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Assessing Environmental Risk of the Retired Filter Bed Area, Battelle West Jefferson

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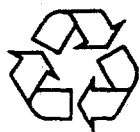
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ASSESSING ENVIRONMENTAL RISK OF THE RETIRED FILTER BED AREA, BATTELLE WEST JEFFERSON

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Abstract

Initial investigations conducted by the U.S. Department of Energy, Chicago Operations Office, and by Argonne National Laboratory used seismic refraction profiling, electrical resistivity depth sounding, conductivity profiling, magnetic gradiometry, and ground-penetrating radar to study environmental geophysics in the area of the Battelle West Jefferson site's radiologically contaminated retired filter beds. The investigators used a combination of nonintrusive technologies and innovative drilling techniques to assess environmental risk at the filter beds and to improve understanding of the geology of the Big Darby Creek floodplain. The geophysical investigation, which showed that the preferred groundwater pathway is associated with a laterally extensive deposit of silty sand to sand that is less than 12 ft deep in the floodplain area, also guided the location of cone penetrometer test sites and piezometer installation. Cone penetrometer testing was useful for comparing continuous logging data with surface geophysical data in establishing correlations among unconsolidated materials.

1 Introduction

An environmental geophysics study was conducted at the radiologically contaminated retired filter beds at the Battelle West Jefferson (BWJ) site (Figure 1), in order to define the hydrogeologic framework, characterize potential contaminant pathways, identify possible leakage points in buried pipelines and drainage tile, and install piezometers.

The BWJ site includes a Nuclear Sciences Area (known as the JN site) and the radiologically contaminated retired filter beds that are located on the floodplain of the Big Darby Creek, designated as a National Scenic River (Figure 2). Battelle conducted a number of characterization efforts in 1989 and 1990 at the West Jefferson Site that involved an intrusive sampling approach for radiological contaminants. Although extensive work was done in some areas, a historical data review jointly conducted by the U.S. Department of Energy, Chicago Office (DOE/CH), and by the Battelle Project Office (DOE-BPO) and Battelle Columbus Laboratory Decommissioning Project (BCLDP) personnel in 1995 indicated that a need existed for understanding the environmental risk at the retired filter beds. It was also recognized that more thorough characterization of potential contaminant pathways along buried pipelines in the vicinity of the retired filter beds and of the risk to Big Darby Creek was needed.

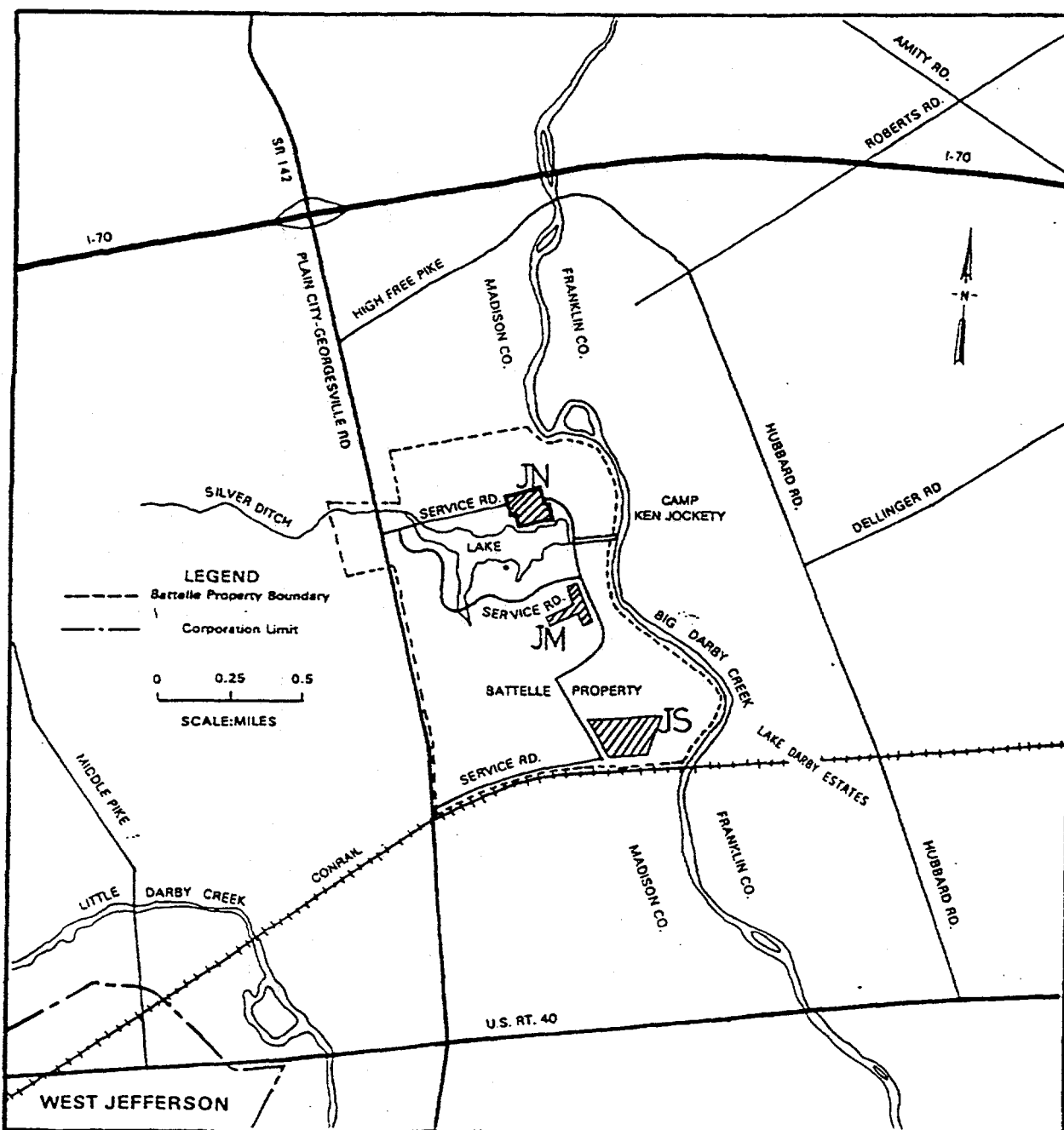


Figure 1. General Location Map of the Battelle West Jefferson Site

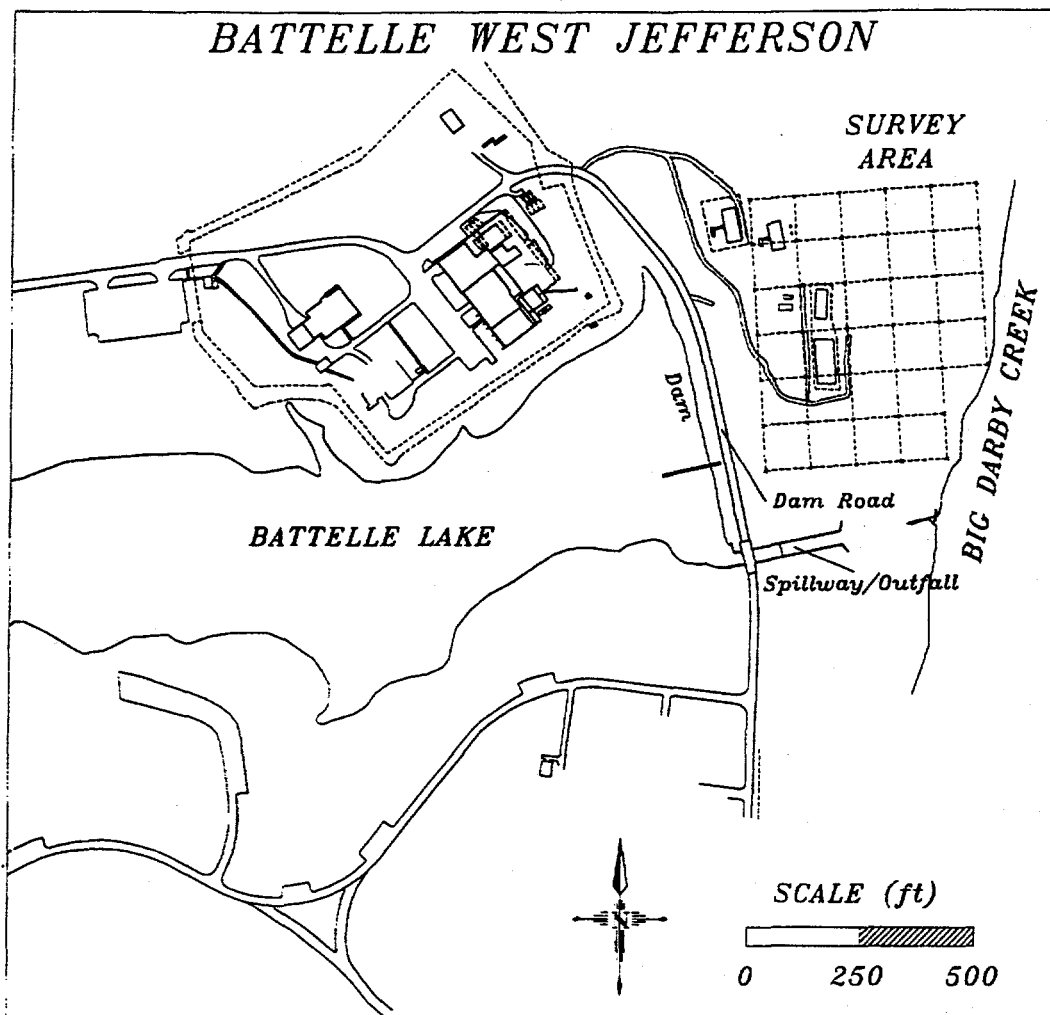


Figure 2. Detailed Site Map of the Battelle West Jefferson Site

In the summer of 1995, after consultation with the Geosciences Group in the Center for Environmental Restoration Systems (CERS), Argonne National Laboratory (ANL), and with DOE/CH staff, DOE-BPO and BCLDP determined that a combination of nonintrusive technologies and innovative drilling techniques was needed to assess the environmental risk associated with radiological contamination at the retired filter beds. ANL/CERS had responsibility for technical management and for contractual arrangements for the cone penetrometer and piezometer installations.

Initial geophysical investigations were conducted by ANL/CERS and DOE/CH during the week of August 18, 1995. Geophysical technologies used at the BWJ site included seismic refraction profiling, electrical resistivity depth sounding, conductivity profiling with the EM-34 and the EM-31, magnetic gradiometry, and ground-penetrating radar (GPR). The geophysical investigation was used to establish the geologic framework in the floodplain area and to guide the placement of cone penetrometer testing (CPT) sites and piezometer locations. Seventeen CPT sites were investigated, six piezometers were installed, and additional GPR transects were completed during the week of September 19, 1995. A supplemental geophysical investigation was also conducted in Area 1, but this was limited to conductivity mapping with the EM-31 and to ground-penetrating radar. The Area 1 work was done in January 1996.

1.1 Geology and Hydrogeology

1.1.1 General Overview

The BWJ site is located in the Till Plains area of the Central Lowland Physiographic province. The site is underlain by unconsolidated deposits that range from 20 to 200 ft in thickness. The unconsolidated materials underlying the uplands part of the site consist primarily of Pleistocene glacial drift and a relatively thin veneer of recent alluvial/fluvial sediments in the surface drainage areas. The glacial drift sediments, or till, consist of a heterogeneous and unsorted mixture of clay, silt, and sand-sized particles, with variable amounts of gravel. Outwash deposits are present as discontinuous lenses within the till in upland areas. In the floodplain of Big Darby Creek, including the retired filter bed area, outwash and fluvial (reworked outwash) sediments are present as a thin but continuous layer below the recent alluvium. Locally, beneath the glacial drift, remnants of lacustrine sediments are present in areas of abandoned Tertiary-age drainage.

1.1.2 Surface Soils

Four types of surface soils are present at the BWJ site: the Crosby-Lewisburg, Lewisburg-Celina, Miamian, and Medway soils (Couchot 1975; USDA 1981). The distribution of surficial soils is shown in Figure 3. The Crosby-Lewisburg soils develop on nearly level to gentle slopes, and the Lewis-Celina soils are situated on gentle slopes. Miamian soils formed in areas of gentle to steep sloping topography. Medway soils occupy floodplain areas and develop where the underlying substrate is alluvium.

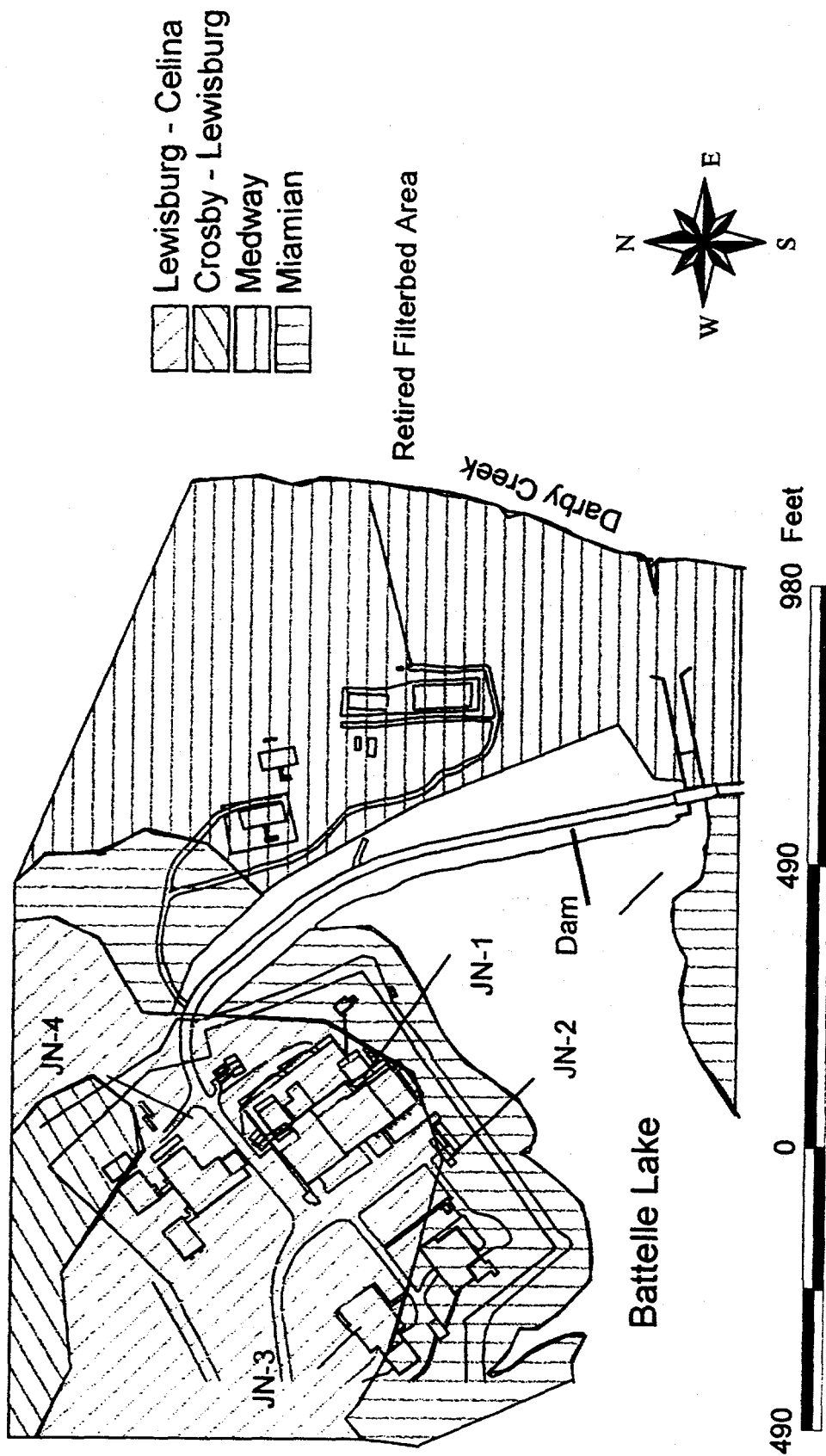


Figure 3. Generalized Soil Map of the Battelle West Jefferson Site

1.1.3 Till Deposits

The glacial drift exposed at the surface in Madison County developed in response to multiple advances and retreats of the ice front during the Wisconsin age. Goldthwait (1969) reported that the drift was deposited from the Scioto Sublobe of the Erie Lobe of the Late Wisconsin glacier. The Scioto and Miami sublobes formed after the Wisconsin age glacier reached the highlands of Bellefontaine, Logan County, and then split into two ice masses that advanced along the respective river valleys (Goldthwait 1952). The BWJ site is geographically located in the area that Orton (1878) referred to as the "Darby Plains," an interfluvium between Little Darby Creek and Big Darby Creek. The uppermost drift in the vicinity of the BWJ site involved Late Woodfordian ice deposits that were deposited between 18,000 and 14,000 years ago (Goldthwait and Van Horn 1993). Figure 4, which shows the general stratigraphy of the Quaternary and bedrock units, was compiled from available information for the Jefferson Township area. Although there is evidence that Illinoian and multiple Wisconsin age glaciers advanced across western Ohio, only the near-surface till has been mapped.

Steiger and Holowaychuk (1971) reported that the Darby Till consists of 34% sand, 46% silt, and 21% clay, on the basis of grain size characterization data. We obtained comparable characteristics for the Darby Till underlying the Battelle site, with particle size fractions of 32% sand, 37% silt, and 27% clay (as mean values), through analysis of existing Battelle geotechnical reports (Burgess and Niple, Ltd. 1966; Jewel 1971). Battelle also conducted numerous soil bores as part of its environmental investigations during 1989-1990 in the north area of the site, also referred to as the "JN Area" and the "Nuclear Science Area." More than 168 environmental soil bores, largely concentrated in six areas, were conducted by Battelle at the BWJ during that period.

The previous Battelle environmental characterization effort involved extensive soil sampling activities; however, the use of the information for stratigraphic purposes is partially limited because liners were pervasively utilized. The geotechnical studies at the dam (Burgess and Niple, Ltd. 1966) and bores at the Hot Cell Area (Jewel 1971) provided the most detailed descriptions of the stratigraphy of the overburden. Most of the environmental bores and associated sampling activities focused on the characterization of the till deposits at upland locations where contamination was known or suspected near the Battelle JN research facilities. Some till and alluvial materials were also penetrated by earlier Battelle soil bores along the north bank of Silver Creek and at the Big Darby Floodplain, particularly at the retired filter bed area.

On the basis of the available Battelle subsurface information, a brown till in the JN area ranges from 11 to 12 ft in thickness. Figure 5 shows the structure contours on the top of a gray till, according to the available Battelle soil bore information. The attitude of this interface appears to exhibit a northwest-to-southeast-trending depression or re-entrant between the dam and the JN-1 area. The thicknesses of the gray and reddish brown till units are variable under the BWJ site, and the information is spatially limited. Figure 6 shows the locations of geologic descriptions that were previously obtained at deep bore sites. Figures 7a and 7b provide a summary of the geological descriptions that have been obtained from the deep bores/wells at the site and from the Camp Ken Jockey area just east of Big Darby Creek. Note that on Figure 7, the top of the reddish brown unit

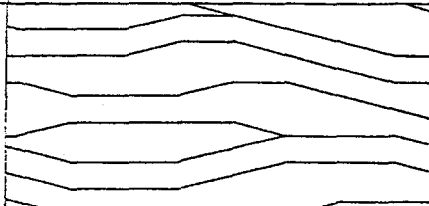
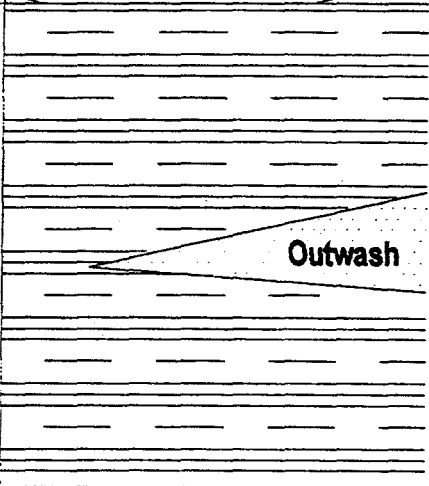
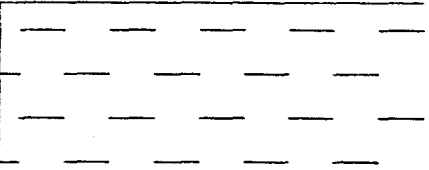
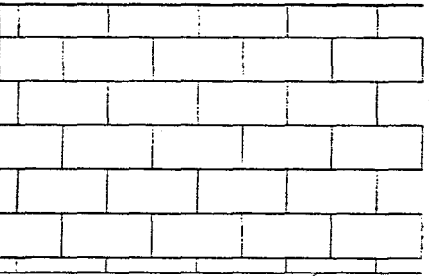
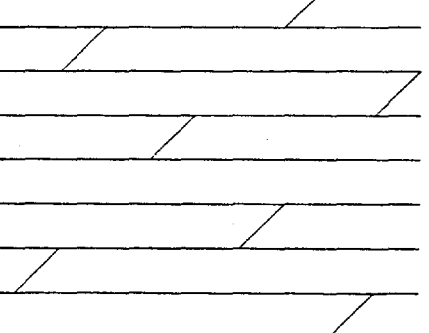
AGE	SUBDIVISION			LITHOLOGY
CENOZOIC	QUATERNARY	RECENT	Alluvium and Fluvatile	
		PLEISTOCENE	Darby Till	
		Late Wisconsinan		
	TERTIARY	PRE- PLEISTOCENE	Lacustrine (Minford Silt)	
PALEOZOIC	DEVONIAN		Columbus Limestone	
	SILURIAN	UPPER SILURIAN CAYUGA GROUP	Bass Islands Dolomite	

Figure 4. Diagram Showing the Quaternary Surficial Deposits and Silurian-Devonian Formations in Jefferson Township, Madison County, Ohio

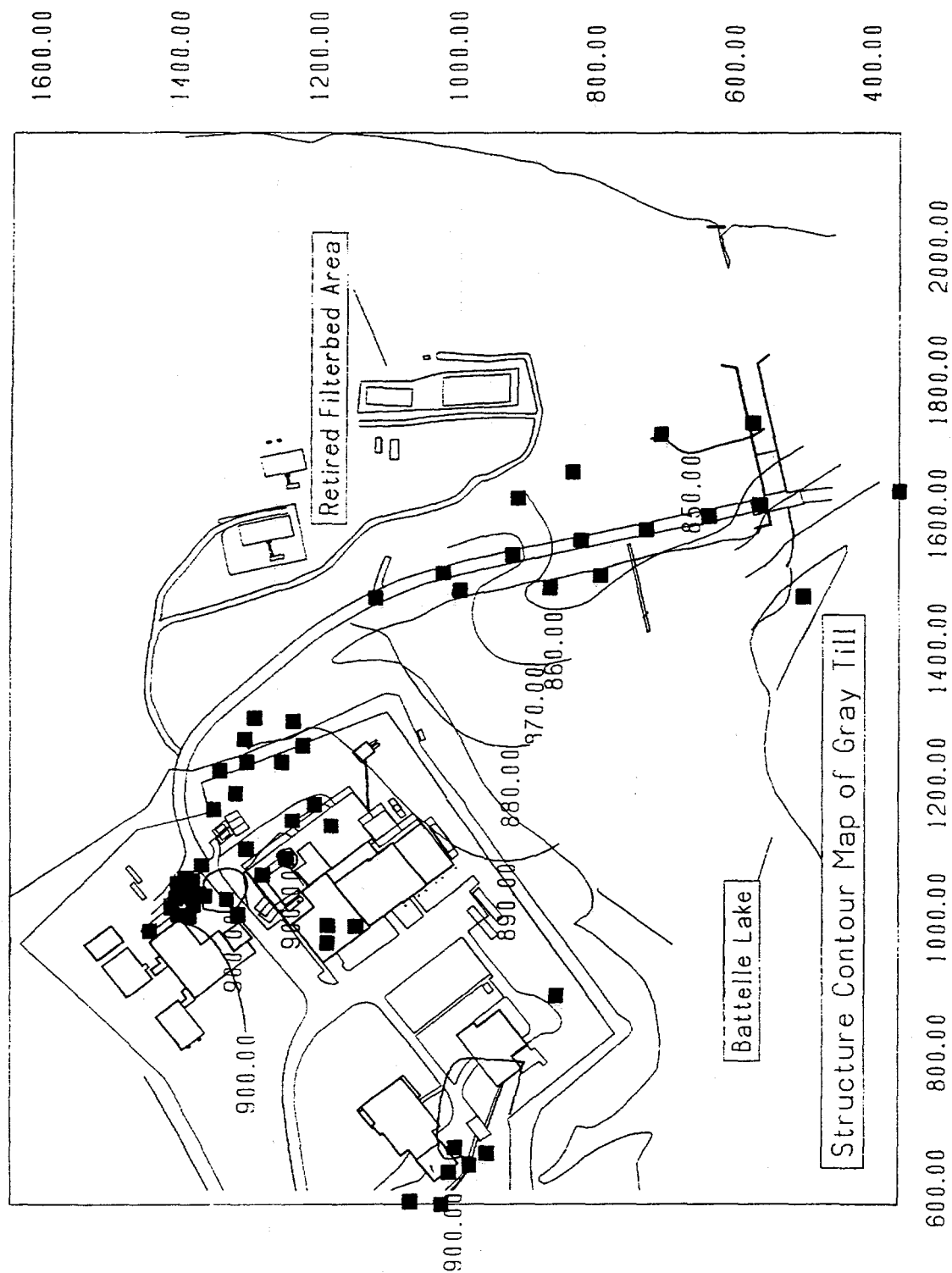


Figure 5. Structure Contour Map on the Top of Gray Till at Battelle West Jefferson Site

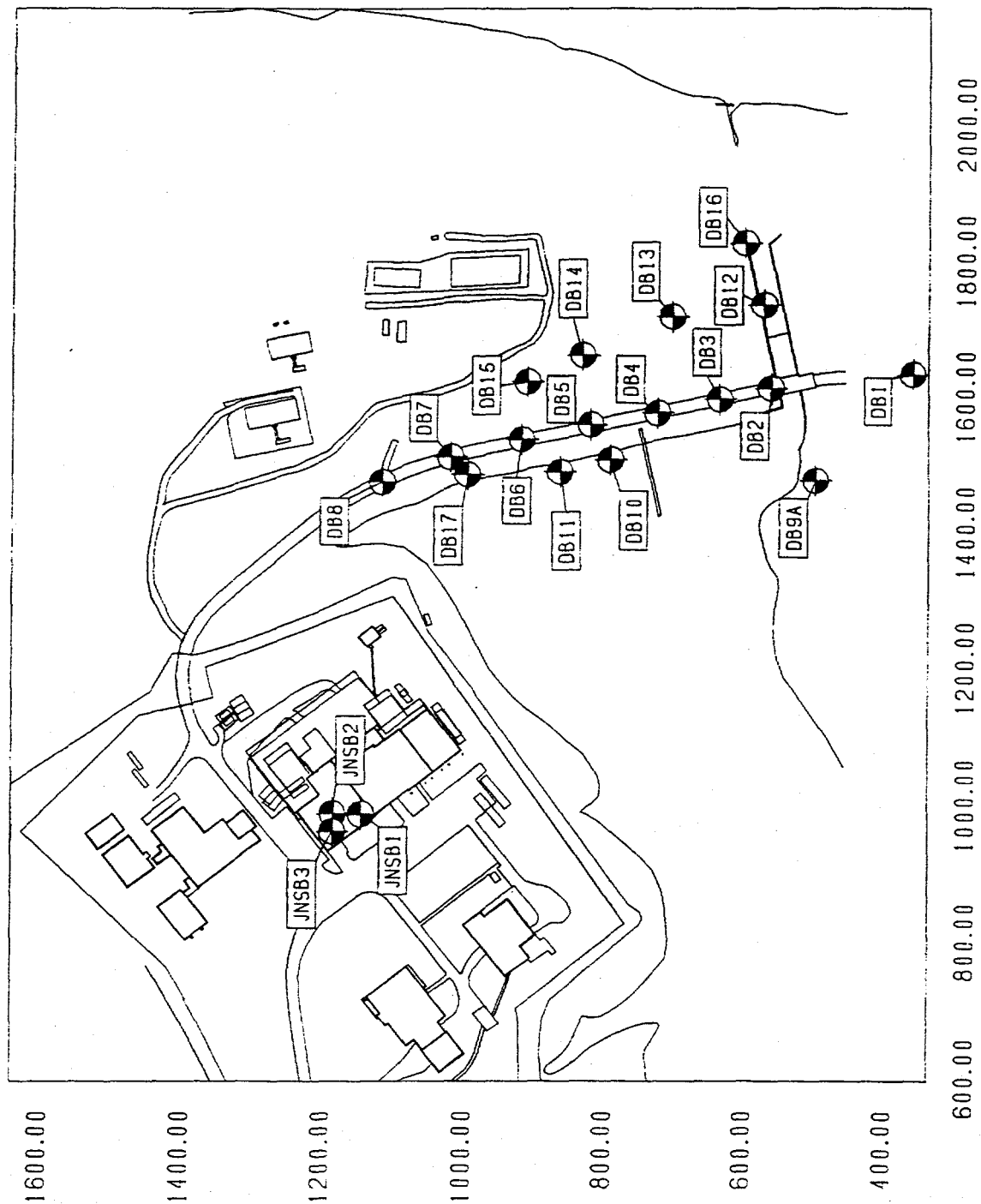


Figure 6. Location of Deep Borings at Battelle West Jefferson Site

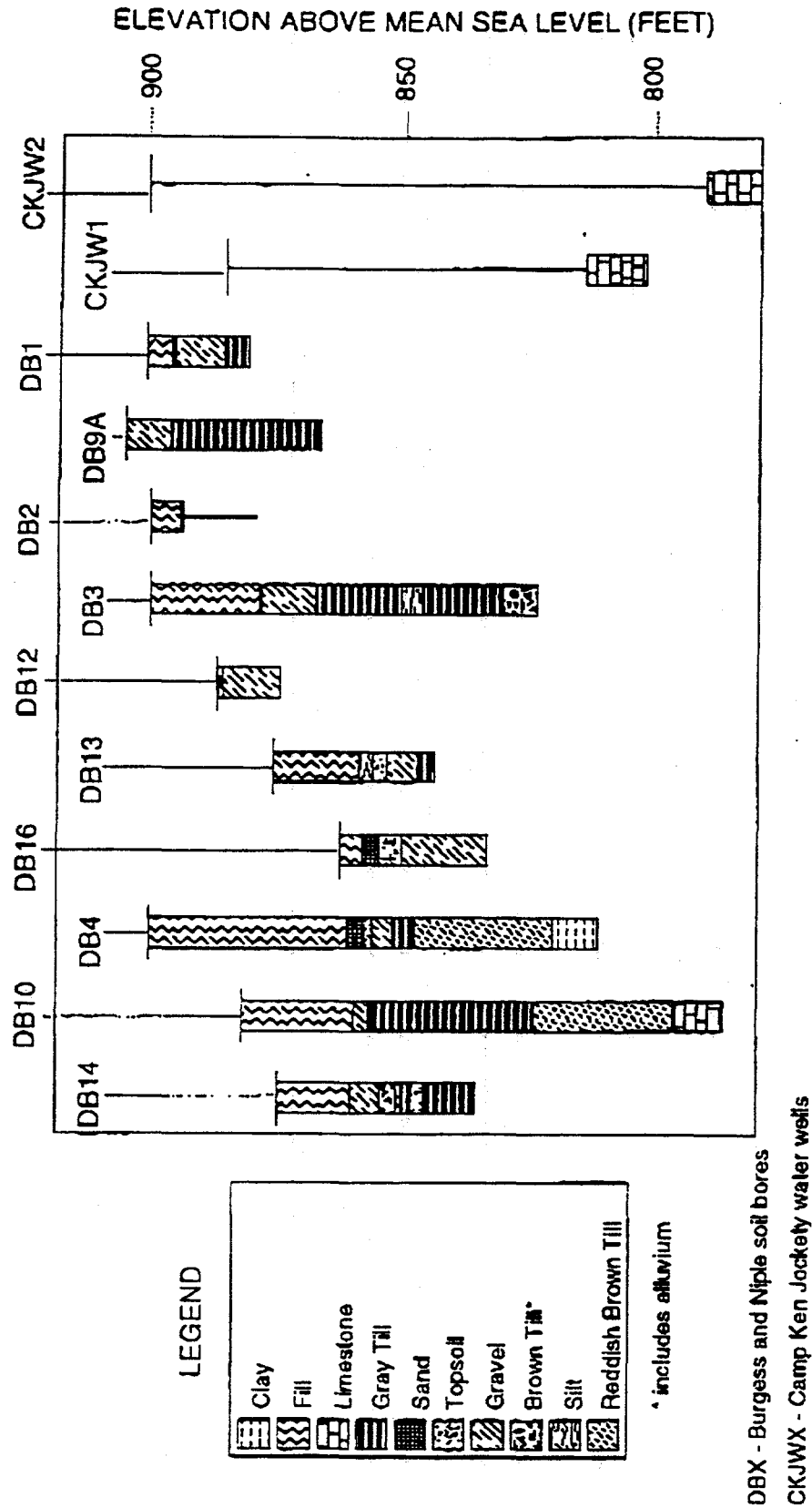
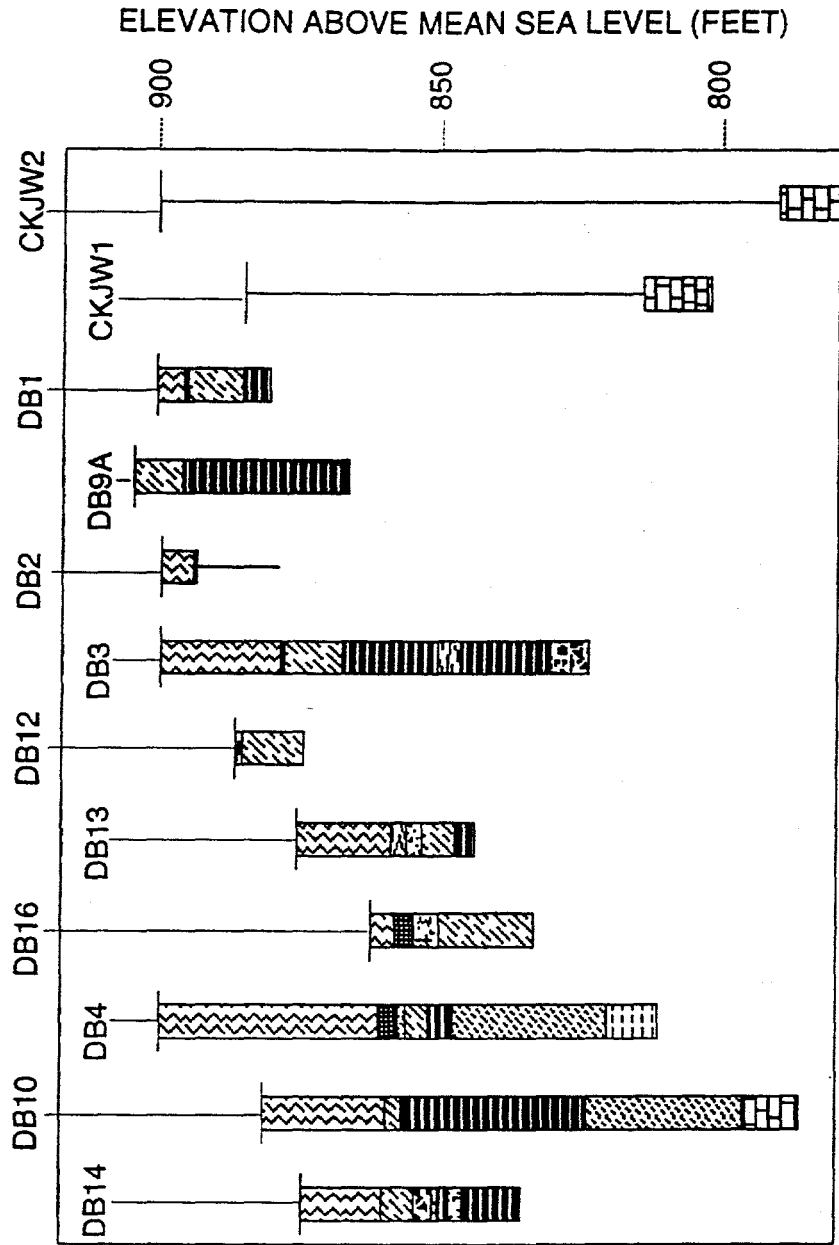


Figure 7a. Geological Descriptions for Deep Borings/Wells at Battelle West Jefferson, Right Panel



DBX - Burgess and Niple soil bores

CKJWX - Camp Ken Jockey water wells

Figure 7b. Geological Descriptions for Deep Bores/Wells at Battelle West Jefferson, Left Panel

underlying the BWJ site is generally encountered below an elevation of 850 ft above mean sea level.

Review of the Ohio Department of Natural Resources (ODNR) water well logs for the surrounding area indicated that drillers often reported that "red clay" was encountered below depths of 40 to 60 ft. Typically, this red clay has been identified just below a gray-blue clay unit or below an underlying sand or gravel unit. On the basis of well log information and estimated surface elevations, a clay characterized by red color was encountered at an elevation of 830 ft in the Battelle North well and at elevations of 841 and 852 ft in the Camp Ken Jockey wells #1 and #2, respectively. It was indicated to range from 20 to 42 ft in thickness.

In previous environmental investigations of the retired filter bed area, between 1988 and 1990, Battelle performed 44 soil bores, which were located both inside and outside the filter bed area. No detailed drawings of the construction of the retired filter beds were available to evaluate the maximum excavation depths. The Battelle soil bores ranged from 10 to 14.5 ft deep, and soil bore logs were prepared for 10 of the holes (R135-R144). Review of the available logs for the retired filter bed area indicated that the base of the fill averaged a depth of 6 ft and was as deep as 9 ft in one location (R138). In the floodplain area, Battelle soil investigations were shallow, and the thickness of the till beneath the alluvial and fill materials was not ascertained. Glacial till was observed at the bases of six of the Battelle environmental soil bores that were performed at the retired filter bed area.

1.1.4 Outwash and Alluvium Deposits

Beard and Gupta (1990) have mentioned that near the Storm Sewer Outfall at the BWJ site (also referred to as Area 1) sandy silty layers that overlie the glacial till along the north bank of Silver Creek (Area 1) are either outwash or alluvium deposits (Figure 8). It is not known, however, if the granular materials described by Beard and Gupta (1990) represent natural deposition or if they may possibly involve fill related to the dam construction. Norris (1959) indicated that the Little Darby Creek valley near West Jefferson features extensive valley train deposits (outwash deposits) that constitute an undeveloped aquifer.

A coarse-grained interval was encountered in the Battelle soil bores at the retired filter bed area below the reported depth of fill and above the identified till. The interval consists of silty sand, gravelly sand, and sand and gravel sediments; this unit was directly underlain by till in six bores. Figure 9 provides a geologic profile based on soil bore data at the retired filter bed area. Although the available soil bore data offer useful information about the glacial and recent stratigraphy in the retired filter bed area, there are some inherent limitations in the reported accuracy of the observations due to the sampling procedures that were employed. Soil cores were continuously collected in plastic liners, but the descriptions of soils were limited to visual examination through the transparent liner and to direct observation at the ends of the liners. Nevertheless, review of the soil characterization data did illustrate that granular sediments (probable outwash deposits) underlie the retired filter bed area. This interpretation would also be

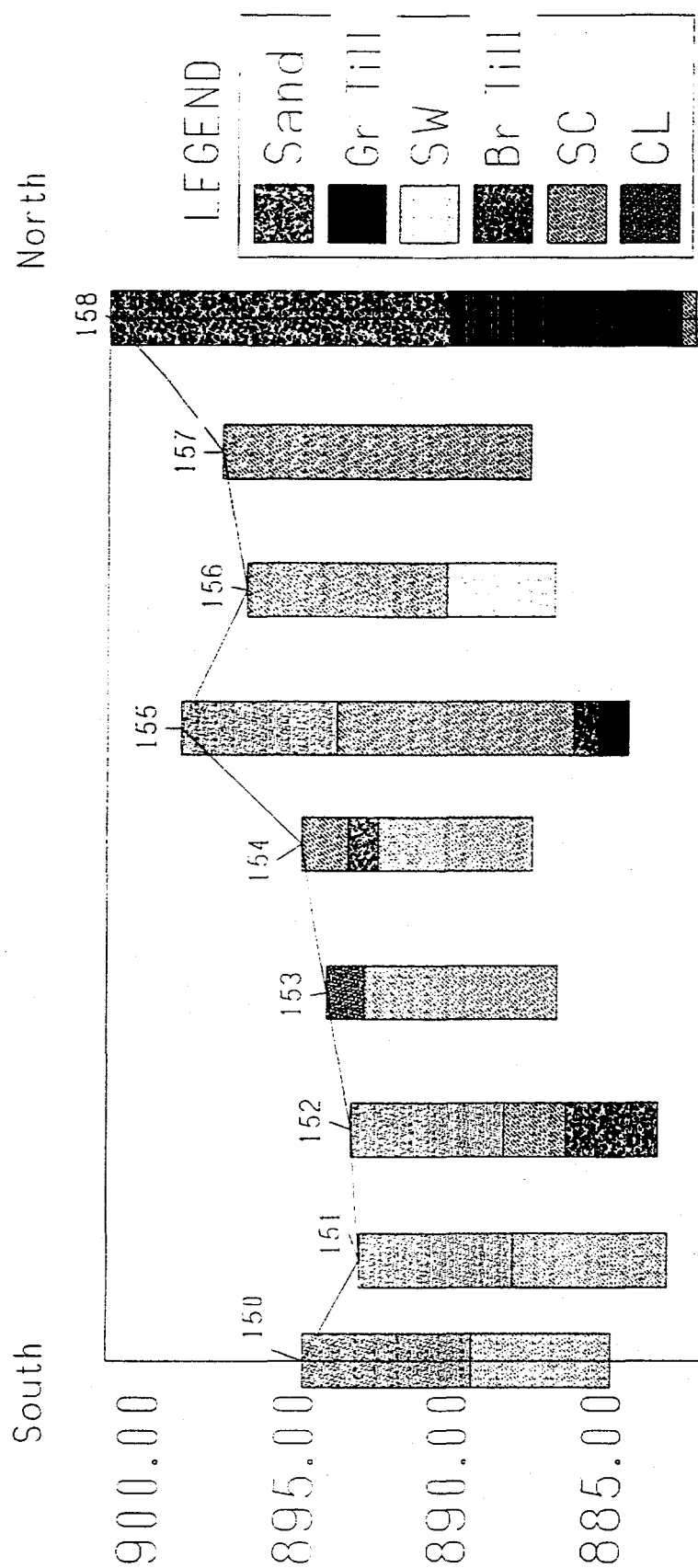


Figure 8. Soil Borings in Area 1 along the North Bank of Silver Creek

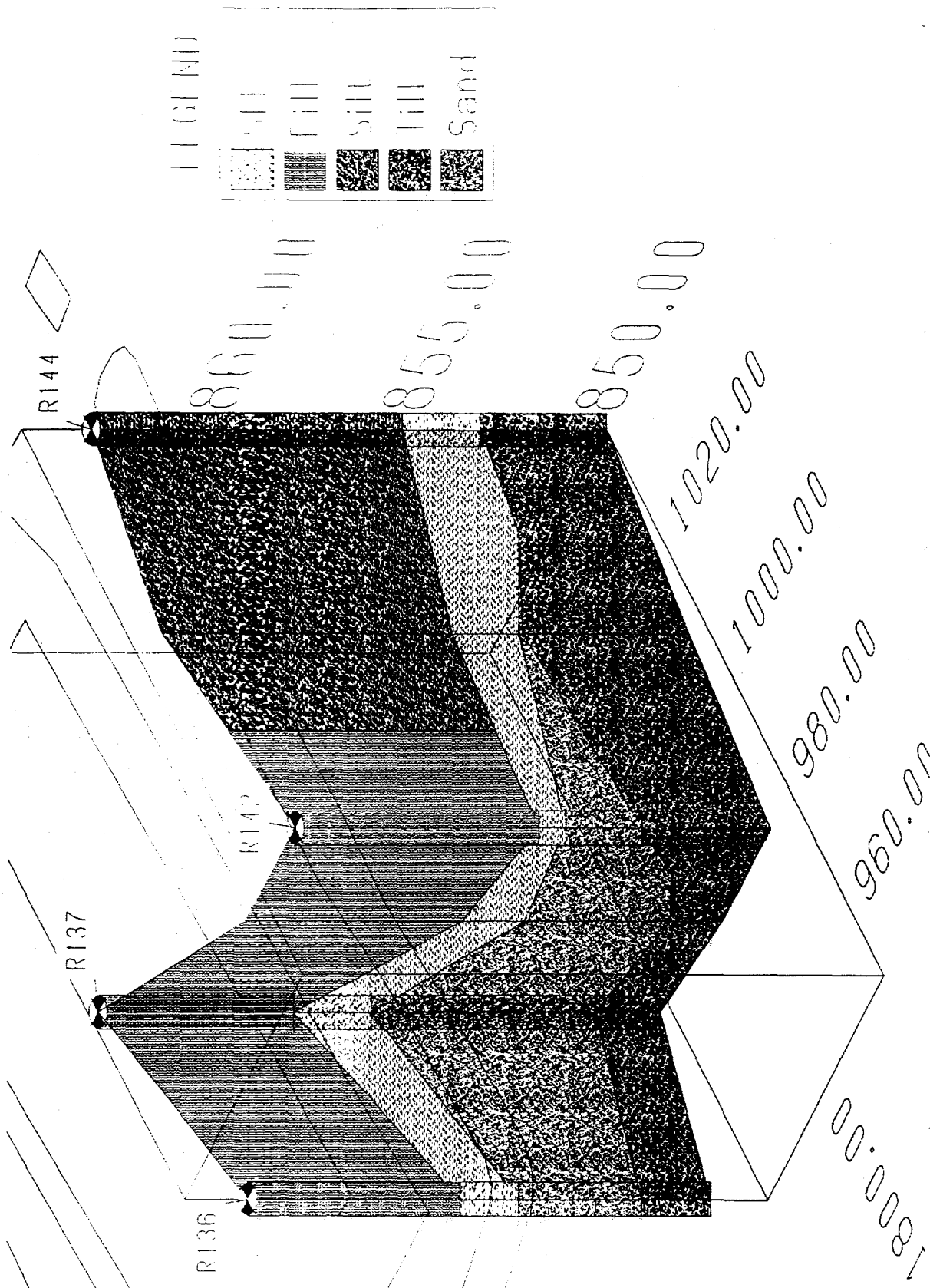


Figure 9. Geologic Profile of Retired Filter Bed Area at Battelle West Jefferson Site

consistent with what is known about the surficial geology in the region. Concerning the recent deposits, Norris (1959) reported that recent alluvium deposits are present along the floodplains in Madison County as thin layers, consisting of sand and silt. Beard and Gupta (1990) reported that the alluvium in the vicinity of the Big Darby Creek floodplain consists "primarily of stratified silt, fine to medium sand, and clay" and that "very thin layers of fine sand were also observed in the clay/silt zones." They also mentioned that the color of the alluvial deposits was "black, gray, red, or brown, and was mottled" in response to the oxidation/reduction environments.

1.1.5 Lacustrine Deposits

Remnants of lacustrine deposits locally underlie the glacial till (Battelle 1961). More extensive lacustrine deposits were also recognized by Norris and Spicer (1958) in their investigation of the ancient Teays River Valley system in Champaign, Clark, and Madison counties. Figure 10 illustrates where the Teays River Valley and related preglacial rivers once existed in Ohio and other nearby states (Teller and Goldthwait 1995).

Bigham et al. (1991) characterized the Minford unit through study of trace elements and particle size distribution, on samples collected near Waverly, Ohio, and from locations in Pike, Jackson, and Scioto counties, Ohio. Table 1 provides a comparison of Bigham's (1991) characterization of the Minford sediments, based on grain size, with information for the lacustrine deposits that locally underlie the Battelle site. Minford sediments were penetrated in two, possibly three, bores that were conducted by Battelle in 1961 to investigate the unconsolidated materials underlying the Silver Creek valley, a tributary to Big Darby Creek. The lacustrine clay is gray to reddish-brown in color with carved or laminated structures. Figures 7a and 7b illustrate where the lacustrine deposits have been recognized in soil bore data. Numerous soil borings (with detailed descriptions) and a suite of soil mechanics tests were performed at that time to investigate the site prior to the design and construction of the Battelle Dam.

1.1.6 Fill Materials

Artificial materials are present at the BWJ site at both the JN areas, in the dam area, and along the floodplain areas of Big Darby Creek. These materials are present at the site due to previous construction activities and underground piping and utility installations. The fill composition varies, depending on whether native materials were solely utilized or if fill was brought in from another area, either on- or off-site. Some granular fill was also emplaced in the retired filter bed area as filter material. According to Beard and Gupta (1990), two types of fill are present at the BWJ site, general fill and engineered fill. General fill consists of reworked native materials, with some addition of crushed rock, and is density-controlled. Engineered fill consists of native or nonnative materials that are emplaced under engineering specifications.

