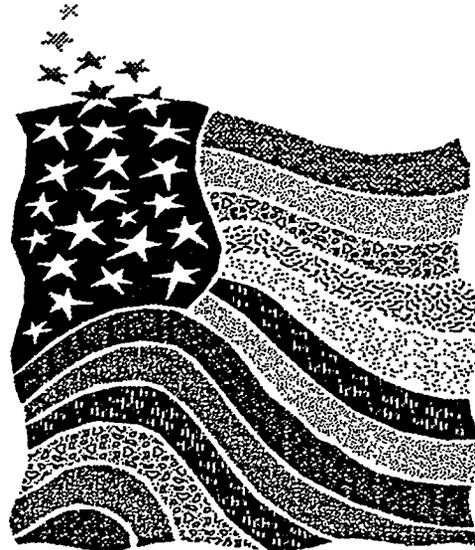


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**Ames Expedited Site Characterization
Demonstration at the Former
Manufactured Gas Plant Site
Marshalltown, Iowa**

**A. J. Bevolo, B. H. Kjartanson
and J. D. Wonder**

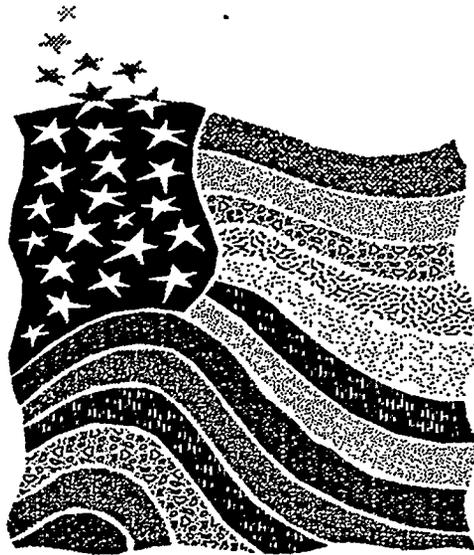
Report Date: March 1996

**Ames Laboratory*
Iowa State University
Ames, Iowa 50011-3020**

***Operated by Iowa State University for
the U. S. Department of Energy under
Contract No. W-7405-ENG-82**

MASTER

or



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EXECUTIVE SUMMARY

Ames Laboratory of the U.S. Department of Energy (DOE) undertook a project sponsored by the Office of Technology Development (OTD) in the Environmental Management (EM) program to promote the adoption of Expedited Site Characterization (ESC) and its associated technologies. The goals of the project were to identify and field site characterization technologies and approaches to solving DOE environmental problems, improve the basis for analyzing site characterization data, compare the various analytical technologies, and encourage stakeholder participation in the environmental arena. An ESC demonstration was carried out at a former manufactured gas plant site (FMGP) in Marshalltown, Iowa. The site was known to be impacted by polynuclear aromatic hydrocarbon (PAH) residues and was selected as the subject site because of its size, proximity, and favorable relations amongst Ames Laboratory, the Iowa Department of Natural Resources (IDNR), and the site owners. It should be noted that IDNR is the lead agency coordinating all the activities of the Marshalltown site and all data and reports must be validated and approved by IDNR before they can be used in any decision-making process.

The Marshalltown FMGP is owned by IES Utilities, Inc. and is located in an old industrial area adjacent to an active railroad switching yard and mainlines. The gas manufacturing processes, used during the operation of the site between the 1880s and 1950s, resulted in a variety of potential environmental contaminants including "coal tar," petroleum products, condensates, and oxides. A portion of these materials were disposed on the site if they could not be resold on the market or used for other purposes. The primary contaminants of interest for this investigation were PAHs.

Previous remedial investigations were conducted at the site by Black&Veatch (B&V) Waste Science and Technology (BVWST). Historical and technical information, gathered in those previous investigations, were used to select technologies and develop scopes of work for the ESC demonstration. Available geologic data indicated a surface layer of fill overlying an upper cohesive unit which was overlying granular alluvial sediments that were overlying a lower cohesive unit and ultimately bedrock. All of these layers occurred at variable depths. Available contaminant data indicated the presence of dissolved, residual, and dense non-aqueous phase (DNAPL) liquid PAH's in soil and groundwater beneath the site. A suite of geophysical survey, geophysical/geotechnical screening-level chemical, and quantitative chemical analytical technologies were selected and applied at the site. The involvement of IDNR, IES and the Ames Laboratory with ESC should not be interpreted as an endorsement of any system or product used in the ESC investigation.

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Geophysical survey techniques including ground penetrating radar, seismic reflection and refraction, electromagnetic offset logging, and borehole logging were applied at the site primarily to define the surface of the bedrock and significant stratigraphic interfaces above the bedrock. Secondary objectives were to provide information regarding the distribution of PAH contamination. Geophysical survey techniques are considered to be the primary component in the early phase of the ESC process.

In addition to the geophysical survey techniques, two minimally intrusive geophysical/geo-technical techniques (cone penetrometer testing and soil electrical conductivity logging) were utilized to define the soil stratigraphy and, in particular, the surface topography of the lower cohesive unit (LCU).

Results of the geophysical surveying were calibrated against both the BVWST data and with the minimally intrusive data collected as a part of this investigation. Cultural interference, such as noise from the railroad tracks and from activities within the site, overhead power lines, buildings and surface metallic objects, near-surface fill material, and a weathered bedrock surface, contributed to difficulties encountered in making and interpreting geophysical measurements. The interpretation of the bedrock surface from the geophysical survey techniques was tenuous and found to be in error by as much as 10 to 15 feet when compared with data from direct intrusive technologies. The negative impact of the cultural interference and relatively difficult stratigraphic conditions make evaluation of the techniques very difficult. All the techniques, however, pointed to the fact that the bedrock surface is weathered, uneven and highly variable.

The Site Characterization and Analysis Penetrometer System (SCAPS) cone penetrometer unit and the Geoprobe soil conductivity probe provided very useful and reliable stratigraphic data. Side-by-side comparisons of the direct push technology logs with BVWST borehole logs indicated stratigraphic correspondence of the unit contacts generally within about one to two feet. It should be noted, however, that the BVWST data tended to produce a slightly deeper granular/lower cohesive unit contact than the direct push data. Usually the major unit stratigraphic contacts were easily picked off of both the cone penetration testing (CPT) and soil conductivity logs and were used to generate a database from which an EarthVision three-dimensional site stratigraphic model was generated.

Based on the previous BVWST site characterization work, the lateral and vertical distribution of the dissolved PAHs and residual non-aqueous phase liquid contamination was estimated. Assessment of the nature and distribution of the PAH contaminants was carried out using three types of technologies: Phase I screening technologies [immunoassays (IMAs), passive and active soil gas, and chemiluminescence], Phase II screening technologies [laser-induced fluorescence probe, soil conductivity probe], and Phase II quantitative technologies [chemical

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analysis of soil samples with gas chromatography/mass spectrometry (GC/MS) instruments in field laboratories].

For the purpose of developing and assessing the site contamination model, the soil stratigraphy was subdivided into six zones:

- middle and bottom of upper cohesive unit (zones 1 and 2 respectively)
- top, middle and bottom of granular unit (zones 3, 4 and 5 respectively)
- top of lower cohesive unit (zone 6)

The Phase I suite of contaminant screening technologies were applied in an effort to evaluate their ability to identify the approximate boundaries of the organically contaminated area. At each surface grid node, Geoprobe sampling equipment was used to collect one shallow (4 to 5 feet deep) and one deep (10 to 15 feet deep) soil sample. Duplicates from soil core samples were analyzed by all three IMA techniques and the chemiluminescence system. In addition, a soil vapor sample was drawn at each sampling level and analyzed using a field gas chromatograph. Finally, a passive soil gas collector containing carbon adsorption elements in a resealable glass container was installed in the ground at the approximate depths of the soil samples.

When indicating the presence or absence of detectable PAHs, the data from each of the three IMA analyses correlated fairly well with each other. Furthermore, each of the three shallow and deep data sets agree very well with each other on the location and shape of the PAH contamination distribution. Results from the chemiluminescence were reported as total PAH and did not correlate as well with other methods used.

Passive soil vapor samplers were analyzed off site by thermal desorption and direct mass spectrometer (MS) analysis. The shallow data agreed well with each other. Little of the heavier PAHs compounds were found in the deeper data set, and as expected, lighter molecular weight PAHs appears to correspond to higher volatility and concentration in soil gas. Active soil gas measurements for aromatic hydrocarbons and naphthalene showed good agreement with passive soil gas and IMA measurements. Overall, the results of the Phase I contaminant screening technologies generally compared well with the BVWST results for stratigraphic zones 1, 2 and 3. A significant finding of the Phase I contaminant screening study was that PAH contamination existed further to the west than it would appear from previous data.

Phase II contaminant screening was performed using the cone penetrometer laser-induced fluorescence (LIF) sensor system and the Geoprobe soil conductivity profiles. Chemical

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analysis of soil samples collected adjacent to LIF "hits" indicated that while the LIF sensor data could not be considered as quantitative, it could reliably detect regions of low, medium or high contamination in a qualitative sense. Average LIF intensities for each of the six stratigraphic zones were interpreted from the LIF panel plots. Contour plots for each zone gave an excellent indication of the distribution of contaminants at the site. The general trend of the contaminated region is still, however, from the northwest to the southeast through the central part of the site. Significant hits were detected in zone 6 (top of the LCU) at only two locations.

Many of the panel plots showed elevated fluorescent intensity values within the upper cohesive unit and within the upper and lower portions of the granular unit. Examination of the LIF panel plots revealed that elevated fluorescence intensity levels commonly occur in the two to four feet of sandy soil immediately overlying the top of the LCU indicating a pooling of DNAPLs on the LCU. When LIF measurements were taken in the top of the LCU, the fluorescent intensity reading typically dropped to near zero. This indicates that the LCU is tending to retard the downward migration of the DNAPL contamination at these locations. In terms of contaminant screening, the LIF may be considered the most direct qualitative methodology for indicating regions of PAH contamination.

Phase II quantitative plume delineation efforts were planned and implemented based on results of the BVWST Remedial Investigation (RI) report, contaminant screening data collected in Phase I and Phase II, and the updated site geologic model. The primary technology evaluation function of this part of Phase II was the comparison and assessment of five on-site extraction methods for PAHs in soil. Soil core samples for this effort were collected with minimal subsurface disturbance using a Geoprobe system. A total of 127 samples were run through one or more of the five extraction methods and analyzed by one of three identical GC/MS systems. The extraction methods used included three organic solvent-based methods (sonication, microscale, microwave-enhanced extraction) plus thermal desorption and supercritical fluid extraction (SFE).

Method bias comparisons indicated that the thermal extraction efficiency is less than the sonication extraction efficiency which is less than the microwave extraction efficiency. The microscale and SFE extraction methods generally gave intermediate results. There was no definitive indication that any extraction method was more precise overall, although there is a tendency for the method precision for the thermal and microscale extraction methods to be significantly less than the precision for the sonication method on the basis of all the available data. On the basis of all the available data, the clayey soil analytical results showed greater variation than the sandy soil results indicating greater precision with sandy samples for all but the thermal extraction method. The 38 subsets of this data, in which all methods gave a greater than non detect (ND) determination, indicate that only the microwave and SFE methods show

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greater variation with clayey than with sandy soil, while the other methods show no variation differences between soil types.

In summary, within the inherent limitations of these analyses, low thermal extraction results with high relative error and high microwave extraction results with low relative error were found, while the absolute value of the bias for both of these methods appears to decrease with increasing analyte molecular weight. A significant finding of the study was the potential for inconsistencies in procedures and results to arise, even within strict adherence to SW-846 methods.

The application, versatility, and high quality of data from direct push technologies was demonstrated at this site. The cone penetrometer demonstrated the reliability and efficiency of both the stratigraphic logging capabilities and LIF sensing capabilities in developing the site stratigraphic model and delineating areas of PAH contamination. The capabilities of the Geoprobe soil conductivity system with respect to maneuverability and operational efficiency were also demonstrated. With proper calibration, the Geoprobe system can be reliably used to fill in stratigraphic data between two locations with known stratigraphic profiles. In addition, again with proper calibration and verification, it can be used to enhance the site contamination model. Both direct push technologies have the capability to provide much more detailed stratigraphic information than conventional auger boring, which is important when considering contaminant fate and transport.

This study also indicated the potential for significant variation of chemical analysis results for PAHs in soils. The uncertainty and potential variability associated with soil matrix effects, sample selection, preparation and extraction procedures far outweigh inaccuracies in the chemical analysis methodologies themselves. The Phase I and Phase II screening results, including olfactory/visual data, gave a far better picture of the distribution and extent of contamination than the quantitative analysis results.

Ames Laboratory is operated for the U.S.-DOE by Iowa State University under Contract No. W-7405-ENG-82 and is a member of ISU's Institute for Physical Research and Technology. This report was prepared as a deliverable on the project "Ames Laboratory Expedited Site Characterization Demonstrations," Technical Task Plan CH1-3-10-05, as part of the Characterization, Monitoring, and Sensor Technology Crosscutting Program in the OTD within the DOE's EM program.

1.0 INTRODUCTION

1.1 Project Goals

The goal of the Ames Expedited Site Characterization (ESC) project is to evaluate and promote both innovative technologies (IT) and state-of-the-practice technologies (SOPT) for site characterization and monitoring. In April and May 1994, the ESC project conducted site characterization, technology comparison, and stakeholder demonstration activities at a former manufactured gas plant (FMGP) owned by Iowa Electric Services (IES) Utilities, Inc., in Marshalltown, Iowa. It should be noted that the Iowa Department of Natural Resources (IDNR) is the lead agency coordinating all the activities of the Marshalltown site and all data and reports must be validated and approved by IDNR before they can be used in any decision-making process.

Three areas of technology were fielded at the Marshalltown FMGP site: geophysical, analytical and data integration. The geophysical technologies are designed to assess the subsurface geological conditions so that the location, fate and transport of the target contaminants may be assessed and forecasted. The analytical technologies/methods are designed to detect and quantify the target contaminants. The data integration technology area consists of hardware and software systems designed to integrate all the site information compiled and collected into a conceptual site model on a daily basis at the site; this conceptual model then becomes the decision-support tool. Simultaneous fielding of different methods within each of the three areas of technology provided data for direct comparison of the technologies fielded, both SOPT and IT.

Ames Laboratory implemented the ESC model, first developed at Argonne National Laboratory (Burton, 1993), by using some of the tools that are coming to be associated with ESC, such as a dynamic work plan and real time data analysis. Because of the Ames Laboratory's approach to stakeholder involvement, the Ames ESC project differs somewhat from past ESC practices. Because of their increasing role in the acceptance and ultimate commercialization of environmental technologies, early stakeholder involvement was sought; establishment and maintenance of close communications with regulators was viewed as particularly important. Significant efforts were made to invite participation from stakeholder communities including local residents, characterization and remediation technology providers, community organizations, and specialized and general state and local media. The demonstration activities of the ESC project provided opportunities not only for the Ames ESC project to communicate the ESC goals and activities to the stakeholders, but also provided opportunities for stakeholders to express their interest in and provide feedback about the technologies fielded as part of the project, and about ESC methodology and its future applications.

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All of these activities support the U. S. Department of Energy (DOE) environmental technology development goals. These goals, which include a directive to seek out and develop better, safer, faster, cheaper technologies and approaches to solving environmental problems, form the basis for analyzing the site characterization data, comparing the various analytical technologies, and encouraging stakeholder participation in the environmental arena.

This document reports the results of the site characterization, technology comparison, and ESC demonstration activities associated with the Marshalltown FMGP site. The involvement of IDNR, IES and the Ames Laboratory with ESC should not be interpreted as an endorsement of any system or product used in the ESC investigation.

The structure of the report basically follows the ESC process. The Marshalltown FMGP site background and the results of a previous remedial investigation (RI) are summarized in Chapter 2. This geological and contamination data was used to build the first conceptual model. Next, the overall ESC characterization strategy for this site is outlined in Chapter 3. The results and analyses of the Phase I and Phase II Ames ESC investigations are summarized in Chapter 4. The Phase I geophysical survey results are presented first and their contribution to the development of the site model assessed. Next, the Phase I contaminant screening results are presented. The results of the Phase I studies are both compared with each other and compared with the original RI data in terms of reliability of data and enhancement of the site conceptual model. Finally, the Phase II minimally intrusive data and the quantitative data are presented. Comparisons are again made with the already existing data and their contribution to the development of the site conceptual model assessed. The summary and conclusions of this investigation are presented in Chapter 5.

1.2 ESC Methodology

The ESC methodology incorporates on-site decision-support technologies that permit site characterizations to be completed in a consolidated package. The principal characteristics of ESC are:

- emphasis on geologic structure and hydrogeology as determinants of contaminant fate and transport,
- use of technologies by expert operators with flexible data quality objectives,
- on-site data processing using mobile laboratories,

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- on-site decision making,
- preference for non-intrusive or minimally intrusive geophysical techniques,
- minimization of intrusive sampling techniques, and
- the same team that plans site work manages site work.

ESC has demonstrated that the characterization phase can be streamlined without compromising data quality. By using both on-site analytical and multiple hydrogeologic technologies, the need to send nearly all samples off site and the need to perform massive subsurface sampling in the absence of local hydrogeologic information is removed. By including on-site decision making, ESC can significantly reduce the probability of having to return to the site to fill data gaps. As a result, the current multiphase sequence of environmental data acquisition--consisting of sample, analyze, plan and sample, that typically takes years--becomes compressed into a single real-time phase, requiring only months to complete.

Because technology gaps exist, even within the context of ESC, the scope of this project involves the use of both SOPT as well as IT. By fielding ITs at actual sites, nontechnical as well as technical barriers are simultaneously identified. Of prime importance is an opportunity to involve regulators in the evaluation and fielding of these technologies. Side-by-side comparison of IT with SOPT technologies, documented standard operating procedures, and confirmatory off-site analysis are some of the necessary features that encourage regulatory acceptance of ITs.

By integrating the innovative ESC technologies into an actual ESC project, it is expected that a more realistic evaluation of these technologies will be possible. Part of this benefit accrues from the active role of the regulator in the evaluation of these technologies. Additional benefit comes from exposure of these technologies to site-specific stakeholders, as well as those who cannot attend the demonstration but who will be reached by the information packages. This systematic approach, involving the demonstration of multiple ESC technologies to those who influence their adoption, is very cost effective.

1.3 Stakeholder Involvement

The Ames ESC team implemented the expedited site characterization model using many of the tools that are essential to ESC, such as a dynamic work plan and real-time data analysis, but Ames Laboratory's practice of ESC is distinctive in its approach to stakeholder involvement. Because of the increasing role of stakeholders in the acceptance and ultimate commercialization

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of environmental technologies--and even more so in the case of a new methodology--early stakeholder involvement was sought.

Establishing and maintaining close communications with regulators was viewed as critically important; significant efforts were made to invite participation from stakeholder communities including local residents, community organizations, educators, students, association members, technology users and providers, trade press and local media. The public demonstration activities of the ESC project provided opportunities not only for the Ames Lab ESC team to communicate ESC goals and activities to the stakeholders, but also provided opportunities for stakeholders to express their interest and give feedback on the ESC methodology, its future applications and the technologies fielded as part of the project.

2.0 SITE BACKGROUND

The Marshalltown FMGP is located south of East Nevada Street between 4th and 6th Avenue in the SE¼ of the NE¼ of Section 35, T.84N., R.18W (see Figure 2.1). The contiguous property presently owned by IES Utilities is also partially located in Section 36. The site contains several buildings from the FMGP and former electric plant and is currently used as the service and materials distribution center for the IES gas and electric operations. It is located adjacent to an active railroad switching yard owned by the Chicago and Northwestern Railroad.

2.1 Physiography/Topography

The site is in an old industrial area of Marshalltown. Nearby industries include an inactive foundry, a scrap metal recycling business and a variety of manufacturers. The site is situated on the edge of the floodplain of a meandering stream (Linn Creek) within a glacial drift terrain. The ground surface is flat to gently sloping, with approximately 10 feet of relief across the site. Linn Creek is a tributary of the Iowa River and flows from west to east approximately 800 feet south of the FMGP site. Its confluence with the Iowa River is located approximately 2.5 miles northeast of the site.

Surface relief between the uplands and valleys is 50 to 150 feet. Maximum upland elevations range generally from 900 to 1000 feet above sea level (ASL) in the Marshalltown area. The Linn Creek and Iowa River floodplains vary in elevation from 860 to 880 feet ASL in the Marshalltown area.

2.2 Geology and Hydrogeology

The general stratigraphy of the glacial sediments in the Marshalltown area consists of loess over Kansan till. The terminal moraine of the younger Wisconsinian glaciation is located approximately 10 miles to the west of Marshalltown. The thickness of glacial deposition varies markedly around the Marshalltown vicinity, from 0 to 150 feet in the upland areas and from 25 to 250 feet in the valleys.

The glacial drift unconformably overlies Mississippian-age limestone and Pennsylvanian shale bedrock. The limestone units encountered immediately below the glacial/alluvial sediments at the site are identified in *Remedial Investigation Report: Marshalltown, Iowa, Former Manufactured Gas Plant Site* (BVWST 1992) as a part of the Mississippian Burlington and Gilmore City Formations and are part of the regional Mississippian aquifer. Outcrops are rare, but several are reported along railroad cuts and stream channels in the Marshalltown area. The

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former bedrock erosional surface is incised by multiple minor channels tributary to the pre-glacial channel of the Iowa River, referred to as the Poweshiek Channel. The Poweshiek Channel more or less follows the general trend of the present Iowa River floodplain and varies from one to two miles in width (Hansen, 1985). The City of Marshalltown is situated above a bedrock knob located south of the Poweshiek Channel. The FMGP site is situated over the northeast flank of the knob.

The near-surface stratigraphy of the site is reported in *Remedial Investigation Report: Marshalltown, Iowa, Former Manufactured Gas Plant Site* (BVWST 1992). According to drilling information reported by BVWST, the depth to bedrock varies from just over 20 feet in the northeast part of the site to about 35 to 40 (or more) feet in the western, central and southern parts of the site; a steep ridge in the bedrock surface with about 25 feet of relief, trends northwest-southeast across the site. Near surface soils consist of a wide range of fill materials (clay, gravel, sand, cinder and other debris) of low plasticity and varying in thickness from 0.5 to 14 feet. This is underlain by fine-grained cohesive soils consisting of low plasticity silty clay with interbedded sandy and gravelly clays, ranging in thickness from 6 to 14 feet.

The cohesive silty clay unit grades into alluvial sands and gravels, varying significantly in silt and clay content, except at the farther northeast portion of the RI area where it is absent. The thickness of the alluvial sands and gravels varies from 0 to 26 feet, with the greatest thickness found near the center of the site, possibly indicating the present of a portion of a former stream channel.

A layer of low plasticity clayey lacustrine soil and low to high plasticity glacial till separates the alluvial soils from bedrock in most areas of the site. This unit was logged as absent in one boring near the east edge of the site. The upper surface of the unit slopes toward the south and generally mimics the bedrock surface.

The water table at the time of the BVWST investigation was approximately 18 to 20 feet below grade and within the granular alluvial soils. Hydraulic conductivity (K) measurements obtained by falling head slug tests indicated K values in the range of 0.0029 to 0.00076 cm/sec for the granular soils. According to the work done by BVWST (1992), groundwater flow in the alluvial sediments is to the south toward Linn Creek. Bedrock groundwater flow characteristics are not well established and appear to be strongly influenced by the activity of production wells in the area which tap the Mississippian aquifer.

2.3 Marshalltown FMGP Site History

A comprehensive summary of the site history is included in *Remedial Investigation Report: Marshalltown, Iowa, Former Manufactured Gas Plant Site* (BVWST 1992). The BVWST report was a primary source for information contained in this section. Additional sources of historic information included a preliminary research report by McDonald (1986), Sanborn Company maps dated from 1884 to 1964, and the Marshall County Historical Museum Library. When the plant first opened in the mid-1870's, gas manufacturing was accomplished by the coal carbonization process. At the time the plant opened under the name Marshalltown Gas Light Company, it occupied only Lot 5 of Barden's subdivision. In 1884, the site consisted of the gas plant building (at the approximate location of the present substation materials building), a coal house, and two gasometers (pressurized gas holders) located north of the plant building (see Figure 2.2). Barbed wire and furniture manufacturing facilities and a stock yard existed to the west of the plant on what is now IES Utilities property. The properties to the east were apparently vacant at this time.

Electric generation began at the site between 1888 and 1892. The electrical plant was built on a portion of the gas plant property and Lots 1, 2 and 3 of Cunningham's Addition. Residential properties and warehouses were present to the east of the gas plant at this time, on what is now the IES property. In 1892, the Marshalltown Gas Company, the Marshalltown Electric Company, and the Marshalltown Street Railway Company consolidated into the Marshalltown Light, Power and Railway Company, bringing the electrical and gas operations under common ownership.

By 1901, the original, smaller gasometer had been removed, and the operation utilized a single 25,000 cubic foot gas holder located west of what is now the regulator building. Between 1901 and 1910, a new 200,000 cubic foot gas holder was built just east of the current regulator building (see Figure 2.2).

The gas manufacturing process was converted from coal carbonization to carbureted water gas between 1910 and 1921, and ownership transferred to the Iowa Railway and Light Corporation. During this period, the original purifier room operations were moved to a separate building (now the IES substation department building) and water gas generators were installed in place of the old purifiers. In addition, a 12,000-gallon tar well was installed east of the new water gas generator building, and an oil storage tank was installed at the north edge of the property west of the original gas holder to feed the carburetion process.

The original coal gasification facilities were demolished in the 1920s. Also during this period, a new 50,000 cubic foot gas holder was constructed immediately south of the 200,000 cubic foot gas holder, and the original 25,000 cubic foot holder was taken out of service but apparently left

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in place until the plant was shutdown completely in 1950. A second oil tank was also added in the 1920s north of the purifier building.

Although documentation was not available regarding the disposition of tar produced by the gas manufacturing processes, a substantial portion of the tar may have been disposed on site. This is evidenced by, among other things, a 1953 photograph in the McDonald (1986) report showing an excavation immediately east of the present electric substation filled with a substance described as tar. The pit was opened for a construction project, and the tar was pumped from the pit and disposed of at an unknown location.

At its maximum extent of operations, the FMGP occupied lots only in Barden's subdivision (lots 1-7) and Westlake's subdivision. The present IES Utilities property, located on and east of the vacated 6th Avenue, was not part of the gas plant and is, therefore, not expected to contain any source areas for gas plant wastes. The former electrical plant located primarily in Cunningham's addition to the west of the FMGP may contain source areas, since the two operations were under the same ownership. It has been documented that waste disposal, some of which appears to have been generated by the FMGP, did occur in the subfloor of the former electrical generation building (BVWST, 1992).

2.4 Previous Investigations/Existing Data

2.4.1 Summary

Documented investigation of waste disposal at this site began with a preliminary study by D. B. McDonald Research Associates in 1986. This investigation consisted of gathering regional hydrologic and geologic data and historical information about the operation of the plant, including interviews with former employees.

Later in 1986, a U. S. Environmental Protection Agency (U.S.-EPA) contractor, Ecology and Environment (E&E), performed a reconnaissance investigation of the site. The E&E investigation included similar historic data and added information regarding fate, transport, and exposure routes of the contaminants of interest. A followup site investigation by E&E in 1987 included surface geophysics and some shallow soil, groundwater, surface water and manhole sampling. The geophysics work consisted of ground penetrating radar in areas where subsurface structures were suspected. The soil samples indicated the presence of PAH compounds at levels substantially above background levels.

A report prepared by Tuthill, Inc., in 1988 contained a detailed synopsis of the site history, including the development and ownership changes of the site. Tuthill also prepared a report in

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1989 which provided a summation of the information contained in the previous reports discussed above. The 1989 report contained data from a public water quality assurance program which had been initiated locally. Also in 1989, Tuthill prepared a detailed report containing more information about the history of the site.

An underground storage tank (UST) was removed in November 1988 from an area near the west end of the site along the east wall of the former spray pond. Soil and groundwater samples were collected as a part of the UST closure operation. Petroleum hydrocarbons in excess of applicable action levels were detected.

BVWST began a detailed RI of the site in 1990. The investigation included a comprehensive program of soil and groundwater sampling and hydrogeologic characterization. The investigation also included sampling and characterization of material contained in the void space beneath the floor of the former electric generation building. The results are documented in a report submitted to the Iowa Department of Natural Resources (IDNR) (BVWST 1992).

As a result of the RI, the following potential contaminant source areas have been identified (refer to Figure 2.2):

- 1) The "tar pit" unearthed during a construction project in 1953, which is located immediately east of the existing electrical substation;
- 2) Tar separator indicated on the west side of former purifier building (Sanborn Company maps from 1921 and subsequent years). Based on references on maps dated after 1921, this tar separator may have been an above-grade construction;
- 3) Tar well located east of the original water gas generator building (Sanborn Company map from 1921) and now located off the northeast corner of the present substation material storage building; and
- 4) Tar separator located south of the former purifier building. This separator was unearthed and the liquid contents removed in 1992. Based on its location, this structure may have been the one identified in the 1921 map as a tar well.

