the South Fork Forked Deer River, and on the west by Central Creek.

The ACW site is on the alluvial plain of the South Fork Forked Deer River, the major stream draining the Jackson area. The river flows from southeast to northwest where it passes near the southwestern corner of the site (fig. 1). Central Creek, a minor tributary to the South Fork Forked Deer River, flows generally westward from an urban area in west Jackson, through a commercial and industrial area, and along part of the northern border of the site. Near the northwestern corner of the site, the creek turns approximately 90 degrees, flows southeastward along the site's western border, and enters the South Fork Forked Deer River near the southwestern corner of the site.

The terrain at the ACW site is flat except for the relief provided by the stream channels, which is about 15 feet in the area. Land-surface altitudes range from about 340 feet above sea level along the South Fork Forked Deer River to about 350 feet near the northeastern corner of the site. The site is partially protected from flooding by levees on the west and south.

Nearby areas to the west and south of the ACW site--called "offsite areas" for purposes of this report--where the ground-water investigation was conducted are on the swampy alluvial plain of the South Fork Forked Deer River and are subject to seasonal flooding. These areas are separated from the site by Central Creek and the embankment of the Seaboard Railroad. Access to the offsite areas is along a utility line right-of-way that crosses the alluvial plain for a distance of about 1/2 mile from improved roads. For these reasons, the offsite areas generally are accessible only during dry times of the year.



Base modified from S&ME, Inc., 1988

Figure 1. Location of the American Creosote Works abandoned plant site at Jackson, Tennessee.

HYDROGEOLOGY

The ACW site is located on the eastern limb of the Mississippi embayment, a broad structural trough or syncline that plunges southward along an axis that approximates the Mississippi River (Cushing and others, 1964). This syncline is filled with a few thousand feet of unconsolidated to semiconsolidated sediments comprising formations of Cretaceous and Tertiary age. These formations dip gently westward into the embayment and southward down the axis. Overlying the Cretaceous and Tertiary sediments in many areas are the fluvial deposits, loess, and alluvium of Tertiary(?) and Quaternary age. Post-Cretaceous geologic units underlying the ACW site are the Clayton Formation, Porters Creek Clay, Old Breastworks Formation, and Fort Pillow Sand of Tertiary age and the alluvium of Quaternary age (table 1).

Aquifer Description and Structural Relations

The Fort Pillow Sand and the alluvium consist primarily of sand with silt and clay lenses at various stratigraphic horizons. These units constitute the Fort Pillow aquifer (Parks and Carmichael, 1989) and the alluvial aquifer. In the area of the ACW site, the Fort Pillow and alluvial aquifers are not separated by a confining unit of any significant thickness or areal extent. However, because differences in silt and clay content in the sands affect contaminant migration in the subsurface beneath the ACW site, the Fort Pillow and alluvial aquifers are treated as separate aquifers in this report.

The uppermost alluvium consists primarily of clay and silt with some interbedded fine sand and serves as a relatively thin (0 to 20 feet thick) upper confining unit for the alluvial and Fort Pillow aquifers. The Clayton Formation and the Porters Creek Clay consist predominantly of clay and serve as a relatively thick (about 215 feet thick) lower confining unit separating the Fort Pillow aquifer from the deeper McNairy aquifer (table 1). The Old Breastworks Formation, between the Porters Creek Clay and the Fort Pillow Sand, consists primarily of very fine to fine sand with clay interbeds and may serve more as a part of the lower confining unit than as an aquifer.

Nine stratigraphic test holes (table 2) were drilled through the alluvium, Fort Pillow Sand, and Old Breastworks Formation into the Porters Creek Clay at onsite stations 4, 6, and 7 and offsite stations OSGW1 through OSGW6 (fig. 2). Lithologic descriptions from samples collected and the geophysical logs made in these test holes are given in Appendix 2.

The boundary between the top of the Porters Creek Clay and the base of the overlying Old Breastworks Formation (where present) or Fort Pillow Sand is the most distinctive contact encountered in the stratigraphic test holes drilled at the three onsite and six offsite stations. The structure-contour map (fig. 2) of the top of the Porters Creek Clay indicates that its contact with the overlying Old Breastworks Formation or Fort Pillow Sand has an approximate dip of 20 to 30 feet per mile to the southwest beneath the central and western parts of the ACW site. In the northeast corner of the ACW site, the altitude of the top of the Porters Creek Clay in stratigraphic test hole Md:G-326 was about 35 feet lower than in the eight other test holes (fig. 2, table 3). This anomaly is interpreted to be relief (perhaps, a channel feature) on an erosional surface at the top of the Porters Creek Clay. Russell and Parks (1975, p. B24) determined that relief on this surface (contact between the Porters Creek Clay and Wilcox Formation in their report) locally is as much as 50 feet in the outcrop area in western Tennessee.

The anomaly in altitude of the top of the Porters Creek Clay at the ACW site could be the result of a fault. Evidence for a fault, however, is equivocal. Layers of rock (claystone or siliceous sandstone) interbedded with silty clay or silty sand that were encountered in the Porters Creek Clay near the bottoms of test holes Md:G-326, Md:G-360, and Md:G-362 (fig. 3, Appendix 2) may represent a continuous unit in the Porters Creek Clay underlying the site. If so, the difference in altitude of the top of the Porters Creek Clay in test hole Md:G-326 and the other test holes supports the hypothesis that the anomaly is the result of relief on an erosional surface.

Table 1. Post-Cretaceous geologic units underlying the American Creosote Works abandoned plant site at Jackson, Tennessee

[Compiled from lithologic and geophysical logs of test holes drilled at the site and at the University of Tennessee Agricultural Experiment Station 1 1/2 miles northwest, and reports by Schneider and Blankenship (1950), Milhous (1959), Parks (1968), Russell and Parks (1975), and Parks and Carmichael (1989)]

System	Series	Group	Stratigraphic unit	Thickness (in feet)	Lithology
Quaternary	Holocene and Pleistocene		Alluvium (Alluvial aquifer)	30-40	Sand, silt, clay, and gravel. Underlies the alluvial plain of the South Fork Forked Deer River. Upper part consists of clay, silt, and fine sand; lower part consists of fine to coarse sand containing some gravel.
Tertiary	Eocene — ? — Paleocene	Wilcox	Fort Pillow Sand (Fort Pillow aquifer)	90-135	Sand, silt, clay, and minor lignite. Consists of lenses of medium to coarse and fine to medium sand with lenses of silt and clay at various stratigraphic horizons.
			Old Breastworks Formation	0-35	Sand, silt, clay, and lignite. Consists of fine to medium and fine to very fine sand with lenses of silt, clay, and lignite.
		Midway	Porters Creek Clay	175	Clay and lenses of sand. Consists of a widespread and thick body of clay with some interbeds of fine sand. Locally contains thin beds of claystone in upper part. Serves as the principal confining layer separating the Fort Pillow aquifer from the McNairy aquifer.
			Clayton Formation	40	Clay, silt, and sand. Overlies the Owl Creek Formation and the McNairy Sand of Cretaceous age.

Table 2. Stratigraphic test holes drilled at onsite stations 4, 6, and 7 and offsite stations OSGW1 through OSGW6 and depth to and altitude of top of the Porters Creek Clay at the American Creosote Works abandoned plant site

[USGS, U.S. Geological Survey]

Station number (see fig. 2)	USGS local well number	Date completed	Altitude of land surface above sea level, in feet	Depth to top of Porters Creek Clay below land surface, in feet	Altitude of top of Porters Creek Clay above sea level, in feet	Total depth of test hole, in feet
			Onsite stations			
4	Md:G-365	11-19-91	344	156	188	223
6	Md:G-366	11-20-91	346	157	189	216
7	Md:G-326	05-15-90	348	194	154	245
			Offsite stations			
OSGW1	Md:G-359	10-08-91	343	154	189	218
OSGW2	Md:G-360	10-10-91	342	160	182	240
OSGW3	Md:G-361	10-22-91	341	157	184	236
OSGW4	Md:G-362	10-29-91	343	160	183	236
OSGW5	Md:G-363	10-27-91	342	158	184	228
OSGW6	Md:G-364	10-25-91	342	158	184	229

Aquifer Characteristics and Ground-Water Flow

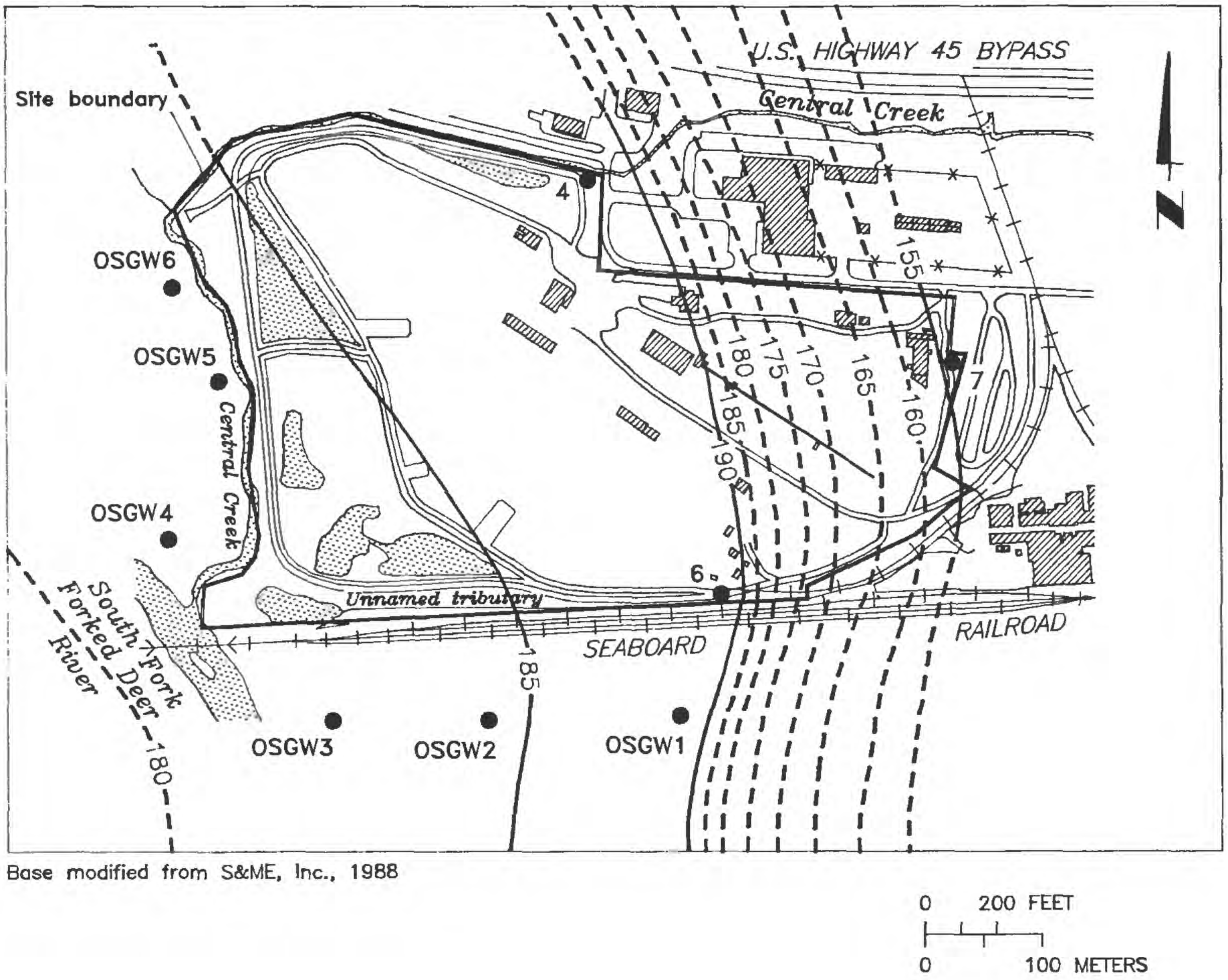
Water levels were measured in 33 onsite wells in March and October 1990 and in 31 onsite and 36 offsite wells in October 1992 (fig. 4; table 3). These data indicate that water levels generally are high throughout the year, ranging from about 1 to 10 feet below land surface. Onsite and offsite clusters of monitoring wells are screened at depths of about 8 to 41 feet below land surface in the alluvial aquifer and 36 to 154 feet below land surface in the Fort Pillow aquifer (table 3). The Fort Pillow and alluvial aquifers are semi-confined beneath the ACW site.

Water levels measured in the onsite and offsite monitoring wells during October 1992 (table 3) were used to prepare potentiometric-surface maps of the alluvial aquifer and the Fort Pillow aquifer. These maps (fig. 5) indicate that relatively small differences in hydraulic head exist between these aquifers. Where wells are in clusters, water levels in the shallowest wells in the alluvial aquifer and the deepest wells in the Fort Pillow aquifer were used for preparation of the maps (fig. 5).

Water levels range from about 340 feet above sea level in wells at the higher altitudes at the northeastern part of the area to about 334 feet above sea level in the southwestern part near the South Fork Forked Deer River (fig. 5). Thus, the horizontal component of ground-water flow is from northeast to southwest across the ACW site toward the river (fig. 5).

Water levels were recorded continuously since February 21, 1990, in well Md:G-284, (fig. 5) screened from 25 to 35 feet in the alluvial aquifer, and since May 30, 1990, in well Md:G-326 (fig. 5) screened from 134 to 154 feet in the Fort Pillow aquifer to determine seasonal water-level fluctuations. Hydrographs for these wells (fig. 6) show that water levels in the shallow and deep zones fluctuate similarly as if the wells are screened in a single aquifer. Hydraulic head differences in wells Md:G-284 and Md:G-326 (fig. 6) are less than 0.5 foot and generally are higher in the alluvial aquifer than in the Fort Pillow aquifer, indicating downward movement of ground water (recharge) beneath this part of the ACW site.

Vertical hydraulic gradients locally are somewhat complex and vary upward or downward among wells in clusters and among clusters, based



Base modified from S&ME, Inc., 1988

EXPLANATION

——180— — — STRUCTURE CONTOUR—Shows altitude of top of the Porters Creek Clay. Dashed where approximately located. Contour interval 5 feet. Datum is sea level

6● ONSITE STATION AT WHICH STRATIGRAPHIC TEST HOLE WAS DRILLED

● OSGW3 OFFSITE STATION AT WHICH STRATIGRAPHIC TEST HOLE WAS DRILLED

Figure 2. Location of onsite stations 4, 6, and 7, offsite stations OSGW1 through OSGW6 where stratigraphic test holes were drilled, and altitude of top of Porters Creek Clay.

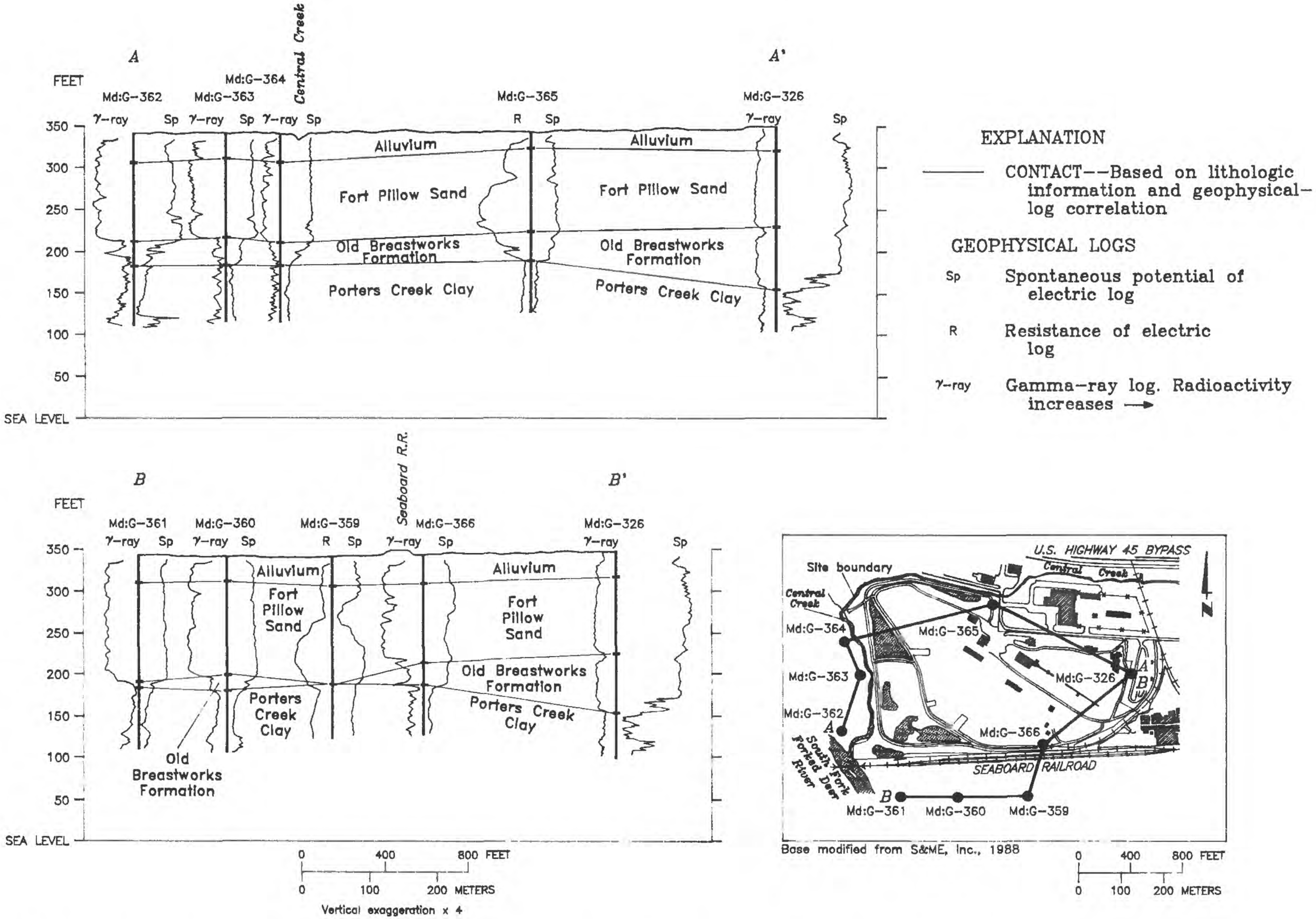
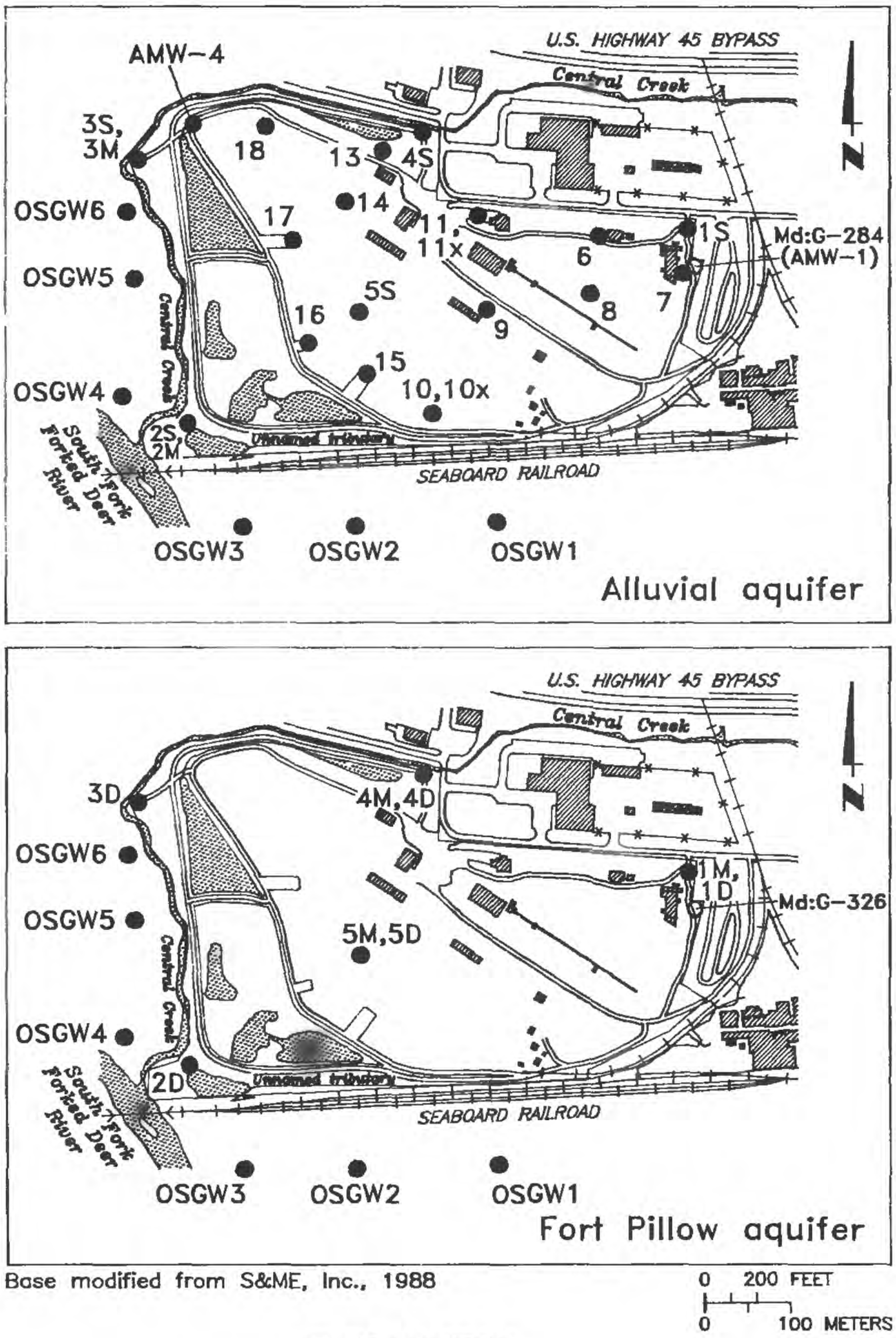


Figure 3. Hydrogeologic sections A-A′ and B-B′ through the area of the American Creosote Works abandoned plant site.



Base modified from S&ME, Inc., 1988

EXPLANATION

● 2D	WELL IN WHICH WATER LEVEL WAS MEASURED AND WELL NUMBER
○ Md:G-326	WELL WITH CONTINUOUS WATER-LEVEL RECORDER AND WELL NUMBER
● OSGW3	OFFSITE STATION AND NUMBER--Six wells at each station. Wells 1-3 screened in the alluvial aquifer and wells 4-6 screened in the Fort Pillow aquifer. For example, OSGW1-1 is screened in the alluvial aquifer and OSGW1-4 is the shallowest of the three wells screened in the Fort Pillow aquifer

Figure 4. Location of wells screened in the alluvial and Fort Pillow aquifers in which water levels were measured in March 1990, October 1990, and October 1992.

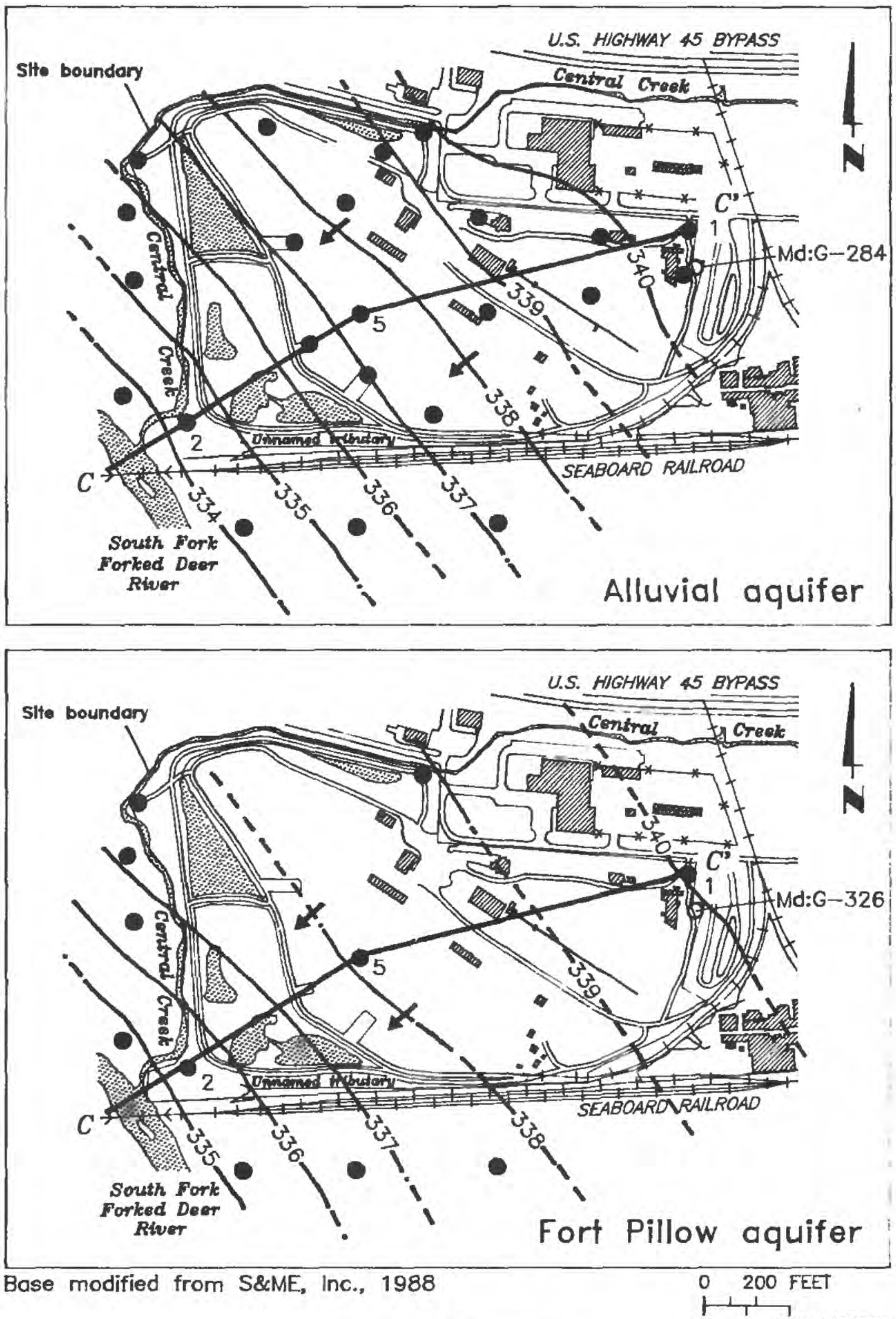
Table 3. Well descriptions and water levels measured in onsite and offsite wells at the American Creosote Works abandoned plant site in March 1990, October 1990, and October 1992

[USGS, U.S. Geological Survey; --, indicates no measurement, because well had not been installed]

Well numbers		Altitude of land surface above sea level, in feet	Screened interval below land surface, in feet	Aquifer in which screened	Water-level below land surface		
Project and map	USGS local for Tennessee				Depth on 3-22-90, in feet	Depth on 10-17-90, in feet	Depth on 10-21-92, in feet
			Onsite wells				
AMW-1	Md:G-284	348	25 - 35	Alluvial	5.90	8.18	8.50
AMW-4	Md:G-287	344	20 - 25	Alluvial	7.43	9.42	no measurement
1S	Md:G-289	350	20.5 - 25.5	Alluvial	7.00	9.41	9.63
1M	Md:G-290	350	54.5 - 59.5	Fort Pillow	7.33	9.64	9.92
1D	Md:G-291	350	112 - 122	Fort Pillow	7.33	9.59	9.93
2S	Md:G-293	342	12 - 17	Alluvial	5.20	7.65	7.44
2M	Md:G-294	342	29.5 - 34.5	Alluvial	5.42	7.87	7.79
2D	Md:G-295	342	116.5 - 126.5	Fort Pillow	4.30	6.52	6.44
3S	Md:G-297	343	8.5 - 13.5	Alluvial	4.95	6.56	6.54
3M	Md:G-298	343	32.5 - 37.5	Alluvial	4.85	6.52	6.36
3D	Md:G-299	343	125.5 - 135.5	Fort Pillow	3.80	5.98	5.88
4S	Md:G-301	347	16.5 - 21.5	Alluvial	5.10	7.29	7.12
4M	Md:G-302	347	52.5 - 57.5	Fort Pillow	4.97	7.36	7.22
4D	Md:G-303	347	117.5 - 127.5	Fort Pillow	5.94	8.15	8.22
5S	Md:G-305	342	14.5 - 19.5	Alluvial	2.32	4.63	4.79
5M	Md:G-306	342	57 - 62	Fort Pillow	1.78	4.11	4.52
5D	Md:G-307	342	100.5 - 110.5	Fort Pillow	1.36	3.60	3.68
6	Md:G-309	348	16.5 - 21.5	Alluvial	5.91	8.20	8.44
7	Md:G-310	349	14 - 19	Alluvial	6.07	8.34	8.67
8	Md:G-311	347	14 - 19	Alluvial	4.66	7.00	7.23
9	Md:G-312	346	15 - 20	Alluvial	4.86	7.30	7.43
10	Md:G-313	343	12.5 - 17.5	Alluvial	2.98	5.44	5.52
10X	Md:G-323	343	11 - 16	Alluvial	2.50	4.93	5.05
11	Md:G-314	347	17 - 21.5	Alluvial	5.15	7.44	7.47
11X	Md:G-324	347	17 - 22	Alluvial	5.00	7.28	7.40
12	Md:G-315	346	14.5 - 19.5	Alluvial	4.72	6.66	no measurement
13	Md:G-316	344	14.5 - 19.5	Alluvial	5.69	5.06	5.07
14	Md:G-317	344	14.5 - 19.5	Alluvial	3.81	5.48	5.17
15	Md:G-318	342	13 - 18	Alluvial	7.00	3.22	4.98
16	Md:G-319	342	12 - 17	Alluvial	2.73	5.06	5.15
17	Md:G-320	342	9.5 - 14.5	Alluvial	2.15	4.36	4.45
18	Md:G-321	344	14.5 - 19.5	Alluvial	3.38	5.49	5.54
None	Md:G-326	348	134 - 154	Fort Pillow	--	8.10	8.39

Table 3. Well descriptions and water levels measured in onsite and offsite wells at the American Creosote Works abandoned plant site in March 1990, October 1990, and October 1992--Continued

Well numbers		Altitude of land surface above sea level, in feet	Screened interval below land surface, in feet	Aquifer in which screened	Water-level below land surface		
Project and map	USGS local for Tennessee				Depth on 3-22-90, in feet	Depth on 10-17-90, in feet	Depth on 10-21-92, in feet
			Offsite wells				
OSGW1-1	Md:G-367	343	13 - 18	Alluvial	--	--	5.63
OSGW1-2	Md:G-368	343	19 - 24	Alluvial	--	--	5.20
OSGW1-3	Md:G-369	343	27 - 32	Alluvial	--	--	5.57
OSGW1-4	Md:G-370	343	42 - 52	Fort Pillow	--	--	5.25
OSGW1-5	Md:G-371	343	92 - 102	Fort Pillow	--	--	5.53
OSGW1-6	Md:G-372	343	128 - 138	Fort Pillow	--	--	5.26
OSGW2-1	Md:G-373	342	10 - 15	Alluvial	--	--	6.27
OSGW2-2	Nd:G-374	342	17 - 22	Alluvial	--	--	5.92
OSGW2-3	Md:G-375	342	24 - 29	Alluvial	--	--	5.75
OSGW2-4	Md:G-376	342	62 - 72	Fort Pillow	--	--	5.42
OSGW2-5	Md:G-377	342	92 - 102	Fort Pillow	--	--	4.88
OSGW2-6	Md:G-378	342	127 - 137	Fort Pillow	--	--	5.30
OSGW3-1	Md:G-379	341	9 - 14	Alluvial	--	--	6.80
OSGW3-2	Md:G-380	341	15 - 20	Alluvial	--	--	7.25
OSGW3-3	Md:G-381	341	24 - 29	Alluvial	--	--	7.43
OSGW3-4	Md:G-382	341	36 - 46	Fort Pillow	--	--	7.25
OSGW3-5	Md:G-383	341	68 - 78	Fort Pillow	--	--	5.85
OSGW3-6	Md:G-384	341	138 - 148	Fort Pillow	--	--	5.58
OSGW4-1	Md:G-385	343	10 - 15	Alluvial	--	--	9.44
OSGW4-2	Md:G-386	343	22 - 27	Alluvial	--	--	9.79
OSGW4-3	Md:G-387	343	36 - 41	Alluvial	--	--	9.55
OSGW4-4	Md:G-388	343	48 - 58	Fort Pillow	--	--	8.52
OSGW4-5	Md:G-389	343	79 - 89	Fort Pillow	--	--	8.04
OSGW4-6	Md:G-390	343	117 - 127	Fort Pillow	--	--	6.73
OSGW5-1	Md:G-391	342	12 - 17	Alluvial	--	--	6.75
OSGW5-2	Md:G-392	342	19 - 24	Alluvial	--	--	6.75
OSGW5-3	Md:G-393	342	27 - 32	Alluvial	--	--	6.80
OSGW5-4	Md:G-394	342	40 - 50	Fort Pillow	--	--	6.47
OSGW5-5	Md:G-395	342	83 - 93	Fort Pillow	--	--	6.01
OSGW5-6	Md:G-396	342	113 - 123	Fort Pillow	--	--	5.73
OSGW6-1	Md:G-397	342	10 - 15	Alluvial	--	--	6.40
OSGW6-2	Md:G-398	342	19 - 24	Alluvial	--	--	6.21
OSGW6-3	Md:G-399	342	27 - 32	Alluvial	--	--	6.38
OSGW6-4	Md:G-400	342	50 - 60	Fort Pillow	--	--	6.00
OSGW6-5	Md:G-401	342	82 - 92	Fort Pillow	--	--	6.40
OSGW6-6	Md:G-402	342	120 - 130	Fort Pillow	--	--	6.20

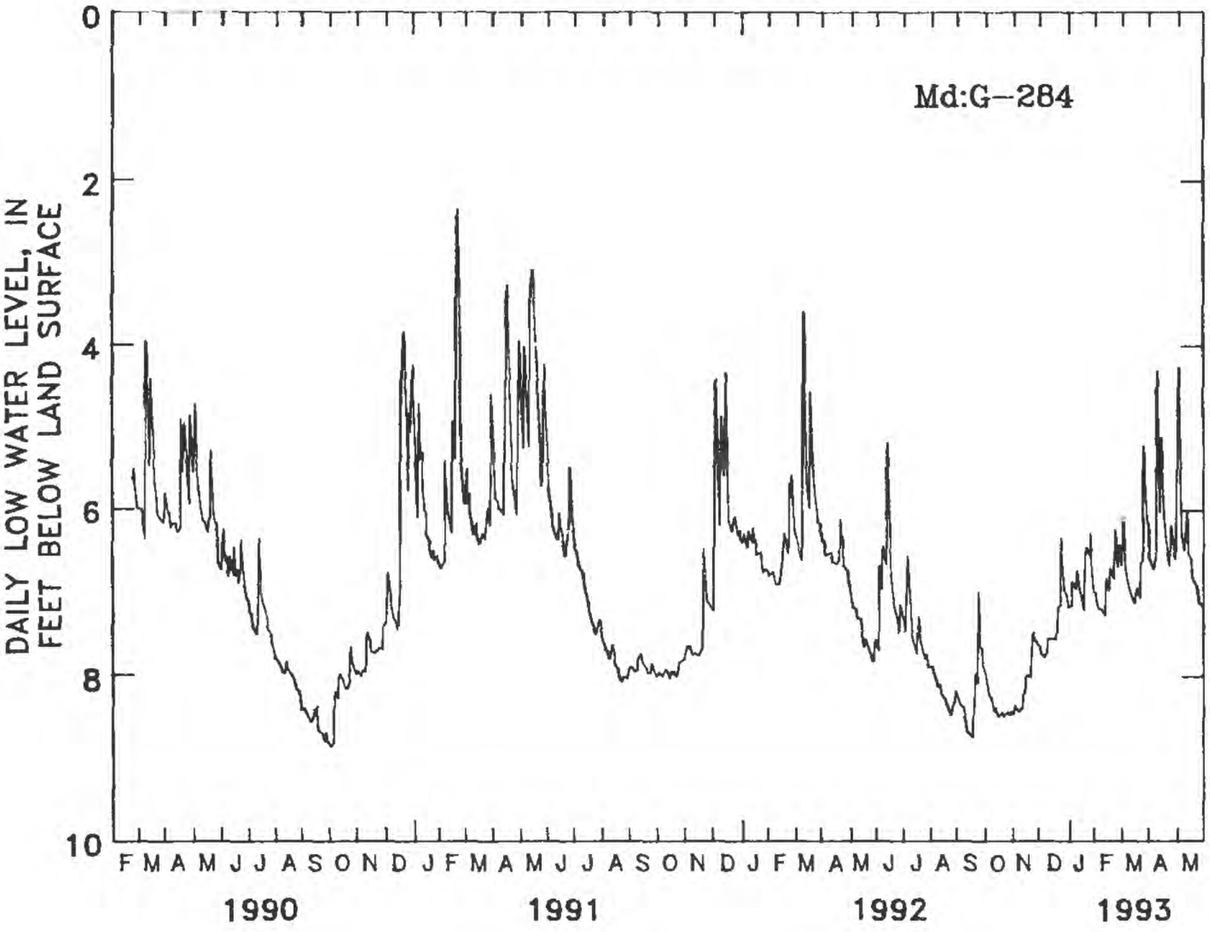


Base modified from S&ME, Inc., 1988

EXPLANATION

—335— —	POTENTIOMETRIC CONTOUR--Shows altitude at which water level stood in wells. Dashed where approximately located. Contour interval 1 foot. Datum is sea level
←	DIRECTION OF GROUND-WATER FLOW
C——C'	LINE OF SECTION--(See figure 7)
●	WELL IN WHICH WATER LEVEL WAS MEASURED
○ Md:G-326	WELL WITH CONTINUOUS WATER-LEVEL RECORDER AND WELL NUMBER
● 2	STATION WITH WELL CLUSTER AND NUMBER

Figure 5. Potentiometric surfaces in the alluvial and Fort Pillow aquifers, October 1992, and location of wells Md:G-284 and Md:G-326.