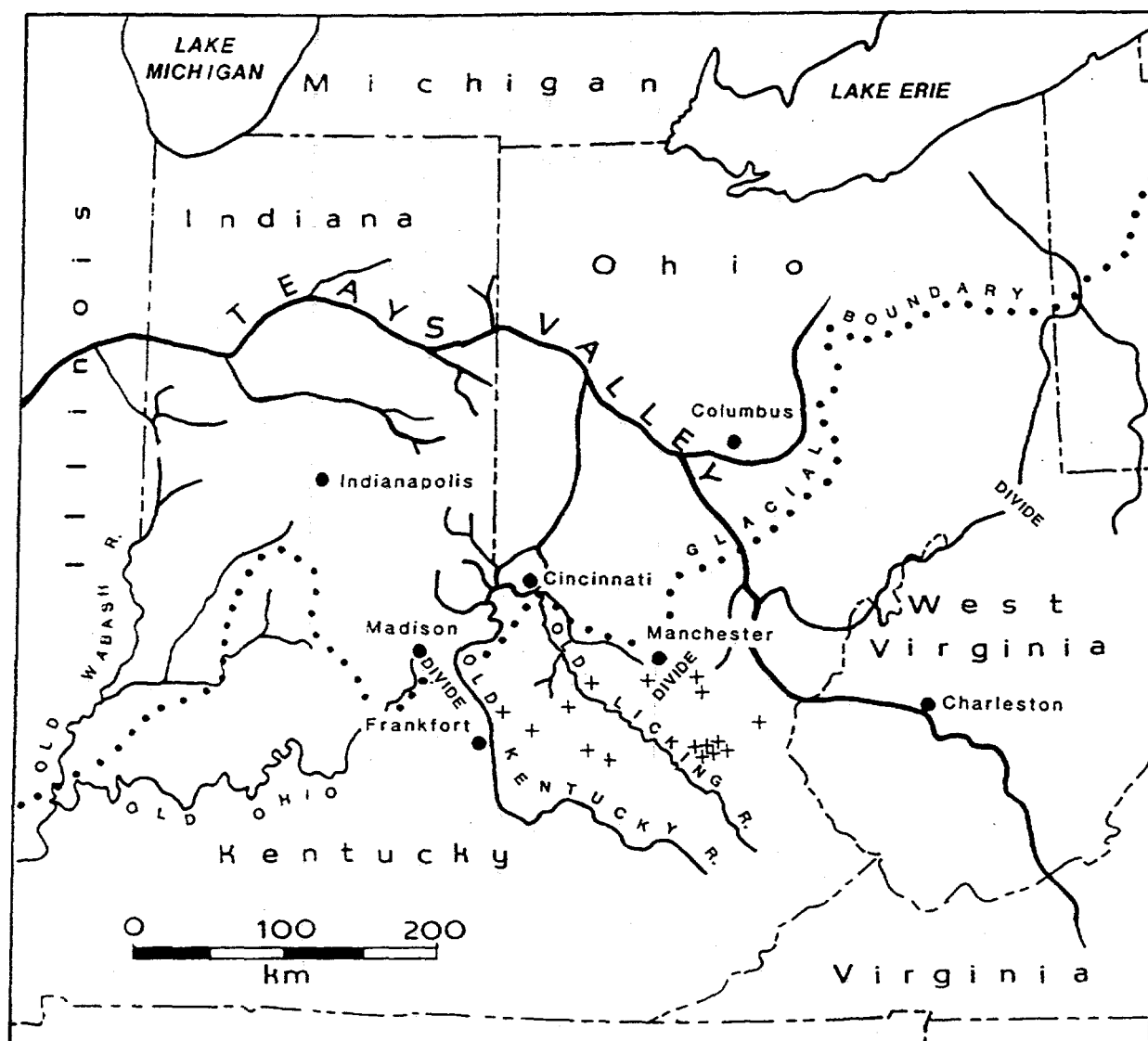


Figure 10. Location of Teays River and Related Preglacial Drainage

Table 1. Comparison of Particle Size Distributions in Lacustrine Clay (Minford Clay) at Battelle West Jefferson Site

Data Source	Clay	Silt
Battelle Dam^a		
Bore 4, 28.5-30 ft	67	23
Bore 5, 48.5-50 ft	59	20
Bore 5, 63.5-65.0 ft	88	9
Minford Data (1991)^b		
Taylor Hill Road Section, Waverly, Ohio ^c	71.9	27.9
Pike, Jackson, Scioto, Ohio Sites ^d	73.5	25.4
		56.0
Post-Minford Data		
Pike, Jackson, Scioto, Ohio Sites ^e	36.4	

^a Depths reported from original ground surface.

^b Note that percentages are mean values.

^c Reported ranges for clay and silt fractions were 59.1-86.3 and 13.7-40.9, respectively.

^d Reported ranges for clay and silt fractions were 64.3-84.3 and 15.5-35.2, respectively.

^e Reported ranges for clay and silt fractions were 18.9-64.2 and 29.4-70.8, respectively.

1.1.7 Bedrock

Elevation of the bedrock surface was estimated, from previous Battelle studies, to be approximately 791 to 797 ft below mean sea level in the northern part of the BWJ area. Available bedrock information consists of the geotechnical bore and water well records that BCLDP personnel obtained from the Ohio Department of Natural Resources, Division of the Geological Survey. Our review of well records also included information on water supplies for the Camp Ken Jockety property, which is located on the eastern side of Big Darby Creek near BWJ.

Review of the bedrock topography map of Norris and Spicer (1958) indicates that a major, subglacial tributary valley appears to connect the BWJ area with the main trunk of the buried Teays Valley to the southwest (Figure 11). Bedrock topography maps compiled by the ODNR, Division of the Geological Survey, between 1990 and 1993 were also reviewed and generally agreed with the results obtained by Norris and Spicer (1958). While the main trunk of the Teays River Valley may possess 400 ft of relief from the general land surface, according to Norris and Spicer (1958), some of the ODNR test holes also encountered lacustrine clay in the shallower portions of the valleys. Their results for the southeastern Madison County area indicate that ODNR Test Hole

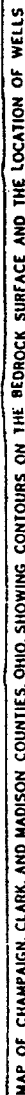


Figure 11. Regional Bedrock Topography Map

No. 8, located along the edge of a buried valley, penetrated approximately 90 ft of lacustrine clay, where bedrock elevation is approximately 760 ft. They also indicate that the 850-ft elevation of those lacustrine deposits at Test Hole No. 8 is the highest occurrence in Madison County.

Groundwater supplies are obtained from the limestone and dolomite rocks that underlie that BWJ site. Klaer and Associates (1963) evaluated the carbonate aquifer at BWJ for the north and middle wells. The tests showed that the yields were 250 gallons per minute (gpm) from the north well and 500 gpm from the middle well.

2 Equipment and Procedures

2.1 Electromagnetic, Resistivity, and Magnetic Measurements

2.1.1 Electrical Conductivity Mapping with the EM-31 and EM-34

Apparent conductivities in the West Jefferson site were measured by means of the Geonics EM-31 and EM-34 electromagnetic (EM) induction instruments. The induction coil of the EM-31 and EM-34 transmits an EM field into the ground, and a receiver measures the secondary electromagnetic field caused by the low-intensity eddy currents induced in the subsurface. The field strength of the secondary currents is almost linearly proportional to the electrical conductivity of the surrounding sediment. The effective depth of penetration is determined by the coil spacing and coil orientation. Conductivities are dependent upon the moisture content and sediment/rock mineralogy. Although the EM-31 provides an effective depth of penetration (approximately 19 ft), the conductivities at roughly 7.7 ft in depth are weighted most heavily (McNeill 1980). Data were collected at 0.5-s intervals with the EM-31 and were stored on the OMNI 720 data logger, which can log quad-phase electrical conductivity data and in-phase inductive data for metals simultaneously, as well as storing survey geometry. For this survey, data were recorded in both quad-phase and in-phase. Internal software permits downloading data directly into an on-site computer.

Apparent conductivities (in mS/m) were obtained with the EM-34 by holding the transmitting and receiving coils on the earth's surface in the same vertical plane (horizontal dipoles) at a spacing of 65.6 ft (20 m). The apparent conductivity values represent weighted averages of the conductivities of the unconsolidated deposits and rocks between the earth's surface and a maximum depth of approximately 49.2 ft (15 m), with the conductivities of geologic units near the Earth's surface weighted most heavily (McNeill 1980). The EM-34 complements the EM-31 observations by providing an understanding of the distribution of electrical conductivities with depth. A longer coil spacing (40 m) was not possible due to cultural interference from the oil pipeline and the metal fencing. Data were collected at 33-ft intervals along N-S lines and were manually recorded in field notebooks.

2.1.2 Vertical Electrical Sounding

Vertical electrical soundings (VES) using the ABEM/BOSS Wenner system were conducted at 20 locations from the dam road to the east. These soundings were used to calibrate the EM data and also to obtain information on depth to bedrock. Twelve soundings were conducted on the floodplain of the creek and eight along the road crossing the dam. One deep sounding using the Schlumberger technique with a maximum-current electrode separation of 600 m was conducted on Route 142, located due west of the survey area and centered between the main facility gate and the south access road.

Apparent resistivities were inverted to layering parameters (resistivities and thickness). Resistivities ranged from 10 to 70 ohm-m in the overburden; whereas, bedrock resistivities ranged

from 100 to several hundred ohm-m. Norris and Spicer (1958) indicated that overburden resistivities range from 16 to 155 ohm-m, while resistivities range from 136 to 410 ohm-m for the limestone bedrock. Wolfe and Richard (1992) published bedrock resistivity values that ranged from 100 to 300 ohm-m for the limestone/dolomite in this area.

2.1.3 Magnetic Gradiometer and Cable Locator

Limited surveys were performed with the Schonstedt MAC-51B magnetic gradiometer and cable locator to assist in defining buried obstacles. It is a dual-mode instrument designed for detecting shallow buried iron and steel objects and tracing underground cables and pipes. The system consists of a transmitter and a dual-function receiver designed to detect anomalous magnetic gradients. The MAC-51B is an audio device used only for rapid detection of magnetic materials for further analysis with complementary instrumentation. A Schonstedt MAC-51B gradiometer was used, in conjunction with the EM-31 data sets, to locate the Shell petroleum pipeline. The trend of pipe was marked across the site with plastic pin flags (Figure 2).

Maps or models are not constructed on the basis of observations made with this instrument because it is not a calibrated system, nor does it have digital data recording. Anomalies are identified by changes in sound amplitude and frequency and are identified on the ground surface with non-metallic markers.

2.2 Ground-Penetrating-Radar Surveys

Ground-penetrating-radar surveying and data processing were accomplished by using the Geophysical Survey Systems, Inc., Radan III software (Galinovsky and Levin 1990) and a model SIR-2 radar connected to a transceiver with a cable approximately 100 ft long. The transmitting and receiving antennas were attached to a rigid frame and separated by a fixed distance of 4.5 ft. Both the 100- and 300-MHz antennas were tested in the bistatic mode. The 300-MHz antenna provided the better data and was used at the site. Profiles were collected in a continuous mode. Adjustments in gains were made to limit interference and enhance signal strength. Data from the SIR-2 system were downloaded directly to the personal computer. The computer was located in a field office so that the radar operator could download, check data quality, and do preliminary processing after a day's run.

Wave-velocity characteristics of near-surface materials were derived from tables of travel-time to depth conversion for various earth materials (Geophysical Survey Systems 1987). For example, the two-way conversion to depth for an average soil (fresh-water-saturated clay to silty sand) is 7-9 ns/ft. As the degree of soil saturation and clay content increase, the maximum penetration depth decreases. At the West Jefferson site, both the 100- and 300-MHz antennas, in a bistatic configuration, were tested. The GPR profiles collected with the 300-MHz antennas at a range setting of 250 ns provided the best data and were used over the entire site.

2.3 Seismic Refraction Profiling

Seismic refraction profiles were recorded at six sites at BWJ. Energy sources consisted of a 16-lb sledge hammer and a Bison Instrument EWG III weight drop. A 24-channel, EG&G ES-2401 seismograph was used to record the refraction data, and 14-Hz geophones manufactured by Geosense, Inc., were used as the receivers. A sampling interval of 0.5 milliseconds (ms) was used for each shot record; the total recording time varied from 256 to 500 ms, depending on the shot-receiver geometry. Geophone spacings were 5 and 10 m (16.7 and 32.1 ft). For the refraction lines on the dam and south entrance road, the geophone spacing was 10 m (32.1 ft). Five-meter (16.7-ft) geophone spacings were used for the four profiles near the filter beds. A maximum shot-to-far-detector distance of 392 m (1,286 ft) was achieved along the dam road seismic profile (Line-1), and a maximum shot-to-far-detector spacing of 180 m (590 ft) was used for the profiles acquired on the floodplain. All profiles were shot in reverse directions to correct for apparent dip on refracting surfaces. The refraction data were processed by using the SIPT program of Scott (1973 and 1977), which is a robust seismic refraction inversion program that uses iterative ray tracing and model adjustment to produce a velocity-depth model.

2.4 Cone Penetrometer Testing

Cone penetrometer testing (CPT) was accomplished at BWJ during the week of September 18, 1995. The CPT tests performed for this investigation were conducted using a 30-ton Applied Research Associates (ARA) penetrometer truck. Electronic cone penetrometers consist of cones at the ends of one-meter sections of 1.7-in-diameter steel rods that are pushed into the ground with hydraulic rams. At BWJ, the cone was configured to measure tip resistance, sleeve resistance, pore pressure, and electrical resistivity. The data from the cone sensors is transmitted to the surface from the probe assembly via a cable running through the push rods. The analog data are digitized, recorded, and plotted by computer in the CPT truck. The depth of penetration is measured by using a string potentiometer mounted on the hydraulic rams. The CPT was performed in accordance with ASTM-D3441 procedures. Cone sensors were checked and calibrated prior to the start of each day or when sensors were replaced.

Tip resistance and sleeve friction together measure the geotechnical properties (strength, compaction, cohesiveness, etc.) of the material being penetrated. As the cone is pushed through a cohesive clay horizon, the cone forms a cavity with relatively little caving-in of the walls. Consequently, both the tip resistance and sleeve friction are relatively low. In low sandy horizons with a low degree of compaction, the less cohesive material generally is difficult to push aside and is likely to keep caving in on the cone, resulting in higher tip resistance and possibly higher sleeve friction. Because of the disturbance of the material around the cone during penetration, in-situ pore pressures are altered. Significantly high pore pressures are developed in cohesive materials with lower permeability, such as clays, because of consolidation around the cone. Pore pressures may also increase initially in sand layers with higher permeability, but the buildup is relatively less compared with clay layers.

Electrical resistivity was also measured during the CPT investigation at BWJ. The resistivity probe consisted of four electrodes separated by high-strength, plastic-reinforced

insulators. The two outer electrodes induce an electric current into the soil, and the two inner electrodes measure the potential drop, which is proportional to the resistivity of the soil. The resistivity is useful for better defining lithologic boundaries. Higher resistivities indicate vadose zone sands and saturated sands below the water table. Lower resistivity measurements indicate an increasing clay content, even when obtaining readings below the water table.

Upon completion of each CPT hole, the rods were removed, steam-cleaned, and screened for radiological contamination by Battelle. Wastewater was placed in containers until after equipment screening and then properly disposed of by BCLDP personnel.

The ability to effectively use CPT to characterize site geology has been reported in literature by Smolley and Kappmeyer (1991), Chiang et al. (1992), and Zemo et al. (1994). Those investigators reported that they used CPT soundings to define stratigraphy, recognize electronic log signatures indicating major changes in lithology, and identify preferred pathways for migration of contaminants. In those reports, the stratigraphy was unraveled through application of published charts (e.g., Robertson and Campanella 1986) that correlate CPT responses to soil behavior and control points where detailed soil descriptions were obtained from on-site bores. Smolley and Kappmeyer (1991) reported success in applying CPT soundings to screen for well locations that met a state regulatory criterion involving a minimum of three feet of aquifer thickness. In the published studies, various investigators have used CPT soundings to determine the optimal location and number of groundwater monitoring wells.

2.5 Piezometer Installation

Six shallow piezometers were installed near the retired filter bed area of BWJ. The piezometers were installed by means of an innovative method that involved the use of the CPT truck. Initially, a pilot hole was pushed to within 1-2 ft above the desired well completion depth, using 1.4-in-diameter penetrometer push rods. The rods were then removed, steam-cleaned, and screened for radiological contamination. All six wells were installed by advancing a 1.5-in-I.D., schedule 80 PVC pipe down the pilot hole outside the 1.4-inch-O.D. penetrometer push rods. A sacrificial steel tip was matched to the outside diameter of a PVC slotted screen, thus leaving no annular space and eliminating the need to backfill and grout. Once the desired depth was reached the penetrometer push rods were withdrawn, leaving the piezometer pipe, screen, and tip in place (Figure 12).

Each piezometer was constructed with a one-meter-long slotted PVC screen and approximately one meter of riser pipe extending above the ground surface. An outer, 4-in.-diameter, schedule 40 PVC casing was cemented around the inner casing and fitted with a sealed, locking cap. The piezometers were all developed by bailing several well volumes (when feasible). Development water was containerized and properly disposed of by BCLDP personnel.

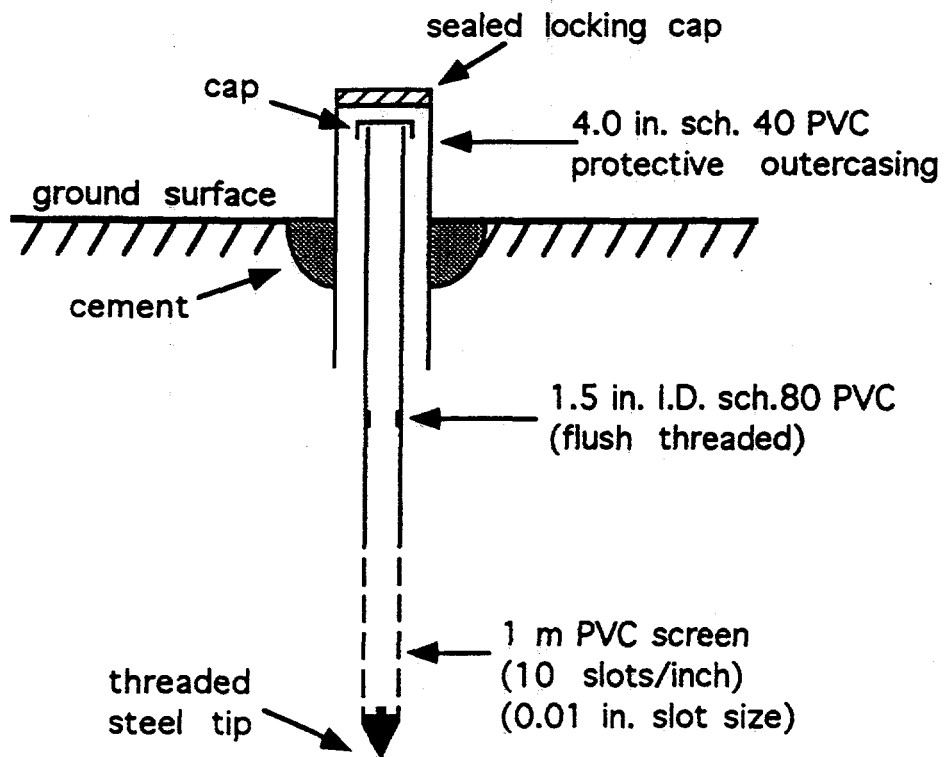


Figure 12. Schematic Drawing of Piezometer Construction

2.6 Surveying

A 100 ft by 100 ft grid was established over a 600 ft by 525 ft study area by Woolpert of Columbus, Ohio, in September 1995, to provide ground control for nonintrusive geophysical surveys. The grid corners and grid nodes were also surveyed for elevations. CPT locations were surveyed for coordinates and ground elevations. Well points were surveyed for coordinates and for ground and top of riser pipe elevations. All elevations were based on the United States Geological Survey (U.S.G.S.) data for the area.

In the fall and winter of 1995-1996, as the data were analyzed, it became apparent to the investigators that the elevations for the existing 2-in. PVC groundwater monitoring wells at the BWJ retired filter beds were suspect. Approximately 13 wells were installed at that location in 1990 by Battelle; these wells were previously surveyed by R.T. Patridge and Associates. The elevations for the tops of the PVC monitoring well casings were suspected to be incorrect when recent groundwater measurements obtained in the existing wells and well points were utilized to plot contours of equal groundwater elevation. R.T. Patridge and Associates were contacted and asked about previous survey records, and in January 1996, they provided copies of the previous survey records that had been completed for Battelle. After available data were checked with Patridge and Associates, they indicated to us in January that the elevations in question were probably casing elevations.

Consequently, Woolpert returned to the BWJ site on April 21, 1996, to resurvey the ground surface and the tops of the casing elevations for the 13 Battelle 2-in. monitoring wells in the retired filter bed area. Woolpert determined that due to differences in data selection (R.T. Patridge data vs. U.S.G.S.), the previous data would need to be shifted -0.79 ft and that after accounting for the data shift, the previous casing elevations were not correct. Table 2 shows the revised elevation data and the earlier data.

**Table 2. Revised Elevation Data for 2-in. Groundwater
Monitoring Wells at the BWJ Retired Filter Bed Area**

Well	Casing Elevation		Ground Elevation
	1990 Data	1996 Data	1996 Data
101	861.58	863.76	860.67
103	862.72	864.90	861.81
110	864.50	865.47	863.36
111	865.99	868.24	865.21
112	864.46	866.96	863.48
113	NA ^a	863.65	861.10
116	863.30	865.60	862.45
118	861.24	863.64	860.11
122	862.59	864.97	861.72
124	862.59	865.03	861.90
125	863.12	865.40	862.28
129	864.02	866.80	863.18
130	863.08	865.30	862.20

^a= not available.

3 Electromagnetic Surveys

3.1 EM-31 Mapping

EM-31 conductivity profiles were collected along north-south lines spaced at 10-ft intervals. Figure 13 was created by gridding and contouring 16,347 conductivity values collected with the EM-31.

The filter bed area proper is readily apparent, as indicated by a high-conductivity perimeter caused by the surrounding chain-link fence. This area extends from about 675N to 960N and from 500E to 760E. Metal covers and pipes, along with electrical utilities, all associated with the water treatment system, are the source of the anomalies within this perimeter.

Another prominent feature in Figure 13 is an abandoned steel petroleum pipeline. It is seen as a conductivity low bordered on either side by a conductivity high. The observed "high-low-high" conductivity anomaly is typical of electromagnetic profiles collected perpendicular to a pipeline or cable by using the EM-31 (McNeill 1980). The pipeline enters the survey area near survey coordinate (940N, 500E) and trends east-southeast until it leaves the survey area at coordinate (850N, 1050E).

A similar type of anomaly is observed along an east-west trend from (480N, 560E) to (460N, 880E). It lies south of the geophysical survey area, but some profiles were extended to the south and crossed this feature. The electromagnetic signature is the same as that observed across the petroleum pipeline. A strong conductivity high is present, extending from the southwest corner of the fenced area to the southern edge of the survey. A discharge pipe and corresponding outfall at the eastern end of the dam spillway are associated with this feature.

Two other lineaments (pipes) are indicated by the EM-31 data in the western portion of the survey area. A pipe(s) extends from near the southwest corner of the fenced area (720N, 550E) toward the south-southeast, intersecting the discharge pipe mentioned above at approximately (480N, 620E). In the northwest corner of the survey area, a linear conductivity minimum, corresponding to a metallic effluent pipe from the north filter site, is located between approximately (1070N, 500E) and (1060N, 570E). The truncation of this anomaly is the result of either a change in pipe material and/or depth or the removal of portions of the pipe. The slight nonlinearity is probably due to a positioning error associated with surveying perpendicular to the steep slope that leads to the fenced north filter site. The maxima along the 500E profile between 980N and 1080N are associated with this fence.

Other high-amplitude anomalies shown in Figure 13 are seen at about (600N, 900E) and (940N, 960E). The source of these generally north-south trending anomalies was noted to be the remnants of a barbed-wire fence. This fence was semicontinuous through the site; it is located about 100 ft west of, and roughly parallel to, the river.

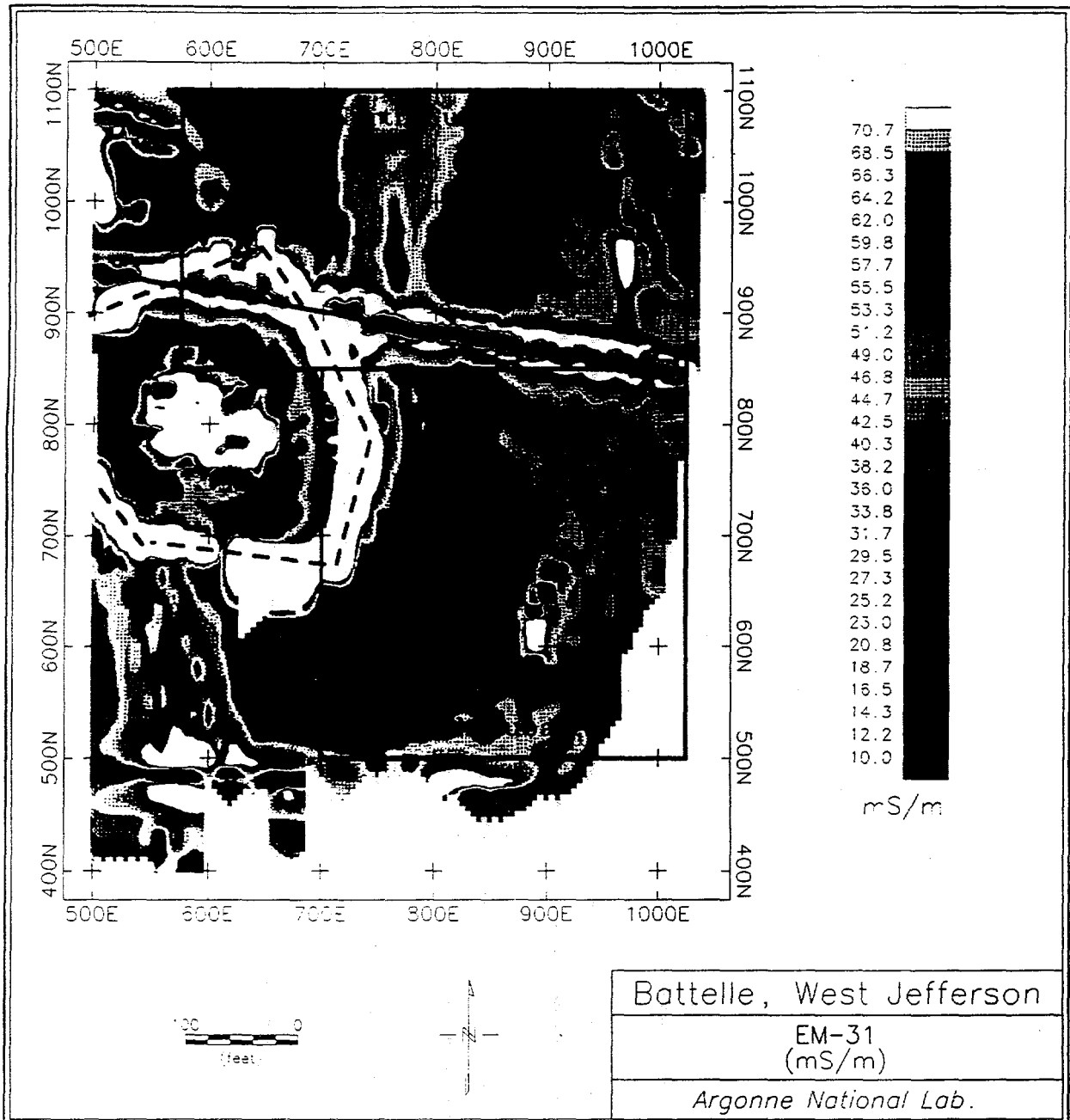


Figure 13. Map of Terrain Conductivity Anomalies Measured by the EM-31 at Battelle West Jefferson

Two subareas in the northern and southeastern portions of the survey area are outlined in Figure 13 and are enlarged as Figures 14 and 15, respectively. These subareas were contoured with a finer interval in order to examine more subtle features that appear at distances away from the higher-amplitude, anthropogenic anomalies.

The subsurface conductivity of the surrounding area is strongly controlled by the degree of saturation, and subsequently, the topography. Figure 14 shows a conductive zone from about 710E to 820E. This broad zone, which bifurcates to the south, corresponds with a topographically low, wet area. The relative conductivity minima on either side of this zone have been correlated with higher ground on topographic maps, the low conductivity being suggestive of a lower degree of saturation. South of the pipeline, the lower conductivity area has an elevation a few feet higher than the adjacent material (Figure 15).

Two lineaments are also observed in the data. The first, in the north subarea (Figure 14), extends from about (1000N, 620E) to (1020N, 710E) and has a positive amplitude of about 6 mS/m. The second lineament, indicated in Figure 15 as an expansion of the southeast subarea, extends from (830N, 805E) to (745N, 915E) and also has a positive amplitude of about 6 mS/m. Also within this expanded portion (Figure 16), other positive EM anomalies, including a U-shaped positive anomaly east of the lineament, are present. These subtle conductivity differences may correlate with previous meander channels of Big Darby Creek. None of the features detected during the survey are thought to represent continuous geologic features, such as thick paleochannel deposits with relatively high hydraulic conductivities in the near-surface zone measured with the EM-31 instrument. Consequently, the EM-31 results did not suggest significant lateral changes in stratigraphy in the shallow subsurface that might serve as preferential groundwater flow pathways.

Figure 17 was generated by using the in-phase component of the EM-31. The in-phase measurements help in delineating anomalies that are produced by metallic objects vs. sedimentological variations. The metallic pipelines, fence, barbed wire, and grates appear clearly in this figure. EM-31 data were also collected in Area 1. These data are presented in Appendix D.

3.2 EM-34 Mapping

Apparent conductivities measured with the EM-34, using a 0.50-mS/m contour interval, are shown in Figure 18. The three-banded conductivity anomaly (high/low/high) caused by the oil pipeline is an artifact of EM measuring devices. Interference effects bias the data, and apparent conductivities within at least 65 ft of this feature are obscured. A similar feature trending approximately E-W south of about 500N is associated with a discharge pipe and outfall at the Big Darby Creek.

North of the pipeline, the pattern of conductivities seems to be influenced by the degree of ground saturation, which is, in turn, controlled by local topography. The conductivity high along the western border of the survey correlates with a topographically low, wet region. On the other hand, the broad conductivity low corresponds with a topographic high. Within this broad conductivity low is a narrow, 4-mS/m minimum of unknown origin.

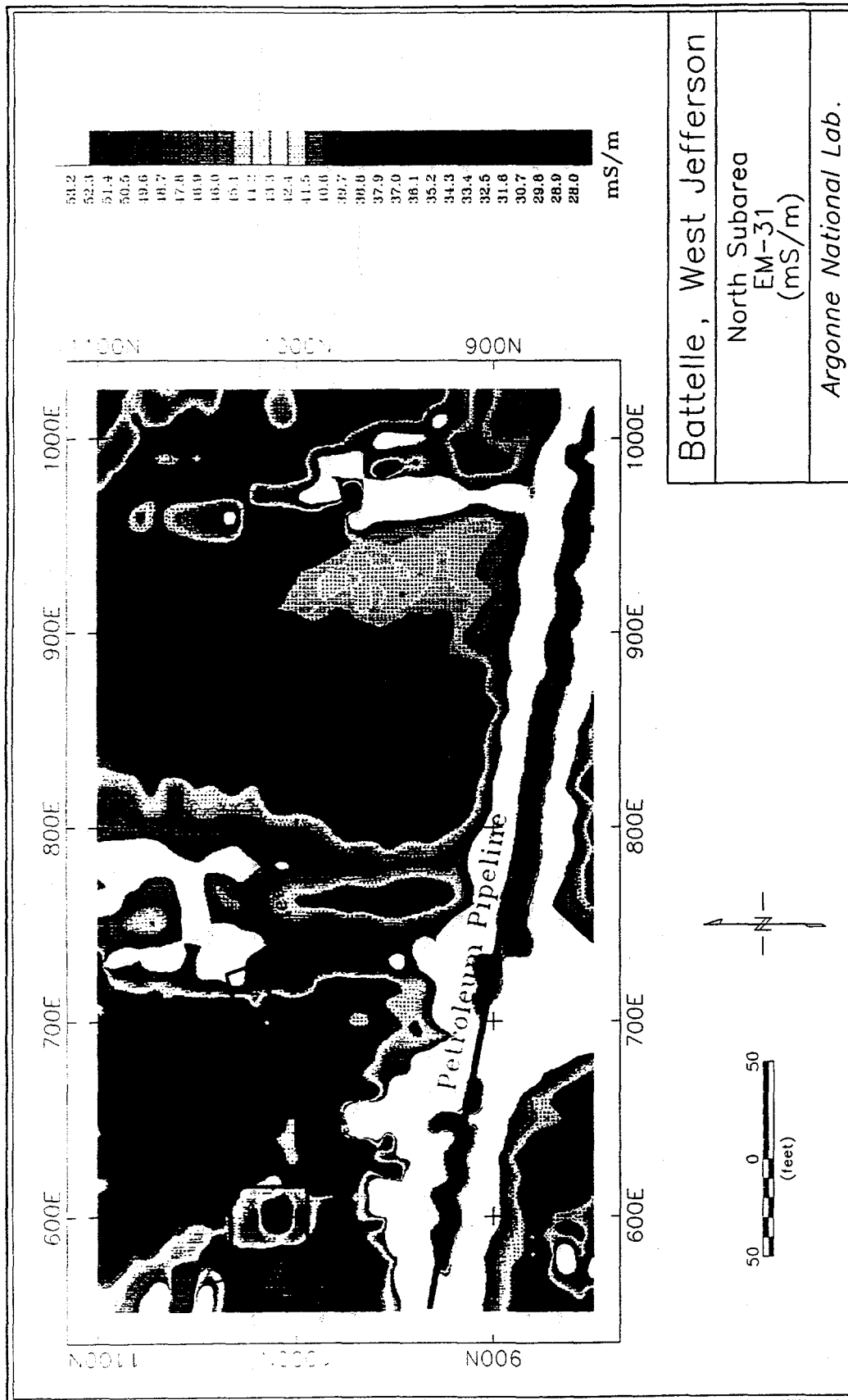


Figure 14. Map of Terrain Conductivity Anomalies Measured by the EM-31 in the North Subarea

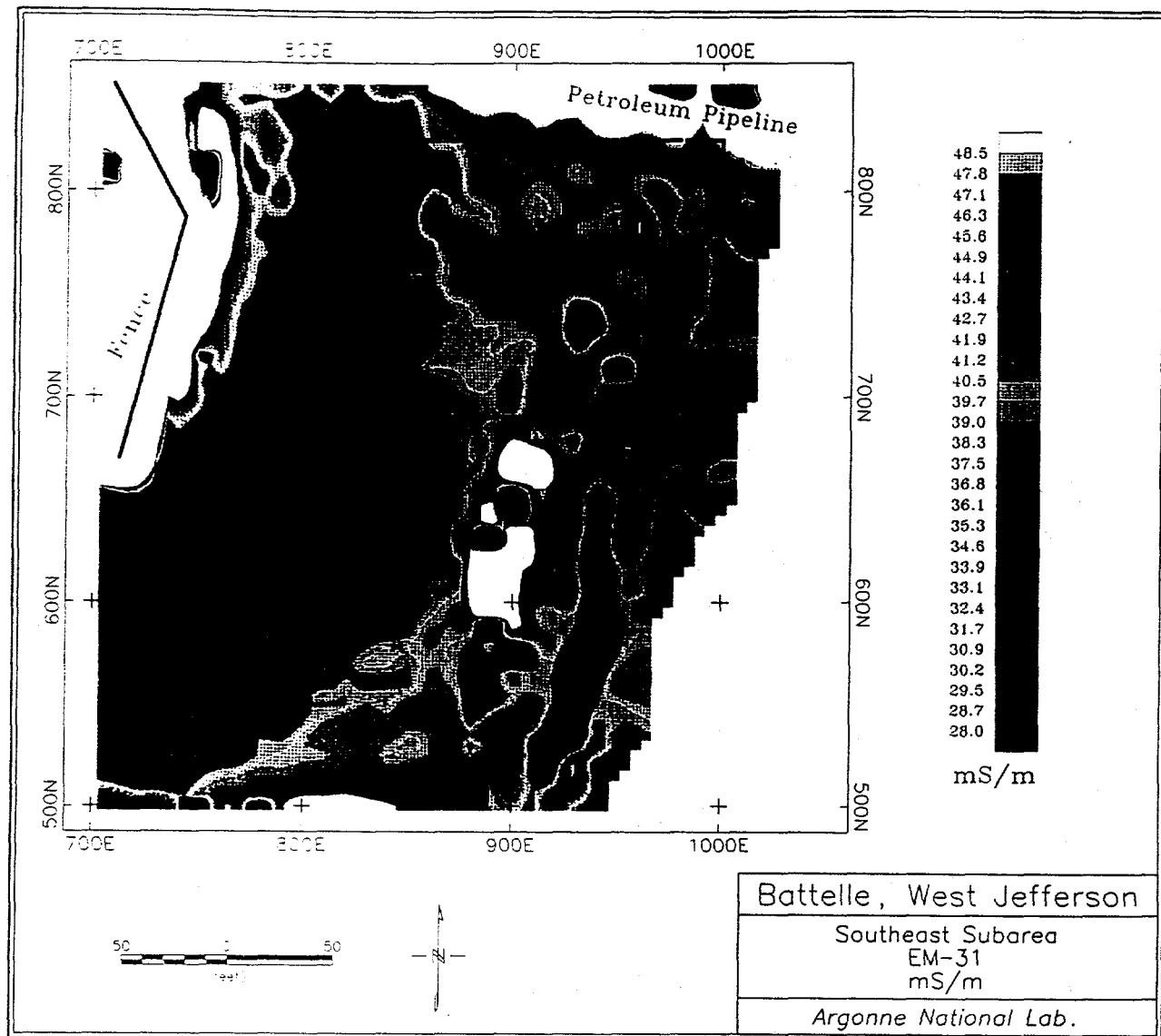


Figure 15. Map of Terrain Conductivity Anomalies Measured by the EM-31 in the Southeast Subarea

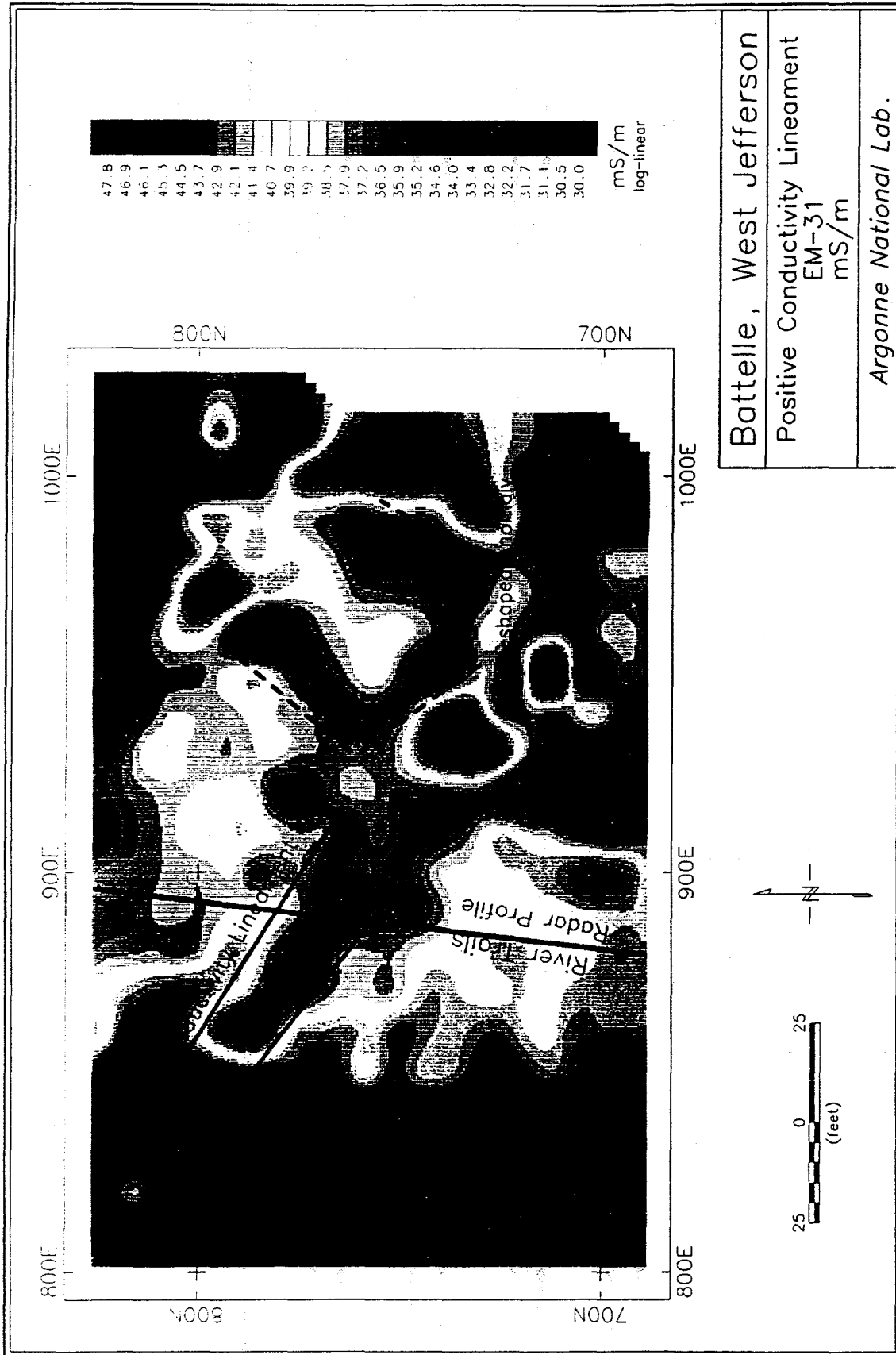


Figure 16. Map of Terrain Conductivity Anomalies Measured by the EM-31 in a Portion of the Southeast Subarea

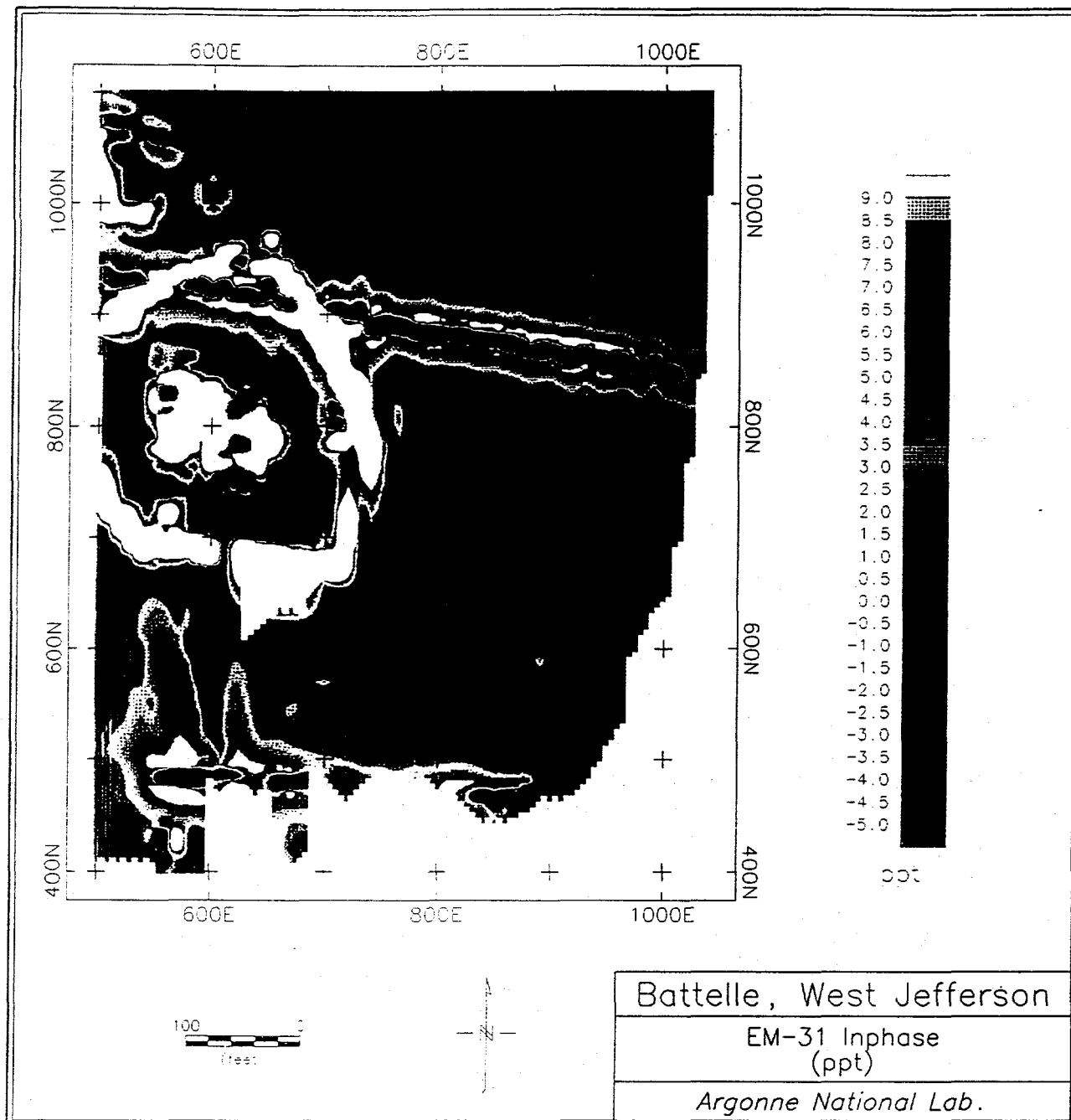


Figure 17. Map of In-Phase Conductivity Anomalies Measured by the EM-31 at Battelle West Jefferson

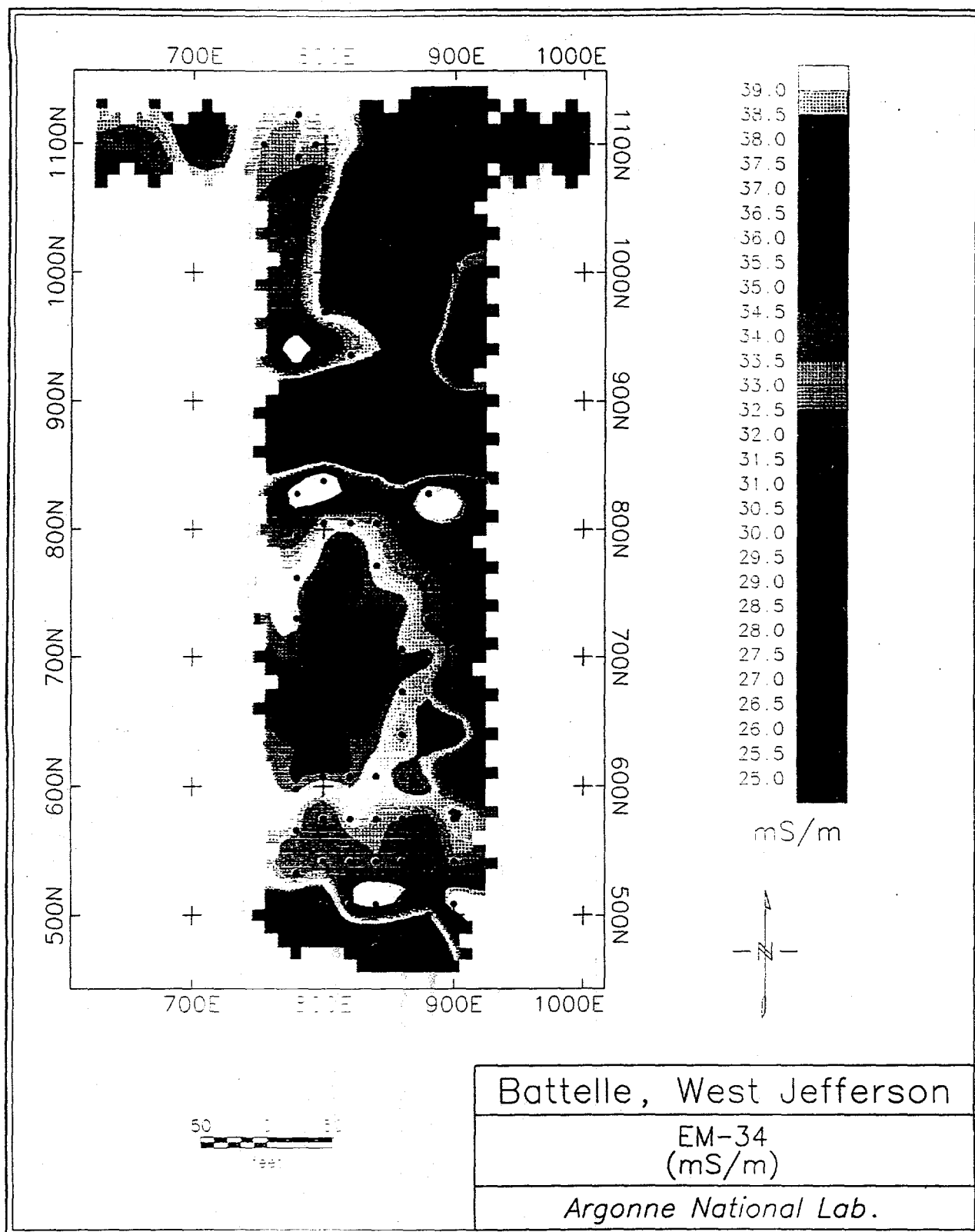


Figure 18. Map of Terrain Conductivity Anomalies Measured by the EM-34 at Battelle West Jefferson

South of the pipeline, broad areas of conductivity highs and lows also correlate with relative lows and highs in the topography. Ground saturation and electrical conductivity increase within a topographically low region.