Other subsurface areas potentially containing high concentrations of PAHs include the alleged coal storage area in the southeast corner of the FMGP operations and identified by EPA studies as containing high contaminant levels, and the perimeter of and below the subfloor of the former electrical generation plant, particularly the area west of the former electric plant.

2.4.2 Remedial Investigation Data Analysis

The previous investigation performed by BVWST included their findings on the extent of the PAH contamination in soils. Seven monitoring wells and 16 borehole locations produced information of several types. Stratigraphic information was obtained from the cuttings and soil samples and is given in the borehole logs. The logs also contain observations on the appearance of the cuttings that were noted as either free product, oil sheen or discoloration or odor indications. Soil samples were taken and analyzed at an off-site laboratory. Seventy-eight samples were taken from locations within the property boundary, of which six were duplicates. Figure 2.3 shows the locations of the on-site boreholes, B-1 to B-16, and the three on-site monitoring wells MW-3, MW-4 and MW-5. No PAH chemical analyses were carried out on soil samples from the B-9, B-10, B-11, B-12 or MW-5 locations.

With respect to the PAH in soils, several trends were evident from the BVWST report. First, for nearly every sample in which PAHs were detected, either naphthalene or phenanthrene was the highest in concentration. {The same pattern was found in our 127 samples analyzed on and off site; see Section 4.4 for further discussion.} This observation permits a considerable simplification in the analysis of the PAH distribution. Instead of 16 PAH plumes we can focus on three types: naphthalene plume, phenanthrene plume and for some methods, as discussed below a modified total PAH plume. The latter type plume can be generated from any observation or measurement that integrates some or all of the PAH concentration distribution into a single value. For instance, visual and odor information from our work and BVWST are important observations because of the extremely low odor detection limit from some of the PAH contamination which we estimate to be in the few mg/kg range. Also, some of the screening methods we used were biased against naphthalene, and, given the general dominance of phenanthrene, they very likely represent information that can be compared to the phenanthrene plume.

Second, the stratigraphic sequences at the site can be grouped into and analyzed in terms of five discrete units; from the ground surface down the units are fill, upper cohesive unit (UCU - principally clay), granular unit (comprised mostly of various types of sand), lower cohesive unit (LCU - clay-like) and bedrock (often weathered). BVWST sampling focused on the upper two units and the top half of the third unit. Only one sample, at location B-4, was taken below the middle of the granular unit. However, visual and odor indications clearly implied that significant contamination was present in the bottom few feet of the granular unit. Based on these results, the PAHs were assumed to be principally located in the upper confining unit and throughout the granular unit with the latter's top and bottom deserving special focus.

The design of our subsurface sampling program was based on these BVWST results and consisted of sampling the following zones:

- middle and bottom of UCU (termed zones 1 and 2 respectively);
- top, middle and bottom of granular unit (termed zones 3, 4 and 5 respectively); and
- top of LCU (termed zone 6).

These zones are shown schematically in Figure 2.4. Instructions were given to all sampling crews to stop probing activities once they penetrated a few feet below the base of the granular unit to prevent introducing any new migration pathways.

Given these observations, we will present and discuss the BVWST and our PAH soil contamination data in the context of a simplified model that focuses on naphthalene, phenanthrene or modified total PAH plumes located in one of the six stratigraphic zones defined above.

2.4.3 Remedial Investigation Results

Table 2.1 lists the naphthalene and phenanthrene concentrations from the BVWST report that correspond to the six subsurface zones. With very few exceptions naphthalene and phenanthrene are co-located. Data from zones 1 through 4 are plotted in Figures 2.5 to 2.8. Because data are sparse and/or not available (NA), closed loop plume boundaries were not drawn. Areas of significant naphthalene and phenanthrene contamination generally lie along a NW-SE line from location B-1 to B-8 and B-13. The highest levels of naphthalene and phenanthrene contamination within the zones examined were found in boreholes B-2, B-4, B-5 and B-6. At the eastern plume edge, zone 4 has a non detect (ND) at B-7 while zone 1 has hits at B-7 and MW-3A indicating that the UCU is more contaminated in the eastern portion of the site than the granular unit. Along the southern site boundary from MW-4 to MW-3 differences occur between naphthalene and phenanthrene in that phenanthrene is present at a few of the borings while naphthalene is absent.

Important information resides in the visual and odor comments in the BVWST logs. To quantify this information, from both BVWST and our work, we employed a logarithmic type scale for these observations. Given that free product has a concentration of approximately 10^6

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mg/kg and slight but definite odor corresponds to a concentration of about 1 mg/kg, the following range was set up:

<u>Observation</u>	<u>Scale</u>
free product	6
product sheen	5
discoloration	4
strong odor	3
mild odor	2
slight odor	1
no odor	0

Table 2.2 contains information interpreted from the BVWST borehole logs. Most of the BVWST data are visual and therefore track the highest concentrations of the PAHs. From Table 2.1 it is clear that nearly all off-site samples were taken from zones 1 through 4; the visual/odor information contained in Table 2.2 adds considerable insight into the high concentration portions of the contaminant distribution. Plots of this visual/odor BVWST data for the six stratigraphic zones are shown in Figures 2.9 to 2.14. All BVWST boreholes penetrate to zone 6 except B-16 where the LCU is absent; therefore, no zone 5 and 6 can be defined. It was possible to draw closed loops for these odor and visually based plumes because there is odor and/or visual data at all locations. It must be kept in mind, however, that there is not a one-to-one correlation between Figures 2.5 to 2.8 and Figures 2.9 to 2.12. Even though BVWST sample analyses may indicate significant contamination, if direct visual or olfactory reference was not made at the appropriate location in the borehole log, then the zone was ascribed a zero; i.e., it is assumed that the contamination was not recognized during the borehole logging or the appropriate depth is not referred to explicitly. Moreover, fuel odor was detected in zones 1 and 3 of B-1; this was, however, not included as a visual or olfactory sign of coal tar residue. Note that MW-4 has not been included in these contour plots as it would tend to draw the plumes across the generation plant building area where essentially no information was available.

All zones have plumes except for zone 6 where no contaminants were identified visually. Boreholes B-2, B-4, B-5, B-6 and B-8 show evidence of significant contamination in the upper 5 zones and establishes the core of the PAH plume. Hits at B-1 in zones 4 and 5 extend their plumes in the NW direction from the core plume. Hits at B-13 for zones 1 and 4 extend their plumes to the SW. Hits at B-14 for zones 1, 3 and 5 are interesting because in the case of zone 1 this merely extends its plume further to the SW but for the other two plumes it indicates that local variations in stratigraphy over relatively small distances can significantly affect the distribution of contaminants in the subsurface. Hits at B-7 extend plumes in zones 2, 3 and 4

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further east from the core plume without the need to invoke a separate plume. Generally the plumes in the upper five zones are about equal in extent with perhaps the zone 3 plume being the smallest.

Given the preliminary plume outlines from the BVWST data and the thicker granular unit west of the B-7 location and its possible role as a migration pathway it was decided to focus the ESC effort on the eastern, southeastern and northwestern portions of the site. The grid laid out for screening activities described in section 4.2 was an attempt to overlap plume boundaries based on these BVWST results.

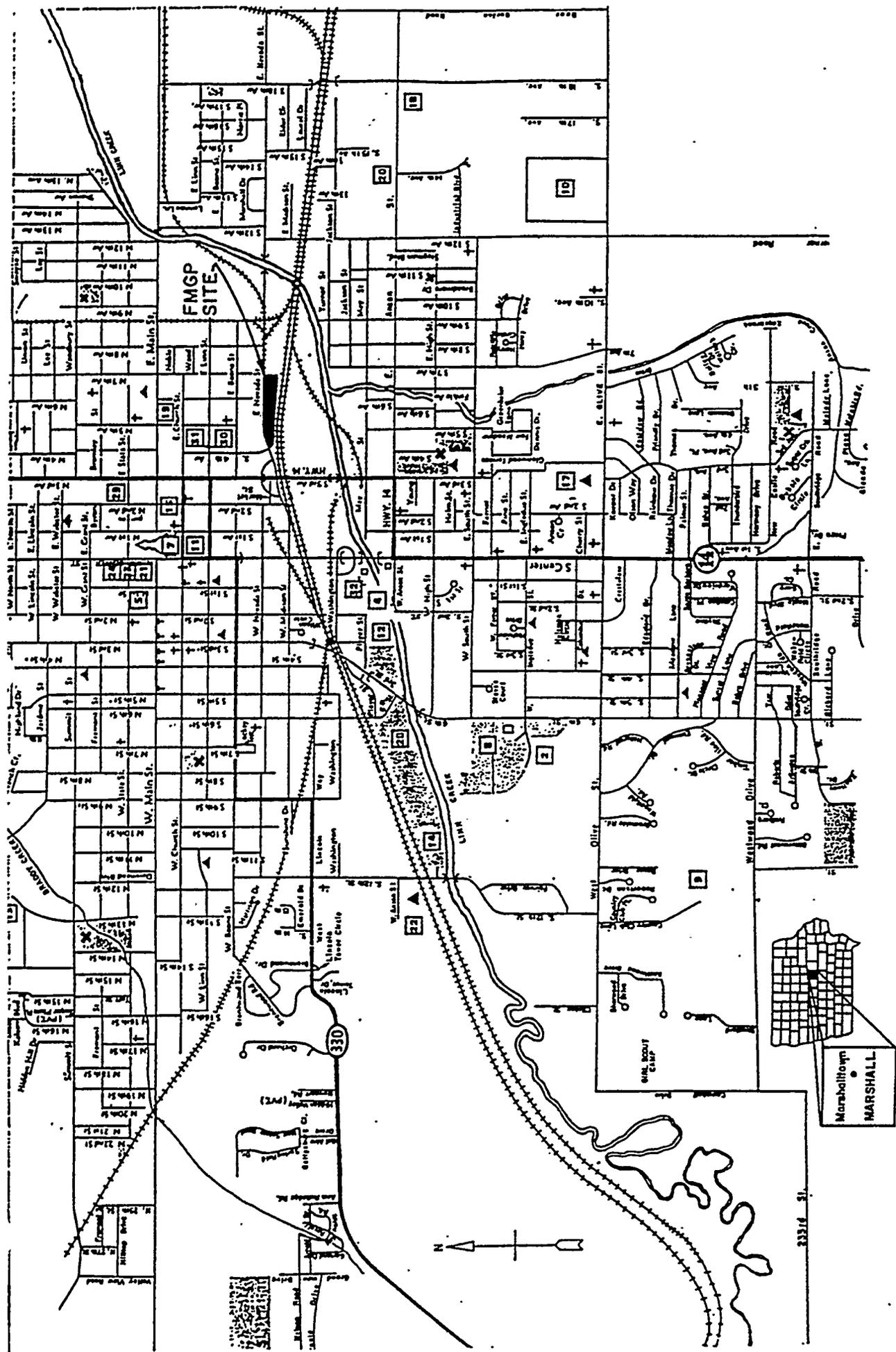


Figure 2.1 Marshalltown FMGP Site Location Map (from BWST, 1992)

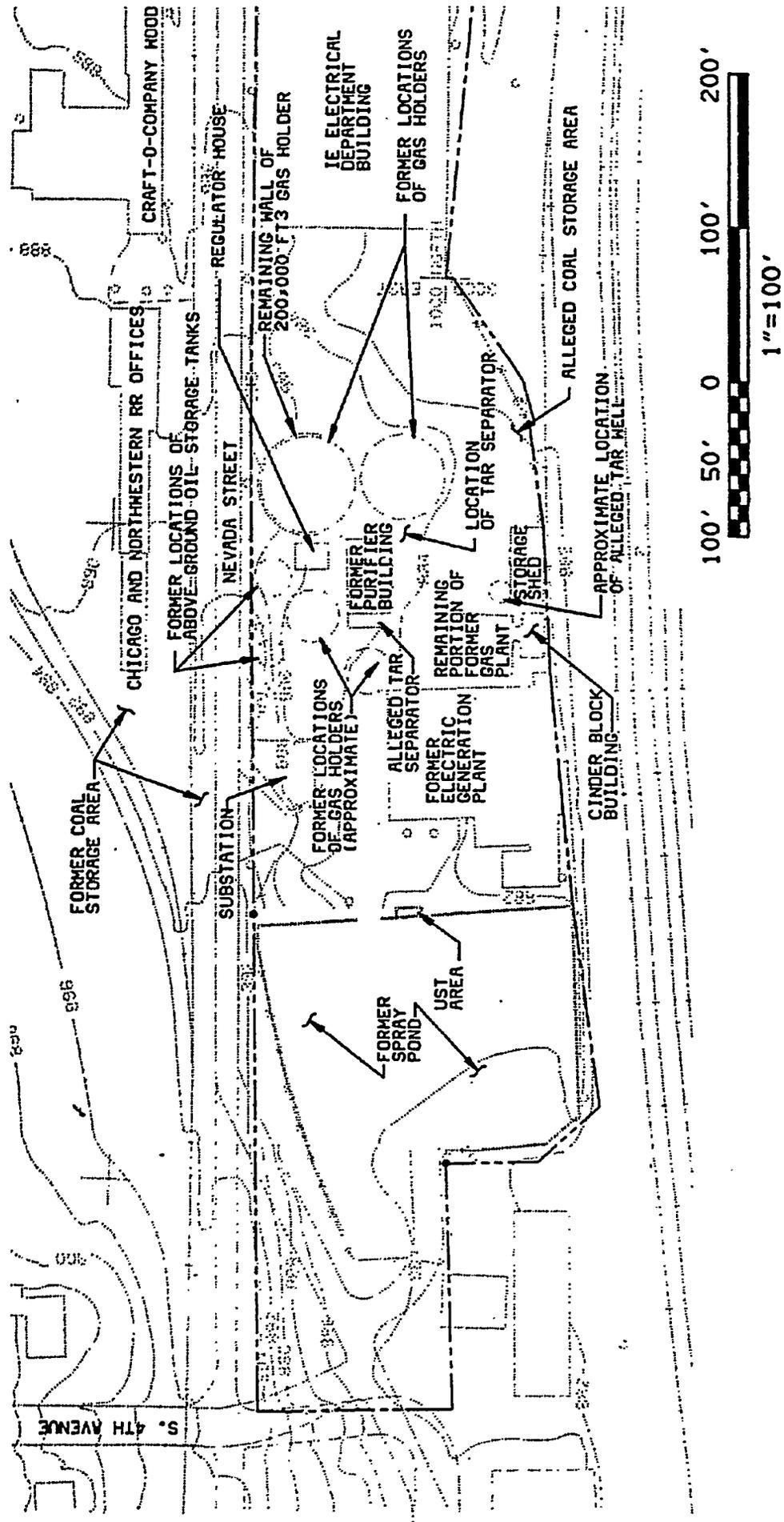


Figure 2.2 Marshalltown FMGP Site Map
(from BWST, 1992)

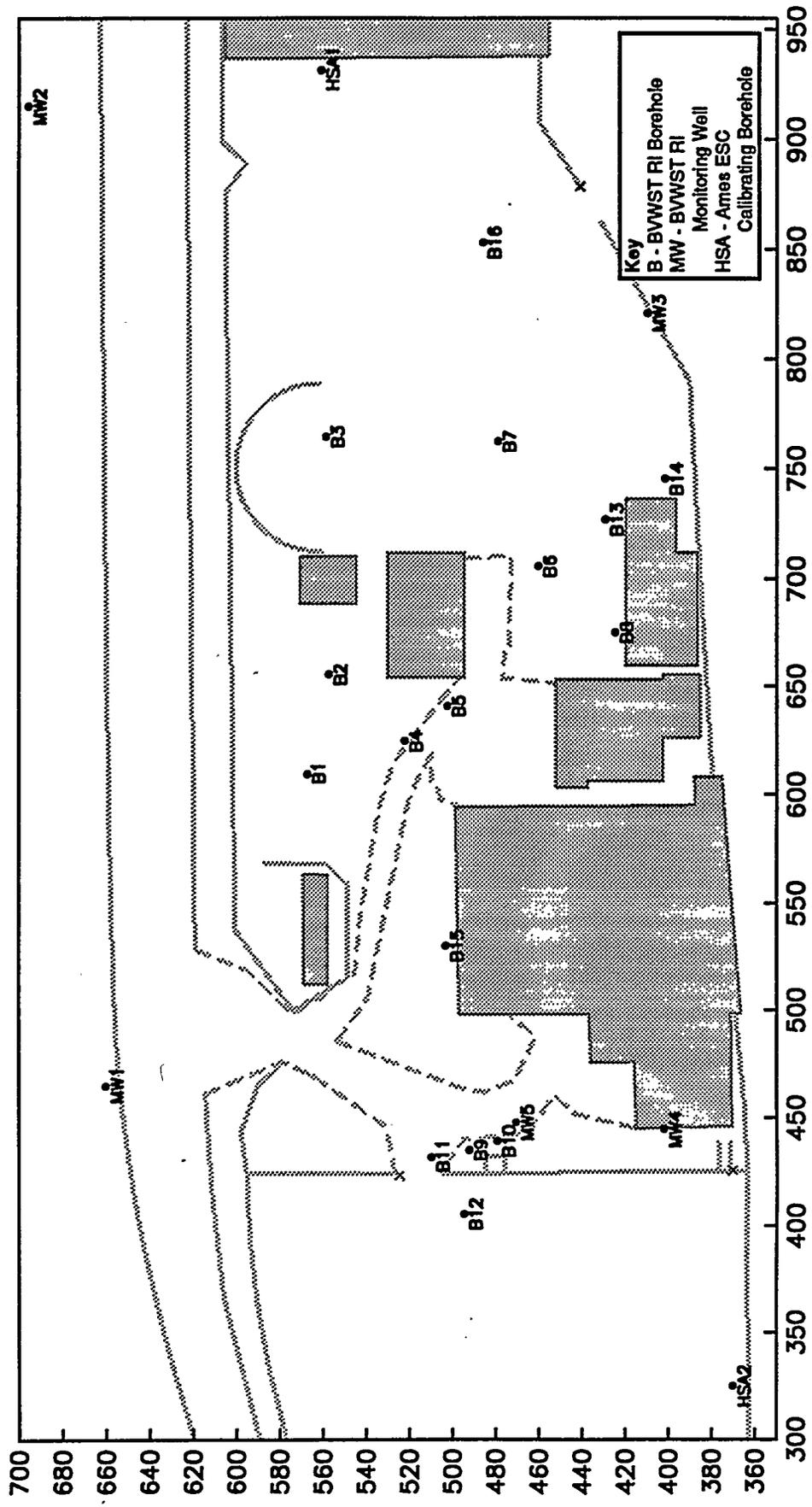
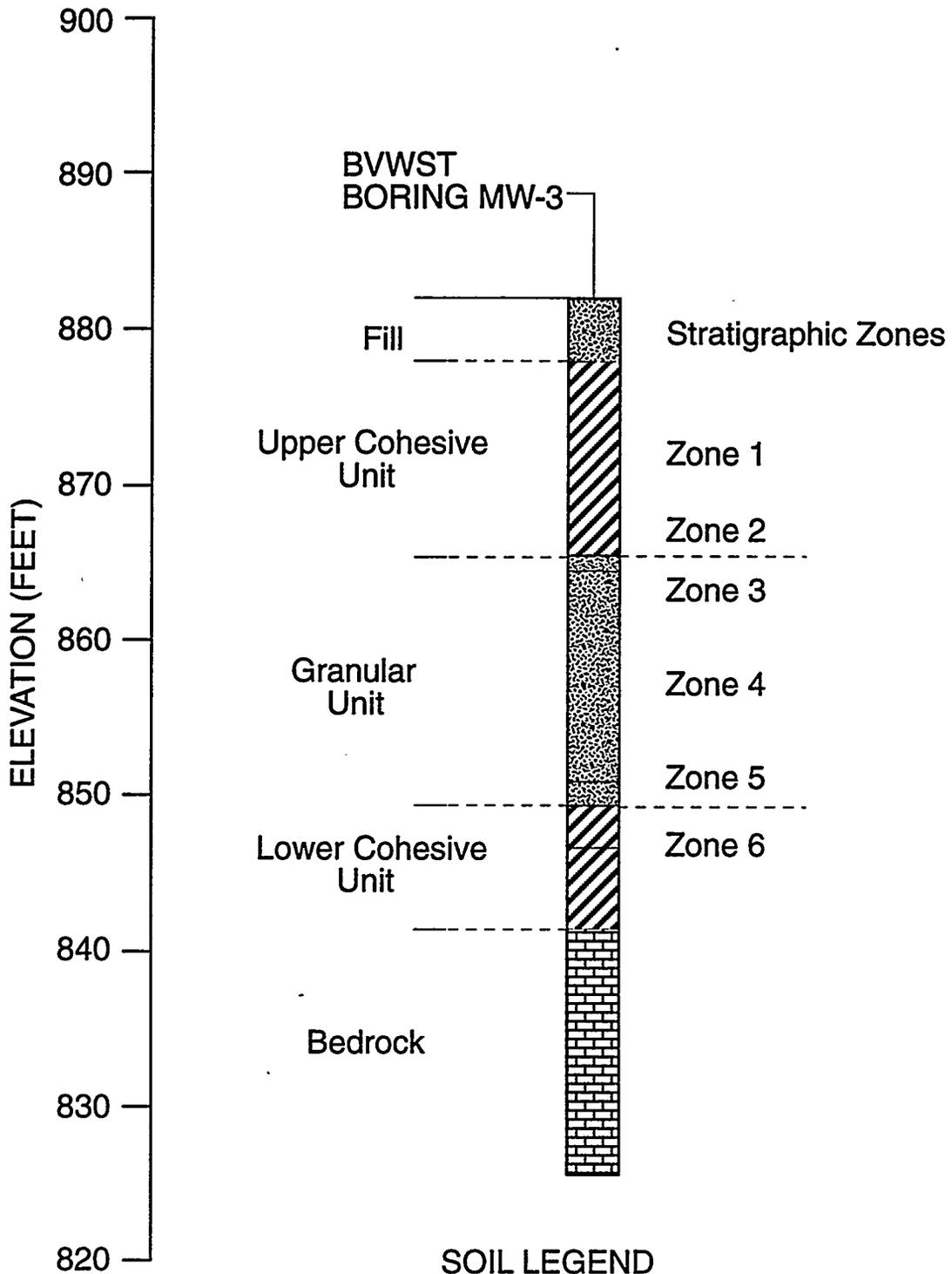


Figure 2.3 Auger Borehole Locations

Figure 2.4 Typical Site Stratigraphic Units and Stratigraphic Zones (after BVWST, 1992)



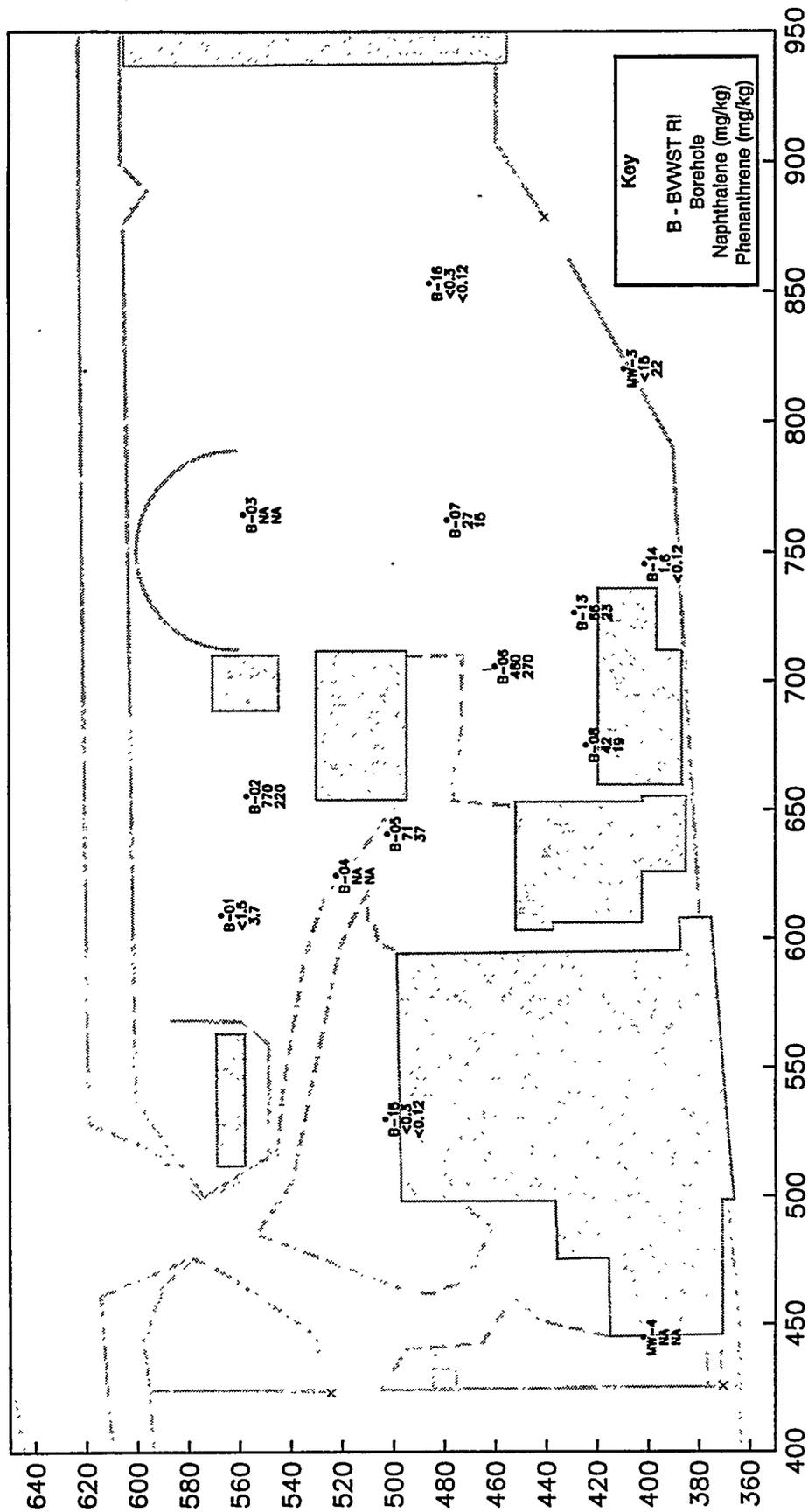


Figure 2.5 BWST Naphthalene and Phenanthrene Concentrations - Stratigraphic Zone 1

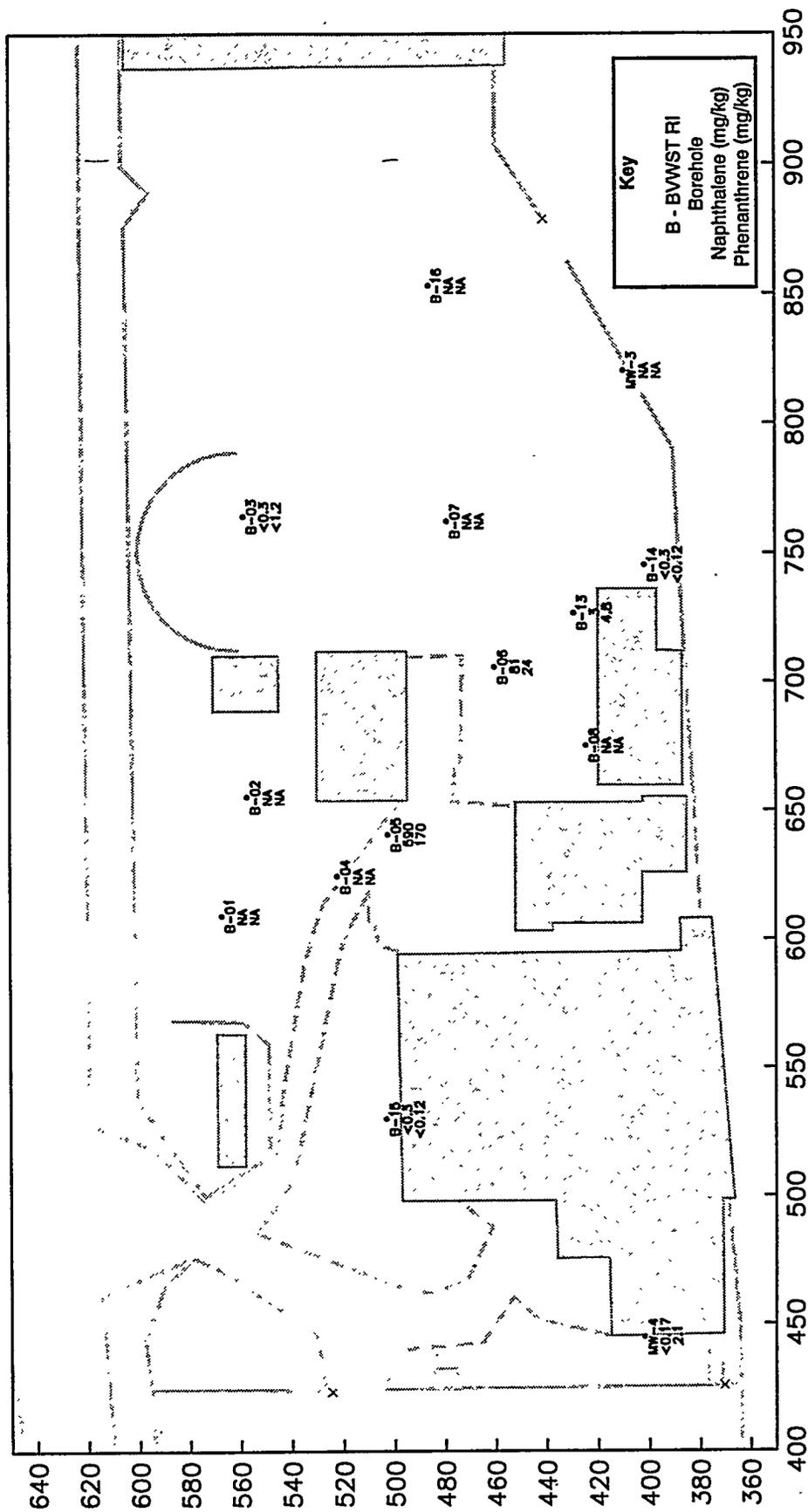


Figure 2.6 BVWST Naphthalene and Phenanthrene Concentrations - Stratigraphic Zone 2