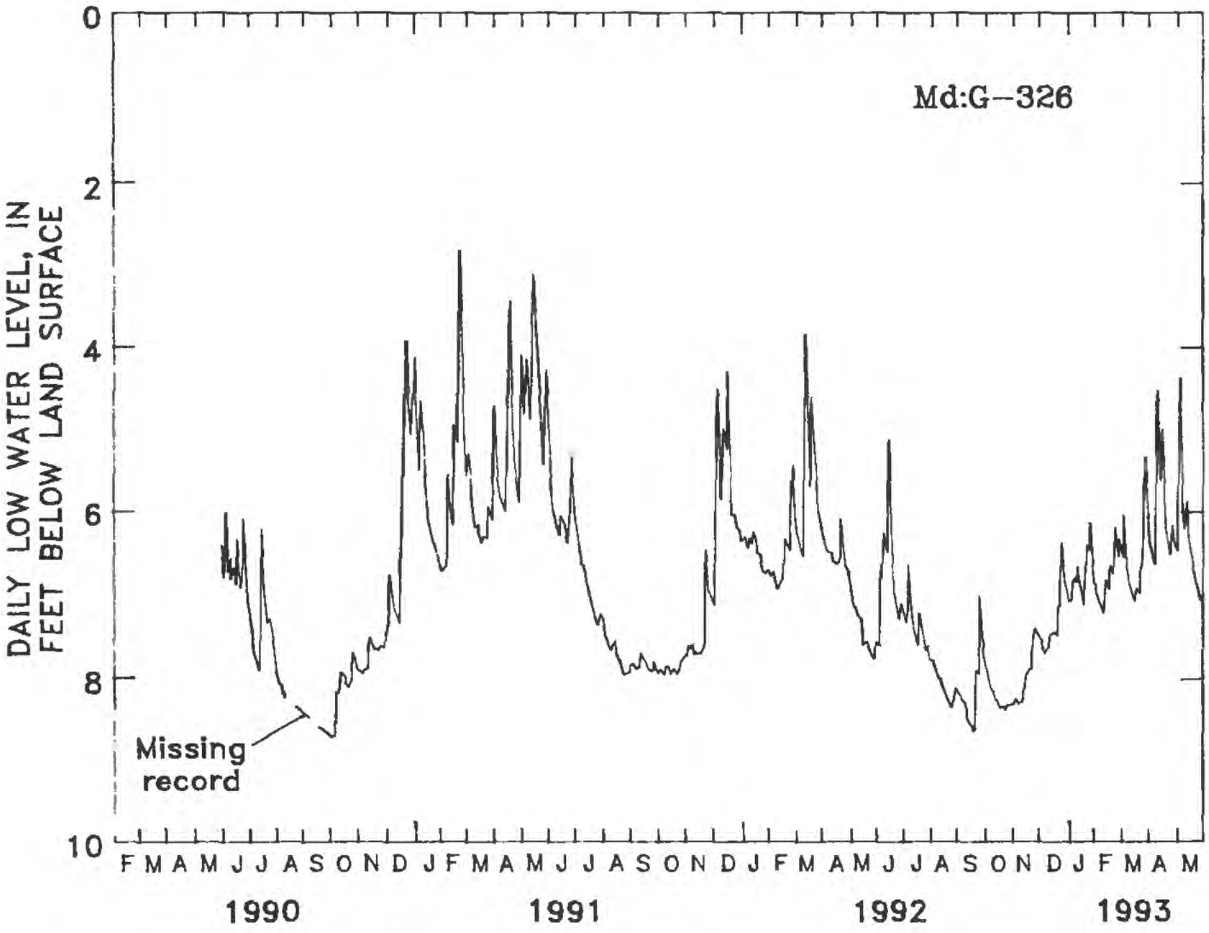


Figure 6. Water levels recorded in well Md:G-284 screened in the alluvial aquifer and well Md:G-326 screened in the Fort Pillow aquifer, February 1990 through May 1993, at the American Creosote Works abandoned plant site.

on water-level measurements (table 3). Water levels generally are slightly higher in the shallower wells than in the deeper wells at onsite stations 1 (wells 1S, 1M, and 1D) and 4 (wells 4S, 4M, and 4D) (fig. 4). These differences in hydraulic head indicate a downward hydraulic gradient in the northeastern and northern parts of the ACW site and recharge to the aquifers. Water levels generally are slightly higher in the deeper wells than in the shallower wells at onsite station 2 (wells 2S, 2M, and 3D), station 3 (wells 3S, 3M, and 3D), and station 5 (wells 5S, 5M, and 5D) (fig. 4). Water levels also are higher in the deeper wells than in the shallower wells at offsite stations OSGW1 through OSGW6 (fig. 4). These differences in hydraulic head indicate upward flow of water in the northwestern, west-central, and southwestern parts of the ACW site and in nearby offsite areas and discharge from the aquifers to the South Fork Forked Deer River. A generalized hydrogeologic section from station 1, through stations 5 and 2, to the South Fork Forked Deer River depicts ground-water flow at the ACW site (fig. 7) for potentiometric conditions during October 1992.

Hydraulic conductivities for the alluvial and Fort Pillow aquifers were determined by computer analysis of filling-rates of the Hydrocone tool for 1-foot intervals during the ground-water sampling as a part of the DPT work at onsite stations (Parks and others, 1993) and at offsite stations OSGW1 through OSGW6 (table 4). Forty measurements of hydraulic conductivity for the alluvial aquifer ranged from 0.195 to 46.8 ft/day, and three measurements of hydraulic conductivity for the Fort Pillow aquifer ranged from 0.009 to 26.4 ft/day. These ranges in hydraulic conductivity measurements indicate considerable heterogeneity in the sediments that make up the alluvial and Fort Pillow aquifers.

Average flow velocities of ground water in the alluvial and Fort Pillow aquifers were calculated using an equation derived from a combination of Darcy's law and the velocity equation of hydraulics (Heath, 1983):

$$v = \frac{Kdh}{ndl}$$

where,

v is the Darcian velocity, which is the average velocity of the entire cross-sectional area, in feet per day;

K is the hydraulic conductivity, in feet per day;

dh/dl is the hydraulic gradient, in foot per foot; and

n is the porosity, in percent by volume.

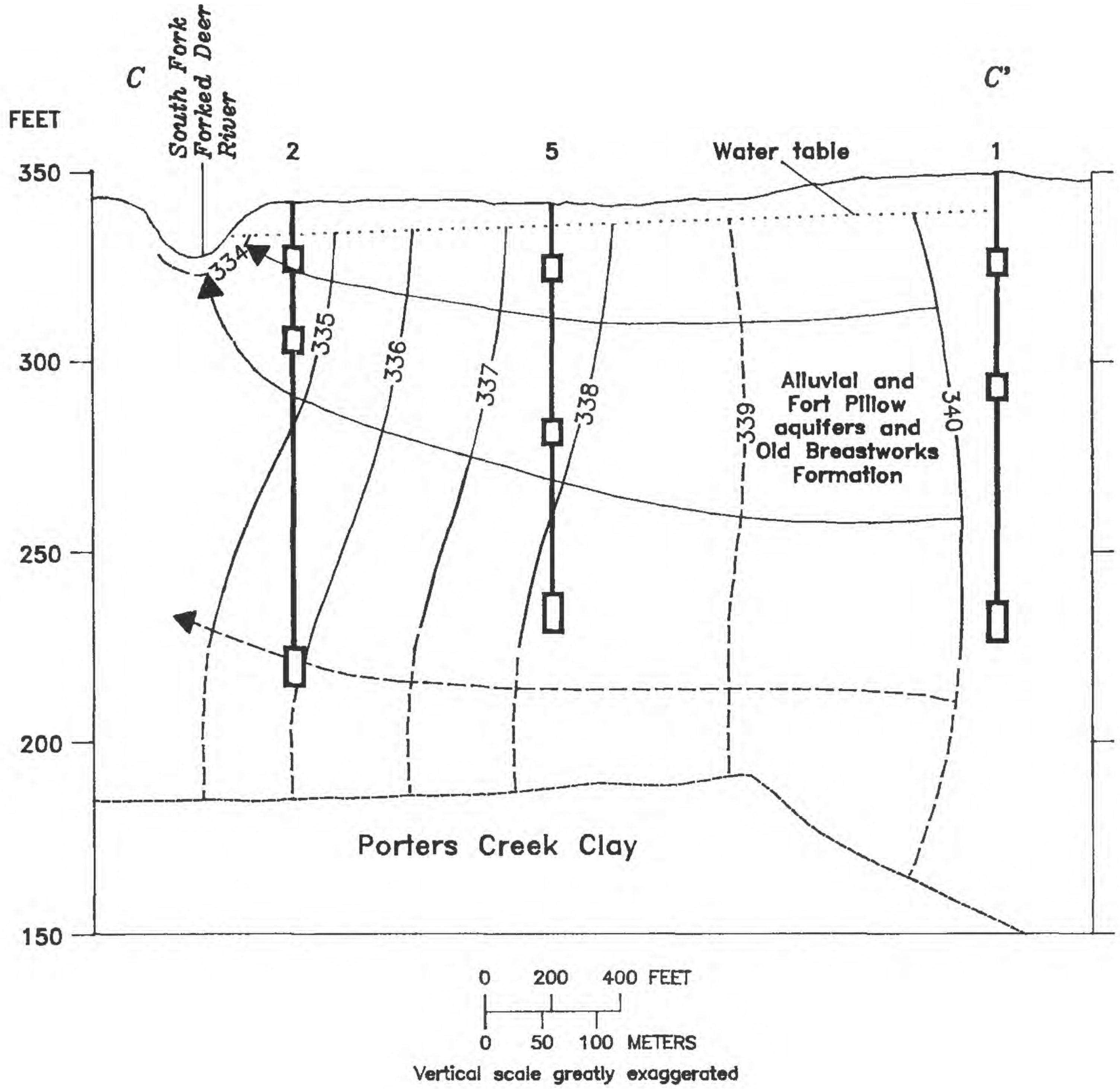
Hydraulic gradients estimated from the potentiometric surface maps (fig. 5) and median values of hydraulic conductivity determined from the DPT results at onsite (Parks and others, 1993) and offsite (table 4) stations were used in the calculations. Porosity was assumed to be 20 percent for both aquifers.

For the alluvial aquifer, an average ground-water flow velocity was calculated using a median hydraulic conductivity of 2.46 ft/day and an estimated hydraulic gradient of 0.0038 foot per foot. These values indicate an average flow velocity of about 0.047 foot per day (17 feet per year). Minimum and maximum values for hydraulic conductivity substituted into this equation indicate minimum and maximum average flow velocities in the alluvial aquifer of about 1.4 and 325 feet per year.

For the Fort Pillow aquifer, an average ground-water flow velocity was calculated using a median hydraulic conductivity of 2.03 ft/day and an estimated hydraulic gradient of 0.0027 foot per foot. These values indicate an average flow velocity of about 0.027 foot per day (10 feet per year). Minimum and maximum values of hydraulic conductivity substituted into the equation indicate minimum and maximum average flow velocities in the Fort Pillow aquifer of about 0.04 and 130 feet per year.

GROUND-WATER QUALITY

For this investigation, ground-water samples were collected at 6 offsite stations with the DPT Hydrocone tool and from 36 wells installed at these stations (6 wells at each station) to determine the extent and magnitude of offsite contamination from the ACW site. Ground-water samples collected with the DPT Hydrocone tool were analyzed for polynuclear aromatic hydrocarbons (PAH's),



EXPLANATION

——335—— EQUIPOTENTIAL LINE—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Interval is 1 foot. Datum is sea level

◀—— GENERALIZED FLOW LINE—Dashed where flow direction is uncertain. Arrow shows direction of flow

2 ONSITE STATION WITH WELL CLUSTER

□ SCREENED INTERVALS OF WELLS IN CLUSTERS

Figure 7. Hydrogeologic section C-C' showing generalized ground-water flow beneath the American Creosote Works abandoned plant site. (See figure 5 for location of hydrogeologic section.)

Table 4. Water levels, hydraulic conductivities, lithologies, and relative densities of sediment in the alluvial aquifer at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site

[Water levels were calculated from hydrostatic-pressure data from the Hydrocone tool; hydraulic conductivities were calculated from hydrostatic-pressure data and filling rates of the Hydrocone tool; lithology was derived from computer analysis of point-stress and friction data from the piezocone tool; relative densities of sediment were calculated from the piezocone point-stress data and are given in units equivalent to numbers of blows per foot as measured by a standard penetration test conducted by driving a split-spoon ssmpler out the bottom of a hollow-stem auger with a 140-pound hammer]

Station number	Hydrocone depth below land surface, in feet	Water level below land surface, in feet	Hydraulic conductivity, in feet per day	Lithology	Relative density of sediment
OSGW1	15 - 16	4.5	0.347	Fine sand	40
	27 - 28	4.5	46.8	Fine sand	19
	29 - 30	4.5	6.81	Clayey fine sand	40
	30.5 - 31.5	4.5	.778	Silty to clayey fine sand	45
OSGW2	9 - 10	5	.289	Fine sand	30
	14 - 15	5	5.51	Silty fine sand	15
	16 - 17	5	1.11	Dense or cemented sands	50
	21 - 22	5	1.94	Silty fine sand	25
	23 - 24	5	1.44	Dense or cemented sands	45
	28 - 29	5	1.83	No data	
OSGW3	13.5 - 14.5	6.5	.773	Fine sand	31
	19 - 20	6.5	3.71	Fine sand	29
	23 - 24	6.5	.888	Fine sand	37
	28 - 29	6.5	2.54	No data	--
OSGW4	14 - 15	7.5	9.55	Silty to clayey fine sand	35
	19 - 20	7.5	.255	Fine sand	29
	22 - 23	7.5	3.56	Fine sand	45
	35 - 36	7.5	.373	Dense or cemented sands	32
	40 - 41	7.5	.735	Fine sand	21
OSGW5	14 - 15	6	1.23	Fine sand	55
	16 - 17	6	2.39	Sandy clay	18
	23 - 24	6	1.77	Fine sand	41
	31 - 32	6	2.16	Fine sand	33
OSGW6	11 - 12	6	9.89	Silty to clayey fine sand	18
	14 - 15	6	20.8	Silty to clayey fine sand	23
	17 - 18	6	11.5	Silty fine sand	24
	21 - 22	6	10.5	Silty to clayey fine sand	20
	26 - 27	6	4.32	Silty fine sand	27
	30 - 31	6	9.83	Fine sand	42

phenolic compounds (including PCP), and nitrogen-containing heterocyclic compounds. The DPT samples also were analyzed for selected volatile organic compounds (VOC's). Water samples pumped from the 36 wells were analyzed for selected VOC's and semi-volatile organic compounds (SVC's). Samples from these wells also were analyzed for trace elements, major inorganic constituents, and water-quality characteristics.

Onsite ground-water-quality data are summarized herein to identify possible contaminants and to provide a geochemical basis for comparison to offsite ground-water contaminant concentrations. Data for organic compounds are from an onsite evaluation of subsurface exploration, sampling, and water-quality-analysis methods (Parks and others, 1993). Data for trace elements are from the RI/FS for the ACW site (S&ME, Inc., 1988). Discussion of the transport and fate of organic constituents of creosote and related contaminants in ground water at the ACW site is based on results of investigations at the American Creosote Works abandoned plant site at Pensacola, Florida (Mattraw and Franks, 1986).

In the discussion that follows (and in tables 8, 10, and 14), references are made to primary maximum contaminant levels (MCL's) in drinking water. The Tennessee Department of Environment and Conservation (TDEC) is the regulatory agency that determines these levels for the State of Tennessee (Tennessee Department of Environment and Conservation, 1993). The TDEC follows the primary MCL's established by the USEPA (U.S. Environmental Protection Agency, 1986, 1992). Therefore, for discussion of organic compounds and trace elements, reference is made to primary MCL's of the TDEC.

Onsite Water Quality

The physical and chemical nature of the contaminants in the subsurface beneath the ACW site is complex. Creosote, a coal-tar distillate used as a wood preservative, is a mixture of about 200 compounds, including PAH's, phenolic compounds, and nitrogen-containing heterocyclic compounds (Goerlitz, 1992; Goerlitz and others, 1985). Sometime after 1950, PCP in a solvent of diesel fuel also was used in the wood-preserving processes (Goerlitz, 1992, p. 338; Chapelle, 1993, p. 367). Diesel fuel contains soluble VOC's, including BTEX's (Chapelle, 1993, table 12.1). At the ACW site, contaminants from the wood-preserving processes have migrated into the subsurface as a non-aqueous phase liquid (NAPL) from onsite sources, such as waste lagoons and treatment areas. As the NAPL migrates, its composition and constituent concentrations change.

Physical and chemical processes that affect the NAPL as it migrates include: (1) partitioning of water-soluble organic compounds from the NAPL to ground water (Pereira and Rostad, 1986); (2) microbial degradation and transformation of creosote and related organic compounds (Baedecker and Lindsay, 1986; Godsy and Goerlitz, 1986; Ehrlich and others, 1982); (3) sorption of organic compounds onto clay mineral surfaces (Goerlitz and others, 1985); and, (4) dilution (Goerlitz, 1992). As an end result of these processes, soluble organic compounds have dissolved in ground water (aqueous phase) from the NAPL and have entered the alluvial and the Fort Pillow aquifers.

The most complete set of organic analyses available for interpretation of onsite ground-water quality were obtained from stations 2 and 5 (fig. 8), using HPLC and GC/PID methods of analysis in conjunction with the evaluation of subsurface exploration, sampling, and water-quality-analysis methods conducted at the ACW site (Parks and others, 1993). Four groups of organic compounds detected in ground-water samples collected at onsite stations 2 and 5 were: (1) PAH's, (2) phenolic compounds (including PCP), (3) nitrogen-containing heterocyclic compounds, and (4) VOC's, primarily BTEX (benzene, toluene, ethylbenzene and total xylenes) compounds (Parks and others, 1993). Although water-quality data were reported previously in the RI/FS report (S&ME, Inc., 1988), organic compound concentrations commonly were reported as "estimated concentrations" or concentrations "below high detection limits." These organic compound concentration data are incomplete for determination of the extent of ground-water contamination and are not summarized herein. However, trace element concentrations in water samples from wells were reported in the RI/FS (S&ME, Inc., 1988), and these data were considered in interpretations of onsite water quality.

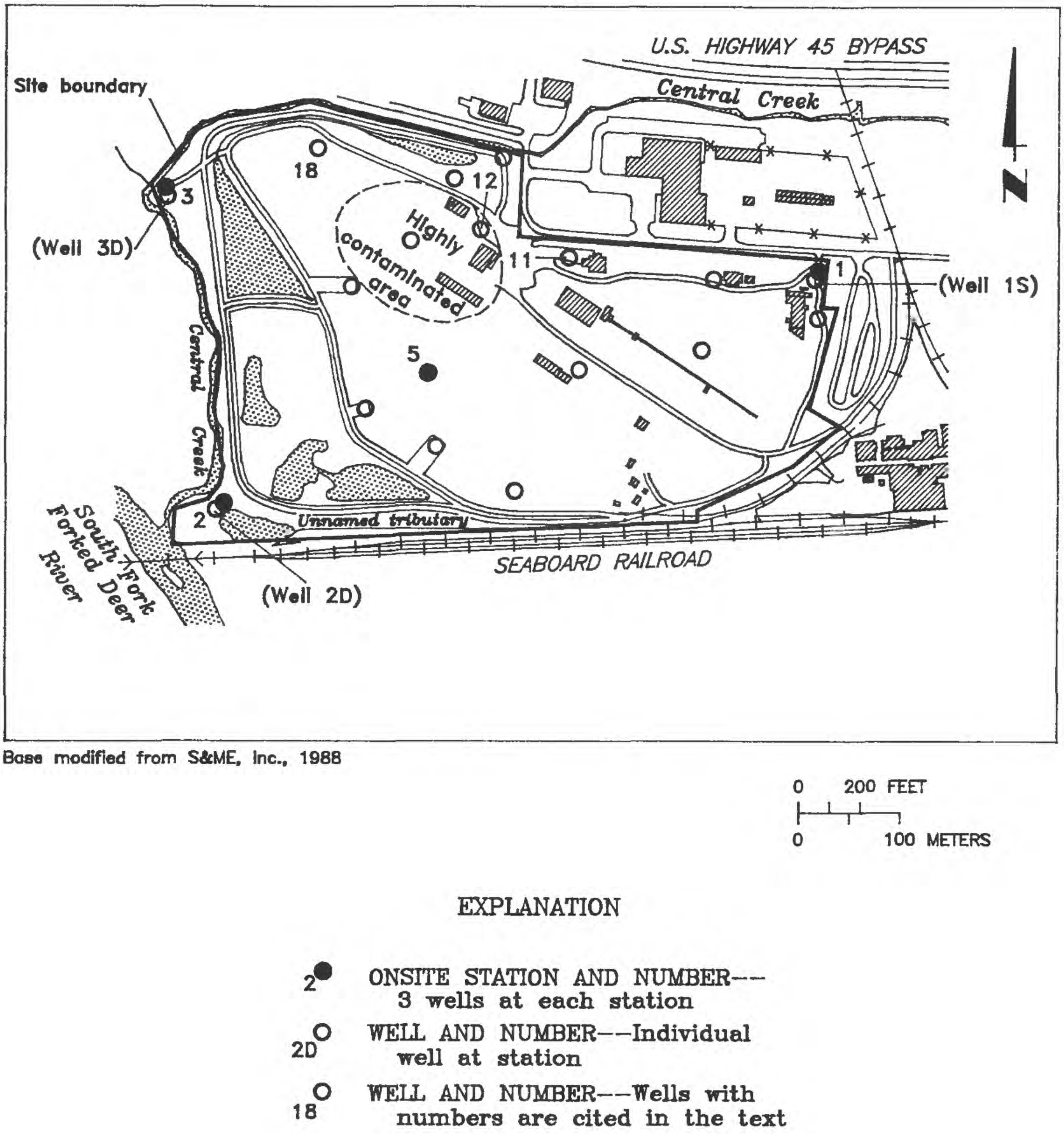

Base modified from S&ME, Inc., 1988

Figure 8. Location of onsite stations and wells where water-quality data were collected for the Remedial Investigation/Feasibility Study and an evaluation of subsurface exploration, sampling, and water-quality-analysis methods. Locations from S&ME, Inc., 1988, and Parks and others, 1993.

The organic compounds that best indicate subsurface contamination from the wood-preserving processes are PAH's, phenolic compounds including PCP, and nitrogen-containing heterocyclic compounds (Goerlitz and others, 1985; Goerlitz, 1992). These three groups of organic compounds were measured in ground-water samples collected with the DPT Hydrocone tool at the ACW site (Parks and others, 1993). At station 5 (located nearest to the highly contaminated area), maximum concentrations of PAH's, phenolic compounds, and nitrogen-containing heterocyclic compounds were measured in ground-water samples from depths of 20 to 21 feet and 31 to 32 feet below land surface (fig. 9). At station 2 (located near the confluence of Central Creek and the South Fork Forked Deer

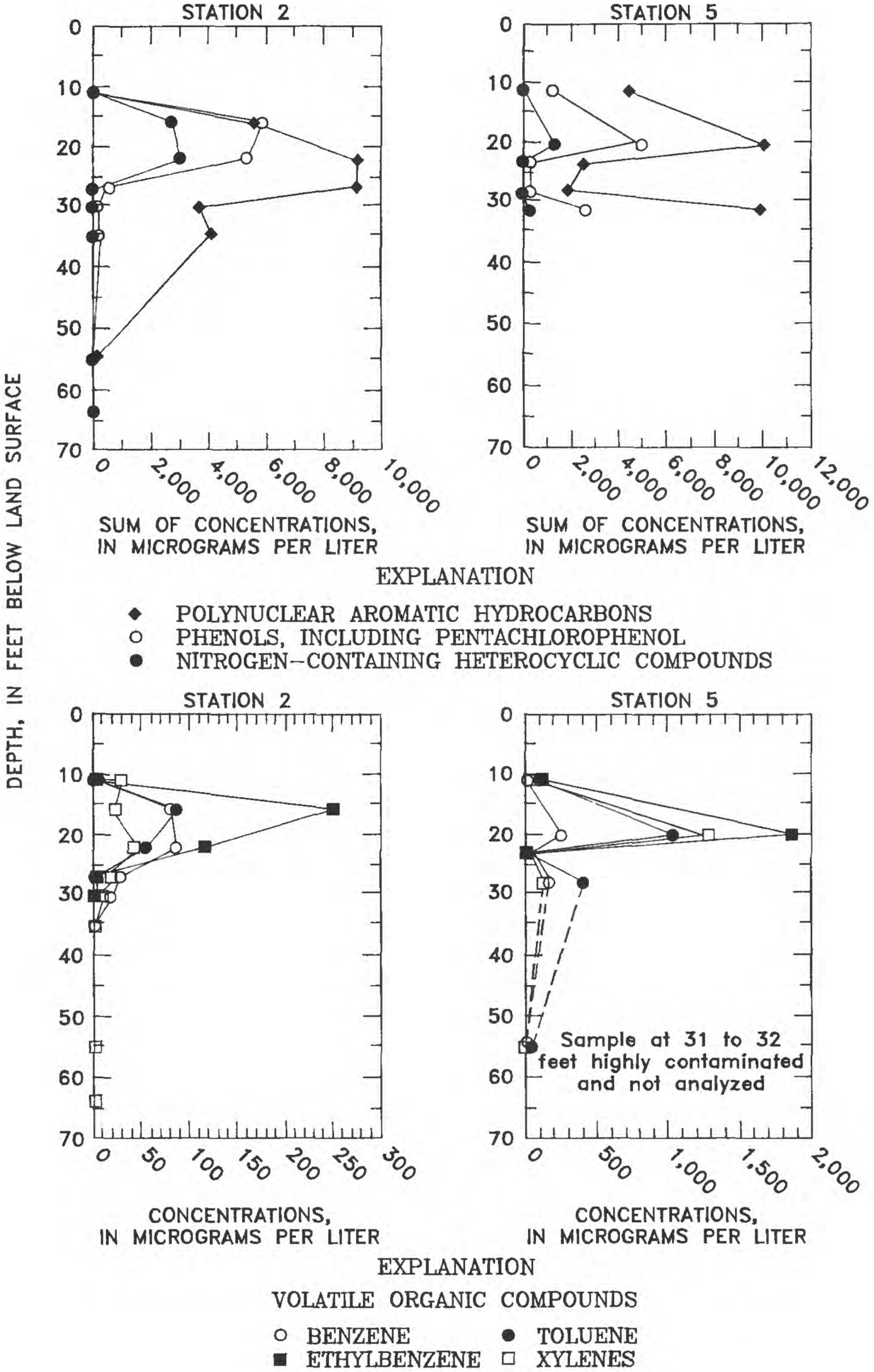


Figure 9. Relation of concentrations of polynuclear aromatic hydrocarbons, phenols (including pentachlorophenol), nitrogen-containing heterocyclic compounds, and volatile organic compounds in ground-water samples to depth of detection at onsite stations 2 and 5 at the American Creosote Works abandoned plant site.

River), maximum PAH concentrations were measured in ground-water samples from depths of 22 to 23 feet and 27 to 28 feet below land surface (fig. 9). Maximum phenolic and nitrogen-containing heterocyclic compound concentrations were measured in ground-water samples from somewhat shallower depths of 16 to 17 feet and 22 to 23 feet at station 2 (fig. 9).

Five PAH compounds detected in ground-water samples collected with the DPT Hydrocone tool from the alluvial aquifer at stations 2 and 5 were: benzothiophene, indene, naphthalene, 2-methyl naphthalene, and 1,2-dihydroacenaphthalene (Parks and others, 1993). The maximum concentration measured for each compound was 1,100 μg/L (benzothiophene at station 5, 20-21 feet); 2,400 μg/L (indene at station 5, 20-21 feet); 7,600 μg/L (naphthalene at station 2, 30-35 feet); 1,200 μg/L (2-methyl naphthalene at station 5, 11-12 feet and at station 2, 30-35 feet); and 780 μg/L (1,2-dihydroacenaphthalene at station 5, 31-32 feet) (Parks and others, 1993).

Naphthalene was the only PAH compound detected onsite in ground-water samples collected with the DPT Hydrocone tool or from wells screened in the Fort Pillow aquifer. Naphthalene concentrations measured were 5 μg/L at station 2 (64-65 feet), 2 μg/L in a sample from well 2D at station 2 (116.5-126.5 feet), and 2 μg/L in a sample from well 3D at station 3 (125.5-135.5 feet) (Parks and others, 1993). The naphthalene concentration measured in the sample from well 3D at station 3 represents the deepest occurrence of a creosote contaminant in ground-water samples collected onsite.

Naphthalene (classified both as a PAH and SVC) may be used as a tracer of creosote contamination for the following reasons. Naphthalene is a primary PAH component of creosote (Goerlitz, 1992). Compared to other PAH's, naphthalene has a greater aqueous solubility, and can partition from the NAPL into ground water (Goerlitz and others, 1986; Pereira and Rostad, 1986). Also, naphthalene may show only limited sorption to aquifer material, especially in sediments having low organic content (Goerlitz and others, 1986). Therefore, naphthalene can travel with or beyond the extent of the NAPL due to partitioning into ground water. However, naphthalene will biodegrade in certain aquifer environments, thus reducing its concentration in ground water (Chapelle, 1993).

The presence of phenolic compounds, specifically PCP, in onsite ground-water samples is significant because PCP is a priority pollutant and a contaminant commonly associated with wood-preserving processes (DaRos and others, 1981). PCP was detected in ground-water samples collected with the DPT Hydrocone tool from the alluvial aquifer at onsite stations 2 and 5 (Parks and others, 1993). PCP concentrations ranged from 120 to 3,200 μg/L at station 5 with a maximum concentration in a sample from 20 to 21 feet below land surface. PCP concentrations ranged from 80 to 1,700 μg/L at station 2 with the maximum concentration measured in a sample from 22 to 23 feet below land surface. PCP was not detected in any water sample from the Fort Pillow aquifer. Most PCP concentrations measured in ground-water samples from stations 2 and 5 exceed the primary MCL of 200 μg/L for PCP (Tennessee Department of Environment and Conservation, 1993).