4 Vertical Electrical Soundings

Electrical depth soundings were conducted at 12 locations on the floodplain (stations WJE1 through WJD7) and eight locations along the road crossing the dam (Figure 19). The earth layer models derived from the resistivity data are shown in Appendix A. In all cases, the resistivity of the bottom-most layer was fixed at 500 ohm-m to ensure model convergence.

The 12 resistivity soundings located on the floodplain were conducted along two N-S profiles, along 900E and 800E. Station spacing was 100 ft and each transect started at 1100N. Resistivity values ranged from 10 to 50 ohm-m in the upper 30 to 145 ft (overburden). Distinct layers in the overburden material could not easily be correlated between soundings; however, depth to bedrock was generally consistent. Few estimates of bedrock resistivities are available, because in most cases, bedrock was modeled with a fixed value of 500 ohm-m. In four earth resistivity models, however, bedrock resistivities ranged between 94 and 184 ohm-m.

Along profile 900E, the depth to bedrock generally increases from approximately 35 ft in the north to about 145 ft in the south. Bedrock depths along the 800E profile are estimated to be as much as 50 ft deeper than those determined along profile 900E. Noise produced by poor coupling between the electrodes and the soil can cause unrealistic estimates of depth.

Electrical resistivity stations WJCI0 to WJCI500 (Appendix A) show the resistivity-with-depth models for the six stations acquired along the road south of the dam. The stations were spaced every 100 ft along a south-to-north profile, with the first station (WJCI0, Appendix A) located adjacent to the oil storage tanks. Resistivities for the overburden range from 16 to 60 ohm-m and from 200 to more than 400 ohm-m for the bedrock. An average depth of approximately 60 ft was determined for the top of the bedrock, with the bedrock surface deepening to the north to approximately 85 ft.

Two resistivity soundings (Stations ND80 and ND0, Figure 19) were acquired on the northeast side of the dam, adjacent to the access road to the filter bed (Appendix A). Resistivities from 10 to 60 ohm-m are interpreted to be representative of the overburden and earthen fill for the dam. At ND80 and ND0, bedrock depths are 79 and 141 ft, respectively. These estimates correlate favorably with two deep borings drilled further south along the dam, which yielded bedrock depths of 108 and 85 ft.

A Schlumberger resistivity sounding was acquired along Rt. 142, with the north end of the electrode array located at the entrance gate to the main facility (Appendix A). The greater electrode spacings used by this array enabled sampling of a larger volume of the bedrock material than that used for the BOSS/Wenner arrays. A three-layer model is required to match the sounding data, with the upper two layers interpreted as overburden (16 and 75 ohm-m). Depth to bedrock is approximately 139 ft.

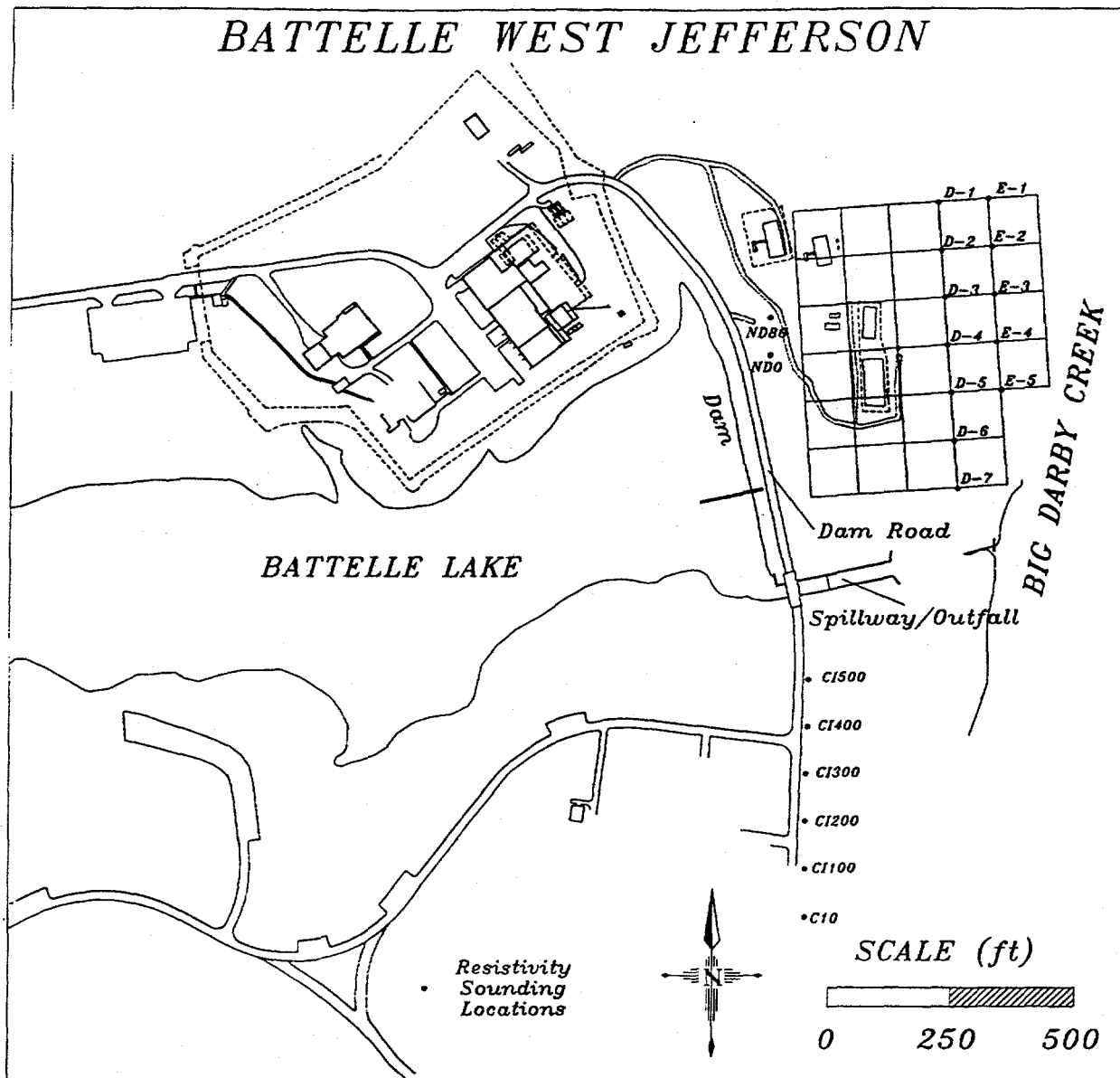


Figure 19. Map of Locations of Resistivity Soundings Conducted at Battelle West Jefferson

5 Ground-Penetrating Radar

The primary objective of the GPR survey was to help to better understand the shallow stratigraphy in and around the retired filter bed area at BWJ. GPR also proved useful in helping to locate some buried anthropogenic features. The dense vegetation within most of the study area limited opportunities for GPR surveying. Profiles were collected in open areas, along existing paths, and along cleared and graded swaths in the more densely vegetated areas. In all, 21 GPR profiles were collected. The location of GPR profiles is shown in Figure 20, and a complete list of the corresponding grid coordinates is given in Appendix B.

Both the 100- and 300-MHz antennas, in a bistatic configuration, were tested at BWJ. The GPR profiles collected with the 300-MHz antennas at a range setting of 250 ns provided the best data and were used over most of the site. The antennas were separated by a fixed distance of 4.5 ft, and profiles were collected in a continuous mode. An all-terrain vehicle was used to tow the antennas for most of the profiles; some profiles required that the antennas be pulled by hand in more densely vegetated areas. All of the profiles shown have been computer-processed with a vertical and horizontal low-pass, finite-impulse-response (FIR) boxcar filter. This filtering helps remove high-frequency noise and enhances structure at depth. Most of the profiles were also migrated by a hyperbolic summation method. Migrating the GPR data helps to remove diffracted reflectors and correct dipping layers. The data quality is quite variable across the entire site, most likely due to highly variable moisture and clay content in the upper 4-6 ft. The interpreted lithologies from the CPT data, which are discussed in Section 9, were used to help guide interpretation of the GPR data. On the basis of a correlation with CPT data, a two-way travel time of 12 ns/ft is used in the following discussion. The maximum resolvable depth was 10-15 ft in most profiles.

Two GPR profiles were collected inside the fence of the current filter bed area at BWJ. GPR profile #4 (Figure 21), collected from south to north, appears to image portions of the two retired filter beds, including underground piping and some dipping reflectors. The shallow, flat-lying reflectors shown in Figure 21 correspond very closely with the locations of the retired filter beds in Figure 20. The interpreted pipes in the middle of the profile required some additional processing in order to better resolve the feature. After this profile was migrated, the hyperbolas resolved into at least two underground pipes. Locations and depths of these pipes, shown in Figure 21, are based on the migrated data. The steeply dipping, V-shaped reflector may be associated with excavation work, and the deeper reflectors may be natural in origin. The profile collected 20 ft east of profile #4 also images the pipes, the dipping V-shaped reflector, and the deeper reflector. However, the shallow flat-lying reflector associated with the retired filter beds is absent, which corresponds with Figure 20. The pipes that are imaged inside the fence are not seen in the GPR profiles collected outside the fence.

The profiles from outside the fence were collected primarily to help gain a better understanding of the shallow stratigraphy at BWJ. At some locations outside the fence, uneven surface conditions and dense vegetation limited the effectiveness of GPR observations. However,

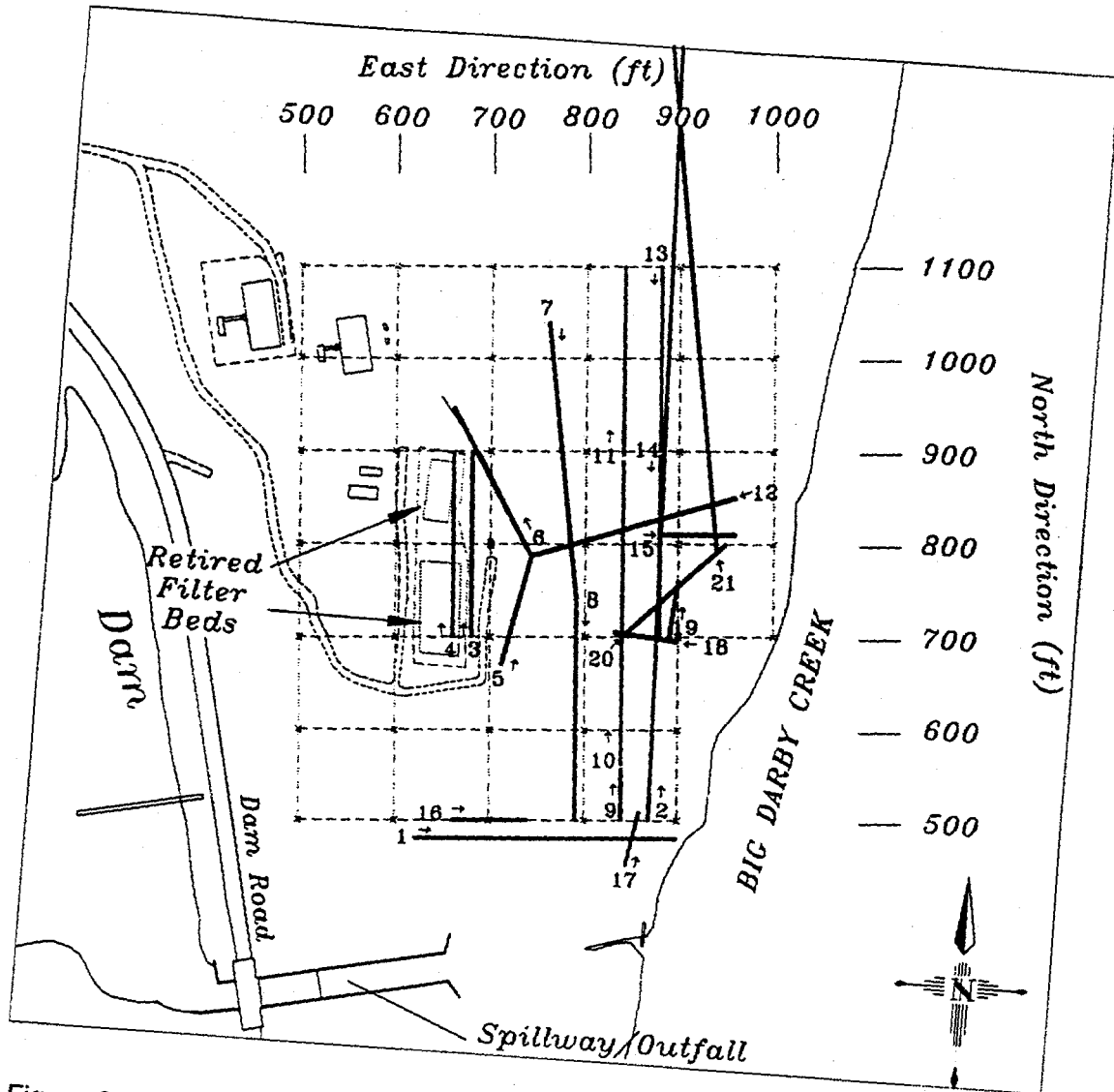


Figure 20. Map of GPR Profile Locations

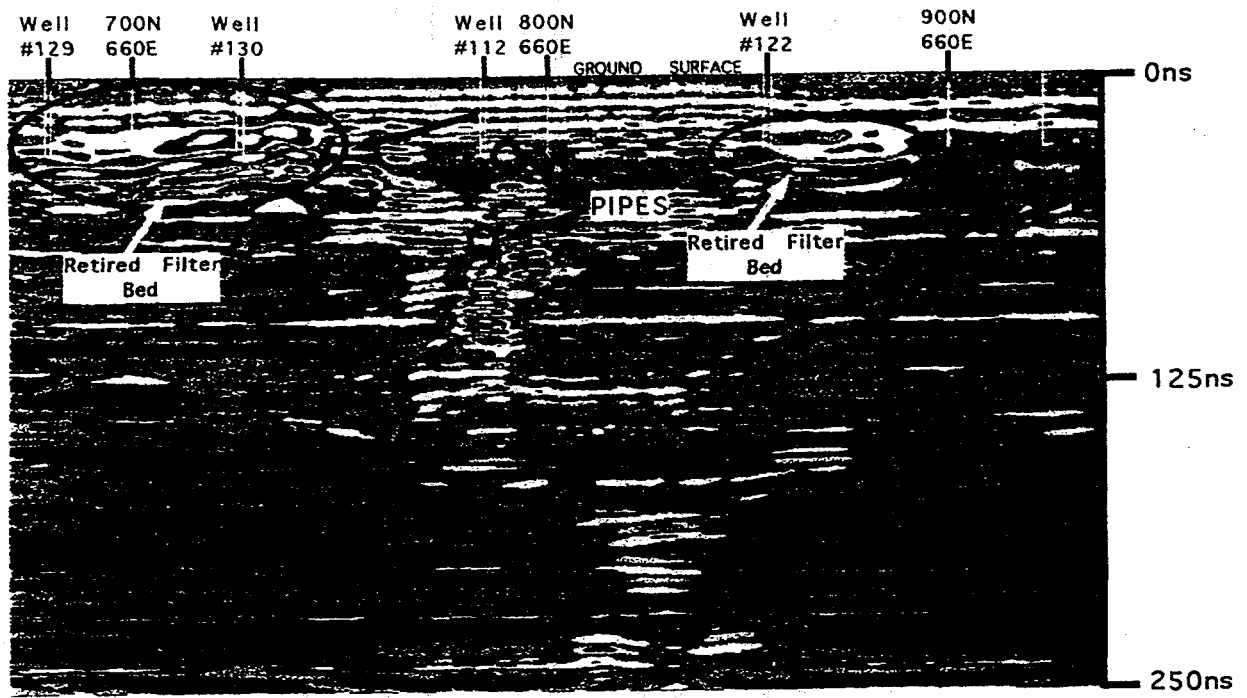


Figure 21. GPR Profile #4 across Retired Filter Beds

geologic structures of interest were imaged where surface conditions were favorable and where lithologic boundaries were sharp and well-defined. Profile #16, which was collected from west to east at the southern boundary of the survey area, is shown in Figure 22. Between 50 and 150 ns, bright yellow/orange reflectors are nearly continuous throughout the profile. The upper and lower boundaries are difficult to define with certainty. Accurate mapping of lithologies with GPR requires contacts of soils/rock with sharply contrasting electrical properties (i.e., electrical resistivity).

Figure 23 shows the first 400 ft of profile #2 (Figure 20). This profile, collected from south to north along the river trail road (roughly along 870E grid coordinates), crosses over four CPT sites (CPT-03 to CPT-06). After a low-pass FIR filter was applied and the profile was migrated, the reflectors became more resolvable. Similar to the profile shown in Figure 22, bright yellow/orange reflectors are observed in the middle of the profile. The top of this unit is not clearly defined, which is also most likely associated with the gradational nature of the contact. On the other hand, the bottom of this unit is more discernible in the first 200 ft of the profile.

Some limited GPR work was performed in Area 1 in an effort to make comparisons with previous Battelle soil bore data. GPR work in Area 1 consisted of several profiles. One of the GPR profiles is presented in Appendix D.

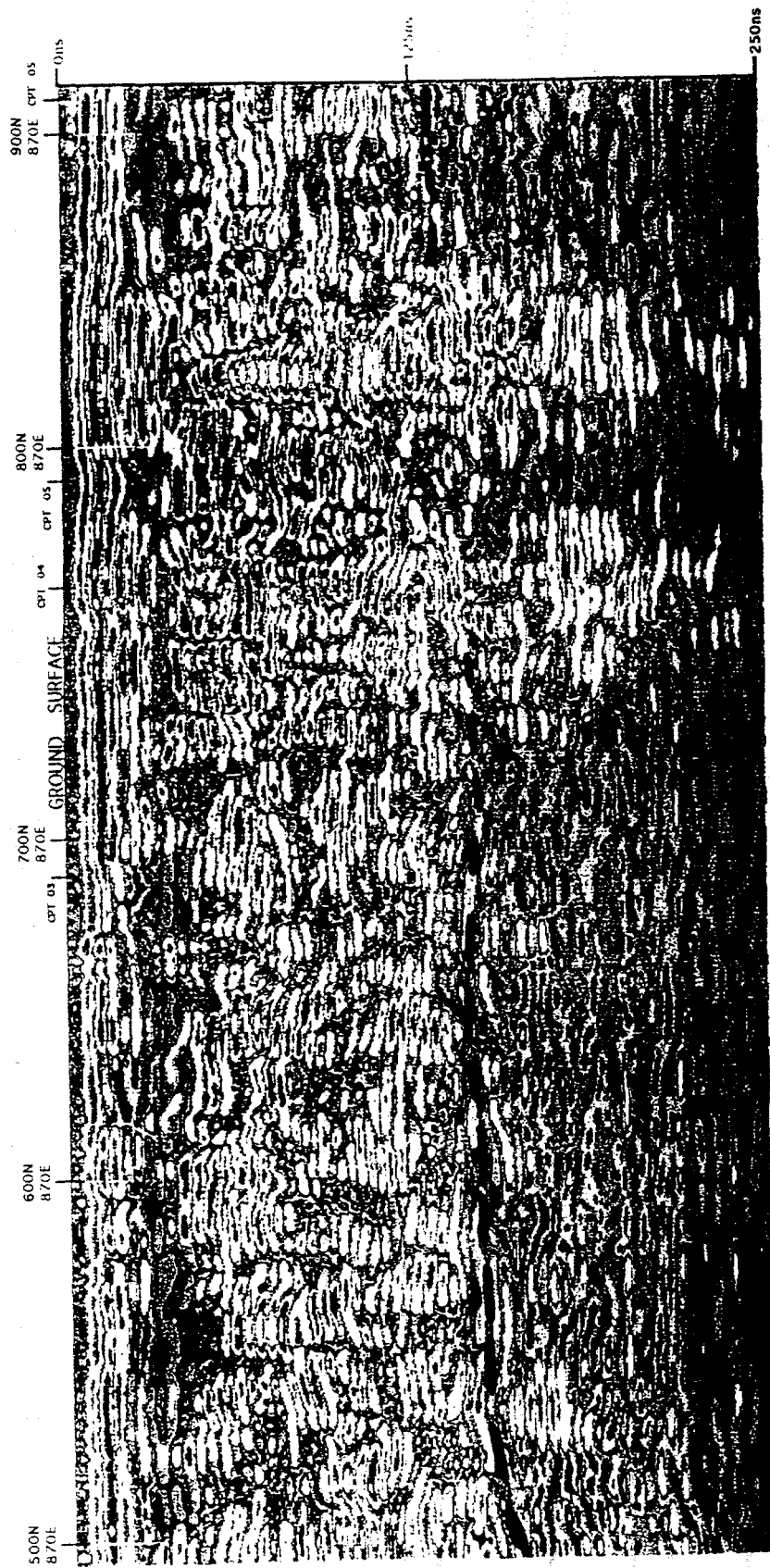


Figure 22. North-South GPR Profile (#2) along Geophysical Grid Coordinate 870E

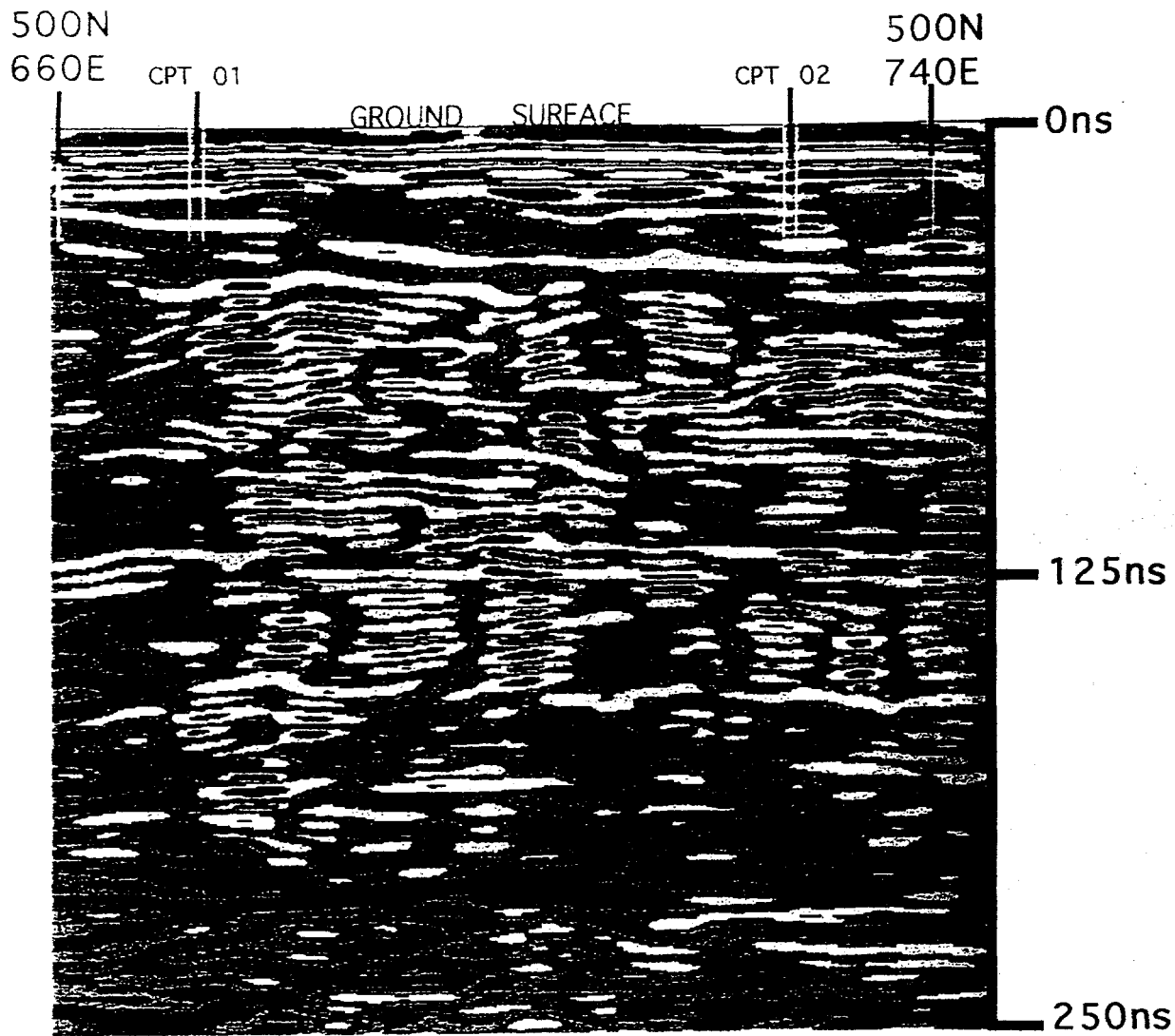


Figure 23. East-West GPR Profile (#16) along Geophysical Grid Coordinate 500N

6 Seismic Refraction Profiling

Seismic refraction profiles were recorded at six sites at BWJ. Four of the profiles (Lines 2, 3, 4, and 6) were located within or near the geophysical survey grid established around the retired filter beds (Figure 24); one profile (Line 1) was shot along the road crossing the Battelle Lake Dam, and one refraction station (Line 5) was sited along the south entrance road near Route 142. Figures 25-27 show the velocity and depth models obtained from the refraction data. Seismic velocities range from 6,234 to 7,744 ft/s for the overburden and 11,150 to 15,420 ft/s for the bedrock. These velocities are consistent with published results for glacial till and limestone in the western Ohio region (Wolfe and Richard 1992).

The velocity-depth structure determined from the refraction profile shot along the road crossing the Battelle Lake Dam (Line 1) is shown in Figure 25. The seismic line is oriented north-to-south, with the northern end of the profile starting near the access road to the filter beds. A four-layer earth model is required to convert the measured travel times into velocities and depths. The upper two layers (2,625 and 3,609 ft/s) are interpreted to represent near-surface soils and earthen fill used for construction of the dam. The third layer, with a velocity of 7,723 ft/s, is interpreted as glacial till. The fourth layer (15,528 ft/s) is interpreted as bedrock. At the northern end of the profile, a bedrock valley is identified beneath the Battelle Lake Dam. However, the bedrock depth at borehole DB-5 is approximately 60 ft shallower than the seismic refraction bedrock surface (Figure 25), indicating that the velocity perturbations associated with the dam fill material were not successfully modeled. The bedrock depths at the southern end of the profile should be unaffected by dam fill material and suggest that the bedrock surface is relatively flat along this profile.

Seismic Line 2 was recorded on a NNW-SSE strike in the grassy area between the dam and the access road to the filter beds. Line 2 extends the velocity-depth information north from Line 1; the velocity-depth structure is shown in Figure 25. Velocities of 7,477 ft/s indicated for the overburden and 12,011 ft/s for the bedrock compare favorably with those obtained along refraction Line 1. The bedrock surface is relatively flat and averages 774 to 792 ft in elevation.

Figures 26 and 27 are velocity-depth cross sections constructed from refraction lines 3, 4, and 6. These profiles were recorded on the floodplain. Line 4 is oriented north-to-south; Line 6, south-to-north along grid coordinate 800E; and Line 3, west-to-east. Seismic velocities in this area range from 6,014 to 7,477 ft/s for the overburden and from 12,418 to 13,285 ft/s for the underlying bedrock. Both Line 4 and Line 6 indicate that the bedrock surface slopes toward the south, changing in elevation from approximately 820 ft on the north to 760-770 ft at the south end of each profile. At the intersections between Line 3 and Lines 4 and 6 (Figure 26), bedrock depths differ by less than 20 ft. The bedrock surface is approximately 33 ft higher in the northwest part of the survey grid than that observed along refraction Line 2 to the west.

The velocity-depth structure determined from refraction Line 5 (south entrance road) is shown in Figure 27. Surface elevations and grid coordinates are unavailable for this profile because it was obtained outside of the geophysical survey area. This refraction information was

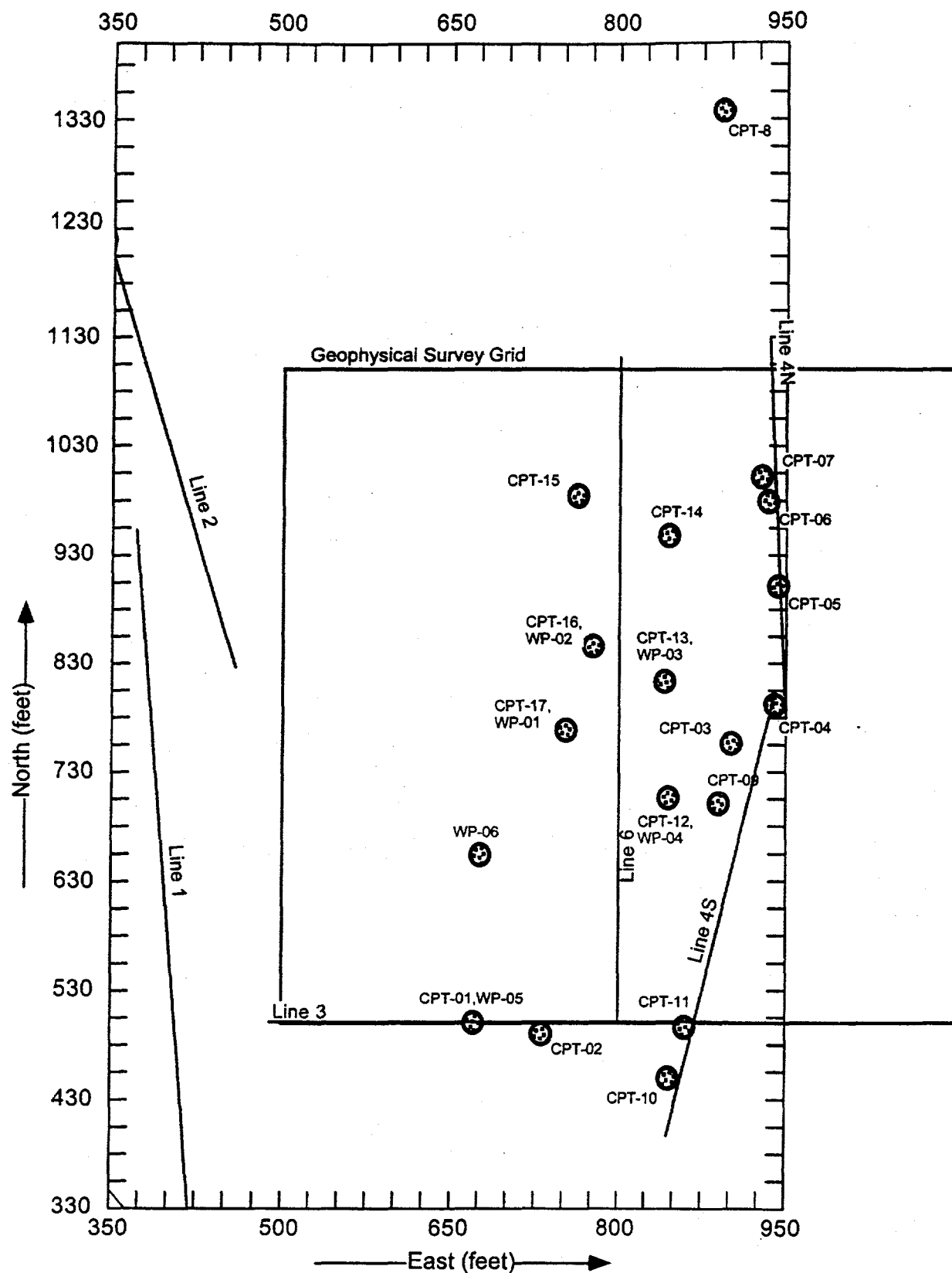


Figure 24. Map Showing Locations of Seismic Refraction Profiles, CPT and Piezometer Sites

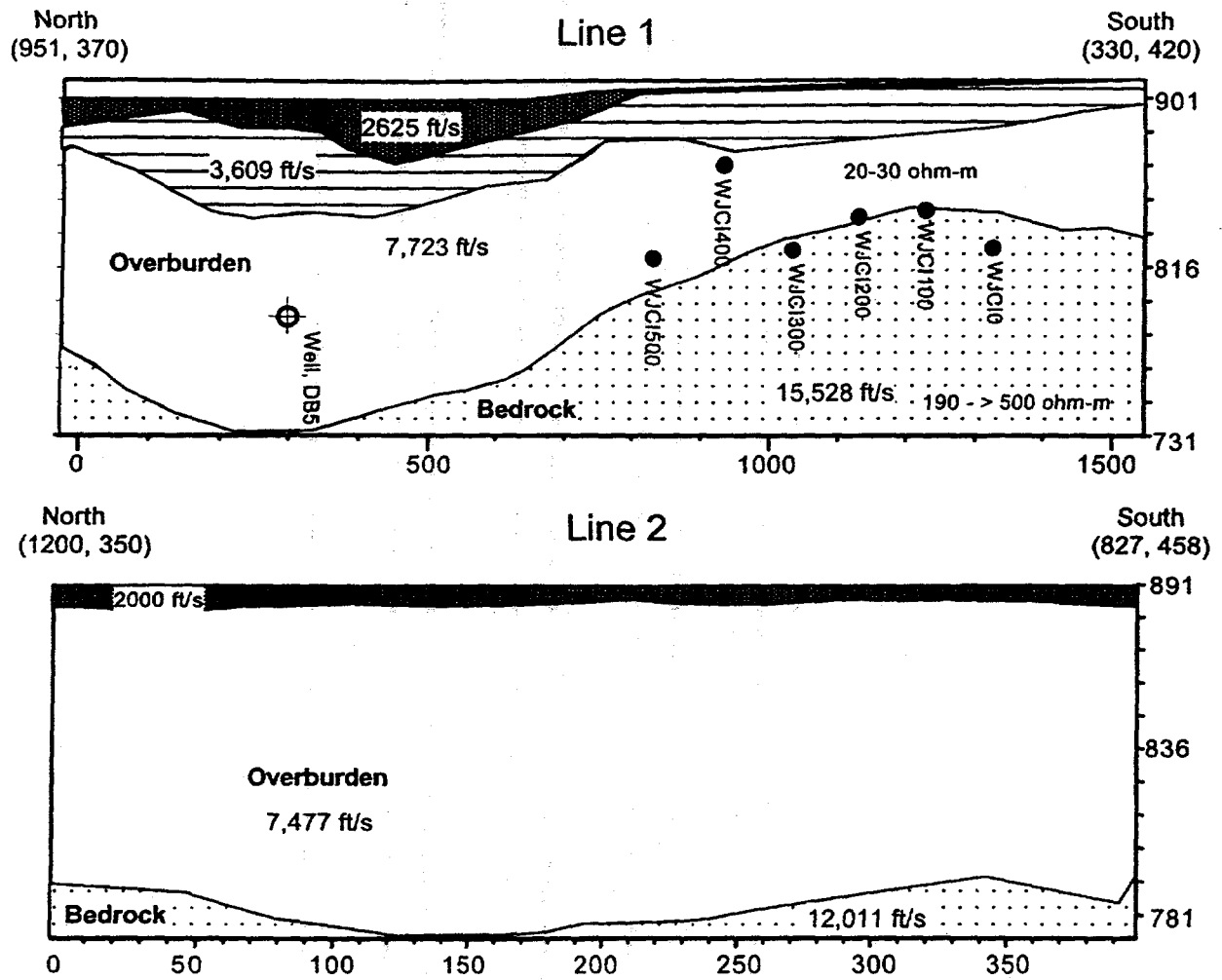


Figure 25. Results of Modeling along Seismic Lines 1 and 2

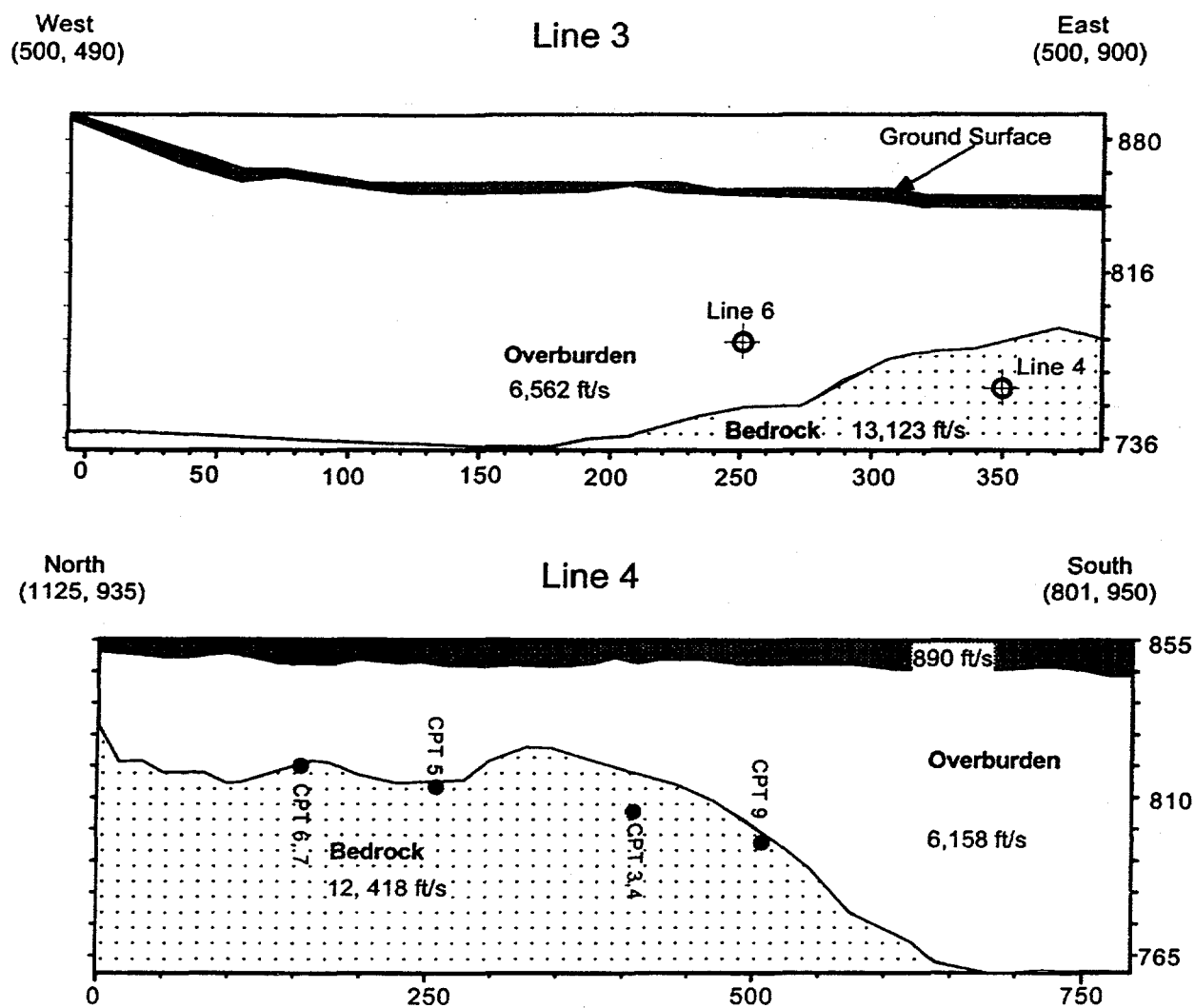


Figure 26. Results of Modeling along Seismic Lines 3 and 4

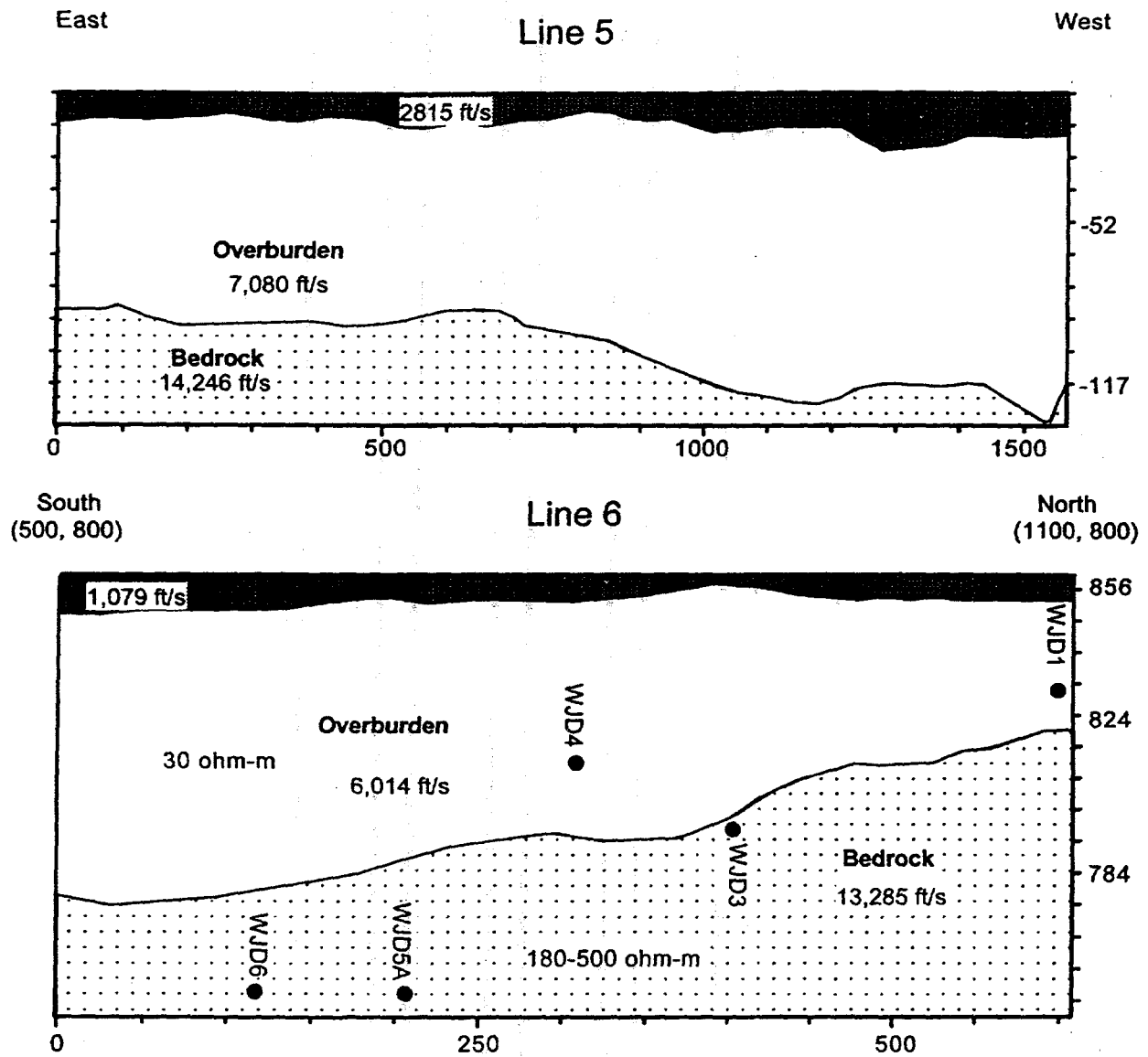


Figure 27. Results of Modeling along Seismic Lines 5 and 6

acquired along the south entrance road to BWJ and is useful in that it provides a more regional definition of the velocity and depth/thickness for the bedrock and overburden material. A three-layer model was used to convert the refraction information into velocities and thicknesses. Bedrock velocities ranged from 13,000 to 16,000 ft/s, with a mean velocity of 14,246 ft/s used in the model. For the overburden, velocities ranged from 6,171 to 7,874 ft/s, and a mean velocity of 7,080 ft/s was used to invert the refraction data. The bedrock surface deepens to the west, changing from approximately 92 ft in depth at the east end of the profile to a maximum depth of 117 ft toward the west end of the profile.

7 Cone Penetrometer Testing

Seventeen CPT soundings were performed along three north-to-south transects in the floodplain of Big Darby Creek just east of the retired filter beds. The locations of the CPT soundings are indicated in Figure 24 and in Table 3; they are labeled CPT01 through CPT17. The soundings were performed over a three-day period, and decisions about the CPT coordinates and the investigation depths were made by the project team in real time. Soundings were located where geophysical results, principally the ground-penetrating radar, suggested that coarser, unconsolidated units might be more developed, and where it was necessary to better understand the geologic and hydrogeologic frameworks.

Table 3 CPT Locations and Elevations at West Jefferson Filter Bed Area

CPT I.D	Grid Coordinates		Ground Surface	
	North	East	Elevation (MSL, ft)	Total Depth Below Ground Surface (ft)
01	499.41	670.94	859.48	45.8
02	495.62	729.57	859.69	77.9
03	758.37	901.44	859.61	52.8 ^a
04 ^b	790	941	~859	51.9 ^a
05	902.62	947.30	859.37	41.9 ^a
06	981.66	932.32	859.49	37.1 ^a
07	1000.27	926.21	859.39	35.1 ^a
08	1337.01	892.42	859.91	19.8 ^a
09	700.06	890.83	860.65	57.7 ^a
10	450.36	845.67	858.34	74.3
11	496.18	860.62	858.40	58.0
12	706.59	845.91	861.82	50.0
13	815.81	841.35	856.72	51.0
14	949.80	844.92	857.26	44.2 ^a
15	985.48	763.49	857.72	22.7
16	851.69	774.81	857.49	37.1
17	768.23	750.14	860.43	50.0

^a Field Interpretations of Refusal on Bedrock.

^b CPT-04 was not surveyed by contracted land surveyor. ANL measured location based on existing survey grid and estimated elevation from other nearby CPT locations.

The primary objectives of the CPT sounding work at the BWJ site were to determine the optimal placement and target depth for the wellpoints and to provide ground truth to the geophysical surveys. Relevant factors that had to be carefully considered while performing this intrusive investigative task included concerns about the proximity of the subject area to a Federal

Scenic River, access limitations with the CPT truck, and a need for streamlined project scope and cost. With respect to the nearby Federal Scenic River, the scope of the nonintrusive and intrusive investigations addressed the concern about preservation of existing vegetation, to the greatest extent possible, and CPT soundings and wells were placed at appropriate setback distances from the Big Darby Creek. Access through the heavily wooded areas of the floodplain was provided by means of selective removal of younger growth trees, less than 6 in. in diameter, in conjunction with limited grading. Access was limited to that existing along the river trail road and to three north-south-trending transects that were utilized to collect supplementary GPR data for establishing the CPT locations in real time. Grading was necessary to remove loose ground litter prior to GPR data collection and to remove terrain obstacles to the CPT truck. Grading, performed with a bobcat and a D5 Caterpillar bulldozer, was done while GPR and CPT work were being performed elsewhere on the site.

The scope of the intrusive investigation was streamlined by utilizing the CPT electrical logging information, tip resistance, sleeve resistance, pore pressure, and soil resistivity curves to establish stratigraphic correlations between CPT holes. As the CPT logging results between holes became available, preliminary stratigraphic interpretations were made in the field to guide the location and depth of the succeeding CPT locations. Figure 28 illustrates the proposed correspondence between stratigraphic correlations established at CPT17 with a previously drilled Battelle shallow soil bore, R144, located inside the fenced retired filter bed area. Good correlation does exist between the electronic logging data at CPT17 and the soil descriptions from that shallow bore. The distance between the CPT17 control hole and R144 is approximately 70 ft. Although the CPT data have been helpful for understanding the stratigraphy, significant enhancements can be made by conducting some deep soil bores and obtaining soil descriptions as improved CPT control points.

On the basis of electric logging data, available subsurface information, and other published literature on CPT responses, the unconsolidated overburden materials were tentatively subdivided into three units, in descending order: (1) an alluvial/fluviol layer consisting of silty clay to silt (CL-ML according to the Unified Soil Classification System), (2) an outwash layer consisting of silty sand (SM) to sand, and (3) a cohesive layer probably consisting of till. The silty clay to silt layer corresponds to the Medway Series soils that were mapped at the BWJ floodplain area (USDA 1981). In Madison County, those Medway Series soils may also include an underlying silty sand or clayey sand (SM or SC) layer at depths of 3 to 5 ft.