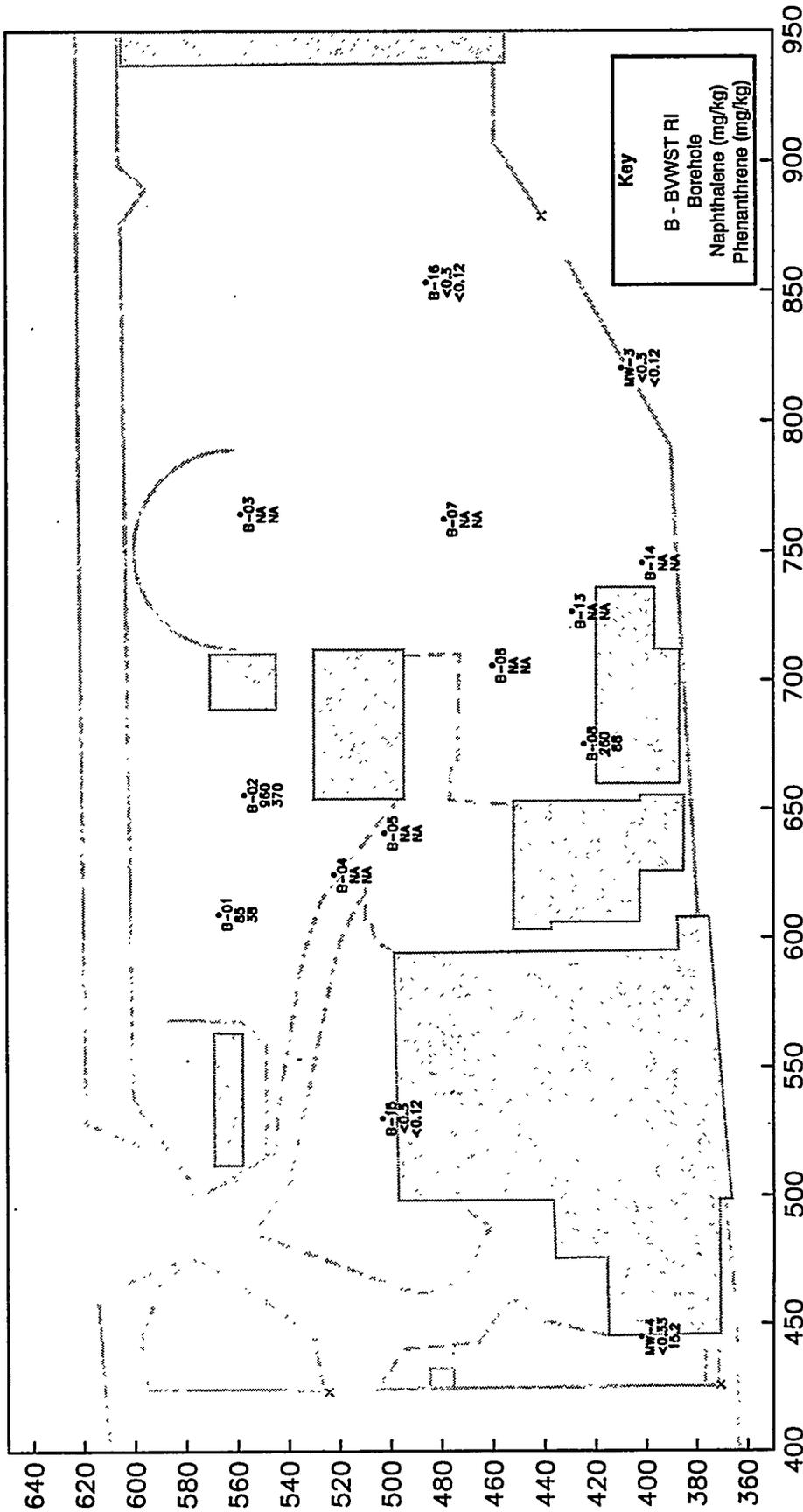


Figure 2.7 BWST Naphthalene and Phenanthrene Concentrations - Stratigraphic Zone 3

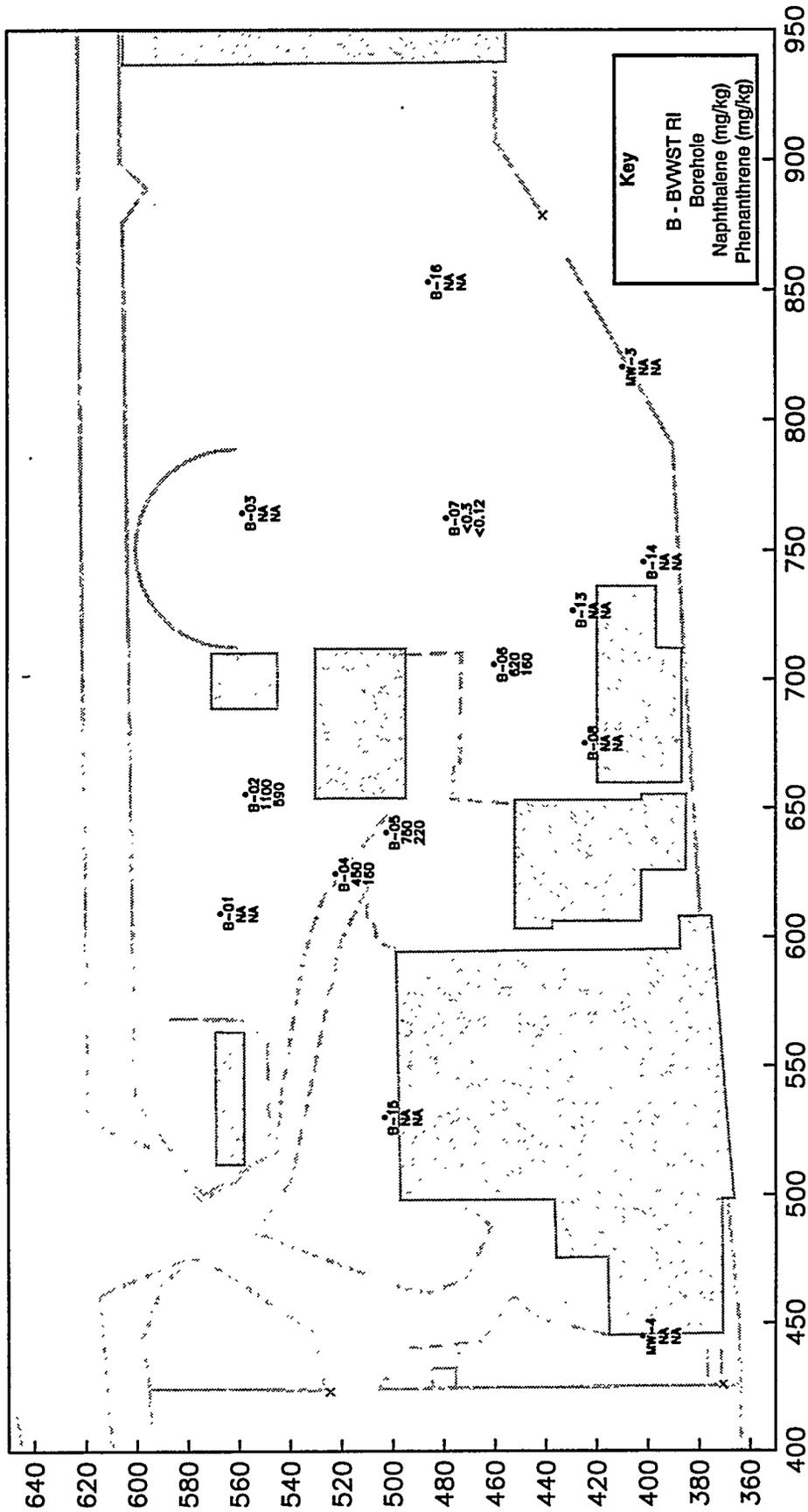


Figure 2.8 BVWST Naphthalene and Phenanthrene Concentrations - Stratigraphic Zone 4

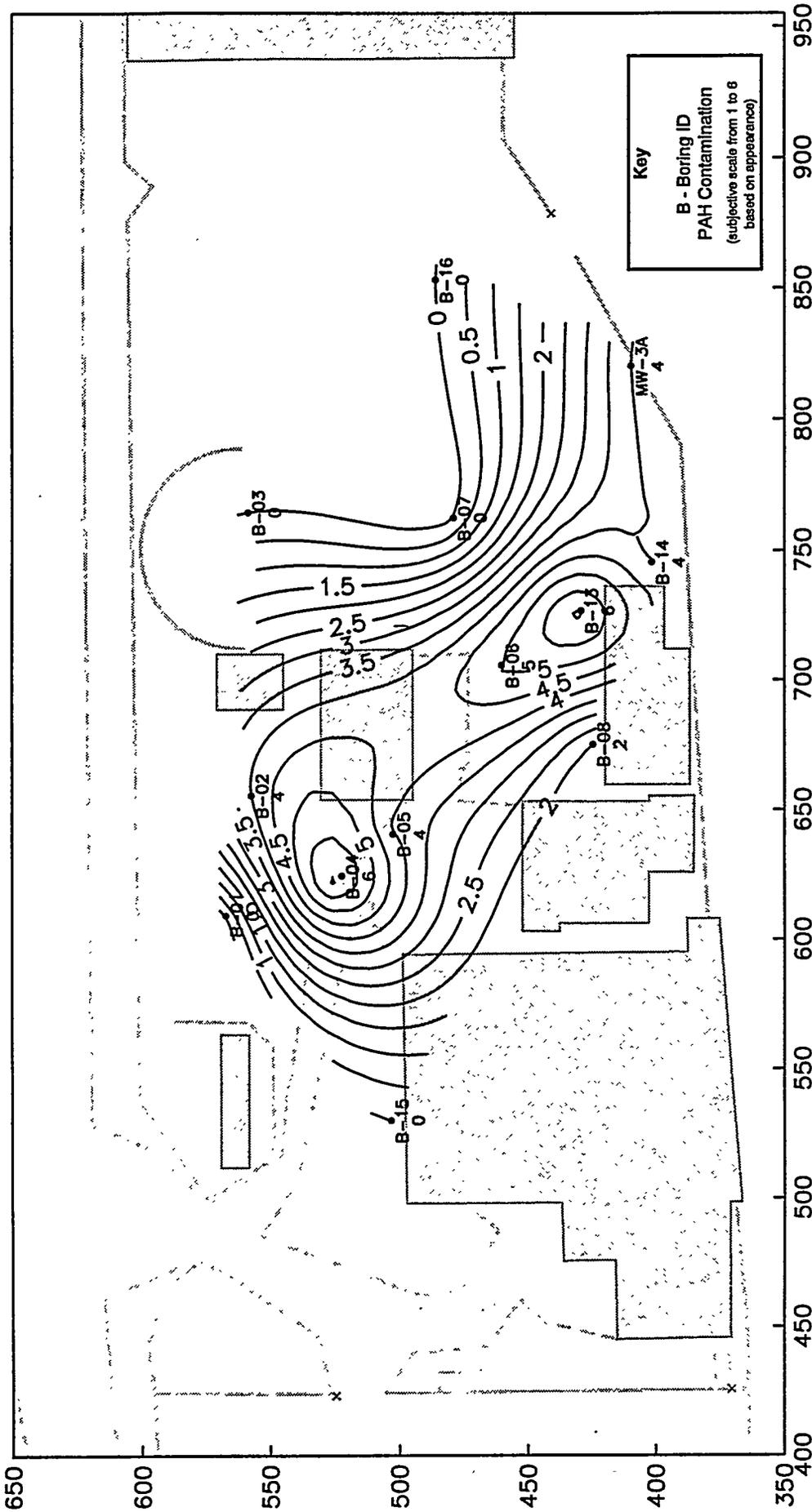


Figure 2.9 BWST Observed Level of PAH Contamination in Soils - Stratigraphic Zone 1

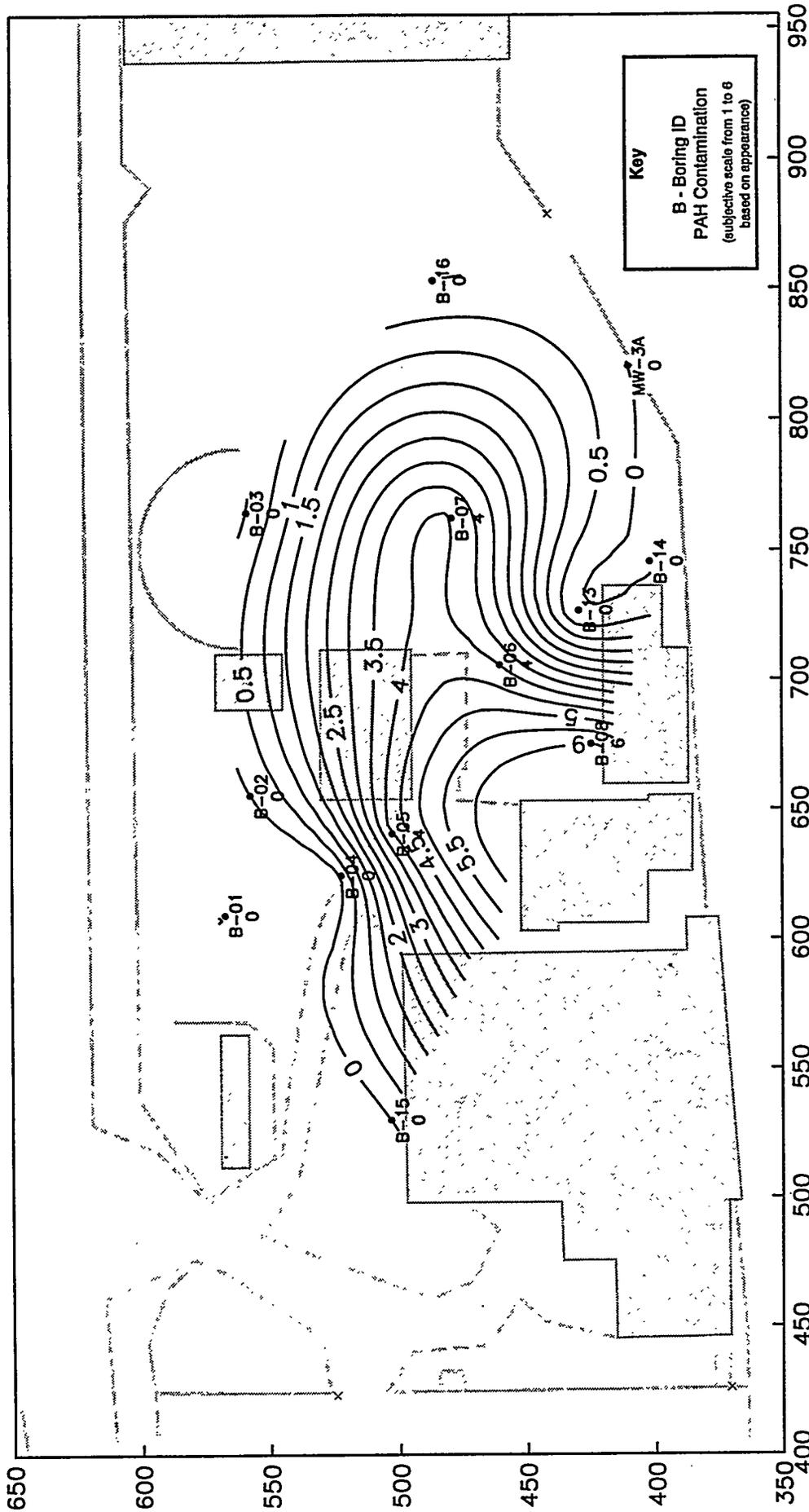


Figure 2.10 BWST Observed Level of PAH Contamination in Soils - Stratigraphic Zone 2

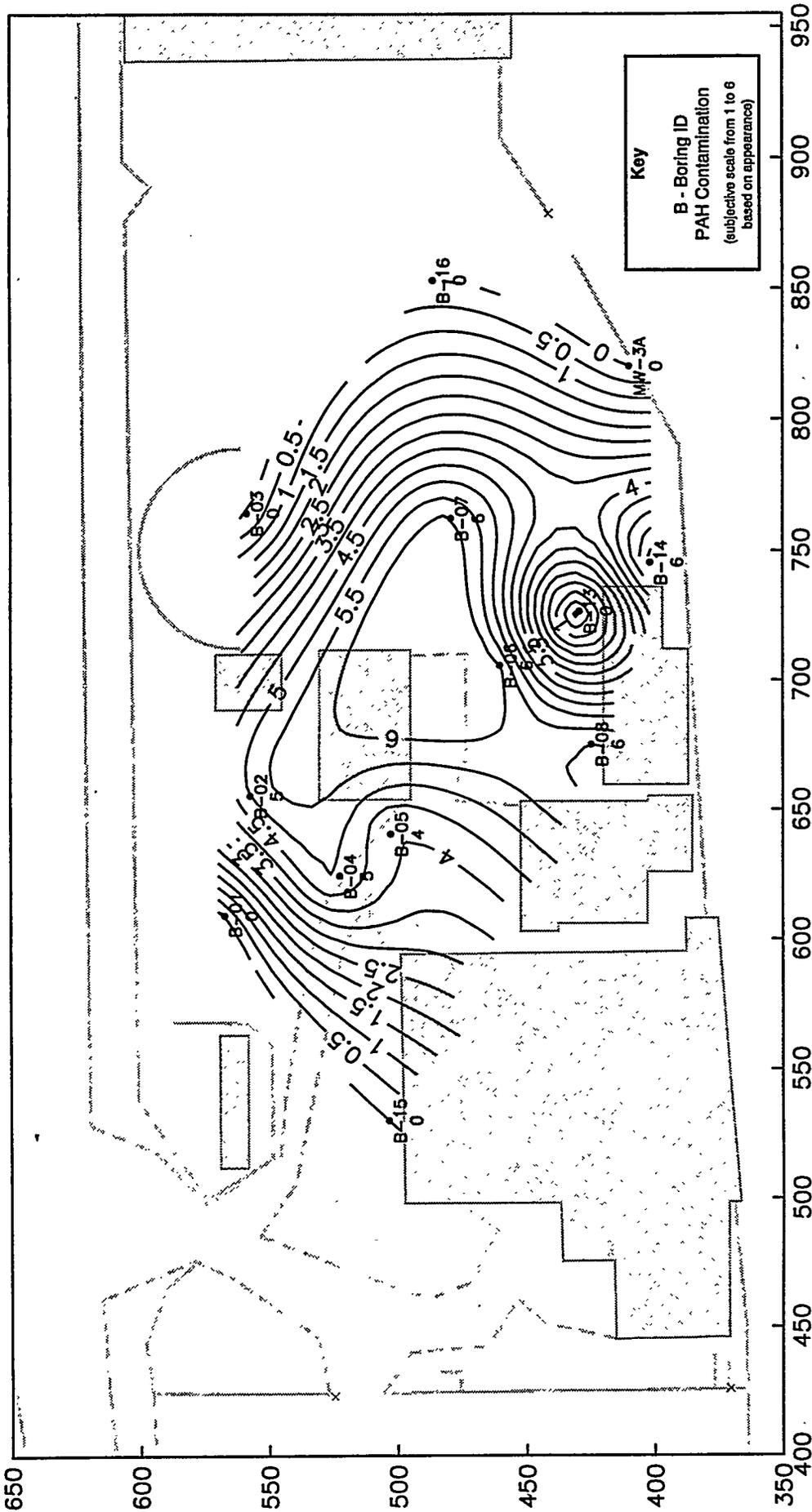


Figure 2.11 BWST Observed Level of PAH Contamination in Soils - Stratigraphic Zone 3

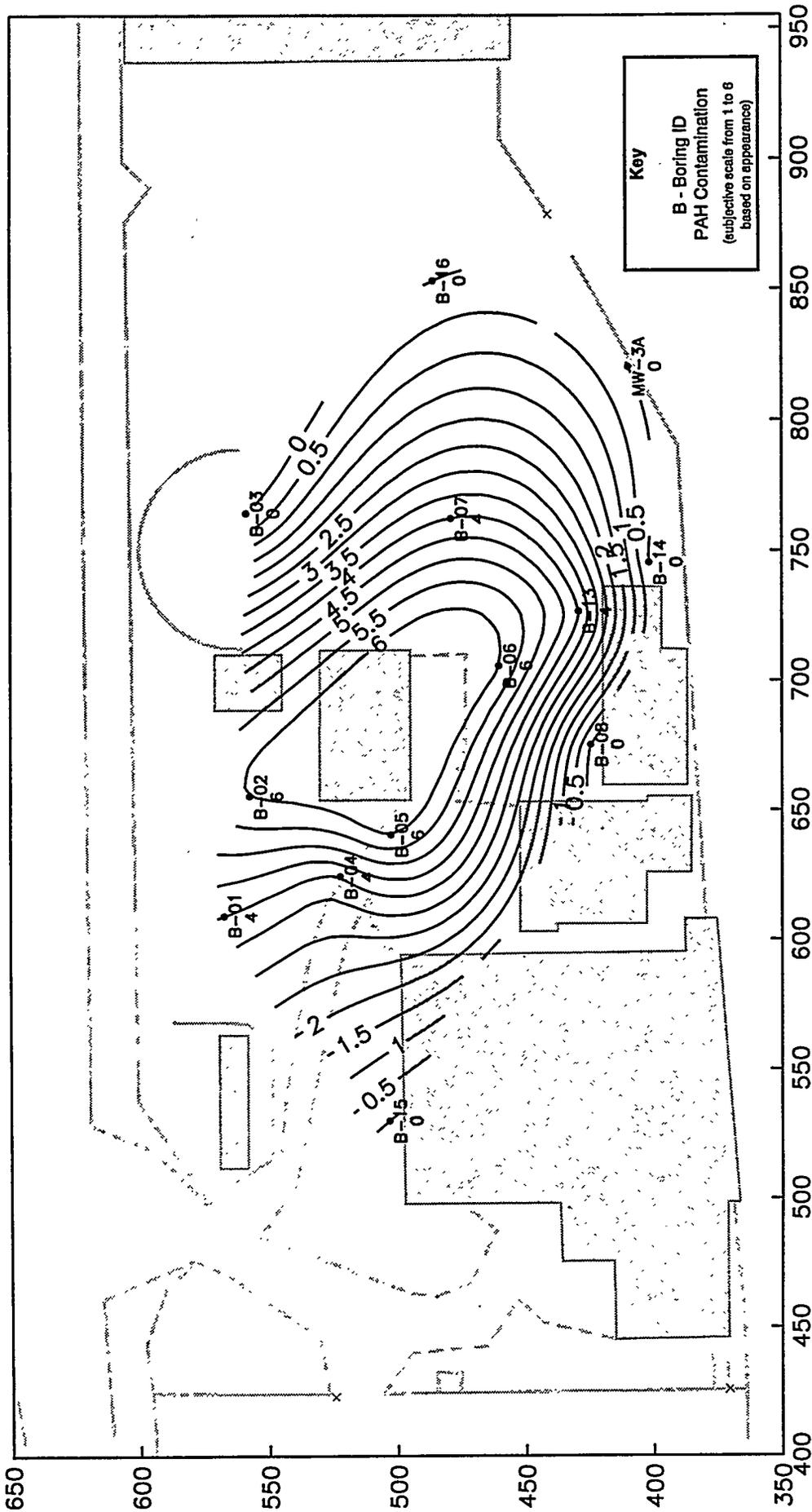


Figure 2.12 BWST Observed Level of PAH Contamination in Soils - Stratigraphic Zone 4

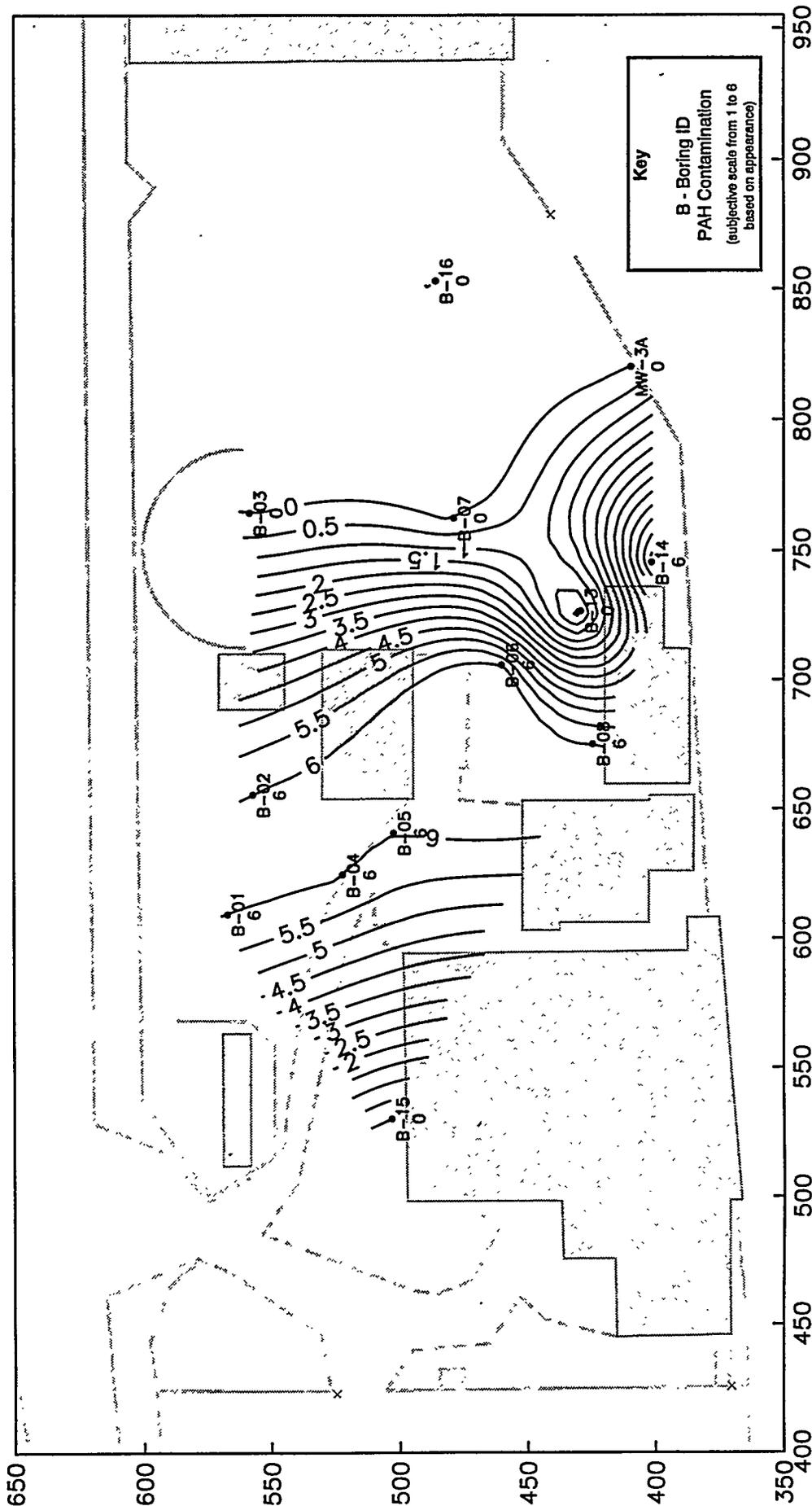


Figure 2.13 BWWT Observed Level of PAH Contamination in Soils - Stratigraphic Zone 5