PCP is considered a tracer of creosote contamination in ground water. Studies suggest that PCP is not readily sorbed to aquifer material (Goerlitz and others, 1986), and seems to resist subsurface microbial degradation or inhibit microbial degradation of other phenols (Godsy and Goerlitz, 1986). Because PCP resists degradation in the subsurface environment, it may serve as a conservative tracer of creosote contamination (Goerlitz and others, 1986).

Concentrations of selected VOC's were measured using GC/PID headspace analysis in conjunction with the evaluation of subsurface exploration, sampling, and water-quality-analysis methods at onsite stations 2 and 5 (Parks and others, 1993). Considering all onsite water samples, maximum VOC concentrations were measured in water samples collected with the DPT Hydrocone tool from the alluvial aquifer at station 5 (20-21 feet), and downgradient station 2 (16-17 feet and 22-23 feet) (fig. 9).

Of the selected VOC analytes, BTEX compounds were detected at the highest concentrations, and these concentrations were measured in water samples from the alluvial aquifer at onsite stations 2 and 5 (fig. 9). Benzene concentrations exceeded the primary MCL of 5 μg/L (Tennessee Department of Environment and Conservation, 1993) in seven of the nine ground-water samples from stations 2 and 5. Benzene concentrations in these samples ranged from 1 to 250 μg/L (Parks and others, 1993). No BTEX compounds were detected at stations 2 and 5 below the ground-water DPT Hydrocone tool sample depth of 30 to 31 feet (Parks and others, 1993).

Other VOC's were detected in ground-water samples collected onsite (Parks and others, 1993). Trichloroethylene was detected in three ground-water samples collected with the DPT Hydrocone tool at onsite station 5, at concentrations of 23 μg/L (23-24 feet), and 6 μg/L (20-21 feet and 54-55 feet) (Parks and others, 1993). These trichloroethylene concentrations exceed the primary MCL of 5 μg/L (Tennessee Department of Environment and Conservation, 1993). Methylene chloride was detected in a ground-water sample collected with the DPT Hydrocone tool from the alluvial aquifer at a concentration of 64 μg/L at station 2 (22-23 feet), and in samples collected with the DPT Hydrocone tool and from a well screened in the Fort Pillow aquifer, at concentrations of 9 μg/L at station 2 (64-65 feet) and 150 μg/L in well 3D at station 3 (125.5-135.5 feet) (Parks and others, 1993). No primary MCL has been established for methylene chloride.

Dissolved trace elements were reported in some water samples collected from onsite wells for the RI/FS (S&ME, Inc., 1988). The trace elements most commonly detected were iron, barium, cadmium, chromium, copper, nickel, and lead. All trace element concentrations were below primary MCL's (Tennessee Department of Environment and Conservation, 1993) with the exception of cadmium (primary MCL 10 μg/L), which was detected at a concentration of 14 μg/L in a water sample from well 1S at station 1 (20.5-25.5 feet).

Concentrations of total dissolved chromium indicate that this constituent may have reached greater depths beneath the site than organic compounds. Total dissolved chromium was measured in water samples from shallow, intermediate, and deep (less than 100 feet) wells at stations 1, 2, 3, and 5 (S&ME, Inc., 1988) (fig. 10). Total dissolved chromium concentrations in samples from deep wells ranged from 11 to 47 μg/L, similar to the range measured in samples from the shallow and intermediate wells (fig. 10). Concentrations of total dissolved chromium measured in water samples from onsite wells do not exceed the primary MCL of 50 μg/L (Tennessee Department of Environnment and Conservation, 1993).

Chromated copper arsenate, fluor-chrome-arsenate phenol, chromated zinc chloride, and acid copper chromate are sometimes used in the wood-preserving processes (DaRos and others, 1981). However, the use of chromated compounds at the ACW facility has not been documented.

The distribution of dissolved arsenic in ground water beneath the site also may indicate ground-water contamination from the wood-preserving processes because arsenic was detected at a concentration of 22,000 μg/kg from well 12 (14.5-19.5 feet) screened in the NAPL (S&ME, Inc., 1988). Dissolved arsenic was detected in water samples from two wells screened in the alluvial aquifer (S&ME, Inc., 1988) at concentrations of 12 μg/L from well 11 (17.0-21.5 feet) and 31 μg/L from well 18 (14.5-19.5 feet) (fig. 8). All dissolved arsenic concentrations reported for water samples from onsite wells are below the primary MCL of 50 μg/L (Tennessee Division of Environment and Conservation, 1993).

High concentrations of dissolved iron were measured in some water samples from onsite wells (S&ME, Inc., 1988); however, the presence and distribution of dissolved iron cannot be related specifically to creosote contamination (Baedecker and Lindsay, 1986). Dissolved iron concentrations ranged between 1,800 μg/L (well 1, 20.5-25.5 feet) to 2,400,000 μg/L (well 18, 14.5-19.5 feet). High concentrations of dissolved iron in these water samples from wells screened in the alluvial aquifer may have resulted from microbial activity or reducing conditions that led to reduction of ferric (Fe^{3+}) iron precipitates to dissolved ferrous (Fe^{2+}) iron in ground water (Chapelle, 1993).

Offsite Water Quality

Thirty-six monitoring wells were installed at offsite stations OSGW1 through OSGW6 near the ACW site for this investigation (fig. 11; Appendix 2). At each station, well clusters were installed, each cluster consisting of 3 wells screened in the alluvial aquifer at depths of less than about 40 feet below land surface, and three wells screened in the Fort Pillow aquifer at depths ranging from about 45 to 150 feet (table 5).

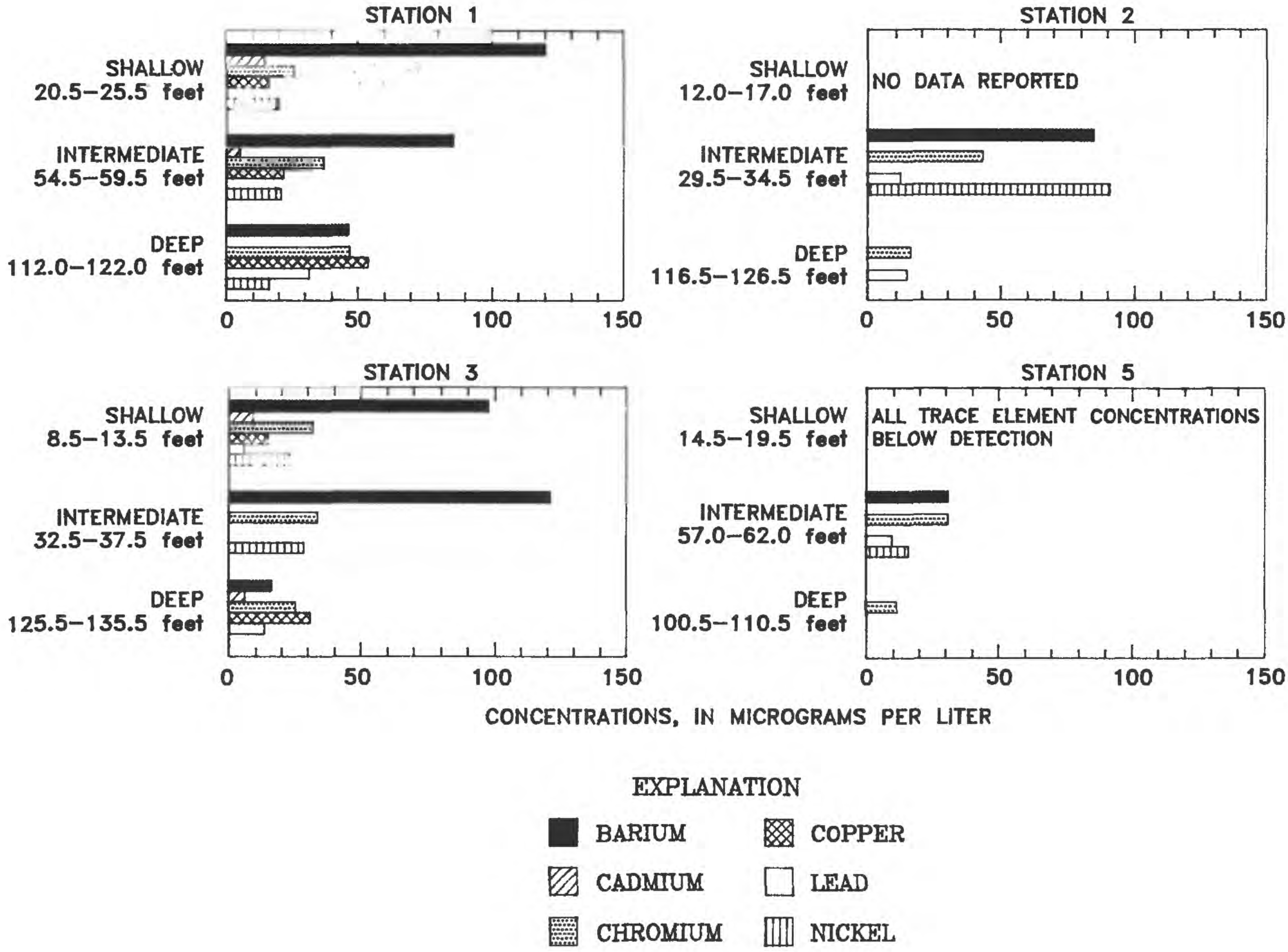
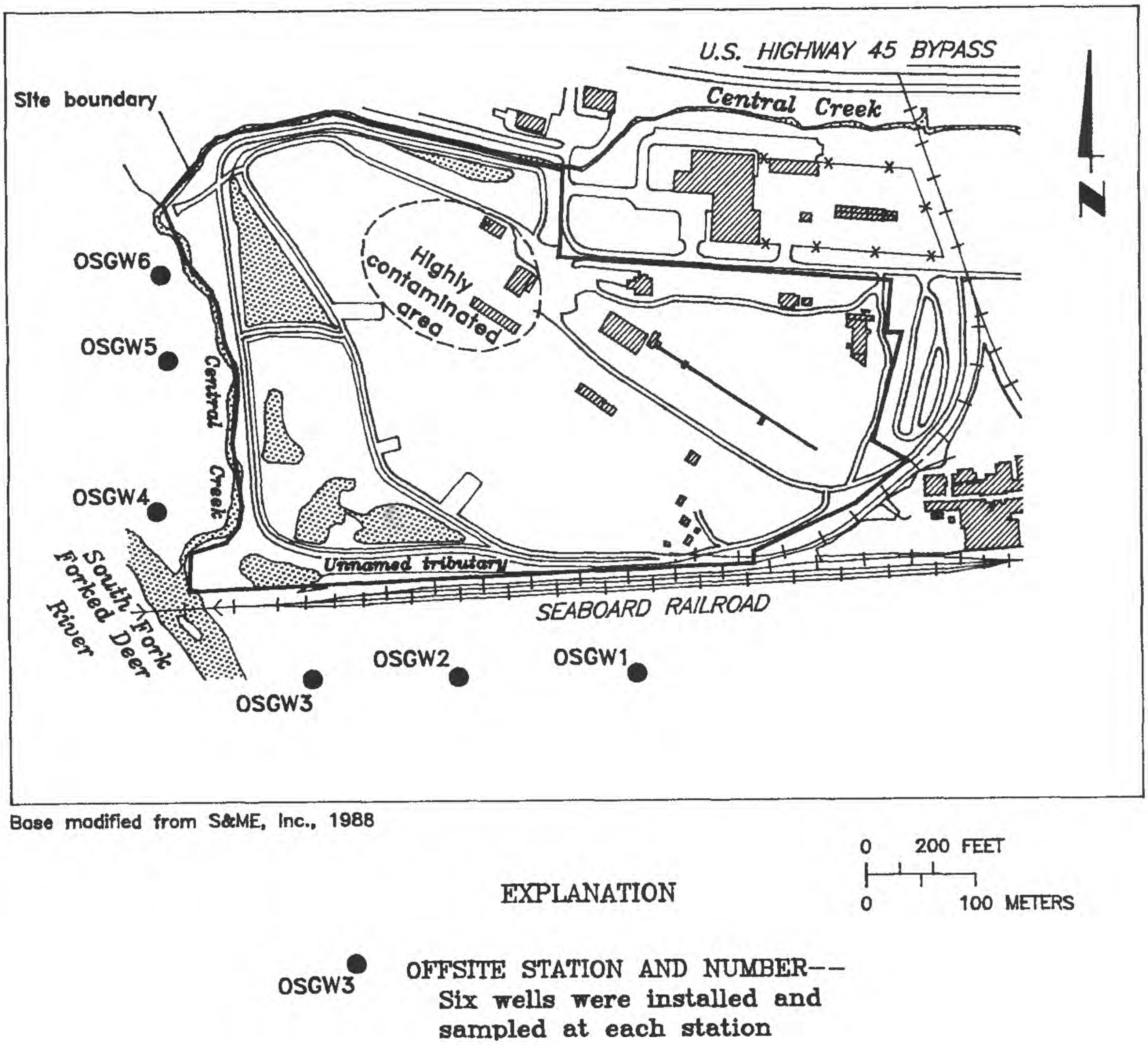


Figure 10. Concentrations of selected trace elements measured in water samples from wells screened at shallow, intermediate, and deep depths at onsite stations 1, 2, 3, and 5 at the American Creosote Works abandoned plant site.

Ground-water samples were collected at the six offsite stations using two methods: (1) samples from the alluvial aquifer were collected using the DPT Hydrocone tool (July 29 to August 3, 1992) and (2) by pumping shallow wells installed at each offsite station (October 22 to November 23, 1992). Hydrocone-tool sampling depths were selected at the tops or bottoms of sand intervals, as interpreted from the logs of point-stress data measured with the DPT piezocone tool at each station (fig. 12). Computer interpolations of lithology from the point-stress logs also were used as the primary guide to selection of screen intervals for shallow wells in the offsite clusters. Water samples from the Fort Pillow aquifer were collected only by pumping the three deep wells installed at each offsite station (October 29 to November 23, 1992). The DPT piezocone and Hydrocone tools could not penetrate into the Fort Pillow aquifer to collect lithologic information (Parks and others, 1993), so screen intervals for deep wells in offsite clusters were selected from interpretation of geophysical logs made in stratigraphic test holes at each station.

To determine the magnitude of offsite contamination, ground-water samples were analyzed for the same four groups of organic compounds that were detected in onsite ground-water samples--PAH's, phenolic compounds (including PCP), nitrogen-containing heterocyclic compounds, and VOC's. In addition, trace elements and major inorganic constituents, and water-quality characteristics were measured in offsite ground-water samples.



Base modified from S&ME, Inc., 1988

Figure 11. Location of offsite stations OSGW1 through OSGW6 where ground-water samples were collected with the Direct Push Technology Hydrocone tool.

Ground-water samples collected using the DPT Hydrocone tool were analyzed for PAH's, phenolic compounds (including PCP), and nitrogen-containing heterocyclic compounds by HPLC (table 6). The HPLC analyses were performed (August 10-11, 1992) by D.F. Goerlitz at the USGS National Research Program (NRP) laboratory in Menlo Park, California, following methods developed at a similar site at Pensacola, Florida (Goerlitz and Franks, 1989).

Only 3 of the 34 offsite ground-water samples collected by the DPT Hydrocone tool showed detectable levels of organic compounds related specifically to wood-preserving processes (D.F. Goerlitz, U.S. Geological Survey, written commun., 1992). Naphthalene was measured in a ground-water sample from station OSGW6 (17-18 feet) at a concentration of 20 µg/L. Naphthalene also was measured in two ground-water samples from station OSGW6 (21-22 feet and 23-24 feet) at concentrations of 10 µg/L. All other ground-water samples were free of organic compounds normally found in ground water contaminated by creosote and PCP (D.F. Goerlitz, U.S. Geological Survey, written commun., 1992).

Splits of 34 offsite ground-water samples collected with the DPT Hydrocone tool were analyzed in the field by Environmental Management Corporation personnel by headspace analysis and GC/PID (July 29-August 3, 1992). Selected VOC's (table 7) from modified USEPA Methods 601, halocarbons (U.S. Environmental Protection Agency,

Table 5. Description of 36 wells installed at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site

[USGS, U.S. Geological Survey]

Well numbers		Latitude	Longitude, in degrees, minutes, and seconds	Altitude of land surface above sea level, in feet	Hydrogeologic unit screened	Screened interval below land surface, in feet	Screen diameter, in inches	Date well installed	Installation method A - auger H - Hydraulic rotary
Project and map	Local USGS for Tennessee								
OSGW1-1	Md:G-367	353628	0885005	343	Alluvial aquifer	13 - 18	2	08-18-92	A
OSGW1-2	Md:G-368	353628	0885005	343	Alluvial aquifer	19 - 24	2	08-18-92	A
OSGW1-3	Md:G-369	353628	0885005	343	Alluvium aquifer	27 - 32	2	08-19-92	A
OSGW1-4	Md:G-370	353628	0885005	343	Fort Pillow aquifer	42 - 52	4	06-25-92	H
OSGW1-5	Md:G-371	353628	0885005	343	Fort Pillow aquifer	92 - 102	4	06-30-92	H
OSGW1-6	Md:G-372	353628	0885005	343	Fort Pillow aquifer	128 - 138	4	06-30-92	H
OSGW2-1	Md:G-373	353627	0885011	342	Alluvial aquifer	10 - 15	2	08-20-92	A
OSGW2-2	Md:G-374	353627	0885011	342	Alluvial aquifer	17 - 22	2	08-20-92	A
OSGW2-3	Md:G-375	353627	0885011	342	Alluvial aquifer	24 - 29	2	08-20-92	A
OSGW2-4	Md:G-376	353627	0885011	342	Fort Pillow aquifer	62 - 72	4	06-02-92	H
OSGW2-5	Md:G-377	353627	0885011	342	Fort Pillow aquifer	92 - 102	4	06-04-92	H
OSGW2-6	Md:G-378	353627	0885011	342	Fort Pillow aquifer	127 - 137	4	06-09-92	H
OSGW3-1	Md:G-379	353627	0885016	341	Alluvial aquifer	9 - 14	2	08-24-92	A
OSGW3-2	Md:G-380	353627	0885016	341	Alluvial aquifer	15 - 20	2	08-24-92	A
OSGW3-3	Md:G-381	353627	0885016	341	Alluvial aquifer	24 - 29	2	08-24-92	A
OSGW3-4	Md:G-382	353627	0885016	341	Fort Pillow aquifer	36 - 46	4	06-23-92	H
OSGW3-5	Md:G-383	353627	0885016	341	Fort Pillow aquifer	68 - 78	4	06-24-92	H
OSGW3-6	Md:G-384	353627	0885016	341	Fort Pillow aquifer	138 - 148	4	08-06-92	H
OSGW4-1	Md:G-385	353632	0885021	343	Alluvial aquifer	10 - 15	2	08-27-92	A
OSGW4-2	Md:G-386	353632	0885021	343	Alluvial aquifer	22 - 27	2	08-27-92	A
OSGW4-3	Md:G-387	353632	0895021	343	Alluvial aquifer	36 - 41	2	08-27-92	A
OSGW4-4	Md:G-388	353632	0895021	343	Fort Pillow aquifer	48 - 58	4	07-29-92	H
OSGW4-5	Md:G-389	353632	0885021	343	Fort Pillow aquifer	79 - 89	4	07-30-92	H
OSGW4-6	Md:G-390	353632	0885021	343	Fort Pillow aquifer	117 - 127	4	08-04-92	H
OSGW5-1	Md:G-391	353637	0885022	342	Alluvial aquifer	12 - 17	2	08-26-92	A
OSGW5-2	Md:G-392	353637	0885022	342	Alluvial aquifer	19 - 24	2	08-26-92	A
OSGW5-3	Md:G-393	353637	0885022	342	Alluvial aquifer	27 - 32	2	08-26-92	A
OSGW5-4	Md:G-394	353637	0885022	342	Fort Pillow aquifer	40 - 50	4	07-14-92	H
OSGW5-5	Md:G-395	353637	0885022	342	Fort Pillow aquifer	83 - 93	4	07-14-92	H
OSGW5-6	Md:G-396	353637	0885022	342	Fort Pillow aquifer	113 - 123	4	07-28-92	H
OSGW6-1	Md:G-397	353639	0885023	342	Alluvial aquifer	10 - 15	2	08-25-92	A
OSGW6-2	Md:G-398	353639	0885023	342	Alluvial aquifer	19 - 24	2	08-25-92	A
OSGW6-3	Md:G-399	353639	0885023	342	Alluvial aquifer	27 - 32	2	08-25-92	A
OSGW6-4	Md:G-400	353639	0885023	342	Fort Pillow aquifer	50 - 60	4	07-07-92	H
OSGW6-5	Md:G-401	353639	0885023	342	Fort Pillow aquifer	82 - 92	4	07-08-92	H
OSGW6-6	Md:G-402	353639	0885023	342	Fort Pillow aquifer	120 - 130	4	07-08-92	H

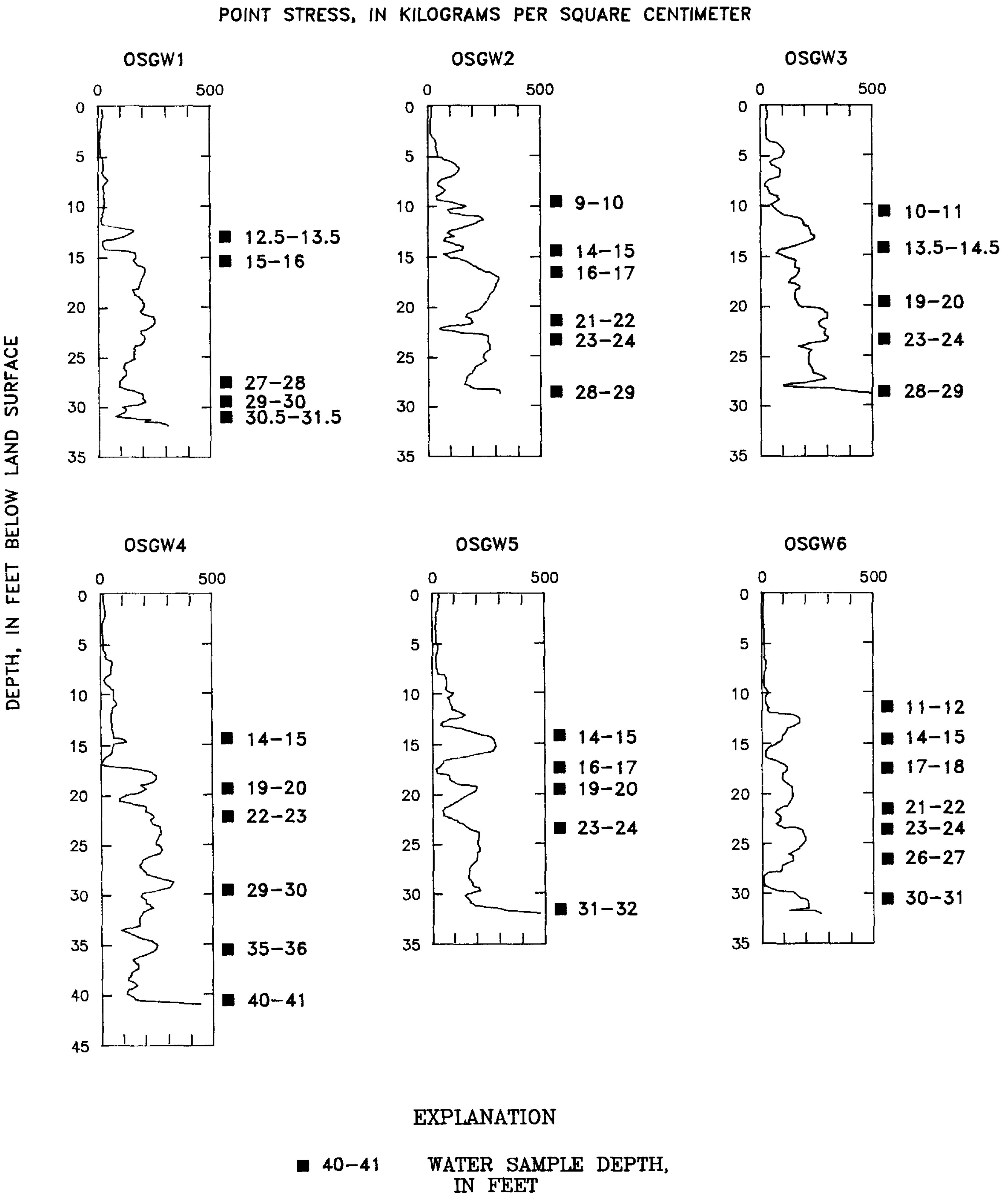


Figure 12. Logs of point-stress data measured with the Direct Push Technology piezocone tool and depths of ground-water samples collected with the Hydrocone tool at offsite stations OSGW1 through OSGW6 at the American Creosote Works abandoned plant site.

Table 6. Polynuclear aromatic hydrocarbons, phenolic compounds (including pentachlorophenol), and nitrogen-containing heterocyclic compounds analyzed in ground-water samples collected with the Direct Push Technology Hydrocone tool at offsite stations OSGW1 through OSGW6 near the American Creosote abandoned plant site

[Minimum detection limit, in micrograms per liter, in parentheses]

Polynuclear aromatic hydrocarbons	Nitrogen-containing heterocyclic compounds
Benzothiophene (1)	Isoquinoline (2)
Indene (1)	Isoquinolinone (2)
Naphthalene (1)	Quinoline (2)
1,2-Dihydroacenaphthalene (1)	Quinolinone (2)
2-Methylnaphthalene (1)	2-Methylquinoline (5)
Phenolic compounds	
2,3-Dimethlyphenol (5)	3,5-Dimethylphenol (5)
2,4-Dimethylphenol (5)	2-Methylphenol (5)
2,5-Dimethylphenol (5)	3-Methylphenol (5)
2,6-Dimethylphenol (5)	Pentachlorophenol (5)
3,4-Dimethylphenol (5)	Phenol (5)

Table 7. Volatile organic compounds analyzed in ground-water samples collected with the Direct Push Technology Hydrocone tool at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site

Minimum detection limit 1 microgram per liter

- Benzene
- Chlorobenzene
- Ethylbenzene
- Methyl-tert-butyl ether
- Toluene
- m-Xylene
- o-Xylene

Minimum detection limit 5 micrograms per liter

- Chloroform
- 2-Chloroethyl vinyl ether
- trans-1,2-Dichloroethylene
- 1,1-Dichloroethane
- 1,2-Dichloroethane
- 1,2-Dichloropropane
- Methylene chloride
- 1,1,2,2-Tetrachloroethane
- Tetrachloroethylene
- 1,1,1-Trichloroethane
- 1,1,2-Trichloroethane
- Trichloroethylene
- Vinyl chloride

1984a), and 602, aromatics (U.S. Environmental Protection Agency, 1984b) are reported here. For comparison, VOC's measured in ground-water samples using GC/PID from onsite stations 2 and 5 were: BTEX's, methyl-tert-butyl ether, 1,1-dichloroethane, methylene chloride, and trichloroethylene (Parks and others, 1993).

BTEX compounds, except benzene, were the most common VOC's measured in offsite water samples collected from the alluvial aquifer with the DPT Hydrocone tool (table 8). The most common BTEX compound was xylene (including both m-xylene and o-xylene), which was detected in some ground-water samples from all offsite stations. Xylene concentrations ranged between 2 μg/L (many samples; table 8) and 790 μg/L (one sample; station OSGW6, 11-12 feet). For comparison, xylene concentrations in ground-water samples from onsite stations 2 and 5 ranged between 9 and 1,300 μg/L in alluvial aquifer samples collected above 35 feet (Parks and others, 1993). Where detected, concentrations of ethylbenzene ranged between 2 and 10 μg/L (table 8). For comparison, ethylbenzene concentrations in ground-water samples from onsite stations 2 and 5 ranged between 2 and 1,900 μg/L in alluvial aquifer samples collected above 35 feet (Parks and others, 1993).

Benzene was measured in onsite ground-water samples from stations 5 and 2 at concentrations exceeding the primary MCL of 5 μg/L (Tennessee Department of Environment and Conservation, 1993), but was not detected in any offsite ground-water sample collected with the DPT Hydrocone tool. Toluene was detected only in offsite ground-water samples from station OSGW6, at concentrations ranging between 2 and 5 μg/L (table 8).

VOC's and SVC's also were measured in offsite water samples collected from the alluvial aquifer and Fort Pillow aquifers by pumping the 36 wells at stations OSGW1 through OSGW6 (Appendix 1). These samples were analyzed for a selected list of VOC's and SVC's (table 9), by the USGS National Water Quality Laboratory (NWQL). VOC concentrations in water samples pumped from wells at offsite stations OSGW1 through OSGW6 are discussed here; SVC concentrations from these same samples are discussed later in the text.

BTEX compounds were the principal VOC's detected in samples pumped from offsite wells screened in the alluvial aquifer, and analyzed by the NWQL. Where detected, BTEX sum concentrations ranged between 0.2 and 4.6 μg/L, with highest BTEX sum concentrations reported for water

Table 8. *Concentrations of volatile organic compounds detected in ground-water samples collected with the Direct Push Technology Hydrocone tool at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site, July-August 1992*

[Analyses conducted by Environmental Management Corp., Orlando, Florida, using a Photovac 10S50 gas chromatograph with photo-ionization detection (GC/PID). Concentrations are in micrograms per liter (µg/L); (TDEC) Tennessee Department of Environment and Conservation, 1993, (MCL) primary maximum contaminant levels for drinking water; "none" indicates no established maximum contaminant level for the compound]

Volatile organic compound	Analytical method minimum detection limit (µg/L)	Offsite station number	Depth of Hydrocone sample (feet)	Concentration detected (µg/L)	TDEC MCL (µg/L)
Ethylbenzene	1	OSGW1	27 - 28	2	none
		OSGW1	30.5 - 31.5	2	
		OSGW2	21 - 22	2	
		OSGW4	14 - 15	10	
		OSGW4	40 - 41	3	
		OSGW5	19 - 20	2	
		OSGW6	17 - 18	6	
		OSGW6	26 - 27	7	
Toluene	1	OSGW6	11 - 12	2	none
		OSGW6	14 - 15	3	
		OSGW6	26 - 27	5	
m-Xylene	1	OSGW1	29 - 30	4	none
		OSGW3	13.5 - 14.5	3	
		OSGW4	14 - 15	3	
		OSGW4	22 - 23	3	
		OSGW5	16 - 17	3	
		OSGW5	31 - 32	9	
		OSGW6	11 - 12	790	
		OSGW6	23 - 24	2	
		OSGW6	26 - 27	10	
		OSGW6	30 - 31	14	
o-Xylene	1	OSGW1	27 - 28	28	none
		OSGW1	29 - 30	3	
		OSGW2	14 - 15	2	
		OSGW2	21 - 22	2	
		OSGW2	23 - 24	2	
		OSGW3	10 - 11	2	
		OSGW4	29 - 30	2	
		OSGW4	35 - 36	12	
		OSGW5	16 - 17	5	
		OSGW5	19 - 20	3	
		OSGW5	31 - 32	15	
		OSGW6	17 - 18	2	
		OSGW6	23 - 24	2	
		OSGW6	26 - 27	15	

Table 9. Volatile and semi-volatile organic compounds analyzed in water samples collected by pumping 36 wells at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site

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Volatile organic compounds

[Minimum detection limit, in micrograms per liter, in parentheses]

Acrolein (20)
Acrylonitrile (20)
Benzene (0.2)
Bromobenzene (0.2)
Bromochloromethane (0.2)
Bromoform (0.2)
n-Butylbenzene (0.2)
sec-Butylbenzene (0.2)
tert-Butylbenzene (0.2)
Carbon tetrachloride (0.2)
Chlorobenzene (0.2)
Chlorodibromomethane (0.2)
Chloroethane (0.2)
2-Chloroethyl vinyl ether (1.0)
Chloroform (0.2)
Chloromethane (0.2)
2-Chlorotoluene (0.2)
4-Chlorotoluene (0.2)
1,2-Dibromo-3-chloropropane (1.0)
Dibromomethane (0.2)
1,2-Dibromoethane (0.2)
1,2-Dichlorobenzene (ortho) (0.2)
1,3-Dichlorobenzene (meta) (0.2)
1,4-Dichlorobenzene (para) (0.2)
Dibromochloromethane (0.2)
Dichlorodifluoromethane (0.2)
1,1-Dichloroethane (0.2)
1,2-Dichloroethane (0.2)
cis-1,2-Dichloroethene (0.2)
1,1-Dichloroethene (0.2)
trans-1,2-Dichloroethylene (0.2)
1,2-Dichloropropane (0.2)
1,3-Dichloropropane (0.2)
2,2-Dichloropropane (0.2)
1,1-Dichloropropene (0.2)
cis-1,3-Dichloropropene (0.2)
trans-1,3-Dichloropropene (0.2)
Ethylbenzene (0.2)
Hexachlorobutadiene (0.2)
Isopropylbenzene (0.2)
p-Isopropyltoluene (0.2)
Methylbromide (0.2)
Methylene chloride (0.2)
Methyl-tert-butyl ether (1)
Naphthalene (0.2)
n-Propylbenzene (0.2)
Styrene (0.2)
1,1,1,2-Tetrachloroethane (0.2)
1,1,2,2-Tetrachloroethane (0.2)
Tetrachloroethylene (0.2)
Toluene (0.2)
1,2,3-Trichlorobenzene (0.2)
1,2,4-Trichlorobenzene (0.2)
1,1,1-Trichloroethane (0.2)
1,1,2-Trichloroethane (0.2)
Trichloroethylene (0.2)
Trichlorofluoromethane (0.2)
Trichlorotrifluoroethane (0.5)
1,2,3-Trichloropropane (0.2)
1,2,4-Trimethylbenzene (0.2)
1,3,5-Trimethylbenzene (0.2)
Vinyl chloride (0.2)
Xylenes (total) (0.2)

Semi-volatile organic compounds

[Minimum detection limit, in micrograms per liter, in parentheses]

Acenaphthene (5)
Acenaphthylene (5)
Anthracene (5)
Benzidine (40)
1,2-Benzo(a)anthracene (10)
Benzo(b)fluoranthene (10)
Benzo(k)fluoranthene (10)
1,1-Benzo(g,h,i)perylene (10)
Benzo(a)pyrene (10)
4-Bromophenyl phenyl ether (5)
Butyl benzyl phthalate (5)
bis (2-Chloroethyl)ether (5)
bis (2-Chloroethyl)methane (5)
bis (2-Chloroisopropyl)ether (5)
4-Chloro-3-methylphenol (30)
2-Chloronaphthalene (5)
2-Chlorophenol (5)
4-Chlorophenyl phenyl ether (5)
Chrysene (10)
Dibenzo(a,h)anthracene (10)
Di-n-butyl phthalate (5)
1,2-Dichlorobenzene (5)
1,3-Dichlorobenzene (5)
1,4-Dichlorobenzene (5)
3,3-Dichlorobenzidene (20)
2,4-Dichlorophenol (5)
Diethyl phthalate (5)
2,4-Dimethylphenol (5)
Dimethyl phthalate (5)
4,6-Dinitro-2-methylphenol (30)
2,4-Dinitrophenol (20)
2,4-Dinitrotoluene (5)
2,6-Dinitrotoluene (5)
Di-n-octyl phthalate (10)
1,2-Diphenylhydrazine (5)
bis(2-Ethylhexyl)phthalate (5)
Fluoranthene (5)
Fluorene (5)
Hexachlorobenzene (5)
Hexachlorobutadiene (5)
Hexachlorocyclopentadiene (5)
Hexachloroethane (5)
Indeno (1,2,3) pyrene (10)
Isophorone (5)
Naphthalene (5)
Nitrobenzene (5)
2-Nitrophenol (5)
4-Nitrophenol (30)
n-Nitrosodimethylamine (5)
n-Nitrosodiphenylamine (5)
n-Nitroso-di-n-propylamine (5)
Pentachlorophenol (30)
Phenanthrene (5)
Phenol (5)
Pyrene (5)
1,2,4-Trichlorobenzene (5)
2,4,6-Trichlorophenol (20)

samples from well OSGW6-1 (table 10). Benzene was measured at concentrations ranging between 0.2 and 0.4 µg/L where detected in water samples from the alluvial aquifer. Toluene was detected in ground-water samples collected offsite, but these low concentrations may be the result of a quality assurance/quality control (QA/QC) problem (Appendix 1). Water samples from 8 of the 24 wells suspected as being affected by a QA/QC problem were resampled in January 1993 and analyzed for VOC's. Neglecting the analyses that might have been affected by a QA/QC problem, toluene was detected in samples from three wells (OSGW4-1, OSGW4-5, and OSGW6-2) at concentrations of 0.2 to 0.3 µg/L (table 10, second sample). Ethylbenzene was detected in two ground-water samples at concentrations of 0.2 µg/L (OSGW6-1) and 0.3 µg/L (OSGW6-3). Xylene concentrations ranged between <0.2 and 1.6 µg/L where detected. Highest xylene concentrations were measured in water samples from wells OSGW6-1, OSGW6-2, and OSGW6-3 (table 10).