Results of this investigation indicate that the recent alluvial/fluviol silty clay and an underlying sand drape over approximately 12 ft of relief on the till surface. The silty clay and the underlying sand unit are continuous in the study area. The sand layer, in particular, was scrutinized to detect thickening trends or areas of enhanced transmissivity. It ranges from 2 to 5 ft in thickness, based on careful scrutiny of the Battelle soil descriptions. At some Battelle bore locations in the retired filter bed area, it appears that further confirmation of the soil stratigraphy may be warranted to better understand the conditions. Figure 9 is a geologic profile, based on Battelle soil bore data, that illustrates the distribution of granular deposits that underlie the retired

Figure 28. Comparison of Geologic Log from Borehole R144 and CPT17 Electronic Log

filter bed area. Analysis of the electrical logging data was fully exploited as a mechanism to recognize subtle trends regarding the thickness of the sand in the CPT holes; however, those possible trends require confirmation with additional soil sampling descriptions. The top of the glacial till in the floodplain area was previously reported in a number of shallow Battelle soil borings, at depths of approximately 12 ft. A structure contour map of the top of the till, based primarily on the CPT correlations, is shown in Figure 29. The surface of the till declines eastward, and a broad ridge of low relief extends east to west. Analysis of the CPT logging curve correlations and characteristics also shows that those deposits and one or more subunits thicken in a south-southeast direction.

Initially, CPT soundings were performed along the river trail road; these involved eight holes (CPT03 through CPT08, CPT10 and CPT11) that penetrated between 78 and 20 ft of unconsolidated overburden materials. Another two CPT soundings, CPT01 and CPT02, were performed just east of the Battelle Lake Dam and reached depths of 46 and 78 ft, respectively. The continuous logging curve data from CPT01 and CPT02 are shown as a geologic profile on Figure 30; this profile corresponds with GPR line #16 (Figure 23). Table 4 provides depths to lithologies of all of the CPT soundings. Figure 31 illustrates the geologic profile, utilizing the electric logging curve data from CPT03 through CPT06 along the frontage trail road. This profile corresponds with the transect of GPR line #4 (Figure 22). The geologic profiles provided in this report can only represent a generalized interpretation of the subsurface geology at this time. More detailed interpretation of the CPT records cannot be performed until some selected deep soil bores are conducted at some of the CPT holes. Additional soil bore data would facilitate detailed delineation of stratigraphic units by enabling the electronic responses to be calibrated with direct observations of the subsurface geology.

Some of the CPT holes were terminated because the sensor tip encountered refusal conditions (i.e., bedrock or, alternatively, very coarse unconsolidated materials). Evaluation of the nonintrusive geophysical survey data supports the conclusion that the observed refusal depths coincide with the top of bedrock. (Note that six out of the eight of the CPT holes along this traverse encountered refusal). An interpreted north-south geologic profile is provided as Figure 32a and b. The profile is an interpretation of the CPT data and portrays a generalized view of the stratigraphy. Numerous localized changes were recognized in the CPT data, but they cannot be confidently interpreted on the basis of the available subsurface geologic information. This diagram does illustrate that the bedrock surface noticeably declines toward the south, with approximately 32 ft of relief between CPT08 and CPT03.

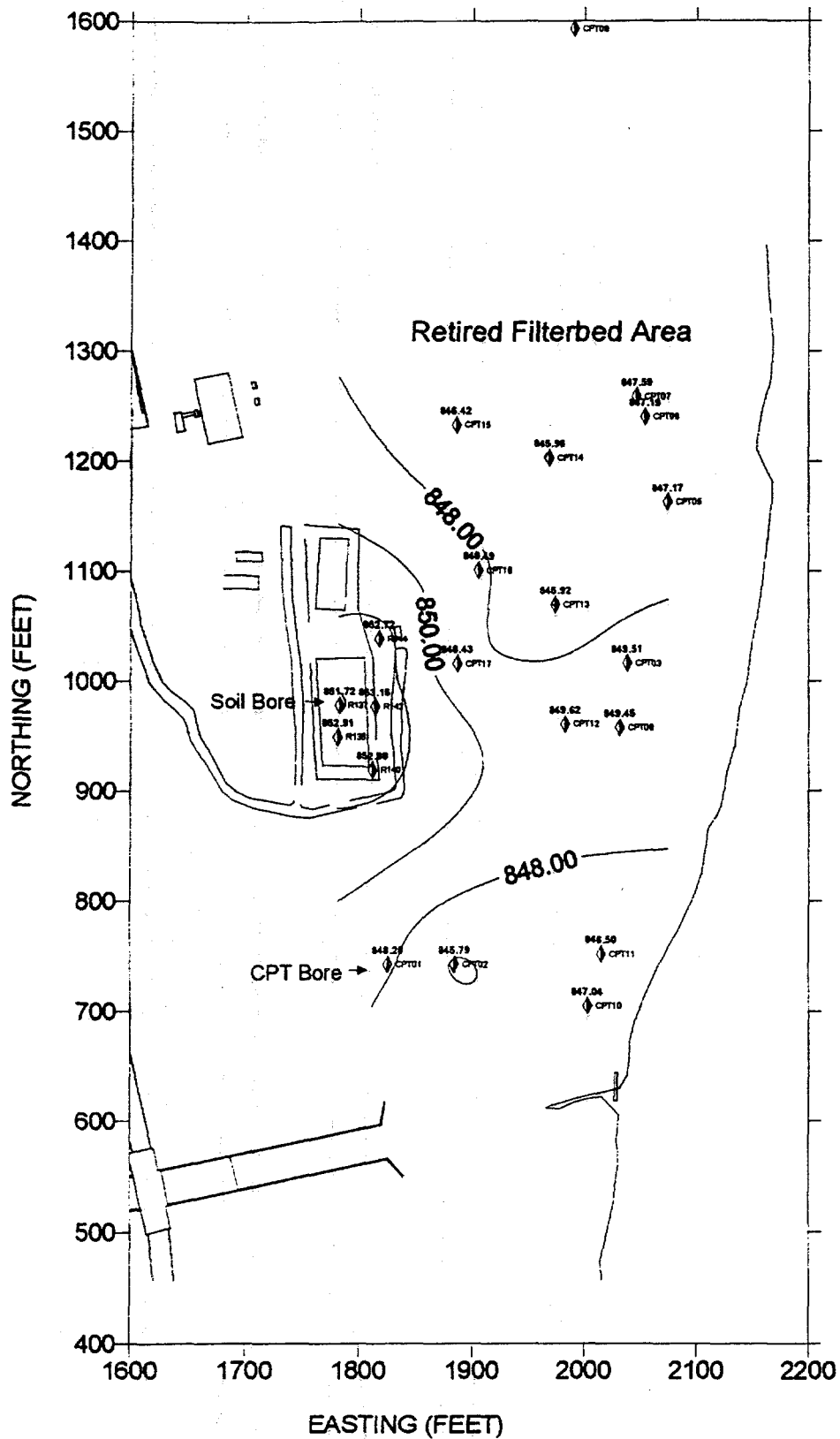


Figure 29. Structural Contour Map of the Top of the Glacial Till

Table 4. Information from Cone Penetrometer Soundings

Location	Surface Elevation TOC (ft, MSL)	Top of Sand Unit Elevation (ft)	Top of Till Unit Elevation (ft)	Top of Clay Unit Elevation (ft)	Bottom Hole Elevation (ft)
CPT01	859.48	853.08	848.28	nde	813.68
CPT02	859.69	851.09	845.79	811.09	781.79
CPT03	859.61	852.81	849.51	absent	806.81
CPT04	859.44	^a	^a	^a	807.1
CPT05	859.37	849.37	847.17	820.67	817.47
CPT06	859.49	850.19	847.19	826.09	822.39
CPT07	859.39	850.39	847.59	826.79	824.29
CPT08	859.92	851.62	846.72	absent	840.12
CPT09	860.65	852.45	849.45	814.65	802.95
CPT10	858.34	849.94	847.04	809.54	784.04
CPT11	858.4	849.8	846.5	809.2	800.4
CPT12	861.82	852.52	849.62	814.32	811.82
CPT13	856.72	849.72	845.92	813.12	805.72
CPT14	857.26	848.76	845.96	818.26	813.06
CPT15	857.72	849.32	846.42	absent	835.02
CPT16	859.69	852.69	848.49	nde	822.59
CPT17	848.28	850.93	848.43	811.63	810.43

^aElevation was measured, but coordinates for this CPT hole are estimated.

Three additional CPT soundings were performed along a north-south transect at the 845 east coordinate line and on a north-south transect along the 750 to 780 east coordinate line. The CPT soundings along the 845 east line included CPT 12 through CPT14 and ranged in depth from 44 to 51 ft. The other transect, involving CPT15 through CPT17, ranged from 23 to 50 ft in depth. At CPT15, refusal was encountered at a depth of approximately 23 ft.

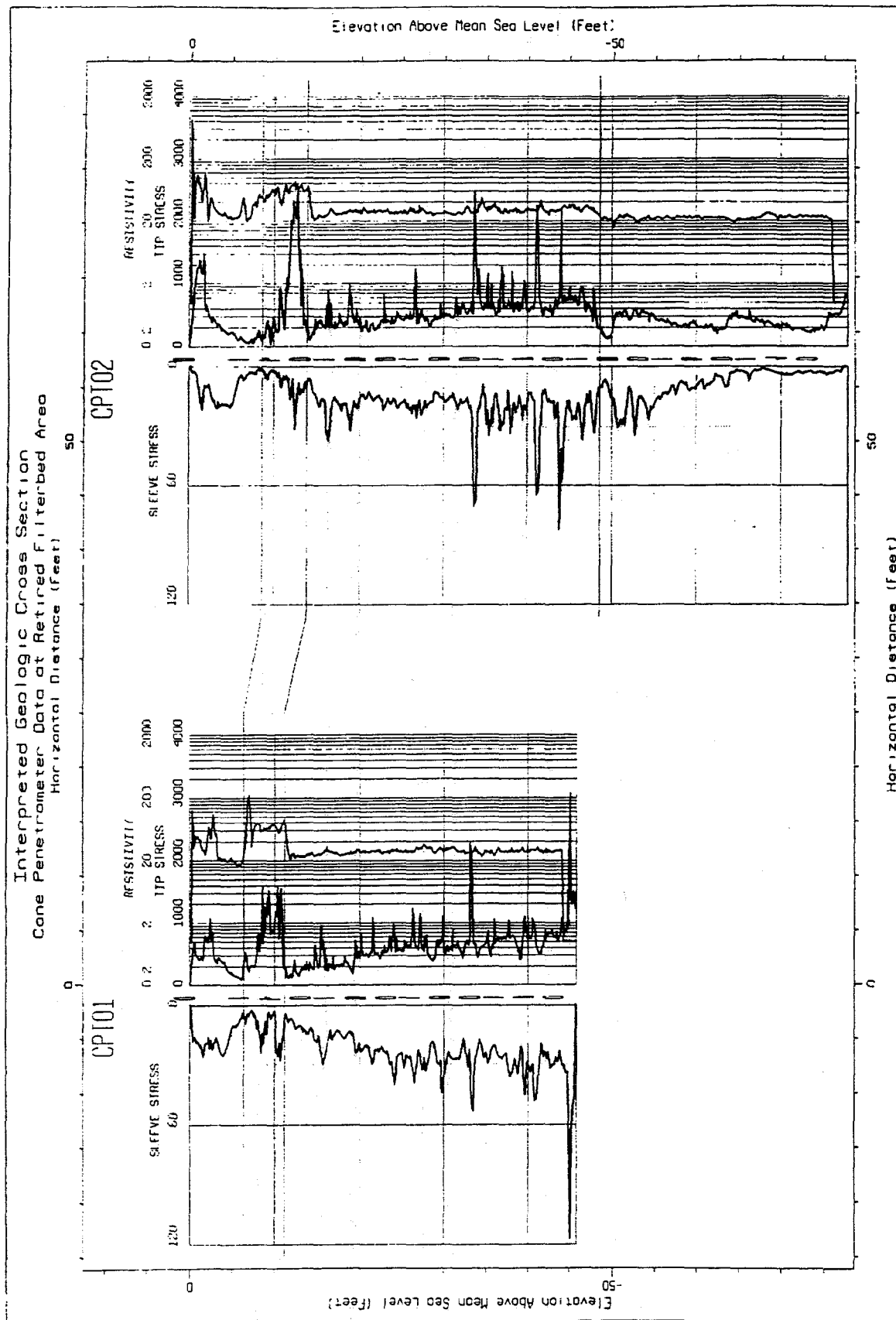


Figure 30. Correlation of CPT Electric Log Data from CPT01 and CPT02

Interpreted Geologic Cross Section Cone Penetrometer Data at Retired Filterbed Area

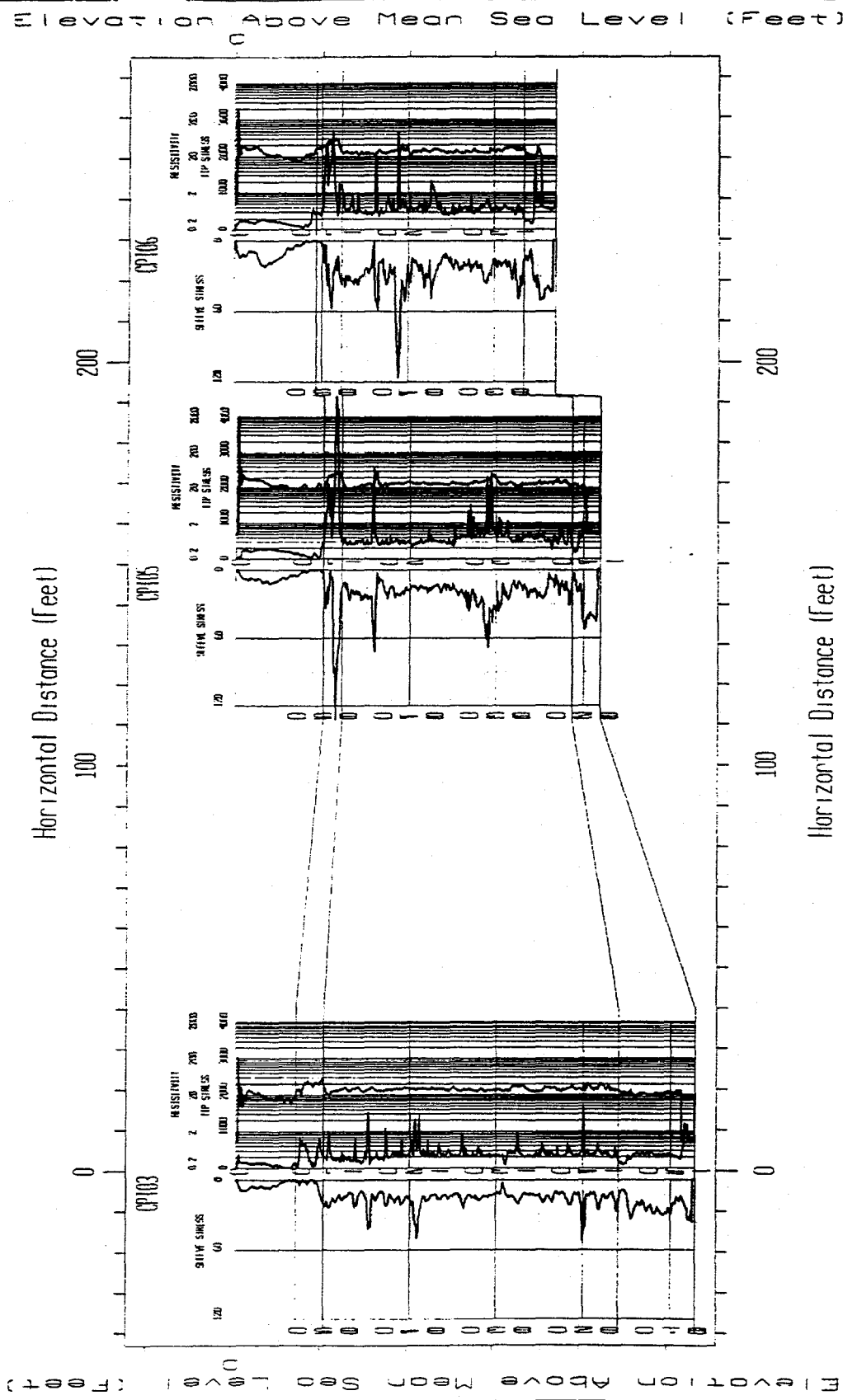


Figure 31. Correlation of CPT Electric Log Data from CPT03, CPT05, and CPT06

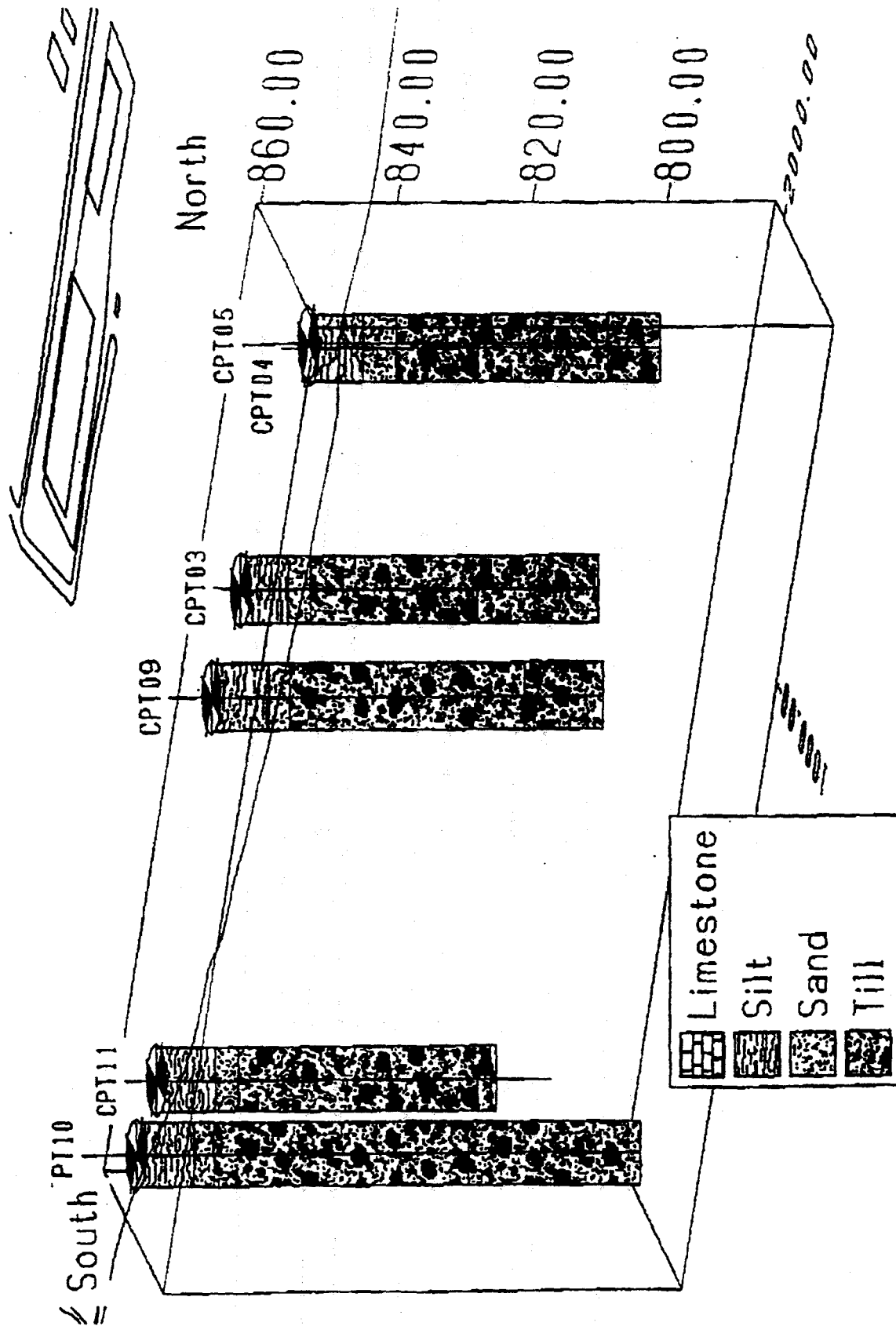


Figure 32a. Interpreted N-S Profile of CPT Borings, Left Panel

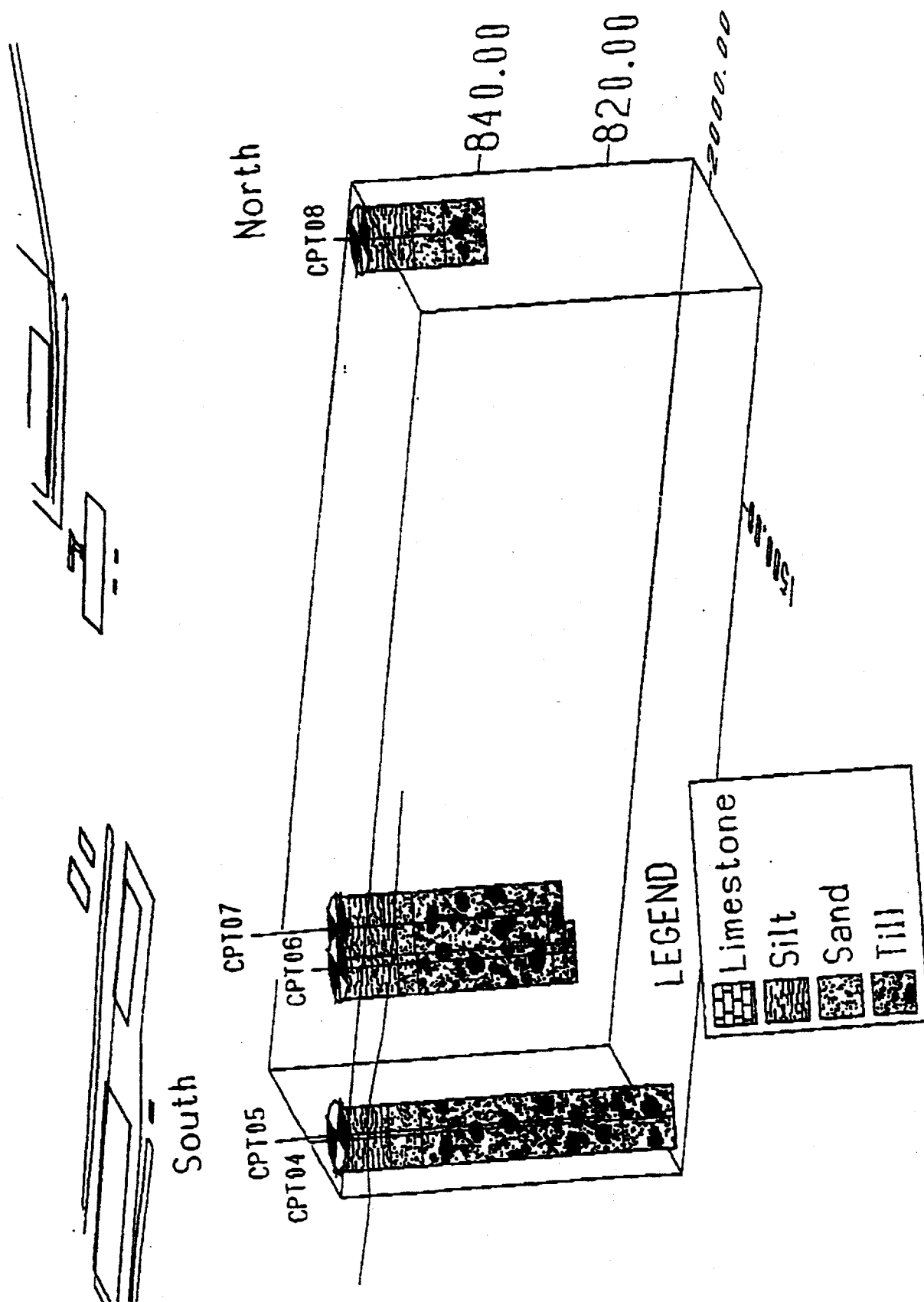


Figure 32b. Interpreted N-S Profile of CPT Borings, Right Panel

8 Piezometer Measurements

Groundwater levels were measured on five occasions at the six wellpoints: September 1995; October 9, 1995; November 8, 1995; November 22, 1995; and June 6, 1996. The measurements were obtained in an effort to better understand the fluctuation of groundwater in response to seasonal and climatic changes. The water levels were measured with an electric tape and reported to ± 0.01 ft. ANL personnel took the initial water level measurements in September 1995, and BCLDP personnel obtained the measurements on the other events. In conjunction with the collection of groundwater levels, Battelle personnel also record barometric pressure and temperature at the time of measurements. As a result of the survey work that Woolpert performed on April 21, 1996, elevation control was obtained at the two Battelle surface water monitoring stations along Big Darby Creek. This was done so that Battelle, in the future, could measure water levels in the river in conjunction with the collection of groundwater measurements.

Details of well construction are listed in Table 5. Table 6 shows the groundwater measurements for the six piezometers, and Figures 33a and 33b illustrate the hydrographs for them. In Figure 33a, WP01, WP02, WP04, and WP06 behave similarly and have groundwater fluctuations between elevations 854 and 857. Figure 33b shows that WP03 and WP05 have a narrower range of groundwater fluctuations, 853 to 854 ft, because of the proximity to the river stage. Associated with the groundwater measurements at the piezometers, BCLDP personnel also measured the groundwater levels in 13 existing monitoring wells in the retired filter bed area on November 22, 1995, and June 6, 1996. Groundwater elevation data for the 13 wells are presented in Table 7. The 13 wells were installed by Battelle in the 1990 investigation and were indicated to be approximately 10 ft deep, with 2.5 ft screens at the base. BCLDP recently sounded the depths of the wells. Although the existing 2-in.-diameter wells were installed blind, a number of wells are situated close to soil bores that were continuously sampled by Battelle. Among the limitations of these wells, the position of the screen may not coincide with the same lithologic unit between the holes or be optimal for monitoring the groundwater conditions. In terms of the new piezometers, five were located adjacent to a CPT hole, and one was installed without an adjacent CPT hole. Figure 34 shows the generalized geology associated with the piezometers at the retired filter bed area.

Table 5. Temporary Piezometer Locations

Piezometer I.D.	Grid Coordinates		Elevation (MSL, ft)	Total Depth
	North	East	Top of Inner Casing	Below Ground Surface (ft)
WP-01	765.10	749.04	863.81	12.06
WP-02	845.23	772.43	863.17	12.85
WP-03	819.71	839.06	859.99	9.80
WP-04	712.13	843.06	865.36	12.84
WP-05	505.08	661.44	863.11	12.72
WP-06	645.28	774.07	866.69	12.84

Table 6. Groundwater Elevation Data for Six Well Points in the Battelle West Jefferson Retired Filter Bed Area

Well	Reference Elevation (ft, MSL)	Groundwater Elevation (ft)				
		9/24/95	10/9/95	11/8/95	11/22/95	6/6/96
WP01	863.81	854.31	855.94	855.3	855.82	857.00
WP02	863.17	854.34	856.04	855.32	855.93	857.22
WP03	859.99	851.82	853.48	852.8	853.35	854.59
WP04	865.36	854.27	855.85	855.22	855.72	856.96
WP05	863.11	848.90	853.37	852.81	853.35	854.30
WP06	866.69	854.26	855.74	855.12	855.59	856.84

Table 7. Groundwater Elevation Data at the Battelle West Jefferson Retired Filter Bed Area

Well	Reference Elevation (ft, MSL)	November 22, 1995		June 6, 1996	
		Groundwater Depth (ft)	Groundwater Elevation (ft)	Groundwater Depth (ft)	Groundwater Elevation (ft)
WP01	863.81	7.99	855.8	6.81	857
WP02	863.17	7.24	855.9	5.95	857.22
WP03	859.99	6.64	853.4	5.4	854.59
WP04	865.36	9.64	855.7	8.4	856.96
WP05	863.11	9.76	853.4	8.81	854.3
WP06	866.69	11.1	855.6	9.85	856.84
122	864.97	8.82	856.2	7.36	857.61
116	865.6	9.41	856.2	7.82	857.78
118	863.64	7.65	856	5.78	857.86
112	866.96	10.71	856.3	9.19	857.77
101	863.76	7.83	855.9	6.5	857.26
124	865.03	8.96	856.1	7.43	857.6
125	865.4	9.38	856	7.81	857.59
103	864.9	8.99	855.9	7.58	857.32
129	866.8	10.77	856	9.31	857.49
130	865.3	9.19	856.1	7.57	857.73
111	868.24	11.96	856.3	10.31	857.93
113	863.65	7.81	855.8	6.89	856.76

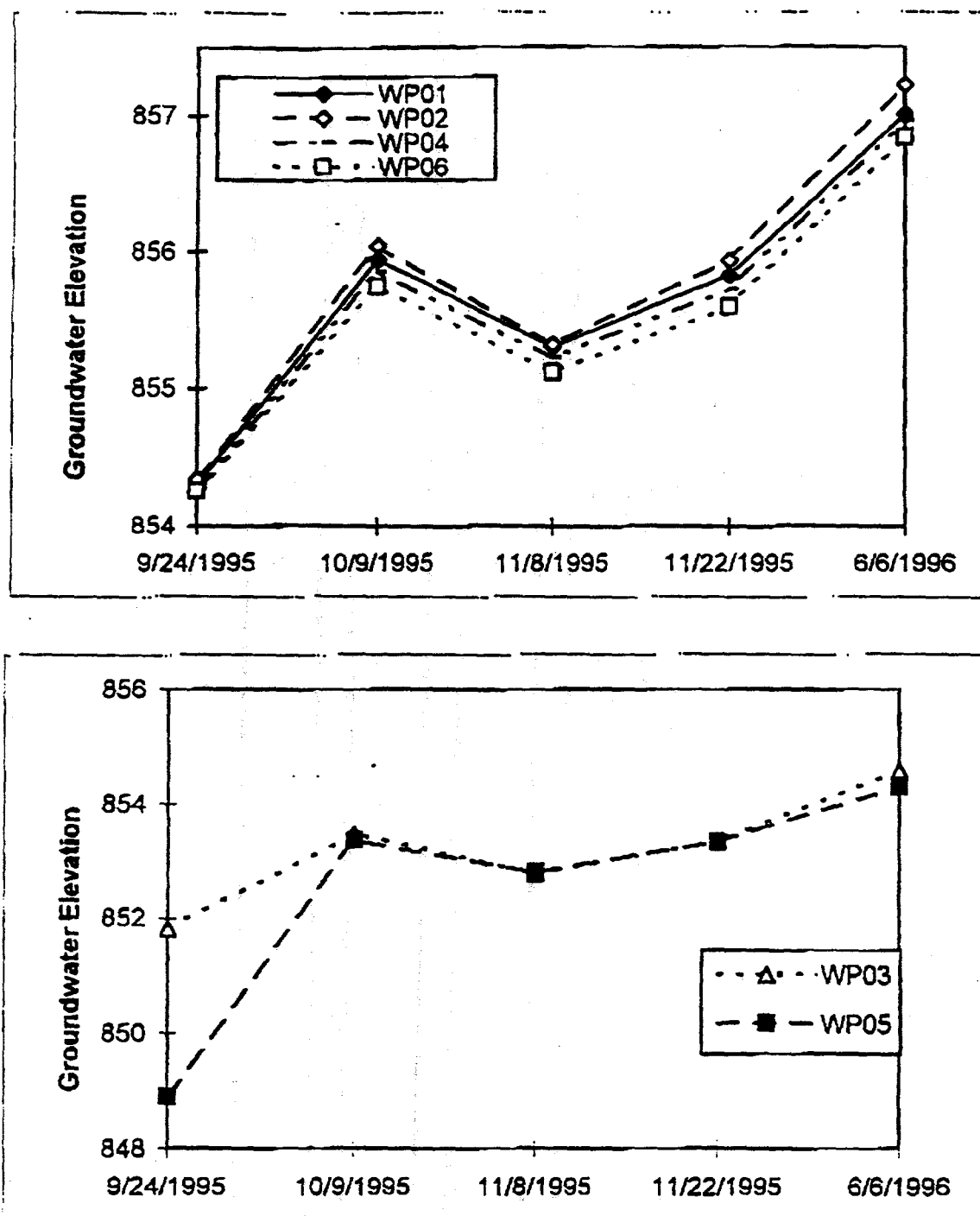


Figure 33. Hydrographs at Battelle West Jefferson Retired Filter Bed Area

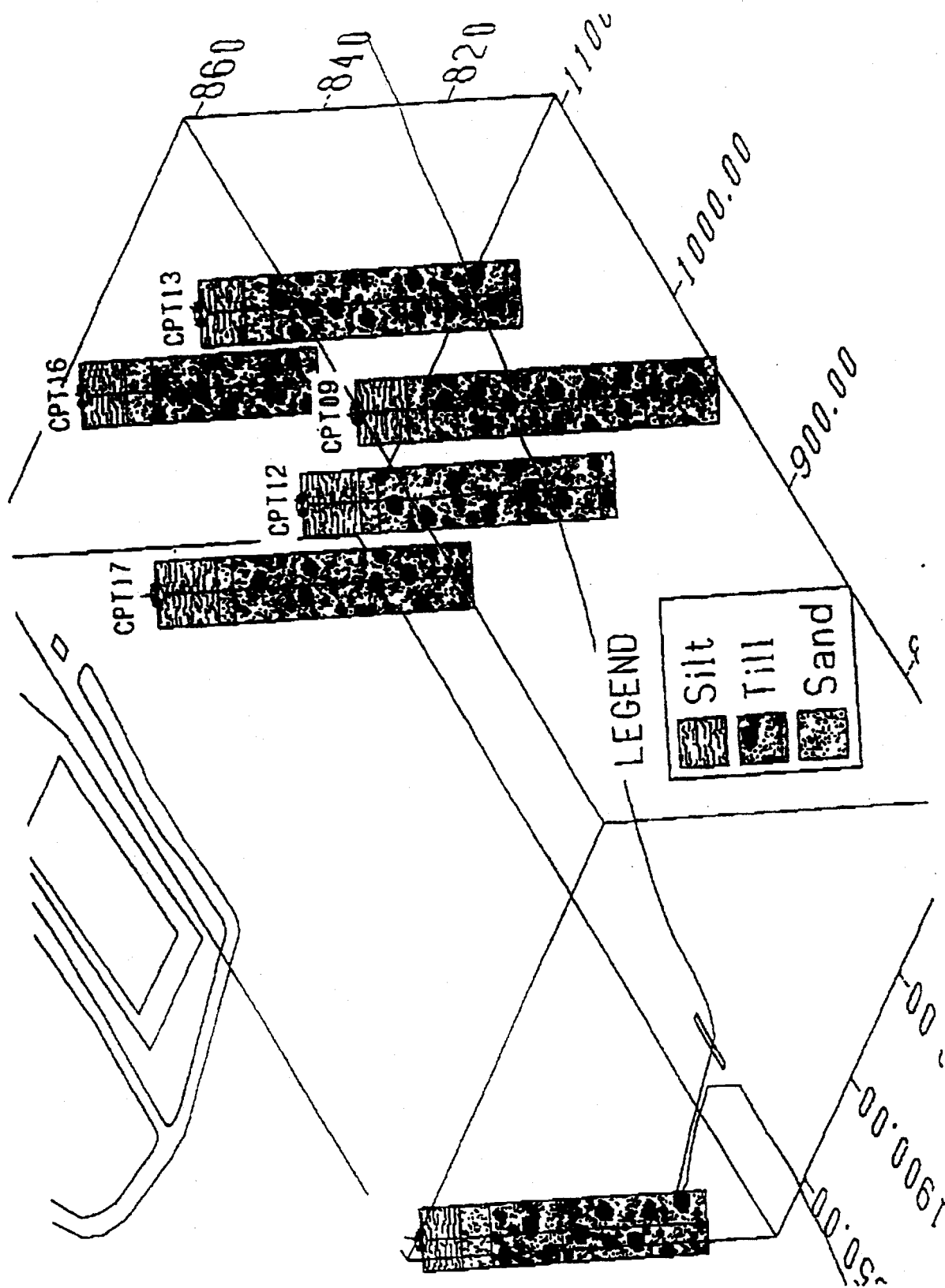


Figure 34. Interpreted Generalized Geology at Piezometer Locations

Groundwater elevations from November 22, 1995, and June 6, 1996, were compiled into estimated potentiometric surface maps (Figures 35 and 36) for the retired filter bed area. The maps are based on groundwater-level measurements from the existing 2-in., PVC-cased wells in the fenced retired filter bed area and from six piezometers. It is recommended that a complete synoptic round of groundwater levels from all the BWJ monitoring wells be collected on the same day sometime in the future. These figures both show that an east-to-west-trending divide exists in the groundwater flow system that extends from the eastern side of the abandoned retired filter beds toward Big Darby Creek. The low-relief topographic ridge on the top of the till that is visible from the CPT data suggests that a groundwater divide exists (Figure 32). Because of the groundwater divide feature, groundwater flow at the site has northeast and southeast components, and that relationship did not change with a rise in water levels during the observation period. On the basis of the November data, the hydraulic gradient between Well 113 and WP03 is calculated to be 0.023 ft per foot for the northeast flow direction. This was determined by dividing the head difference (4.45 ft) by the corresponding well separation distance (193.6 ft). Likewise, the hydraulic gradient in the southeast flow direction was calculated to be 0.017 ft per foot between Well 110 and WP05, by dividing 2.49 ft of head change by 145.45 ft of map distance. Hydraulic conductivity values are not known at the retired filter bed area, but the hydraulic conductivity averaged 4.1 ft per day from previous Battelle field measurements on similar coarse sediments present on the north bank of Battelle Lake (formerly Silver Creek). An estimate of horizontal groundwater velocity can be made by multiplying the hydraulic gradient by the hydraulic conductivity and dividing the product by effective porosity. A horizontal groundwater velocity of 0.38 feet per day was obtained by using 0.25 as the estimated effective porosity value $([0.023 \text{ ft/foot} \times 4.1 \text{ ft/day}]/0.25)$. That amounts to a groundwater velocity of about 138 ft per year.

Figure 37 is an east-to-west-trending hydrogeologic profile (A-A') that illustrates the groundwater conditions in the vicinity of the filter bed, based on available well data. The configuration of the potentiometric surface is shown for the two observation periods and there was approximately 1-1.5 ft of fluctuation along the profile.

Groundwater sampling was performed in the piezometers on two occasions, October 1995 and June 1996.

BCLDP Environmental Support Group personnel performed groundwater sampling at the six piezometers (WP01 through WP06) on October 9, 1995, and on June 5, 1996. The purpose of the sampling was to screen for the possible presence of radionuclide contamination in the groundwater immediately east of the retired filter bed area. According to discussions with John Tholen of BCLDP, those sampling activities were conducted according to approved Battelle procedures, EM-SP-009 (Revision 1), and those procedures require purging of at least three well volumes prior to sample collection. The analytical work, involving gross alpha, gross beta, and gamma spectroscopy, was performed by the Battelle Laboratory facility at West Jefferson. A summary of the test results is provided in Appendix E. A number of duplicates were also tested for gross alpha and beta as a quality control measure. These analytical test results will also be reported in the next annual BCLDP Site Environmental Report. The data presented in Appendix E

Figure 35. Potentiometric Surface Map for November 22, 1995, at Battelle West Jefferson

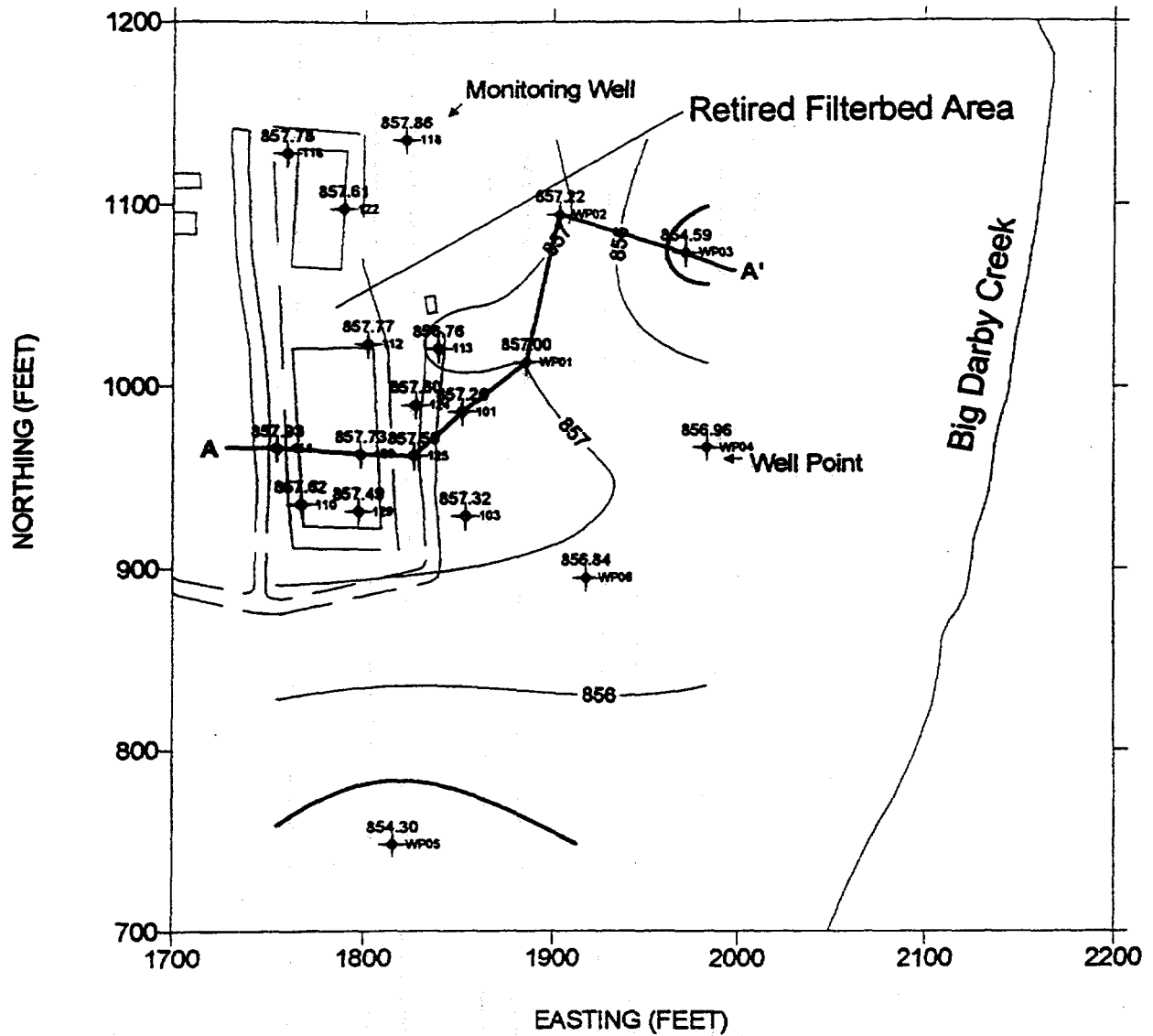


Figure 36. Potentiometric Surface Map for June 6, 1995, at Battelle West Jefferson

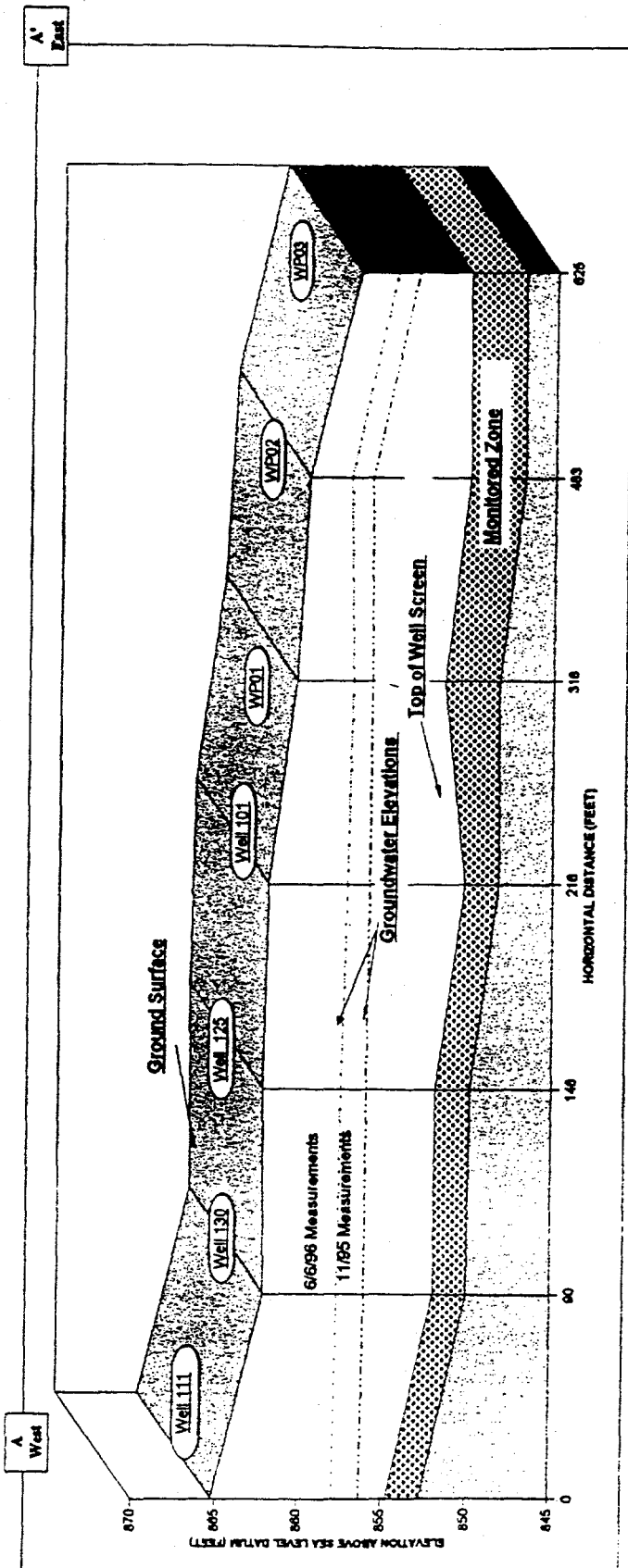


Figure 37. Hydrogeologic Profile A-A' at Battelle West Jefferson

shows that gross beta levels in WP06 were 206 and 200 pCi/L. This is elevated relative to the other piezometers sampled on October 5, 1995. In contrast, the gross beta results for WP06 from the June 5, 1996, sampling were not elevated with respect to the other piezometers.

9 Discussion

By characterizing the bedrock surface beneath the area and the overburden sediments, nonintrusive geophysical surveys conducted at BWJ have placed constraints on the hydrogeologic framework. Piezometers were installed at six locations to test the groundwater for radiological contamination.

9.1 Pleistocene/Holocene Stratigraphy and Structure

Surveys employing EM, GPR, and CPT technologies were used to characterize any structures within the overburden that might be a pathway for contaminant migration and to locate the underground oil pipeline and any other anthropogenic structures in the geophysical survey area. A list of anomalies detected with the electromagnetic tools is presented in Table 8.

Table 8. Anomalies Detected by Electromagnetic Instruments

Coordinates		EM-31	EM-34	Possible Source
E	N			
500-1050	940-850	√	√	Pipeline
675-960	500-760	√		Filter bed
500-740	640-957	√		Fence
560-880	480-460	√	√	Discharge pipe and outfall
550-480	720-620	√		Buried metallic pipeline
500-570	1070-1060	√		Buried metallic pipeline
500	980-1080	√		Fence
900	600	√		Barbed wire
960	940	√		Barbed wire
710-820	920-1100	√		Topographic low and wet area
620-710	1000-1020	√		Unknown
805-915	830-745	√		Unknown
970	770	√		Unknown
980	960-1120		√	Unknown
600	1010	√		Concrete pit

EM-31, when compared with a topographic map of a segment of the survey area, shows a correlation between the surface topography and the electrical character of the sediments. This correlation arises from the degree of saturation of the soil, with the lower areas being more saturated and thus, more conductive. A more detailed topographic map of the survey area is needed to distinguish the difference due to saturated vs. unsaturated surface topography, as well as subsurface sediment variation.

Conductivities measured with the EM-34 correlate closely with those of the EM-31 (Figure 38). The subtle conductivity minimum detected with the EM-34 along 900E is absent from the EM-31 data, suggesting a deeper source for this anomaly. Differences detected within about 60-70 ft of the pipeline can be attributed to cultural interference.