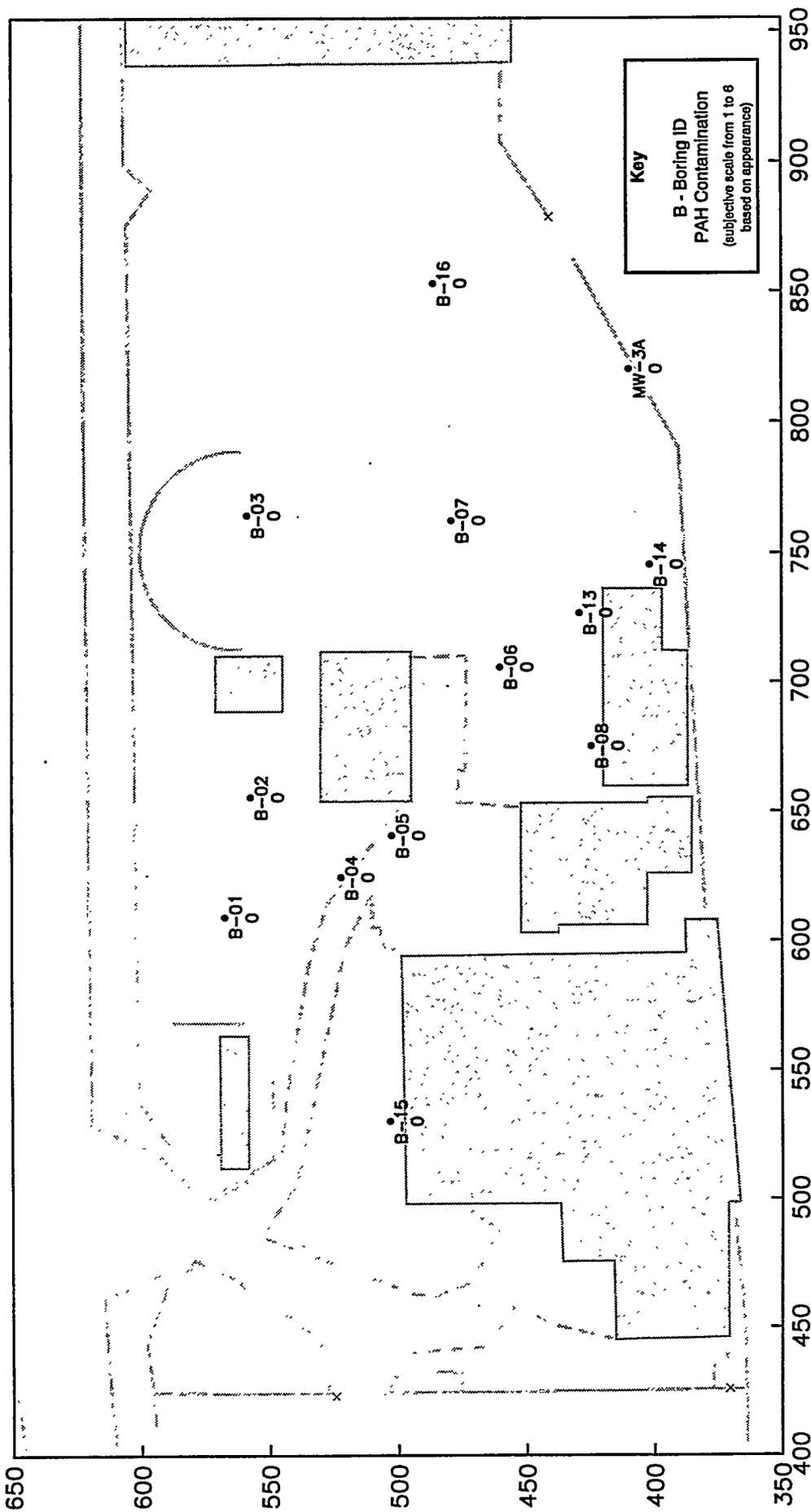


Figure 2.14 BWST Observed Level of PAH Contamination in Soils - Stratigraphic Zone 6

**TABLE 2.1 BVWST RI NAPHTHALENE AND PHENANTHRENE CONCENTRATIONS IN SOIL (mg/kg)
BY STRATIGRAPHIC ZONE**

Borehole		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
B-1	Naphthalene	<1.5	NA	85	NA	NA
	Phenanthrene	3.7	NA	38	NA	NA
B-2	Naphthalene	770	NA	960	1100	NA
	Phenanthrene	220	NA	370	590	NA
B-3	Naphthalene	NA	<0.3	NA	NA	NA
	Phenanthrene	NA	<0.12	NA	NA	NA
B-4	Naphthalene	NA	NA	NA	450	1800
	Phenanthrene	NA	NA	NA	160	430
B-5	Naphthalene	71	590	NA	750	NA
	Phenanthrene	37	170	NA	220	NA
B-6	Naphthalene	480	81	NA	620	NA
	Phenanthrene	270	24	NA	160	NA
B-7	Naphthalene	27	NA	NA	<0.3	NA
	Phenanthrene	15	NA	NA	<0.12	NA
B-8	Naphthalene	42	NA	260	NA	NA
	Phenanthrene	19	NA	88	NA	NA
B-13	Naphthalene	66	3	NA	NA	NA
	Phenanthrene	23	4.8	NA	NA	NA
B-14	Naphthalene	1.6	<0.3	NA	NA	NA
	Phenanthrene	<0.12	<0.12	NA	NA	NA
B-15	Naphthalene	<0.3	<0.3	<0.3	NA	NA
	Phenanthrene	<0.12	<0.12	<0.12	NA	NA
B-16	Naphthalene	<0.3	NA	<0.3	NA	NA
	Phenanthrene	<0.12	NA	<0.12	NA	NA
MW3	Naphthalene	<15	NA	<0.3	NA	NA
	Phenanthrene	22	NA	<0.12	NA	NA
MW4	Naphthalene	NA	<0.17	<0.33	NA	NA
	Phenanthrene	NA	2.1	15.2	NA	NA

Note: Entries with "<" symbol signify that the compound was not detected at a level equal to or greater than the value reported.

TABLE 2.2 BVWST RI OBSERVED LEVEL OF PAH CONTAMINATION BY STRATIGRAPHIC ZONE

Borehole	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
B-1	0	0	0	4	6	0
B-2	4	0	5	6	6	0
B-3	0	0	0	0	0	0
B-4	6	0	5	4	6	0
B-5	4	4	4	6	6	0
B-6	5	4	6	6	6	0
B-7	0	4	6	4	0	0
B-8	2	6	6	0	6	0
B-13	6	0	0	4	0	0
B-14	4	0	6	0	6	0
B-15	0	0	0	0	0	0
B-16	0	0	0	0	0	0
MW3	4	0	0	0	0	0

Note:

<u>Observed Level Of PAH Contamination</u>	<u>Designation</u>
Free Product	6
Product Sheen	5
Discoloration	4
Strong Odor	3
Mild Odor	2
Slight Odor	1
No Odor	0

3.0 CHARACTERIZATION STRATEGY

3.1 Introduction

In keeping with the stated project goals (Section 1.1), the characterization strategy for the Marshalltown site focused on the evaluation, comparison and promotion of both SOPT and IT characterization and monitoring technologies. Geophysical, chemical analysis and data integration technologies were fielded in two phases. Phase I involved largely non-invasive, screening type measurements while Phase II involved more invasive geophysical and contaminant analysis measurements. The Phase I and Phase II timelines with the fielded technologies and providers are shown on Figures 3.1 and 3.2, respectively. The technologies fielded and approaches used in fielding the technologies are described in the following sections.

3.2 Geophysical Technologies

As geophysical survey technologies play an integral role in the ESC methodology, the evaluation of both IT and SOPT geophysical survey technologies formed a significant part of this project. It must be stressed, however, that the Marshalltown FMGP site conditions were far from ideal for conducting high quality geophysical surveys. Cultural interferences such as overhead power lines, buildings, fences and storage areas and the relatively high conductivity UCU impacted the resolution and depth of penetration, respectively, of the ground penetrating radar while noise from the nearby railroad yard and on the site itself and the relatively high velocity surface fill layer impacted the resolution and interpretation of seismic surveying. These factors need to be considered in the evaluation of the geophysical survey technologies.

ITs included a shallow reflective seismic technique using a high-frequency, vibratory energy source, a 3-D ground penetrating radar (GPR) data analysis technique and a vertical induction profiling technique termed electromagnetic offset logging. The SOPTs included seismic reflection and refraction, GPR data acquisition and borehole geophysics. Reasonable correlations with information from the invasive technologies were sought.

Mobilized invasive technologies included hollow stem auger equipment to drill boreholes for calibrating purposes and minimally intrusive technologies represented by Geoprobe® and cone penetration test (CPT) direct push technologies. While the Geoprobe® was used in Phase I as a part of the contaminant screening tests, the direct push technologies, following established ESC protocols, were largely used in Phase II to further develop the site model and confirm data from Phase I. Comparison was made between the capabilities of the CPT system and the Geoprobe®, in terms of stratigraphic logging, sampling and contaminant screening capabilities. The

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Marshalltown site provided a nearly ideal setting to evaluate the respective merits of these two push technologies because the soil types are amenable, the depths of interest are 50 feet or less, and physical access issues that impact truck mobility were evaluated at this site. The heterogeneous upper fill layer and the uneven bedrock surface did, however, create difficulties for these direct push technologies as described later.

3.3 Contaminant Distribution

The contaminant distribution was investigated in two phases, first the screening phase, and second, the quantitative phase. The major goals of this part of the work were to assess the ease of use and reliability of the ITs fielded and to compare the results of the screening technologies with the quantitative and BVWST results.

3.3.1 Screening Phase

Nearly all of the techniques used in the screening phase, including the immunoassay kits (IMA), passive sorbent, and the chemiluminescence (CL) optical method can be considered innovative. The IMA methods are just being approved by U.S.-EPA. Our data, collected from kits from more than one IMA provider and taken from split samples under carefully controlled conditions, will add considerable weight to the effective adoption of IMA methods within and outside DOE.

Only a few passive sorbent methods are known for semivolatile PAHs and few potential users realize that they are applicable to saturated as well as unsaturated soils. This is in contrast to volatile organic compound (VOC) passive sorbent methods that are in widespread use but only in unsaturated soil conditions. Likewise, active soil gas methods have been rarely applied to PAHs because of the much reduced volatility of PAHs.

One of the target compound PAHs at Marshalltown is naphthalene, whose vapor pressure defines the boundary between semivolatile organic compounds (SVOCs) and VOCs. Thus naphthalene is the SVOC with the highest vapor pressure and likely would form the highest volume plume. Naphthalene is also an attractive target compound because it was one of the most common PAHs detected in the previous characterizations and it is one of the three most common compounds that make up coal tar. Typically naphthalene ranges from about one to ten percent by volume of typical coal tar waste. However, some of the methods, such as IMA, may not be very sensitive to naphthalene. The relative sensitivity of these screening methods to various PAHs were a focus of the technology evaluation.

Screening measurements with the active and passive soil gas equipment, IMA kits and the CL technique were carried out at the same sampling locations to facilitate direct comparison. A

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network of sampling locations, with a shallow and deep sample at every location was set up and carried out in Phase I.

The innovative CPT laser induced fluorescence (LIF) sensor, in its present state of development and validation, does not have the ability to assist in the quantitative delineation of the PAH plume near the action levels nor can it distinguish more than a subset of the 16 PAHs of interest. It can, however, detect the presence of petroleum, oil or lubricant contaminants down to the range of 100 mg/kg and also qualitatively distinguish areas of low, medium or high contamination. Moreover, a continuous profile of LIF response and stratigraphy with depth can be obtained from each push location. Given these capabilities, the role of the CPT unit was to confirm the degree and extent of contamination indicated by the BVWST data and the other screening technologies in Phase I and to provide guidance for selecting locations for soil samples for quantitative chemical analysis. In addition, once the detailed topography of the upper surface of the LCU has been defined, potential shallow depressions near the edges of the main body or bodies of the PAH plume(s) can be directly sampled for free phase, saturated soil, or less contaminated soil for the existence of isolated PAH plumes.

Although considered a stratigraphic logging tool, the Geoprobe® soil conductivity sensor provided an indirect indication of the presence of coal tar residue through a drop in conductivity. This technique of contaminant distribution screening was also investigated through comparison of the conductivity logs with nearby CPT LIF pushes and quantitative data from soil samples.

3.3.2 Quantitative Phase

The quantitative phase focused on comparing the performance and results of five field extraction methods: 1) sonic solvent (SOPT), 2) thermal desorption (TT), 3) supercritical fluid extraction (IT), 4) microwave extraction (IT), and 5) microextraction (IT) coupled with field gas chromatography/mass spectrometry (GC/MS) systems with the results of standard contract laboratory program (CLP) off-site chemical analyses. Samples for the field GC/MS systems were collected using a Geoprobe® truck. Although field duplicates were taken during the subsurface probing to address site soil inhomogeneity, it was necessary to collect a sufficient quantity of each sample so that, after homogenization, they could be split and analyzed by each of the extraction modules.

Little new information about the contaminant distribution was gained from these split samples. However, they were necessary for the comparative evaluation of the extraction methods. Although some of these extraction methods had been used before and may even have EPA approval, their evaluation under identical conditions will benefit their adoption and implementation by DOE and others. Variations in recovery percentages among the extraction

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methods that were due to soil type are suspected to be important in the selection of appropriate extraction methods for similar soil types. In order to isolate the extraction percentage from the variance among the GC/MS instruments, spiked aliquots were injected directly into the column. Moreover, spiked soil samples were used to evaluate the percent recovery and method detection limits for each of the extraction methods.

Although really a part of the screening phase, samples co-located with the contaminant screening network described above were taken and analyzed off site to provide a direct comparison for the screening technologies. In addition, soil samples were also collected within several feet of CPT LIF push locations to provide a direct comparison of the LIF results with an on-site total recoverable petroleum hydrocarbon (TRPH) method and off-site chemical analysis results.

3.4 Data Integration

EarthVision software from Dynamic Graphics, Inc., was used for data integration and visualization a daily basis to assess the status of the geologic and contaminate conceptual site models and to plan the next day's sampling locations. Data handling, analysis and visualization in EarthVision could be improved with a more flexible database arrangement and also with the inclusion of geostatistical capabilities such as kriging and quantitative uncertainty analysis.

Data from the previous BVWST site investigation were processed with EarthVision prior to going to the site. An experienced operator from Dynamic Graphics, Inc. was on site to facilitate data integration and operation of the EarthVision program during Phase II when daily upgrades of the site model were generated. In particular, 2-D contoured stratigraphic maps were produced which helped to identify gaps in the data; this information was extremely useful in planning the next sampling locations. A computer-compatible projection system facilitated the display of the site model and critical data. This system was used primarily during the stakeholder presentations. During Phase II geostatistical calculations were vital for making unbiased estimates of the subtle data gaps that remained.

April 1, 1994

Drill two calibrating cored holes
Obtain site - specific soil banks

April 4 to 9, 1994

Analytical
Soil gas experiment

Active: Global Environmental - GC based
Passive: NERI - install sorbers

IMA analysis
Ensys, Millipore and Quantix
Chemiluminescence

Geologic
GPR - D'Appolonia
Seismic Reflection - Resolution Resources, Inc.
Borehole Logging - D'Appolonia

April 18 to 22, 1994

Collect seismic data - Coleman Black Hawk
Retrieve NERI sorbers for off-site analysis

April 25, 1994

Mobilize Geoprobe and two mobile laboratories - McLaren/Hart
Mobilize CPT - Corps of Engineers
Mobilize Geoprobe - Geoprobe Systems

April 26, 1994

Set up mobile laboratories and mobilize Geoprobe - McLaren/Hart
Calibration probing using SCAPS - Corps of Engineers
Begin Sampling - Geoprobe Systems
Set up microscale and microwave extraction modules - PACE

April 27, 1994 to May 7, 1994

Soil sampling with two Geoprobes and CPT if necessary
Perform vertical induction profiling - GEHM
Use Geoprobe/CPT resistivity and CPT LIF to search for free
phase/saturated soil regions
GC/MS soil and groundwater analysis with five extraction methods
Integrate data daily

May 2 to 4, 1994

Conduct tours for stakeholders

4.0 RESULTS AND EVALUATIONS

4.1 Non-Intrusive Methods for Geological Characterization - Geophysical Surveys

This section discusses the methods employed and the results obtained for non-intrusive geophysical survey technologies applied at the site. The technologies include ground penetrating radar (GPR), seismic refraction and reflection, electromagnetic offset logging (EOL) and borehole geophysical logging. The last two geophysical methods employed down-well tools but did not require any new intrusive activity to be accomplished. They are, therefore, included with the non-intrusive activities. A comprehensive evaluation of all geophysical applications was made by Technos, Inc. (1994).

4.1.1 Ground-Penetrating Radar

Description

The GPR survey, carried out by D'Appolonia Environmental Services, Inc., consisted of four phases: 1) common midpoint (CMP) testing to aid in the interpretation of signal velocity and depth of penetration; 2) a series of closely spaced, parallel profiles covering most accessible areas within the perimeter fence of the site; 3) processing of parallel profile data as a 3-D data set; and, 4) one common depth point (CDP) profile through the site using multiple transmitter-receiver offsets.

Common Midpoint Test. A CMP test was accomplished using a 100 megahertz (MHz) antenna in bistatic configuration and a Geophysical Survey Systems, Inc., (GSSI) SIR® System-10A. One north-south and one east-west trending line was run using a common central point (local coordinates 477N-845E; see Figure 4.1). Data were collected along each line beginning with minimum antenna separation and gradually increasing antenna offset to a maximum of 75 feet. A profile of average two-way velocities were determined from the data for the E-W line.

Parallel Profiles. A total of 36 radar profiles were obtained in parallel east-west orientations using a 300 MHz antenna in monostatic mode and a GSSI SIR® System-10A (see Figure 4.1). A closely-spaced bistatic antenna configuration was originally planned but was abandoned due to instrumental interference. Profile lines were spaced 5 feet apart and set up in all areas sufficiently free of obstructions to allow data acquisition. Individual shots were taken at 6-inch intervals along each line. A total of 9851 shots were taken, with each shot consisting of 1024 time-amplitude measurements. Data were acquired by towing the antenna on a wheel-mounted sled and recorded on an Exabyte 8mm tape to a two-way travel time window of 200 nanoseconds

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(ns). Data for the profiles were processed and color depictions of the radar data were developed using the RADAN program.

3-D Data Set. Additional processing of the 300 MHz data was performed by D'Appolonia Environmental Services for the purpose of compiling the data into a three-dimensional set. This was accomplished by first converting the RADAN data into ASCII format using the RTOA16 provided by the GPR system manufacturer. The ASCII data represented the amplified and filtered trace amplitude profiles at each of the 9851 shot locations. Data was recorded to a range of about 180 ns.

The number of time-amplitude measurements in each shot was then reduced to make data processing possible in a PC format. However, the reduction method was not consistent throughout the data set. The data set from the south half of the site was reduced to include only every other point in the top half and the bottom half was discarded, partly as a result of aerial interferences in the data. The remaining data set was reduced by inclusion of only every fourth measurement.

Map coordinates were then assigned to each shot measurement using Microsoft EXCEL. This was followed by a trace subtraction routine to eliminate background "noise." This was accomplished by subtracting from each individual shot trace the shot trace three measurements ahead (i.e., the fourth trace was subtracted from the first, the fifth was subtracted from the second, and so on). This routine was employed by D'Appolonia to effectively remove all but dipping reflections because these were the targets of interest for imaging as three-dimensional time slices. Following the trace subtraction routine, the individual line-specific files were compiled into master files. Due to the size of the master files and the memory limitations of the PC, the eastern half of the site had to be compiled into three separate master files and the western half of the site was compiled as a fourth master file.

The XYZ master files were imported into the GEOSOFT™ contouring program by segregating into smaller files with common Z coordinates (i.e., the same two-way travel time). These horizontal "time-slices" were then contoured as 2-D data sets by GEOSOFT™.

Common Depth Point Profile. Data were collected from the southeast edge to the northwest corner of the site along an uninterrupted 620-foot line. The location of the line is shown in Figure 4.1. Data were collected using 100 MHz antennae in bistatic configuration with three different transmitter/receiver offsets. The purpose of this survey was to enable CMP processing of the data in a manner similar to seismic reflection data. The 100 MHz antennae would presumably allow deeper penetration of the radar signal, but with less resolution than the 300 MHz antenna.

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A transmitter/receiver pair was first towed along the line in zero-offset configuration and measurements were made at 10-foot station spacings. Then two pairs of antennae at approximately 5-foot and 10-foot offsets were towed along the line in both directions. Measurements were taken with the transmitter antennae on the individual station marks. This system provided five measurements at each station (zero-offset, plus two non-zero offsets with receiver antennas on each side of the station). Individual measurements were recorded to a range of 900 ns.

Data processing was conducted using PC-based software from the Lookout Geophysical Corporation of Golden, Colorado. Processing of the data was performed in the following steps:

- 1) Conversion of the raw RADAN data into SEG-Y format using software provided by GSSI.
- 2) Low and high pass filtering.
- 3) Derivation of average velocities.
- 4) Application of normal moveout correction.
- 5) Automatic statics correction.
- 6) CMP stacking of records (three-fold).

Results

Common Midpoint Test. Based on the CMP test and subsequent data acquisition and processing, the GPR contractor interpreted the maximum depth of resolvable reflections to exceed 75 feet (see Figure 4.4). Above ground reflectors, such as buildings and overhead wires, tended to interfere with some of the reflections from deeper than about 15-20 feet.

The interpreted velocity profile is provided in Table 4.1. For comparison and reference, a table of approximate electrical conductivities, relative dielectric constants and travel times for various earth materials is presented in Table 4.2. It is not clear why the two-way travel time in the depth range of 21 to 30 feet is so low; this depth would be below the water table and according to the value given for approximate travel time for a saturated sand material is low by about a factor of two.

Parallel Profiles. An example of a typical 300 MHz profile collected from the site is reproduced in Figure 4.2. Based on velocity determinations made by the CMP test, the window of data to 180 ns is roughly equivalent to a depth profile to 30 feet. Equivalent interpreted depths have

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been superimposed along the left vertical axis of the figure. Complex reflections are demonstrated in the first ~30 ns, which corresponds to the top 6 to 7 feet in the subsurface. This may be attributable to fill material. Below this level, several strong horizontal reflections are interpreted by the contractor as instrument artifacts (e.g., reflection at ~120 ns). Reflections from overhead power lines are visible as broad parabolic reflections (see Figure 4.2 at 50 ns). Reflections from buildings at the ends of profiles appear as steeply sloping multiple reflections at the ends of the lines, and buildings parallel to the lines appear as multiple strong, shallow reflections near the surface. Slabs of concrete are visible as bright "ringing" reflections near the surface.

In general, the data were less noisy on the eastern side of the property as a result of the relative openness of the site. On the western side, the former electric plant building on the south, the substation on the north, and the former purifier building on the east produced strong interfering reflections. No stratigraphic information could be obtained from this data set.

3-D Data Set. The processing performed on the 3-D data set (described above) was useful in reducing the intensity of or eliminating "noise" in the data, particularly in the first approximately 40 ns where ringing is strongest. Color contour images of the individual time slices were prepared and are included in D'Appolonia's report for various depths between approximately 2 feet and 12 feet. The time slice map for 13 ns (an interpreted depth of ~3 to 3.5 feet) is shown in Figure 4.3. Most of the visible anomalies display a strong north-south orientation as a result of the inhomogeneous distribution of data points (very closely spaced in the east-west direction (6 inches) as compared to the north-south direction (5 feet)).

The most visible anomalies in the time-slice maps are above-ground features, such as buildings and large metallic objects. The strong anomaly immediately to the east of the 500N-800E intersection is surface interference from a parked trenching machine. Anomalies which are not as easily attributable to surface objects include a linear feature (interpreted as possibly a buried utility line) at the west end of the site trending NNE-SSW, a roughly square feature at the west end of the east half of the site (possibly an unusually strong reflection from the buildings), and numerous small anomalies dispersed across the site but particularly abundant in the southern portions. These small anomalies are notably more scarce to absent in certain areas, such as beneath the concrete pad of the former gas holder east of the former purifier building (see Figure 2.1 for reference). Several of these anomalies are interpreted by the contractor as buried metallic objects. In the deepest time slice (65 ns or about 12 feet), the interference from overhead power lines became the most salient features. No stratigraphic information could be obtained from this data set.

Common Depth Point Profile. Data collected by the 100 MHz multi-offset, bistatic antenna configuration and processed by CDP methods are displayed in wiggle trace and trace amplitude

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format in Figure 4.4. Surface landmarks are indicated on the figure for reference. Strong coherent reflections are apparent between two-way travel times of about 60 and 130 ns. This is followed by an absence of reflections down to about 240 ns. From 240 ns to about 700 ns, reflections are intense and regular, with the exception of around 600 ns; reflections beyond a two-way travel time of about 550 ns are interpreted by the contractor as "ringing" between horizons.

Based on the results of the CDP survey, a maximum depth to resolvable targets of 75 feet (approx. 550 ns) was interpreted by the contractor for the 100 MHz antenna configurations, and reflections to a two-way travel time of 550 ns were interpreted to be from actual horizons in the ground. The reflection at about 100 ns is believed to represent the water table. The soil-bedrock interface was interpreted as the coherent reflections at about 240 ns or approximately 40 to 45 feet. An aberration in the data at shot points 18-20 (Figure 4.4) was interpreted as a possible bedrock pinnacle. However, the line passed within several feet of a metal gate and chain link fence at this location, which may provide a more likely explanation of the anomaly. In addition, the interpreted bedrock reflection contains gaps between shot points 13 and 19, shot points 23 and 26, and shot points 49 and 52.

Productivity/Output

The time needed to accomplish the scope of work described above was six field days, although half of this time was non-productive because of equipment problems. The actual collection of data required one day for the 3-D data set, less than one day for the bistatic multi-offset line, and several hours for the CMP test.

Post-processing was accomplished off site over a period of about four weeks. Delays in processing were encountered primarily as a result of difficulty in converting multi-offset radar data to SEG-Y format.

Commentary

Two significant indications suggest potentially poor radar performance at this site (Technos, Inc., 1994). It is generally accepted that penetration of radar signals is severely limited by geologic strata with relatively high values of electrical conductivity. Borehole geophysical logging and Geoprobe conductivity probing (discussed in Section 4.3.2) indicate that the conductivity of the UCU is on the order of 50 to 150 mS/m. Empirical data suggests that the maximum depth of radar penetration is related to the electrical conductivity (σ) by the expression:

$$\text{Depth (max)} < 40/\sigma \text{ to } \text{Depth (max)} < 80/\sigma.$$

Using the lower range of σ would thus limit the depth of penetration to about 0.8 to 1.6 m (2.6 to about 5 feet). Moreover, the heterogeneous nature of the upper fill would tend to disperse and attenuate the radar signal.

The second indication of poor radar performance is the abundance of air reflectors in the data. The 300 MHz GSSI antennae are fully shielded and do not normally show any response from air reflectors (Technos, Inc., 1994). The fact that air reflectors are seen indicates a poor impedance match between the antennae and the ground (i.e., the signal is simply being reflected off the ground and into the air). In addition, the contractor refers to problems with the bi-static configuration of the 300 MHz system, which was apparently unresolved, problems with a survey wheel and limitations with the PC based software being used to process the data. A significant part of the data set was not used because of the limitations of the software; this could have an adverse impact on processing and interpretation.

In short, the results of this GPR survey should be viewed with caution.

4.1.2 Seismic Reflection

Both seismic reflection and refraction surveys were completed at the site in an effort to provide detail of the bedrock surface beneath the alluvial soils and, if possible, to provide information regarding stratigraphic interfaces above the bedrock. The two surveys were conducted by different contractors, so the systems and operating parameters differ and will be discussed individually. The seismic reflection survey was carried out by Resolution Resources, Inc.

Description

Three seismic reflection profiles were collected on each of three sides of the site. Two east-west trending lines were collected outside the perimeter fence on the north and south, and one shorter line was collected along the west side within the site. These lines will hereafter be referred to as the "north," "south" and "west" lines, respectively. Figure 4.5 shows the locations of the lines. The line locations were chosen by the contractor to potentially identify geologic features which may influence shallow (i.e., above bedrock) and deep (i.e., below bedrock) groundwater flow and to verify the existence of lineaments in bedrock structure believed by the contractor to be visible in aerial photography. A total of 2,845 feet of 24-fold seismic line data was collected.

A noise test was conducted at the west end of the south line on an unused portion of the railroad right-of-way.