BTEX concentrations measured in water samples collected with the DPT Hydrocone tool from the alluvial aquifer generally are 10 times greater than BTEX concentrations measured in water samples pumped from wells screened in this aquifer. One reason for this disparity is that the interval sampled by DPT was 1 foot, while the screened interval for wells in alluvial aquifer was 5 feet. VOC concentrations may be diluted in samples from pumped offsite wells because of the greater vertical interval sampled, and the heterogeneous distribution of contaminants in the aquifer. Although precautions against VOC loss were performed and the ground-water samples were chilled before express transport (Appendix 1), it is possible that VOC concentrations could diminish by volatilization during sample collection and transport.

Individual BTEX compounds in water samples collected from the alluvial aquifer with the DPT Hydrocone tool were measured at concentrations commonly ranging between 2 and 28 µg/L (table 8). Individual BTEX compounds in water samples collected from the 18 wells screened in the alluvial aquifer were measured at concentrations less than 2.1 µg/L (table 10). Considering the spatial distribution of BTEX compounds, at least one BTEX compound was detected in water samples collected with the DPT Hydrocone tool at each offsite station (table 8). In contrast, BTEX compounds were not detected in water samples collected from wells at stations OSGW1, OSGW2, and OSGW3 (table 10). Therefore, a greater number of BTEX compounds were detected at higher concentrations in offsite water samples from the alluvial aquifer collected with the DPT Hydrocone tool. However, results from both sample collection methods indicate that BTEX compounds (primarily xylenes) were detected in water samples from the alluvial aquifer at depths less than about 35 feet, with highest BTEX concentrations measured in water samples from offsite stations OSGW5 and OSGW6 (table 10).

Minor differences between the first and second sample concentrations of benzene and xylene are reported for water samples from wells at stations OSGW5 and OSGW6 (table 10). Benzene and xylene concentrations were usually (but not always) lower in the second water sample, by 0.7 µg/L or less. These differences in concentrations between the first and second samples may be the result of the 2-month period between sample collection, or different lengths of time the wells were purged before sampling. Benzene and xylene were not detected in blanks, so these differences are not attributed to a QA/QC problem.

BTEX concentrations are significantly lower in ground-water samples collected from offsite stations than those collected onsite, regardless of the sample collection method used. In water samples collected with the DPT Hydrocone tool in the alluvial aquifer at onsite stations 2 and 5, ethylbenzene was detected at the highest concentrations, ranging between 2 and 1,900 µg/L (fig. 9). Similar ranges in benzene, toluene, and xylene concentrations also were measured in these samples (Parks and others, 1993).

Considering ground-water samples from all offsite stations, xylene was the BTEX compound detected at the highest concentrations. Xylene concentrations ranged between 0.2 and 790 µg/L in water samples collected with the DPT Hydrocone tool (table 8); and ranged between <0.2 and 0.3 µg/L in pumped water samples (table 10). Where detected, ethylbenzene and toluene ranged between 2 and 10 µg/L in water samples collected with the DPT Hydrocone tool (table 8); and <0.2 and 0.3 µg/L in pumped water samples (table 10).

Table 10. Concentrations of volatile and semi-volatile organic compounds detected in water samples collected by pumping 36 wells at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site, October 1992-January 1993

[Concentrations are in micrograms per liter (μg/L); (TDEC) Tennessee Department of Environment and Conservation, 1993, (MCL) primary maximum contaminant level for drinking water; values given as < (less than) indicate that the concentration was below the level of detection for the analytical method used and do not indicate the presence or absence of a compound; "none" indicates no established maximum contaminant level for the compound; -- indicates no second sample collected]

Synthetic organic compound	Analytical method minimum detection limit	Wells in which detected	Concentration detected		TDEC MCL
			First sample	Second sample	
		Volatile organic compounds			
Benzene	0.2	OSGW4-3 (Md:G-387)	0.4	--	5
		OSGW5-3 (Md:G-393)	.2	<0.2	
		OSGW6-1 (Md:G-397)	.4	--	
		OSGW6-3 (Md:G-399)	.4	--	
		OSGW6-5 (Md:G-401)	.2	--	
		OSGW6-6 (Md:G-402)	.2	< .2	
Bromodichloromethane	.2	OSGW5-4 (Md:G-394)	.2	--	none
Bromoform	.2	OSGW5-4 (Md:G-394)	.4	--	none
Chloroform	.2	OSGW1-5 (Md:G-371)	.2	--	none
		OSGW5-4 (Md:G-394)	.2	--	
Dibromochloromethane	.2	OSGW5-4 (Md:G-394)	.7	--	none
1,2-Dichlorobenzene	.2	OSGW2-1 (Md:G-373)	.6	--	none
cis-1,2-Dichloroethylene	.2	OSGW6-1 (Md:G-397)	.2	--	none
Ethylbenzene	.2	OSGW6-1 (Md:G-397)	.2	--	none
		OSGW6-3 (Md:G-399)	.3	--	
Naphthalene	.2	OSGW4-1 (Md:G-385)	.6	--	none
		OSGW4-2 (Md:G-386)	3.0	--	
Toluene	.2	OSGW4-1 (Md:G-385)	.2	--	none
		OSGW4-5 (Md:G-389)	.2	--	
		OSGW6-2 (Md:G-398)	2.1	.3	

Table 10. Concentrations of volatile and semi-volatile organic compounds detected in water samples collected by pumping 36 wells at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site, October 1992-January 1993--Continued

Synthetic organic compound	Analytical method minimum detection limit	Wells in which detected	Concentration detected		TDEC MCL
			First sample	Second sample	
		Volatile organic compounds--Continued			
Trichloroethylene	.2	OSGW6-1 (Md:G-397)	1.6	--	5
		OSGW6-2 (Md:G-398)	.90	.2	
		OSGW6-3 (Md:G-399)	.20	--	
1,2,4-Trimethylbenzene	.2	OSGW6-1 (Md:G-397)	.3	--	none
		OSGW6-2 (Md:G-398)	< .2	.2	
		OSGW6-3 (Md:G-399)	.4	--	
		OSGW6-5 (Md:G-401)	.2	--	
		OSGW6-6 (Md:G-402)	.2	< .2	
Total Xylenes	.2	OSGW4-6 (Md:G-390)	.7	--	none
		OSGW5-5 (Md:G-395)	.2	--	
		OSGW6-1 (Md:G-397)	1.0	--	
		OSGW6-2 (Md:G-398)	< .2	.4	
		OSGW6-3 (Md:G-399)	1.6	--	
		OSGW6-5 (Md:G-401)	.9	--	
		OSGW6-6 (Md:G-402)	.7	< .2	
		Semi-volatile organic compounds			
bis(2-Ethylhexyl)phthalate	5	OSGW1-5 (Md:G-371)	9	--	6
		OSGW1-6 (Md:G-372)	27	--	
		OSGW2-5 (Md:G-377)	9	--	
		OSGW3-6 (Md:G-384)	25	--	
		OSGW4-6 (Md:G-390)	8	--	
		OSGW5-4 (Md:G-394)	15	--	
		OSGW6-5 (Md:G-401)	13	--	
Butyl benzyl phthalate		OSGW6-2 (Md:G-398)	9	--	

Benzene was not detected in any offsite water sample collected with the DPT Hydrocone tool (table 8); however, benzene concentrations ranged between <0.2 and 0.4 μg/L in the first samples from pumped wells screened in the alluvial aquifer (table 10).

A conservative estimate shows that BTEX concentrations in water samples from the alluvial aquifer have been reduced significantly. Xylene concentrations have been reduced by at least 50 percent as this compound has migrated with ground water toward the offsite stations.

BTEX compounds were not detected in any water sample collected from the Fort Pillow aquifer at onsite stations 2 and 5 (Parks and others, 1993). BTEX compounds were detected in water samples from several of the 18 wells screened in the Fort Pillow aquifer at the offsite stations. These water samples were collected from pumped wells, because the DPT Hydrocone tool could not penetrate into the Fort Pillow aquifer. Benzene was measured in samples from wells OSGW6-5 (82-92 feet) and OSGW6-6 (120-130 feet) at a concentration of 0.2 μg/L (table 10). Xylenes also were measured in these samples at concentrations of 0.9 and 0.7 μg/L, respectively (table 10).

Trihalomethanes (bromodichloromethane, dibromochloromethane, bromoform, and chloroform) were detected in one water sample from well OSGW5-4 (40-50 feet) pumped from the Fort Pillow aquifer at concentrations ranging between 0.2 and 0.7 μg/L (table 10). The presence of trihalomethanes in a water sample from the Fort Pillow aquifer is problematic because trihalomethanes are not by-products of the wood-preserving processes, and no trihalomethanes were detected in water samples from onsite wells. The sum of trihalomethane concentrations (including bromoform, chloroform, bromodichloromethane, dibromochloromethane) in a sample from well OSGW5-4 is 1.5 μg/L, which is below the primary MCL of 100 μg/L for this class of compounds (U.S. Environmental Protection Agency, 1992).

SVC's in water samples collected offsite from the 36 wells at the six stations were analyzed by the NWQL (table 9). The list of analytes includes PAH's and phenolic compounds including PCP that characterize creosote contamination. However, this list does not contain many of the phenolic and nitrogen-containing heterocyclic compounds analyzed by HPLC (Parks and others, 1993) (table 6). Some HPLC analytes (such as substituted naphthalenes, methyl phenols, and quinoline) are alteration products specific to creosote contamination (Goerlitz and others, 1985); however, these compounds are not routine SVC analytes by the NWQL (table 9).

SVC's, PAH's, phenolic compounds, and phthalic acid esters that were detected onsite in ground-water samples at stations 2 and 5 (Parks and others, 1993) or from shallow monitoring wells (S&ME, Inc., 1988) were: acenaphthene, acenaphthylene, anthracene, 1,2-benzo(a)anthracene, benzo(b and/or k)fluoranthene, benzo(a)pyrene, bis(2-ethylhexyl)phthalate, chrysene, fluoranthene, fluorene, naphthalene, PCP, phenanthrene, phenol, 2,4-dimethylphenol, and pyrene. SVC's analyzed for (but not necessarily detected; S&ME, Inc., 1988) in onsite ground-water samples, but not included on the NWQL list of analytes were: biphenyl, dibenzofuran, dibenzothionate, substituted naphthalenes (1-methylnaphthalene, 2-methylnaphthalene, dimethylnaphthalene, trimethylnaphthalene, phenylnaphthalene), methylphenanthrene, methylpyrene, and naphthenecarbonitrile.

PAH's represent 85 percent of the compounds in creosote by weight (Goerlitz and others, 1985). As a group, these compounds show slight aqueous solubility, and tend to partition to non-aqueous phases. Of the PAH's considered here, naphthalene has the highest aqueous solubility at a concentration of 30 milligrams per liter (mg/L) (Goerlitz, 1992), compared to anthracene and phenanthrene, which have a greater molecular weight and lower aqueous solubility. Despite the common presence of PAH's in onsite ground-water samples, no PAH's were detected in water samples from wells at the offsite stations when analyzed for SVC's (table 10). However, when ground-water samples were analyzed for naphthalene as a VOC by the NWQL, it was detected in samples from offsite wells OSGW4-1 (10-15 feet) and OSGW4-2 (22-27 feet), screened in the alluvial aquifer, at concentrations of 0.6 and 3.0 μg/L, respectively (table 10).

Several environmental factors probably contributed to the attenuation of PAH concentrations as ground water migrated from onsite to offsite areas. These factors are microbial degradation (Goerlitz and others, 1985; Madsen and others, 1991), and sorption onto clay-mineral surfaces.

Phenolic compounds as a group show greater aqueous solubility than PAH's, with the exception of PCP. The aqueous solubility of dimethyl phenols (4,000 mg/L) and phenols (80,000 mg/L; Goerlitz, 1992) suggests that these compounds may partition from the NAPL into ground water. In contrast, experimental calculations suggest that PCP has an aqueous solubility of 5 to 10 mg/L at a pH range of 5 to 6 (Goerlitz and others, 1985), similar to the pH range measured in offsite ground-water samples. Compared to other phenols, PCP would tend to remain in the NAPL.

Phenols and methylphenols were shown to be degraded by microbes at the Pensacola, Florida ACW abandoned plant site (Goerlitz and others, 1986; Goerlitz, 1992). Dimethylphenols and PCP resist or possibly inhibit biodegradation (Chapelle, 1993). Of all phenolic compounds analyzed for (table 6), dimethylphenols (for example 2,4-dimethylphenol and 3,5-dimethylphenol) would be expected to travel with ground water because of their relatively high aqueous solubilities and resistance to biodegradation. However, no dimethylphenols or PCP were detected in water samples from wells at the offsite stations.

Nitrogen-containing heterocyclic compounds such as quinoline represent approximately 5 percent of the compounds in creosote by weight (Goerlitz and others, 1985). These compounds are readily altered in both aerobic and anaerobic conditions. Consequently, nitrogen-containing heterocyclic compounds commonly are not detected in ground-water samples except by immediate analysis or in samples preserved with mercuric chloride bactericide (Godsy and Goerlitz, 1986; Goerlitz, 1992). No nitrogen-containing heterocyclic compounds were detected in water samples from wells at offsite stations (D.F. Goerlitz, U.S. Geological Survey, written commun., 1992), which were preserved with mercuric chloride and analyzed immediately on receipt at the NRP laboratory.

Two other SVC's were detected in offsite ground-water samples: bis(2-ethylhexyl)phthalate and butyl benzyl phthalate. Both compounds are used as plasticizers in PVC resins, with bis(2-ethylhexyl)phthalate used most commonly (U.S. Environmental Protection Agency, 1990). Bis(2-ethylhexyl)phthalate was measured in some water samples from offsite wells screened in the Fort Pillow aquifer, at concentrations ranging between 8 and 27 μg/L (table 10). These plasticizers are not associated specifically with wood-preserving processes, and are considered ubiquitous in the environment (U.S. Environmental Protection Agency, 1990). Currently, MCL's have not been established for phthalates, although a MCL of 100 μg/L has been proposed for butyl benzyl phthalate (U.S. Environmental Protection Agency, 1990). All phthalate concentrations measured in offsite ground-water samples were below this proposed MCL.

Dissolved trace elements were measured in samples from the 36 wells at the offsite stations (table 11). Barium, cobalt, iron, manganese, nickel, strontium, and zinc commonly were detected; however, concentrations of these trace elements were below established primary MCL's (Tennessee Division of Environment and Conservation, 1993) in all water samples from offsite wells. For comparison, the dissolved trace elements that commonly were detected in onsite ground-water samples were barium, cadmium, chromium, copper, iron, lead, and nickel (S&ME, Inc., 1988).

Maximum dissolved iron concentrations were measured in water samples from offsite wells screened in the alluvial aquifer, specifically in samples from depths of 10 to 18 feet (table 11). Iron concentrations in these samples ranged between 70 and 20,000 μg/L, with the highest concentration measured in a water sample from well OSGW6-1 at a depth of 10 to 15 feet (table 11). These high iron concentrations cannot be related specifically to contamination from wood-preserving processes, although ferrous (Fe^{2+}) iron may exist in solution due to reducing conditions or a result of microbial activity in the alluvial aquifer (Chapelle, 1993).

Dissolved chromium was measured at concentrations ranging from 11 to 47 μg/L in onsite water samples from the alluvial and Fort Pillow aquifers (S&ME, 1988) (fig. 10). By comparison, chromium was measured in some water samples from offsite wells screened in both the alluvial and Fort Pillow aquifers, but at concentrations of 1 to 2 μg/L (table 11). All chromium concentrations measured in offsite ground-water samples were below the primary MCL of 50 μg/L (Tennessee Department of Environment and Conservation, 1993).

Dissolved barium commonly was detected in offsite water samples from the alluvial aquifer and

Table 11. Concentrations of dissolved trace elements detected in water samples collected by pumping 36 wells at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site

[USGS, U.S. Geological Survey; µg/L, micrograms per liter. Values gives as < (less than) indicate that the concentration was below the level of detection for the analytical method used and do not indicate the presence or absence of a constituent; –, indicates no data]

Well numbers		Screened interval below land surface, in feet	Date sampled	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)
Project and map (fig. 11)	USGS local for Tennessee									
OSGW1-1	Md:G-367	13 - 18	10-22-92	<10	<1	77	<0.5	<1	<1	4
OSGW1-2	Md:G-368	19 - 24	10-22-92	<10	<1	61	< .5	<1	1	<3
OSGW1-3	Md:G-369	27 - 32	10-22-92	<10	<1	48	< .5	1	<1	<3
OSGW1-4	Md:G-370	42 - 52	11-04-92	<10	<1	53	< .5	<1	<1	<3
OSGW1-5	Md:G-371	92 - 102	11-04-92	<10	<1	32	.6	<1	<1	<3
OSGW1-6	Md:G-372	128 - 138	11-04-92	<10	<1	34	.7	<1	<1	<3
OSGW2-1	Md:G-373	10 - 15	10-22-92	<10	<1	99	< .5	1	<1	14
OSGW2-2	Md:G-374	17 - 22	10-23-92	<10	<1	70	< .5	<1	<1	<3
OSGW2-3	Md:G-375	24 - 29	10-23-92	<10	<1	57	< .5	<1	<1	<3
OSGW2-4	Md:G-376	62 - 72	11-06-92	<10	<1	74	.7	<1	<1	<3
OSGW2-5	Md:G-377	92 - 102	11-06-92	<10	<1	44	.7	<1	<1	<3
OSGW2-6	Md:G-378	127 - 137	11-05-92	<10	<1	32	.7	<1	<1	<3
OSGW3-1	Md:G-379	9 - 14	10-28-92	20	<1	89	< .5	<1	<1	8
OSGW3-2	Md:G-380	15 - 20	10-28-92	20	<1	60	< .5	<1	2	<3
OSGW3-3	Md:G-381	24 - 29	10-30-92	<10	<1	44	< .5	<1	<1	<3
OSGW3-4	Md:G-382	36 - 46	10-29-92	<10	<1	47	< .5	<1	2	<3
OSGW3-5	Md:G-383	68 - 78	10-29-92	<10	<1	52	< .5	<1	<1	<3
OSGW3-6	Md:G-384	138 - 148	11-03-92	–	<1	25	.7	<1	2	<3
OSGW4-1	Md:G-385	10 - 15	11-20-92	10	<1	47	< .5	<1	<1	6
OSGW4-2	Md:G-386	22 - 27	11-20-92	<10	<1	41	< .5	2	<1	<3
OSGW4-3	Md:G-387	36 - 41	11-20-92	40	<1	14	< .5	1	<1	<3
OSGW4-4	Md:G-388	48 - 58	11-20-92	10	<1	27	< .5	<1	2	<3
OSGW4-5	Md:G-389	78 - 89	11-23-92	<10	<1	20	< .5	2	<1	<3
OSGW4-6	Md:G-390	117 - 127	11-20-92	<10	<1	9	< .5	<1	<1	<3
OSGW5-1	Md:G-391	12 - 17	11-19-92	<10	1	180	< .5	2	<1	37
OSGW5-2	Md:G-392	19 - 24	11-19-92	<10	<1	57	< .5	<1	<1	<3
OSGW5-3	Md:G-393	27 - 32	11-19-92	<10	<1	55	< .5	<1	<1	<3
OSGW5-4	Md:G-394	40 - 50	11-09-92	20	<1	33	.7	<1	<1	<3
OSGW5-5	Md:G-395	83 - 93	11-19-92	10	<1	47	< .5	<1	<1	<3
OSGW5-6	Md:G-396	113 - 123	11-23-92	<10	<1	20	< .5	2	<1	<3
OSGW6-1	Md:G-397	10 - 15	11-06-92	<10	5	76	.8	3	<1	<3
OSGW6-2	Md:G-398	19 - 24	11-07-92	<10	<1	66	< .5	<1	<1	<3
OSGW6-3	Md:G-399	27 - 32	11-08-92	<10	<1	51	.5	<1	<1	<3
OSGW6-4	Md:G-400	50 - 60	11-08-92	<10	<1	43	.6	<1	1	<3
OSGW6-5	Md:G-401	82 - 92	11-08-92	<10	<1	39	< .5	2	<1	<1
OSGW6-6	Md:G-402	120 - 130	11-07-92	<10	<1	17	.7	<1	<1	<3

Table 11. Concentrations of dissolved trace elements detected in water samples collected by pumping 36 wells at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site--Continued

Well numbers									
Project and map (fig. 11)	USGS local for Tennessee	Screened interval below land surface, in feet	Date sampled	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Molybdenum, dissolved (µg/L as Mo)
OSGW1-1	Md:G-367	13 - 18	10-22-92	<1	640	<1	<4	600	<10
OSGW1-2	Md:G-368	19 - 24	10-22-92	<1	14	<1	<4	130	<10
OSGW1-3	Md:G-369	27 - 32	10-22-92	1	13	<1	<4	48	<10
OSGW1-4	Md:G-370	42 - 52	11-04-92	1	10	<1	7	32	<10
OSGW1-5	Md:G-371	92 - 102	11-04-92	<1	11	<1	<4	4	<10
OSGW1-6	Md:G-372	128 - 138	11-04-92	2	5	<1	<4	49	<10
OSGW2-1	Md:G-373	10 - 15	10-22-92	<1	70	<1	<4	1,600	<10
OSGW2-2	Md:G-374	17 - 22	10-23-92	<1	13	<1	<4	260	<10
OSGW2-3	Md:G-375	24 - 29	10-23-92	<1	7	<1	<4	6	<10
OSGW2-4	Md:G-376	62 - 72	11-06-92	<1	7	<1	<4	15	<10
OSGW2-5	Md:G-377	92 - 102	11-06-92	1	5	<1	5	3	<10
OSGW2-6	Md:G-378	127 - 137	11-05-92	<1	11	<1	<4	31	<10
OSGW3-1	Md:G-379	9 - 14	10-28-92	<1	1,100	<1	<4	660	<10
OSGW3-2	Md:G-380	15 - 20	10-28-92	<1	11	<1	<4	72	<10
OSGW3-3	Md:G-381	24 - 29	10-30-92	<1	5	<1	<4	4	<10
OSGW3-4	Md:G-382	36 - 46	10-29-92	<1	10	<1	<4	21	<10
OSGW3-5	Md:G-383	68 - 78	10-29-92	<1	6	<1	<4	19	<10
OSGW3-6	Md:G-384	138 - 148	11-03-92	3	67	<1	<4	80	<10
OSGW4-1	Md:G-385	10 - 15	11-20-92	<1	2,800	<1	<4	1,200	<10
OSGW4-2	Md:G-386	22 - 27	11-20-92	<1	8	<1	<4	450	<10
OSGW4-3	Md:G-387	36 - 41	11-20-92	<1	9	<1	<4	4	<10
OSGW4-4	Md:G-388	48 - 58	11-20-92	<1	9	<1	<4	8	<10
OSGW4-5	Md:G-389	78 - 89	11-23-92	<1	8	<1	<4	34	<10
OSGW4-6	Md:G-390	117 - 127	11-20-92	<1	7	<1	<4	97	<10
OSGW5-1	Md:G-391	12 - 17	11-19-92	<1	9,200	<1	<4	2,700	<10
OSGW5-2	Md:G-392	19 - 24	11-19-92	<1	9	<1	<4	4	<10
OSGW5-3	Md:G-393	27 - 32	11-19-92	<1	8	<1	<4	7	<10
OSGW5-4	Md:G-394	40 - 50	11-09-92	2	21	<1	<4	34	<10
OSGW5-5	Md:G-395	83 - 93	11-19-92	<1	5	<1	5	16	<10
OSGW5-6	Md:G-396	113 - 123	11-23-92	1	5	<1	<4	84	<10
OSGW6-1	Md:G-397	10 - 15	11-06-92	<1	20,000	<1	<4	2,300	<10
OSGW6-2	Md:G-398	19 - 24	11-07-92	1	20	<1	<4	25	<10
OSGW6-3	Md:G-399	27 - 32	11-08-92	2	15	<1	<4	29	<10
OSGW6-4	Md:G-400	50 - 60	11-08-92	<1	6	<1	<4	13	<10
OSGW6-5	Md:G-401	82 - 92	11-08-92	2	8	<1	<4	19	<10
OSGW6-6	Md:G-402	120 - 130	11-07-92	1	7	<1	<4	6	<10

Table 11. Concentrations of dissolved trace elements detected in water samples collected by pumping 36 wells at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site--Continued

Well numbers		Screened interval below land surface, in feet	Date sampled	Nickel, dissolved (µg/L as Ni)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
Project and map (fig. 11)	USGS local for Tennessee								
OSGW1-1	Md:G-367	13 - 18	10-22-92	3	<1	<1	100	<6	30
OSGW1-2	Md:G-368	19 - 24	10-22-92	4	<1	<1	120	<6	14
OSGW1-3	Md:G-369	27 - 32	10-22-92	5	<1	<1	48	<6	13
OSGW1-4	Md:G-370	42 - 52	11-04-92	2	1	<1	120	<6	53
OSGW1-5	Md:G-371	92 - 102	11-04-92	<1	<1	<1	60	<6	26
OSGW1-6	Md:G-372	128 - 138	11-04-92	2	<1	<1	95	<6	45
OSGW2-1	Md:G-373	10 - 15	10-22-92	15	<1	<1	120	<6	31
OSGW2-2	Md:G-374	17 - 22	10-23-92	2	1	<1	120	<6	14
OSGW2-3	Md:G-375	24 - 29	10-23-92	2	3	<1	120	<6	5
OSGW2-4	Md:G-376	62 - 72	11-06-92	<1	2	<1	140	<6	18
OSGW2-5	Md:G-377	92 - 102	11-06-92	3	1	<1	85	<6	19
OSGW2-6	Md:G-378	127 - 137	11-05-92	1	<1	<1	72	<6	8
OSGW3-1	Md:G-379	9 - 14	10-28-92	4	<1	<1	92	<6	12
OSGW3-2	Md:G-380	15 - 20	10-28-92	3	<1	<1	130	<6	11
OSGW3-3	Md:G-381	24 - 29	10-30-92	<1	2	<1	110	<6	7
OSGW3-4	Md:G-382	36 - 46	10-29-92	<1	3	<1	120	<6	31
OSGW3-5	Md:G-383	68 - 78	10-29-92	<1	3	<1	110	<6	17
OSGW3-6	Md:G-384	138 - 148	11-03-92	2	<1	<1	70	<6	27
OSGW4-1	Md:G-385	10 - 15	11-20-92	2	<1	<1	50	<6	<3
OSGW4-2	Md:G-386	22 - 27	11-20-92	<1	<1	<1	100	<6	6
OSGW4-3	Md:G-387	36 - 41	11-20-92	<1	<1	<1	38	<6	4
OSGW4-4	Md:G-388	48 - 58	11-20-92	<1	<1	<1	56	<6	15
OSGW4-5	Md:G-389	78 - 89	11-23-92	1	<1	<1	55	<6	7
OSGW4-6	Md:G-390	117 - 127	11-20-92	<1	<1	<1	40	<6	15
OSGW5-1	Md:G-391	12 - 17	11-19-92	1	<1	<1	110	<6	18
OSGW5-2	Md:G-392	19 - 24	11-19-92	<1	1	<1	100	<6	8
OSGW5-3	Md:G-393	27 - 32	11-19-92	<1	1	<1	100	<6	16
OSGW5-4	Md:G-394	40 - 50	11-09-92	2	1	<1	80	<6	160
OSGW5-5	Md:G-395	83 - 93	11-19-92	<1	<1	<1	94	<6	7
OSGW5-6	Md:G-396	113 - 123	11-23-92	2	<1	<1	62	<6	4
OSGW6-1	Md:G-397	10 - 15	11-06-92	4	<1	<1	78	6	12
OSGW6-2	Md:G-398	19 - 24	11-07-92	1	1	<1	140	<6	7
OSGW6-3	Md:G-399	27 - 32	11-08-92	2	1	<1	180	<6	7
OSGW6-4	Md:G-400	50 - 60	11-08-92	<1	1	<1	92	<6	12
OSGW6-5	Md:G-401	82 - 92	11-08-92	1	<1	<1	120	<6	27
OSGW6-6	Md:G-402	120 - 130	11-07-92	<1	<1	<1	84	<6	8

the Fort Pillow aquifer, at concentrations ranging between 9 and 180 μg/L (table 11). These concentrations are below the primary MCL of 1,000 μg/L (Tennessee Division of Health and Environment, 1993). The median barium concentrations for water samples from wells screened in the alluvial aquifer (60 μg/L) and the Fort Pillow aquifer (33 μg/L) are consistent with the median barium concentration reported for U.S. public water supplies (43 μg/L; Hem, 1985).

Dissolved strontium commonly was detected in offsite ground-water samples at concentrations ranging between 38 and 180 μg/L (table 11). The median strontium concentrations for water samples collected from the alluvial aquifer (110 μg/L) and Fort Pillow aquifer (85 μg/L) are consistent with the median value of strontium concentration reported for U.S. public water supplies (110 μg/L; Hem, 1985).

Selected water-quality characteristics and concentrations of dissolved major inorganic constituents were measured in water samples from the 36 wells at the offsite stations (table 12). Generally, median values for dissolved solids, hardness, and specific conductance were higher in samples from wells screened in the alluvial aquifer, compared to those from wells screened in the Fort Pillow aquifer. The range of pH in water samples from the alluvial aquifer (5.3 to 6.5) was comparable to the pH range measured in samples from the Fort Pillow aquifer (5.4 to 6.5) (table 12).

Dissolved major inorganic constituent concentrations in offsite water samples did not differ significantly between the alluvial aquifer and the Fort Pillow aquifer (fig. 13). Mean values of selected major inorganic constituent concentrations were generally higher in the alluvial aquifer, particularly for chloride and sulfate.

Dissolved chloride concentrations, and values for dissolved solids and hardness were high in water samples from wells screened in the alluvial aquifer at stations OSGW5 and OSGW6, compared to concentrations of these constituents in other water samples from the alluvial aquifer (table 12). High chloride, dissolved solids, and hardness concentrations are not specific indicators of contamination from the wood-preserving processes; however, higher concentrations of these constituents and characteristics indicate slight degradation of water quality in alluvial aquifer wells at stations OSGW5 and OSGW6. This interpretation is consistent with the measurement of BTEX compounds and trichloroethylene in water samples from these wells screened in the alluvial aquifer.

POTENTIAL FOR WATER-SUPPLY CONTAMINATION

Potential for contamination of water-supply wells was assessed during this investigation because of concern that contaminants from the ACW site may have reached upgradient municipal wells at the JUD South Well Field east of the site, or downgradient domestic, industrial, and agricultural-supply wells west of the site (fig. 14). Many of these wells are screened in the Fort Pillow aquifer (table 13). The regional ground-water flow direction in the Fort Pillow aquifer generally is from east to west in the area of the South Well Field and the ACW site (Parks and Carmichael, 1990a, fig. 2), neglecting the effects of pumping at the well field.