Three geologic units within the unconsolidated overburden material have been interpreted from comparison of CPT logs with existing knowledge of the geology in the area and published tables of CPT responses. However, without other geologic control (such as a deep borehole), the exact composition of each unit must be considered speculative. An alluvial/fluvial layer, probably consisting of silty clay to silt, is interpreted to lie near the surface. At a depth of 6-10 ft, a distinctive unit 2-5 ft thick is observed in all CPT logs (Figures 30 and 31); it is probably an outwash layer consisting of coarser-grained sediments, probably silty sand to sand. A cohesive layer, consisting primarily of tills, is observed beneath the sandy layer.

GPR profiles alone are often difficult to interpret. However, several CPT holes lie adjacent to profiles 2 (Figure 22) and 16 (Figure 23), providing a unique "ground-truthing" for the GPR observations. Note that both GPR profiles suggest the presence of a reflective geologic unit within the unconsolidated overburden at depth. However, the unit's upper and lower boundaries are not always well-defined and may be gradational in places. The bottom of this contact is more difficult to pick out on both GPR profiles and CPT electric logs. Both techniques may be mapping the same geologic unit; the lower boundary of this unit is distinct near the southern end of GPR profile 16 (Figure 22) and at 10 ft below the ground surface on the electric log from CPT-03 to CPT-04 and CPT-05 (Figure 30). If the GPR anomalies correlate with the outwash layer defined from CPT observations, then a relatively high two-way travel time of 12 ns/ft is needed, suggesting a material of very high porosity.

Although distinct channels were not detected by means of geophysical observations, the outwash deposit, consisting of a thin silty sand to sand layer observed at depths of less than 12 ft, represents a significant pathway for contaminant migration at Battelle West Jefferson.

The location of the buried oil pipeline is defined by anomalies in the EM-31, EM-34, and magnetic gradiometer observations. Failure to detect the oil pipeline as a GPR anomaly suggests that the pipe diameter is small and/or that the pipe is deeply buried. Two other lineaments (pipes) were detected as EM-31 anomalies in the western half of the survey area, between (720N, 550E) and (480N, 620E) and between (1070N, 500E) and (1060N, 570E).

Other anthropogenic structures are detected within the fenced filter bed area. GPR transects depict at least two EW-trending buried pipes adjacent to the retired filter beds. Since interference from surface metals within the fenced area prevents the electromagnetic methods (EM-31 and EM-34) from detecting these pipes, the lateral extent of these pipes is unknown; they were not detected by any geophysical technique outside of the fenced area. Inside this area, GPR reflections from the former filter beds are observed. Other GPR reflections at greater depths may originate from fill material or geologic sources.

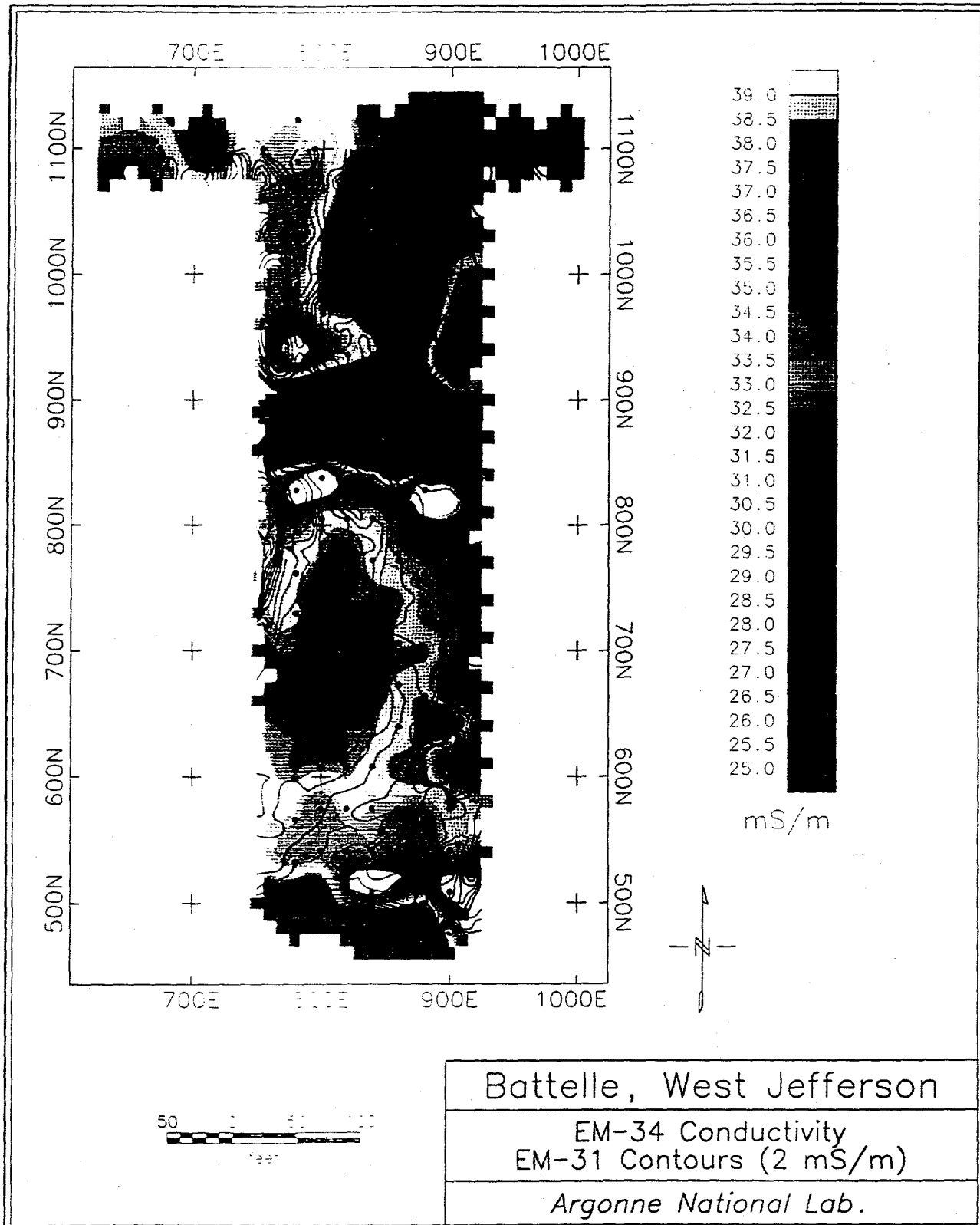


Figure 38. Map of Terrain Conductivities Measured by the EM-34, Overlaid with Contours of EM-31 Anomalies

9.2 Bedrock Topography

Measured resistivities for the overburden and bedrock are consistent with previously published values. Overburden resistivities ranged from 16 to 70 ohm-m with layer thicknesses from 30 to 180 ft. Resistivities measured from CPT logs are comparable, ranging from 18 to 80 ohm-m in the upper 78 ft of overburden. The resistivity of the bedrock showed the greatest variation, ranging from approximately 95 to greater than 500 ohm-m. Norris and Spicer (1958) also noted variations in the bedrock resistivity values and determined that the bedrock resistivity within preglacial valleys will be lower than observed in bedrock uplands.

Is it of concern that the bedrock surface could be misidentified because the lower limit of the bedrock resistivity (100 ohm-m) is within the range of resistivities observed for till and gravel deposits (22 to 600 ohm-m; see Norris and Spicer 1958). Comparison between the bedrock elevations determined from the refraction and resistivity data is required to verify that observed changes in resistivity (from 16 to 70 ohm-m to greater than 100 ohm-m) correspond to the overburden bedrock interface. In Figures 25 and 27, the depths obtained from the resistivity inversion are overlain on the velocity-depth cross sections for refraction Lines 1 and 6. Each resistivity depth point is indicated on the cross section by a solid circle and station number label. For Line 1, four of the resistivity depths plot within 15 ft of the seismic refraction bedrock surface. Agreement between the two depth estimates varies between about 15 ft at the northern end of Line 6 to about 25-30 ft at the southern end.

Depths to bedrock obtained by CPT observations provide ground truth for seismic refraction modeling along Line 4. Bedrock depths of six of the CPT holes (3-7, 9) plot on the bedrock surface determined from seismic refraction modeling (Figure 26). At CPT holes #3 and #4, the differences in bedrock elevations are slightly larger because of high gradients in the bedrock surface at this location.

A bedrock topography map constructed from elevations obtained from seismic refraction modeling and CPT holes is shown in Figure 39. Bedrock elevations obtained from seismic refraction Line 1 were excluded from this figure because of the possible bias introduced from the anthropogenic structures associated with the dam. The seismic profiles are plotted as heavy lines. Within the survey area, the bedrock surface slopes to the southwest, changing in elevation from approximately 840 ft in the NE corner to 730 ft near the southern boundary of the geophysical survey area. The configuration of the bedrock surface beneath the dam was not resolvable with the data collected.

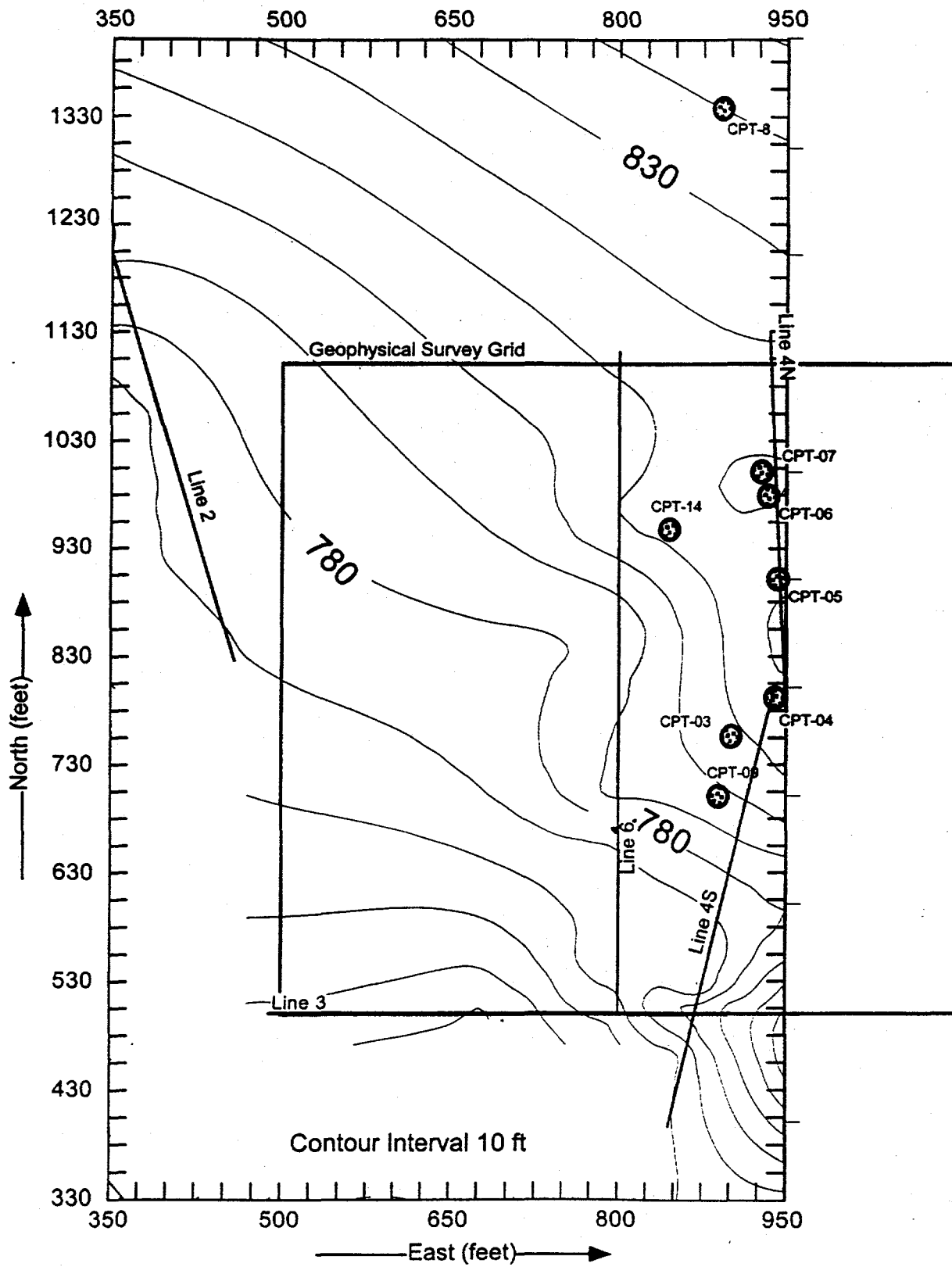


Figure 39. Map of Bedrock Elevations Determined from Seismic Modeling

10 Conclusions and Recommendations

The geophysical investigation yielded an improved understanding of the geology of the filter bed area and of the floodplain of the Big Darby Creek. The study established that the preferred groundwater pathway is associated with a laterally extensive, silty-sand to sand deposit that is less than 12 ft deep in the floodplain area. Resistivity and seismic refraction data provide a framework to improve understanding of the geology of the till deposits and the bedrock surface in the area of the floodplain. The intrusive CPT technology is particularly useful for comparing continuous logging data with surface geophysical data and in establishing correlations among the unconsolidated geologic materials.

The following recommendations are made with respect to future geophysical surveys:

1. Conduct a geophysical survey involving resistivity and seismic refraction profiles and soundings to determine the depth of bedrock and the suspected buried valley underlying the JN/Battelle Lake area, as well as on the south shore of Battelle Lake. This information will help in understanding the geological framework of the Battelle site and the distribution of granular and more transmissive layers as potential pathways.
2. Conduct natural gamma logging on the existing groundwater monitoring wells.

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APPENDIX A:

RESISTIVITY DEPTH SOUNDING CURVES

WJE1A

L #	Resistivity (Ω -m)	Thickness (meters)
1	25.6	1.1
2	49.4	2.5
3	8.4	2.3
4	132.7	58.4
5	500.0*	

* Indicates Fixed Parameter

WJE2

L #	Resistivity (Ω -m)	Thickness (meters)
1	23.1	5.7
2	54.8	24.4
3	64.1	2.1
4	500.0*	

* Indicates Fixed Parameter

WJE3

L #	Resistivity (Ω -m)	Thickness (meters)
1	25.7	0.3
2	21.4	1.7
3	27.1	8.1
4	59.6	23.2
5	500.0*	

* Indicates Fixed Parameter

WJE4

L #	Resistivity (Ω -m)	Thickness (meters)
1	31.3	0.3
2	20.1	1.8
3	29.0	12.4
4	46.9	15.3
5	500.0*	

* Indicates Fixed Parameter

WJE5

L #	Resistivity (Ω -m)	Thickness (meters)
1	37.7	0.6
2	12.9	0.4
3	28.2	6.6
4	39.0	29.3
5	500.0*	

* Indicates Fixed Parameter

WJD1

L #	Resistivity (Ω -m)	Thickness (meters)
1	16.6	2.7
2	26.8	7.7
3	94.2	49.2
4	500.0*	

* Indicates Fixed Parameter

WJD2

L#	Resistivity (Ω -m)	Thickness (meters)
1	4.6	1.7
2	0.1	0.0
3	21.5	

All parameters are free

WJD3

L#	Resistivity (Ω -m)	Thickness (meters)
1	16.4	0.5
2	141.9	0.2
3	26.7	19.5
4	180.0	108.6
5	500.0*	

* Indicates Fixed Parameter

WJD4

L#	Resistivity (Ω -m)	Thickness (meters)
1	29.7	1.3
2	38.8	8.3
3	6.9	5.0
4	500.0*	

* Indicates Fixed Parameter

WJD5A

L#	Resistivity (Ω -m)	Thickness (meters)
1	235.4	0.2
2	35.5	23.8
3	11.3	8.5
4	500.0*	

* Indicates Fixed Parameter

WJD6

L#	Resistivity (Ω -m)	Thickness (meters)
1	46984.7	0.1
2	30.1	32.6
3	183.6	179.7
4	500.0*	

* Indicates Fixed Parameter

WJD7

L#	Resistivity (Ω -m)	Thickness (meters)
1	83.5	0.5
2	6.2	0.2
3	24.9	12.4
4	41.2	31.4
5	500.0*	

* Indicates Fixed Parameter

WJC10

L#	Resistivity (Ω -m)	Thickness (meters)
1	11.0	0.8
2	24.1	4.9
3	35.0	20.4
4	500.0*	

* Indicates Fixed Parameter

WJCI100

L#	Resistivity (Ω -m)	Thickness (meters)
1	13.7	1.3
2	24.1	15.0
3	194.3	94.9
4	500.0*	

* Indicates Fixed Parameter

WJCI200

L#	Resistivity (Ω -m)	Thickness (meters)
1	2197.3	0.1
2	22.0	2.6
3	27.1	18.4
4	240.1	235.7
5	500.0*	

* Indicates Fixed Parameter

WJCI300

L #	Resistivity (Ω -m)	Thickness (meters)
1	3.7	0.0
2	16.6	2.8
3	27.8	23.1
4	2128.9	19.0
5	500.0*	

* Indicates Fixed Parameter

WJCI400

L #	Resistivity (Ω -m)	Thickness (meters)
1	14.5	0.6
2	23.3	10.3
3	6.0	2.6
4	500.0*	

* Indicates Fixed Parameter

WJCI500

L #	Resistivity (Ω -m)	Thickness (meters)
1	47.5	0.2
2	18.1	4.2
3	28.3	21.7
4	500.0*	

* Indicates Fixed Parameter

WJND0

L#	Resistivity (Ω -m)	Thickness (meters)
1	25.3	0.9
2	415.9	0.9
3	28.2	41.4
4	500.0*	

* Indicates Fixed Parameter

WJND80

L#	Resistivity (Ω -m)	Thickness (meters)
1	113.0	0.2
2	24.8	3.0
3	66.8	10.2
4	10.2	10.8
5	500.0*	

* Indicates Fixed Parameter

W JEFF

L#	Resistivity (Ω -m)	Thickness (meters)
1	15.8	3.8
2	74.5	38.7
3	500.0*	

* Indicates Fixed Parameter

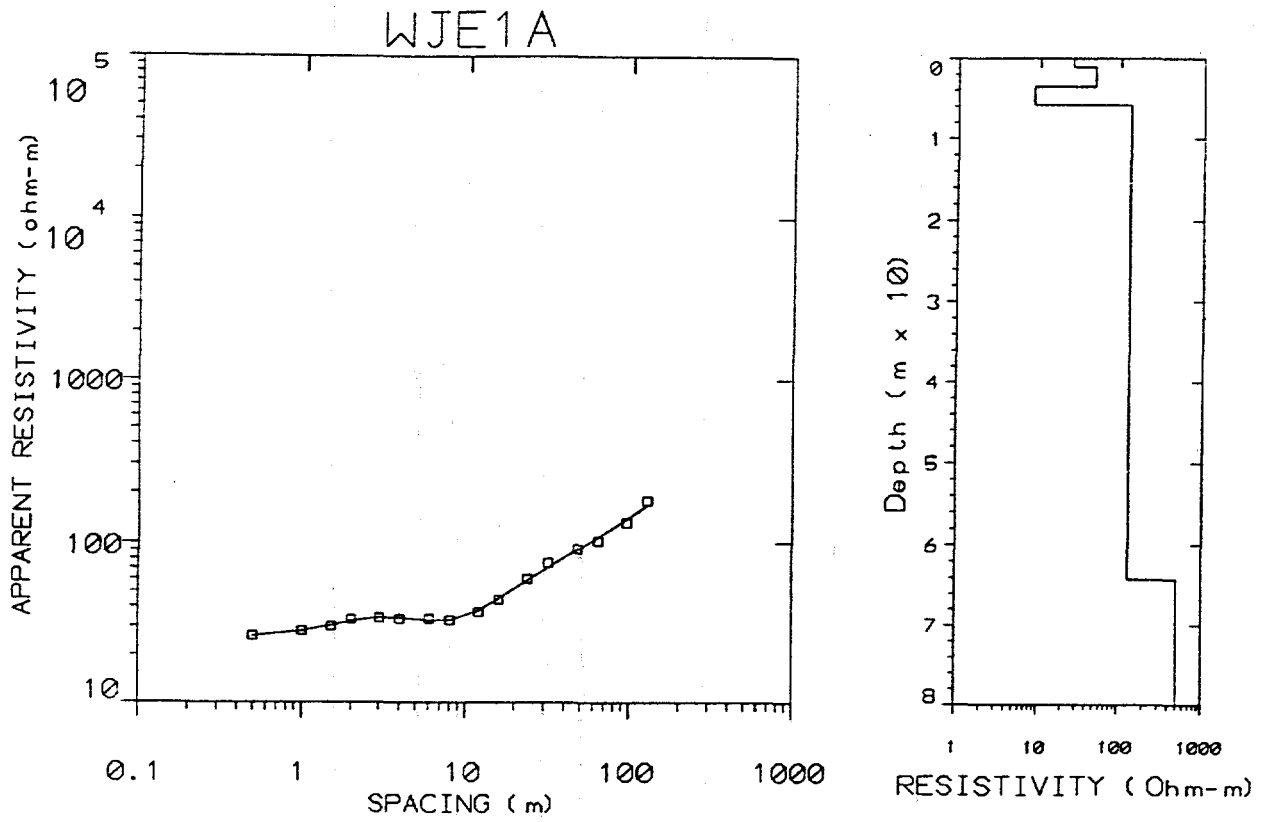


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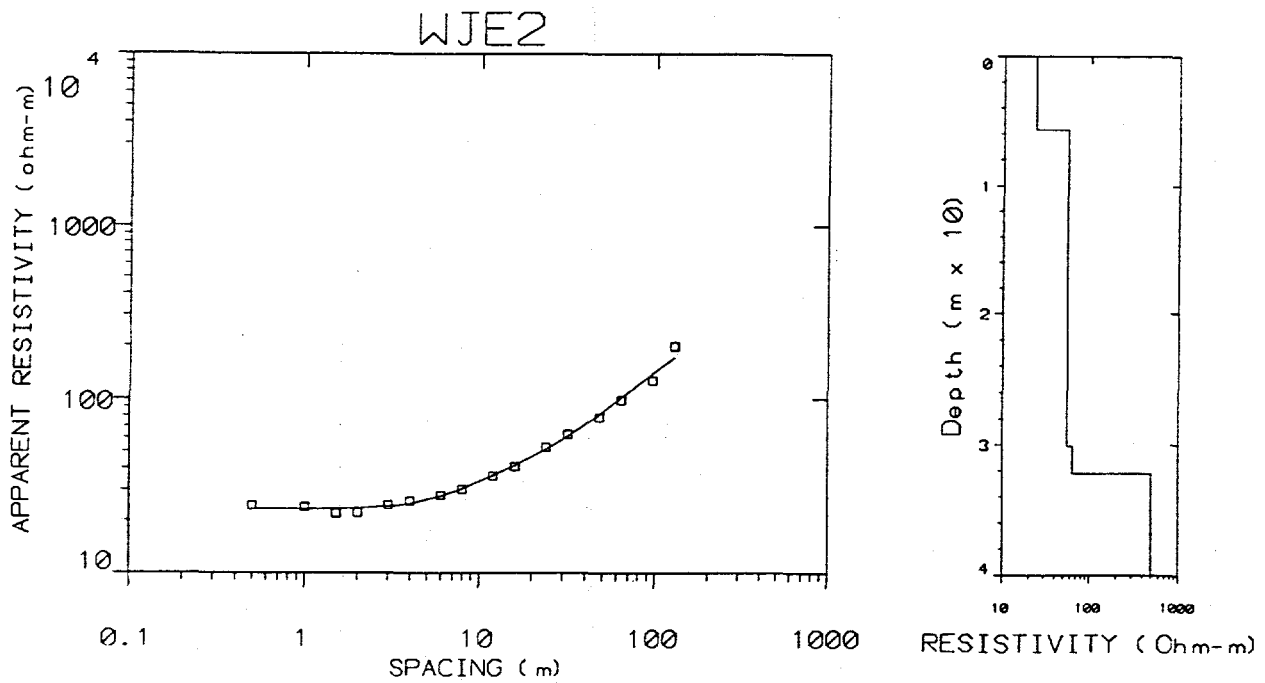


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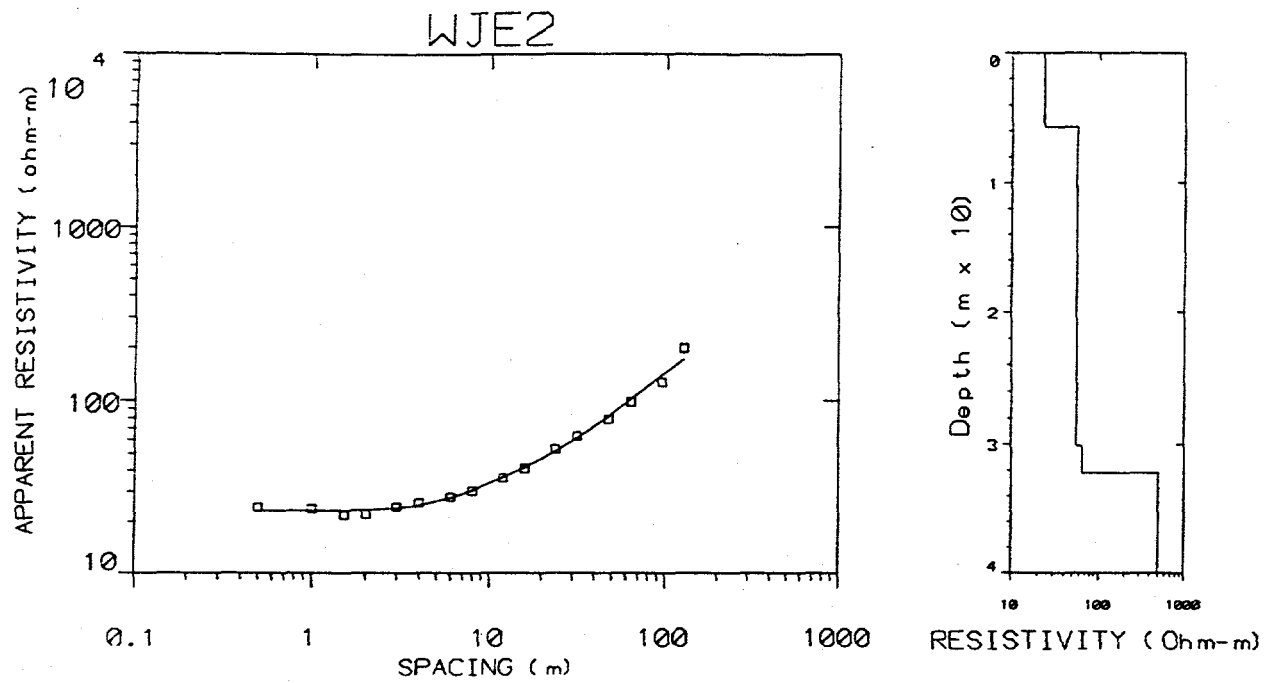


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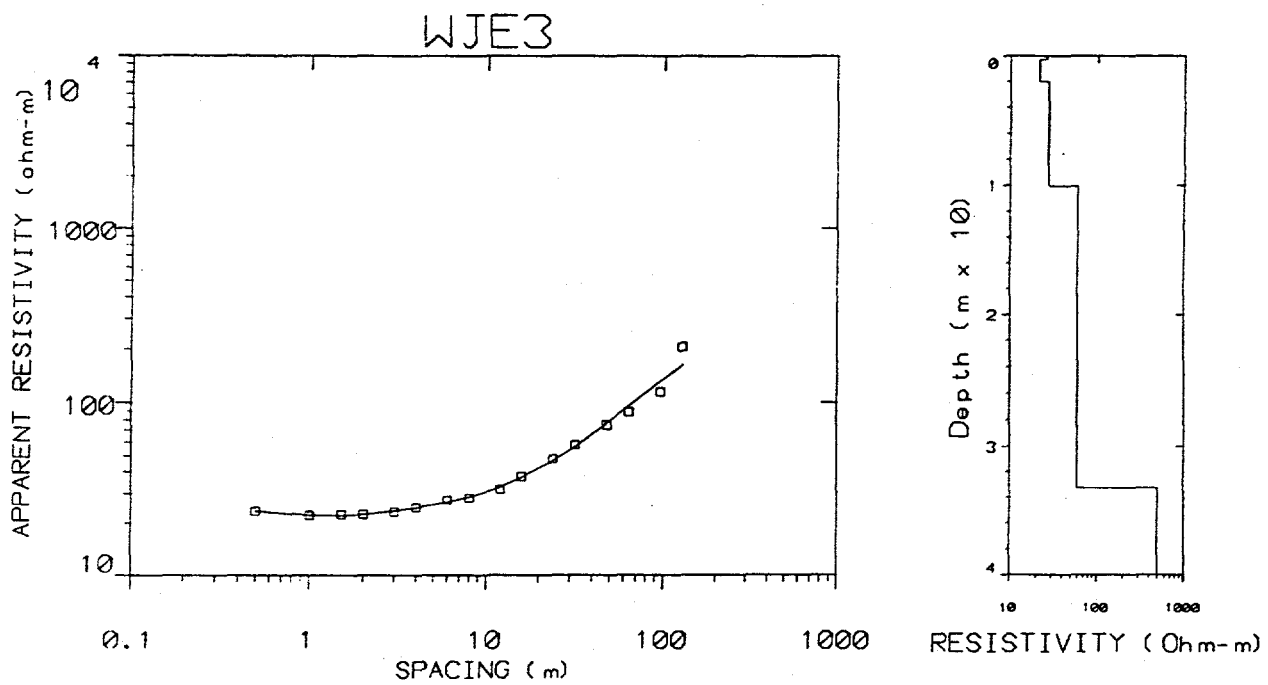


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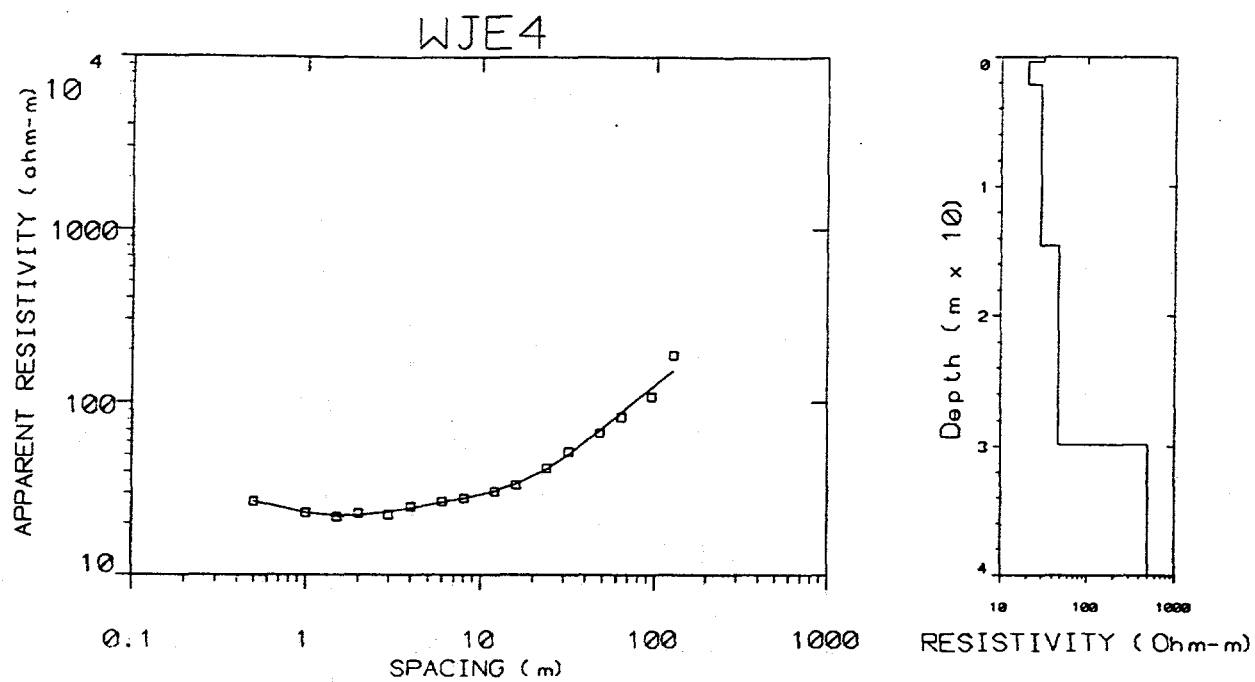


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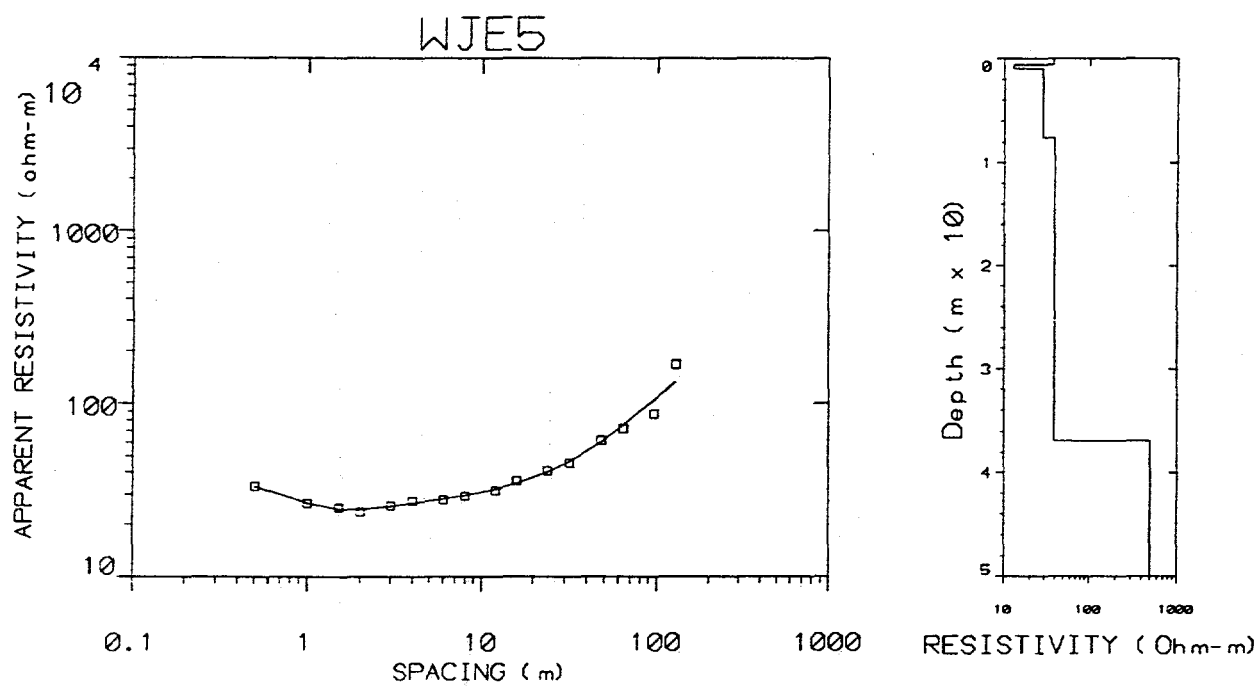


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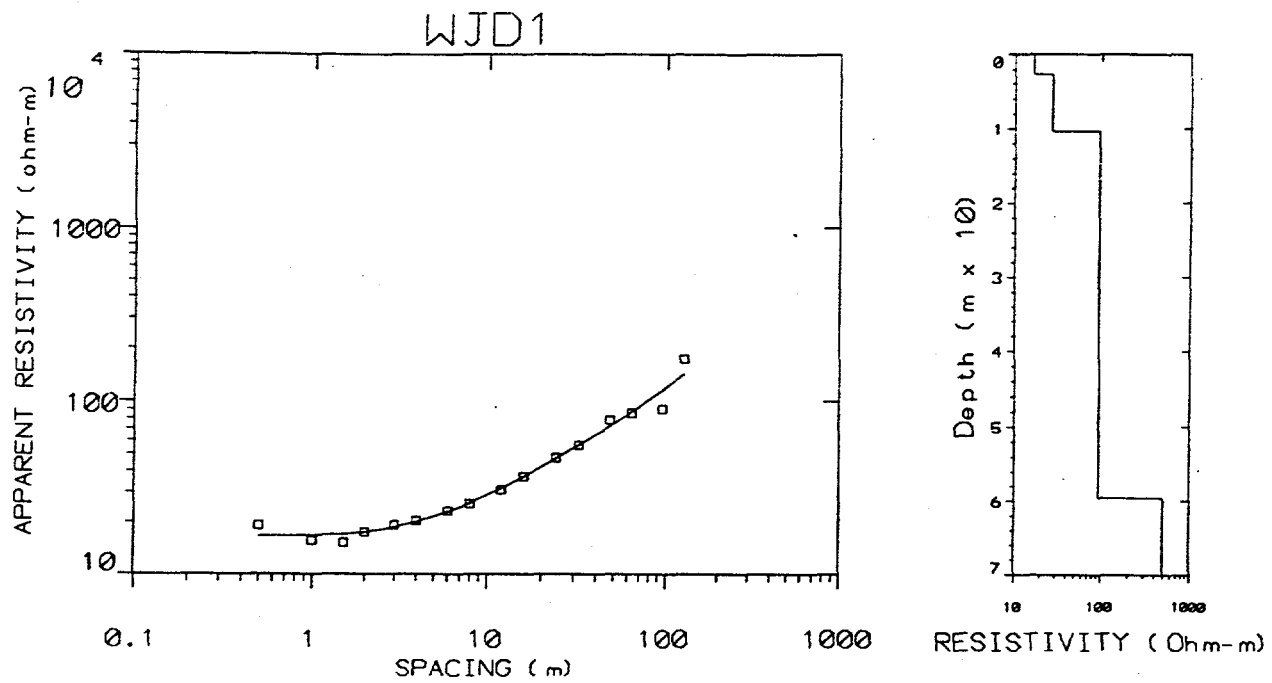


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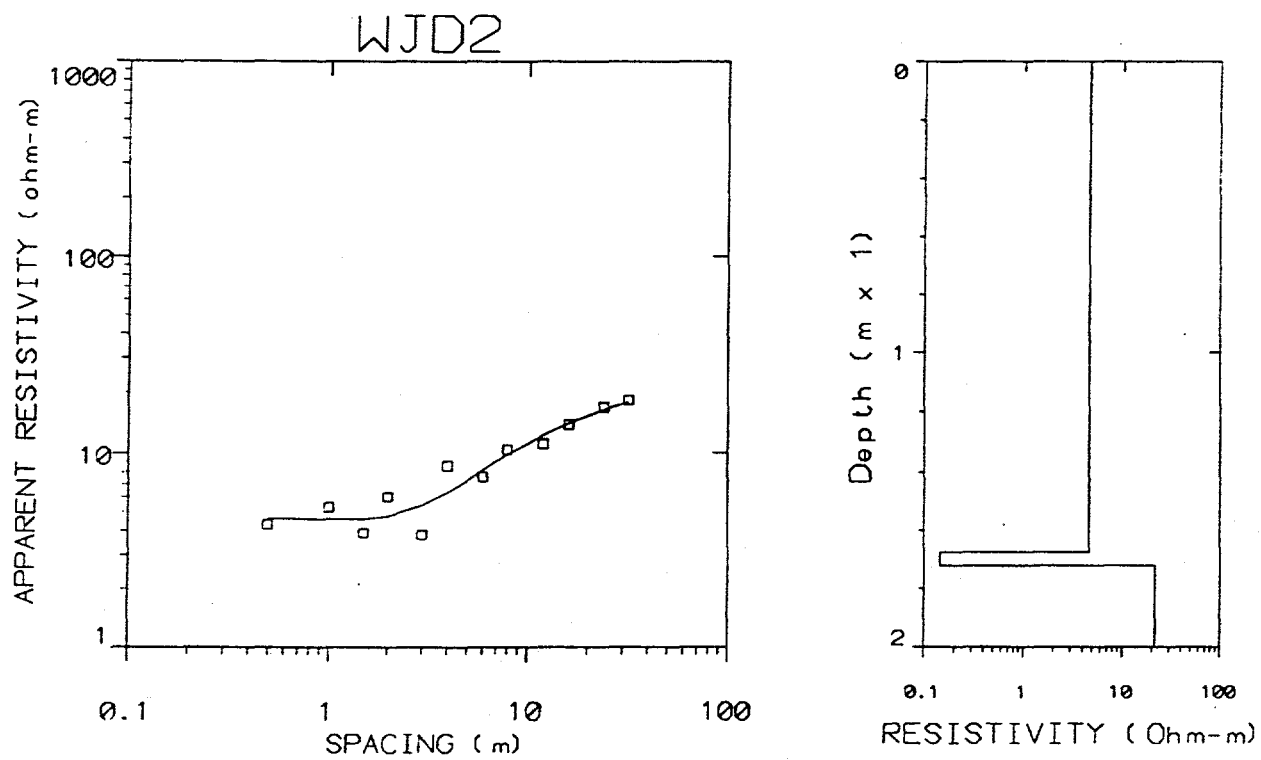


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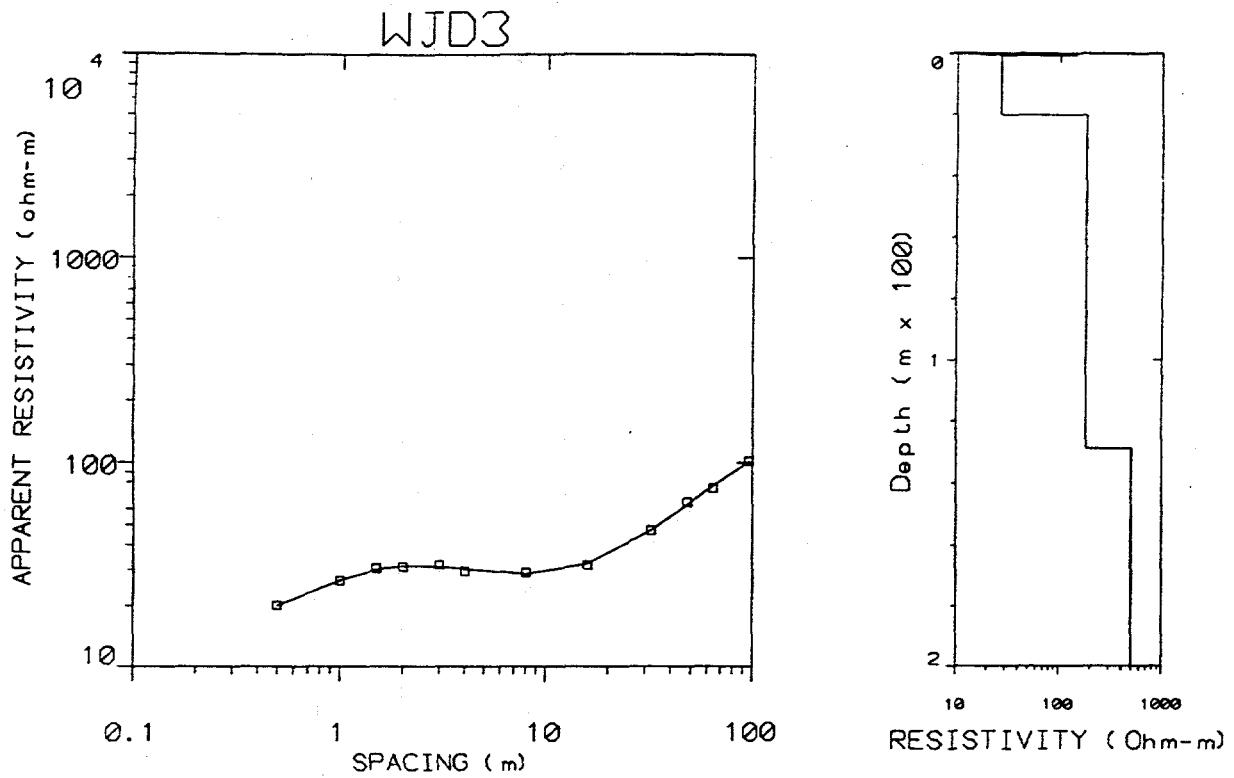


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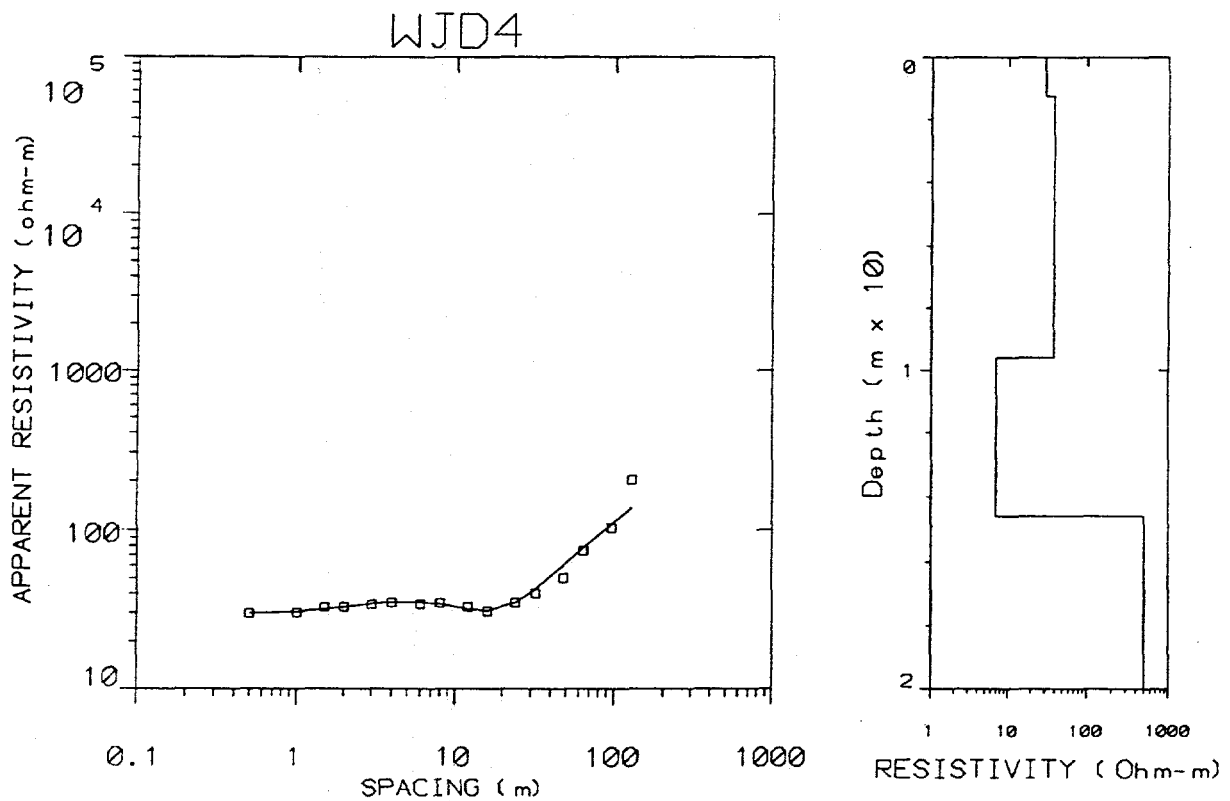


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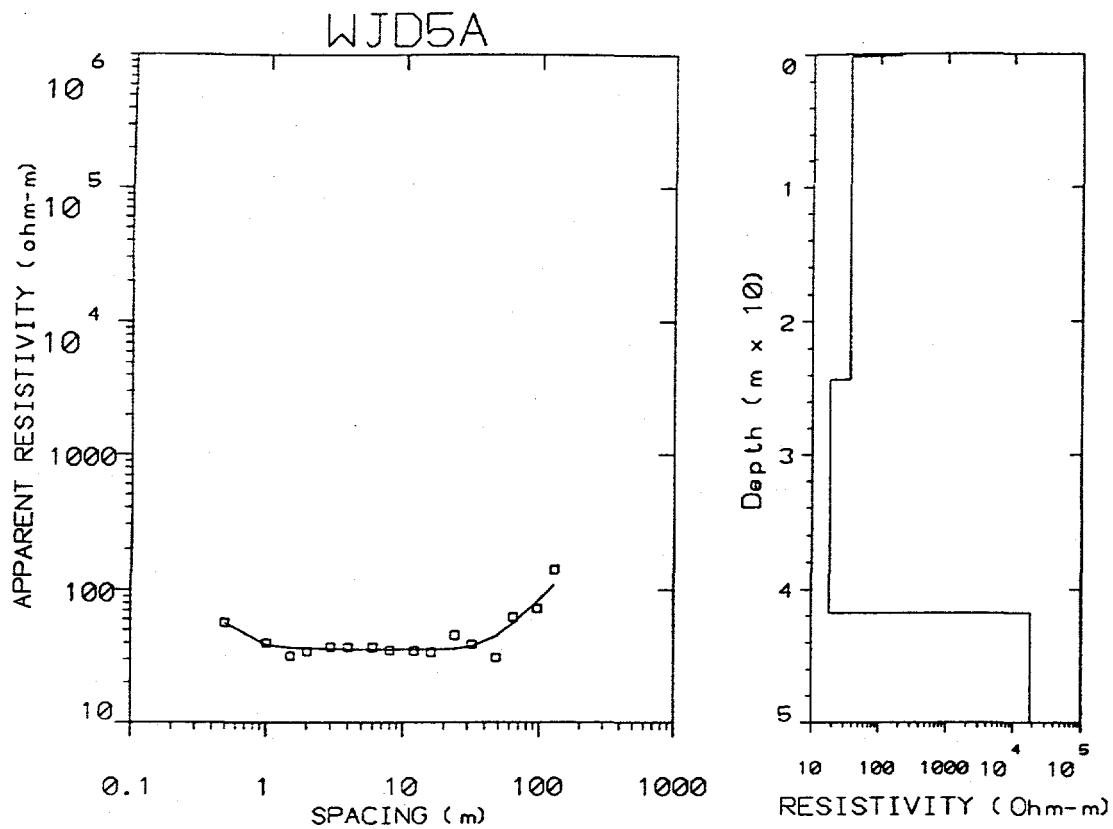