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The following operating parameters were chosen by the contractor following the noise test:

Sample Rate	0.250 ms
Channels	48
Record Length	250 ms
Low Cut Acquisition Filter	70 Hz
High Cut Acquisition Filter	500 Hz
Geophone Spacing	5 feet
Minimum Offset	0 feet

A 12-pound sledge hammer source with six pops per source location was used, and signals were received with Mark Products 40 Hertz (Hz) geophones and recorded on a Geometrics Strataview seismograph.

Vertical seismic profiles (termed check shot surveys by Technos, Inc., 1994) were performed in wells MW-1B and MW-3B using a 30 Hz downhole receiver. The receiver was lowered into each of the wells and locked in place with an inflatable bladder. Measurements were taken at 2.5-foot intervals to a total depth of 55 and 57 feet, respectively, in the two wells. A 12-pound sledge was used at a distance 10 feet from the well at 10 pops per station.

Processing was performed using Seistrix 3 software developed by Interprex. The following data processing steps were performed following downloading of the data to a PC:

- Edit field data -- remove noisy records or bad data traces;
- CDP sort -- assemble individual traces from different records into records having a common reflecting point;
- Digital filter -- eliminate noise in frequency domain;
- Velocity Analysis -- build model of velocity vs. depth, required to correct data for normal moveout and estimate depth from the time section, by applying various velocities to a select set of CDP records and choose the velocity which produced the most coherent section;
- Static correction -- apply time corrections to compensate for elevations differences in geophones and sources;
- Mute -- remove refraction (first arrival) from reflection section;

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- Normal moveout correction -- remove the differences in travel time that result from differences in distance from source to near and far geophones;
- CDP stack -- summation of moveout-corrected traces in the CDP records; and
- Automatic gain compensation -- rescales amplitudes across the individual stacked traces, increasing the amplitude of late events.

The stacked and corrected traces were then plotted on hard copy for viewing. A static correction of 8.3 ms was added to traces in the south line to adjust for the difference in elevation between the north and south lines. No static correction appears to have been made along the individual lines.

Results

A copy of the interpreted seismic reflection profiles are contained in Figure 4.6. The vertical dimension is two-way travel time in milliseconds (ms) rather than depth in feet. The three key stratigraphic contacts between the UCU, granular unit, and LCU were interpreted from the profiles by the contractor. In addition, "disrupted" areas (incoherent reflections) in the bedrock structure were interpreted. These were interpreted by the contractor to be associated with the lineaments they had identified on the aerial photographs prior to commencement of work.

The check shot surveys carried out in MW-1 and MW-3 were used to calculate the reflection time to the stratigraphic contact of interest. The results are shown in Figure 4.7. An apparent low velocity zone between about 12 feet and 22 feet in well MW-1B may be noted. In addition, the velocity below 25 feet differs greatly between the two wells. Correlation between the top of the LCU in the check shot survey and the interpreted cross section is good (see Figure 4.6a), but the bedrock contact appears to be somewhat deeper in the cross section than on the check shot survey (i.e., according to the formula presented in the contractor's report). The bedrock should be at about 43 ms, whereas the cross section shows bedrock at a depth of about 50 ms. Further comparisons of the seismic reflection interpretations with intrusive data are made in Section 4.3.3.

Productivity/Output

Data was collected by a two-person crew over a period of five days, including time involved in reconnoitering the geology of the Marshalltown area. Data processing was accomplished on a daily basis, and updated plots of processed lines were viewed at the site as work progressed. All field work and data processing was completed by experienced personnel.

Commentary

The air photo lineaments referred to above and illustrated in Figure 4.5 appear to be related to human activity (e.g., edges of rows of trees, dredging for drainage purposes, etc.) rather than geologic structure (Technos, Inc., 1994). In terms of acquisition of the data, it is believed that considering the depth to bedrock of about 40 to 50 feet, a geophone spacing of one to two feet would have been more appropriate than the 5 foot spacing that was used. The resulting long source-to-geophone offset (on the order of 240 feet) would cause serious phase distortions for all reflectors above and including those from the bedrock (Technos, Inc., 1994). It is also believed that the shallowest reflectors in the 20 to 30 ms range are too discontinuous to be considered as representing stratigraphic contacts.

As a final note on the efficacy of this work, a second contractor (Coleman Energy and Environmental Systems-Blackhawk Geosciences Division) was hired to conduct a seismic reflection survey using a variable frequency electromechanical source produced by OYO Corporation along side a manual hammer source. However, walkaway tests using both sources produced no identifiable reflecting events, as interpreted by the contractor. Despite this, the contractor collected 150 feet of data to be processed by reflection techniques, although no interpretations were derived from this data.

4.1.3 Seismic Refraction

Description

The seismic refraction survey carried out by Coleman Energy and Environmental Systems-Blackhawk Geosciences Division used both compressional (P-wave) and shear (S-wave) impact sources for the primary function of characterizing the bedrock surface. In general, the site exhibited some unfavorable features including a high velocity near-surface fill layer which attenuated the seismic signal (particularly high frequencies), and high ambient noise from the railyard and activity on and around the site.

Equipment used for the collection of refraction data included an OYO DAS-1 48-channel seismograph, OYO 28 Hz geophones, 24 channel CMP cable, Bison EWG-1 assisted weight drop, azimuthal traction plate, and an I/O 240M-channel roll box.

Compressional Wave Survey. Nine P-wave refraction lines were collected at various locations around the site (see Figure 4.8); lines 1 and 2 were not interpreted due to significant cultural interferences. The lines were located primarily inside the perimeter fence and were constrained such that the effects of visible cultural refractors would be minimized. For six of the lines, a 24-

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geophone array was laid out at a spacing of 5 feet giving a total line length of 115 feet. A 48-geophone array was used for lines 1, 2 and 10, giving a total line length of 235 feet.

A mechanically assisted drop weight was used to generate the signal. Due to the low signal to noise ratio, up to 40 blows were used on long source-to-receiver offsets. Five shot locations were used for forward and reverse shot directions. Distant shot locations were restricted due to physical inaccessibility.

Refraction data processing consisted of the following steps:

- 1) Import data into OSIPAK software system for first break analysis;
- 2) Pick first breaks on individual traces;
- 3) Import first breaks into GREMIX program for refraction analysis;
- 4) Assign layers to arrivals;
- 5) Pick X-Y distances for Generalized Reciprocal Method (GRM) analysis; and
- 6) Compute depths and velocities of refracting layers.

Engineered fill at the near surface throughout the site created a near surface high speed (11,000 ft/s) refractor, which was the first seismic event to appear on the records. This event was ignored when picking first arrival from the records. The later events were picked based on consistency between adjacent records and their velocities.

As a result of the near-surface high velocity fill layer and possibly also a thin layer of saturated sediments, a condition called a "hidden layer" existed in which the layers below the high velocity layer cannot be recognized. This problem was resolved by applying the GRM analysis. GRM analysis does not allow mapping of the bottom of the hidden layer, but does allow mapping of layers below this hidden layer. A full treatment of the hidden layer case is given by Palmer (1980) and Lankston (1989).

The velocity of a refractor is calculated from the slope of the time-distance relationship of the time of arrival picks. The velocity of the refractor interpreted to be the limestone bedrock at the site was in the range of 6,000 to 7,000 ft/s, which is consistent with published velocities for weathered limestone. Some of the lines which were oriented N-S showed significantly higher velocities, although this fact may be the result of interpretive error.

Shear Wave Survey. Five S-wave refraction lines were collected at locations corresponding with P-wave lines 1 to 5. S-waves were generated using an azimuthal traction plate to create waves of opposite polarity. The reversed polarity allowed the masking of compressional energy which may have been produced by the source, thus enhancing the ability to pick the first arrival of the shear wave. Internal geophone elements were modified from vertical orientation to horizontal with consistent polarity throughout the array.

First arrivals of shear waves were picked manually by superimposing corresponding traces and noting the location on each pair where simultaneous opposite polarity motion was observed. This process was made more difficult by ambient noise and a traction plate that provided lower energy signals than the EWG-1 wave generator.

Results

Compressional Wave Survey. Depth to bedrock profiles were interpreted by the contractor for eight of the P-wave lines. The remaining two lines were not interpreted due to suspected interfering signals refracted from nearby buildings or other sources. Four of the interpreted profiles are reproduced in Figures 4.9 to 4.12. Note that depth to bedrock from nearby BVWST boreholes and seismic line intersection point depths to bedrock are also included on these profiles. Combining these results with the BVWST borehole data allowed the contractor to produce revised bedrock elevation contours based on combined borehole and seismic refraction data. Contours of bedrock elevation with the BVWST data alone are shown on Figure 4.13, and contours including the seismic refraction data are shown on Figure 4.14.

The following may be concluded regarding the seismic refraction profiling:

- 1) Overall, the depths to bedrock interpreted from the seismic survey correspond to the BVWST data. Comparisons with MW-3 and B-16 are within several feet. Moreover, the general trends observed with the contours correspond to general trends of the existing data; i.e., generally greater depth to bedrock in the vicinity of Lines 6 and 10 and shallower bedrock in the northern and eastern parts of the site. In particular, BVWST boreholes B-1, B-2, B-4 and B-5 all indicate depths to bedrock of over 40 feet. This tends to provide support for the results of line 6.
- 2) The seismic data also indicate a bedrock high or ridge which trends north-south in the region of 800E to 850E from the northern part of the site. A bedrock knob or pinnacle was also identified in the vicinity of 830E, 450N (see Figure 4.14).

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- 3) Comparison of the depth to bedrock at points where the seismic lines intersect indicate correspondence within about two to three feet. A notable exception is at the intersection of lines 5 and 7 where the depths to bedrock deviate by more than 10 feet.

Shear Wave Survey. The combined effects of high ambient noise and inherently low source energy from the traction plate resulted in indistinguishable first shear wave arrivals at far geophones for the S-wave surveys. As a result of the lack of far offset data, little information could be obtained from the S-wave effort, and this data was, therefore, not used to derive depth to bedrock information.

Productivity/Output

Work was accomplished by a three-man crew over the course of seven work days, including walkaway tests for refraction and reflection. Raw field records were viewed in the field; however, processed refraction profiles were not available until after processing was completed off site.

Commentary

Despite the fact that a 1-foot geophone spacing was used, no reflections were observed from the shallow bedrock or overlying stratigraphic soil units using either the hammer or vibratory source. This result casts much of the seismic reflection survey reported in Section 4.1.2 in doubt.

Despite the cultural interferences at the site, the results of the seismic refraction survey correlate reasonably well (generally to within about two to three feet) with the BVWST existing data. It must be kept in mind, however, that most of the data is concentrated in the eastern portion of the site and the depth to bedrock shown in the western portion of the site would have a higher level of uncertainty; note also that the most detail in the contour maps corresponds to the area of the most intensive surveying. Further comparisons with the intrusive data collected at the site will be made in later sections.

4.1.4 Borehole Geophysical Logging

Description

D'Appolonia Environmental Services, Inc., of Monroeville, PA, was contracted to apply a suite of borehole logging technologies to four existing wells and two new cased boreholes at the site. This information was then correlated with stratigraphic logs developed by BVWST and Ames

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Laboratory for the respective holes to evaluate the quality and quantity of stratigraphic data which can be obtained by these methods in similar settings.

Natural Gamma. Natural gamma logging is a passive-type log which measures naturally occurring gamma radiation in the soils or rock formation surrounding the well or borehole, primarily from isotopes of potassium, radium and thorium. These elements tend to be more abundant in clay-rich soil and shale. This tool usually provides qualitative information about the stratigraphy of the formation on a gross scale. Fine details of sedimentation can not be resolved by this method.

Gamma-Gamma. This logging tool uses a gamma ray source and gamma detectors to measure backscattering and attenuation by the materials surrounding the well or borehole to gain an understanding of bulk density. Only qualitative information can be obtained due to interference of well materials and annular media. The tool used for this project was a D'Appolonia Model 501DR Depthprobe with a 10mCi cesium-137 source and it had the capability of determining wet and dry density by using the moisture content output from the neutron log (discussed below).

Neutron. This method involves the use of a neutron source inside the logging tool which interacts with borehole and formation materials, resulting in backscattered neutrons and gamma ray production. Most of the interactions are with hydrogen atoms, primarily contained in water molecules. Therefore, neutron logging is used for determining moisture content and formation porosity in saturated conditions. The Model 501DR Depthprobe with a 50mCi americium-241/beryllium source was used. The detectors on the tool sense either low energy (thermal) neutrons or gamma radiation from slow neutron absorption. The data generated was used in the calculation of wet and dry density values for the gamma-gamma logs.

Induction. The boreholes were also logged using electromagnetic induction. The tool used for this activity was a Geonics EM-39, with a transmitter-receiver coil spacing of 50 cm. The transmitter coil induces electric currents in the formation media. The magnetic fields of these currents are then detected by the receiver coil. The coils are configured such that peak response is approximately 30 cm from the axis of the borehole, well outside of the well and annular sealing materials. The recorded data are computed as ground conductivity in units of milli-Siemens per meter (mS/m).

Results

The density, natural gamma and induction logs for MW-1, MW-2, MW-3, HSA-2, MW-5 and HSA-1 have been plotted along with the BVWST borehole logs by Technos, Inc., in Figures 4.15 to 4.20, respectively. The stratigraphic logs for boreholes HSA-1 and HSA-2 may be found in

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Appendix A. The natural gamma logs generated for MW-1, MW-2 and MW-3 displayed a relatively high degree of scatter with respect to stratigraphic variations. Subtle details in the soil units above bedrock could not be confidently identified. The transitions from the upper cohesive unit to the granular unit to the LCU were marked by a gradual decrease in the gamma count. However, the logs provided good information about the occurrence of unweathered bedrock, marked by a steady low gamma radiation level. The most abrupt change in the soil units in any of the gamma logs was in HSA-2 at a depth of 14 to 17 feet, where the gamma count dropped by a factor of 5 (see Figure 4.18). This depth corresponded to a transitional zone between firm clay above 14 feet and poorly graded sand below 17 feet.

The gamma-gamma logs showed scatter similar to the natural gamma logs, and the variations in density in the overburden soils were not sufficient to use this technology for detailed stratigraphic logging. However, the logs showed consistently high density readings at and below the bedrock surface (weathered and unweathered). A notable exception to these results was the log for HSA-2, which showed a dramatic rise in density between 23 and 24 feet that persisted to the bottom of the hole at 45 feet (although the density log data continues inexplicably to >49 feet; these two facts may indicate an error in the depth scale for this log).

The induction (conductivity) data showed much less scatter than the nuclear-derived data, with the exception of some spurious readings in MW-2 at a depth range of 24 to 27 feet (Figure 4.16). While large differences exist between conductivity values in the cohesive units and the granular unit, the contacts are gradual in the EM-39 logs and cannot be pinpointed by this method alone. As with the natural gamma logs, HSA-2 displayed the sharpest boundary between the upper cohesive and the granular units.

Typical ranges in conductivity and resistivity for the stratigraphic units were as follows:

<u>Soil Unit</u>	<u>Conductivity (mS/m)</u>	<u>Resistivity (ohm-m)</u>
UCU	55-82	12-18
Granular	50-65	15-20
Weathered Lmst.	45-55	18-22
Unweathered Lmst.	45	22

Productivity/Output

The suite of logs described above was accomplished on six wells with a total of approximately 250 feet of log collected. The work was accomplished in four (4) working days by a two-person crew. With the exception of an obstruction in well MW-4, preventing it from being logged, no significant logistical or equipment problems were encountered.

Commentary

The advantage of using state-of-the-practice borehole logging techniques for geologic characterization of the site is that they provide qualitative records of subsurface physical properties useful in making further interpretations using other complimentary technologies. In particular, the borehole logging data was useful in making positive identification of unweathered bedrock horizons, which was not possible by any other means, including drilling logs which are typically highly subjective. A clear disadvantage of borehole logging is the requirement for new intrusive drilling activity or pre-existing wells and the concomitant generation of potentially contaminated waste material.

4.1.5 Electromagnetic Offset Logging (EOL)

Description

The electromagnetic offset logging technique used at this site is based on a geophysical technique originally used to prospect for metallic (conductive) orebodies and oil and gas reservoirs. The system used consisted of a surface source coil and a downhole receiver. The source coil is a 12-turn, 2-meter coil, operated with a very low frequency alternating current of 10 amperes, creating an effective electromagnetic moment of 500 ampere-meters squared ($\text{amp}\cdot\text{meters}^2$). The current induced in the downhole receiver coil by the primary and secondary magnetic fluxes created by the source coil is recorded as voltage data.

The EOL survey was performed by The GEHM Corporation and Entech Engineering, Inc. The source coil was placed on a 20-foot grid pattern. The survey area was approximately 200 x 200 feet (approximately 1 acre). A total of 126 offset logs were acquired, of which 29 were rejected during editing prior to modeling. The final offset log coverage and source locations are depicted in Figure 4.21, which shows that 97 offset logs were used for modeling. Data from each source coil location was logged from surface grade to 50 feet below grade. Vertical sampling in each log was performed on a 0.1 foot interval.

The signals from the receiver coil are passed through a High-Q, inverted-notch filter specific to the source coil frequency. This filter enhances signal-to-noise ratio. The filtered signal is then passed to an integrator which performs additional signal-to-noise enhancement by summing and averaging the signal over many tens of cycles.

At each source coil station location, the receiver travels the full depth of the selected well or borehole and records a "continuous" record of the induced current. Variations in the receiver coil signal should reflect variations in subsurface resistivity beneath the source coil. After a

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complete vertical offset log is recorded, the source coil is moved to another station and the process is repeated. A 3-D matrix of data is generated from this process.

The last steps of the field processing involve digital sampling of the integrator voltage output, plotting of field records of the output for quality control, and field evaluation of detected anomalies. The digital data passing quality control checks is stored on floppy disk for further processing off site. Details of the processing were not disclosed by the contractor but were identified as involving the following steps:

- 1) Automated editing and removal of extreme noise as unusable offset logs.
- 2) Automated amplitude static corrections to eliminate variations in the individual logs caused by changes in source strength in and around noise features.
- 3) Automated signal-to-noise enhancement using 0.1-foot samples to generate resolution for the final 0.5-foot sampled offset logs input to the model process.
- 4) Generation of one-dimensional log models.
- 5) Design of two-dimensional and three-dimensional model weights.
- 6) Three-dimensional surface-integral modeling.

The final steps are development of 3-D images, maps and cross-sections using EarthVision software and annotation using Silicon Graphics' Showcase software.

Results

A simple resistivity spectrum involving six resistivity ranges (colors) was chosen to model and present the data. The resistivity values in the spectrum reflect the following geologic strata:

<u>Soil Type</u>	<u>Resistivity (Ω-m)</u>	<u>Resistivity (Ω-m)*</u>	<u>Conductivity (mS/m)+</u>
clay	<45	45-55	>22
silty clay	45-55	55-80	18.2-22
silty sand	55-80	80-120	12.5-18.2
clean sand and gravel	80-120	120-300	8.3-12.5

* - same soils containing hydrocarbons

+ - corresponding conductivity of water saturated soil types indicated in the first column

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A 3-D resistivity image produced from the data is shown as Figure 4.22. This figure illustrates two significant regions with resistivity >55 ohm-meters (conductivity <18.2 mS/m). The eastern region, which comes very close to the surface near borehole B-7, contains a significant core of material with >120 ohm-meters resistivity. Having ruled out the possibilities of an enormous free-product plume (based on intrusive sampling) or a large bedrock knob, the contractor attributes this to "a dichotomy condition of electrical resistivity resulting from the presence of hydrocarbon containing vertical fractures." It is not clear in the contractor's report where these fractures are believed to be located. The presence or absence of such fractures could not be verified within the scope of this investigation.

Productivity/Output

Data acquisition began on April 27, 1994 and was completed April 29, 1994. Processing began the following day with the first model being created on May 1, 1994. Ames Laboratory personnel were briefed on the preliminary findings on May 2, 1994.

Commentary

The contractor has not alluded to the potential for significant cultural interferences to affect the EOL results at this site. In fact, the transmitter loop was deployed within a few feet of vehicles, chain link fences, stacks of steel piping and even within buildings (including a steel shed). Adding to this the fact that only one receiver well was used, a limitation which the contractor did recognize, it may be concluded that the data were acquired under less than ideal conditions. There presently is no physical evidence to support the contractor's hypothesis of vertical fractures containing hydrocarbons in this region. Furthermore, the proprietary algorithm for processing raw logs could not be evaluated. Without a clear understanding of how the data was handled, it is not possible to comment on the integrity of the method used.

The resistivity values measured in this survey are significantly higher than those measured with the EM-39 logging tool (i.e., the highest resistivity values measured with the EM-39 are on the order of 22 ohm-m for the unweathered limestone (corresponding conductivity of 45 mS/m)). Since the EM-39 borehole logging technique is a well established SOPT, these results may be considered as more representative of the site soil and rock resistivity characteristics. Comparisons will also be made with the Geoprobe conductivity logging in a later section.

4.1.6 Summary - General Comments on Geophysical Surveying Results

Of the geophysical techniques used at the site, only the seismic refraction and borehole logging appear to provide confident data. The results of the seismic refraction compared reasonably well

(usually within about two to three feet) with the existing BVWST data in terms of defining the bedrock surface. The borehole logging results were also verified by the BVWST borehole logs. The borehole logging results added no new information to the characterization effort beyond the interpreted interface between weathered and unweathered bedrock; these results, however, were useful for calibrating and verifying some of the other intrusive techniques discussed in later sections of this report.

The GPR data added little useful information to the characterization effort. The 300 MHz data appeared to locate shallow foundations and services, but this aspect of GPR logging was not an important part of this project. For the 100 MHz survey, it is unlikely that the depth of penetration of the radar signal was as deep as the contractor claims. There is also significant potential error in trying to determine the depth to bedrock. The bedrock high or pinnacle noted by the contractor at stations 18 to 20 (see Figure 4.4) tends to correspond to a bedrock high determined by the refraction survey. The GPR 100 MHz line is superimposed on the refraction depth to bedrock map on Figure 4.23. Significant uncertainty in the two-way travel times, however, make interpreting the depths to any better than within 5 to 10 feet impossible.

As there are no depth indications on the seismic reflection "interpreted" profiles and no clear indication in the contractor's report as to how to calculate the depths, quantitative evaluations and comparisons with other data are not possible. Qualitative comparisons of stratigraphic profiles produced by the seismic reflection interpretations with those produced from intrusive data showed poor matches. The EOL survey data does not appear to correlate with any observed features at the site and the contractor's explanation of the observed anomalies appears questionable.

It appears that the seismic reflection and EOL contractors may have come to the site with preconceived notions of the conditions at the site. The seismic reflection contractor found lineaments in the bedrock from the same aerial photos that other experts who viewed them could not confirm, and the EOL contractor seemed to be focused on finding large hydrocarbon plumes. The level of confidence in the results obtained by these two methods is not high.

4.2 Phase I Contaminant Screening Technologies

Based on a previous site characterization performed by BVWST, the lateral and depth distribution of the PAH contamination could be qualitatively estimated (see Chapter 2). This site was considered an important opportunity to evaluate a variety of screening technologies for SVOCs. In addition, the results could be used to confirm the previous plume estimates and to assist with the planning of the Phase II contaminant screening and sampling/quantitative analysis activities.

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MLs 3 to 27 were laid out to bound the expected edges of the PAH plumes (see Figure 4.24). The sampling locations were set up in triangles with about a 50 foot separation between the locations; due regard was given to the interfering structures on the site. ML-1 and ML-2 were assigned to the calibrating hollow stem auger boreholes which were placed on the extreme east and west edges of the site (HSA-1 and HSA-2, respectively), well away from suspected contamination zones. The sampling network covered most of the site except its extreme western edge.

The suite of Phase I screening technologies fielded included kits from all three of the available IMA vendors that could detect PAHs at the time of the demonstration (Ensys, Millipore and Quantix), an innovative CL system, and active and passive soil gas measurements.

A Geoprobe system mobilized on site by the active soil gas measurement contractor, Global Environmental, Inc., was used to actively sample for soil gas, install the passive gas instruments and take soil core samples to provide duplicate samples for the IMA and CL techniques at each of the 24 MLs. Two depths were investigated at each ML; one shallow, typically at a depth of about 5 feet, and the other deeper, at a depth of 10 to 15 feet. As a result, there were a total of 48 sampling locations for the screening program. The shallow depth samples were recommended by Northeast Research Institute (NERI), the passive soil gas vendor. The deeper measurements were an attempt to sample below the relatively impermeable upper cohesive unit and improve the detectability of the active soil gas measurements for the deeper lying PAHs. According to BVWST, the water table was typically in the middle of the granular unit in 1992. However, historic heavy rains in the summer of 1993 raised the water table into the lower levels of the upper cohesive unit on the western half of the site. Since active soil gas measurements require unsaturated soils, the deeper set of samples on the west portion of the site had to be taken in the upper cohesive unit rather than in the upper reaches of the more permeable granular unit.

Because the results of the IMA and CL tests are basically only qualitative, it was decided that duplicate soil samples would be used rather than splits. These soil samples were taken as close as possible to the locations where the soil gas measurements were made. In addition, six duplicate soil samples were taken and analyzed off site for moisture content and PAH concentration by high pressure liquid chromatography (HPLC).

4.2.1 Immunoassay

Description

IMA is a technology that was developed by the medical testing community and is based on the very high selectivity of enzyme reactivity that permits sensitive analysis of organics in the presence of many potentially interfering compounds. The IMA kits, which require little training

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or expertise to use, give results on site in a matter of minutes using color-coded liquid extractants. However, they detect a weighted average of the PAHs of interest and can only be used in a screening mode. Ensys and Millipore are gravimetric measurements while Quantix is volumetric. Each company was contracted for 75 kits and associated training for three employees, which was done at the Ames Laboratory prior to site measurements. The three Ames Laboratory employees who were trained by the IMA vendors made all of the on-site IMA measurements. The employees had no formal training in the use of the IMA test kits prior to this project. Evidence of operator dependence was not apparent in the IMA results, confirming the ease of use of this method and minimal requirements for the analyst.

Results

The results from the three IMA analyses are reported in units of parts per million (ppm) by weight for Ensys and Millipore and ppm by volume for Quantix in Table 4.3. In some cases values are given as ranges. A row with n.a. means that the sample was not analyzed or that a sample suitable for IMA analysis could not be obtained.

From Table 4.3 it can be seen that the results from the three different IMA test kits for each sample correlate very well in terms of indicating the presence or absence of detectable PAHs. In order to examine the spatial variation of the level of PAH contamination indicated by the IMA results, the results of Table 4.3 have been plotted at their respective MLs and contoured. Considering that the Ensys and Millipore data are reported in terms of concentration ranges, log scale-type contours were used; the Quantix results were contoured directly. The contour plots are presented in Figures 4.25 to 4.27 for the shallow depths and in Figures 4.28 to 4.30 for the deeper measurements.

Several trends are evident from these figures. Careful inspection of the six figures shows that a single curve can be drawn that separates the ND results from those with some detected level of PAH and that these curves are nearly coincident for each of the two measurement depths. Moreover, the three shallow and three deep contour plots agree very well with each other on the location and shape of the PAH contamination distribution. The deep measurements tend to place the centroid of the plume further west than the shallow data; this result was not anticipated based on the BVWST measurements (e.g., see Figures 2.9 to 2.11). Indeed, the sampling network chosen for this data set was based on the BVWST data set and was expected to overlap both the eastern and western edges of the PAH plume. This was the first sign that contamination in the 10 to 15 foot depth range extended further west than expected.

The efficacy of the IMA test results may be evaluated by comparison with the HPLC analytical results contained in Table 4.3. Since the IMA technique is relatively insensitive to naphthalene, the total PAH concentration less the concentration of naphthalene is used for comparison. Of

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six possible agreements, Ensys had four agreements and two false positives; Millipore had three agreements, two false positives and one false negative; and Quantix had two agreements, three false negatives and one false positive. In assessing these results, it is important to note that:

- as IMA kits are biased to false positives, the relative percentage of false negatives is a better indicator of performance,
- duplicate rather than split samples were used, and,
- Ensys and Millipore are gravimetric, while Quantix is volumetric.

4.2.2 Chemiluminescence

Description

The CL technique, developed and manufactured by Tauw Milieu of The Netherlands, was discovered by Golder Associates of Albuquerque, New Mexico through a DOE EM-50 OTD contract to seek out foreign-based environmental technologies. Golder Associates arranged for Tauw Milieu to field and demonstrate their CL technique at the Marshalltown site. The technology is being commercially marketed in Europe. It was selected because of its simplicity and potential for quantitative analysis. Because we used duplicate and not split samples, however, the quantitative analysis capability could not be reliably evaluated.

After proprietary liquid phase extraction from a soil sample, a chemical is added to the extract and the luminescence is monitored by a simple solar cell-based detector that converts the emitted light signal into an electrical current. The enhanced luminescence is easily visible to the naked eye in the shade of a sunlit day. Calibration factors, using the results of HPLC analyses on representative site samples, are required to convert the measured intensity of the light to concentration. Results are reported in terms of total PAH concentration (not including naphthalene) in units of ppm.