Concern about contamination problems at the JUD South Well Field (fig. 14) and a need for hydrologic information to plan a well-head protection program for the JUD North and South Well Fields were the impetus for two previous USGS investigations. A pilot study was conducted to assess data needs and to demonstrate several methods for a preliminary delineation of areas contributing water to the JUD well fields (Broshears and others, 1991). A second study included the use of a computer model to simulate the three-dimensional ground-water-flow system in the sand aquifers in the Jackson area for hydrologic conditions in April 1989. A particle-tracking-program was applied to output from the flow model to determine areas contributing water to the JUD well fields (Bailey, 1993).

For this investigation, the particle-tracking program was used to determine whether water from the area of the ACW site could have reached the JUD South Well Field under pumping conditions in 1978, a time when pumping at this well field was at a maximum. Although the simulation showed that most ground water from the area of the ACW site traveled southward to the South Fork Forked Deer River, some particles of water were shown to be deflected toward the South Well Field because of

Table 12. Water-quality characteristics and concentrations of major inorganic constituents in water samples from 36 wells at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site

[USGS, U.S. Geological Survey; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter. Values gives as < (less than) indicate that the concentration was below the level of detection for the analytical method used and do not indicate the presence or absence of a constituent]

Well numbers		Screened interval below land surface, in feet	Date sampled	Field temperature water (°C)	Field pH (standard units)	Field specific conductance (µS/cm at 25°C)	Solids, residue at 180 °C dissolved (mg/L)	Field alkalinity (mg/L as $CaCO_3$)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)
Project and map	USGS local for Tennessee									
OSGW1-1	Md:G-367	13 - 18	10-22-92	18.3	5.8	194	130	16	44	11
OSGW1-2	Md:G-368	19 - 24	10-22-92	19.8	5.5	204	128	14	45	11
OSGW1-3	Md:G-369	27 - 32	10-22-92	18.3	5.7	145	86	10	36	9.4
OSGW1-4	Md:G-370	42 - 52	11-04-92	21.1	6.3	184	121	35	53	16
OSGW1-5	Md:G-371	92 - 102	11-04-92	20.5	6.0	96	72	28	28	7.6
OSGW1-6	Md:G-372	128 - 138	11-04-92	15.4	6.2	96	69	24	22	5.5
OSGW2-1	Md:G-373	10 - 15	10-22-92	18.9	5.6	237	150	24	54	12
OSGW2-2	Md:G-374	17 - 22	10-23-92	18.5	6.1	209	131	20	50	12
OSGW2-3	Md:G-375	24 - 29	10-23-92	18.4	6.5	206	136	23	53	13
OSGW2-4	Md:G-376	62 - 72	11-06-92	19.4	6.3	201	132	28	62	15
OSGW2-5	Md:G-377	92 - 102	11-06-92	15.4	6.0	127	100	32	32	8.5
OSGW2-6	Md:G-378	127 - 137	11-05-92	18.8	6.5	110	71	28	28	7.9
OSGW3-1	Md:G-379	9 - 14	10-28-92	19.0	5.9	195	124	14	43	10
OSGW3-2	Md:G-380	15 - 20	10-28-92	18.3	6.0	247	164	26	59	14
OSGW3-3	Md:G-381	24 - 29	10-30-92	17.2	6.1	217	135	21	53	13
OSGW3-4	Md:G-382	36 - 46	10-29-92	19.9	6.5	198	128	27	47	12
OSGW3-5	Md:G-383	68 - 78	10-29-92	18.9	6.5	181	118	26	40	10
OSGW3-6	Md:G-384	138 - 148	11-03-92	16.8	5.9	74	64	23	19	5.3
OSGW4-1	Md:G-385	10 - 15	11-20-92	18.6	5.9	127	66	24	24	5
OSGW4-2	Md:G-386	22 - 27	11-20-92	18.0	5.6	201	124	14	49	12
OSGW4-3	Md:G-387	36 - 41	11-20-92	18.5	5.8	63	40	13	14	3.5
OSGW4-4	Md:G-388	48 - 58	11-20-92	18.8	5.6	84	68	12	18	4.6
OSGW4-5	Md:G-389	78 - 89	11-23-92	17.4	5.9	81	48	18	15	4.1
OSGW4-6	Md:G-390	117 - 127	11-20-92	16.7	5.7	34	26	19	9	2.6
OSGW5-1	Md:G-391	12 - 17	11-19-92	19.2	6.0	305	159	32	50	13
OSGW5-2	Md:G-392	19 - 24	11-19-92	17.1	5.4	263	156	10	50	12
OSGW5-3	Md:G-393	27 - 32	11-19-92	20.0	5.3	261	152	11	54	13
OSGW5-4	Md:G-394	40 - 50	11-09-92	17.0	5.9	168	99	24	42	12
OSGW5-5	Md:G-395	83 - 93	11-19-92	16.9	5.4	110	93	24	28	7.3
OSGW5-6	Md:G-396	113 - 123	11-23-92	16.4	5.7	74	55	12	14	3.6
OSGW6-1	Md:G-397	10 - 15	11-06-92	19.7	6.0	200	107	36	33	8.4
OSGW6-2	Md:G-398	19 - 24	11-07-92	18.4	5.6	361	224	12	68	17
OSGW6-3	Md:G-399	27 - 32	11-08-92	19.1	5.4	430	292	7	91	23
OSGW6-4	Md:G-400	51 - 61	11-08-92	16.6	5.8	197	121	19	49	12
OSGW6-5	Md:G-401	82 - 92	11-08-92	16.9	5.8	141	108	27	37	10
OSGW6-6	Md:G-402	120 - 130	11-07-92	15.7	5.9	74	56	18	20	5.9

Table 12. Water-quality characteristics and concentrations of major inorganic constituents in water samples from 36 wells at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site--Continued

Well numbers		Screened interval below land surface, in feet	Date sampled	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
Project and map	USGS local for Tennessee									
OSGW1-1	Md:G-367	13 - 18	10-22-92	3.9	17	1.6	13	40	<0.1	19
OSGW1-2	Md:G-368	19 - 24	10-22-92	4.1	18	1.8	14	43	< .1	20
OSGW1-3	Md:G-369	27 - 32	10-22-92	2.9	10	1.6	2.9	12	< .1	15
OSGW1-4	Md:G-370	42 - 52	11-04-92	3.2	12	4.2	14	7.1	< .1	13
OSGW1-5	Md:G-371	92 - 102	11-04-92	2.1	9.2	2.1	2.1	3.8	.1	14
OSGW1-6	Md:G-372	128 - 138	11-04-92	1.9	12	1.5	7	7.3	< .1	14
OSGW2-1	Md:G-373	10 - 15	10-22-92	5.9	21	1.4	15	53	< .1	21
OSGW2-2	Md:G-374	17 - 22	10-23-92	4.7	16	1.6	16	33	< .1	12
OSGW2-3	Md:G-375	24 - 29	10-23-92	5.0	15	1.6	15	22	< .1	14
OSGW2-4	Md:G-376	62 - 72	11-06-92	6.0	14	2.0	13	27	< .1	19
OSGW2-5	Md:G-377	92 - 102	11-06-92	2.7	12	5.6	10	5.3	< .1	14
OSGW2-6	Md:G-378	127 - 137	11-05-92	2.1	11	1.1	8.1	2.4	< .1	14
OSGW3-1	Md:G-379	9 - 14	10-28-92	4.4	17	1.3	13	45	< .1	20
OSGW3-2	Md:G-380	15 - 20	10-28-92	5.8	20	1.7	15	53	< .1	15
OSGW3-3	Md:G-381	24 - 29	10-30-92	4.9	16	1.7	16	29	< .1	12
OSGW3-4	Md:G-382	36 - 46	10-29-92	4.1	15	3.3	15	17	< .1	13
OSGW3-5	Md:G-383	68 - 78	10-29-92	3.6	15	1.6	14	16	< .1	13
OSGW3-6	Md:G-384	138 - 148	11-03-92	1.3	10	1.4	6.8	3.4	< .1	16
OSGW4-1	Md:G-385	10 - 15	11-20-92	2.7	7.2	1.0	8.6	12	< .1	22
OSGW4-2	Md:G-386	22 - 27	11-20-92	4.5	15	2.2	19	24	< .1	15
OSGW4-3	Md:G-387	36 - 41	11-20-92	1.3	5.4	1.0	5.0	1.5	< .1	14
OSGW4-4	Md:G-388	48 - 58	11-20-92	1.6	8.0	3.0	8.0	2.0	< .1	14
OSGW4-5	Md:G-389	78 - 89	11-23-92	1.2	8.8	1.4	6.8	2.4	< .1	14
OSGW4-6	Md:G-390	117 - 127	11-20-92	0.6	5.6	1.4	0.9	1.7	< .1	13
OSGW5-1	Md:G-391	12 - 17	11-19-92	4.3	25	2.7	45	27	< .1	22
OSGW5-2	Md:G-392	19 - 24	11-19-92	4.9	24	2.1	38	24	< .1	16
OSGW5-3	Md:G-393	27 - 32	11-19-92	5.3	21	2.3	33	24	< .1	15
OSGW5-4	Md:G-394	40 - 50	11-09-92	3.0	12	1.5	12	13	.3	17
OSGW5-5	Md:G-395	83 - 93	11-19-92	2.3	8.8	9.0	10	4.1	< .1	16
OSGW5-6	Md:G-396	113 - 123	11-23-92	1.1	7.1	1.3	7.7	1.3	< .1	15
OSGW6-1	Md:G-397	10 - 15	11-06-92	2.9	9.7	1.9	8.7	11	.1	23
OSGW6-2	Md:G-398	19 - 24	11-07-92	6.2	39	2.6	69	26	< .1	18
OSGW6-3	Md:G-399	27 - 32	11-08-92	8.2	41	2.8	80	39	< .1	18
OSGW6-4	Md:G-400	51 - 61	11-08-92	4.5	17	1.8	17	22	< .1	19
OSGW6-5	Md:G-401	82 - 92	11-08-92	2.9	13	2.9	11	7.0	< .1	16
OSGW6-6	Md:G-402	120 - 130	11-07-92	1.3	5.8	1.3	5.2	1.2	< .1	15

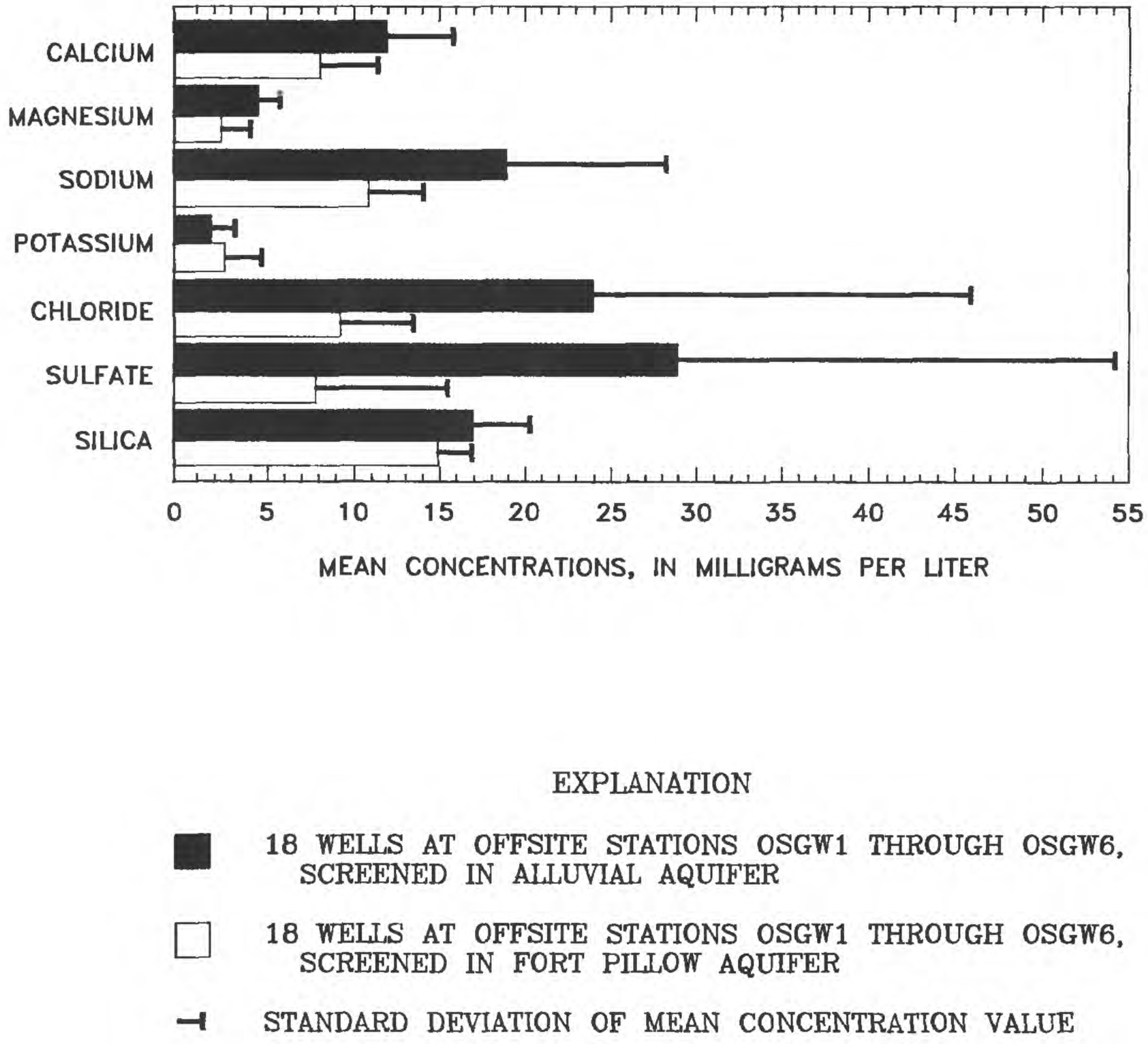


Figure 13. Mean concentrations and standard deviations for major inorganic constituents measured in water samples from 18 wells screened in the alluvial aquifer and 18 wells screened in the Fort Pillow aquifer at offsite stations OSGW1 through OSGW6 near the American Creosote Works abandoned plant site.

pumping stress at the well field. However, simulations for 10- and 20-year time-of-travel indicated that particles originating at the ACW site and traveling toward the South Well Field did not travel far enough to reach the nearest wells in the well field (Z.C. Bailey, U.S. Geological Survey, written commun., 1990).

Seven water-supply wells were sampled for water quality during November to December 1992 and January 1993 to determine whether contaminants associated with the wood-preserving processes could be detected in the Fort Pillow or alluvial aquifers upgradient or downgradient from the ACW site. These wells were selected from an inventory of 50 water-supply wells (table 13) located within a 2-mile radius of the ACW site (fig. 14). The samples were analyzed for the same VOC's and SVC's (table 9), trace elements (table 11), and water-quality characteristics and major constituents in ground water (table 12) as the samples from the 36 wells installed at offsite stations OSGW1 through OSGW6 near the ACW site.

Wells W9 and W13 are JUD municipal wells (table 13) that were installed in 1968 and 1975, and both are located about 1 mile east of the ACW site (fig. 14). These wells are 129 and 159 feet deep, respectively, and are screened in the Fort Pillow aquifer. VOC's were detected in water samples collected from both wells on November 24, 1992, and January 25, 1993 (table 14). Chloroform was detected at concentrations of 0.2 μg/L (wells W9 and W13, both samples). Tetrachloroethylene

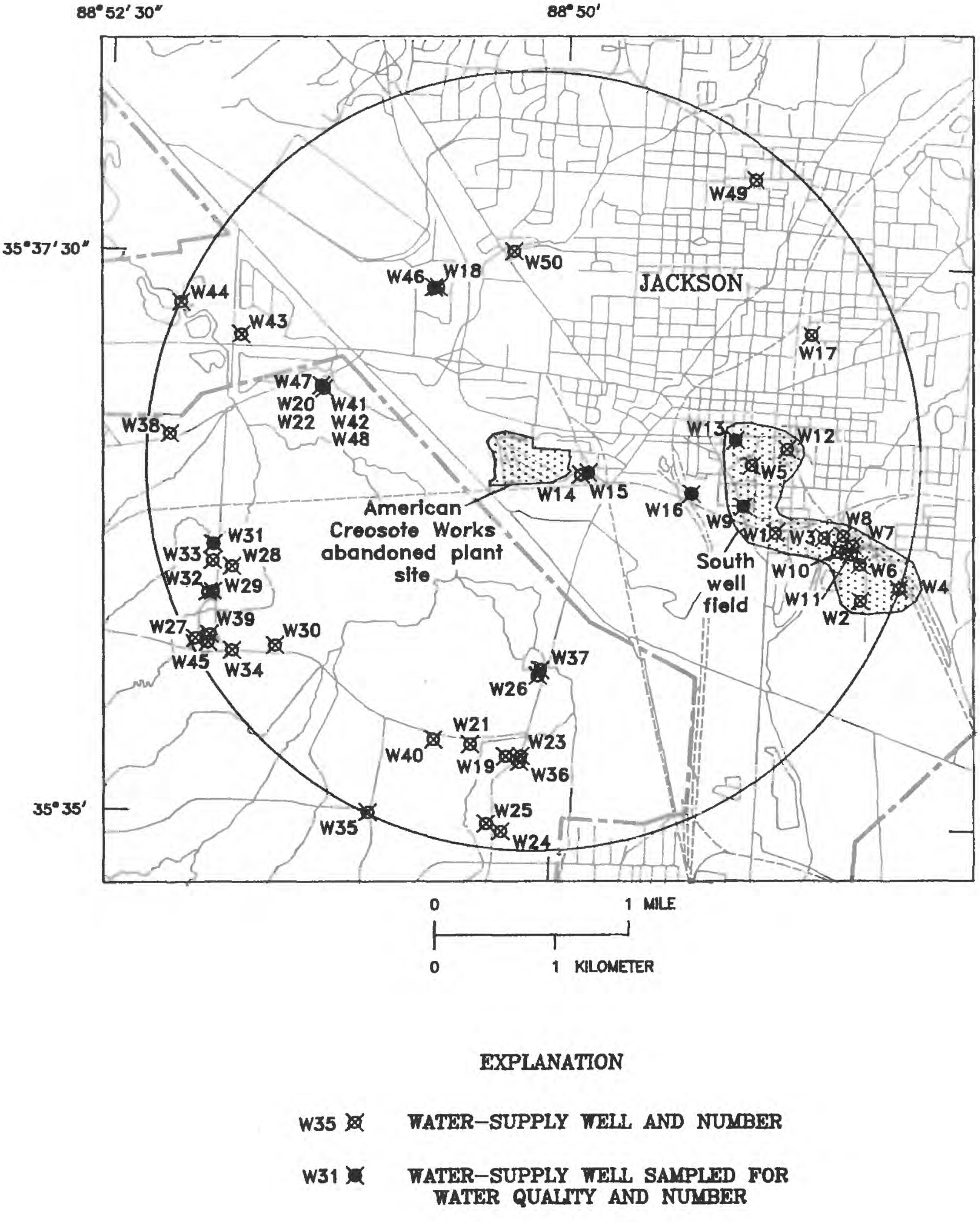


Figure 14. Location of the Jackson Utility Division South Well Field, water-supply wells inventoried within a 2-mile radius of the American Creosote Works abandoned plant site, and 7 wells from which samples were collected for water-quality analysis.

Table 13. Records of water-supply wells inventoried within a 2-mile radius of the American Creosote Works abandoned plant site

[These records were located in the files of the Tennessee Department of Environment and Conservation (TDEC), Division of Ground Water Protection, the Jackson Utility Division (JUD), and the U.S. Geological Survey. Water-bearing units are: MCNR - McNairy Sand, FRPL - Fort Pillow Sand, MMPS - Memphis Sand, TRRC - terrace deposits (fluvial deposits), ALVM - alluvium. Use of water: M - municipal, I - industrial, C - commercial, A - agricultural, D - Domestic, U - unused. –, indicates that the data were not reported in the records. Numbers in parentheses after JUD wells follow their numbering system; those after other wells are the TDEC system.]

Well numbers									Water level below land surface			
Project and map	USGS local for Tennessee	Well owner	Date drilled	Altitude, in feet	Well depth, in feet	Water-bearing unit	Well diameter, in inches	Screen length, in feet	Depth, in feet	Date	Pumping or flow rate, in gallons per minute	Use of water
W1	Md:G-1	Jackson Utility Division (fountain at water plant)	1902	359	529	MCNR	12	–	flows	1902	300	U
W2	Md:G-10	Jackson Utility Division (7)	1952	352	147	FRPL	12 X 10	50	56	1978	1,016	U
W3	Md:G-12	Jackson Utility Division (9)	1959	358	157	FRPL	12	50	49	1959	1,200	M
W4	Md:G-14	Jackson Utility Division (8)	1961	360	168	FRPL	12	50	–	–	–	U
W5	Md:G-52	Jackson Utility Division (11)	1968	383	166	FRPL	12	40	45	1968	750	M
W6	Md:G-53	Jackson Utility Division (6)	1952	363	155	FRPL	12 X 10	40	38	1952	1,280	M
W7	Md:G-88	Jackson Utility Division (4)	1964	361	148	FRPL	12	50	42	1964	675	M
W8	Md:G-89	Jackson Utility Division (3)	1964	361	150	FRPL	12	50	42	1964	1,000	M
W9	Md:G-278	Jackson Utility Division (12)	1968	360	129	FRPL	12	40	2	1968	750	M
W10	Md:G-279	Jackson Utility Division (2)	1964	353	150	FRPL	12	50	46	1964	850	M
W11	Md:G-280	Jackson Utility Division (5)	1961	355	176	FRPL	12	68	66	1961	1,016	M
W12	Md:G-281	Jackson Utility Division (10)	1972	400	140	FRPL	12	50	63	1972	–	M
W13	Md:G-283	Jackson Utility Division (13)	1975	388	159	FRPL	12	50	60	1975	–	M
W14	Md:G-327	Morgan Lumber Company	–	352	30?	ALVM	4	10	8	1992	–	I
W15	Md:G-328	Morgan Lumber Company	–	352	–	MCNR	–	–	flows	1990	–	U
W16	Md:G-329	Jackson Wood Products (217) (once Ashby Veneer & Lbr.Co.)	1964	359	132	FRPL	6	27	18	1964	160	I
W17	Md:G-330	The Beare Company (659)	1968	432	149	FRPL	8	20	95	1968	250	I
W18	Md:G-331	UT Agri. Exper. Sta. (835)	1969	365	90	MMPS	4	18	45	1969	100	A
W19	Md:G-332	V.L. Stewart (1079)	1971	352	58	FRPL	4	4	20	1971	–	D
W20	Md:G-333	City Concrete (1175)	1972	338	130	FRPL	4	20	–	1972	–	I
W21	Md:G-334	A.L. Williams (1336)	1973	355	40	ALVM	2	4	20	1973	–	D
W22	Md:G-335	City Concrete (1658)	1976	338	122	FRPL	4	20	–	–	–	I
W23	Md:G-336	Wayne Vann (1836)	1977	349	37	ALVM	4	10	2	1977	–	D
W24	Md:G-337	W. Jobe Robinson (1869)	1978	365	165	FRPL	4	10	120	1978	10	D
W25	Md:G-338	Paul Smith (1935)	1978	373	93	FRPL	4	5	25	1978	10	D

Table 13. Records of water-supply wells inventoried within a 2-mile radius of the American Creosote Works abandoned plant site--Continued

Well numbers									Water level below land surface			
Project and map	USGS local for Tennessee	Well owner	Date drilled	Altitude, in feet	Well depth, in feet	Water-bearing unit	Well diameter, in inches	Screen length, in feet	Depth, in feet	Date	Pumping or flow rate, in gallons per minute	Use of water
W26	Md:G-339	Murray Ragan (2263)	1981	342	60	FRPL	4	10	30	1981	–	D
W27	Md:G-340	George Robinson (2299)	1980	408	120	MMPS	4	5	80	1980	10	D
W28	Md:G-341	J.H. Webb (255)	1964	362	69	MMPS	2	5	22	1964	–	D
W29	Md:G-342	Donald Edwards (583)	1968	373	110	FRPL	2	6	20	1968	6	D
W30	Md:G-343	J.W. Austin (831)	1969	370	59	MMPS	4	5	40	1969	–	D
W31	Md:G-344	Taylor Roebuck (1042)	1971	350	90	FRPL	2	5	15	1971	7	D
W32	Md:G-345	Edd Tramell (1138)	1971	375	92	MMPS	4	4	60	1971	15	D
W33	Md:G-346	Charles Graves (2801)	1985	360	73	MMPS	4	40	40	1985	10	D
W34	Md:G-347	Lacey Rose (3209)	1988	394	120	FRPL	4	10	40	1988	18	D
W35	Md:G-348	Turner Dairy (3104)	1987	432	180	FRPL	4	40	–	–	–	I
W36	Md:G-349	Betty Plunk (2825)	1985	350	38	ALVM	4	10	3	1985	12	D
W37	Md:G-350	Top Star Grocery (937)	1970	345	53	FRPL	4	5	28	1970	50	C
W38	Md:G-351	Albert Fly (379)	1966	343	35	ALVM	1 1/4	6	18	1966	–	U
W39	Md:G-352	Thomas Springer (994)	1971	423	118	MMPS	4	4	80	1971	15	D
W40	Md:G-353	Keith Turner (1260)	1972	367	40	TRRC	1 1/4	4	25	1972	7	D
W41	Md:G-354	City Concrete (3081)	1986	338	90	FRPL	4	20	10	1986	50	I
W42	Md:G-355	City Concrete (2628)	1983	338	105	FRPL	4	20	10	1983	–	I
W43	Md:G-356	Euther Davidson (1263)	1972	338	42	ALVM	2	4	19	1972	–	C
W44	Md:G-357	Nicks Construction (2024) (once Mid South Materials)	1978	338	90	FRPL	4	20	–	–	30	I
W45	Md:G-358	D.W. Morris (328)	1965	422	113	MMPS	2	4	80	1965	–	D
W46	Md:G-403	UT Agricultural Exp. Station	1987	365	190	FRPL	6	30	–	–	120	A
W47	Md:G-404	City Concrete	1988	338	140	FRPL	6	40	–	–	160	I
W48	Md:G-405	City Concrete (3226)	1988	338	165	FRPL	4	10	–	–	30	I
W49	Md:M-571	James Avent (2609)	1983	452	145	MMPS	4	10	50	1983	10	A
W50	Md:M-572	Sun and Swim (1716)	1976	362	138	FRPL	4	16	60	1976	25	C

Table 14. Concentrations of volatile organic compounds detected in water samples collected from seven water wells within a 2-mile radius of the American Creosote Works abandoned plant site, November 1992-January 1993

[Concentrations are in micrograms per liter (μg/L); (TDEC) Tennessee Department of Environment and Conservation, 1993, (MCL) primary maximum contaminant levels for drinking water; values given as < (less than) indicate that the concentration was below the level of detection for the analytical method used and do not indicate the presence or absence of a compound; "none" indicates no established maximum contaminant level for the compound; -- indicates no second ssmple collected]

Synthetic organic compound	Analytical method minimum detection limit	Wells in which detected	Concentration detected		TDEC MCL
			First sample	Second sample	
Chloroform	0.2	W9 (Md:G-278)	0.2	0.2	none
		W13 (Md:G-283)	.2	.2	
		W14 (Md:G-327)	.2	–	
		W16 (Md:G-329)	.2	.2	
1,1-Dichloroethane	.2	W14 (Md:G-327)	.3	--	none
cis-1,2-Dichloroethylene	.2	W16 (Md:G-329)	< .2	.2	none
Methylene chloride	.2	W14 (Md:G-327)	.3	--	none
		W46 (Md:G-403)	.6	–	
Tetrachloroethylene	.2	W9 (Md:G-278)	2.4	2.5	none
		W13 (Md:G-283)	2.2	3.1	
		W16 (Md:G-329)	45	69	
Trichloroethylene	.2	W14 (Md:G-327)	.2	–	5
		W16 (Md:G-329)	1.1	1.2	
Trichlorofluoromethane	.2	W16 (Md:G-329)	.5	.4	none
Trichlorotrifluoroethane	.5	W14 (Md:G-327)	1.5	–	none

detected at concentrations of 2.4 and 2.5 μg/L (well W9) and at 2.2 and 3.1 μg/L (well W13).

Detection of chloroform and tetrachloroethylene in wells W9 and W13 is consistent with analytical data obtained from these wells in September and November 1987 (Broshears and others, 1991, table 5). These previous analyses showed that chloroform was detected at concentrations of 0.2 and 0.3 μg/L (well W9) and 0.3 μg/L in both samples (well W13). Methylene chloride also was detected at a concentration of 1.2 μg/L previously in a 1987 sample from well W13 (Broshears and others, 1991, table 5), but was not detected in the ground-water samples collected for this investigation.

During September and November 1987, 2 samples were collected from each of 11 wells in the JUD South Well Field and analyzed for 16 VOC's (Broshears and others, 1991, p. 12-13). Tetrachloroethylene was measured in water samples from eight wells at concentrations ranging between 0.2 and 23 μg/L (Broshears and others, 1991, table 5). Trichloroethylene was measured in water samples from three wells at concentrations ranging between 0.3 and 3.3 μg/L. Low concentrations of trans-1,2-dichloroethylene (0.2 to 0.6 μg/L) and benzene (0.2 to 1.4 μg/L) also were measured in water samples from three wells. Groundwater Management, Inc., (GM) in an unpublished report to JUD, 1987, speculated that the source of these VOC's may be a leaky sewer receiving effluent from a past or present user of the compounds (Broshears and others, 1991, p. 11).

Tetrachloroethylene, trichloroethylene, and their degradation products are among the most commonly observed contaminants found in shallow ground-water systems (Chapelle, 1993, p. 377). Tetrachloroethylene and trichloroethylene are used in great volumes as dry-cleaning fluids, refrigerants, degreasing agents, and solvents. These compounds also are relatively resistant to microbial degradation under conditions commonly found in shallow ground-water systems (Chapelle, 1993, p. 377).

Wells in the JUD South Well Field (fig. 14; table 13) are located within an older part of Jackson that is interspersed with industrial and commercial establishments, including switching yards and maintenance facilities for railroads. Therefore, the occurrence of the tetrachloroethylene, trichloroethylene, and chloroform in the Fort Pillow aquifer at the JUD South Well Field is problematic inasmuch as these compounds may have entered the aquifer from a single source, such as the leaky sewer speculated by GM, or from multiple sources in the well-field area. No VOC's or SVC's commonly associated with the wood-preserving processes were detected in water samples from wells W9 and W13.

Well W16, an industrial well installed in 1964 (table 13), is about 3/4-mile east of the ACW site (fig. 14). This well is 132 feet deep, and is screened in the Fort Pillow aquifer. Several VOC's were detected in water samples collected from this well on November 25, 1992, and January 25, 1993 (table 14). Tetrachloroethylene was detected at concentrations of 45 and 69 μg/L, trichloroethylene at 1.1 and 1.2 μg/L, trichlorofluoromethane at 0.5 and 0.4 μg/L, chloroform at 0.2 μg/L (both samples), and cis-1,2-dichloroethylene at 0.2 μg/L (one sample).

Detection of tetrachloroethylene and trichloroethylene in water samples from well W16 extends the area where these compounds have been detected in samples from water-supply wells screened in the Fort Pillow aquifer about 1/4 mile farther west than had been determined previously (Broshears and others, 1991). In addition, tetrachloroethylene (45 and 69 μg/L) in water samples from well W16 represents higher concentrations than any measured in samples from wells in the JUD South Well Field (Broshears and others, 1991, table 5). These VOC's are not commonly associated with wood-preserving processes, although trichloroethylene has been detected in water samples from the alluvial aquifer beneath the ACW site (Parks and others, 1993).

Well W14 is an industrial well reported to be 30 feet deep (table 13). If the reported depth is accurate, this well is in the alluvial aquifer. Well W14 was sampled in January 1993 because of its proximity (within a few hundred feet) to the ACW site (fig. 14). Chloroform was detected in water sample collected from this well at a concentration of 0.2 μg/L, 1,1-dichloroethane at 0.3 μg/L, trichloroethylene at 0.2 μg/L, and trichlorotrifluoroethane at 1.5 μg/L (table 14). In addition to these VOC's, several trace elements were detected in water samples from this well at relatively high concentrations (table 15). Cadmium was detected at 13 μg/L, chromium at 6 μg/L, cobalt at 89 μg/L, nickel at 13 μg/L, and vanadium at 11 μg/L. The source of the VOC's and relatively high concentrations of trace elements detected in the water sample from well W14 is problematic inasmuch as the well is not located (fig. 14) in the direction of ground-water flow in the alluvial aquifer from the ACW site (fig. 6). Well W14 is located in an industrial area downgradient from a railroad switching yard and maintenance facility and an old cemetery.