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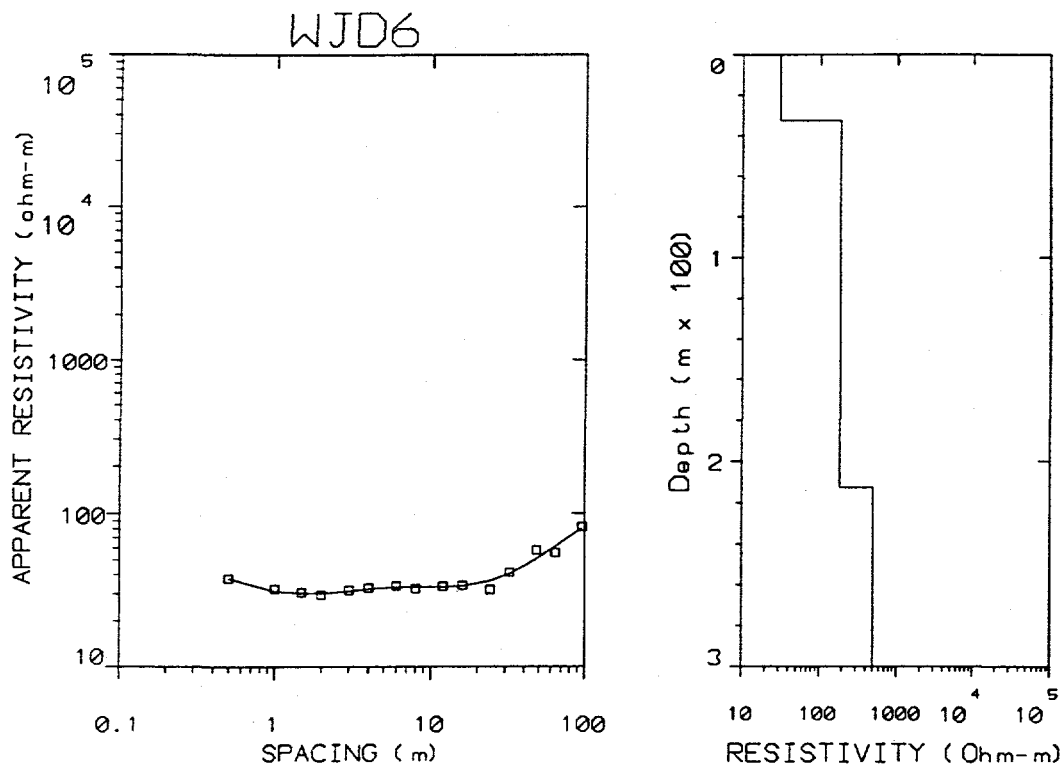


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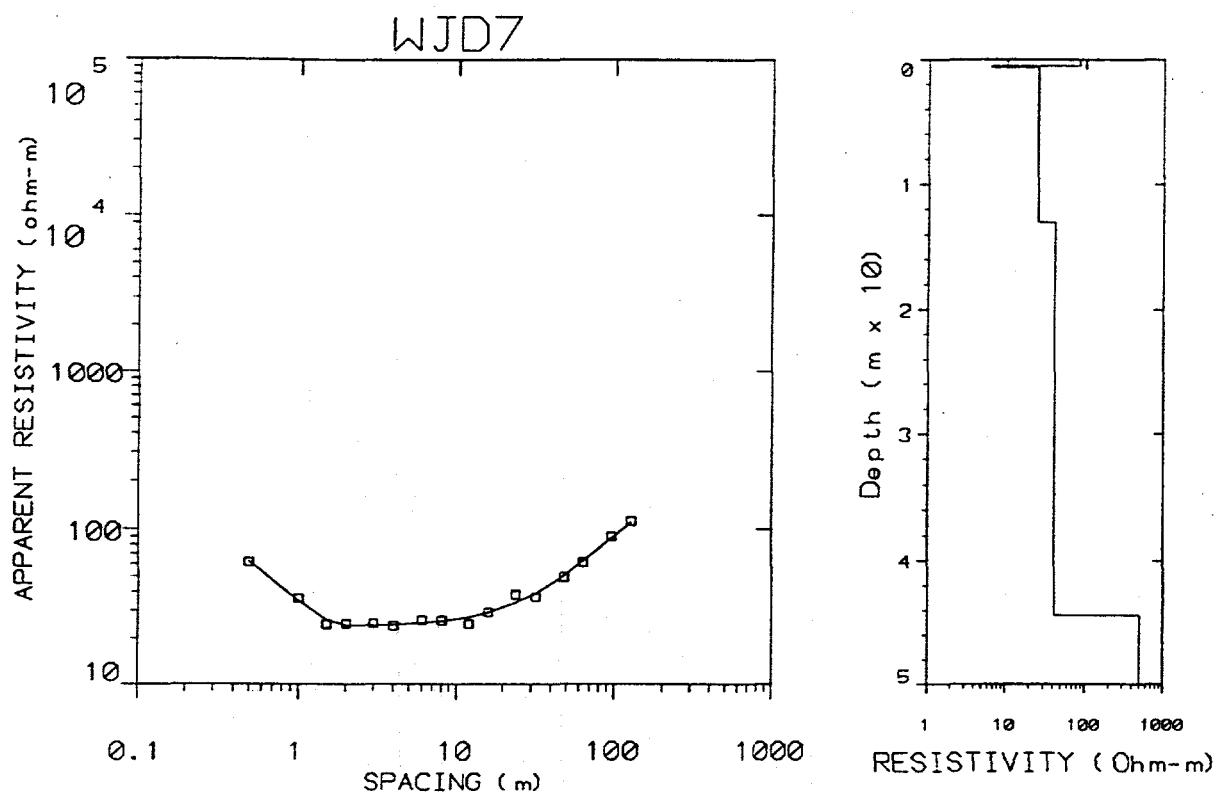


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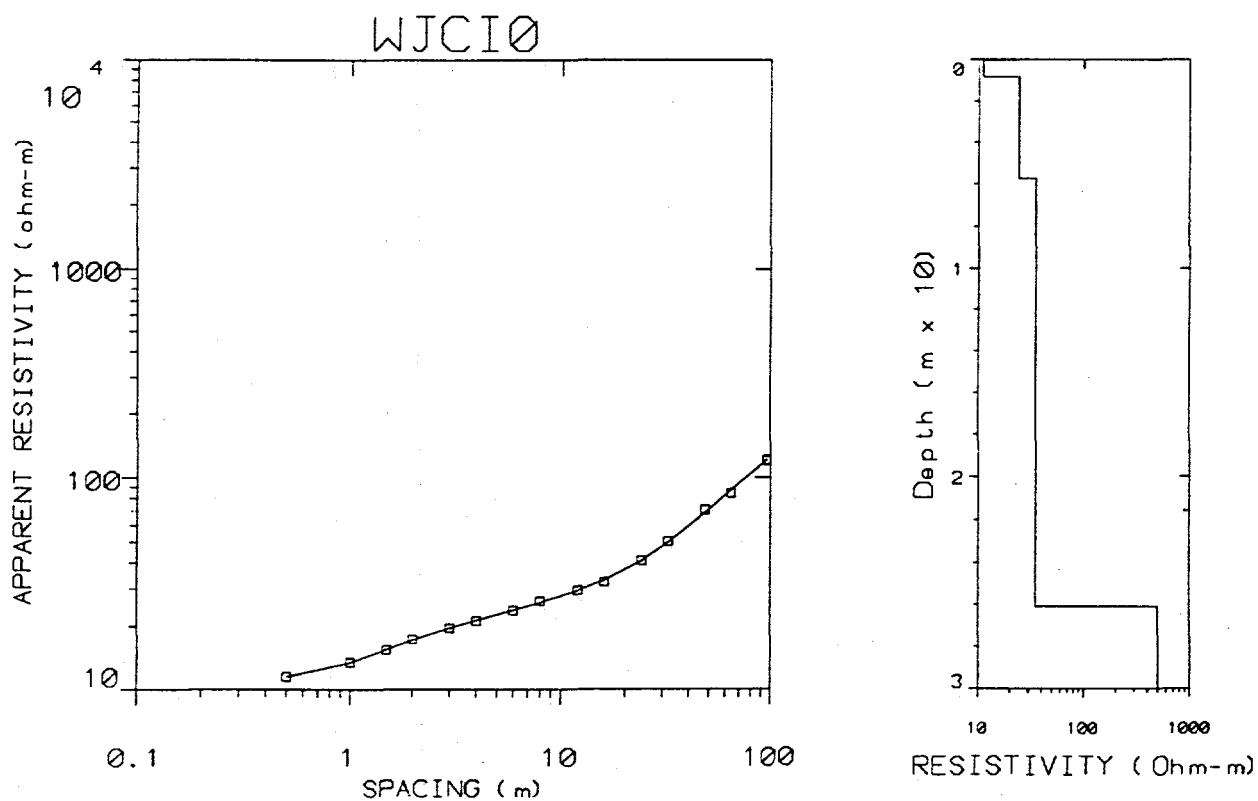


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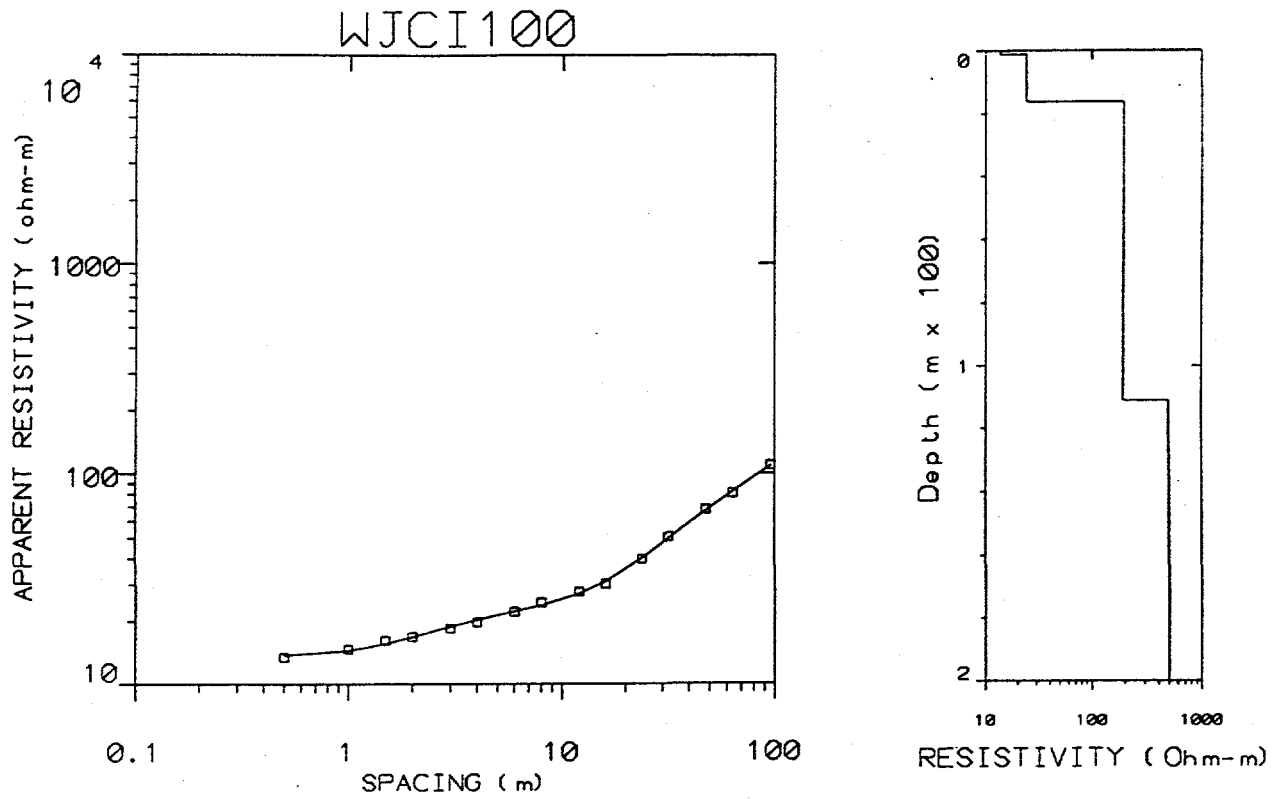


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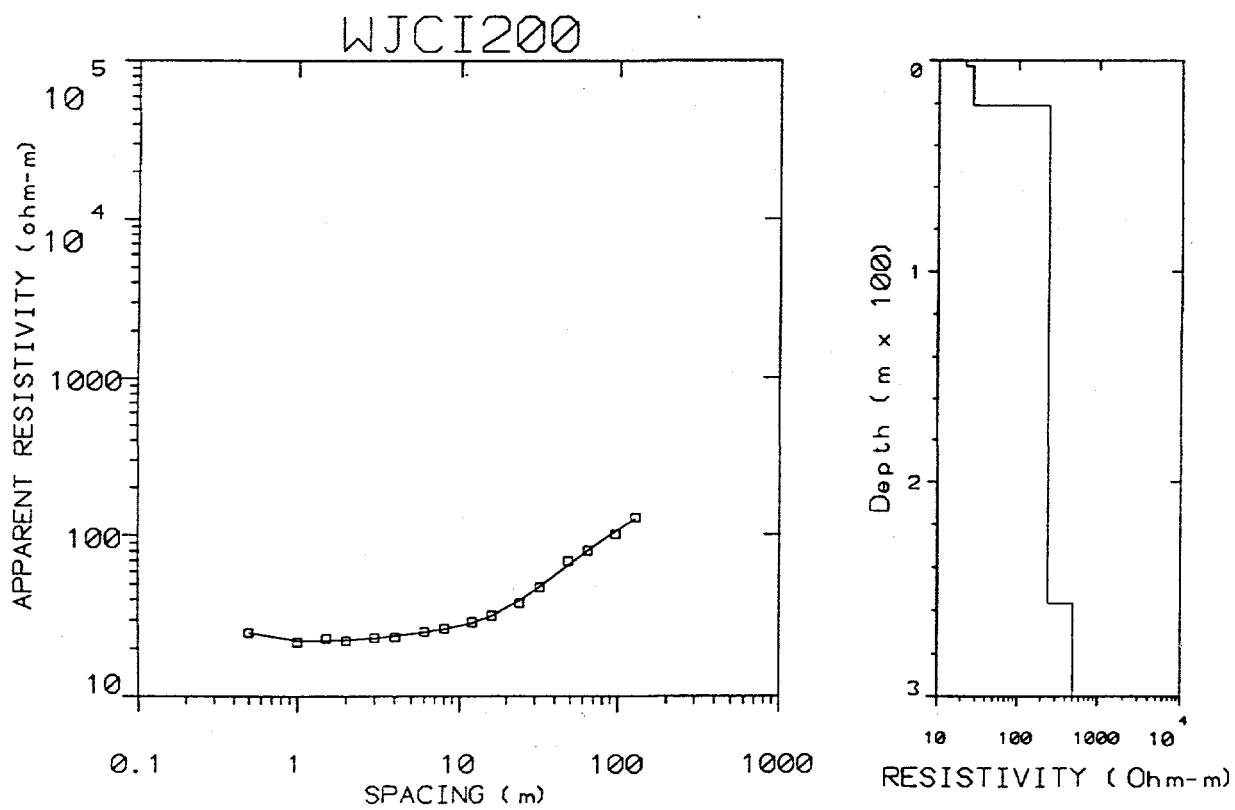


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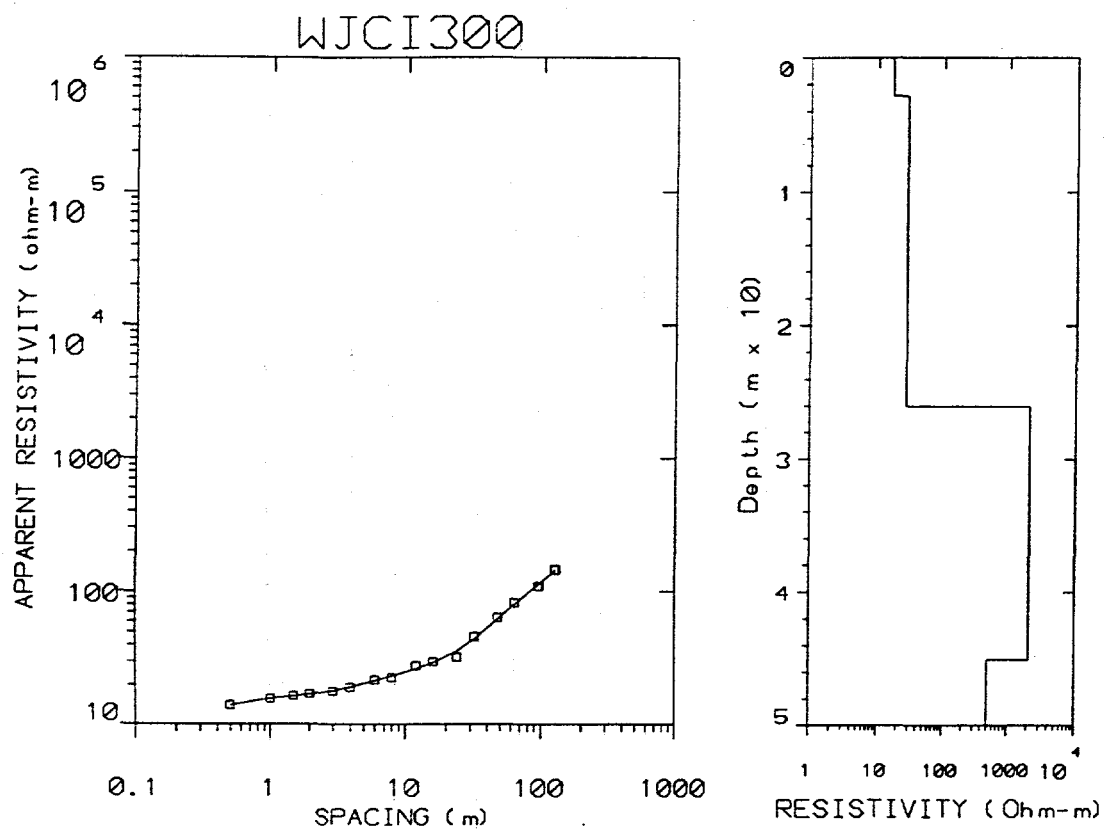


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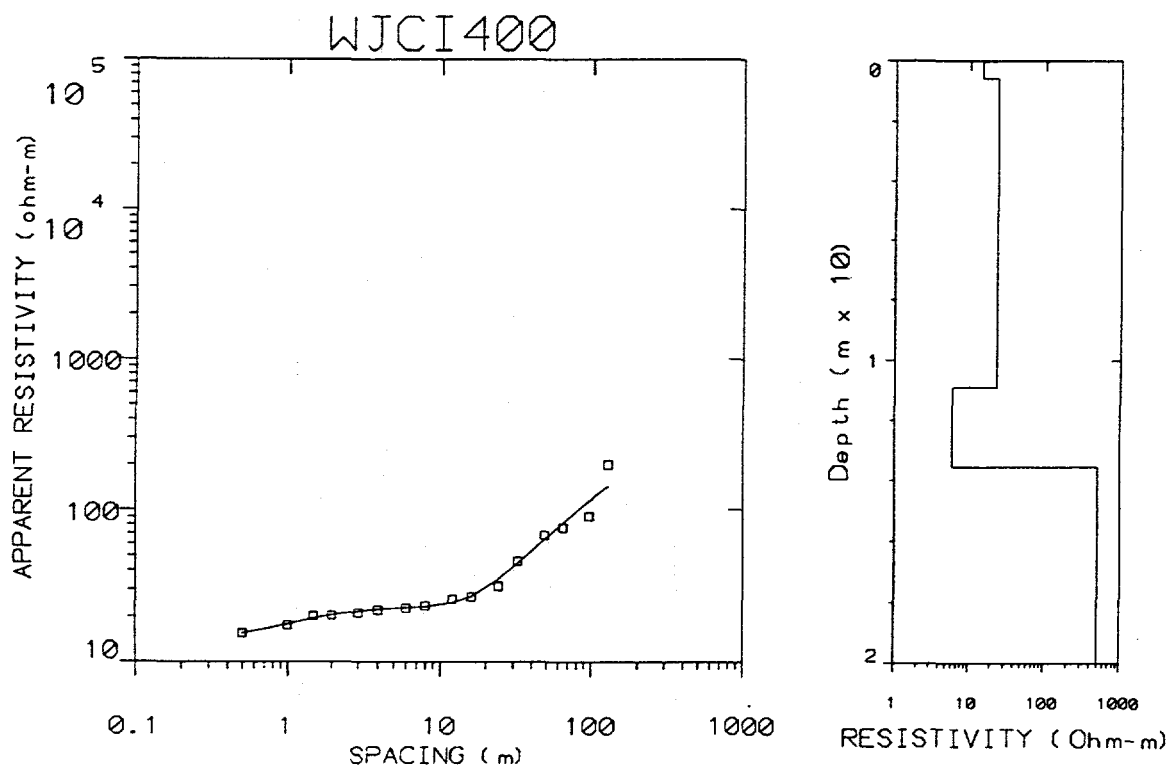


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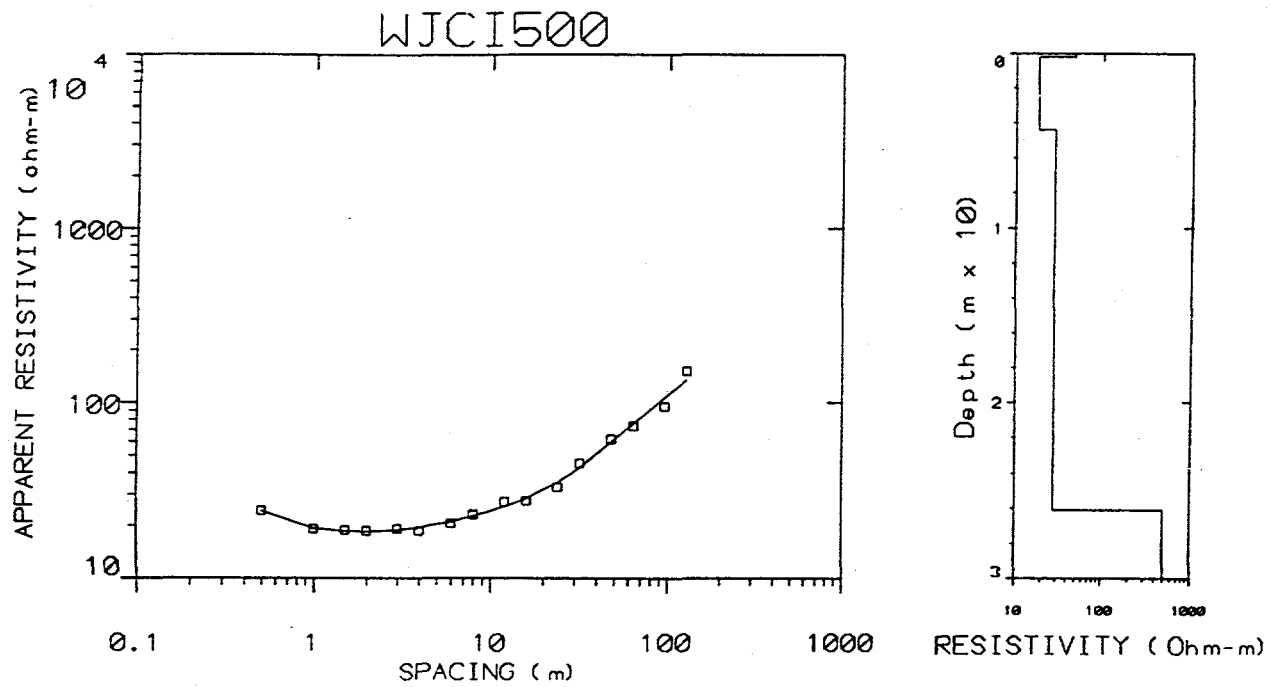


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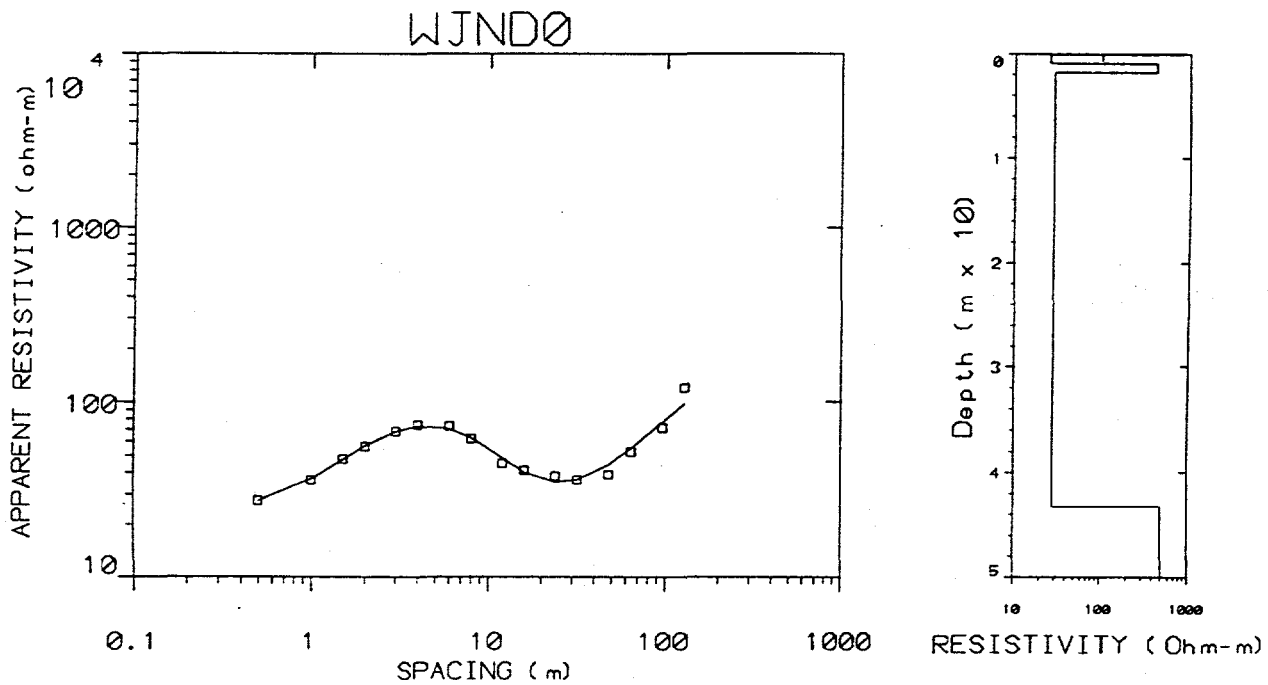


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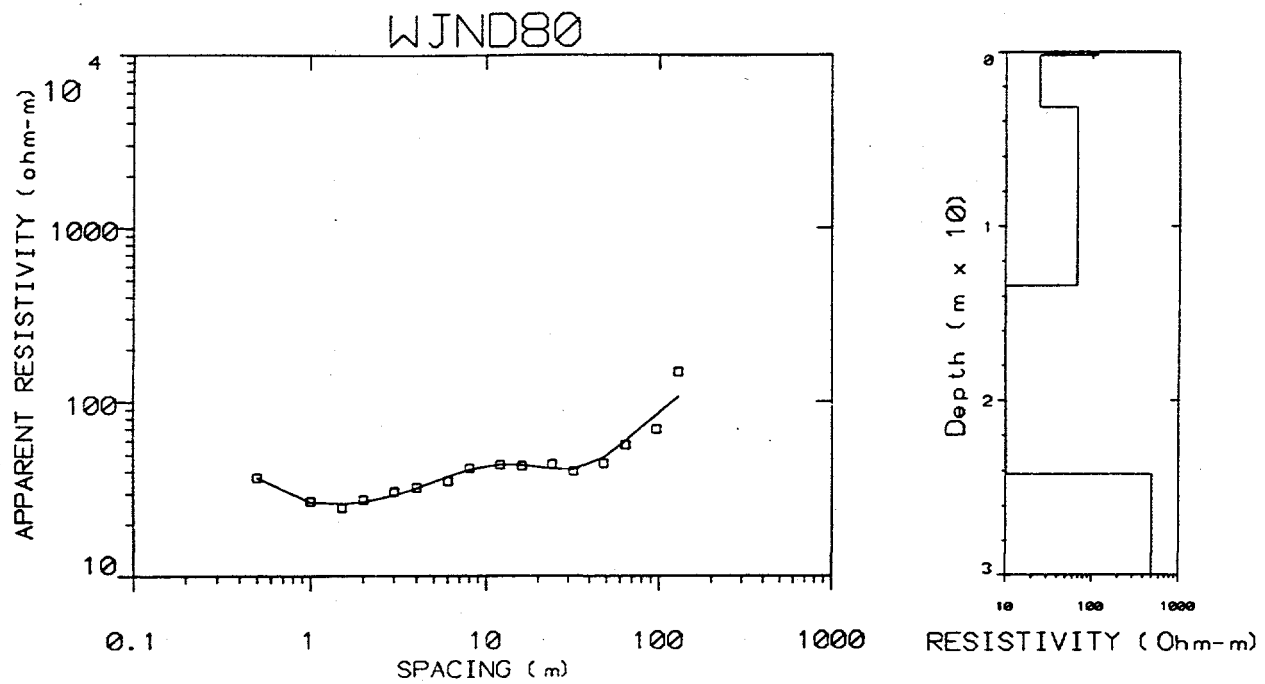


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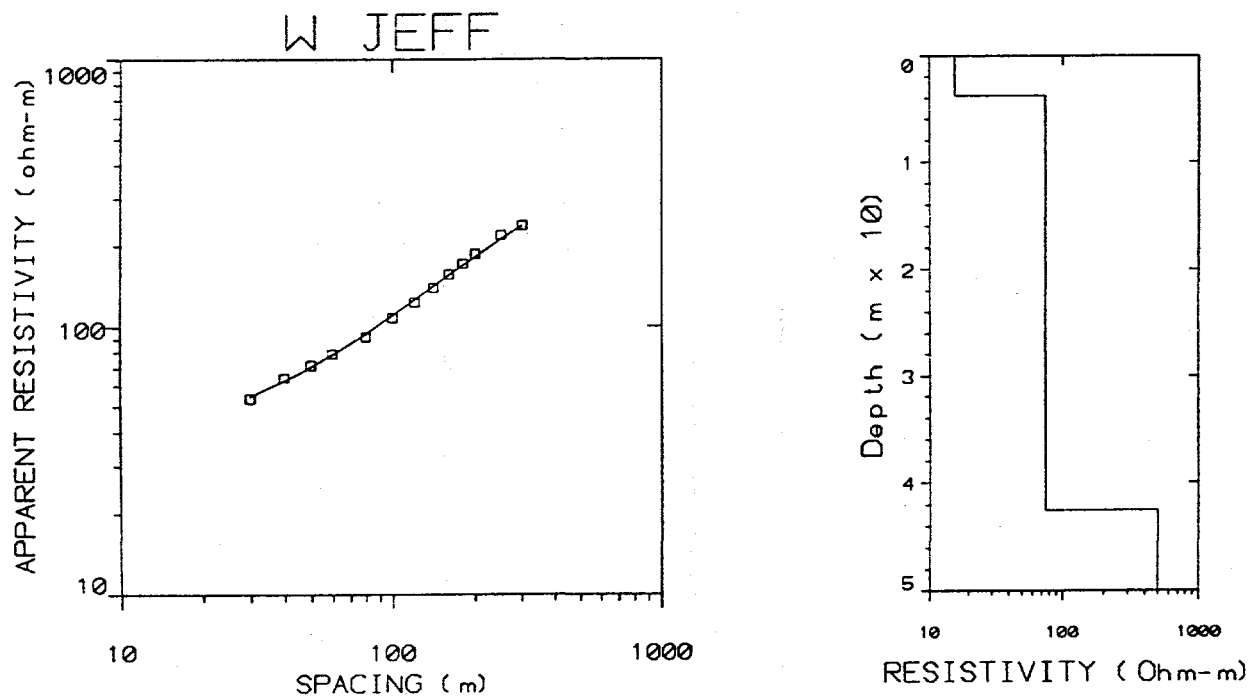


Figure A.22.

APPENDIX B:

**COORDINATES OF GROUND-PENETRATING-RADAR
PROFILES AT BATTELLE WEST JEFFERSON**

**West Jefferson Filter Bed
Ground-Penetrating Radar Profile Line Coordinates**

Profile #	Start Coordinates		End Coordinates	
	North	East	North	East
1	480	620	480	900
2	500	870	1340	900
3	700	680	900	680
4	700	660	900	660
5	670	712	787	743
6	787	743	947	660
7	1040	760	740	790
8	740	790	500	790
9	500	840	560	840
10	560	840	890	840
11	890	840	1100	840
12	850	960	787	743
13	1100	880	900	880
14	900	880	700	880
15	810	880	810	960
16	500	660	500	740
17	450	845	510	860
18	695	900	705	830
19	695	890	760	900
20	700	840	800	950
21	790	940	1340	890

APPENDIX C:

CPT SOUNDINGS

CPT-01

APPLIED RESEARCH ASSOCIATES, INC.

09/20/95

North 500

East 675

Elevation

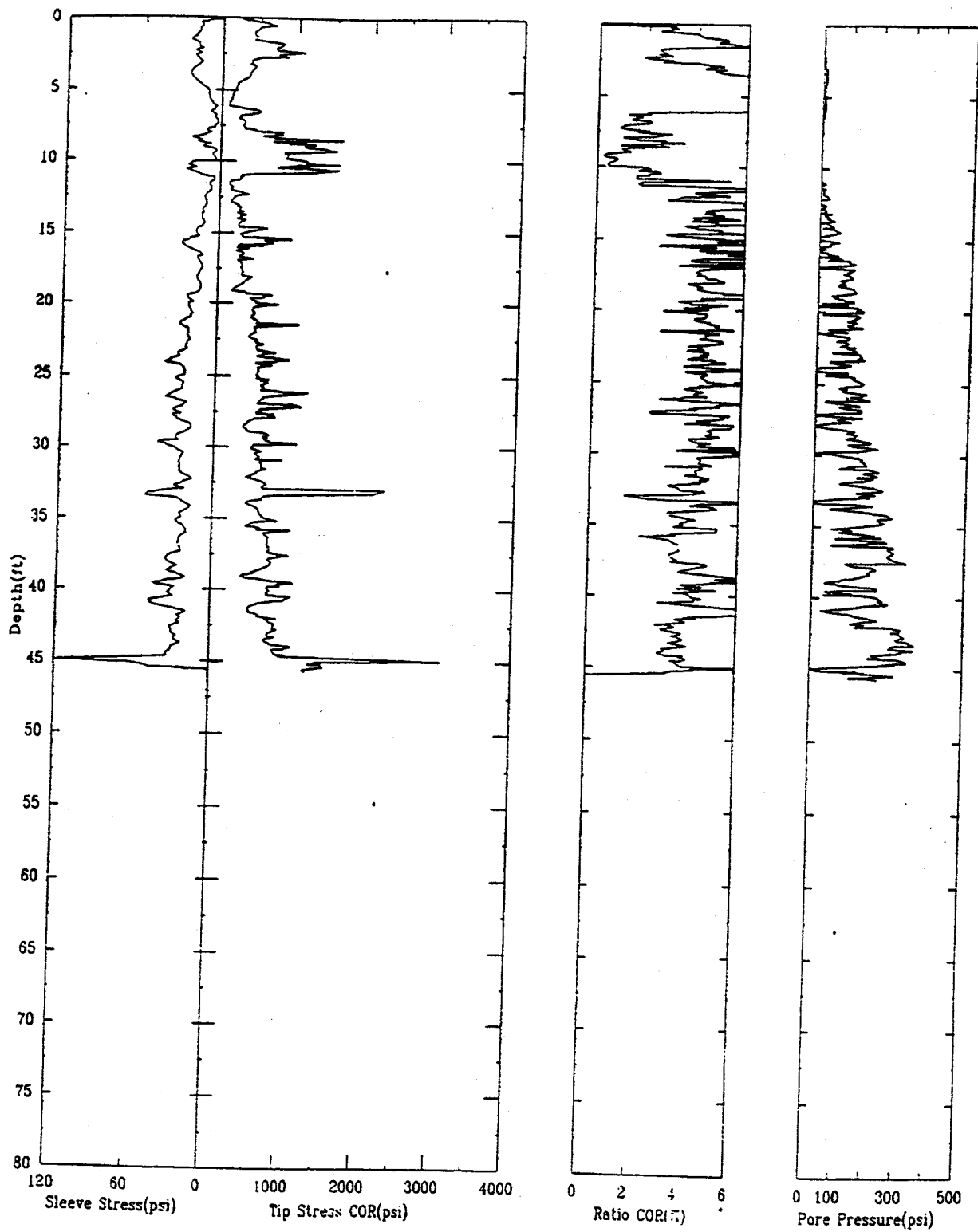


Figure C.1a.

CPT-01

APPLIED RESEARCH ASSOCIATES, INC.
North 500 East 675 Elevation

09/20/95

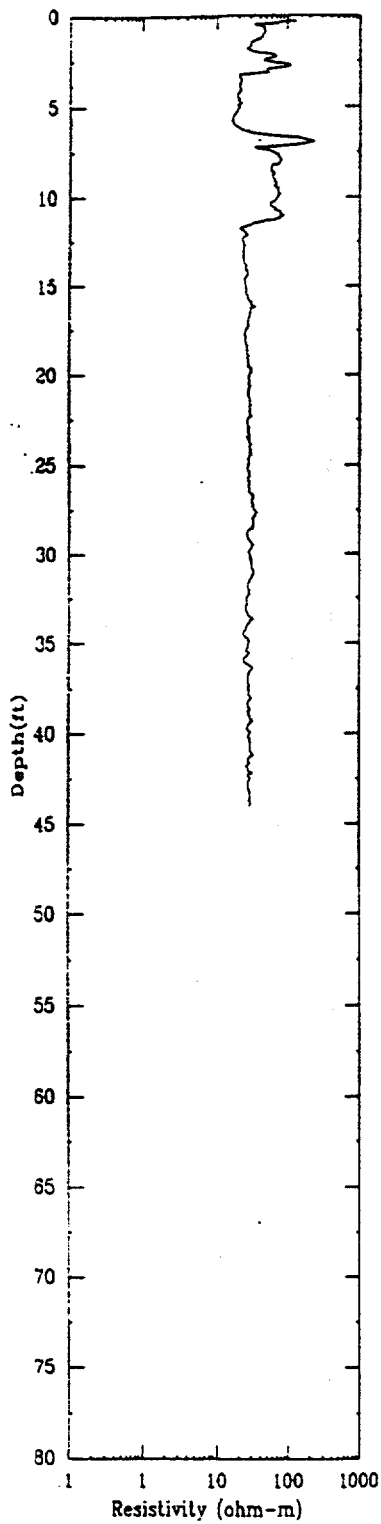


Figure C.1b.

CPT-02

APPLIED RESEARCH ASSOCIATES, INC.

North 498

East 730

Elevation

09/20/95

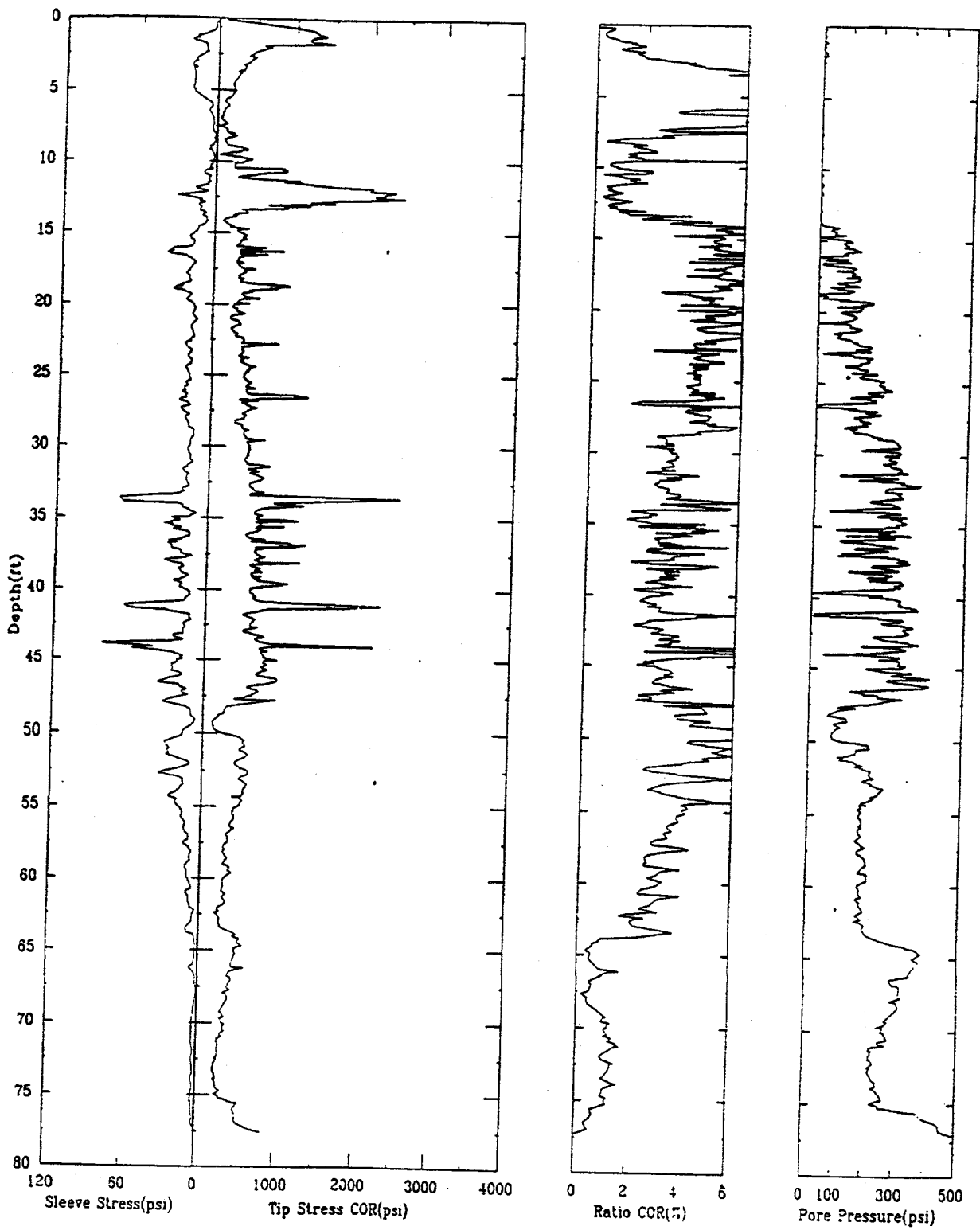


Figure C.2a.

CPT-02

APPLIED RESEARCH ASSOCIATES, INC.
North 498 East 730 Elevation

09/20/95

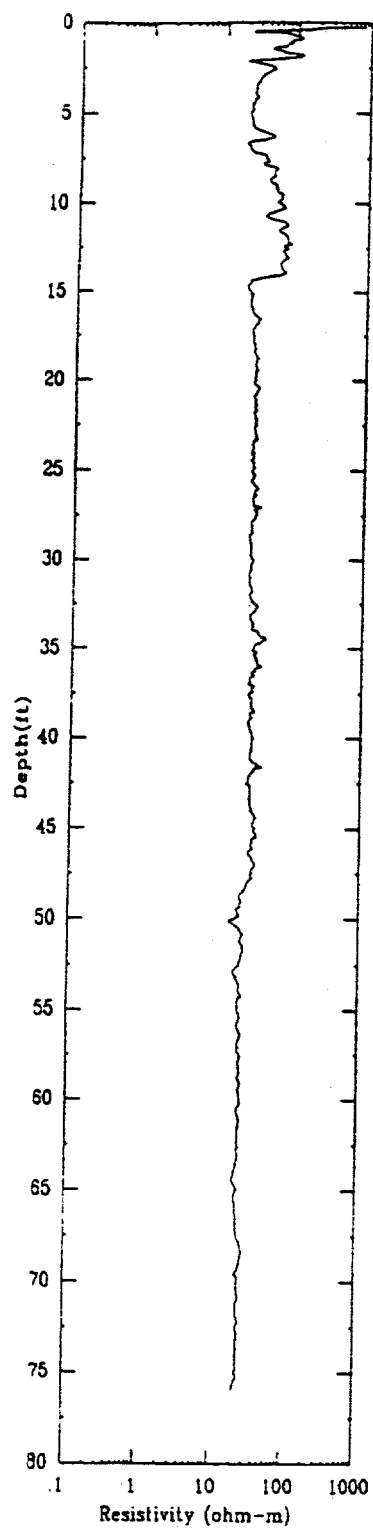


Figure C.2b.

CPT-03

APPLIED RESEARCH ASSOCIATES, INC.

09/20/95

North 760

East 900

Elevation

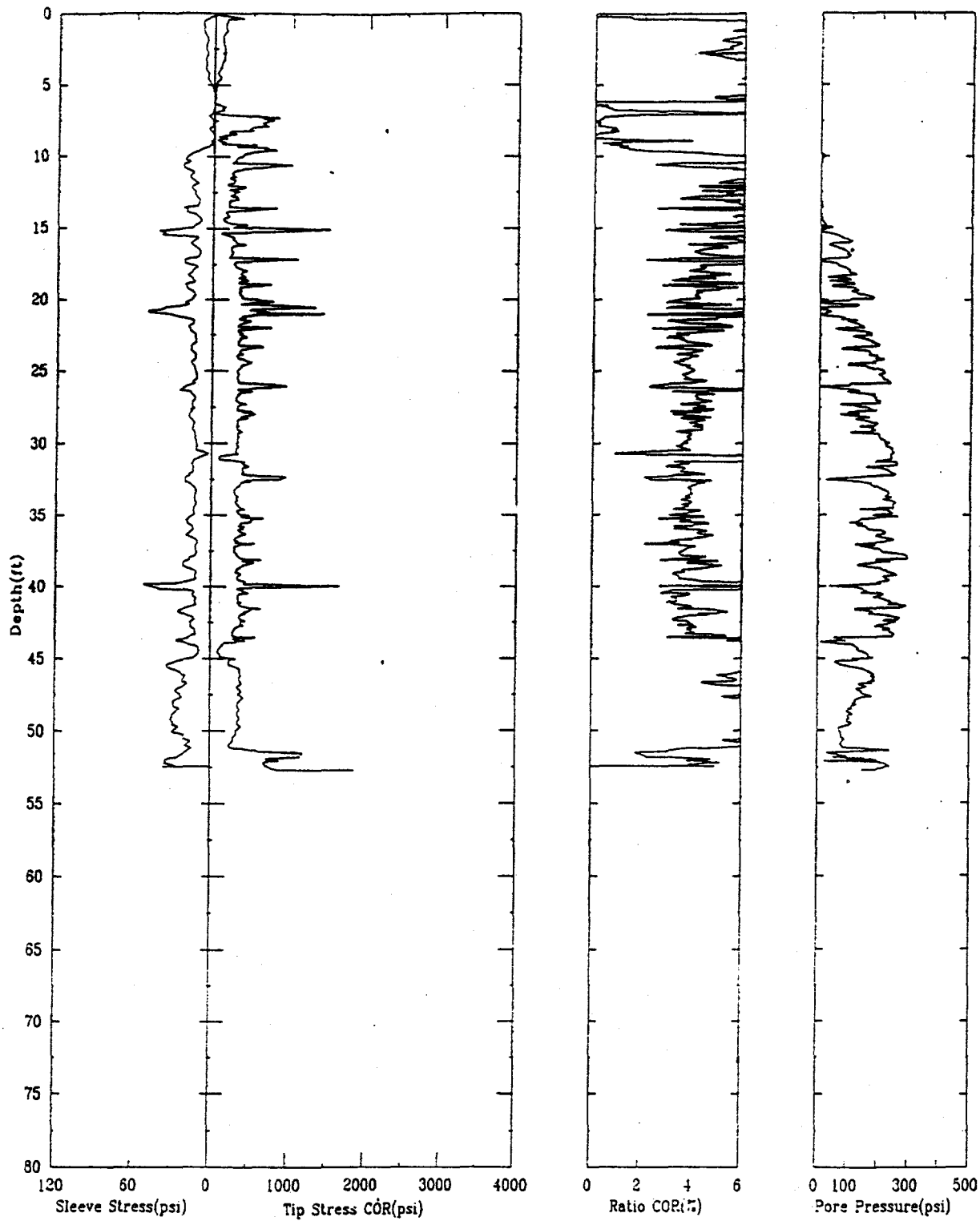


Figure C.3a.