Results

The results of the CL analysis are given in Table 4.4 and log contour plots of the CL results for the two depths are given in Figures 4.31 and 4.32. The shallow and deep plume configurations defined by the CL results generally correspond with those defined by the IMA results. Some western movement of the deeper plume, as indicated by the deep IMA results, is also evident in the CL results. The presence of a single plume as evidenced by the capability to draw one curve

separating ND measurements from detects is also confirmed for the CL data and correlates well with the IMA results.

When comparing the CL measured concentrations with the HPLC results (less naphthalene), within a factor of two, three agreements, two false negatives and one false positive may be observed. The measured results also agree in a general sense with the IMA results.

4.2.3 Passive Soil Gas

Description

The passive soil gas measurements were made using the NERI Petrex system, which has been widely used for VOC detection but only rarely for SVOC detection. Unlike active gas measurements, this system has the advantage of being able to operate within the saturated zone. (Attempts to field a similar system from Gore Technologies were not successful because of procurement difficulties.)

Each Petrex soil gas sampler consists of two or three adsorption elements or collectors (ferromagnetic wire coated with activated charcoal) housed in a resealable glass container in an inert atmosphere. The Petrex system requires placement of an unsealed sampler into a covered hole for a period of 5 to 10 days. Volatile gases are adsorbed through vapor diffusion from the soil over the exposure period in the soil. After the samplers are retrieved from the holes, resealed and returned to the vendor, one collector from each sampler is analyzed by Thermal Desorption/Mass Spectrometry (TD-MS). Selected second collectors were analyzed by Thermal Desorption-Gas Chromatography/Mass Spectrometry (TD-GC/MS) for compound confirmation. GC/MS measurements are only attempted if the MS spectra are too complex in the direct mode and some degree of separation is required before MS analysis can be reliably made. Total time from insertion of the collectors to receipt of the analytical results was 20 days for the Ames Laboratory's samples. The results for naphthalene, anthracene/phenanthrene (A/P) and fluoranthene/pyrene (F/P) are reported in ion counts in Table 4.5. Anthracene/phenanthrene and fluoranthene/pyrene are grouped together because they have the same atomic masses and their spectral peaks are indistinguishable.

Results

Figures 4.33 and 4.34 display contour plots of the ion count results for the shallow and deep naphthalene measurements. Comparing shallow to deep data for naphthalene clearly shows the previously noted western trend of this contaminant plume for the deep measurements. The shallow and deep results for A/P are plotted in Figures 4.35 and 4.36, respectively, while the shallow and deep data for F/P are plotted in Figures 4.37 and 4.38, respectively. The plots for the

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deep A/P and F/P measurements continue to show hits in the western portion of the site which the shallow plots do not indicate. In addition, it may be noted that the relative size of the plumes shrinks from naphthalene to A/P to F/P. Little detectable F/P or A/P was found in the deep data set. In fact only ML-12 and ML-18 have detectable concentrations of A/P in the shallow zone while ML-12, ML-18 and ML-25 have detectable concentrations in the deep zone. Clearly the higher number of naphthalene hits compared to the other measured PAHs is due to its relatively higher volatility, which is crucial for this type of adsorptive technique which relies on vapor transport through the soil; the higher the volatility, the larger the volume of soil which will have vapors accessible to the detector. The relative distribution and concentration of naphthalene and phenanthrene, derived from the quantitative information and discussed later, strongly suggests that the reduced counts for the phenanthrene relative to naphthalene is not due to reduced concentration of phenanthrene.

4.2.4 Active Soil Gas

Description

The active soil gas measurements were performed by Global Environmental, Inc., of South Dakota using their Geoprobe system to extract soil gas from the shallow and deep zones as defined previously. The active soil gas technique basically requires unsaturated soils; if saturated soil was encountered and soil vapor could not be collected, the space in the Geoprobe core sleeve was sampled before capping. The concentrations of BTEX and naphthalene gases were measured directly in the field with both a gas chromatography/flame ionization detector (GC/FID) and gas chromatography/photoionization detector (GC/PID) instrument. (Although the contract called for measurements of naphthalene as the most volatile PAH, the vendor also provided quantitative results for BTEX gases as well.) The HP5890-Series II gas chromatography (GC) instrument was calibrated on site using reference gas standards. The results for both the GC/FID and GC/PID measurements for both the shallow and deep zones are given in Table 4.6; the BTEX results, although included in Table 4.6, are not discussed in this report. The results are reported in units of $\mu\text{g/L}$ of vapor.

Results

The data in Table 4.6 shows that the PID was more sensitive to naphthalene than the FID. In cases where naphthalene was detected by the FID the agreement with the corresponding PID measured concentration was very good. Log contour plots of the shallow and deep FID naphthalene data are shown in Figures 4.39 and 4.40. A single plume is evident at the lateral resolution of the grid at both depths. Some data are not available due to difficulties with inserting the Geoprobe rod to the proper sampling depth. The centroid of the plume at the shallow depth is to the southeast of the centroid of the deeper plume and, as seen with the some

of the other screening technologies, the deeper plume extends further to the west than the shallow plume. The active soil gas plumes generally agree with the plumes deduced from the IMA and the CL results. The naphthalene passive gas contour plots (see Figures 4.33 and 4.34) tend to indicate larger plumes than the active soil gas results in both the shallow and deep zones. Note in particular that significant hits were detected at ML-11, ML-12, ML-13 and ML-18 in the passive gas measurements while the active gas measurements had non detects at these locations. The passive gas measurements thus seem to be more sensitive to detecting naphthalene than the active gas measurements.

This use of GCs to search for SVOC plumes is not typically attempted because of the lowered volatility of the SVOCs compared to the VOCs. Clearly, where naphthalene is suspected, active soil gas measurements with unmodified VOC GC columns can be used with some expectation of success.

4.2.5 Summary - Phase I Contaminant Screening Technologies

The results of the Phase I contaminant screening technologies generally compare well with the BVWST results for stratigraphic zones 1, 2 and 3 presented in Chapter 2. The plumes are generally centered around the former purifier building (see Figure 2.2) and extend down toward the storage shed at the southern end of the site. Analytical results for BVWST boreholes B-02, B-04, B-05 and B-06 generally indicated the highest levels of PAH contamination. All of the Phase I screening results tend to yield plumes centered near the former purifier building. Analytical results for boreholes B-08, B-13 and B-14 indicated that the top two stratigraphic zones in the southcentral part of the site also contained PAH contaminants. The Ensys and Millipore IMA results and the passive gas results for the deep screening zone for ML-12 and ML-18 have indicated significant PAH contamination in this region; the other screening techniques have partially detected it (CL) or completely missed it (active gas). A significant finding of the Phase I contaminant screening study was that PAH contamination existed further to the west than it would appear from the BVWST data. In particular, the BVWST analytical data for B-15 from zone 2, corresponding to the deep screening tests, indicate no PAH contamination (the analytical results for samples from this depth range gave non detects). The deep zone IMA results and passive gas results, in particular, exhibit significant levels of PAH contamination at ML-24 and ML-25, indicating that the plume could in fact extend farther to the west.

4.3 Phase II Minimally Intrusive Geological Characterization and Contaminant Screening

Two minimally intrusive, direct push characterization technologies were fielded during the Phase II investigations at Marshalltown: an innovative cone penetrometer testing (CPT) system

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(the Site Characterization and Analysis Penetrometer System (SCAPS)) and an innovative Geoprobe direct sensing soil conductivity sensor. The SCAPS was contracted through the Kansas City District, Corps of Engineers while the soil conductivity sensor unit was contracted through Geoprobe Systems of Salina, Kansas. The objectives of this phase of the investigation were to confirm and further refine the site geologic and contamination conceptual models as defined through the Phase I activities (following the ESC approach) and to compare and evaluate the CPT and Geoprobe systems. A key objective for the direct push technologies was to further define the topography of the LCU. While an integral part of the stratigraphy, this is especially important considering the transport characteristics of the denser-than-water non-aqueous phase liquid (DNAPL) coal tar residue and potential remediation schemes, such as free product pumping. These technologies, however, are limited in providing direct data to the define the surface of the bedrock.

Besides providing continuous stratigraphic profiles, the SCAPS was equipped with a LIF sensor system which could detect petroleum, oil and lubricant contaminants in the subsurface. A continuous log of LIF response with depth could be provided at a push location. The Geoprobe conductivity sensor provided a continuous log of conductivity with depth at a push location. As indicated in Section 4.1.5, the resistivity of a soil increases (conductivity decrease) with increasing hydrocarbon contamination; thus, in addition to providing stratigraphic information, the Geoprobe conductivity logs could also be used as a contaminant screening tool.

Another valuable source of data for comparison with the CPT and Geoprobe conductivity data and for further development of the site geologic and contamination models was the visual description logs associated with each of the soil samples collected for quantitative chemical analysis (which is described in Section 4.4). The soil samples for this effort were collected by McLaren/Hart Environmental Engineering Corporation personnel operating a Geoprobe Model 8-MU sampling system. Core samples two feet long by one inch in diameter were collected from the six subsurface zones at specified depths. A detailed descriptive log of each of the 127 samples collected was kept and data on core recovery, date, time, sample number, depth, soil description, water content and visual/odor evidence of contamination were recorded.

The following sections describe the SCAPS CPT and the Geoprobe systems and geological characterization results using these technologies. This is followed by contaminant screening results using these technologies. Comparisons with other technologies and results were made and the site geologic and contamination models were updated and revised in the light of these results.

4.3.1 Cone Penetration Testing

Description

The SCAPS CPT system was developed by the U.S. Army Engineer Waterways Experiment Station (WES) of Vicksburg, Mississippi under the sponsorship of the U.S. Army Environmental Center. The objective of SCAPS is to provide a cost-effective and rapid method to determine in situ soil conditions and detect and delineate petroleum, oil, and lubricant (POL) contaminants for site screening and characterization. The SCAPS is comprised of a twenty ton truck equipped with hydraulic rams used to push instrumented sensor probes into the ground. Data acquisition, processing, and storage are handled via electronic signal processing and an onboard computer system. The SCAPS utilizes tip and sleeve resistance measurements for continuous soil stratigraphic profiling while simultaneously using either resistivity or LIF to obtain further subsurface information such as pore fluid characteristics and the presence of POL contaminants. The SCAPS graphic output, or "panel plot," displays the soil classification data, and either fluorescence intensity and peak wavelength or resistivity data plotted against penetration depth (in feet) below ground surface. An example panel plot is shown in Figure 4.41. The panel plot information may be viewed in real time on an onboard computer screen; this real-time information is especially useful in determining when to terminate the push. In addition, soil and groundwater samples may be obtained from selected depths. A Hogentogler sampler was used at this site to collect one inch diameter by eight inch long soil samples. The SCAPS has the ability to grout through the cone tip on retraction of the push rods.

Soil Profiling Capabilities. Strain gages in the cone tip are used to measure the resistance against the cone tip (end bearing stress) and sleeve friction as the cone is advanced into the ground. Both measurements are recorded in tons per square foot. Empirical relationships have been developed to classify the soil type based on the cone tip and sleeve friction measurements (e.g., Olsen, 1988; Olsen and Farr, 1986; and Chiang, Loos and Klopp, 1992). This technology has been applied in geotechnical engineering site investigations for several decades.

Panel plot outputs from the CPT instrumentation show the tip and friction sleeve resistance as well as the soil classification based on the friction ratio versus depth (see Figure 4.41). Environmental factors such as grain size and gradation, angularity of particles, overconsolidation ratio, soil density, and coefficient of lateral pressure influence the tip and friction sleeve resistance (Douglas and Olsen, 1981). CPT soil classification may be ambiguous in mixed soils. Therefore, a continuously logged soil borehole from the site should be used to calibrate and verify the CPT soil classification log.

Laser Induced Fluorescence (LIF) Sensing. The SCAPS LIF system sends 337 nm excitation pulses from a nitrogen laser down a fiber optic cable in the cone rods through a sidewall

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mounted sapphire window to induce fluorescence of the POL fluorophores. The sapphire window is about two feet above the cone tip and provides a rugged and relatively optically clear interface between the soil and the ends of the fiber optic cable. The induced fluorescence is collected on a separate fiber optic cable and returned to the surface where it is spectrally analyzed using a linear photodiode array in a continuous window mode.

The fluorescence spectrum consists of photon counts measured at a rate of 1024 points over the wavelength range from 300 to 800 nm for every 2 cm depth interval. The panel plots showing the fluorescence results are produced by plotting the maximum fluorescence intensity over the 350 to 600 nm range, and the corresponding wavelength at which the maximum intensity occurred (see Figure 4.41). Since different fluorescing compounds have different characteristic fluorescent spectra, a change in wavelength associated with the maximum intensity is indicative of a different compound or set of compounds giving rise to the fluorescence.

Laser excitation of many (three or more) ring PAH compounds will cause fluorescence, however, excitation wavelengths lower than 337 nm are required to cause fluorescence of lighter aromatic hydrocarbons such as BTEX compounds. Interferences which can affect LIF response include fluorescing minerals, fluorescent dyes used as tracers or in antifreeze fluids, optical brighteners used in laundry detergents and septic system effluents, and sunlight penetrating the optical window in the top few inches of soil. Accordingly, a high intensity fluorescence does not always signify that a contaminant is present; however, experience with LIF technology has shown that the technique is generally reliable as an indicator of PAH contamination (Stenback et al. 1994).

The efficiency of the laser signal depends on several factors including abrasion of the sapphire window and pitting and misalignment of the optic fiber. To recognize and correct for a signal degradation, the energy transmission of the LIF sensor is evaluated before and after each LIF penetrometer push. Prior to each LIF push, the LIF probe is suspended from the chuck and a cuvette of rhodamine solution is placed against the sapphire window. The laser is fired on the cuvette. The process is repeated after each push. Any degradation of the LIF response to the rhodamine solution is assumed to be linear and a linear correction is applied to the fluorescence data obtained during that particular push.

LIF intensity data is commonly presented as the response or counts above background, where the background LIF response is obtained from an uncontaminated, representative sample of soil from the site. The soil sample is pressed against the sapphire window and the laser pulsed to obtain ten emission spectra. This background distribution would then be subtracted from subsequent LIF measurements to obtain the LIF response above background.

Results

The CPT push locations are shown on Figure 4.42. A total of 43 stratigraphic logs were acquired at 34 push locations. The panel plots for all of the pushes are in Appendix B. To avoid opening a conduit for potential contaminant migration into lower stratigraphic units, penetration tests were ended, in most cases, as soon as fluorescence data were collected down to the top of the LCU. Because of problems with probe breakage and apparent coarse gravel and cobbles in the 16 to 20 foot depth range early in the program, an uninstrumented "dummy probe" was used to pre-push holes at many of the locations. In fact, an LIF and a resistivity probe were broken at ML-33 and another resistivity probe was broken at ML-115. Due to the dummy rod pushes, however, many of the CPT logs have no soil stratigraphic data in the upper 20 feet. Of the several resistivity pushes which were accomplished at this site, review of the data indicates significant fluctuation of resistivity values from one location to another, in much the same material. Hardware difficulties are suspected; the data were not used.

Soil Stratigraphy. To calibrate the stratigraphic information generated by the CPT, two pushes were made in close proximity to wells MW-3 and MW-4 installed and logged by BVWST. Side-by-side comparisons are made in Figures 4.43 and 4.44. A high degree of correlation can be seen between the adjacent logs. The CPT push location ML-28 was about 19 feet northeast of MW-3; the surface elevations are within several inches of each other. There is less than a one foot difference in the depth to the upper cohesive unit/granular unit contact when the logs are compared, and there appears to be a gradational contact between the base of the granular unit and the LCU demonstrated in both logs. However, the LCU is about three feet deeper at MW-3 than at the CPT push location.

The CPT push at ML-32 was located about 9 feet north of MW-4. The depth to the upper cohesive unit/granular unit contact is within one foot. In both the CPT log and the BVWST borehole log, the UCU grades over about a 2-foot depth from clay to a sand-gravel mix (top of the sand-gravel at 19.5 to 20 feet). In both logs, the bottom portion of the granular unit or top portion of the LCU contain interbedded sandy and silty clay strata, although the CPT logs seem to portray slightly thinner layers; a gradational contact between the granular unit and the LCU is again apparent. It should be noted that the CPT stratigraphic logs yield significantly more detail on fine stratification than the hollow stem auger boreholes. This can be extremely important when considering the fate and transport of DNAPLs, which would be influenced by finer details of the stratigraphic layering. The CPT is, however, susceptible to unfavorable subsurface conditions such as rubbly fill, coarse gravels and cobbles.

The repeatability of the CPT stratigraphic logging capability was evaluated by comparing CPT logs ML032-F and ML032-R (LIF and resistivity pushes, respectively), which were pushed near well MW-4 and separated by about 5 feet (see Figure 4.45). The most significant differences

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visually between the CPT logs occurs in the top 10 feet, presumably in fill material. Otherwise the logs show virtually the same stratigraphic profile. A clear conclusion of the comparison between the borehole logs and CPT data is the increased level of stratigraphic resolution which can be obtained with the CPT.

Contacts between the stratigraphic units at the site were interpreted from the CPT panel plots and used to develop the site geological model. This is discussed in more detail in Section 4.3.3.

Contaminant Screening. In order to assess the efficacy of the LIF sensor response, nineteen soil samples were collected by the SCAPS truck at locations where LIF pushes indicated the presence of significant subsurface contamination. The soil samples were collected within several feet laterally of LIF hits of interest. The samples were analyzed by WES personnel for TRPH, (mg/kg) by EPA Method 418.1 using a field-portable equipment. The samples were homogenized and a portion of each sample was held against the LIF probe sapphire window while a fluorescence spectra was obtained for comparison with the TRPH analyses. These data are listed in Table 4.7. The first number in the Sample ID represents the map location. LIF intensity data from the adjacent CPT pushes were available for direct comparison with the TRPH analytical results. These data are listed in Table 4.8. Generally, the data from Tables 4.7 and 4.8 indicate that fluorescence intensities greater than about 200 counts are associated with moderate to high TRPH levels (high defined as > 500 mg/kg and low defined as <100 mg/kg), fluorescence intensities less than 100 counts are associated with low TRPH levels, and fluorescence intensities between 100 and 200 counts are associated with TRPH levels ranging from low to high. However, four samples with TRPH reported as <25 mg/kg show fluorescence intensities near 150 counts (see Table 4.7) and sample 81-1 shows high TRPH contamination with a fluorescence intensity (collected following a dummy probe pre-push) less than 100 counts (see Table 4.8). These exceptions aside, the LIF intensity shows qualitatively where contaminated soil exists.

Also noted in Table 4.8 are the locations where LIF readings were taken in dummy probe pre-push areas. Both large diameter (1.75 inch) and small diameter (1.44 inch) dummy probe rods were used in pre-pushing. The diameter of the LIF probe is 1.44 inches. Three factors could potentially affect LIF readings taken in a pre-push hole: the sapphire window may not be in proper contact with the soil; the hole may cave slightly on removal of the pre-push rods; or, contaminants from lower zones may be smeared on the pre-push hole wall as the rods are removed. Table 4.8, however, indicates reasonable correspondence between the LIF readings and TRPH results from adjacent soil samples, even in push ML-60 where the larger pre-push rods were used.

The panel plots for all of the LIF pushes carried out were examined and average LIF intensities were determined for each of the six stratigraphic zones. These data are tabulated in Table 4.9.

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Details on pre-pushes are also included in Table 4.9. Zones 1, 2 and 3 would be most affected by the pre-pushes. In this regard, while data for the top three zones are presented, and the adjacent samples lend support to the efficacy of the data in the pre-pushed region of the hole, LIF data in the top three zones should be viewed as having a higher uncertainty than the data in the lower zones.

Logarithmic scale contour plots of the average LIF intensity for the six stratigraphic zones are shown in Figures 4.46 through 4.51. In the upper four zones the most significant feature is the heavily contaminated zone in the northwest portion of the site, just to the east of the substation. The general trend of the contaminated region is still, however, from the northwest to the southeast through the central part of the site. Relatively high LIF readings were also noted in the region of ML-97 in the upper four zones. The main plume for zone 5 (base of the granular unit) extends from just west of the former purifier building to the southern portion of the site; elevated LIF readings near the southern site boundary indicate that contamination has most likely moved off the site in this zone. Significant hits were only detected in zone 6 (top of the LCU) at ML-76 and ML-95 (see Figure 4.51).

Examination of the LIF panel plots revealed that elevated fluorescence intensity levels commonly occur in the two to four feet of sandy soil immediately overlying the top of the lower cohesive unit indicating a pooling of DNAPL on the lower cohesive unit. When LIF measurements were taken in the top of the lower cohesive unit, the fluorescence intensity reading typically dropped to near zero (for example, see Figure 4.41). This indicates that the lower cohesive unit is tending to retard the downward migration of the DNAPL contamination at these locations.

Many of the panel plots show elevated fluorescence intensity values within the upper cohesive unit and within the upper and lower portions of the granular unit (see Appendix B for plots). Elevated fluorescence intensities are occasionally found at several locations in sandy soils overlying fine grained soils suggesting the presence of lenses acting as localized barriers to vertical migration of contaminants causing contamination to pool on top of the lens (e.g., see Figure 4.41). Elevated fluorescence intensities also occur in the granular unit with no apparent stratigraphic barrier to limit contaminant transport. These occurrences appear to be associated with light non aqueous phase liquids which tend to float on the groundwater table at about 20 to 22 feet below ground surface (see Figure 4.41). An interpretation suggesting varying compounds with differing transport behavior is consistent with the distinct fluorescence spectra observed from the samples analyzed by WES as mentioned above (Stenback and Kjartanson, 1994 and 1995).

Although the BVWST borehole B-1 indicates some fairly significant contamination in zone 3 (see Figure 2.7) in the northwest part of the site, the CPT LIF data suggest that this area of the

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site is more heavily contaminated than is indicated by the BVWST data alone. Moreover, the CPT LIF results in this region tend to confirm the hits in the deep zone by the IMA (see Figures 4.28 to 4.30) and the passive gas naphthalene tests (see Figure 4.34) - the deep zone for these tests approximately corresponds to zone 2. The CPT LIF responses in the southern part of the site agree both with the BVWST data and the IMA and passive soil gas screening data for the deep zone. In addition, the lobe centered at ML-97 in the LIF data is captured very nicely by the deep IMA screening data, which has this lobe centered on ML-9 some 4 feet to the south of ML-97. No evidence of this lobe appears in the shallow IMA data. The passive soil gas data for the shallow and deep zones, especially for naphthalene, shows this feature as well. Only shallow GC/PID naphthalene shows this feature while no evidence for it appears in any of the CL data. The relatively low but persistent LIF hits at ML-33 on the eastern side of the site are not confirmed by any other measurements of the PAH concentration in this region.

Productivity/Output

A total of 43 stratigraphic logs at 34 locations were generated by the CPT system over the course of 10 working days. The system averaged approximately 208 pushed feet per day. Encounters early on with coarse gravel and cobbles that resulted in broken probes, led to a decision to push an uninstrumented "dummy" probe to a depth of 15 to 20 feet at many of the locations before advancing the instrumented probes. For this reason, stratigraphic information was not generated in the upper 15 to 20 feet of many probe holes. Moreover, this reduced the stratigraphic profiling productivity to an average of about 90 feet per day.

Several factors limited the use of the SCAPS in some parts of the site. The unit is designed for use on level to gently sloping terrain with clayey to sandy soils with small gravel sizes. The air-space above the truck must be free of obstructions such as power lines, and the large size of the truck requires ample open space to maneuver. The CPT probes will not penetrate boulders, cobbles, rubble, highly compacted soils, or sound bedrock.

Analog printouts of each log were produced within an hour of completion of the hole. Digital data (as text files) were not available until near the end of the field work because of formatting problems.

The CPT instrumentation was unique in its efficient production of reproducible stratigraphic information which was of high vertical resolution and accuracy, coupled with minimum ground disturbance. A clear disadvantage was its high susceptibility to unfavorable subsurface conditions (coarse gravels, buried debris, etc.) and to above ground features (tight work spaces, surface pavements, etc.).

4.3.2 Soil Conductivity Probe

Description

A percussion soil probe system designed for direct sensing of soil conductivity was developed recently by Geoprobe Systems, Inc., (Christy et al., 1994). The system was field tested at Marshalltown as a comparable technology to the stratigraphic logging capabilities of the CPT system.

The probe is approximately 1-1/8 inches in diameter and about 8 inches long with four electrically isolated contact rings. The inner rings are 1 inch apart while the outer rings are separated by a little over 2 inches. The probe is advanced into the ground using a hydraulically powered percussion probing machine. Percussion is applied to the top of the probe rods at a rate of about 30 Hz and may result in instantaneous forces greater than 12,000 pounds transmitted through the probe rods (Christy et al., 1994). A signal cable attached to the probe is run through the inside of the rods to a laptop computer-based data recording system. Depth measurements are obtained from a stringpot system configured to measure the distance from the driving mechanism to the ground surface. Data derived from this system are used to determine both the depth of the probe and the probing speed. Conductivity measurements are displayed with respect to depth in near-real-time on the computer screen. Data were recorded in spreadsheet format and downloaded at the end of each field day.

Soil bulk electrical conductivity (termed simply 'conductivity') varies with soil type, water content, pore fluid chemistry and type and level of contamination. High conductivities are associated with clayey soils, low conductivities with sandy and gravelly soils, and sand/silt/clay mixtures have conductivities that lie somewhere in between. Because the conductivity varies somewhat for a given soil type between sample locations, comparing the conductivity log with a soil boring log or CPT soil classification log is essential to properly interpret the conductivity log. The true value in this technique is being able to extend stratigraphic information laterally from a known vertical profile or to fill in areas between known vertical profiles. Changes in conductivity are caused by changes in soil type, water content, and soil or groundwater contamination. Accordingly, when used alone, the conductivity log leaves some doubt regarding an accurate soil classification. It is quite effective, however, at delineating changes in the subsurface properties.

Research by Geoprobe Systems, Inc., has shown the probe to produce reproducible logs and to provide a high degree of vertical resolution for the discrimination of soil/sediment units (Christy, et al., 1994). The probe electrodes can be operated in either a Schlumberger array (using all four electrodes) or dipole array (using only the upper pair of electrodes). The dipole array has the potential of providing a higher degree of vertical resolution due to the closer electrode spacing.

Results

A total of 27 conductivity profiles were collected. Their locations are shown on Figure 4.52. The conductivity versus depth logs may be found in Appendix C. Each push was terminated on a confident identification of having encountered the LCU (typically indicated by a rapid rise in soil conductivity) or, in locations where the LCU was absent, on probe refusal.

Soil Stratigraphic Logging Capabilities. As with the CPT technique, the first soil conductivity push was made adjacent to BVWST MW-3; this location is also called ML-28. The ML-28 locations were within 19 feet of MW-3; surface obstructions disallowed a closer approach. Figure 4.53 shows the three profiles arranged with correlating vertical scales: soil conductivity on the left, the BVWST borehole log in the middle, and the CPT stratigraphic log on the right. The conductivity log is plotted in reverse (i.e., increasing conductivity toward the left) so that an inflection to one direction or the other in conductivity is analogous to a similar inflection on the CPT stratigraphic log (e.g., an inflection to the left in either log would typically be indicative of a higher content of fine grained soils). With the exception of approximately the top six feet, where the conductivity data is erratic, the correlation with the borehole log for MW-3 is good. The top three to five feet of most conductivity logs demonstrated this same erratic conductivity behavior. Possible explanations for this behavior include nonuniform infiltration of highly saline solutions from winter road salting operations, poor ground-to-probe contact at shallow depths and/or the erratic nature of the surficial fill.

Although, the soil conductivity log does not give a soil type interpretation directly, the UCU/granular contact could be inferred by the distinct drop in soil conductivity between about 15 and 17 feet. It should be noted, however, that drops or dips in conductivity may also be associated with coal tar residue contamination (discussed in more detail in the following section) or gravelly layers.

Figure 4.53 shows that the depth to the gradational UCU-granular contact is within one foot on all three of the logs. In terms of identifying the granular unit/LCU contact, however, both the CPT and conductivity log indicate that the contact is about two to three feet higher in the stratigraphic profile than the BVWST log indicates. The granular unit/LCU contact is inferred by a distinct rise in the conductivity values. Both of these contacts could be easily identified in most of the soil conductivity logs. The largest variation among the logs is the significant amount of silt and clay between about 21 and 25 feet indicated by the CPT log. Neither the conductivity log nor the BVWST log gave an indication of this. The soil conductivity logs can give the same level of stratigraphic detail as the CPT logs when properly calibrated and verified.

Figure 4.54 shows another comparison of CPT and soil conductivity pushes close to a BVWST borehole. The CPT push at ML-60 and the soil conductivity push at ML-45 are within 13 feet of B-8. The three logs gave good stratigraphic correlation. The soil conductivity log gives the UCU/granular unit contact within one to two feet of the depth indicated on the BVWST log. Similarly, the granular unit/LCU contact is at a depth within one to two feet on all three logs. The CPT log tends to show it about two feet higher than the BVWST log.