Most contaminants at the ACW site migrate in the alluvial aquifer southwestward toward the South Fork Forked Deer River at depths less than about 35 feet below land surface (Parks and others, 1993). Contaminants in the alluvial aquifer and possibly the upper part of the Fort Pillow aquifer that reach the South Fork Forked Deer River are discharged in ground water entering the river (fig. 7). However, some contaminants migrating at greater depths in the Fort Pillow aquifer may travel under the South Fork Forked Deer River and continue westward along the regional ground-water flow direction in that aquifer (Parks and Carmichael, 1990a, fig. 2). The average ground-water flow velocity for the Fort Pillow

Table 15. Concentrations of dissolved trace elements detected in water samples collected from seven water-supply wells within a 2-mile radius of the American Creosote Works abandoned plant site

[USGS, U.S. Geological Survey; µg/L, micrograms per liter. Values gives as < (less than) indicate that the concentration was below the level of detection for the analytical method used and do not indicate the presence or absence of a constituent]

Well numbers										
Project and map (fig. 14)	USGS local for Tennessee	Screened interval below land surface, in feet	Date sampled	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (ug/L as Co)
W9	Md:G-278	105 - 155	11-24-92	<10	<1	48	<0.5	<1	<1	<3
W13	Md:G-283	85 - 125	11-24-92	20	<1	49	< .5	<1	<1	<3
W14	Md:G-327	20 - 30	01-26-93	<10	2	71	< .5	13	6	89
W16	Md:G-329	105 - 132	11-25-92	10	<1	47	< .5	<1	8	<3
W31	Md:G-344	85 - 90	12-01-92	10	<1	4	< .5	<1	<1	<3
W46	Md:G-403	160 - 190	11-24-92	<10	<1	11	< .5	<1	<1	<3
W47	Md:G-404	100 - 140	01-26-93	<10	<1	4	< .5	2	4	<3

Well numbers									
Project and map (fig. 14)	USGS local for Tennessee	Screened interval below land surface, in feet	Date sampled	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Molybdenum, dissolved (µg/L as Mo)
W9	Md:G-278	105 - 155	11-24-92	2	<3	<1	<4	24	<10
W13	Md:G-283	85 - 125	11-24-92	2	8	3	<4	3	20
W14	Md:G-327	20 - 30	01-26-93	<1	56,000	<1	<4	4,900	<10
W16	Md:G-329	105 - 132	11-25-92	1	16	<1	<4	99	<10
W31	Md:G-344	85 - 90	12-01-92	3	13	<1	<4	<1	<10
W46	Md:G-403	160 - 190	11-24-92	1	43	<1	<4	2	<10
W47	Md:G-404	100 - 140	01-26-93	<1	35	<1	<4	3	<10

Well numbers									
Project and map (fig. 14)	USGS local for Tennessee	Screened interval below land surface, in feet	Date sampled	Nickel, dissolved (µg/L as Ni)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)
W9	Md:G-278	105 - 155	11-24-92	<1	<1	<1	170	<6	<3
W13	Md:G-283	85 - 125	11-24-92	1	<1	<1	120	<6	6
W14	Md:G-327	20 - 30	01-26-93	13	<1	<1	500	11	27
W16	Md:G-329	105 - 132	11-25-92	<1	<1	<1	150	<6	6
W31	Md:G-344	85 - 90	12-01-92	<1	<1	<1	6	<6	<3
W46	Md:G-403	160 - 190	11-24-92	<1	<1	<1	16	<6	<3
W47	Md:G-404	100 - 140	01-26-93	<1	<1	<1	12	<6	7

aquifer calculated for this investigation--10 feet per year--indicates that contaminants entering the ground-water flow system 50 years ago may have migrated about 500 feet downgradient from the ACW site. The maximum flow velocity calculated for the Fort Pillow aquifer--130 feet per year--indicates that contaminants may have migrated to distances of about 1 1/4 miles downgradient from the site.

The closest wells west of the ACW site are about 1 to 1 1/2 miles distant (fig. 14). These wells range in depth from about 60 to 190 feet and are screened in the Memphis aquifer (Parks and Carmichael, 1990b) or the Fort Pillow aquifer (table 13). Three wells (W31, W46, and W47) screened in the Fort Pillow aquifer were sampled to determine if contaminants could be detected in the ground water downgradient from the site (fig. 14).

Well W31 is a domestic well 90-feet deep, well W46 is an agricultural well 190-feet deep, and well W47 is an industrial well 140-feet deep (table 13). No VOC's or SVC's were detected in water samples collected from these wells in November 1992 to January 1993, except for methylene chloride at a concentration of 0.6 µg/L in well W46 (table 14). Methylene chloride commonly is used in water-quality laboratories and may have been detected in the water sample from well W46 as a laboratory contaminant.

Water-quality characteristics and concentrations of dissolved major inorganic constituents were measured for the first samples collected from the seven water-supply wells sampled during this investigation (table 16). Comparison of water-quality data from wells W9, W13, W16, W31, W46, and W47 with minimum, median, and maximum concentrations

Table 16. Water-quality characteristics and concentrations of major inorganic constituents detected in water samples collected from seven water-supply wells within a 2-mile radius of the American Creosote Works abandoned plant site

[USGS, U.S. Geological Survey; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter. Values given as < (less than) indicate that the concentration was below the level of detection for the analytical method used and do not indicate the presence or absence of a constituent; --, indicate no data]

Well numbers		Screened interval below land surface, in feet	Date sampled	Field temperature water (°C)	Field pH (standard units)	Field specific conductance (µS/cm at 25°C)	Solids, residue at 180°C dissolved (mg/L)	Field alkalinity (mg/L as $CaCO_3$)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)
Project and map	USGS local for Tennessee									
W9	Md:G-278	105 - 155	11-24-92	16.6	6.2	253	157	36	74	19
W13	Md:G-283	85 - 125	11-24-92	17.2	6.0	198	120	20	54	13
W14	Md:G-327	20 - 30	01-26-93	15.2	6.2	798	476	121	191	50
W16	Md:G-329	105 - 132	11-25-92	16.9	6.0	261	150	35	75	20
W31	Md:G-344	85 - 90	12-01-92	16.0	5.6	27	33	13	5	1.2
W46	Md:G-403	160 - 190	11-24-92	15.6	5.8	37	38	9	7	1.8
W47	Md:G-404	100 - 140	01-26-93	--	5.8	33	22	11	7	1.8

Well numbers		Screened interval below land surface, in feet	Date sampled	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
Project and map	USGS local for Tennessee									
W9	Md:G-278	105 - 155	11-24-92	6.3	12	5.1	12	50	<0.1	15
W13	Md:G-283	85 - 125	11-24-92	5.3	12	3.1	12	37	< .1	16
W14	Md:G-327	20 - 30	01-26-93	16	28	8.7	91	60	.1	22
W16	Md:G-329	105 - 132	11-25-92	6	15	4.8	16	43	< .1	15
W31	Md:G-344	85 - 90	12-01-92	0.4	2.4	0.5	1.7	0.3	< .1	12
W46	Md:G-403	160 - 190	11-24-92	.7	3.7	.8	3.0	.3	< .1	14
W47	Md:G-404	100 - 140	01-26-92	.6	3.0	.6	1.0	.9	< .1	13

in water samples from six wells screened in the Fort Pillow aquifer in Madison County, Tennessee (Parks and Carmichael, 1989, table 2), indicate that water-quality characteristics and concentrations of major constituents were consistent and show no evidence of contamination. These data also are consistent with major inorganic constituent concentrations measured in water samples from the 18 wells screened in the Fort Pillow aquifer at offsite stations OSGW1 through OSGW6 (table 12).

Some concentrations of dissolved major inorganic constituents measured in the water sample collected from well W14 are elevated (table 16) in comparison to data from the 18 wells screened in the alluvial aquifer at offsite stations OSGW1 through OSGW6. Chloride concentrations and values for dissolved solids and hardness are three to four times higher in the water sample from well W14. Concentrations of these constituents and characteristics, and some trace elements and VOC's, indicate degradation of water quality at well W14, although it is not suspected that this degradation is the result of past activities at the ACW site.

SUMMARY AND CONCLUSIONS

An investigation was conducted by the U.S. Geological Survey at the American Creosote Works (ACW) abandoned plant site at Jackson, Tennessee, to determine the extent and magnitude of ground-water contamination in nearby offsite areas and to assess the potential for water-supply contamination from the site. During its approximate 50-year period of operation (from the 1930's to 1981), activities at the ACW facility caused significant contamination of soil, surface water, and ground water. Both creosote and pentachlorophenol were used in the wood-preserving process, and these compounds are the primary contaminants affecting ground-water quality at the site.

The Fort Pillow Sand of Tertiary age and alluvium of Quaternary age make up the Fort Pillow and alluvial aquifers, parts of which underlie the ACW site. The combined thickness of these aquifers beneath the site is about 150 feet. The uppermost part of the alluvium, which consists primarily of clay, silt, and fine sand, serves as a relatively thin upper confining unit for the Fort Pillow and alluvial aquifers. Below the Fort Pillow aquifer is a thick section of clay, which serves as a lower confining unit separating the Fort Pillow and alluvial aquifers from the deeper McNairy aquifer. The Fort Pillow and alluvial aquifers, which consist primarily of sand, are not separated by a confining unit of any significant thickness or areal extent. However, differences in silt and clay content in the sands affect contaminant migration in the subsurface beneath the site.

The alluvial and Fort Pillow aquifers beneath the ACW site are semi-confined. Water levels generally are high throughout the year, ranging from 1 to 10 feet below land surface. The potentiometric surfaces in the alluvial and Fort Pillow aquifers at the site slope to the southwest toward the nearby South Fork Forked Deer River. Average ground-water flow velocities in these aquifers are about 17 and 10 feet per year, respectively. The pattern of vertical hydraulic gradient is somewhat complex--downward, indicating recharge, in the northern part of the site, and upward, indicating discharge, in the southern part toward the South Fork Forked Deer River.

Contaminants from the wood-preserving processes have migrated into the subsurface as an oily or non-aqueous phase liquid (NAPL) from onsite sources such as waste lagoons and treatment areas. The NAPL has descended into the alluvial aquifer, and migrated downgradient with ground-water flow and along zones of higher hydraulic conductivity in the alluvial aquifer or the Fort Pillow aquifer, creating a potential for ground-water contamination away from the ACW site.

Four groups of organic compounds detected onsite in the NAPL and ground water were: (1) PAH's, (2) phenolic compounds (including PCP), (3) nitrogen-containing heterocyclic compounds, and (4) VOC's (primarily BTEX's). Maximum concentrations of organic compounds were detected in samples from the onsite alluvial aquifer at depths less than 35 feet below land surface.

Naphthalene, PCP, and quinoline are the principal ground-water contaminants resulting from wood-preserving processes detected onsite. Naphthalene was the most common PAH detected in water samples from the alluvial aquifer. This compound was detected at concentrations ranging between 2 and 7,600 μg/L. PCP concentrations ranged between 80 and 3,200 µg/L in these same samples, with many sample concentrations exceeding the proposed MCL for drinking water of 200 µg/L. Quinoline was not detected in any ground-water sample.

VOC's (specifically BTEX's) were contained in solvents used during the wood-preserving processes. Of the BTEX compounds, ethylbenzene was detected at the highest concentrations. Where detected, benzene concentrations exceeded the primary MCL of 0.5 µg/L for drinking water in seven of the nine water samples from the alluvial aquifer at onsite stations.

Few organic compounds were detected in water samples from onsite wells screened in the Fort Pillow aquifer. Naphthalene was the only PAH detected. This compound was measured at a concentration of 2 µg/L at station 3 (125.5-135.5 feet). Other VOC's detected were trichloroethylene at a concentration of 6 µg/L (station 5; 54-55 feet), and methylene chloride in two samples at concentrations of 9 µg/L (station 2; 64-65 feet) and 150 µg/L (station 3; 125.5-135.5 feet).

Ground-water samples collected from offsite stations with the DPT Hydrocone tool were analyzed for PAH's, phenolic compounds (including PCP), and nitrogen-containing heterocyclic compounds using HPLC. Ground-water samples also were analyzed for selected VOC's (including BTEX compounds) using GC/PID. Water samples pumped from the 36 wells at 6 offsite stations were analyzed for selected VOC's and SVC's. Dissolved trace elements and major inorganic constituents also were measured, and water-quality characteristics were determined for these samples.

Relatively low concentrations of naphthalene, trihalomethanes, and other VOC's were detected in water samples from the alluvial aquifer at offsite stations. Naphthalene was detected in a total of five samples from offsite wells screened in the alluvial aquifer. Using the HPLC method, naphthalene was detected at concentrations of 10 µg/L (2 samples), and 20 µg/L (one sample) at depths of 17 to 24 feet. Using the GC/PID method, naphthalene was detected at concentrations of 0.6 and 3.0 µg/L at depths of 10 to 27 feet. Trihalomethanes were detected in one water sample from a well screened in the Fort Pillow aquifer, at a sum concentration (bromoform, chloroform, bromodichloromethane, and dibromochloromethane) of 1.5 µg/L.

BTEX's were the most commonly detected VOC's in water samples collected using DPT method and by pumping wells at offsite stations. Considering the BTEX data in ground-water samples collected by the DPT method from the alluvial aquifer, toluene and ethylbenzene concentrations ranged between 2 and 10 µg/L, and xylene concentrations ranged between 2 and 790 µg/L. Benzene was not detected in any offsite ground-water sample collected by the DPT method. Because of differences in the sampling methods, the concentrations in ground-water samples collected by the DPT method are generally 10 times greater than concentrations detected in samples collected by pumping wells.

BTEX concentrations in water samples pumped from offsite wells screened in the alluvial aquifer ranged between <0.2 and 1.6 µg/L, for each compound, where detected. BTEX compounds also were detected in samples pumped from the wells screened in the Fort Pillow aquifer. Benzene was detected at a concentration of 0.2 µg/L in two ground-water samples (82-92 feet and 120-130 feet). Xylenes also were detected at concentrations of 0.9 and 0.7 µg/L in these same samples, respectively.

Concentrations of all organic compounds were low in water samples collected from offsite wells. Sorption of contaminants on clay-mineral surfaces and microbial degradation are suspected to have limited the migration of PAH's from the ACW site and contributed to the attenuation of PAH's, phenolic compounds, and nitrogen-containing heterocyclic compounds offsite.

Trace elements were measured in water samples collected from all wells at offsite stations. Barium, cobalt, iron, manganese, nickel, strontium, and zinc were detected most commonly. Concentrations of trace elements were below primary MCL's in all ground-water samples.

To assess the potential for contamination of water-supply sources from the ACW site, 7 wells selected from 50 wells inventoried within a 2-mile radius of the site were sampled for water-quality data. These samples were analyzed for the same organic compounds and inorganic constituents as were the water samples from 36 wells at the six offsite stations. Two municipal wells and an industrial well were sampled, all screened in the Fort Pillow aquifer east (upgradient) of the ACW site.

Tetrachloroethylene, trichloroethylene, chloroform, and other VOC's were detected in water samples from these wells. The detection of these compounds, which are not commonly associated with the wood-preserving processes, is problematic inasmuch as multiple sources for these compounds exist in the area of the wells.

An industrial well screened in the alluvial aquifer in immediate proximity (upgradient) of the ACW site also was sampled. VOC's and relatively high concentrations of some trace constituents, chloride, dissolved solids, and hardness were detected. Degradation of water quality in this well is not directly attributable to contamination from the wood-preserving processes.

A domestic well, an industrial well, and an agricultural-supply well west (downgradient) of the ACW site were sampled for water-quality analysis. No organic or inorganic contaminants were detected in the water samples from these wells, except a low concentration of methylene chloride in one well.

REFERENCES CITED

Baedecker, M.J., and Lindsay, Sharon, 1986, Distribution of unstable constituents in ground water near a creosote works, Pensacola, Florids, *in* Mattraw, H.C., Jr., and Franks, B.J., eds., Movement and fate of creosote waste in ground water, Pensacola, Florida; U.S. Geological Survey Toxic Waste-Ground-Water Contamination Program: U.S. Geological Survey Water-Supply Paper 2285, p. 9-17.

Bailey, Z.C., 1993, Hydrology of the Jackson, Tennessee, area and delineation of areas contributing ground water to the Jackson well fields: U.S. Geological Survey Water-Resources Investigations Report 92-4146, 54 p.

Broshears, R.E., Connell, J.F., and Short, N.C., 1991, A pilot study for delineation of areas contributing water to wellfields at Jackson, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 89-4201, 33 p.

Chapelle, F.H., 1993, Ground water microbiology and geochemistry: New York, John Wiley & Sons, Inc., 424 p.

Cushing, E.M., Boswell, E.H., and Hosman, R.L., 1964, General geology of the Mississippi embayment: U.S. Geological Survey Professional Paper 448-B, 28 p.

DaRos, Bruce, Fitch, Bill, Franklin, Carole, Friedman, Mike, Merrill, Richard, and Wolbach, Dean, 1981, Wood preserving industry multimedia emission inventory (Project summary): U.S. Environmental Protection Agency-600/S2-81-066, p. 1-6.

Ehrlich, G.G., Goerlitz, D.F., Godsy, E.M., and Hult, M.F., 1982, Degradation of phenolic contaminants in ground water by anaerobic bacteria; St. Louis Park, Minnesota: Ground Water, v. 20, no. 6, p. 703-710.

Godsy, E.M., and Goerlitz, D.F., 1986, Anaerobic microbial transformations of phenolic and other selected compounds in contaminated ground water at a creosote works, Pensacola, Florids, *in* Mattraw, H.C., Jr., and Franks, B.J., eds., Movement and fate of creosote waste in ground water, Pensacola, Florida; U.S. Geological Survey Toxic Waste-Ground-Water Contamination Program: U.S. Geological Survey Water-Supply Paper 2285, p. 55-58.

Goerlitz, D.F., 1992, A review of studies of contaminated groundwater conducted by the U.S. Geological Survey Organics Project, Menlo Park, California, 1961-1990, *in* Lesage, S., and Jackson, R.E., eds., Groundwater contamination and analysis at hazardous waste sites: New York, Marcel Dekker, Inc., 545 p.

Goerlitz, D.F., and Franks, B.J., 1989, Use of on-site high performance liquid chromatography to evaluate the magnitude and extent of organic contamination in aquifers: Ground Water Monitoring Review, v. 9, no. 2, p. 122-129.

Goerlitz, D.F., Godsy, E.M., Troutman, D.E., and Franks, B.J., 1986, Chemistry of ground water at a creosote works, Pensacola, Florida, *in* Mattraw, H.C., Jr., and Franks, B.J., eds., Movement and fate of creosote waste in ground water, Pensacola, Florida; U.S. Geological Survey Toxic Waste-Ground-Water Contamination Program: U.S. Geological Survey Water-Supply Paper 2285, p. 49-53.

Goerlitz, D.F., Troutman, D.E., Godsy, E.M., and Franks, B.J., 1985, Migration of wood-preserving chemicals in contaminated groundwater in a sand aquifer at Pensacola, Florida: Environmental Science and Technology, v. 19, no. 10, p. 955-961.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3rd ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Madsen, E.L., Sinclair, J.L., and Ghiorse, W.C., 1991, In situ biodegradation: Microbiological patterns in a contaminated aquifer: Science, v. 252, p. 830-833.

Mattraw, H.C., and Franks, B.J., eds., 1986, Movement and fate of creosote waste in ground water, Pensacola, Florida: U.S. Geological Survey Water-Supply Paper 2285, 63 p.

Milhous, H.C., 1959, Well logs in Tennessee: Tennessee Division of Geology Bulletin 62, 606 p.

Parks, W.S., 1968, Geologic map of the Jackson South quadrangle, Tennessee: Tennessee Division of Geology GM 438-SE, scale 1:24,000.

Parks, W.S., and Carmichael, J.K., 1989, Geology and ground-water resources of the Fort Pillow Sand in western Tennessee: U.S. Geological Survey Water-Resources Investigations Report 89-4120, 20 p.

_____1990a, Altitude of potentiometric surface, fall 1985, and historic water-level changes in the Fort Pillow aquifer in western, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 89-4048, 8 p.

_____1990b, Geology and ground-water resources of the Memphis Sand in western Tennessee: U.S. Geological Survey Water-Resources Investigations Report 88-4182, 30 p.

Parks, W.S., Carmichael, J.K., and Mirecki, J.E., 1993, Evaluation of subsurface exploration, sampling, and water-quality-analysis methods at an abandoned wood-preserving plant site at Jackson, Tennessee: U.S. Geological Survey Water-Resources Investigations Report 93-4108, 22 p.

Pereira, W.E., and Rostad, C.E., 1986, Geochemical investigations of organic contaminants in the subsurface at a creosote works, Pensacola, Florida, *in* Mattraw, H.C., Jr., and Franks, B.J., eds., Movement and fate of creosote in ground water, Pensacola, Florida: U.S. Geological Survey Toxic Waste-Ground-Water Contamination Program: U.S. Geological Survey Water-Supply Paper 2285, p. 33-40.

Russell, E.E., and Parks, W.S., 1975, Stratigraphy of the outcropping Upper Cretaceous, Paleocene, and lower Eocene in western Tennessee (including descriptions of younger fluvial deposits): Tennessee Division of Geology Bulletin 75, 118 p.

S&ME, Inc., 1988, Final remedial investigation report, American Creosote Works Site, Jackson, Tennessee: Prepared by S&ME, Inc., Atlanta, Georgia, for the U.S. Army Corps of Engineers, Kansas City, Missouri (under contract no. DACW41-86-C-0014), S&ME Document No. 86015A-0146, July 1988.

Schneider, R.R., and Blankenship, R.E., 1950, Subsurface geologic cross section from Claybrook, Madison County to Memphis, Shelby County, Tennessee: Tennessee Division of Geology Ground-Water Investigations Preliminary Chart 1.

Tennessee Department of Environment and Conservation, 1993, Regulations for public water systems and drinking water quality: Tennessee Department of Environment and Conservation, Division of Water Supply, chapter 1200-5-1, 174 p.

U.S. Environmental Protection Agency, 1984a, Appendix A to Part 136 - Methods for organic chemical analysis of municipal and industrial wastewater, Method 601 - purgeable halocarbons: 40 CFR Part 136, Federal Register, v. 49, no. 209, October 26, 1984, p. 29-39.

_____1984b, Appendix A to Part 136 - Methods for organic chemical analysis of municipal and industrial wastewater, Method 602 - purgeable aromatics: 40 CFR Part 136, Federal Register, v. 49, no. 209, October 26, 1984, p. 40-48.

_____1986, Maximum contaminant levels (Subpart B of part 141 National interim primary drinking-water regulations): 40 CFR Part 136, Parts 100 to 149, Federal Register, revised July 1, 1986, p. 524-528.

_____1990, National primary and secondary drinking water regulations; synthetic organic chemicals and inorganic chemicals: 40 CFR Parts 141, 142, and 143, Federal Register, v. 55, no. 143, July 25, 1990, p. 30370-30448.

_____1992, National primary and secondary drinking water regulations (Subpart B of Part 141 Maximum contaminatn levels for inorganic chemicals): 40 CFR Part 141, Chapter 1 (7-1-92 edition), Section 141.11, p. 596-597.

APPENDIX 1

Field Work and Procedures

APPENDIX 1: FIELD WORK AND PROCEDURES

Field work preformed for the offsite ground-water investigation at the American Creosote Works (ACW) abandoned plant site included: (1) inventorying water-supply wells within a 2-mile radius of the site, (2) drilling and geophysical logging 9 stratigraphic test holes at 6 offsite stations (OSGW1 through OSGW6) and 3 onsite stations (4, 6 and 7), (3) collecting ground-water samples using Direct Push Technology (DPT) methods at the 6 offsite stations and analyzing these samples using gas chromatography with photo-ionization detection (GC/PID) and high-performance liquid chromatography (HPLC) methods, (4) measuring water levels in 33 onsite monitoring wells and 36 offsite wells and maintaining continuous water-level recorders on 2 onsite wells, (5) installing and developing 36 wells at the 6 offsite stations, (6) sampling the 36 offsite wells and 7 water-supply wells within a 2-mile radius of the ACW site. A description of these tasks and the general procedures followed are summarized below.

Water-Well Inventory

An inventory of domestic, commercial, industrial, agricultural, municipal, and unused water-supply wells within a 2-mile radius of the ACW site was conducted by the U.S. Geological Survey (USGS) from June through August 1990. This was a follow-up of an inventory of water wells located in this area for the RI/FS (S&ME, Inc., 1988). The USGS inventory was limited to wells for which driller's records were available in the files of the U.S. Geological Survey (USGS), Tennessee Department of Environment and Conservation (TDEC) (Division of Ground Water Protection), and the Jackson Utility Division (JUD). Records of a few wells with potential for water-quality sampling also were obtained from water-well contractors.

Fifty wells with records were located in the field on USGS 7 1/2-minute topographic quadrangles. During the inventory, many other wells were located for which records were not available from government sources.

Stratigraphic Test Holes

An onsite stratigraphic test hole (Md:G-326) was drilled in May 1990 using the hydraulic-rotary method by Wilson Well Company, Inc., Whiteville, Tennessee. Samples of the cuttings from the test hole were collected every 10 feet, to a total depth of 245 feet. Electric and natural-gamma ray geophysical logs were made in the uncased test hole by USGS. The test hole then was completed as a water-level observation well, using 4-inch polyvinyl chloride (PVC) casing and screen. The screen was set from 134 to 154 feet below land surface.

Eight stratigraphic test holes were drilled by the USGS during October through November 1991. A test hole was drilled at each of the six offsite stations (OSGW1 through OSGW6) and onsite stations 4 and 6. Four-inch-diameter test holes were drilled by the hydraulic-rotary method using a trailer-mounted Central Mine Equipment (CME) Model 55 drilling rig. A Gel-X bentonite mixed with JUD city water was used as the drilling fluid. During the drilling, samples of cuttings from the test holes were collected at 10-foot intervals.

When total depth was reached, the drill stem was removed from the bore hole, and electric and natural-gamma ray geophysical logs were made in each test hole. The test holes were then abandoned, and the bore holes backfilled to land surface with a cement/bentonite-grout mixture.

DPT Methods of Exploration and Sampling

Direct Push Technology (DPT) subsurface exploration and sampling methods were conducted at offsite stations OSGW1 through OSGW6 during July through August 1992. A previous evaluation of these methods at onsite stations 2 and 5 (Parks and others, 1993) resulted in a decision to use these methods at the six offsite stations to the depth of refusal of the DPT equipment. The DPT work at the six offsite stations consisted of four components: (1) collection of lithologic data with the piezocone tool, (2) collection of ground-water samples using the Hydrocone tool, (3) field analysis of ground-water samples collected with the Hydrocone tool by the GC/PID method, and (4) laboratory analysis of splits of these samples by the HPLC method.

Lithologic data was collected at each of the six offsite stations by pushing the Piezocone tool to the depth of refusal of the DPT equipment. Point-stress, sleeve-friction, and pore-pressure data recorded as the tool was pushed through the sediments were used to identify lithologies and determine water levels. Five to seven 1-foot sampling intervals at each station were selected from this data for collection of ground-water samples with the Hydrocone tool. Hydraulic conductivity of the sampling intervals was estimated from filling rates of the Hydrocone tool as the samples were collected.

Headspace analyses of ground-water samples collected from each sampling interval were made in the field for a reduced list of VOC's from modified USEPA Methods 601 and 602 using the contractor's GC/PID. In addition, splits of the ground-water samples were collected with the Hydrocone tool for analysis of selected creosote and PCP related organic compounds using HPLC methods. The results of the GC/PID and HPLC analyses were used to refine previously selected screen depths for wells installed at the six offsite stations at depths shallower than about 40 feet.

Well Installation and Development

Thirty-six monitoring wells were installed at the six offsite stations by the USGS during June through August 1992 using a trailer-mounted CME Model 55 drilling rig. These wells were installed in clusters of six wells at each of the six offsite stations where the stratigraphic test holes were drilled and the DPT work was conducted.

Shallow wells (13 to 42 feet deep) at each station were installed by augering methods. Clean, 3 1/4- or 6 1/4-inch inside diameter, hollow-stem augers with a removable plug in the bit were used to drill these wells. Augers of this size allowed for an appropriate length of nominal 2-inch inside diameter Schedule 40 threaded and flush-jointed PVC casing and screen to be installed inside the augers to the completion depth of each well. Five-foot long, 0.010-inch slot screens were used for the shallow wells. Clean, 2-inch-diameter casing and screen with a drive point were lowered to the bottom of the augers. The plug in the bit was pushed out using the drive point attached to the bottom of the screen. The augers were pulled back about 7 feet to a point where the bit was about 2 feet above the top of the screen.

It was planned to pour a clean, well-graded sand through the augers to pack the annular space from the bottom of the hole to a point 2 feet above the top of the screen (bottom of the augers). In most cases, collapse of the bore hole around the screen and casing occurred too rapidly to pour a sand pack around the screen. However, a weighted tape was used to measure the depth to the top of the collapse to insure that it was at least 2 feet above the top of the screen. Bentonite pellets (1/2-inch diameter) then were emplaced above the sand pack through the augers to form at least a 2-foot thick seal above the sand pack and around the casing. A neat-cement grout consisting of a mixture of about 6 gallons of potable water per 94-pound bag (1 cubic foot) of Portland Type I cement (creating a grout weight of about 15.5 pounds per gallon) was prepared. This grout was pumped with a pressure-grouting machine through a hose lowered to the base of the augers, and grouting was conducted as each 5-foot auger flight was extracted from the auger hole. By this method, the auger hole was backfilled with cement grout from the top of the bentonite seal to land surface.

Deep wells (46 to 148 feet deep) at each station were installed by the hydraulic-rotary method. Gel-X bentonite mixed with JUD city water was used as the drilling fluid. Clean drilling tools were used to drill a nominal 8-inch-diameter hole to the desired completion depth of each well. Once completed, the appropriate length of clean, nominal 4-inch inside diameter Schedule 40 threaded and flush-jointed PVC casing and screen was connected together and lowered to the bottom of the hole. Ten-foot long, 0.010-inch slot screens for the deep wells. JUD city water was pumped down the casing and out through the screen to flush the drilling mud from the casing and thin the mud in the annular space. A clean, 1-inch-diameter PVC tremie pipe then was placed in the annular space and a sand pack, bentonite-slurry seal, and neat-cement grout were installed around the casing and screen in each deep well, similar to that installed in the shallow wells.

The wells then were capped and 7-foot-long, 4-inch-diameter, lockable, steel well protectors were installed over the wells. The well protectors were anchored about 2 feet below land surface and extended about 5 feet above land surface to accommodate seasonal high water in the offsite areas. Finally, a cement apron 4-feet square and 4-inches thick was poured around the well protectors to seal the well from contamination from surface sources.

Development of the wells consisted of alternating pumping and recovery of the wells to remove materials smaller than the screen slot-opening width from the adjacent sand packs and formations. Development of the shallow wells was conducted using a 2-inch centrifugal pump. Water-level drawdowns in the deep wells exceeded the depth at which the centrifugal pump could be used. Therefore, these wells were developed with a 4-inch submersible pump. All wells were pumped until they produced clear, sediment-free water.

Water-Level Measurements

Water-level measurements were made with an electric tape. After each measurement, the tape was decontaminated before measuring the next well. The probe was washed with a Liquinox and de-ionized water solution, followed by a de-ionized water rinse, a pesticide-grade methanol rinse, and a high purity organic-free water rinse. Water-level measurements were made in the 36 offsite wells prior to sampling for water quality to provide data from which the volumes of water to be evacuated from the wells could be calculated and the pump-setting depths could be determined. Water-level measurements in the 33 onsite wells were made after the 36 offsite wells to lessen the chances of cross-contamination.

Well Sampling for Water Quality

Prior to sampling the 36 offsite wells, all equipment was decontaminated. A submersible pump used to evacuate some of the wells was decontaminated by pumping copious amounts of a Liquinox soap and JUD city water solution followed by JUD city water and finally de-ionized water. Other sampling equipment (centrifugal pump intake and bailer wire) that contacted the water samples was decontaminated with a Liquinox soap and JUD city water solution, followed by rinsing with de-ionized water, pesticide-grade methanol, and high purity organic-free water. Equipment that contacted water for inorganic analysis only was decontaminated with a Liquinox soap and de-ionized water solution followed by a rinse with de-ionized water. The sample-split churn also was rinsed with water from the next well sampled.

Wells were purged of a minimum of three casing volumes of water before sampling and until measurements of pH, specific conductance, and temperature had stabilized. A centrifugal pump fitted with a 6-foot long, stainless steel-tube intake (for easy decontamination) was used to purge wells. When water-level drawdowns were greater than the suction lift of this pump, a 2-inch stainless-steel submersible pump was used to evacuate the wells. During purging, pumping rates were generally about 1 gallon per minute.

Ground-water samples were collected with disposable Teflon bailers. The bailer wire was stainless-steel with a Teflon sheath that was decontaminated before use at the next well, following the procedure described above. Samples for dissolved inorganic analyses were filtered through a 0.45-micron filter and preserved with nitric acid to lower the pH to less than 2. Ground-water samples for VOC and SVC analysis were chilled immediately after collection and sent by overnight mail to the USGS laboratory.

Ten quality control/quality assurance samples were collected during the sampling. Three of these samples were duplicate ground-water samples, three were trip blanks, and four were field-equipment blanks. The field-equipment blanks consisted of high-purity organic-free water that had been rinsed over the equipment used to collect the samples.

VOC analyses for water samples from 24 wells sampled at stations OSGW1, OSGW2, OSGW3, and OSGW6 showed concentrations of 1 to 3 μg/L of toluene in all of the samples, including a field-equipment blank. Once this problem was identified, sampling was stopped and efforts were made to determine the cause of the toluene QA/QC problem. The source was not determined, and after a 2-week hiatus, sampling resumed with minor changes: (1) a different source of high purity organic-free rinse water was used and (2) the disposable bailers were rinsed with high purity organic-free water before use. Analyses of successive samples collected at stations OSGW4 and OSGW5 did not detect toluene at concentrations above the detection limit (0.2 μg/L), indicating that the QA/QC problem had been resolved.

To confirm that detection of toluene was a QA/QC problem during the earlier sampling, wells OSGW1-2, OSGW1-6, OSGW2-3, OSGW2-6, OSGW3-2, OSGW3-6, OSGW6-2, and OSGW6-6 were resampled January 6 and 7, 1993, and re-analyzed for VOC's. Wells OSGW1-2, OSGW2-3, OSGW3-2, and OSGW6-2 were selected for resampling because these wells had the highest concentrations of toluene measured in samples from the alluvial aquifer. Wells OSGW1-6, OSGW2-6, OSGW3-6, and OSGW6-6 were selected because these were the deepest wells screened in the Fort Pillow aquifer in which toluene had been measured. Concentrations of toluene in the second set of water samples from these wells were below the detection limits, except for a concentration of 0.3 μg/L in well OSGW6-2.