CPT-03

APPLIED RESEARCH ASSOCIATES, INC.
North 760 East 900 Elevation

09/20/95

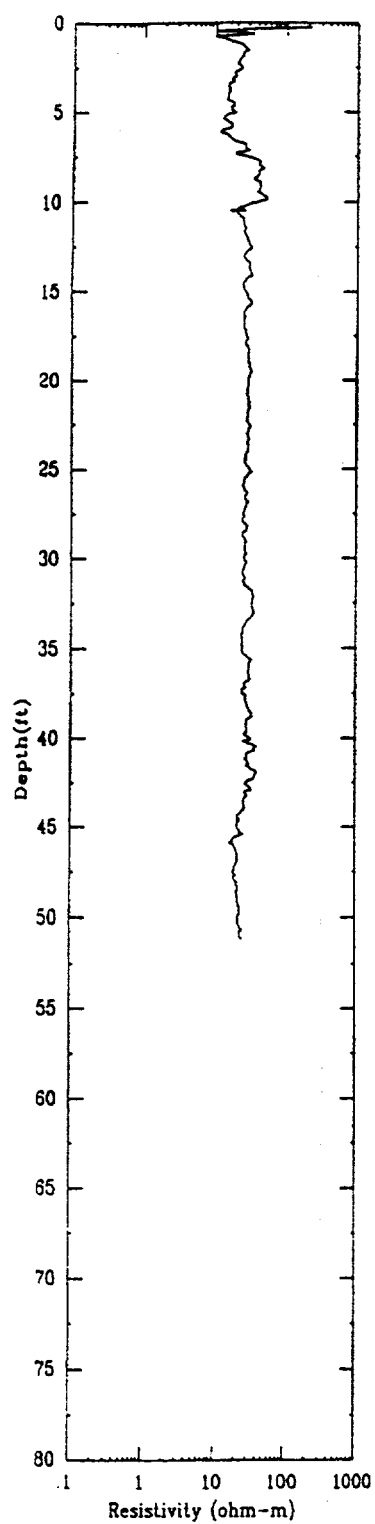


Figure C.3b.

CPT-04

APPLIED RESEARCH ASSOCIATES, INC.

09/20/95

North 790'

East 941

Elevation

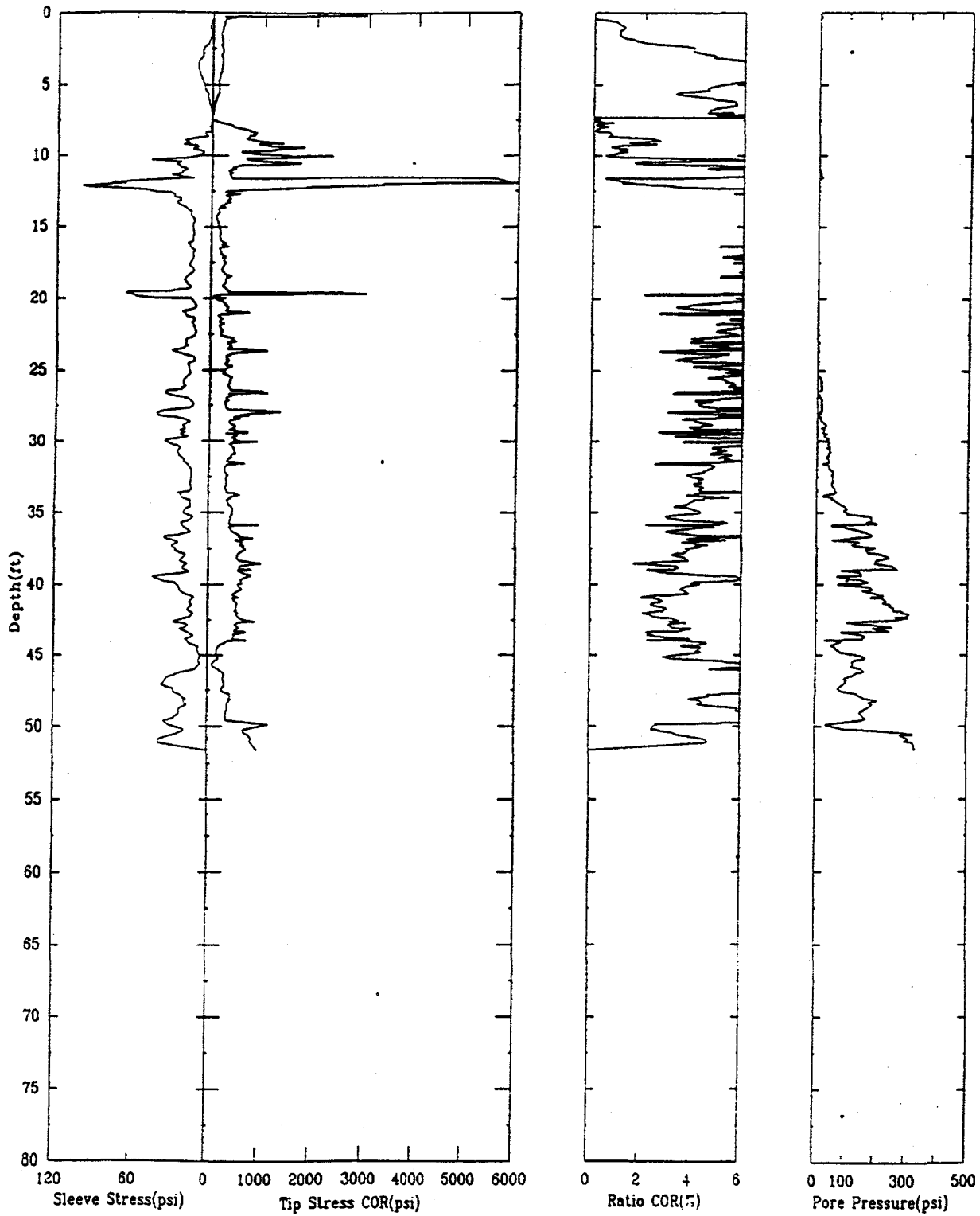


Figure C.4a.

CPT-04

APPLIED RESEARCH ASSOCIATES, INC.
North 790 East 941 Elevation

09/20/95

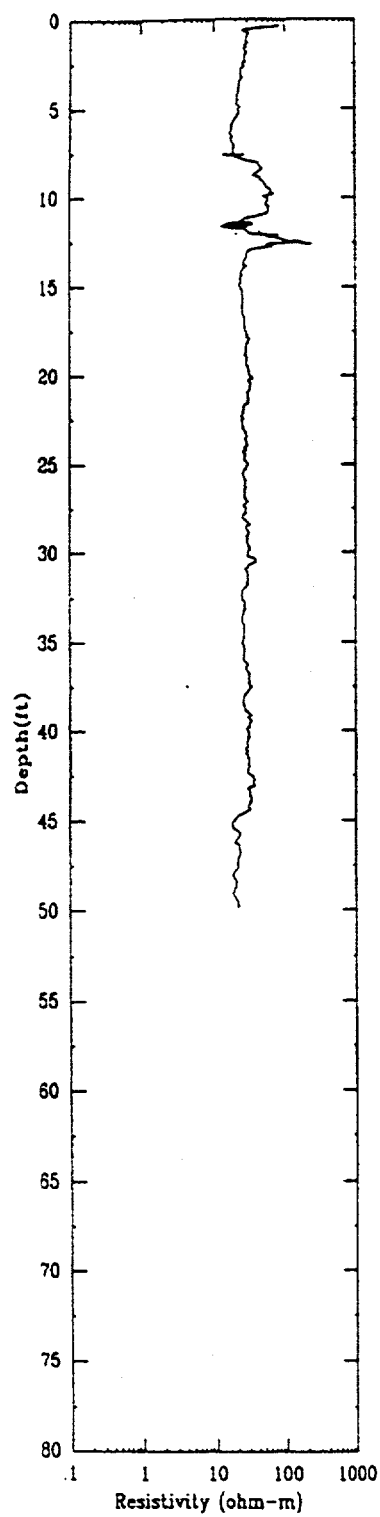


Figure C.4b.

CPT-05C

APPLIED RESEARCH ASSOCIATES, INC.

09/21/95

North 902

East 947

Elevation

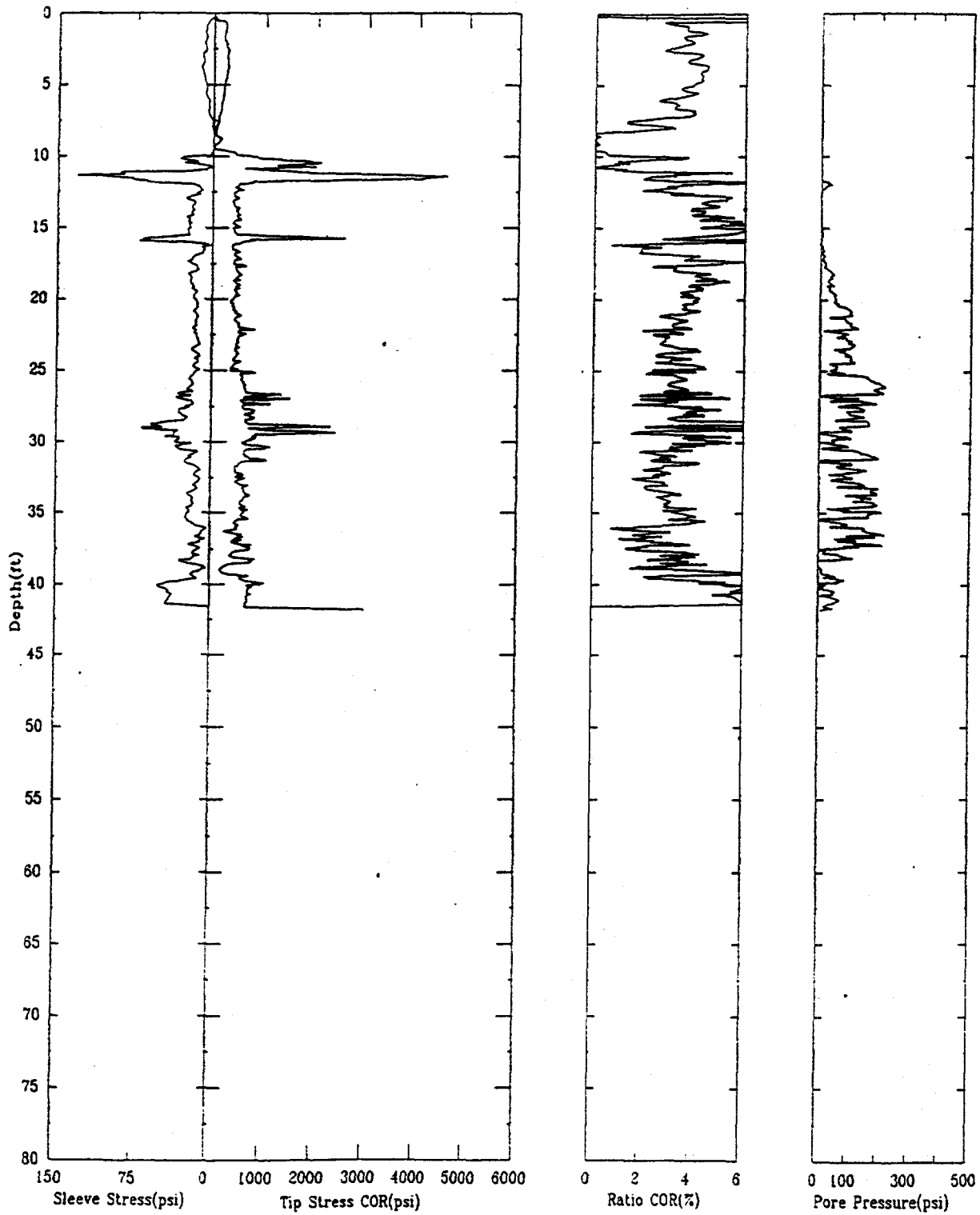


Figure C.5a.

CPT-05C

APPLIED RESEARCH ASSOCIATES, INC.

09/21/95

North 902

East 947

Elevation

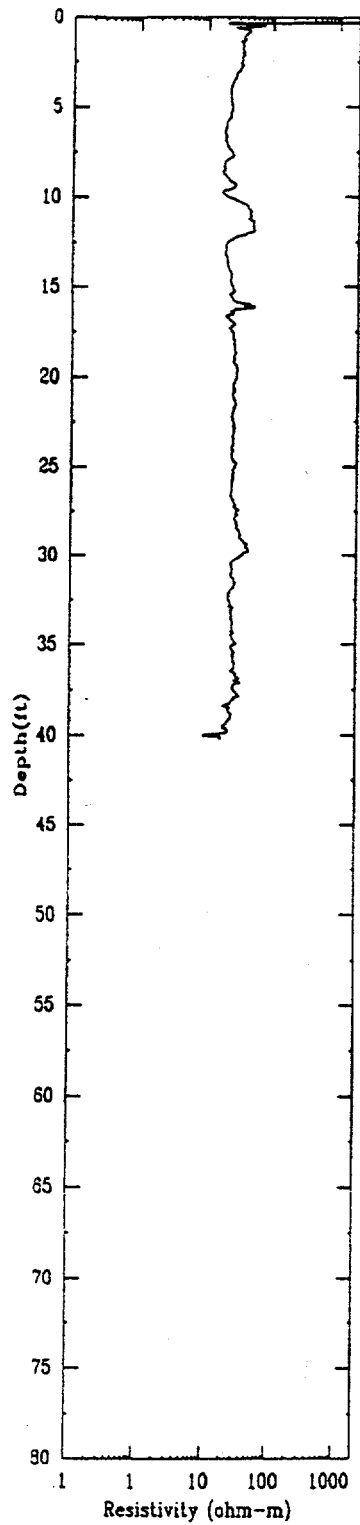


Figure C.5b.

CPT-6

APPLIED RESEARCH ASSOCIATES, INC.

09/21/95

North 980,

East 932

Elevation

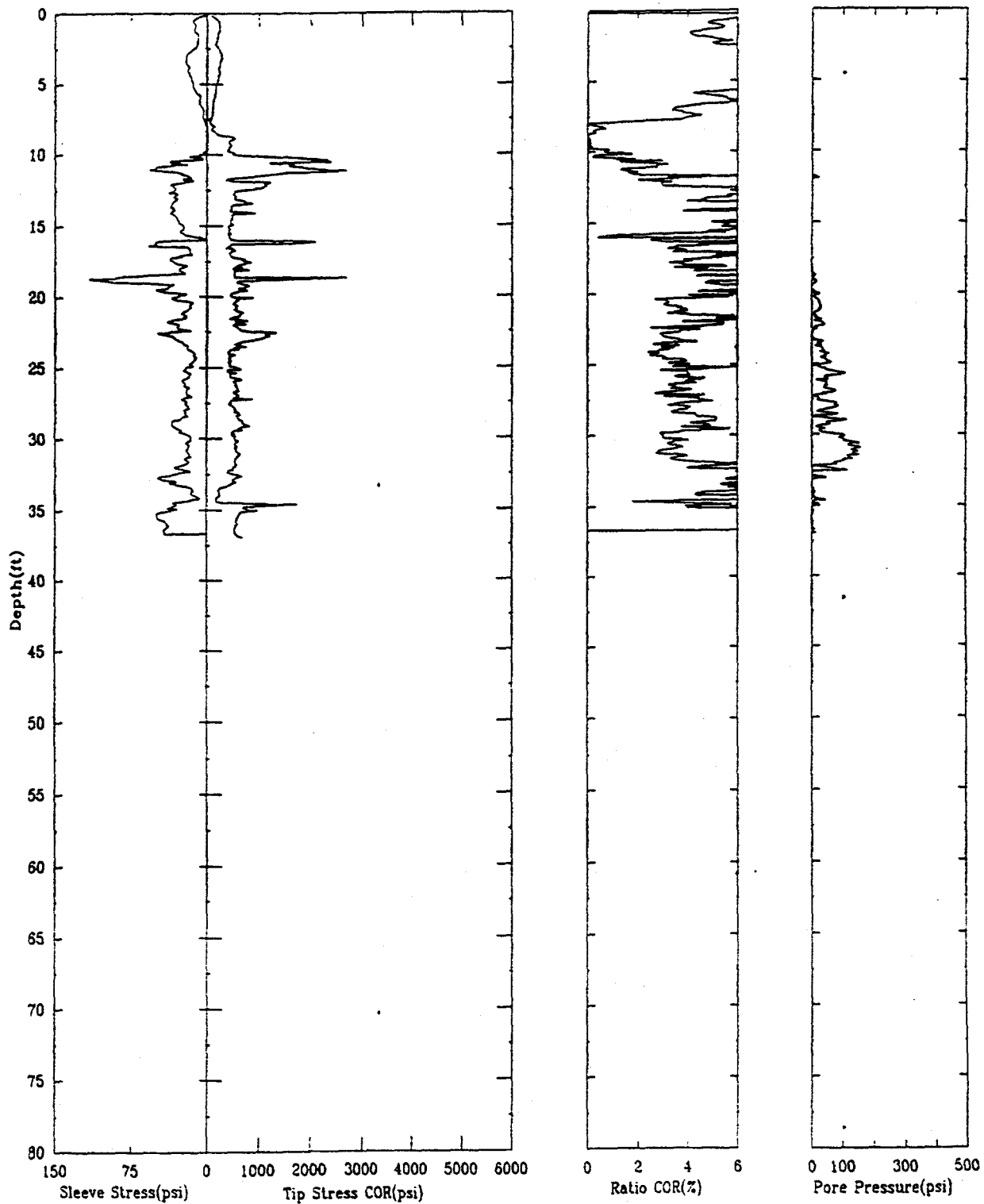


Figure C.6a.

CPT-6

APPLIED RESEARCH ASSOCIATES, INC.
North 980 East 932 Elevation

09/21/95

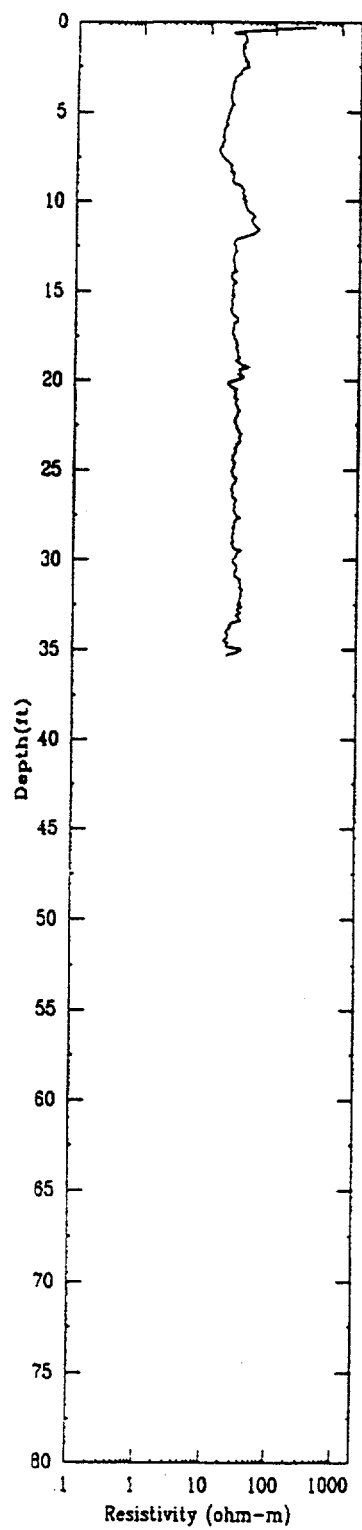


Figure C.6b.

CPT-7

APPLIED RESEARCH ASSOCIATES, INC.

09/21/95

North 1000

East 927

Elevation

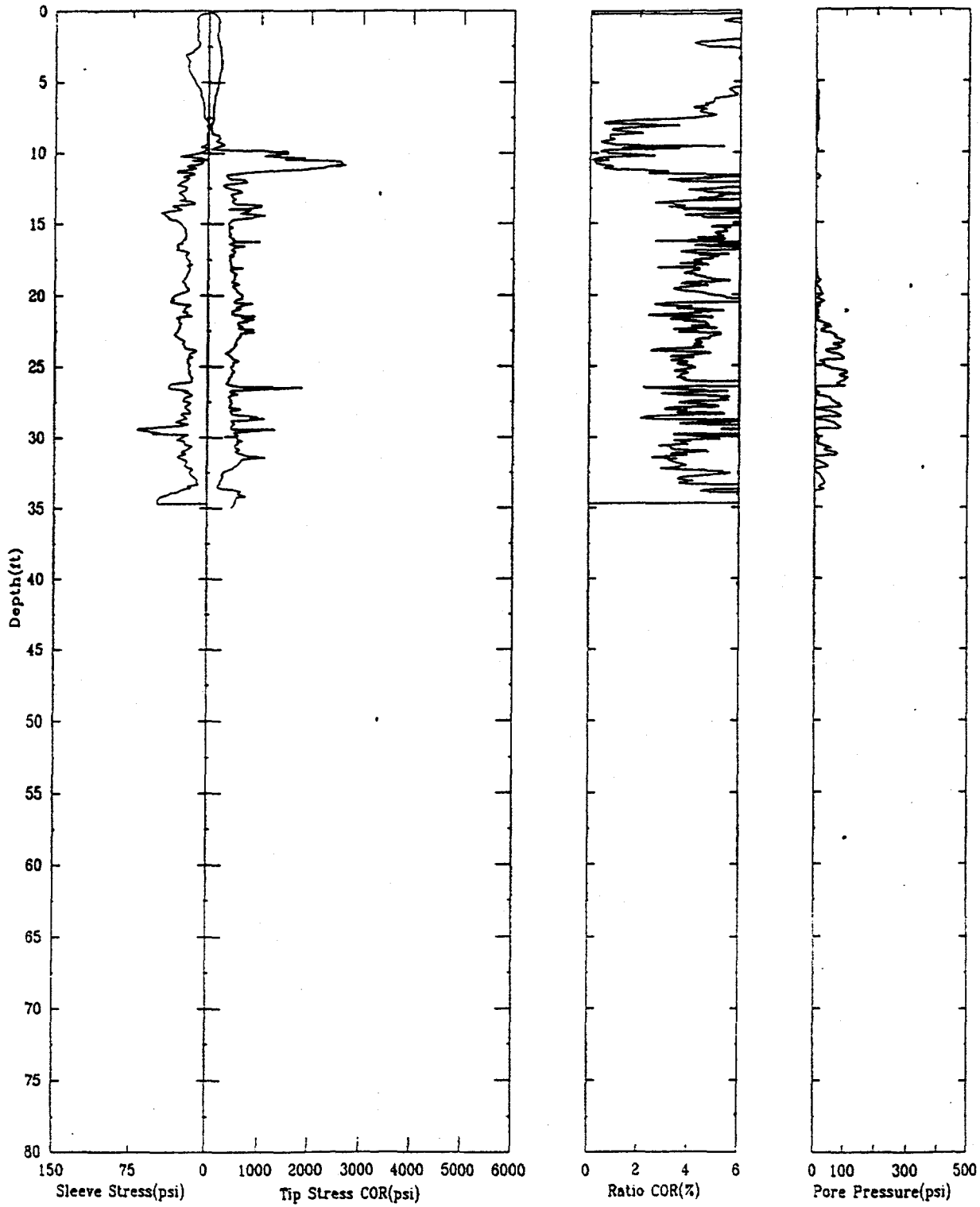


Figure C.7a.

CPT-7

APPLIED RESEARCH ASSOCIATES, INC.

09/21/95

North 1000

East 927

Elevation

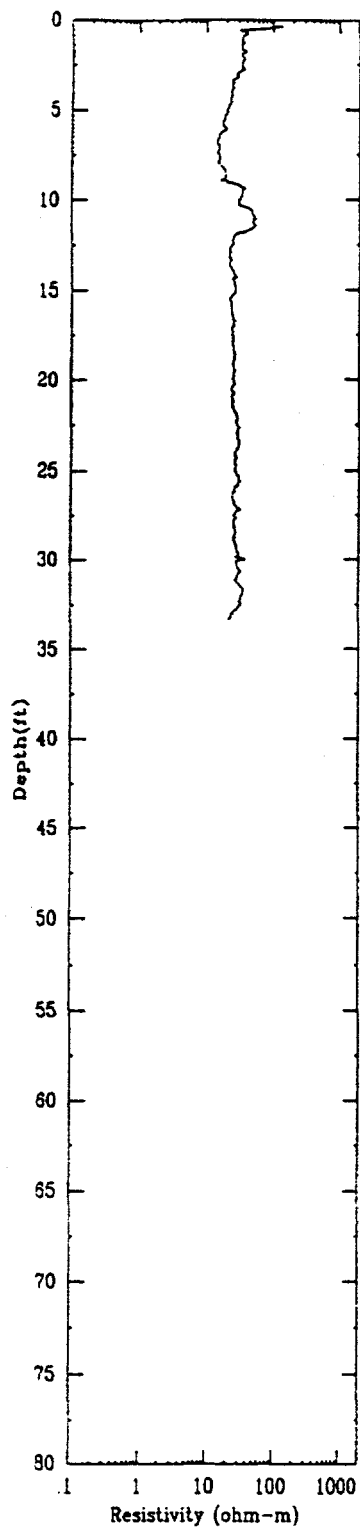


Figure C.7b.

CPT-8

APPLIED RESEARCH ASSOCIATES, INC.

09/21/95

North 1240

East 870

Elevation

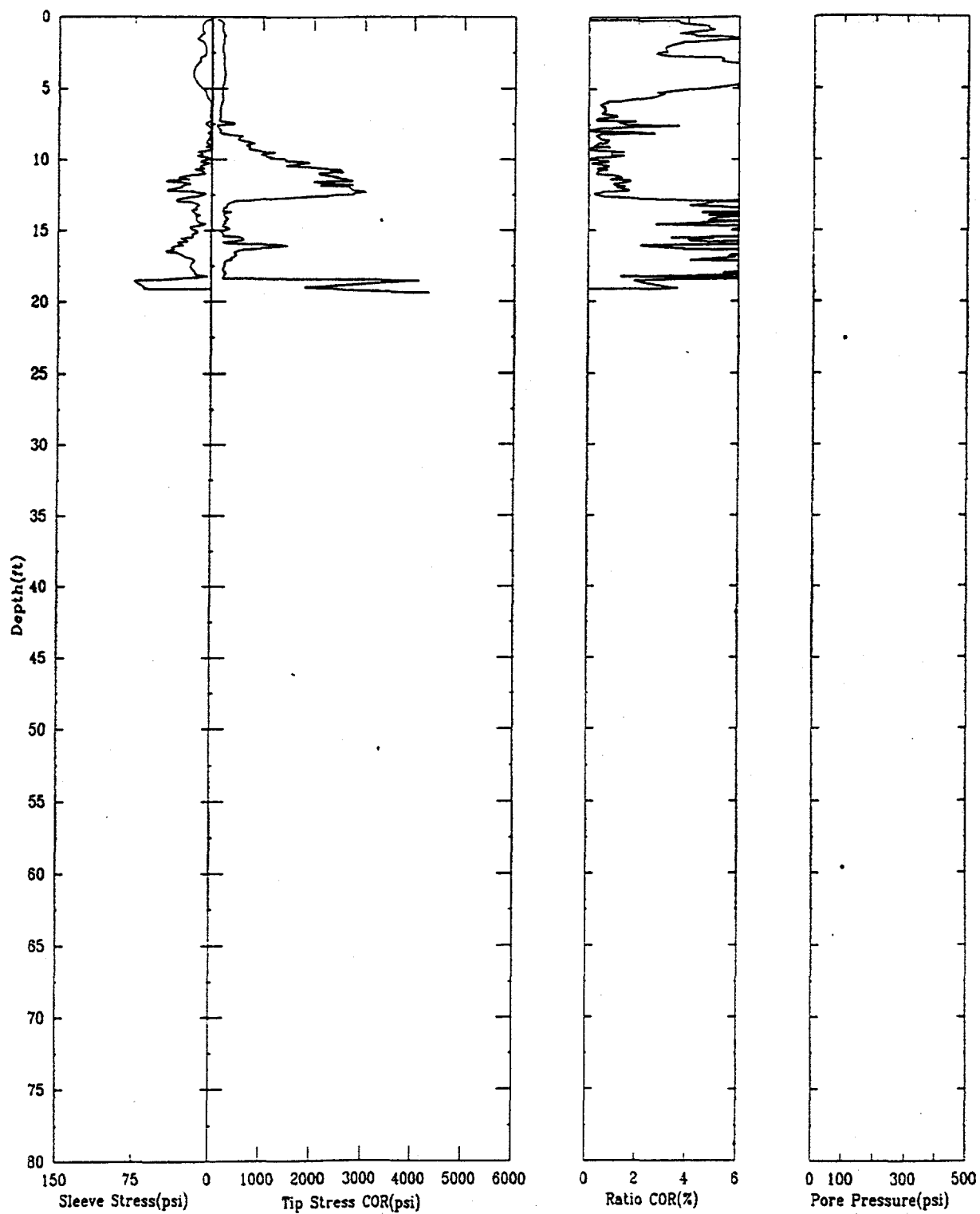


Figure C.8a.

CPT-8

APPLIED RESEARCH ASSOCIATES, INC.

09/21/95

North 1240

East 870

Elevation

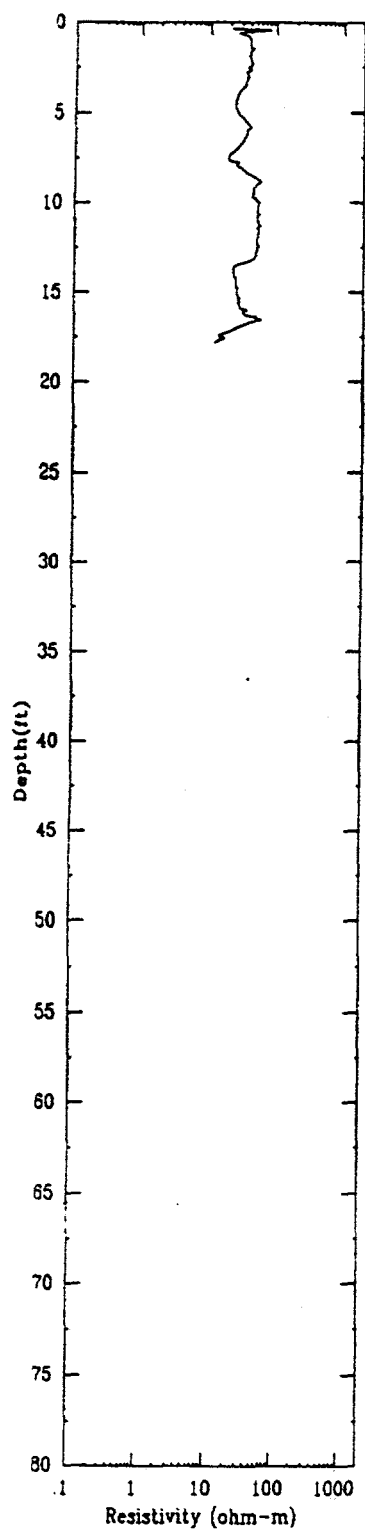


Figure C.8b.

CPT-9

APPLIED RESEARCH ASSOCIATES, INC.

09/21/95

North 700

East 891

Elevation

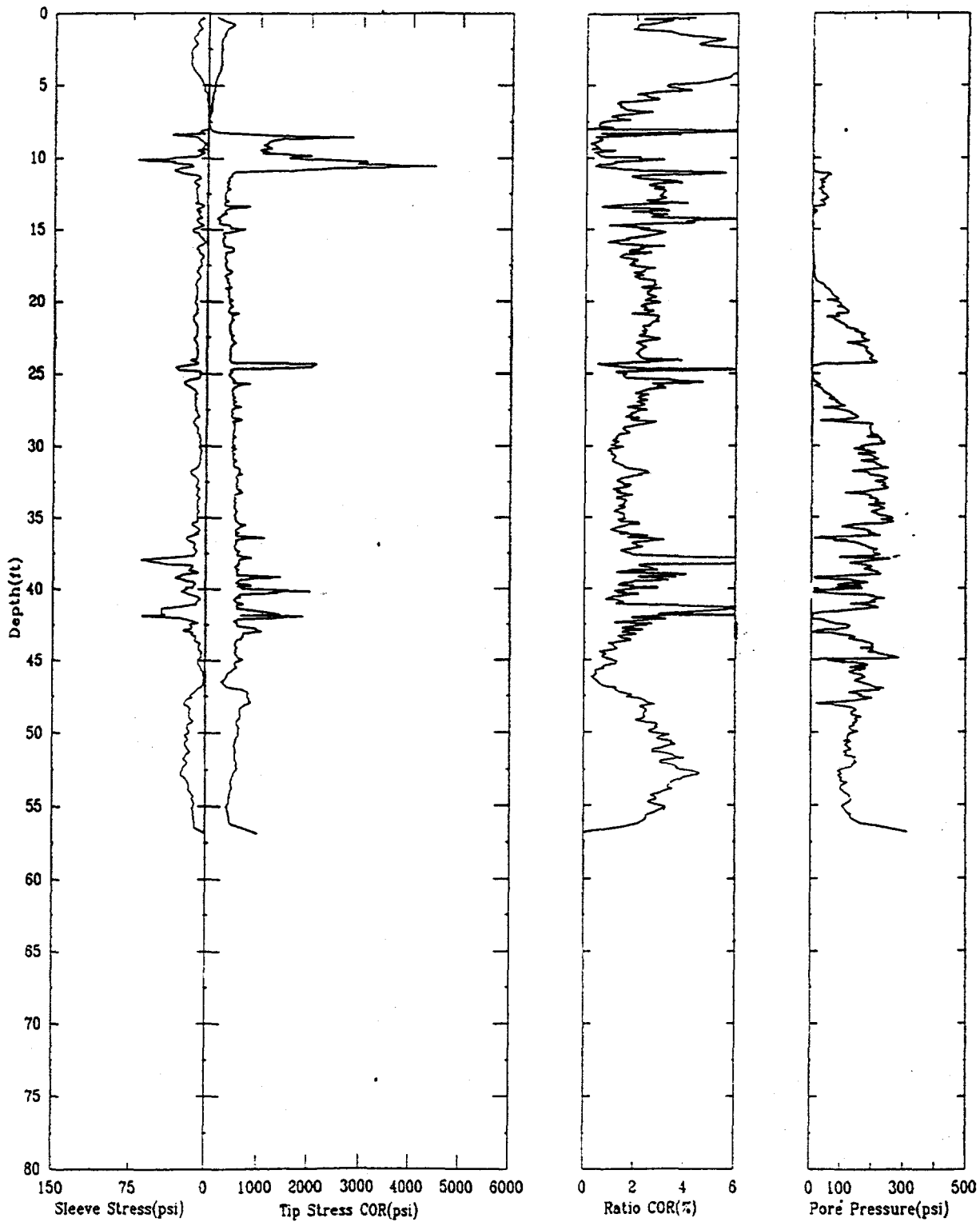


Figure C.9a.

CPT-9

APPLIED RESEARCH ASSOCIATES, INC.
North 700 East 891 Elevation

09/21/95

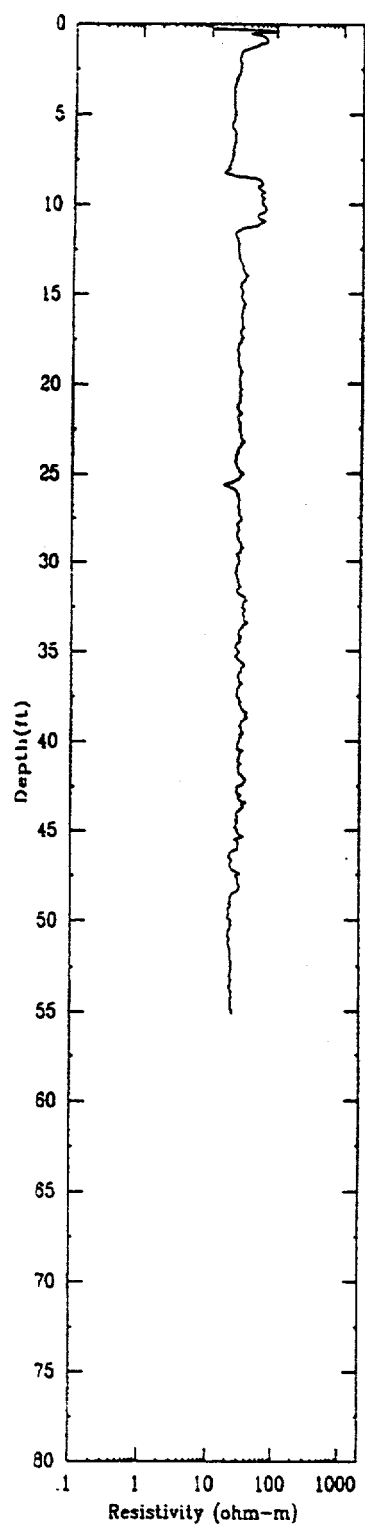


Figure C.9b.

CPT-10

APPLIED RESEARCH ASSOCIATES, INC.

09/21/95

North 451

East 850

Elevation

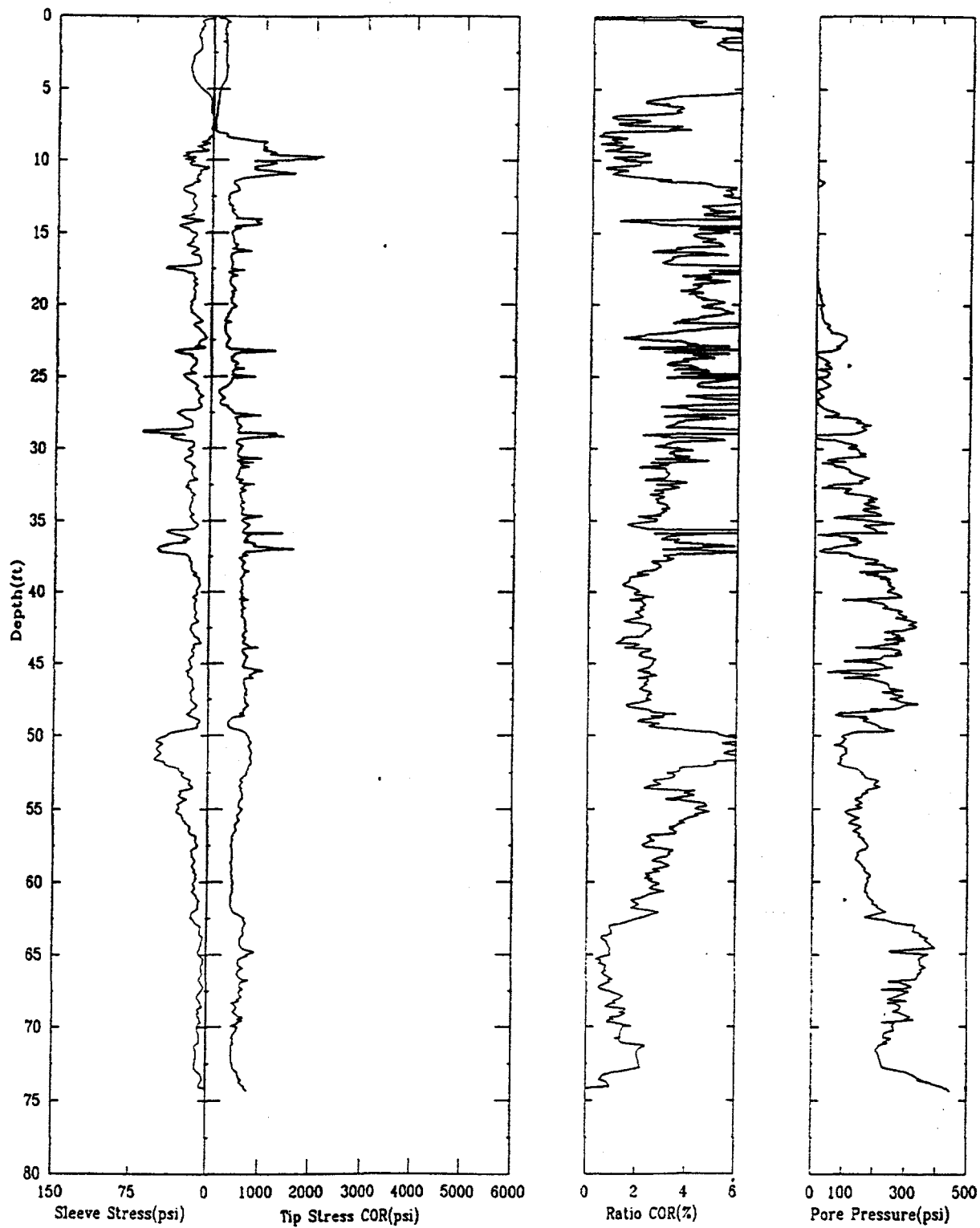


Figure C.10a.

CPT-10

APPLIED RESEARCH ASSOCIATES, INC.
North 451 East 850 Elevation

09/21/95

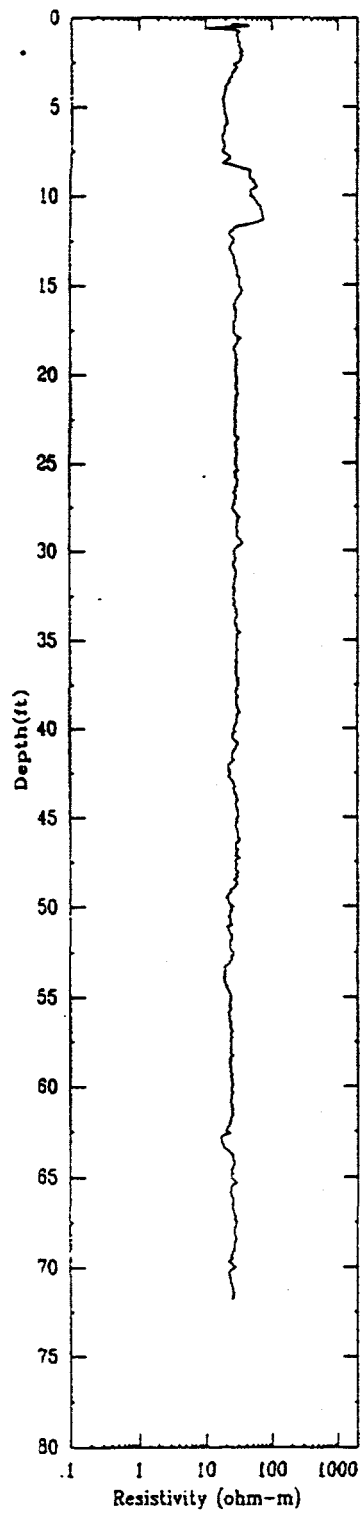


Figure C.10b.

CPT-11

APPLIED RESEARCH ASSOCIATES, INC.

09/22/95

North 497

East 860

Elevation

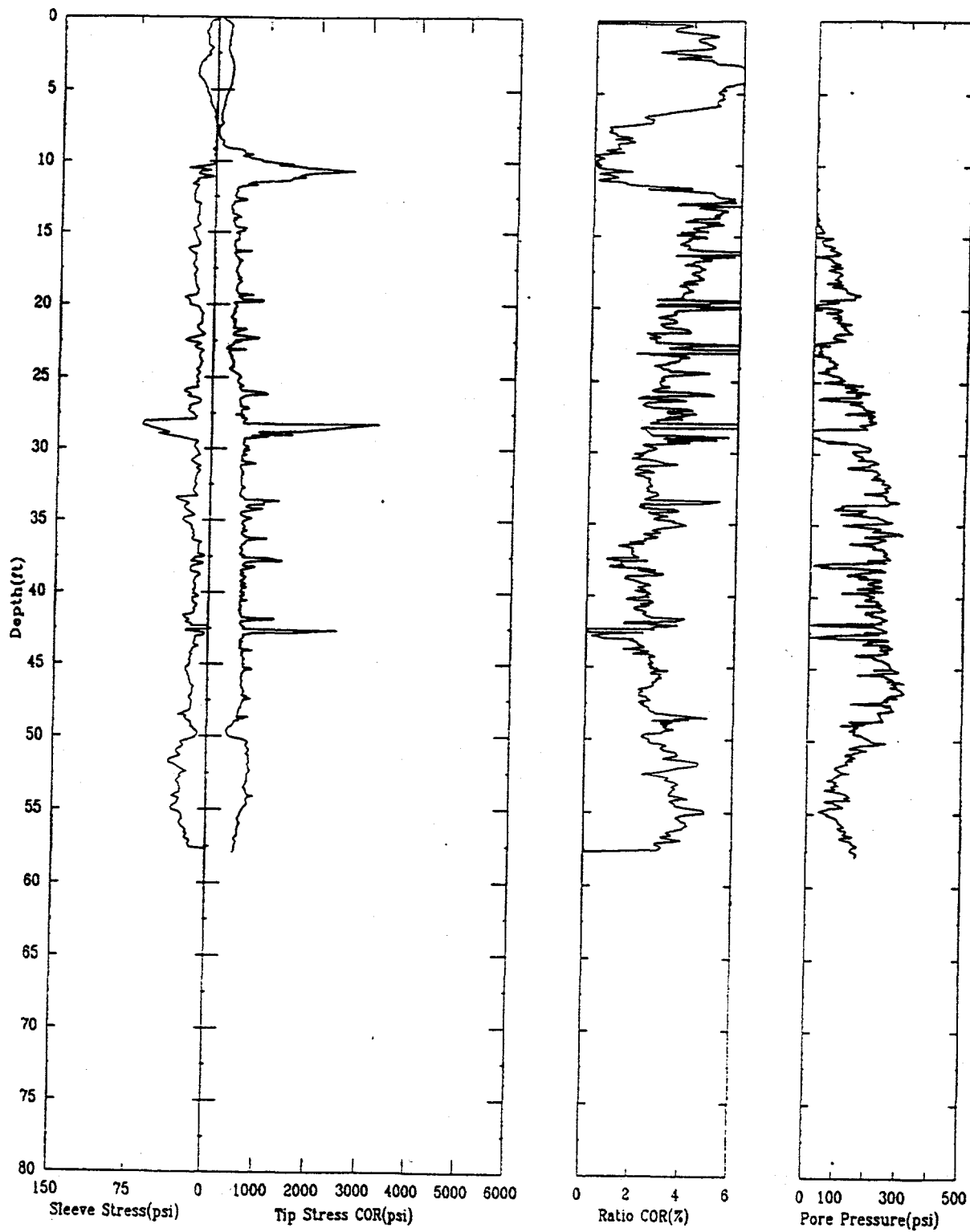


Figure C.11a.

CPT-11

APPLIED RESEARCH ASSOCIATES, INC.
North 497 East 860 Elevation

09/22/95

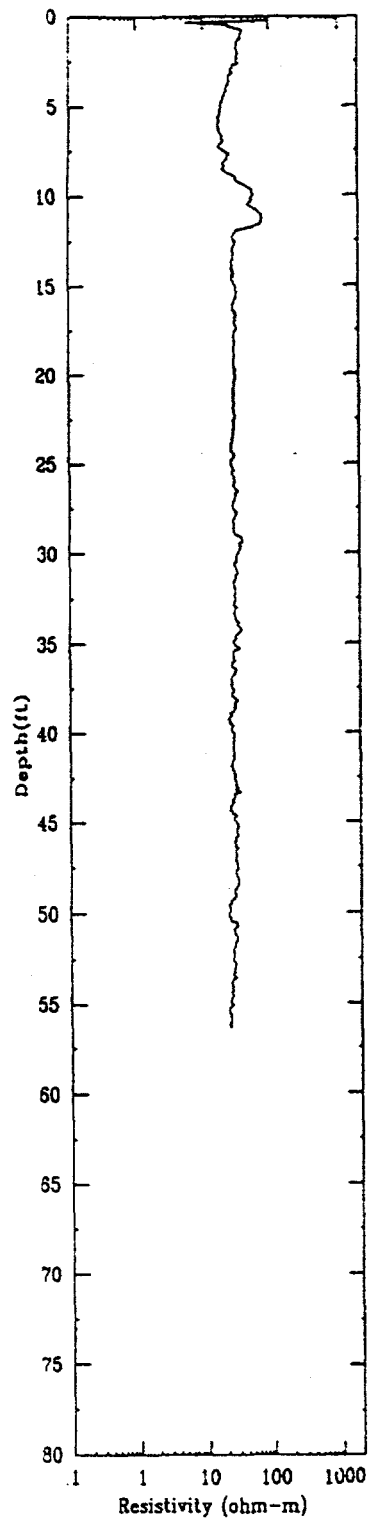


Figure C.11b.

CPT-12

APPLIED RESEARCH ASSOCIATES, INC.