Conductivity levels change somewhat from one location to the next; some trends are apparent, however. The clayey soils at the site tend to have conductivities in the range of 60 to 140 mS/m (resistivity from 7 to 17 ohm-m) and the sands about 30 to 40 mS/m (25 to 33 ohm-m), with gravels generally showing a conductivity dip of about 5 to 10 units below the level for a sandy soil. These values are similar to those reported in Christy et al., 1994 for an alluvial site in central Kansas containing interbedded sands, silts and clays. When the soil conductivity log ML-28 is compared with the borehole induction log for MW-3 (Figure 4.17), it may be noted that the borehole induction log is flatter both in terms of the ranges in magnitude of the values (i.e., the soil conductivity log shows higher clay conductivities and lower sand conductivities) and definition of stratigraphic contacts (i.e., the borehole induction log shows a much smoother or "rounder" transition from one unit to another). The soil conductivity probe is in direct contact with the soil and has a rather small measuring volume due to the relatively close spacing of the electrodes; the induction borehole logging, on the other hand, needs to extend farther out into the soil to avoid measuring simply the conductivity of the monitoring well materials. This may have resulted in a loss of resolution.

Contaminant Screening Capabilities. During the implementation of the Geoprobe soil conductivity probe system for the purpose of defining stratigraphic variations, a marked downward inflection or dip in conductivity was recorded in several logs at the bottom of the granular unit. This was underlain directly by the LCU, as interpreted from the logs. It was surmised that the dip in the conductivity log may be the result of the presence of free phase coal tar residue containing PAHs in that zone, rather than a natural condition arising out of stratigraphic changes. As noted previously, the bulk soil conductivity is significantly influenced by the pore fluid conductivity; soils contaminated with PAH will have a lower conductivity and will show a dip in their conductivity log. An example of this is illustrated in Figure 4.55. This is the same group of BVWST boring, soil conductivity and CPT logs presented in Figure 4.54, except that the CPT LIF log is given in this figure rather than the stratigraphic log. A subtle dip in the conductivity log from about 33 to 35 feet corresponds to a strong LIF hit from about 32 to 34 feet. Moreover, dips in the conductivity log at about 22 to 23 feet tend to correspond to an LIF hit at about 20 to 22 feet. Both the soil conductivity and LIF hits are confirmed by the visual descriptions in the BVWST log (see Figure 4.55). A comparison between a soil conductivity push (ML-54) and a nearby CPT push (ML-109) is shown in Figure 4.56. Conductivity dips corresponding to LIF hits may be noted from 5 to 7 feet, 20 to 21 feet and 34

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to 36 feet. Following these observations, an analysis was conducted to evaluate potential correlations of soil conductivity dips with the presence of coal tar residue.

By comparing the Geoprobe conductivity logs with the CPT logs (soil classification and LIF) and/or the physical soil sample descriptions from the daily logbook, we gained some understanding regarding the extent to which such dips in the conductivity correlate with PAH contamination and/or the presence of gravel (or rock fragments as they are often referred to in the field logbook) which will also cause a lower conductivity. The conductivity logs contain many such dips, some obvious, others more subtle, as well as portions of conductivity trace that are quite erratic showing irregular peaks and troughs. Most of these dips do not have either a CPT log or physical soil sample to compare with to assess the cause of the conductivity change; however, a few do and these are listed in Table 4.10. Table 4.10 shows the location identification where a particular conductivity sounding was performed, the depths at which dips in the trace occurred which can be correlated with the CPT or McLaren/Hart (MLH) data, the suspected cause of the conductivity dip based on the CPT or sample description logs, the source of information (CPT or MLH and location), and the approximate horizontal distance between the conductivity push and the information source. In some cases the information source and conductivity were taken at the same location and show identical (X,Y) coordinates, however, such cases were actually separated by one or two feet and are listed as being two feet apart in Table 4.10.

Based on the data presented in Table 4.10, we find that dips in the conductivity profile occur adjacent to uncontaminated gravelly soil about 25 percent of the time, and adjacent to contaminated soil free of gravel about 60 percent of the time. The remainder of the dips for which a correlation was possible occurred near gravelly soil which showed evidence of PAH contamination; this is not surprising since the PAH contaminants tend to migrate through the coarse grained soil matrix (as well as within tension cracks, root holes and fractures within clayey soils). It seems clear that, although the bulk of conductivity dips correspond to PAH contaminated soil, occasionally we see that dips in the conductivity trace are due to the presence of gravel (or cobbles) with little or no PAH contamination.

Productivity/Output

The conductivity logging system produced 1022 feet of log in 32 holes over a period of six working days. The system was operated by a two-person crew. Operation by a one-person crew is possible, although productivity would be significantly lower. The data required minimal post-processing (deletion of negative or repeat values). Digital conductivity and probing speed data and field printouts were provided at the end of each work day for integration into the existing site model.

Occasional problems encountered during the completion of this work included electrode failure, probe point mechanical failure, intermittent negative values in conductivity data and erratic or extremely high conductivity values in the upper few feet of most profiles. Another short-coming of the system was its inability to easily identify weathered carbonate bedrock, which was encountered in some locations where the LCU was absent. Weathered bedrock displayed erratic conductivity values which were not easily distinguished from inhomogeneity in the overlying units. The probing speed output might be useful in this regard. In any case, positive identification of the material could only be made subsequently with core samples.

The advantage of this system is its ability to provide a large number of profiles in a relatively short time. Moreover, if required, it can be operated by a single person. It is also rather versatile in that it can maneuver into small spaces and can penetrate most soil subsurface materials.

4.3.3 Interpretation from Minimally Intrusive Methods

In this section the data collected by the minimally intrusive methods are compared at a number of locations where CPT, soil conductivity and soil sampling pushes and BVWST boreholes were advanced within several feet of one another; these data collections are referred to as "data clusters." The data are compared both in terms of stratigraphy and level of contamination. In addition, the minimally intrusive data are compiled and analyzed on a site wide basis and assessed in terms of their contribution to the development and refinement of the site geologic and contamination models. Specific comparisons are made with both geophysical survey and BVWST data. Data resolution, sensitivity and reliability issues are addressed. Moreover, the evolution of the site geologic model, on a day-by-day basis, according to the ESC approach, is presented. The usefulness of 3-D visualization and geostatistical techniques, such as kriging, is also assessed.

Stratigraphic Interpretation

Twelve clusters of CPT stratigraphic, MLH soil core sample, Geoprobe soil conductivity and BVWST borehole logs were identified; the locations of these data clusters are shown in Figure 4.57. The selected clusters and stratigraphic details are listed in Table 4.11.

The SCAPS CPT panel plots give a soil classification according to clay, silt mixtures, sand mixtures, sands, and sands and gravels. The BVWST boreholes provide a stratigraphic log. The MLH soil classification is a visual description recorded in the daily logbook as each soil sample was collected. The Geoprobe soil conductivity log (Geoprobe in the table) provides a more subjective soil classification interpretation; when calibrated against known soil types, however, the main soil unit contacts and stratigraphy become relatively easy to interpret from the logs. As shown in Table 4.11, the soil classification schemes agree quite well, with only a few exceptions,

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and these can generally be explained by local soil heterogeneities which may exist both vertically and horizontally over a distance of several feet at this site.

Depths to contacts between the upper cohesive unit and the granular unit, the granular unit and the LCU and the overlying soil (either LCU or granular unit) and bedrock were interpreted from the CPT stratigraphic and soil conductivity logs and input into a database for EarthVision. This database is included as Table 4.12. The stratigraphic correlations between the push technologies and the BVWST borehole log data in the two previous sections demonstrated that the contacts between soil units can generally be interpreted from the CPT and soil conductivity logs with confidence; interpretation of the bedrock surface from the CPT and soil conductivity logs is somewhat more subjective. In most cases the advance of the CPT or soil conductivity probe was terminated after having penetrated a few feet of the LCU; the surface of the bedrock in the three-dimensional EarthVision model may be considered only approximate, therefore. In the eastern part of the site, however, both the CPT and the soil conductivity probes are believed to have come to refusal in bedrock at a number of MLs (e.g., broken resistivity and LIF CPT probes at ML-33 at depths of 16 feet and 26.5 feet, respectively). Moreover, a continuously sampled Geoprobe push was carried out directly adjacent to the soil conductivity push at ML-34 (see Figure 4.52) to provide quantitative stratigraphic data to calibrate the soil conductivity sensor in the eastern portion of the site where the bedrock is relatively shallow. The surface of the weathered bedrock is not readily apparent even in this calibrated soil conductivity push, however. Defining the surface of the weathered bedrock with the push technologies, therefore, may be considered quite uncertain.

Two stratigraphic cross sections were prepared using the push technology stratigraphic data alone. The locations of the cross sections are shown on Figure 4.58. Section AA' (Figure 4.59) was prepared using soil conductivity data as the primary stratigraphic information; the soil conductivity logs are shown superimposed on the figure. As noted previously, the contacts between the soil stratigraphic units are generally well defined, as illustrated on the western side of the cross section between ML-45 and ML-59. Stratigraphic contacts from BVWST borehole and CPT push logs close to the cross section were added at the appropriate locations along the cross section; it may be noted that the UCU/granular unit contact given by the three technologies' logs corresponds to within about two feet while the granular unit/LCU contact corresponds to within about one foot. This may be considered excellent stratigraphic correspondence between the technologies. The surface of the bedrock rises sharply in the region of ML-37 to ML-36; sections of weathered bedrock several feet thick overlying unweathered bedrock have been interpreted from the soil conductivity logs in the eastern part of the section. It may be noted that the contacts between stratigraphic units are not nearly so clear in the eastern part of the cross section as in the western part.

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The second cross section BB' runs from the northwestern part of the site to the extreme eastern part of the site (see Figure 4.58). This section, shown in Figure 4.60, was drawn using both soil conductivity and CPT stratigraphic data. This cross section illustrates that significantly more stratigraphic detail may be interpreted from the push technology logs than from borehole logs. This cross section also shows the same general pattern of a relatively sharply rising bedrock surface in the eastern part of the site. Comparisons with BVWST boreholes B-4 and B-6 are good (see Figure 4.60). BVWST borehole B-5 shows the LCU surface about three feet lower than in the cross section. This could be indicative of a localized low spot in the LCU surface; note that the LCU surface drawn from the push technology data also dips down, but not as strongly, in the same general area. This could also be a result of differing interpretations of the depth to the frequently gradational lower contact.

A three-dimensional stratigraphic model of the subsurface was created using EarthVision based on the interpreted stratigraphic contacts from the push technologies as noted above and listed in Table 4.12. Several sections or vertical "cuts" were made through the model to allow comparison with the BVWST borehole data. An east-west cut was made through the model at 500N (see Figure 4.61). Logs from nearby BVWST boreholes were overlaid on the cross section at the appropriate locations. Correlation is generally quite good, except in the region of B-7 where the depth to the LCU is about 12 feet deeper. This cross section has the same general stratigraphic patterns as section BB' (see Figure 4.60), including the dip in the LCU in the vicinity of 600E. A major difference is, however, the rise in the LCU surface near 800E.

Further comparisons between BVWST data and the three-dimensional model were made using several north-south cuts through the three-dimensional model. The north-south cut at 850E is shown as Figure 4.62. The base of the granular unit is indicated to be one foot higher at the location of BVWST borehole B-16 which is superimposed on the cut. Note that the LCU was not detected at B-16. A second north-south cut at 825E is included as Figure 4.63. The log for MW-3 is superimposed on the cut. Agreement of the model soil stratigraphic contacts with those shown on MW-3 is within about one foot. A third north-south cut at 750E is included as Figure 4.64. The BVWST logs for boreholes B-3, B-7 and B-14 are included for comparison. The surface of the LCU is within about one foot of the modeled surface at BVWST boreholes B-3 and B-14. The surface of the LCU is indicated as being three feet deeper than the model at the location of borehole B-7. Correlation between the UCU/granular unit contact is within one foot at the locations of boreholes B-7 and B-3. Borehole B-14 shows this contact about six feet deeper than the model. These cross sections indicate generally good correspondence with the BVWST logs.

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Key aspects of the ESC process are:

- data integration
- evaluation
- updating of the site geologic and contamination conceptual models on a daily basis, and
- flexible decision making in the field.

To demonstrate this aspect of the process, the evolution of an important geologic site characteristic, the surface elevation of the LCU (or base of the granular unit where the LCU is absent), was examined as the Phase II investigation progressed. The LCU surface elevation plan was generated using soil conductivity, soil sampling and CPT stratigraphic data. The surface elevation plans for Day 1, Day 2, Day 4 and Day 10 are shown as Figures 4.65 to 4.68, respectively. It may be noted that the most significant changes in the LCU elevation plan occurred in the first 4 days; the Day 4 and Day 10 plans are not significantly different. Figure 4.68 illustrates that the LCU generally dips towards the southwest; a relatively steep ridge with a rise of about 10 feet trends from the northwest to the southeast across the site.

As noted above, EarthVision uses a spline function to develop the contours and no estimate of uncertainty is made. Stenback (1995) has used a geostatistical approach to characterize the elevation of the LCU surface and to estimate the degree of uncertainty in the contours themselves. This approach uses a median polish algorithm (see Cressie, 1991) to account for trend in the surface elevations. The residuals from the median polish were analyzed using a geostatistical approach whereby a variogram was generated and kriging equations were used to model the correlation structure in the residuals. A measurement error variance of 0.25 feet² was included in the calculations. The values generated by the kriging algorithm were added to the median polish surface. These values were in turn input into the contouring program Surfer; the contour plot shown in Figure 4.69 was generated. Note that this surface is in general similar to that shown in Figure 4.68. A contour plot of the prediction standard deviation corresponding to the surface elevation contours shown in Figure 4.69 is shown as Figure 4.70. Note that the standard deviations are lowest in the areas where there is the most data. A further evaluation of the veracity of the kriged surface was carried out by comparing the LCU surface elevation given by kriging to that given by the BVWST boreholes at the BVWST borehole locations. The results are summarized in Table 4.13. It may be noted that the BVWST data suggest a lower LCU surface for 12 of the 17 comparisons. In addition, the most significant deviations are at BVWST boreholes B-2, B-7 and B-13. These differences are also apparent by direct comparison of the nearest direct push log to the BVWST borehole location. The differences are probably due to some local variation and heterogeneity in the stratigraphy as well as some interpretation error. This is not surprising given the gradational contacts in some locations.

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the conductivity trace was generally irregular and a clear signal was not apparent; a "no PAH signal" entry indicates that the conductivity trace was relatively level with no apparent dips which would indicate PAH contamination. The MLH sample logs generally indicate whether any product was noticed visually, such as sheen, or free phase product, together with an olfactory determination, such as no odor, mild odor, or strong odor. The CPT data is reported as an average LIF intensity over the region of comparison. Finally, the BVWST logs generally give a visual indication of contamination, such as free product, tarry substance or oil sheen.

The data in Table 4.14 indicate generally good agreement between the olfactory, visual and CPT classifications. Discrepancies can generally be accounted for by comparisons within several feet vertically. For example, in Cluster 5 both McLaren/Hart and BVWST show free product from depths of 30 to 32 feet, but the CPT LIF intensity is only about 50 counts indicating relatively low PAH levels within this depth range. However, the CPT LIF intensity is about 300 counts or more over the depth range from 32 to 34 feet, indicating high PAH levels over that interval. This example provides further evidence of local heterogeneities in the soil stratigraphy.

The Geoprobe conductivity often shows good agreement with the other methods, but occasionally shows ambiguous results. The ambiguity arises for several reasons. First, because factors other than PAH contamination, such as soil type or pore fluid chemistry, can contribute to a low conductivity reading. Second, the conductivity trace is often quite irregular due to thinly interbedded seams of silts, sands, clays and gravels; accordingly, abrupt swings in the conductivity trace make interpreting the dips very difficult. An example of a strong correlation between soil conductivity (ML-54), CPT LIF (ML-109) and soil sample descriptions (ML-118) is data cluster 4. Recall that excellent contamination correlation was observed between ML-54 and ML-109 in Figure 4.56. The MLH soil sample descriptions support the soil conductivity and CPT LIF interpretations.

Because the CPT soil classification is based on a cone tip and friction sleeve resistance, which depends on the shear strength of the soil, among other things, one might expect that the soil classification could be affected by the PAH contamination. However, examination of data showing levels of PAH contamination based on LIF measurements, no evidence is seen to suggest that the CPT soil classification is affected by the presence of PAH contamination. In particular, compare clusters 4, 5, 6 and 7 in Tables 4.11 and 4.14. In addition, examination of Table 4.14 shows no evidence that any significant PAH contamination is drawn down with the CPT probe thereby producing falsely elevated LIF response in a relatively clean soil underlying a contaminated region.

As discussed and illustrated in Chapter 2 for the BVWST RI data, important information resides in the visual and odor comments in the MLH logs. The same logarithmic type scale used in Chapter 2 is used again here. Given that free product corresponds to a concentration of about 10^6

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mg/kg and slight but definite odor corresponds to a concentration of about 1 mg/kg, the following range is again appropriate:

<u>Observations</u>	<u>Scale</u>	<u>Observations</u>	<u>Scale</u>
free product	6	mild odor	2
product sheen	5	slight odor	1
discoloration	4	no odor	0
strong odor	3		

Table 4.15 contains visual/odor information interpreted from the MLH sample logs using the above scale. Contour plots of this MLH data for the six stratigraphic zones are shown in Figures 4.76 to 4.81. In general, these results compare closely with what was interpreted from the CPT LIF pushes (see Figures 4.46 to 4.51). The most significantly contaminated regions are to the north and east of the storage shed and to the south and east of the substation. The eastern limits of the most significantly contaminated areas identified by the MLH visual/odor data closely correspond to those indicated by the CPT LIF contour plots. When comparing the CPT LIF and visual/odor plots, it should be noted that different map (data) locations are being used to generate the plots and thus the shapes of the plumes will be somewhat different. The density of MLH sampling locations is heavily biased to the eastern part of the site; the rationale and background for this bias is discussed in more detail in the next section. Examination of the visual/odor contours for zone 5 (Figure 4.80) indicates that the most significantly contaminated regions are confined to the depressed area (i.e., below the NW-SE trending ridge) of the surface of the LCU; this trend corresponds to that observed in the CPT LIF zone 5 contour plot (see Figure 4.50). Visual levels of contamination identified in the soil samples at ML-94, ML-96 and ML-57 confirm the significant contamination detected by the LIF sensor in the northwestern part of the site near the substation. Moreover, major hits at ML-86 and ML-88 indicate that the contamination extends to the extreme northwest corner of the site. Therefore, as was first indicated by the Phase I screening data, and confirmed by the CPT LIF data, these data again confirm regions of significant contamination in the northwestern part of the site.

Figure 4.82 shows the same cross section produced in Figure 4.59 (AA' in Figure 4.58) with zones of heavy coal tar residue contamination added as indicated from the BVWST logs and interpreted from the soil conductivity and CPT LIF logs. Only regions with LIF intensity greater than about 200 counts were included. The most heavily contaminated regions are at the base of the fill, within the UCU, at the top of the granular unit and at the base of the granular unit. Continuity of contamination from one location to another is evident. The apparent levels of contamination drop off sharply between ML-59 and ML-37; this is the same region where the bedrock and LCU rise sharply.

In terms of contaminant screening, the CPT LIF is the most direct qualitative methodology for indicating regions of PAH contamination. The LIF responses have been corroborated by side-by-side sampling with chemical analyses, by correspondence with nearby BVWST logs and indirectly by the soil conductivity logs. The CPT LIF contaminant screening program has indicated the extent of the heavily contaminated zone in the northwestern part of the site near the substation and also highlighted the extent of coal tar residue contamination which is sitting on the LCU. An attempt to capture a three-dimensional view of the LIF signal intensity is given in Figure 4.83. These are visualizations based on the continuous nature of the LIF data with depth and the extensive probings near the edges of the PAH plume. Figure 4.84 is a three-dimensional EarthVision plot showing areas of significant contamination (LIF intensity >100) sitting on top of the LCU shown as a continuous pink layer. It may be noted that the region of coal tar residue contamination resting on the LCU generally follows the surface topography of this unit. There is a good chance, therefore, that the DNAPL is moving off the site to the south, flowing down the gradient of the LCU.

4.4 Quantitative Chemical Analysis of Soil Samples

4.4.1 Introduction

As noted in the introduction to Section 4.3, soil samples for quantitative chemical analysis were collected by McLaren/Hart Environmental Engineering Corporation of Warren, NJ using a two-person crew operating a Geoprobe Model 8-MU sampling system. Cores two feet long and one inch in diameter were collected from the six subsurface zones at specified depths. In general, soil samples were only taken at locations and depths where information content was expected to be maximum based on all prior evidence, including BVWST information, Geoprobe conductivity logging, CPT LIF and CPT soil stratigraphic data. Occasionally a two-foot section was requested from a depth with the expectation that two contiguous zones would contribute equally to the two-foot core. In these cases the prior stratigraphic evidence was of such quality that nearly all of these types of cores met our stringent expectations and two distinct samples could be generated from one core. A detailed descriptive log of the 123 core samples collected from 29 MLs (see Figure 4.85 for locations) was kept and data on recovery, date, time, sample number, depth, soil description, water content and visual/odor evidence of contamination were recorded. A total of 127 soil samples were selected from the core samples and analyzed on site for the 16 target PAH compounds. Twenty-one additional samples were so contaminated that they were simply archived and qualitative GC/MS fingerprinting of the free product phase was done using the sonication extraction method.

A major effort at Marshalltown was the fielding of five separate on-site GC/MS-based extraction schemes for semi-volatile PAHs in soils. The extraction methods used were sonication,

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supercritical fluid extraction (SFE), thermal desorption, microscale and microwave extraction. These five extraction schemes were coupled to three GC/MS instruments. Three subcontractors were involved in this unusual activity; successful implementation of this activity required their complete cooperation in the field. McLaren/Hart provided all three GC/MSs in two mobile laboratories and three of the extraction modules and their associated expert operators. Their sonic solvent system consisted of a Tekmar Sonic Disrupter coupled to an HP Series II 5890 GC with an HP 5970B MS detector, while their SFE system included an HP Model 7680T SFE Module coupled to an HP Series II GC with an HP 5972 MS detector. Their thermal extraction unit consisted of a Thermex extractor from Ruska Instruments with the same GC/MS unit as was used for the SFE. They provided space in their mobile laboratories to accommodate the microscale extraction module and a qualified chemist who was fielded by PACE of Minneapolis, MN. A CEM Corporation Model 1000 Microwave Extractor was used by the same PACE chemist inside the McLaren/Hart mobile laboratory. Very little additional training was required to operate the CEM unit and it was provided by CEM at the site. Eighteen samples were also sent off site and analyzed by MBT Environmental Laboratories, a division of McLaren/Hart, using Method 8270B for SVOCs. Only the 16 targeted PAHs were measured by MBT. Autosamplers were used to permit overnight analysis. The sonication and microscale extraction analyses were done on one GC/MS instrument, the supercritical fluid and microwave extraction analyses were done on a second GC/MS instrument, and the thermal extraction was done on a third GC/MS instrument.

A critical issue in the evaluation of the extraction methods was how the samples were to be homogenized before being split and sent to the six extraction methods (five on site and one off site). Unless the split samples could be considered homogeneous, any deviation of the reported PAH concentration could not be assigned confidently to the extraction method rather than the sample concentration variance. A minimum of six inches of core length was required to satisfy the soil quantity requirements for all six methods. In consultation with local and national experts, the homogenization process decided on was to select the core to be homogenized, remove it, cut it into small chunks with a knife and mix it thoroughly using a gloved hand. The chopping and kneading process was repeated until the resulting specimen was visually and tactually uniform. The cycle was then repeated once more. The sample was then separated into seven pieces and distributed to the various measurement systems, with one sample held in reserve.

In terms of the site characterization goal of this project, samples were selected starting from outside the expected plume area followed by moving toward the suspected plume with the intent of using the low quantitation limits of the GC/MSs to map the action level limits of the plume. This plan conflicted with the technology evaluation goal of the project because it led to a large number of ND samples that could not be used for the technology comparison task. Nevertheless, this site sampling plan was followed for the first several days of soil sampling. In addition,

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estimates of the sample analysis throughput were lower than expected and if this approach were continued very few contaminated samples would be available for a systematic comparison of the five extraction methods. As a result, after the first few days the sampling and analysis plan was modified so that only samples judged to be contaminated were automatically sent to all five extraction modules. Other samples were first analyzed using the sonication method. These samples were then sent to the other extraction systems only if the sonication results confirmed that PAH contamination was present. Even with this revised system implemented, however, a significant number of the samples analyzed returned ND results.

A fortunate circumstance was realized after a few days that made the criteria for selecting the contaminated samples for further analysis relatively easy. It was noticed that soil samples that were characterized as having a slight but definite odor turned out to have PAH concentrations in the 1 to 10 mg/kg range. This allowed better estimates as to which samples to send for analysis without incurring any idle GC/MS instruments.

Table 4.16 lists the attributes of the samples that were analyzed by one or more of the five on-site extraction methods, including sample number, map location (ML), depth, soil type, stratigraphic zone from which the sample was taken, recovery, extraction methods used and an indication of whether the sample contains PAHs above the detection limits. The analytical results of each sample for the 16 PAHs, organized by on-site extraction type, are given in Appendix D. A uniform method detection limit of 1 mg/kg was applied by McLaren/Hart for each extraction method and for each analyte for the data reported in Appendix D. Some of the samples were diluted five, ten, or even 100 fold prior to testing; if such a diluted sample returned a non-detect result (ND, below the method detection limit), then it was recorded as <5, <10, or <100 mg/kg, respectively (depending on the level of dilution) on the original MLH data summary (McLaren/Hart, 1994). Due to the inherent significant uncertainty, these results were not used in any of the analyses reported here and were excluded from the data set. Moreover, the undiluted sample non detect values (<1 mg/kg) were assigned values of 0.5 mg/kg for analysis purposes. This assumption is relatively conservative (as opposed to assigning them a value of zero) and minimizes potential error. Data reported as being outside the linear working range of the GC/MS instrument were simply used as reported.

The analytical results reported in Appendix D will be used both for comparing and evaluating the on-site extraction methods in Section 4.4.2 and for characterizing the PAH plume in Section 4.4.3.

4.4.2 Comparison of Extraction Methods

Extraction Method Data

Because a substantial portion of the results of the 127 soil samples tested on site by McLaren/Hart were below the method detection limit, 15 samples taken from 10 MLs with a relatively high proportion of results above the detection limit were chosen for comparison purposes and extraction method analysis. Moreover, most of these samples contain data from three or more of the five extraction methods that we wish to compare. The sample (map) locations, MLH sample identification, site coordinates, sample depth, and logged soil type from which the data were taken are listed in Table 4.17. For the data in this analysis, some samples were not tested by all extraction methods resulting in a 12.4 percent loss of potential data; of the remaining data, 33.4 percent are recorded as below the method detection limit. Out of 240 possible data subgroups (15 samples times 16 analytes), only 38 subgroups contain a measured value above the method detection for all five extraction methods. Because of this difficulty, all ND data were excluded from our analyses, unless stated otherwise.

Data Analysis

A series of percent recovery tests were carried out at the onset of the field program to examine the relative extraction efficiency of the different extraction methods. The percent recovery data were generated, in most cases, by testing five or six soil samples in duplicate, spiked with 50 mg/kg of each of the PAH compounds, for each method. One exception to this is the microwave percent recovery, which is based on only two samples run in duplicate. The data from the percent recovery tests are summarized in Table 4.18.

A preliminary analysis of the extraction method comparison data was carried out by Stenback and Kjartanson, 1994 (samples MT-2-G017.2 and MT-2-G111.1 were not included in this analysis). This preliminary analysis indicated that the microscale and microwave extraction techniques were the most efficient techniques while the off site and the thermal techniques were generally the least efficient. The differences in concentration given the techniques for the same sample were significant, up to an order of magnitude or more. Possible explanations for this behavior were explored. During the microscale and microwave extraction procedures the extract was exposed to the atmosphere for a short time, potentially allowing some evaporation of extract solvent. This was not accounted for in subsequent calculations and could be responsible for the positive bias observed in the associated PAH concentration measurements. The off-site, fixed base laboratory method called for concentration of the soil sample extract to a greater extent, in accordance with the EPA 3550 method, than was done with the on-site extractions. Because the PAH analytes tested are semivolatile, it is possible that some analyte could be lost along with solvent during the concentration step thereby resulting in a bias downward. The off-site samples

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were capped and cooled during shipping to avoid losses due to evaporation during sample shipping and handling. Shipping and handling losses are known to be potentially significant with VOCs, but were not thought to be significant with SVOCs. The significant differences and deviations observed in the preliminary analysis triggered a more in depth analysis of the results; this more in depth analysis is reported in Stenback and Kjartanson, 1995.