General procedures followed during the sampling of the 7 offsite water-supply wells within a 2-mile radius of the American Creosote Works abandoned plant site were similar to the procedures for the 36 offsite wells, except the water-supply wells were pumped for at least 1 hour before sampling. Equipment that contacted water samples collected for inorganic analysis was decontaminated with a Liquinox soap and de-ionized water solution followed by a rinse with de-ionized water. The sample-split churn also was rinsed with water pumped from the next well to be sampled. Prior to sampling, the wells were purged using a minimum of three casing volumes and until measurements of pH, specific conductance, and temperature stabilized. Water samples were collected from discharge points as close to the well as possible.

The existing pump in well W14 did not work and prevented the use of the submersible or centrifugal pump. Therefore, the well was purged and sampled with a peristaltic pump, which could have caused a decrease in the VOC concentrations as a result of the vaccum created when the pump is used. The slow pumping rate precluded pumping three casing volumes of water prior to sampling, but measurements of pH, temperature, and specific conductance had stabilized.

APPENDIX 2

Lithologic and geophysical logs for stratigraphic test holes drilled at 3 onsite and 6 offsite stations and well construction diagrams for 36 wells installed at the 6 offsite stations, American Creosote Works abandoned plant site at Jackson, Tennessee

APPENDIX 2:

Lithologic and geophysical logs for stratigraphic test holes drilled at 3 onsite and 6 offsite stations and well construction diagrams for 36 wells installed at the 6 offsite stations

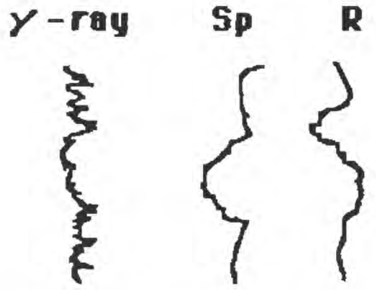
EXPLANATION

GEOPHYSICAL LOGS

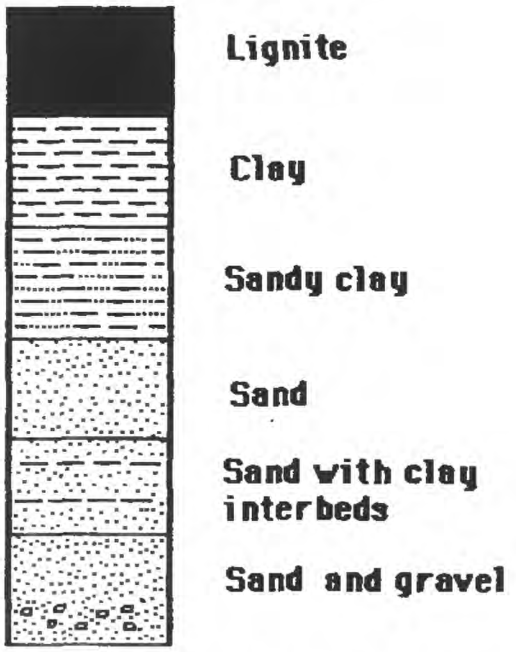
γ-ray NATURAL GAMMA-RAY LOG. RADIOACTIVITY INCREASES ⟶

Sp SPONTANEOUS POTENTIAL OF ELECTRIC LOG

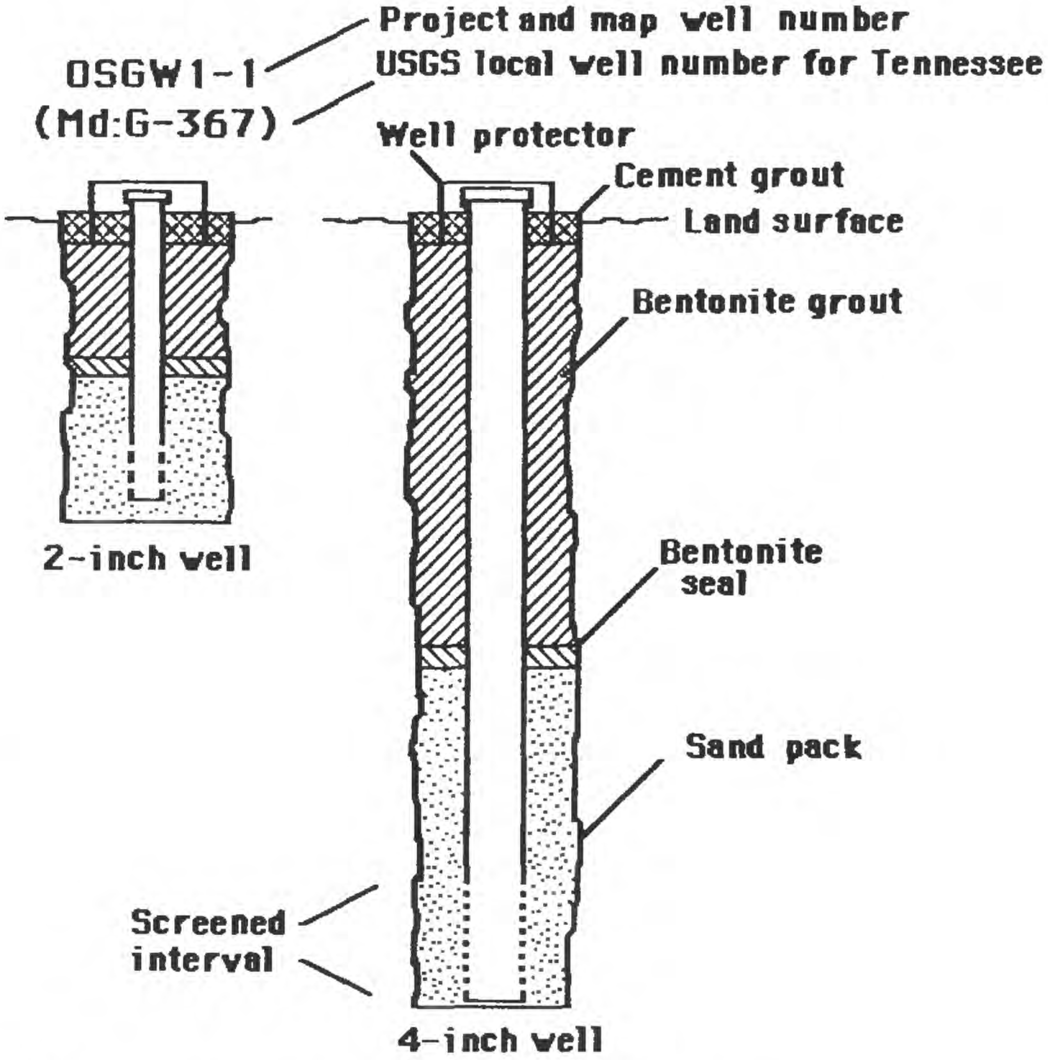
R RESISTANCE OF ELECTRIC LOG



LITHOLOGIC SYMBOLS



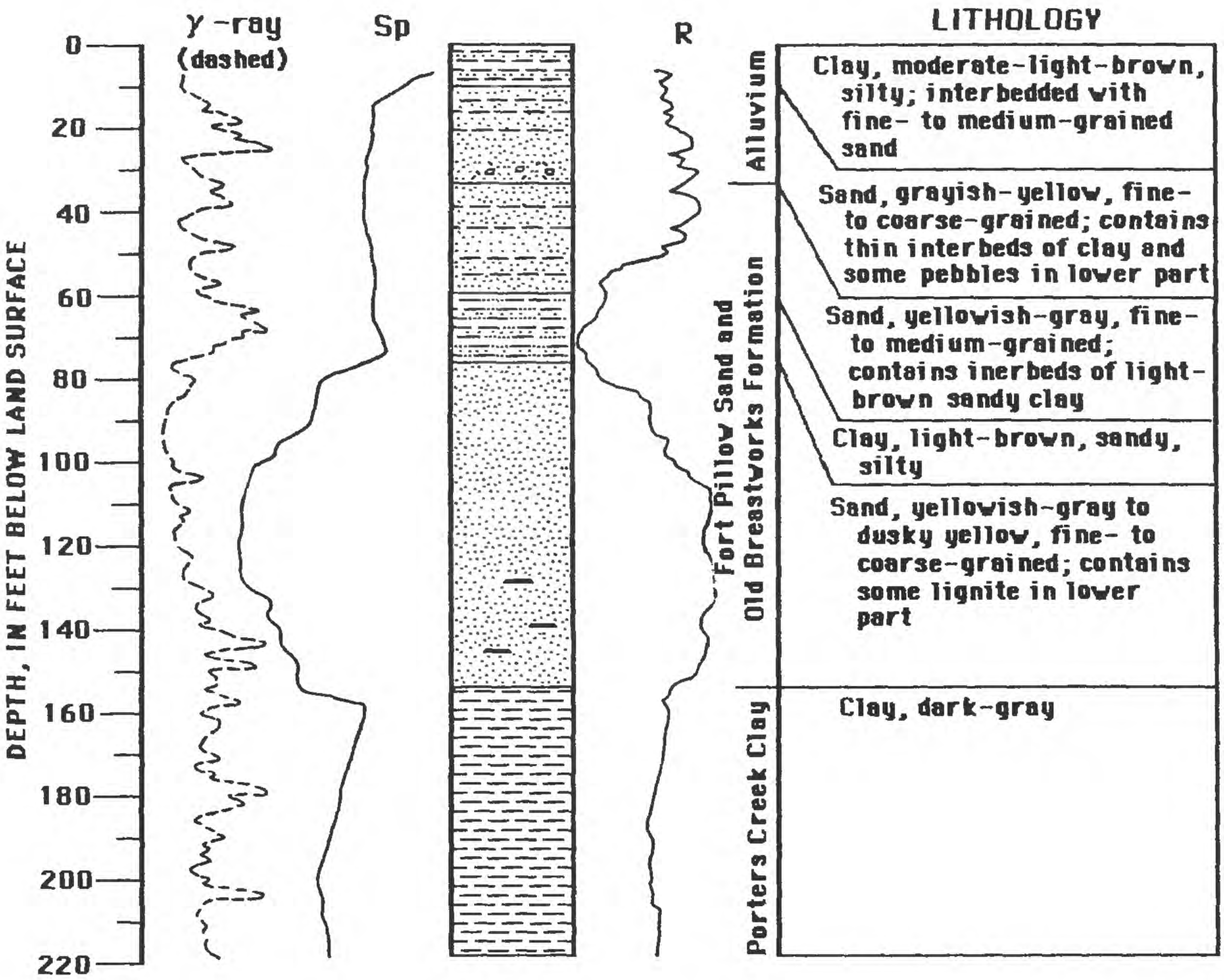
Lithology is from driller's logs, geophysical logs, and 10-foot-interval samples. Descriptions of colors are from the "Rock Color Chart" of the Geological Society of America. Sand sizes are from a visual comparison card based on the Wentworth grade scale of particle size.



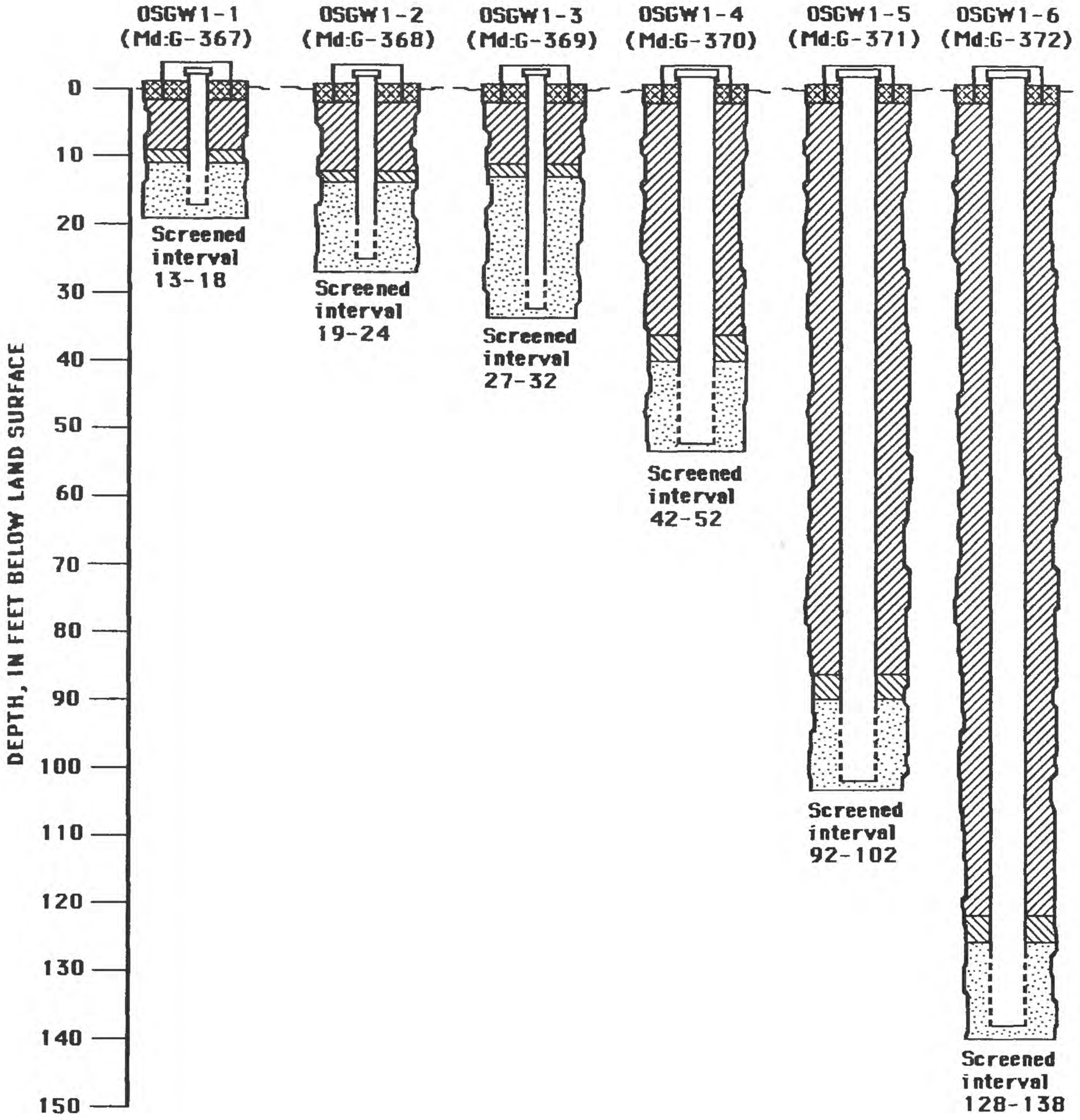
Observation wells at the six offsite stations near the American Creosote Works abandoned plant site are constructed with 2- and 4-inch polyvinyl chloride (PVC) casing and screens. The wells were developed with a submersible and centrifugal pump until the wells produced clear, sediment-free water.

OFFSITE STRATIGRAPHIC TEST HOLE 1 (Md: G-359) AT STATION OSGW1

Location: About 1,200 feet east of the South Fork Forked Deer River
and 200 feet south of the Seaboard Railroad
Latitude: 35 36'28" Longitude: 88 50'05"
Altitude of land surface: 343 feet above sea level
Date completed: October 8,1991
Total depth reached: 218 feet below land surface

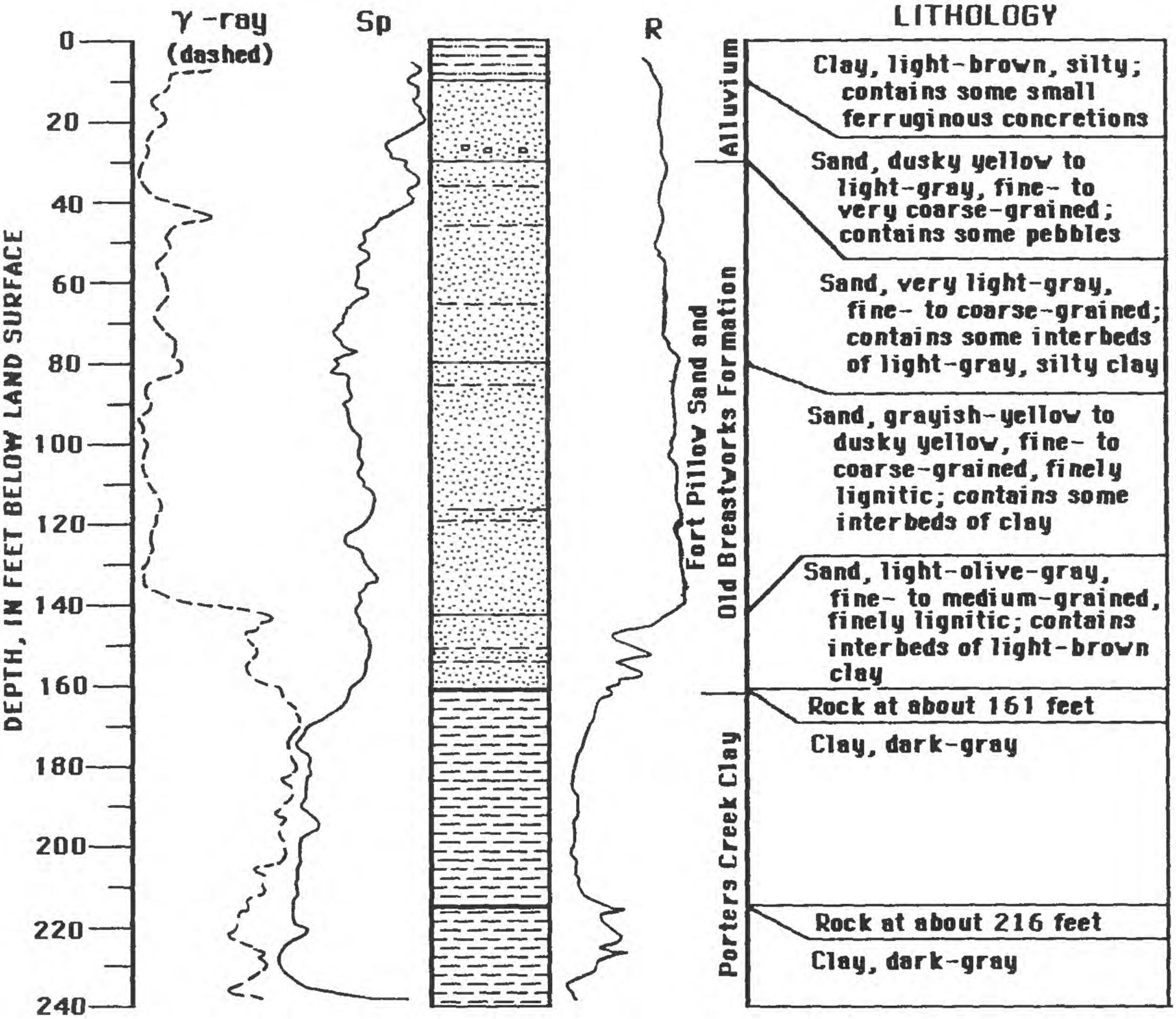


STATION OSGW1



OFFSITE STRATIGRAPHIC TEST HOLE 2 (Md: G-360) AT STATION OSGW2

Location: About 700 feet east of the South Fork Forked Deer River
and 200 feet south of the Seaboard Railroad
Latitude: 35 36'27" Longitude: 88 50'11"
Altitude of land surface: 342 feet above sea level
Date completed: October 10,1991
Total depth reached: 240 feet below land surface



Clay, light-brown, silty; contains some small ferruginous concretions

Sand, dusky yellow to light-gray, fine- to very coarse-grained; contains some pebbles

Sand, very light-gray, fine- to coarse-grained; contains some interbeds of light-gray, silty clay

Sand, grayish-yellow to dusky yellow, fine- to coarse-grained, finely lignitic; contains some interbeds of clay

Sand, light-olive-gray, fine- to medium-grained, finely lignitic; contains interbeds of light-brown clay

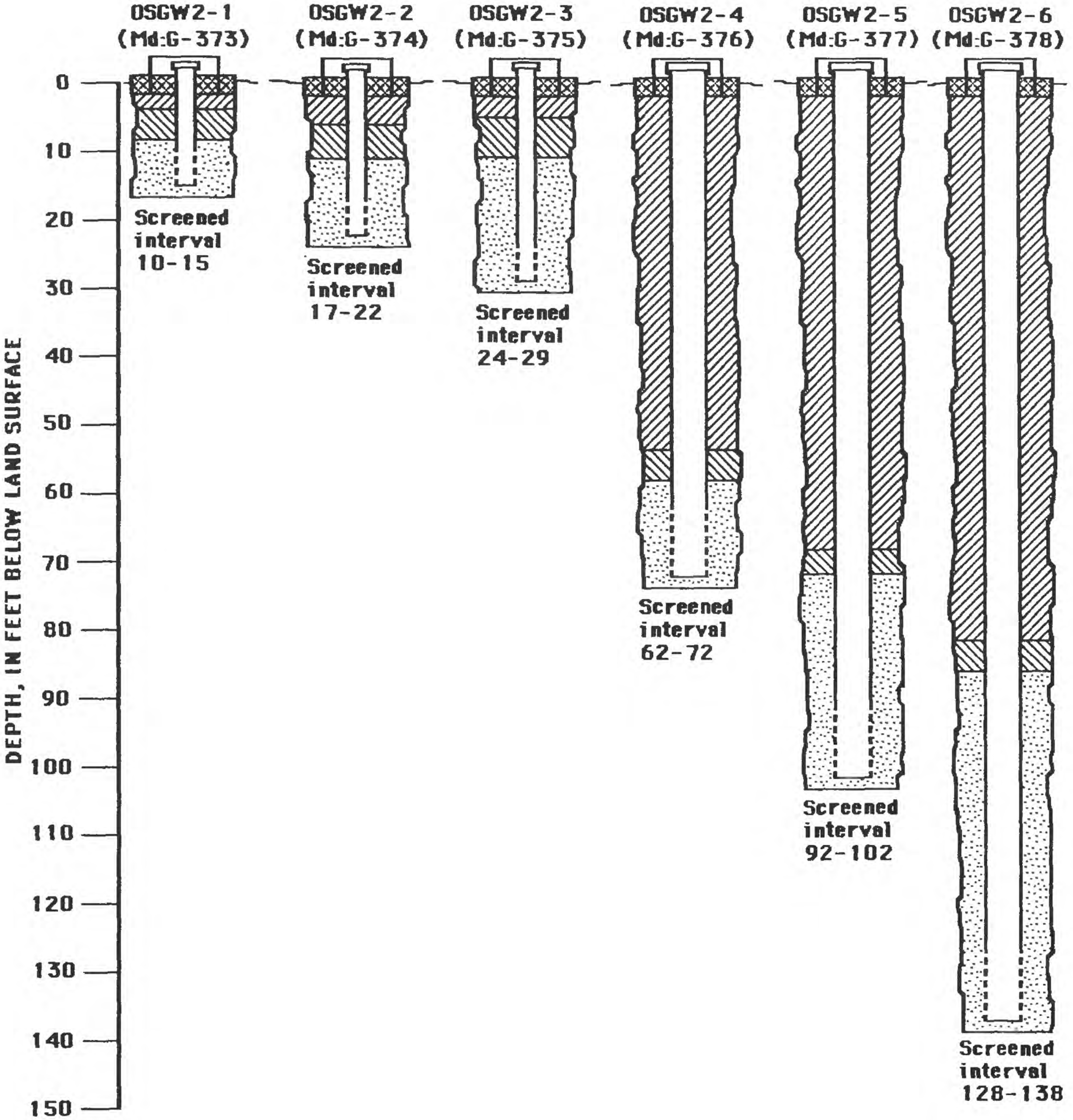
Rock at about 161 feet

Clay, dark-gray

Rock at about 216 feet

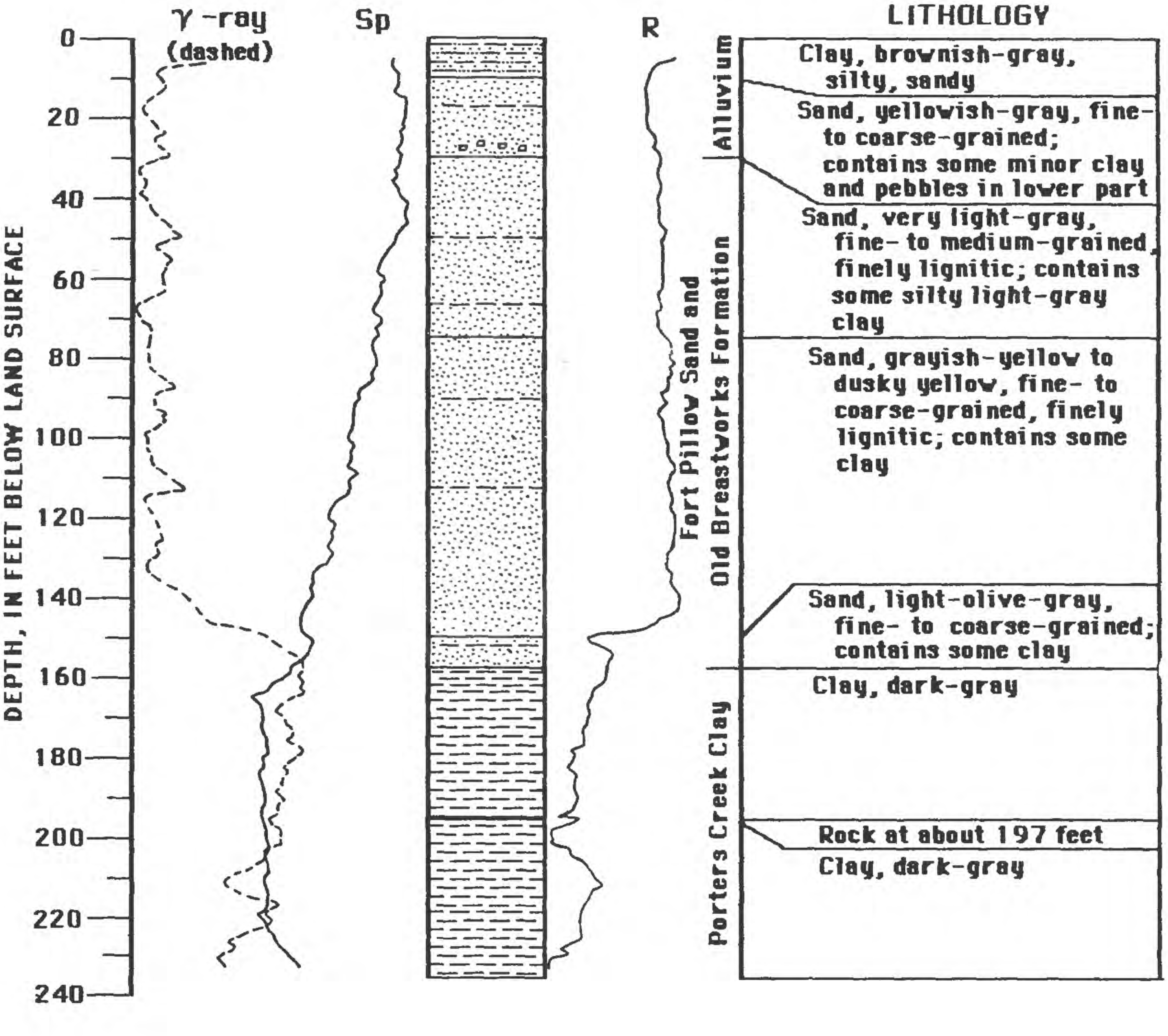
Clay, dark-gray

STATION OSGW2

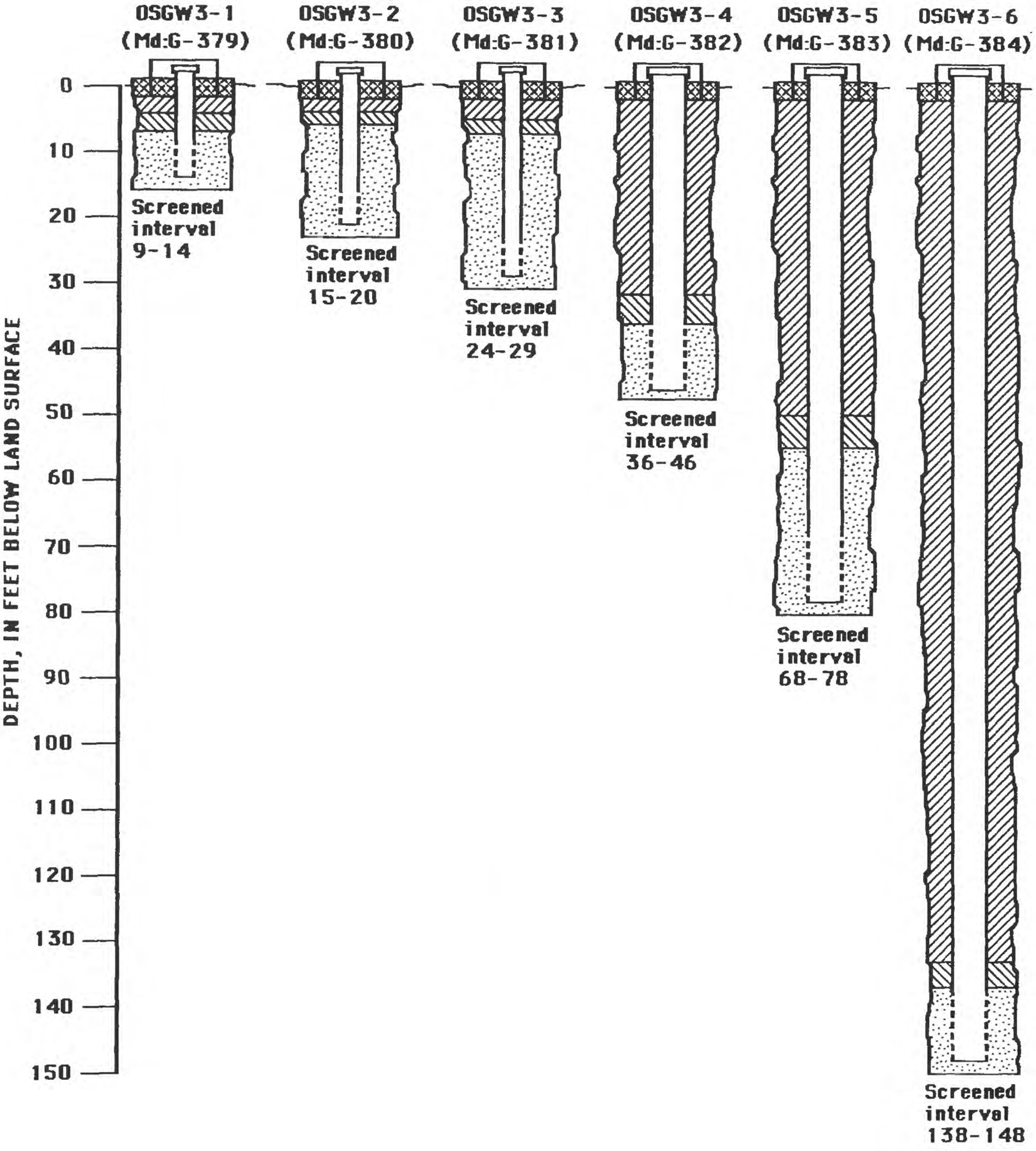


OFFSITE STRATIGRAPHIC TEST HOLE 3 (Md: G-361) AT STATION OSGW3

Location: about 300 feet east of the South Fork Forked Deer River
and 200 feet south of the Seaboard Railroad
Latitude: 35 36'27" Longitude: 88 50'16"
Altitude of land surface: 341 feet above sea level
Date completed: October 22, 1991
Total depth reached: 236 feet below land surface