09/22/95

North 705

East 843

Elevation

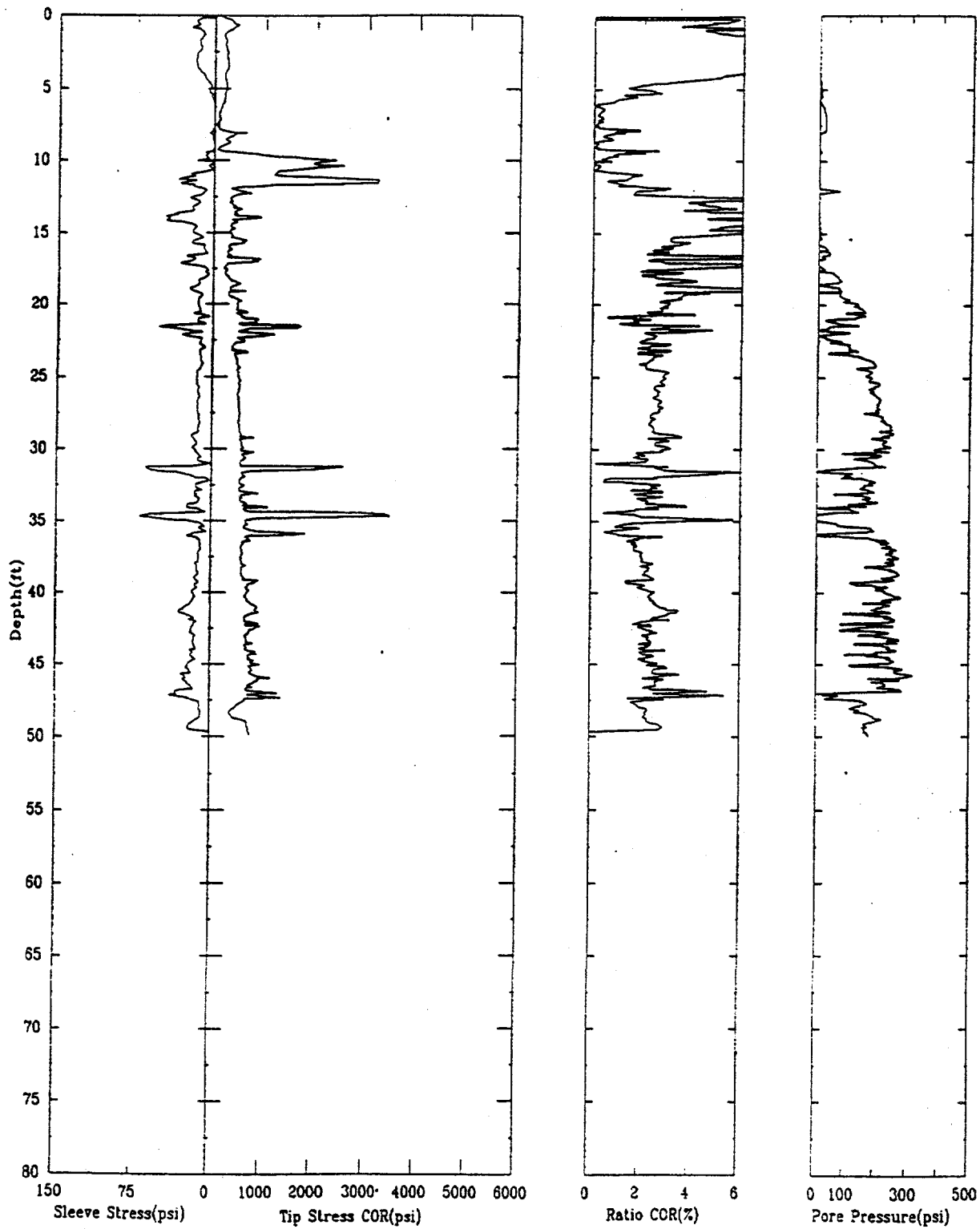


Figure C.12a.

CPT-12

APPLIED RESEARCH ASSOCIATES, INC.
North 705 East 843 Elevation

09/22/95

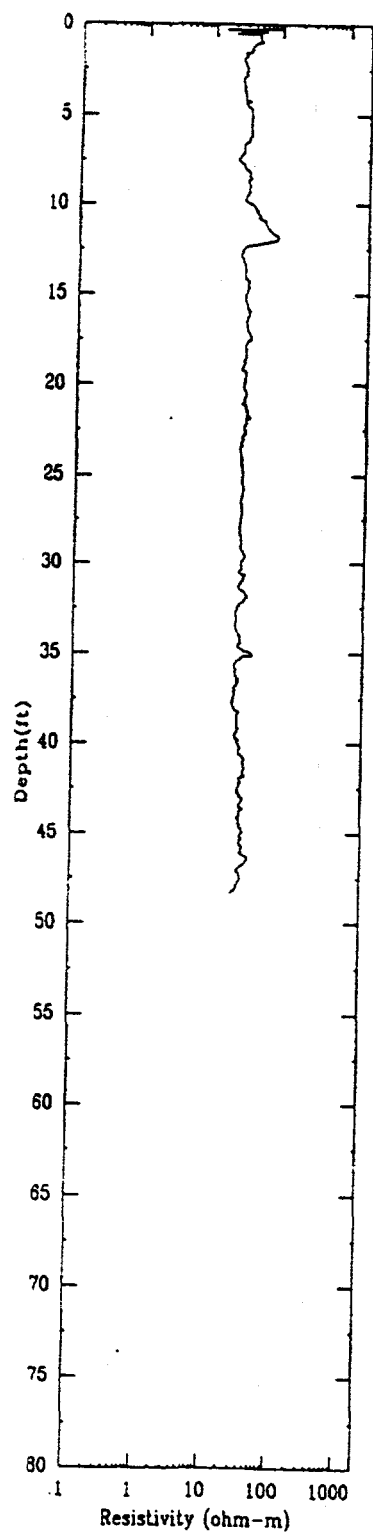


Figure C.12b.

CPT-13

APPLIED RESEARCH ASSOCIATES, INC.

09/22/95

North 817

East 844

Elevation

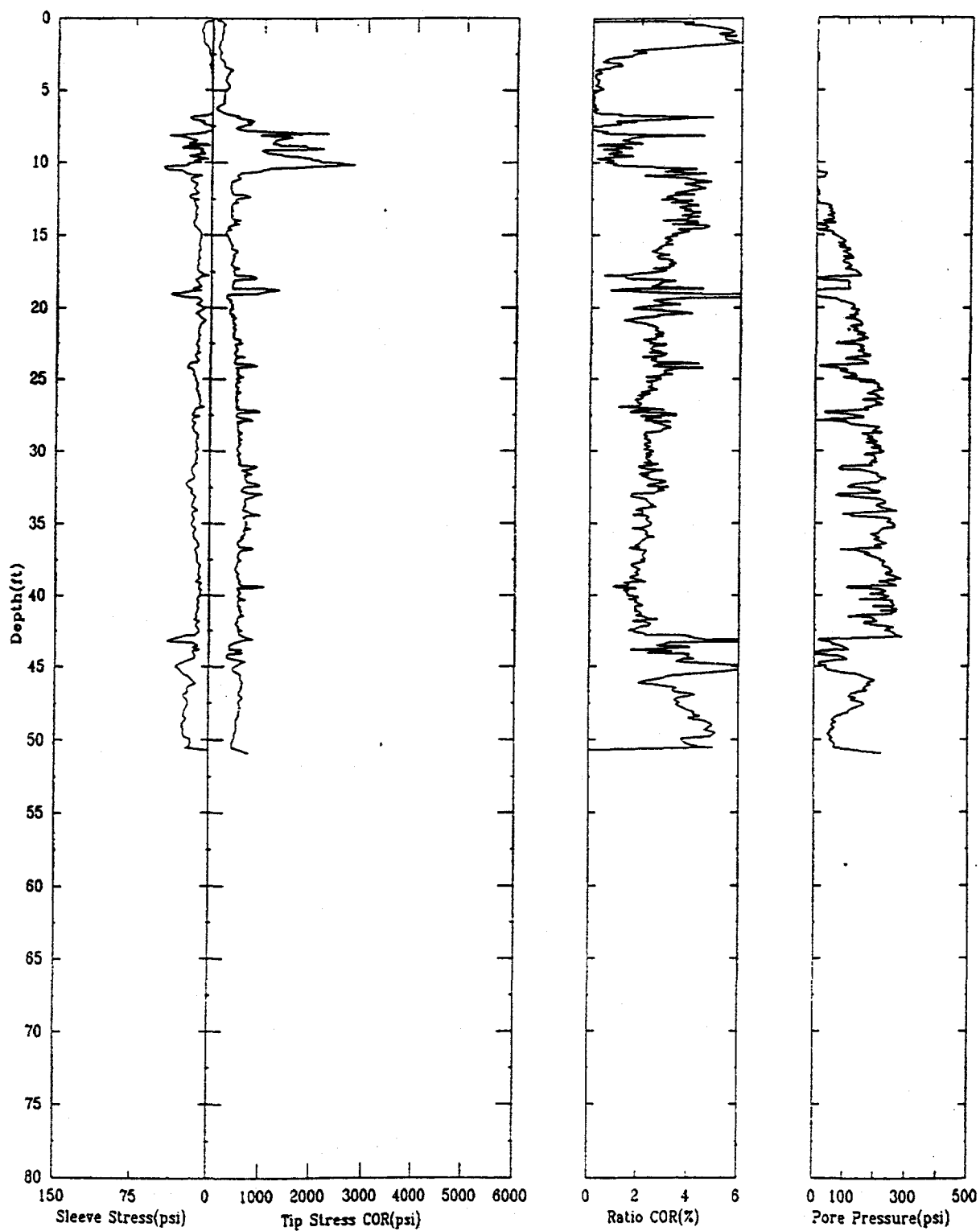


Figure C.13a.

CPT-13

APPLIED RESEARCH ASSOCIATES, INC.
North 817 East 844 Elevation

09/22/95

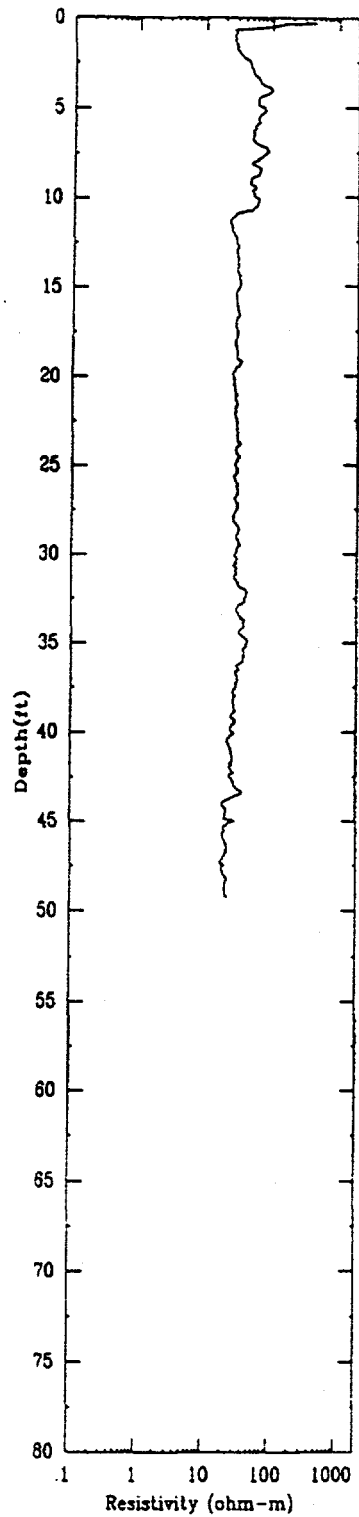


Figure C.13b.

CPT-14

APPLIED RESEARCH ASSOCIATES, INC.

09/22/95

North 950

East 846

Elevation

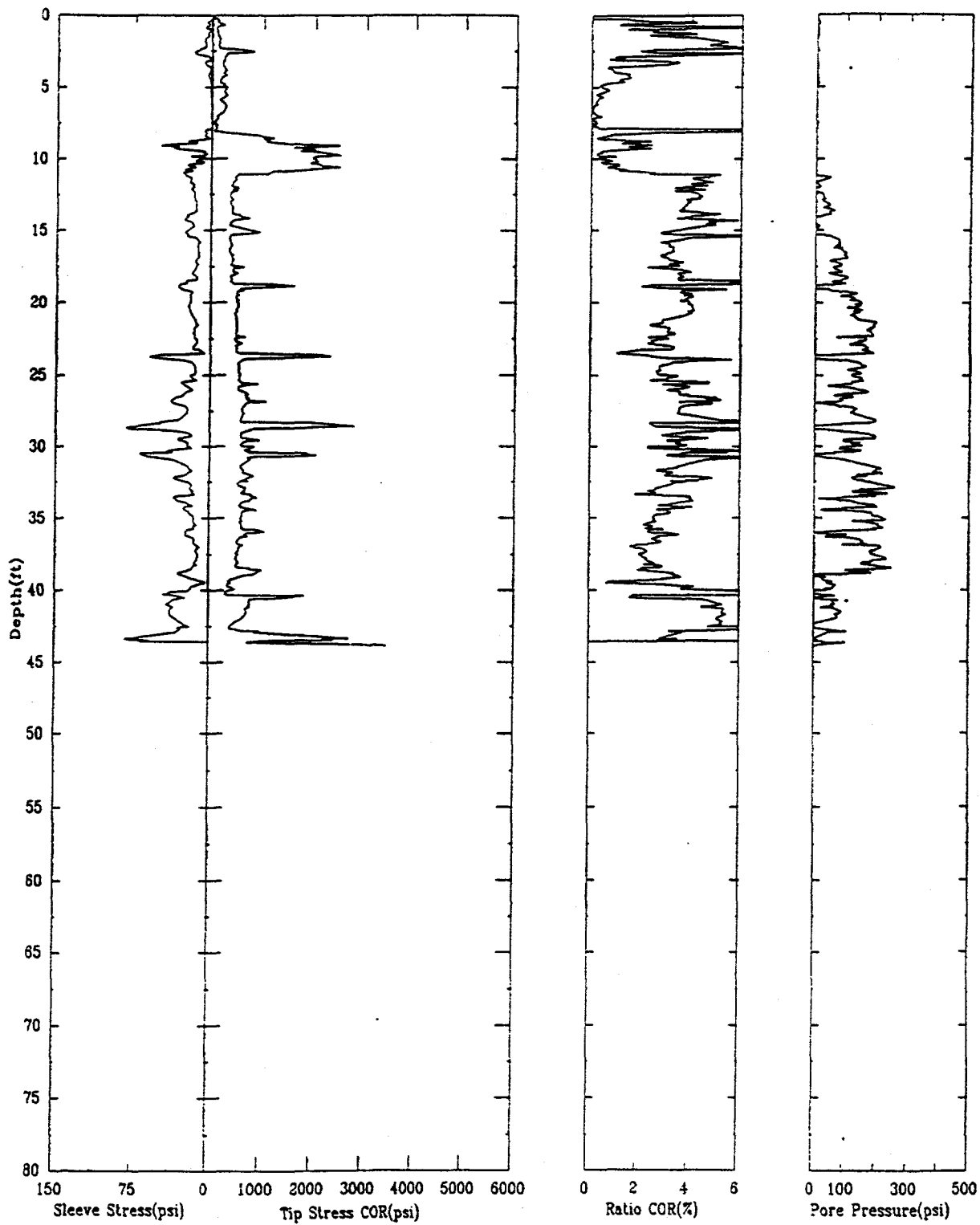


Figure C.14a.

CPT-14

APPLIED RESEARCH ASSOCIATES, INC.
North 950 East 846 Elevation

09/22/95

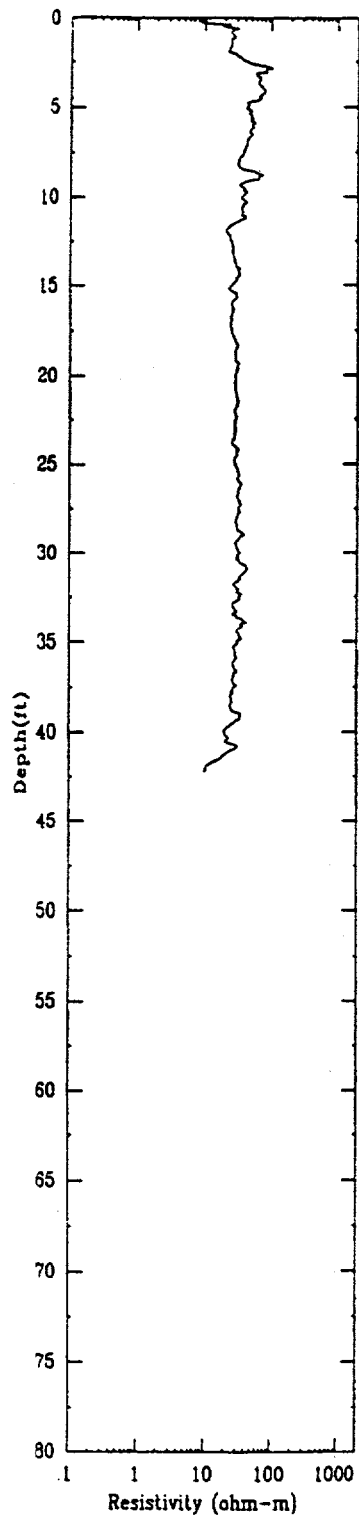


Figure C.14b.

CPT-15

APPLIED RESEARCH ASSOCIATES, INC.

09/22/95

North 985

East 760

Elevation

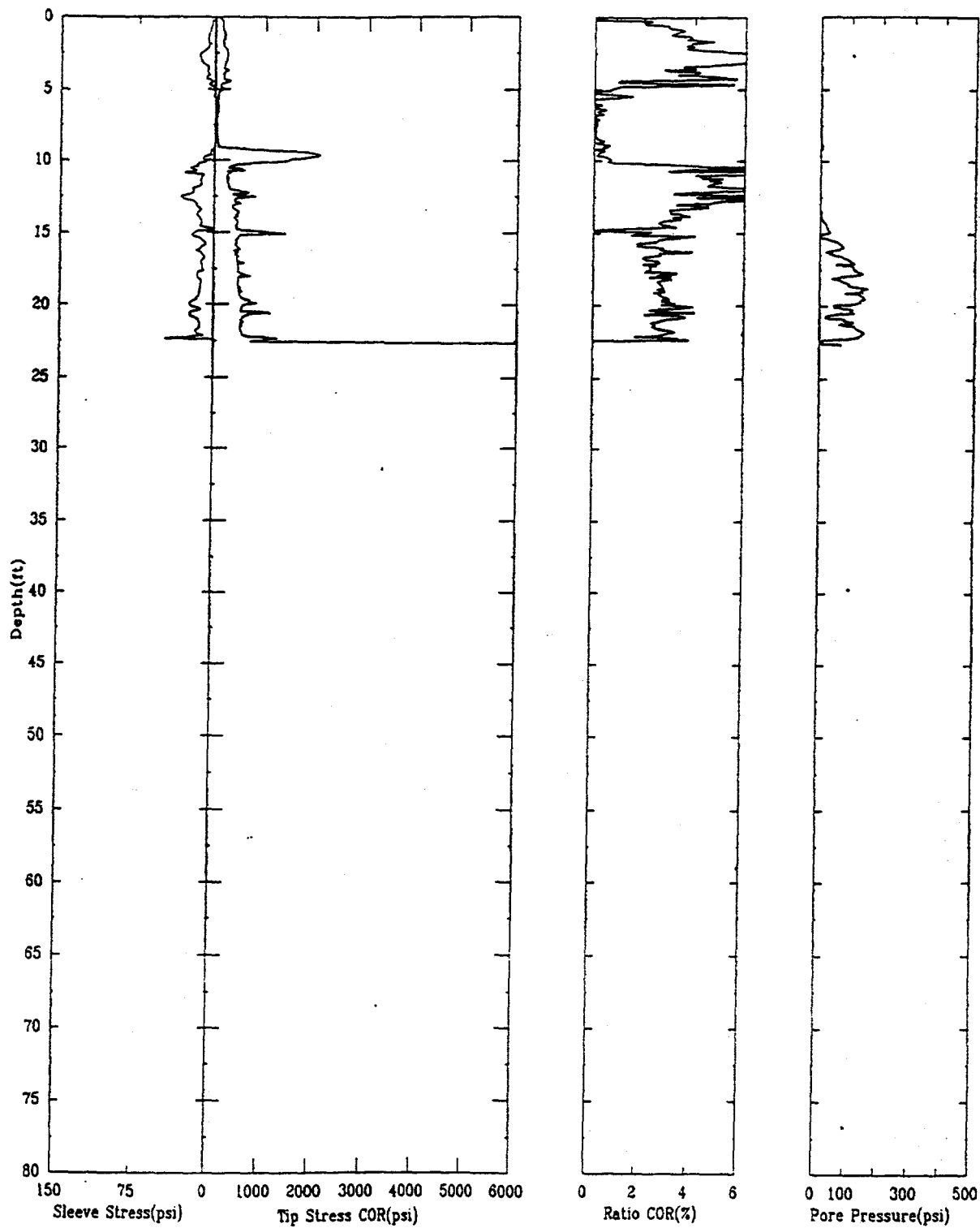


Figure C.15a.

CPT-15

APPLIED RESEARCH ASSOCIATES, INC.
North 985 East 760 Elevation

09/22/95

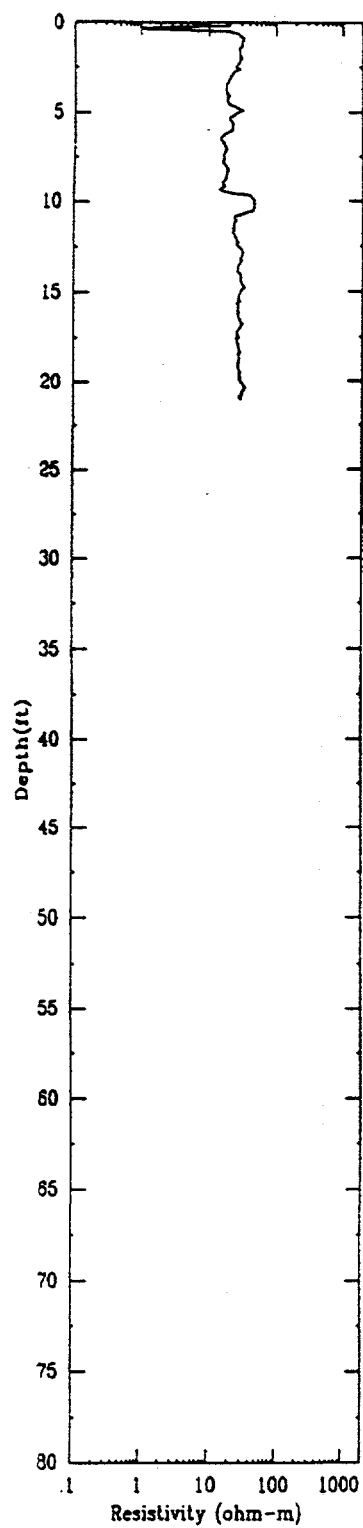


Figure C.15b.

CPT-16

APPLIED RESEARCH ASSOCIATES, INC.

09/22/95

North 850

East 780

Elevation

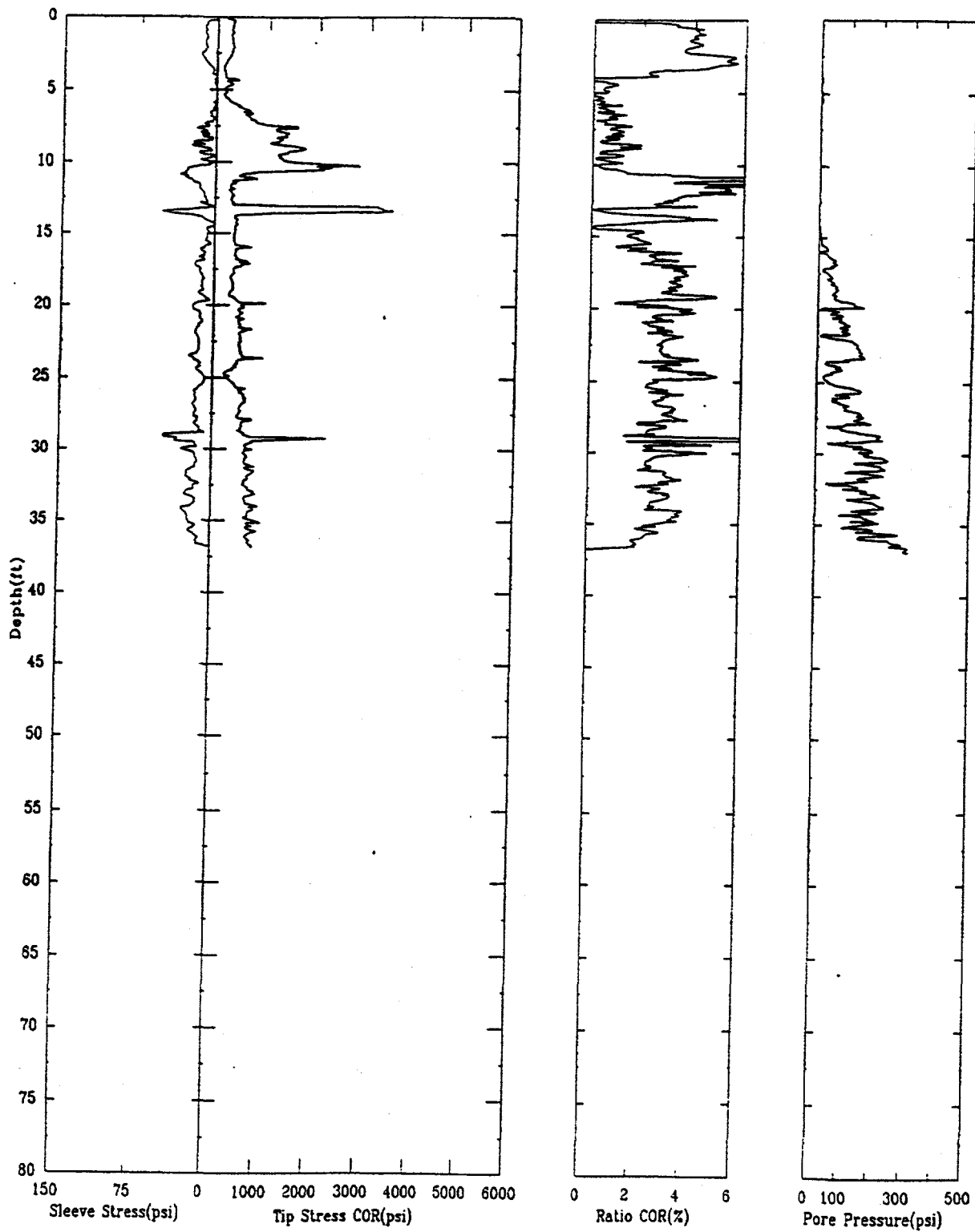


Figure C.16a.

CPT-16

APPLIED RESEARCH ASSOCIATES, INC.
North 850 East 780 Elevation

09/22/95

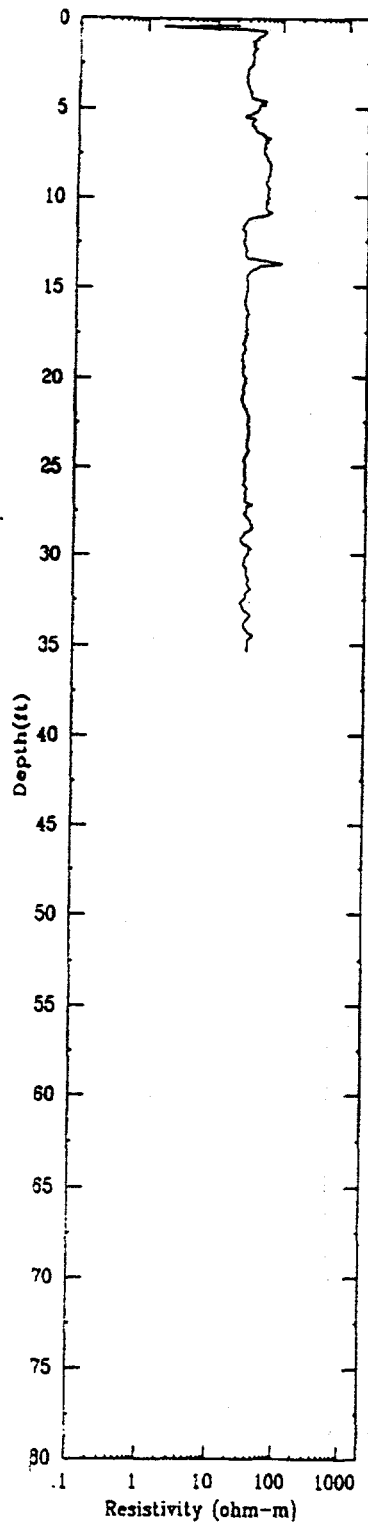


Figure C.16b.

CPT-17

APPLIED RESEARCH ASSOCIATES, INC.

09/22/95

North 768

East 750

Elevation

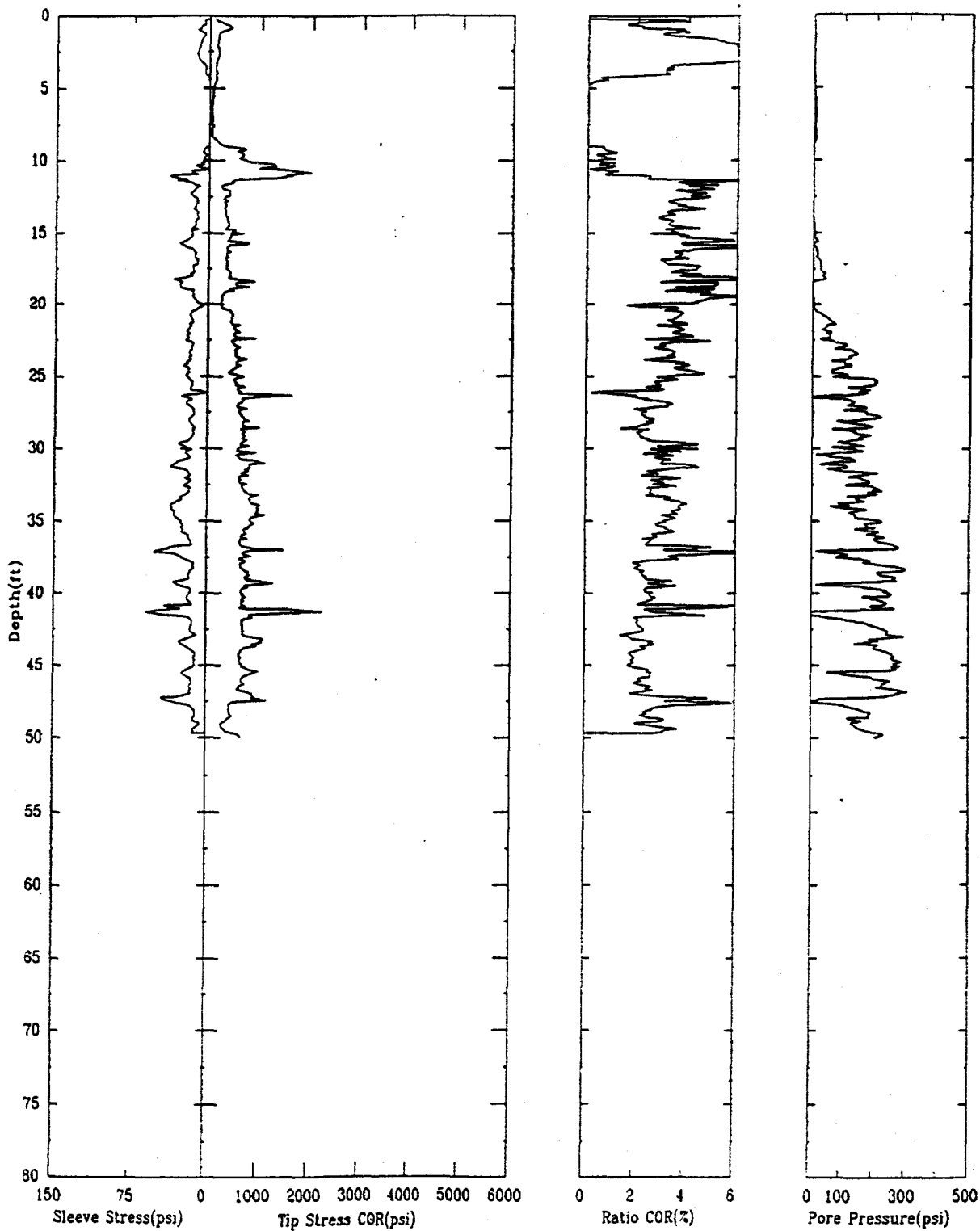


Figure C.17a.

CPT-17

APPLIED RESEARCH ASSOCIATES, INC.
North 768 East 750 Elevation

09/22/95

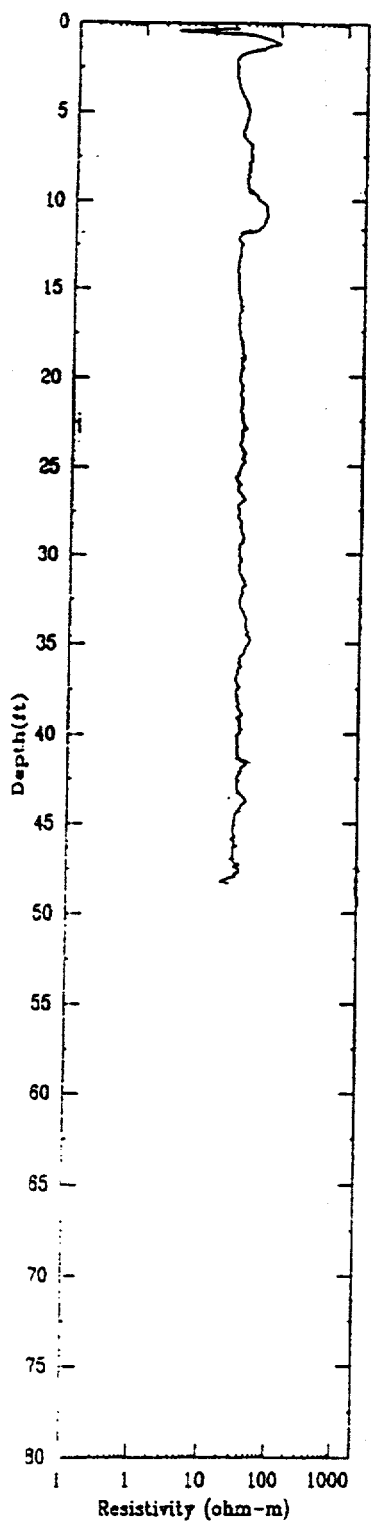


Figure C.17b.

APPENDIX D:

EM-31 AND GPR DATA FROM AREA 1

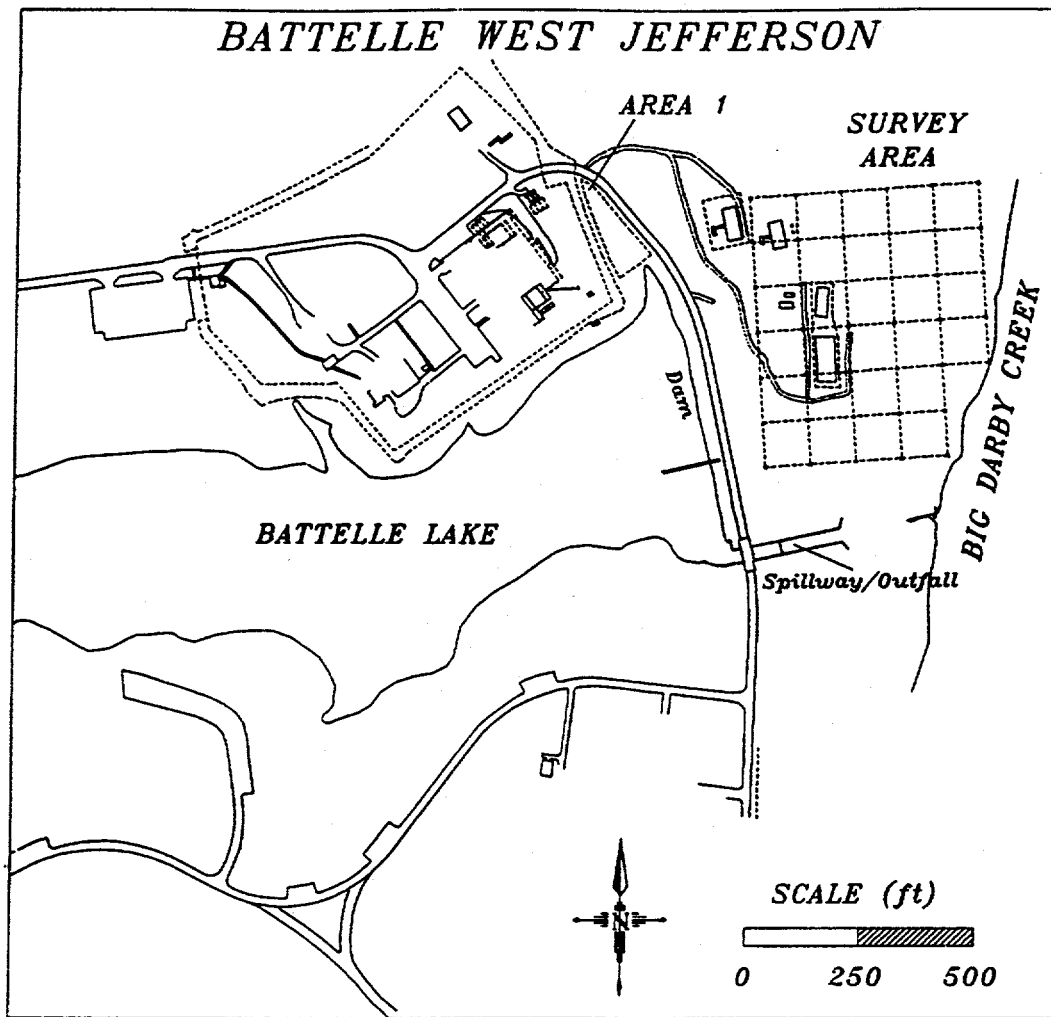


Figure D.1.

Battelle - West Jefferson
Area 1 EM-31 Survey

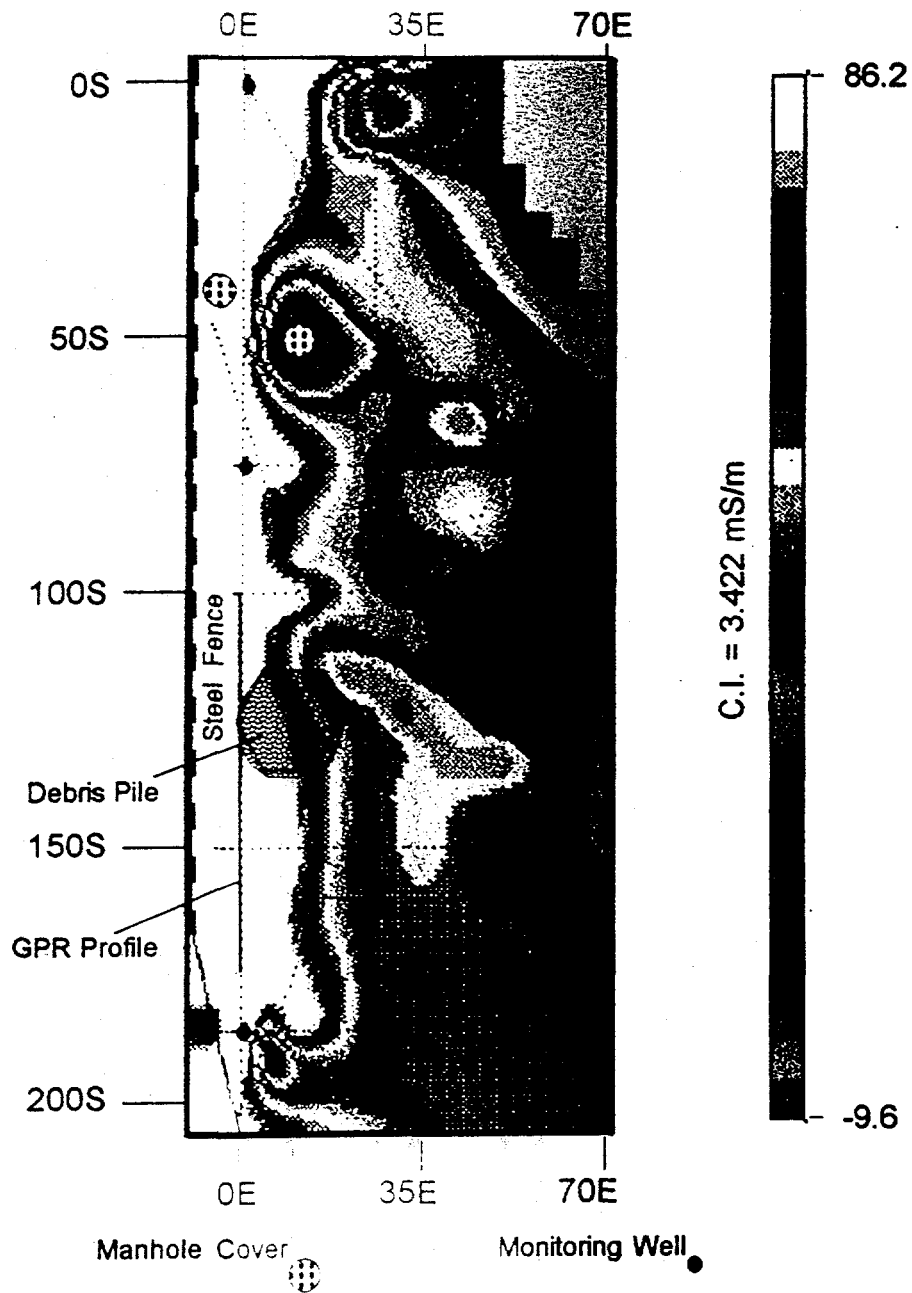


Figure D.2.

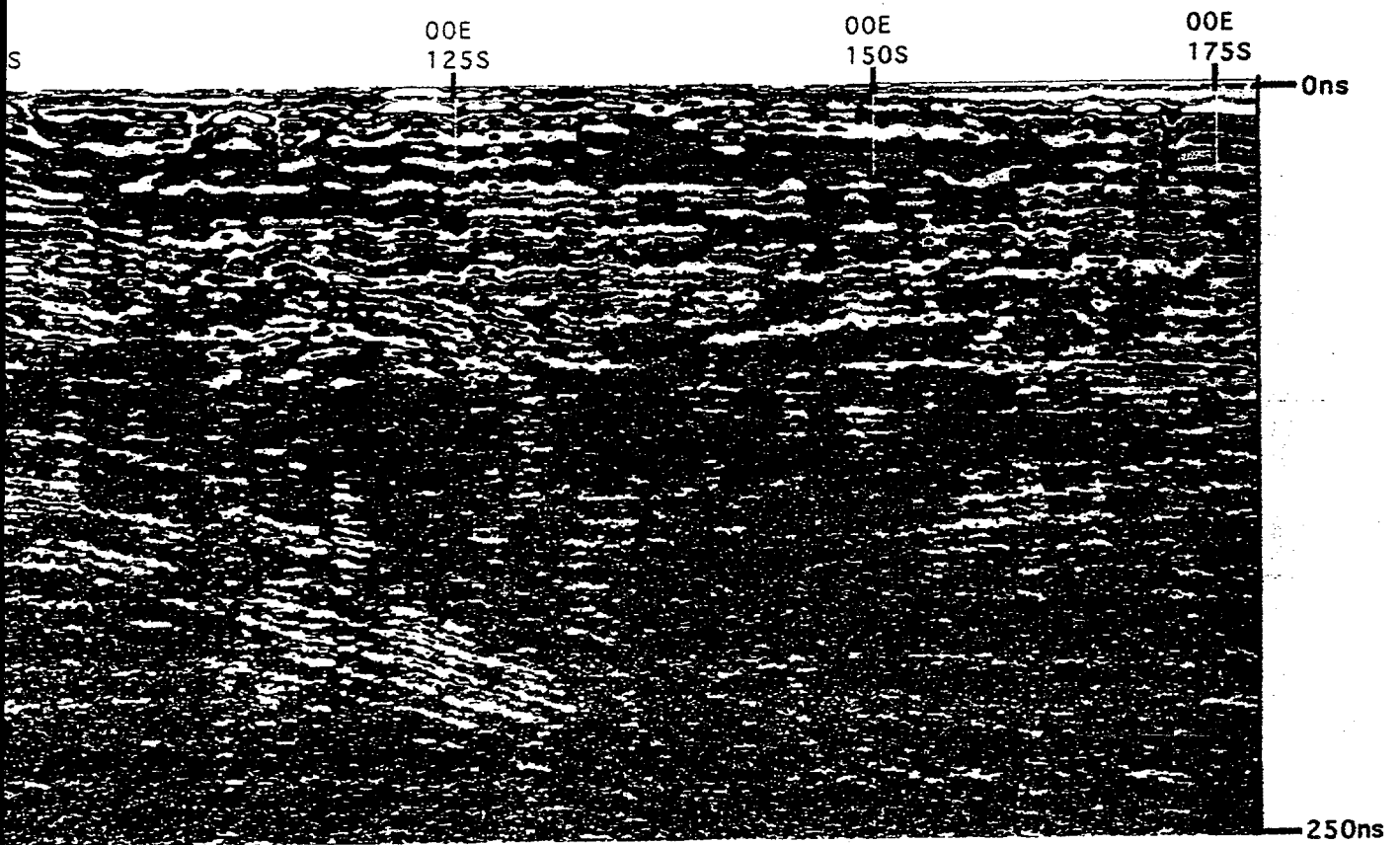


Figure D.3.

APPENDIX E:

ANALYTICAL CHEMISTRY RESULTS AT BATTELLE WEST JEFFERSON

Radiological Testing of Groundwater Samples Collected from Wellpoints on October 9, 1995
(Concentrations in pCi/L)

Wellpoint Locations	WP01	WP02	WP03	WP04	WP05	WP06
Alpha	10.85 ± 5.04	6.12 ± 5.355	15.65 ± 5.42	16.03 ± 6.31		0.8 ± 5.18
Alpha (Duplicate)	20.63 ± 6.44	6.21 ± 5.43	8.98 ± 4.11	12.34 ± 5.74		21.92 ± 7.20
Beta	46.59 ± 3.568	43.69 ± 3.57	85.48 ± 5.17	58.08 ± 3.87		208.28 ± 8.18
Beta (Duplicate)	50.83 ± 3.68	3.79 ± 3.36	90.41 ± 5.50	64.63 ± 4.21		200 ± 8.04
Gamma Spec ¹						
Co-57	1.718	1.767	2.439	2.368	1.879	1.764
Co-60	2.019	1.568	3.017	4.09	2.121	1.479
Sb-125	5.903	5.439	8.414	10.09	5.966	5.318
Cs-134	2.078	1.713	2.953	3.51	1.948	1.764
Cs-137	2.287	1.881	3.21	4.175	2.242	1.813
Eu-152	5.089	5.228	7.247	7.013	4.982	5.224
Eu-154	3.581	3.731	5.069	4.865	3.522	3.834
Th-234	43.05	49.58	54.08	46.95	42.76	41.93
U-235	14.32	14.43	18.62	18.67	14	14.07
Am-241	4.744	5.583	16.68	13.64	4.583	5.482

Radiological Testing of Groundwater Samples Collected from Wellpoints on June 5, 1998
(Concentrations in pCi/L)

Wellpoint Locations	WP01	WP02	WP03	WP04	WP05	WP06
Alpha	8.98 ± 3.828	9.981 ± 4.256	27.416 ± 6.414	15.868 ± 4.574	26.465 ± 5.423	28.551 ± 7.391
Alpha (Duplicate)	15.764 ± 4.544					
Beta	12.160 ± 1.989	10.94 ± 2.005	8.364 ± 1.884	4.474 ± 1.714	9.877 ± 1.915	30.938 ± 2.851
Beta (Duplicate)	7.504 ± 1.837					
Gamma Spec ¹						
Co-57	1.941	1.738	1.564	2.604	1.43	2.69
Co-60	2.515	1.483	1.987	3.382	1.294	4.858
Sb-125	7.088	5.324	5.775	9.907	4.281	11.02
Cs-134	2.172	1.743	2.028	3.247	1.504	4.049
Cs-137	2.634	1.637	2.271	3.684	1.827	4.539
Eu-152	5.791	5.192	4.637	7.853	4.263	7.762
Eu-154	4.141	3.833	3.279	5.43	3.006	5.428
Th-234	45.78	42.59	45.72	58.9	39.2	51.5
U-235	16.91	14.2	13.15	20.68	11.41	22.1
Am-241	5.757	5.612	5.983	18.57	4.898	16

¹ All reported values were less than or equal to the minimum detectable activity (MDA).