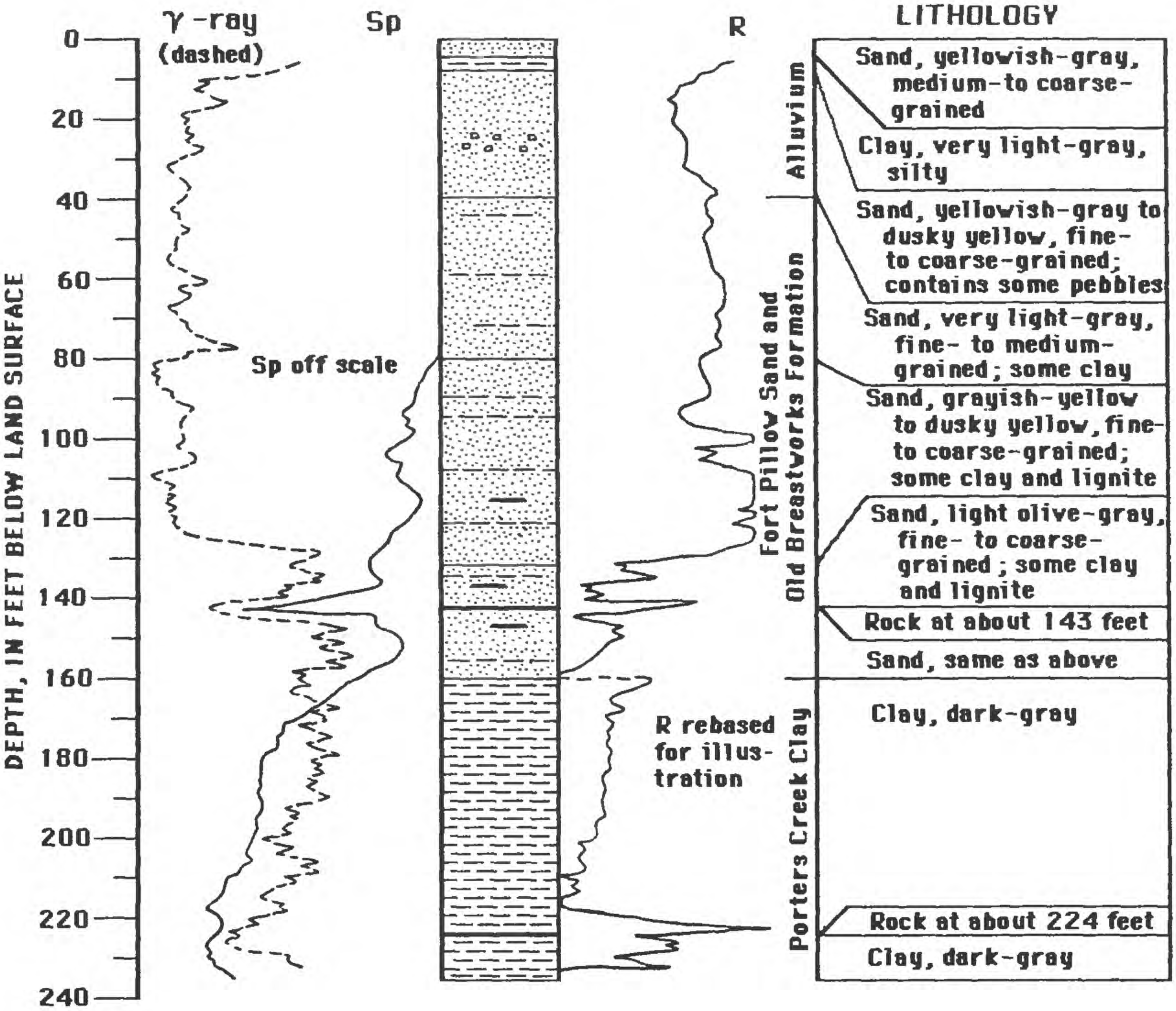


STATION OSGW3

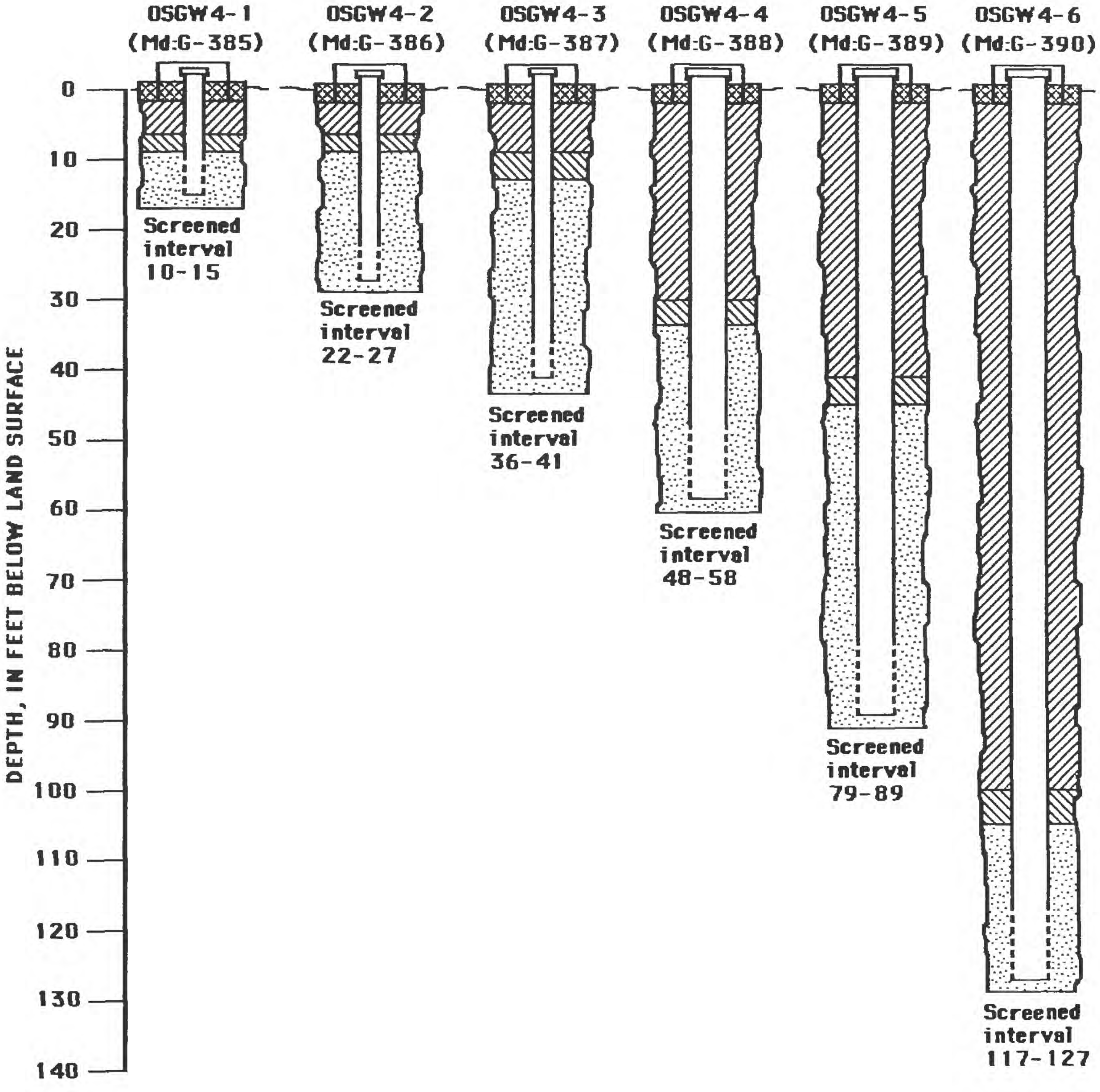


OFFSITE STRATIGRAPHIC TEST HOLE 4 (Md: G-362) AT STATION OSGW4

Location: About 300 feet west of Central Creek and
300 feet north of the Seaboard Railroad
Latitude: 35 36'32" Longitude: 88 50'21"
Altitude of land surface: 343 feet above sea level
Date completed: October 24, 1991
Total depth reached: 236 feet below land surface

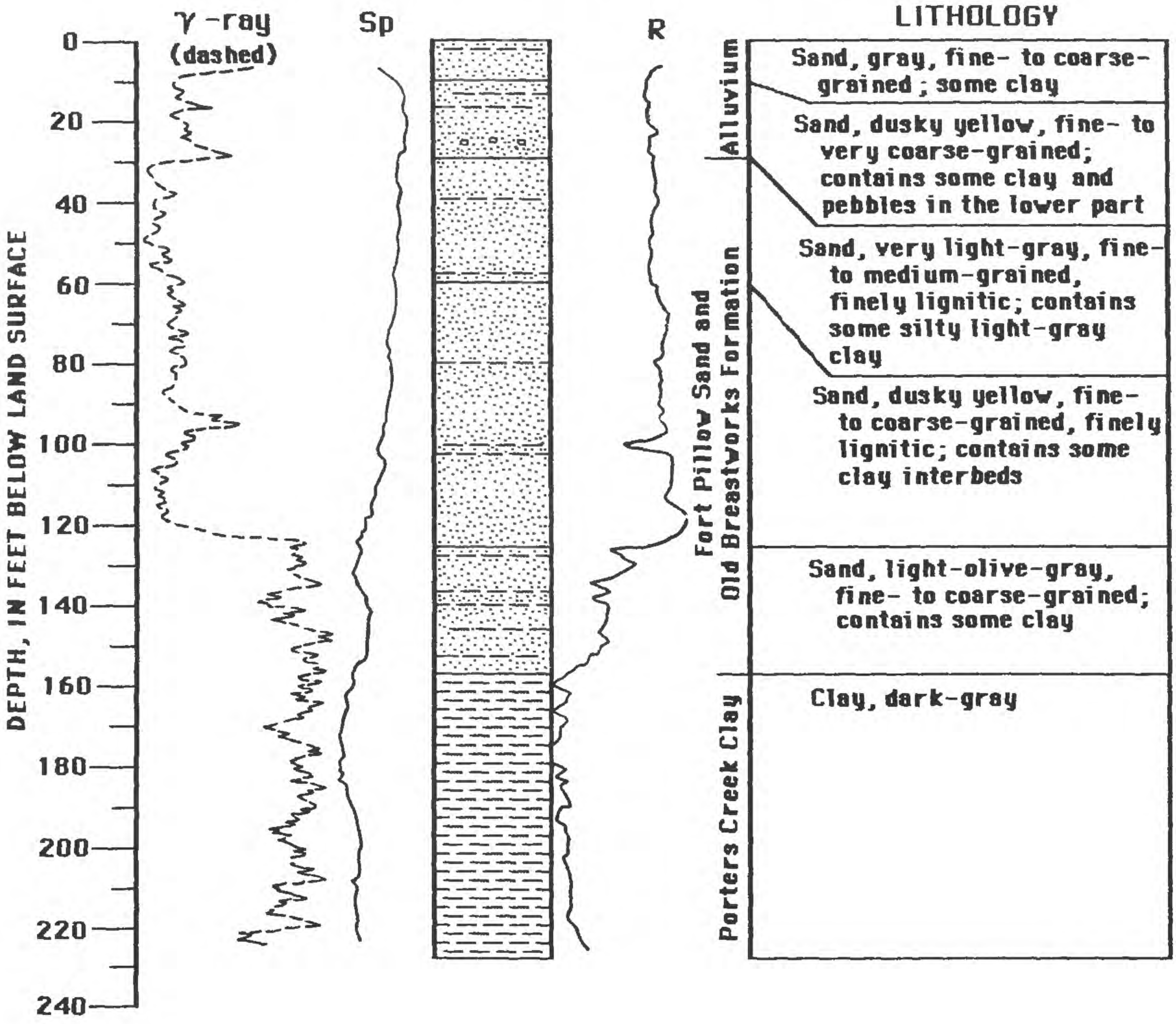


STATION OSGW4

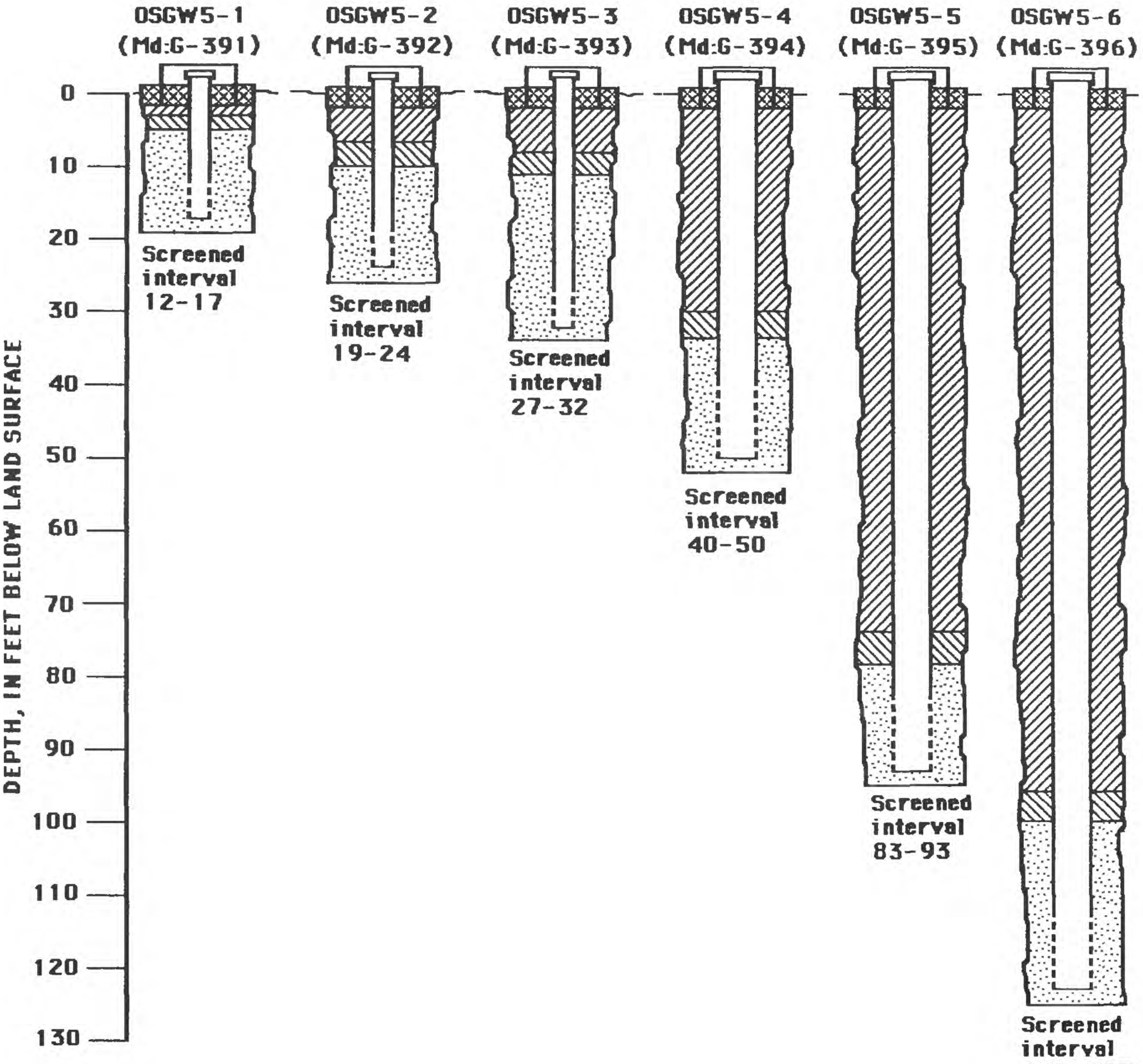


OFFSITE STRATIGRAPHIC TEST HOLE 5 (Md: G-363) AT STATION OSGW5

Location: About 100 feet west of Central Creek and
700 feet north of the Seaboard Railroad
Latitude: 35 36'37" Longitude: 88 50'21"
Altitude of land surface: 342 feet above sea level
Date completed: October 27, 1991
Total depth reached: 228 feet below land surface

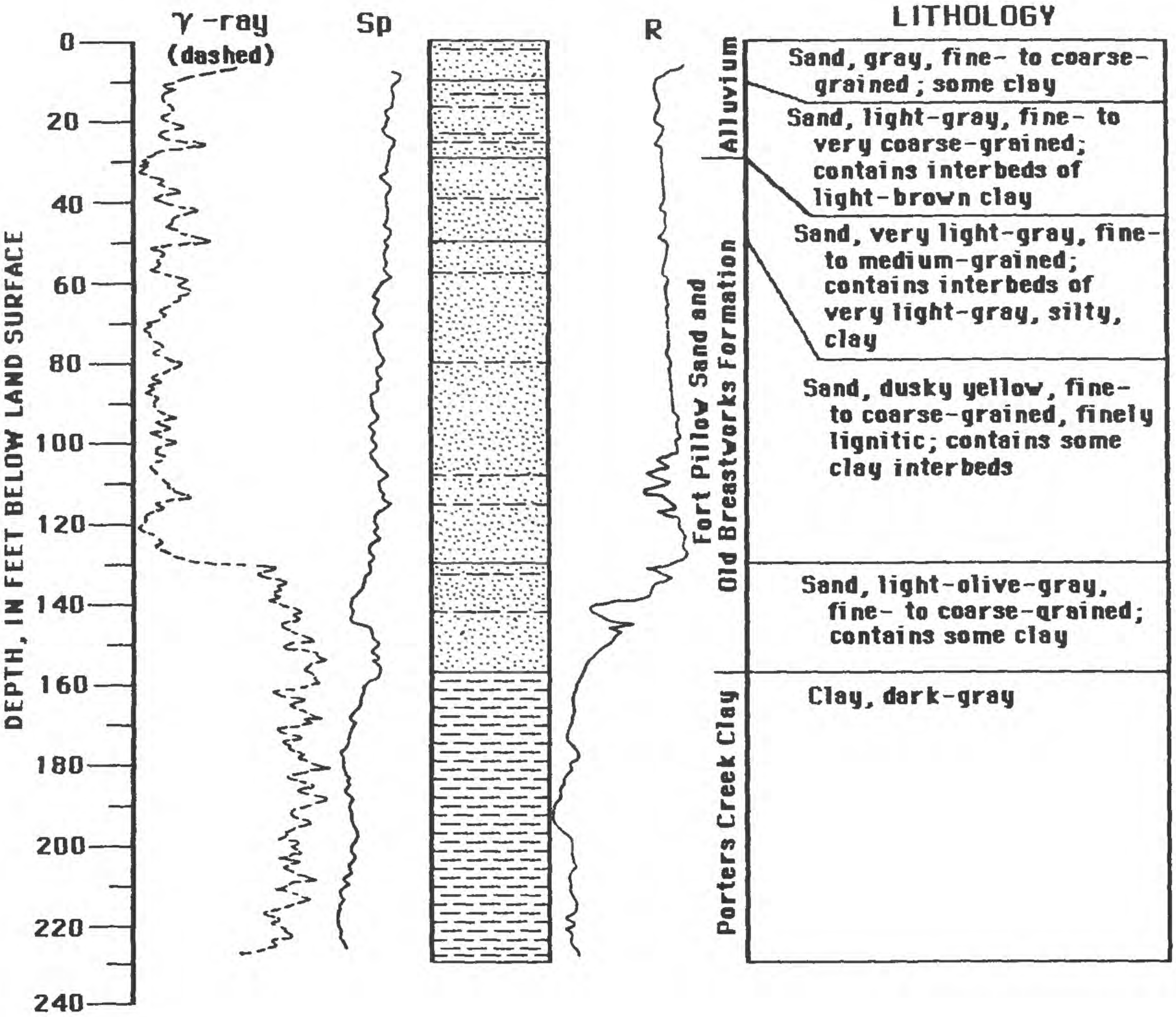


STATION OSGW5

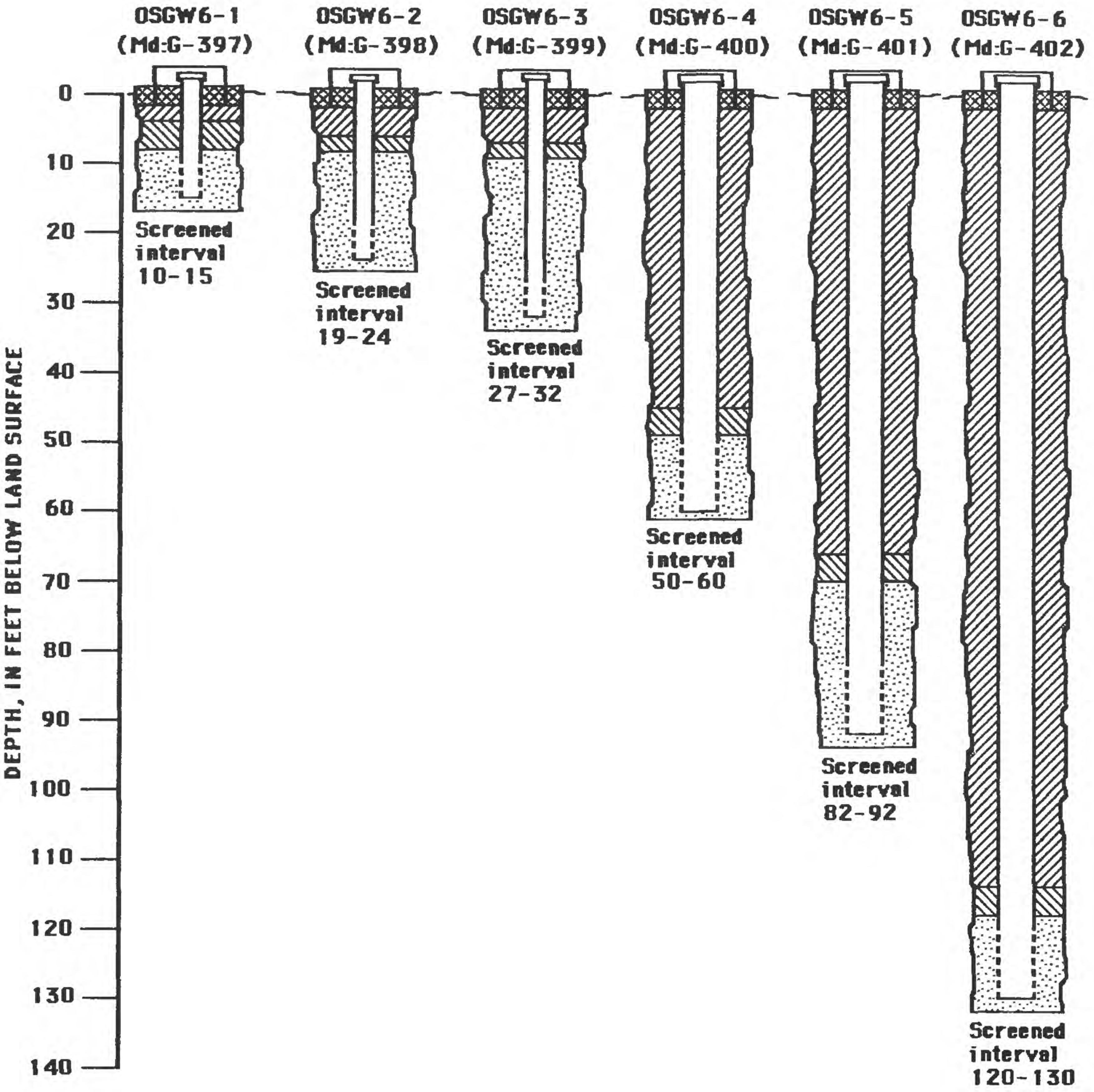


OFFSITE STRATIGRAPHIC TEST HOLE 6(Md: G-364) AT STATION OSGW6

Location: About 200 feet west of Central Creek and
1,000 feet north of the Seaboard Railroad
Latitude: 35 36'39" Longitude: 88 50'23"
Altitude of land surface: 342 feet above sea level
Date completed: October 25,1991
Total depth reached: 229 feet below land surface

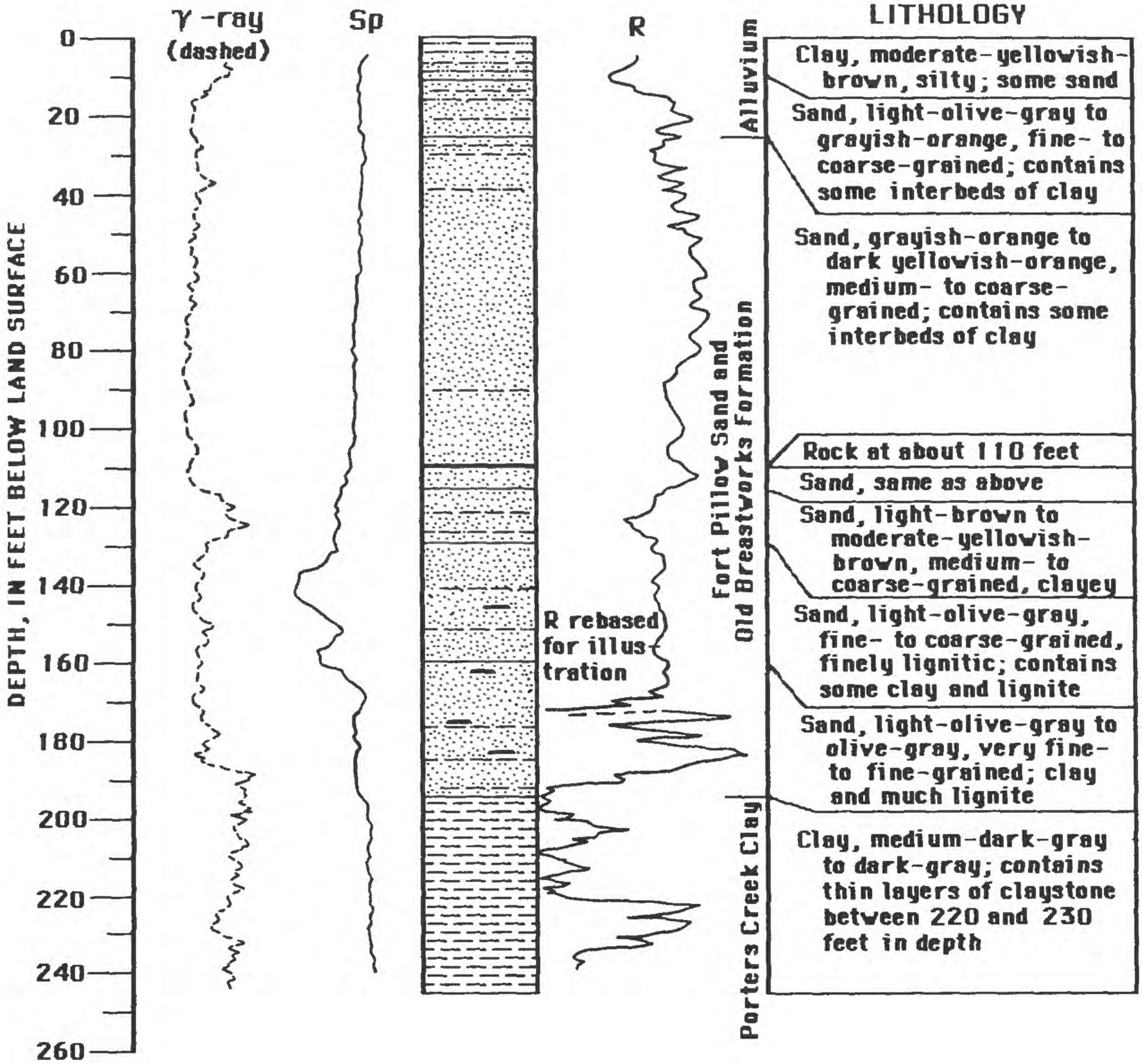


STATION OSGW6



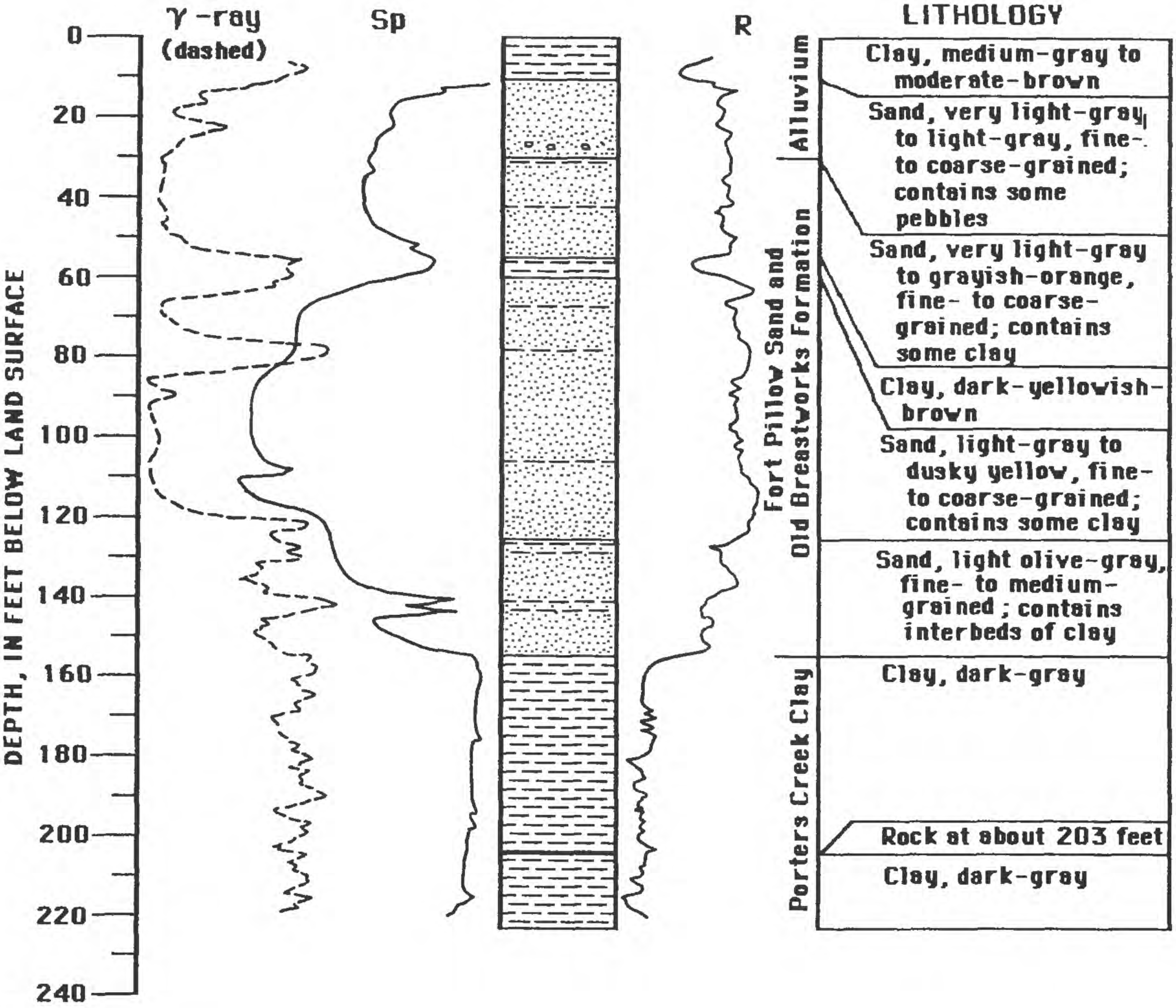
ONSITE STRATIGRAPHIC TEST HOLE 1 (Md: G-326) AT STATION 7

Location: In the northeast part of the American Creosote Works
site near monitoring wells 7 and AMW-1
Latitude: 35 36'38" Longitude: 88 49'55
Altitude of land surface: 348 feet above sea level
Date completed: May 15, 1990
Total depth reached: 245 feet below land surface



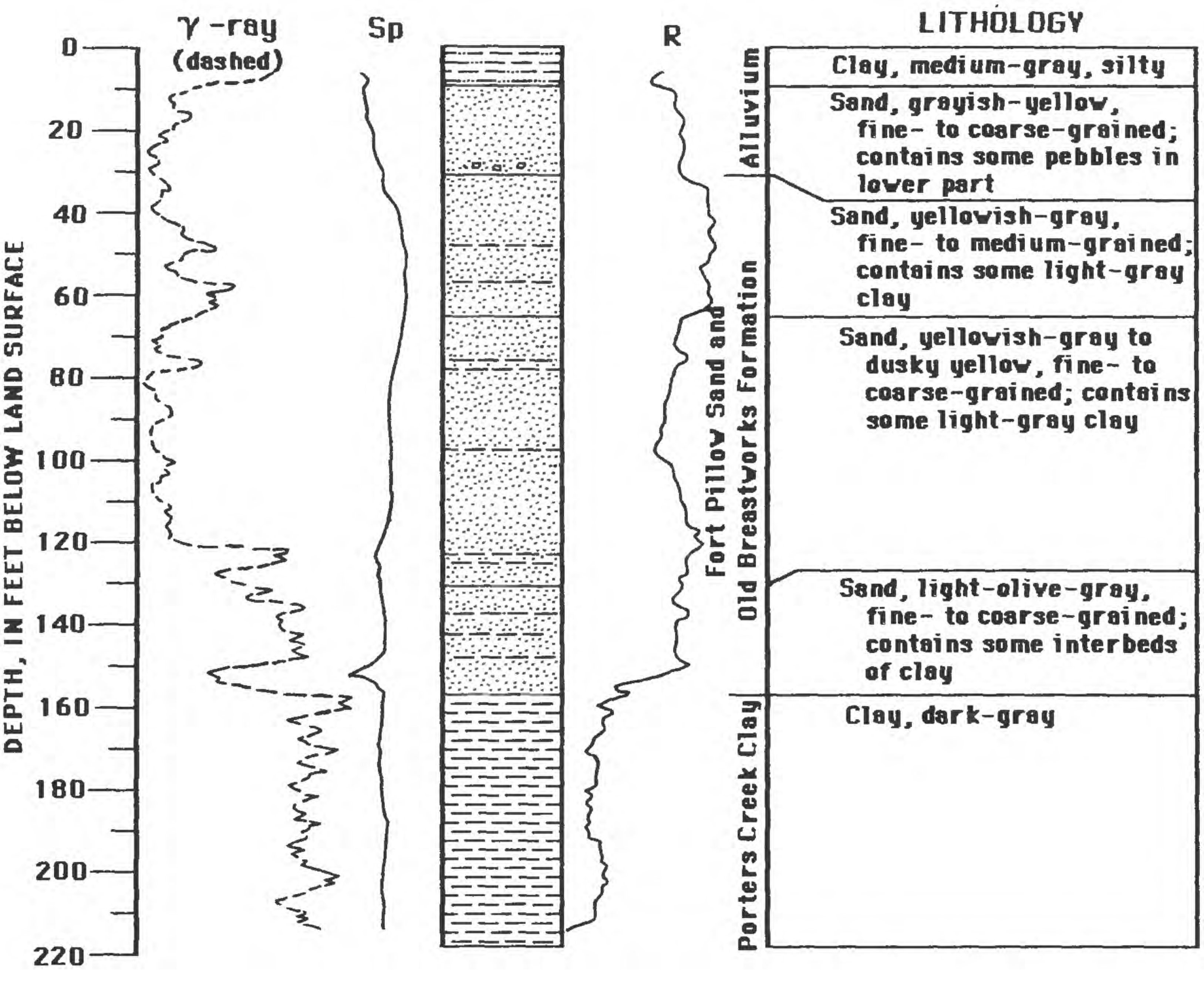
ONSITE STRATIGRAPHIC TEST HOLE 2 (Md: G-365) AT STATION 4

Location: In the northern part of the American Creosote Works site
about 50 feet south of monitoring wells 4S, 4M, and 4D
Latitude: 35 36'42" Longitude: 88 50'08"
Altitude of land surface: 344 feet above sea level
Date completed: November 19, 1991
Total depth reached: 223 feet below land surface



ONSITE STRATIGRAPHIC TEST HOLE 3 (Md: G-366) AT STATION 6

Location: In the southern part of the American Creosote Works site
about 100 feet north of the Seaboard Railroad
Latitude: 35 36'31" Longitude: 88 50'03"
Altitude of land surface: 346 feet above sea level
Date completed: November 20, 1991
Total depth reached: 218 feet below land surface



Clay, medium-gray, silty

Sand, grayish-yellow, fine- to coarse-grained; contains some pebbles in lower part

Sand, yellowish-gray, fine- to medium-grained; contains some light-gray clay

Sand, yellowish-gray to dusky yellow, fine- to coarse-grained; contains some light-gray clay

Sand, light-olive-gray, fine- to coarse-grained; contains some interbeds of clay

Clay, dark-gray

*USGPO: 1993-550-223/80021