A major difference in this analysis from the preliminary analysis is that each datum was divided by the average percent recovery values from Table 4.18, expressed as a decimal, for that method and analyte. Because no percent recovery data for the thermal extraction procedure are available, no adjustment for this method was made in the following data analysis. {As an aside, the percent recovery data for the remaining four extraction methods are in agreement directionally with the biases noted in the Stenback and Kjartanson, 1994 report.} The off-site analysis results were also excluded from this analysis. Additionally, nonparametric statistical significance tests were performed because some of the data being compared do not appear to come from normally distributed populations. Other minor differences are discussed as they arise below. There is no accepted method, or known true values, against which to compare these data; accordingly, method comparisons here are made relative to the other methods in this study.

Method Bias and Precision. To detect method bias, examine method precision, compare sandy versus clayey soil sample results and look for differences between methods as a function of analyte, the data were grouped by soil sample and analyte (15 soil samples by 16 analytes = 240 categories). Depending on which extraction methods were used to obtain a result for that particular sample and analyte category, up to five measurements may exist within each category. The arithmetic average within each category was determined, i.e., averaging over extraction methods, and each individual value was then normalized by dividing it by its category mean. A derivation of some properties of this normalized variable, and reasons for its use, was given in Stenback and Kjartanson, 1994 and is not elaborated on here. The means, standard deviations and number of observations (soil samples) for the normalized analyte/method subgroups are listed in Table 4.19. These give some idea of method bias and relative precision for each analyte and method.

Due to the data normalization, bias is measured relative to one (1.0), i.e., means significantly less than one suggest a bias downward while means significantly greater than one suggest a bias upward. Method precision is measured by the standard deviations under the assumption that the method standard deviation is proportional to the mean analyte concentration. In other words, the standard deviations give an estimate of the proportionality constant, K, between the method standard deviation (σ) and the mean analyte concentration (μ), that is, $\sigma = K\mu$.

Means of the normalized data by extraction method, i.e., averages taken over samples and analytes, were compared to detect relative biases between methods using the nonparametric

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Kruskal-Wallis procedure using a 0.01 level of statistical significance. The results of the bias comparisons are displayed below.

Kruskal-Wallis Analysis

<u>Method</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>n</u>	<u>Mean Comparisons</u>		
Thermal	0.71	0.55	112	*		
Sonication	0.84	0.36	128		*	
SFE	1.01	0.38	166			*
Microscale	1.13	0.46	178			*
Microwave	1.28	0.43	100			*

Comparisons with no overlapping asterisk are significantly different at the 0.01 level, based on the Kruskal-Wallis test at an overall significance level of 0.01. n is the number of observations above ND.

On the basis of the results presented in the table above, several of the extraction methods appear to provide significantly different results. The thermal and sonication methods show a bias downward. The microwave method shows a bias upward. The microscale and SFE methods show no bias relative to each other. With the exception of the SFE and microscale methods which do not show a statistically significant difference, this indicates that the extraction efficiency increases in the order in which the extraction method means increase, as listed in the Kruskal-Wallis analysis table above.

Soil samples were treated as replicates and differences between method precision were evaluated using a nonparametric procedure. The variances, σ^2 , provide an estimate of the proportionality constant, K, between the method standard deviation, σ , and the mean analyte concentration (μ), that is, $\sigma = K\mu$. Two variance estimates are given here. The first comes from a combination of all the data for a given method and calculation of the variance by standard formulae. This may be biased upward due to differences between analyte means because the variance estimated this way includes variation between samples and variation, if any exists, due to differences between analyte means. The second calculation gives a pooled estimate of the variance by calculating a variance for each analyte (for each method) and pooling these together using their degrees of freedom according to standard variance pooling formulae. This method accounts for differences between analyte means, if any exists. Comparison of the two estimated variances (or standard deviations) will indicate whether differences between analyte means are significant or not. The table below shows the results of the two estimates of the standard deviation. A nonparametric test for variance differences between extraction methods (Conover, 1980, page 241) using an overall significance level of 0.01 was performed. The comparison results are displayed in the table on the next page.

Nonparametric Variance Analysis

Method	σ	df	Pooled σ	df	Comparison	
Sonication	0.36	127	0.37	113	*	
SFE	0.38	165	0.39	150	*	*
Microwave	0.43	99	0.44	85	*	*
Microscale	0.46	177	0.46	163		*
Thermal	0.55	111	0.52	96		*

Comparisons with no overlapping asterisk are significantly different at the 0.01 level of significance.
 σ = standard deviation, df = degrees of freedom.

Comparison of the two standard deviation estimates displayed in the table above show that there is not an appreciable difference between the two. The implication of this is that the majority of observed variation exists between samples, and only a relatively small amount of variation exists between analytes. One exception to this is seen in the thermal extraction data for the analyte benzo(a)pyrene which is discussed further in the Clayey Versus Sandy Soil Samples section below. Additionally, the Extraction Method Bias by Analyte section below does indicate some effect on some measured analyte levels with respect to the molecular weight of the analyte.

On the basis of the comparisons in the table above, the sonication method shows significantly less variation, or greater precision, than the microscale and thermal extraction methods. The microscale, microwave, thermal and SFE methods do not show any clear significant differences in method precision from one another. Due to the nature of our data transformation (division of each data value by its analyte/sample subgroup mean), the presence of a negative bias in the method mean will tend to result in an underestimation of the method standard deviation while a positive bias will tend to result in an overestimation of the method standard deviation. Accordingly, the low standard deviation for the sonication method may be due to the fact that the sonication mean also appears to be biased downward. However, this does not explain the large standard deviation observed with the thermal extraction data, hence, it seems clear that the thermal extraction data are quite variable, i.e., this analysis suggests that the thermal extraction method has poor analytical precision (the method detection limit data discussed below are in agreement with this conclusion).

Clayey Versus Sandy Soil Samples. To detect differences in method extraction between sandy versus clayey soil samples, data as described above and used to generate the Kruskal-Wallis and nonparametric variance analysis tables above were split into clayey and sandy groups. The nonparametric Mann-Whitney test was used to test for differences between clayey versus sandy sample means by extraction method. A squared ranks test described by Conover (1980, page

239) was used to compare method precisions. The results of these comparisons are displayed in Table 4.20.

The results shown in Table 4.20 indicate that the extraction efficiency for clayey samples is significantly less (lower mean) than for the sandy samples for supercritical fluid extraction. Otherwise, the other extraction methods show no significant differences (mean test p-values >0.01) in extraction efficiency between sandy and clayey soil samples. All extraction methods except the thermal extraction method indicate that the variation with clayey samples is significantly greater (less precision) than the variation with sandy samples at the 0.01 level of statistical significance.

It is worth noting that an analysis of the sandy versus clayey sample subgroups, as listed in Table 4.20, using pooled estimates of the standard deviations and classical Student's t-tests yields the same conclusions as the nonparametric mean tests listed in Table 4.20. Comparison of the variances using pooled standard deviations and classical F-tests give the same conclusions as reached in Table 4.20 with the one exception that the variance for sandy samples is significantly less than the variance for clayey samples for the thermal extraction method. This occurs because the pooled standard deviation estimates are nearly identical to those given in Table 4.20 with the one exception that the standard deviation estimate for the sandy soils with the thermal extraction data is s (pooled) = 0.30 (rather than $s = 0.42$, as in Table 4.20). This is due to significant differences between analytes for the thermal method, in particular, the extremely low results for benzo(a)pyrene. This results in a statistically significant difference between sandy and clayey samples with p-value < 0.001 using an F-test.

Extraction Method Bias by Analyte The means, sample sizes, and molecular weights for the extraction methods are listed in Table 4.19 and these means are plotted by analyte in Figure 4.86. Figures 4.87 and 4.88 show the means for clayey and sandy samples plotted by analyte, respectively. The analytes are listed in order of increasing molecular weight (MW), with the slight exception of the last two, dibenzo(a,h)anthracene (MW=278) and benzo(g,h,i)perylene (MW=276), in Figures 4.86, 4.87 and 4.88. Bars indicating a significant difference (two-sigma, or 95% confidence level) between two means are shown on each figure. These figures indicate the trends in the extraction methods noted previously; i.e., thermal extraction generally least efficient and microwave and microscale generally the most efficient. The figures also indicate a general decrease in absolute bias with increasing analyte MW for microscale, microwave and thermal extraction.

Method Detection Limit Data A soil sample selected from the site was spiked at 10 mg/kg with each contaminant, homogenized and split into 35 subsamples (five methods times seven individual analytical tests) for a method detection limit (MDL) study that took place during the first few days that the McLaren/Hart mobile laboratory was on site. Analyses for each of the 16

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analytes of interest were run seven times (six for SFE) using each of the five extraction methods. The standard deviations of these analyses were used to obtain a method detection limit that is equal to a Student's t quantile for 99% confidence (upper-tail) times the standard deviation for each method and analyte. The averages and standard deviations for the MDL data are summarized in Table 4.21.

Using the spiked value of 10 mg/kg as a basis for comparisons, the column averages and their standard errors (Std. Error of the Ave.) listed in the last two rows of Table 4.21 indicate that the sonication method shows a slight overall negative bias, microscale shows an overall positive bias and SFE shows no significant overall bias. These results are consistent with previous analyses. The microwave method shows an overall negative bias and the thermal method shows a large overall positive bias by a factor of about two. These results are inconsistent with previous analyses, as indicated in the Kruskal-Wallis analysis. It is not clear why the thermal method results are so high and variable and why the microwave method results are so low; however, these data were collected early in the program before laboratory procedures were well established.

The method detection limits for each analyte and method are listed in Table 4.22. With the exception of the microwave method MDL data, these data suggest that the detection limit of 1.0 mg/kg that was used in reporting analytical results was too low. All methods other than microwave show MDLs consistently greater than 1.0 mg/kg. The thermal extraction method MDL values range from 8.2 to 58.4 mg/kg over all analytes. The SFE extraction method MDL values range from 6.4 to 10.8 mg/kg over all analytes.

For comparison, the overall relative errors based on the MDL study (Table 4.21) and from data presented previously are listed in Table 4.23. The relative error is the standard deviation divided by the mean, and is expressed here as a percentage. For the clayey, sandy, and combined relative errors, the means listed in Table 4.20 were used along with pooled estimates of the standard deviations. The pooled standard deviation estimates are essentially identical (within about 10 percent) to the standard deviations listed in Table 4.20, with the exception of the sandy/thermal extraction data (as mentioned above) which shows nearly a 30 percent decrease with pooling.

Examination of Table 4.23 indicates that, with the exception of the sandy soil SFE data, the relative errors for the field measurements are considerably greater than indicated by the data collected for the MDL study. This is not too surprising for several reasons. It is not unreasonable to expect field data to be somewhat more variable than data collected under controlled laboratory conditions. Due to the ND data and the fact that not all extraction methods were used with each sample, under-representation of data within some analyte/sample subgroups may have introduced some bias and increased variance in our analysis of this data.

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The relative error calculations shown in Table 4.23 clearly indicate that the microscale and microwave methods have low relative error, sonication has intermediate relative error, and the thermal and SFE methods have high relative error, based on the MDL study data. For all five extraction methods, the relative error with clayey soils is greater than the relative error with sandy soils. For the field clayey and sandy samples combined, the microwave extraction shows the lowest relative error and the thermal method shows the greatest relative error, in agreement with the MDL study data. The combined sample field data indicate that the sonication, microscale, and SFE methods show only slightly greater relative error than the microwave method, and are not significantly different from one another.

Summary of Extraction Method Analysis

Method bias and precision conclusions are summarized in Table 4.24 and are discussed below. The method bias comparisons clearly indicate that the thermal extraction efficiency is less than (lower mean, negative bias) the sonication extraction efficiency which is less than the microwave extraction efficiency (higher mean, positive bias). The microscale and SFE extraction methods generally give intermediate results.

There is no definitive indication that any extraction method is more precise overall (see Table 4.24). On the basis of all the available data, the method precision for the thermal and microscale extraction methods is significantly less than the precision for the sonication method. As indicated in Table 4.24, a second parallel statistical analysis was carried out using 38 cases from the data set which gave analytical determinations for all five extraction methods above the method detection limit; this would eliminate this potential source of bias. These results indicate that there are no significant differences in precision between any of the extraction methods (see Table 4.24).

On the basis of all the available data, the clayey soil analytical results show greater variation than the sandy soil results indicating greater precision with sandy samples for all but the thermal extraction method. The 38 subsets of this data whereby all methods gave a greater than ND determination indicate that only the microwave and SFE methods show greater variation with clayey than with sandy soils, while the other methods show no variation differences between soil types.

The means for the microwave extraction data tend to decrease with analyte molecular weight (see Table 4.24). The means for the thermal extraction data tend to increase with analyte molecular weight. This indicates that the absolute value of the microwave and thermal method biases decrease for the higher molecular weight analytes. The SFE means tend to decrease with

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increasing analyte molecular weight with the sandy soil samples, but this effect was not observed with the clayey samples.

The MDL study performed on site indicates that the MDL is greater than 1.0 mg/kg for all extraction methods except the microscale method. The relative errors based on the field data generally indicate poorer analytical precision than is indicated by the MDL data. The MDL study data sets are small and were collected over a relatively short time frame during which the on-site procedures were being established. The MDL data indicate that the microwave method shows a negative bias while the thermal method shows a large positive bias; these results conflict with biases indicated by the field data for both the thermal and microwave methods.

Because of the large portion of potential data for which no analysis was performed and because of the high proportion of ND data, the data in this analysis do not always have equal representation between soil types, analytes, or extraction methods, i.e., the data are unbalanced. Accordingly, we have attempted to draw conclusions with some scrutiny and caution. Nevertheless, the above mentioned differences between these extraction methods seem apparent on the basis of this analysis. In particular, we find low thermal extraction results with high relative error and high microwave extraction results with low relative error, while the absolute value of the bias for both of these methods appears to decrease with increasing analyte molecular weight.

As is often the case with studies of this nature, similar field studies performed by other workers may yield somewhat different, possibly even conflicting, results. Even our analysis does not give clear results in some cases, for example, compare columns two and three in Table 4.24 above. In light of this, and because of the need to gain regulatory acceptance of field laboratory data for a full realization of the expedited site characterization process, at the very least, these data clearly point out the need for enhanced field quality assurance and quality control (QA/QC) and further field- and field-versus-fixedlaboratory method comparisons and/or method validations.

4.4.3 Site Characterization Implications

To enable comparisons with the BVWST data and the contaminant screening data presented previously, the quantitative data are plotted at the relevant MLs in terms of naphthalene concentration, phenanthrene concentration, and total PAH concentration per zone. As discussed in Section 4.4.1, five on-site extraction techniques and three GC/MS instruments were used to generate the quantitative data. Due to its strong negative bias, the off-site laboratory data is not included in this analysis. Moreover, because the thermal extraction results are generally low, have high relative error and suspicious method detection limit data (see Table 4.21), the thermal extraction data were also excluded from the analysis. Because there was no clear indication as to

which of the remaining methods produced the "best" overall data, in terms of extraction efficiency, precision and accuracy, a representative concentration for each PAH compound for each of the samples listed in Appendix D was calculated by taking an average over the extraction method concentration results available (without the thermal extraction results) for each sample. These results are presented in Appendix D. Note that ND data were treated as discussed previously; i.e., ND data from diluted samples were deleted and the standard ND data were assigned a concentration of 0.5 mg/kg.

Naphthalene and Phenanthrene Distribution

The naphthalene and phenanthrene concentration distributions by zone are given in Figures 4.89 to 4.100. In these figures the label NA means that no average was calculated for that location while no label below the ML designator mean that no data was taken at that location. It is instructive to first compare these results with the BVWST RI results presented in Chapter 2. As noted previously, the heavy concentration of MLH measurement locations on the eastern part of the site has defined the eastern edge of the contaminated zone well, but makes direct comparison with other areas of the site difficult. Comparisons which can be made are as follows.

For zone 1, comparing Figures 4.89 and 4.90 with Figure 2.5, it may be noted that the concentrations measured at ML-112 and ML-118 are generally in the same order of magnitude as those measured at B-6, which is situated between the two MLs. In addition, the concentrations measured at ML-116 closely correspond with those measured at the nearby B-7. Significant differences between these same BVWST and MLH locations, however, in zones 2, 3 and 4 indicate that quantitative levels of contamination can vary significantly over relatively small distances, due largely to the heterogeneous movement of the DNAPL coal tar residue through the subsurface and also subsampling techniques; i.e., the measured concentration could be very much a function of how the analytical samples are actually selected from the core sample. In this regard, as noted previously, some of the most heavily contaminated MLH samples were fingerprinted for PAH compounds rather than analyzed for concentrations of individual PAHs. The areas of contamination outlined by the BVWST and MLH data, taking into account the different sampling locations, are, however, generally the same.

It is also instructive to compare the MLH naphthalene data from the upper two zones with the deep Phase I passive and active screening naphthalene results. Comparing Figures 4.34, 4.40, 4.89 and 4.91 indicates that the plume defined by the passive gas system (Figure 3.34) more closely corresponds to the MLH data than the active gas plume (Figure 4.40), particularly on the eastern edge. The plumes are, however, generally similar in extent. This further supports, in particular, the passive gas screening technique in defining the general areas of contamination.

Total PAH Distribution

Contour plots of total PAH concentration from the MLH data are given in Figures 4.101 to 4.106. In these figures the label NA means that no average was calculated for that location while no label below the ML designator mean that no data was taken at that location. These plots are included as they would be used in regulatory decision making. As with the naphthalene and phenanthrene contour plots discussed in the last section, the data are biased to the eastern part of the site, thus allowing the eastern edge of the contaminated zone to be well defined. In addition, some of the more heavily contaminated samples, particularly in the northwestern part of the site near the substation have not been analyzed for PAH compound concentrations. In this regard, the visual/odor plots presented in Figures 4.76 to 4.81, although only qualitative, are probably a better representation of the distribution of contaminants on the site than the quantitative data presented here. As in the previous section, this data are compared with Phase I screening data. Moreover, comparisons with Phase II screening data are made.

Comparison of zones 1 and 2 (Figures 4.101 and 4.102) with the deep zone IMA results (Figures 4.28 to 4.30) indicate general similarity of the plumes defined except in the area near the substation in the northwestern part of the site, for the reasons discussed previously. The eastern edges of the plumes defined by the IMA results conform to the McLaren/Hart results reasonably well.

Comparison of the MLH data with the CPT LIF data (contoured in Figures 4.46 to 4.51) gives the eastern edge of the plume in approximately the same locations for the stratigraphic zones. As with the MLH visual/odor data, however, much more CPT LIF data is available to better define the extent of contamination within the zones than the MLH quantitative data.

Summary of Site Characterization Implications

Due to the poor distribution of the sampling locations and the fact that heavily contaminated samples were systematically excluded from quantitative PAH analysis, this data adds little to further the development of the site contamination model. It does, however, confirm the eastern edge of the contaminated area as defined by the screening techniques and also correlates well, in places, with the quantitative BVWST data. A key issue is that while the screening tools have been able to define the areas of contamination much more clearly, they do so only in a qualitative sense. Quantitative data like the MLH data presented in this section is required for regulatory decision making.

4.5 Analysis of Groundwater Samples

Groundwater samples were collected from ML98, ML90, ML104, ML80 and ML106 using a Geoprobe mill-slotted well point and Watera-type (tubing with bottom check valve) sampling tools. Samples were collected from two depths at each map location; the shallow samples were collected from the upper region of the granular unit while the deep samples were collected from the lower part of the granular unit. Three 40 mL volatile organic analysis (VOA) samples with no headspace and a one liter PAH sample were collected at each location. The samples were analyzed on site using the ultrasonic extraction method. The chemical analysis results of the samples for the 16 target PAHs are given in Table 4.25. Also given in Table 4.25 are the sample MLs, depths acquired and, for reference, the solubility of each of the PAH compounds in water at 25°C. All of the groundwater samples were unfiltered except for a second GW005 sample which was passed through a 0.45µm filter. Sample GW006 at ML98 contained significant free product and was deemed too contaminated for analysis. Note that the IDNR standard for individual PAHs in groundwater is 0.2 µg/L, except for naphthalene which is 20 µg/L.

Table 4.25 indicates that the solubilities of the PAH compounds in water generally decrease as the molecular weight of the compound increases. The measured concentrations of the PAH compounds generally follow the trend of their solubilities; as with the results of the soil samples, naphthalene and phenanthrene are generally the two PAH compounds with the highest concentrations. Filtering, based on the analysis of the one unfiltered sample, appears to reduce the concentration of PAH contaminants in groundwater by about 50%. The distribution of naphthalene and phenanthrene in groundwater for the shallow depths are shown in Figure 4.107 while the distribution of naphthalene and phenanthrene in groundwater for the deep region are shown in Figure 4.108. The concentrations are the highest in the region north of the storage shed, at ML98 and ML90, and decrease from ML80 to ML106 toward the eastern portion of the site. This pattern corresponds to the distribution of contaminants and the plumes defined by the Phase I screening and Phase II screening and quantitative technologies results.

It may be noted that PAH compounds were detected above the IDNR standards in every one of the groundwater samples analyzed. Due to the distance of the sampling locations from BVWST monitoring wells and the different groundwater sampling collection procedures, direct comparison of these results with the BVWST results is not possible. It is apparent, however, that the concentrations given in the central part of the plume are significantly higher than any concentrations recorded by BVWST.

4.6 Stakeholder Activities

4.6.1 Communications Strategy

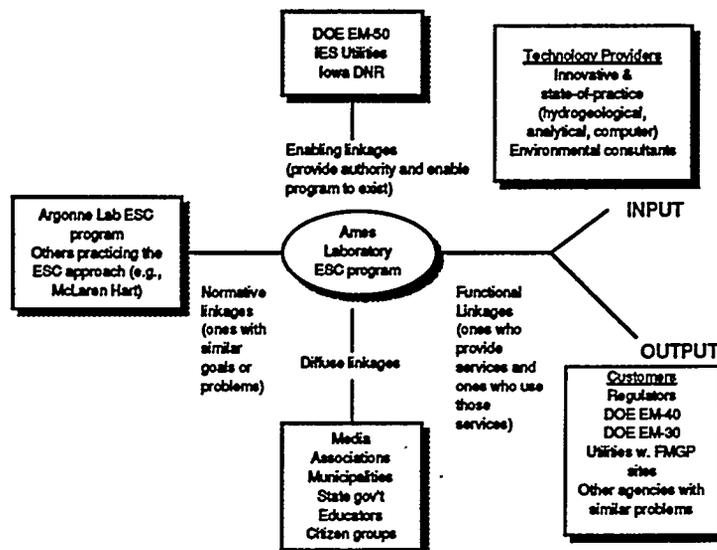
Ames Laboratory's application of ESC is distinctive in its approach to stakeholder involvement. Because of the increasing role of stakeholders in the acceptance and ultimate commercialization of environmental technologies (DOE, 1994)--or in this case, an environmental methodology--early stakeholder involvement was sought. Early communication with stakeholders is important because it enables ESC project managers to apply the approach so that ESC meets the technical, regulatory and public interest needs at a specific site.

In our ESC communication efforts with Marshalltown stakeholder groups, we employed a two-way symmetric communication model (Grunig, 1984) that aims for a balanced exchange of information between the organization (or program) and stakeholders, so that each group can learn from the other. The model seeks mutual understanding as its goal and is characterized by formative and evaluative research on audience/stakeholder interests and attitudes.

4.6.2 Objectives and Audience

Our objectives were to 1) increase the awareness of the ESC methodology among stakeholder groups, and 2) encourage a two-way exchange of information. We began by identifying stakeholders using a framework of organizational linkages as shown below.

Sample framework of organizational linkages used to identify stakeholders.



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IES Utilities, Inc., the site owner, was an enabling "public" or stakeholder, critically important to the success of our communication efforts. Shortly after the company had agreed to let their site be used for the demonstration, and several months before the field work was to begin, the Ames ESC technical and communications team members met with both IES environmental managers and public relations representatives to discuss the public events desired for ESC stakeholder involvement.

The early scheduling of this meeting was critical for effectively introducing the Ames ESC project not merely as a technical effort but also as a stakeholder involvement effort. We presented the idea of sponsoring an open session giving interested publics (community members, regulators, DOE officials, educators, students, etc.) an opportunity to observe the approach, discuss its use, express concerns, tour the site and see the technologies used for ESC at work.

These activities met with IES approval and were in fact consistent with the company's philosophy of openness and proactive communications which they had used on several previous environmental projects, and had seen the resulting benefit.

The stakeholders or "publics" that were of primary concern to IES Utilities were:

- their own employees: that they understand the ESC work that was to take place and have the first chance to ask questions about it;**
- the regulatory community: being under the oversight of the Iowa Department of Natural Resources (IDNR), IES Utilities was concerned that stakeholder/public involvement efforts be responsive to the opinions and suggestions of the overseeing regulators;**
- the general public: that members of IES' large customer base would recognize that the company's support of this project demonstrated their commitment to economic incentives and customer focus; and**
- environmental communicators: that Ames ESC efforts include a focus on reporters with an environmental focus.**

In response to these communication concerns, the Ames ESC team agreed to:

- present information sessions to explain ESC to IES employees before the work began and allow for open dialogue;**
- meet with overseeing regulators to discuss stakeholder involvement, and to include these regulators in the planning and approval of such things as press releases, announcements, etc.;**

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- prepare a publicity plan for inviting specific groups, organizations and individuals in Iowa, the region and the nation to the ESC public conference/tour and share this plan with IES; and
- maintain regular communication with IES and regulators to keep them informed and get their input on specific stakeholder involvement plans as they were being developed.

In subsequent meetings, the overseeing regulator, Dr. Johanshir Golchin, environmental engineer and project coordinator with the IDNR, encouraged broad public participation and suggested names of organizations and individuals to invite to the planned conference.

4.6.3 Identification of Stakeholders and Planned Activities

Using the framework of organizational linkages, Ames developed a detailed list of stakeholder groups to invite (see Appendix F), and distributed this list to IES Utilities and IDNR for comments. We collected names of members of these stakeholder groups, totalling approximately 900 individuals. In addition, we sent announcements to newsletters, newspapers and electronic bulletin board services to publicize our event to an even wider group of stakeholders.

Personal phone calls were made to association presidents, newsletter editors, regulatory branch heads, DOE funding officials and other influential individuals to draw their attention to our written material and to solicit their help and support in promoting our event to their constituents. As we did this, we received suggestions for tailoring the content of the conference to the needs of particular stakeholders. For example, an environmental consultant in South Dakota suggested that by offering CEU credits for the event, regulators in that region could more easily arrange to attend. Personal contact with the public information bureau chief at the Iowa Utilities Board helped us assess the level of technical understanding of our potential attendees.

Because our objective was to increase the awareness and understanding of ESC (and its relationship to cleanup needs) and to encourage a two-way exchange of information, we designed the public conference to include a non-technical overview of the cleanup process, a presentation on ESC concepts and how it was applied to the Marshalltown FMGP site, tours of the various technologies at the site and a question and answer wrap-up. We mailed the conference brochure to over 900 people approximately one month before the event. Participants were only be charged for the luncheon meal. We offered an identical agenda on three consecutive days, May 11, 12, 13, 1994, to give stakeholders more flexibility in attending. The final agenda included the following sessions:

Overview of Environmental Cleanup. Designed to provide a context for understanding the importance of characterization, this session offered, in lay terms, background information on a number of aspects of environmental remediation: steps in the remediation process, the regulations involved, interpreting EPA numbers, assessing risk and defining technical terms.

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ESC at Marshalltown, IA. This session described ESC within the context of environmental management elements: risk, economics, stakeholder involvement, cleanup problems and cleanup technologies. We then described details of the approach, as applied to the characterization of coal tar wastes at the Marshalltown FMGP site, and the technologies used.

Tours of the site. Participants visited the Former Manufactured Gas Plant Site, and viewed more than 12 SOPT and ITs in action in the field. Contractors were present to explain their technologies and answer questions.

Question and Answer Wrap-Up. This session allowed DOE Headquarters program managers, IDNR regulators, Ames ESC team members, technology providers and other participants to openly exchange ideas, questions and comments on the ESC approach.

4.6.4 Evaluation of Objectives

Our first objective was to increase awareness. Conference attendance totalled 177 registrants, most of whom were not familiar with the ESC methodology or the technologies beforehand. The following stakeholder groups were represented:

Interested citizens and activists	3 %
Educators	5 %
International visitors (Bolivia)	8 %
City government	2 %
State government	4 %
Regulators (state level)	22 %
Site owners (utility industry primarily)	10 %
Technology providers and users	
Industry (consultants & contractors)	34 %
DOE	2 %
Other federal agencies	2 %
Ames Laboratory	8 %

Comments received on the participant evaluation forms helped us assess, in a more qualitative way, whether the ESC event had increased awareness. The tour of the FMGP site, and of the technologies being used to characterize the site, seemed particularly effective in increasing an awareness and understanding of what is involved in ESC. Comments from the Visitors' Day included:

- *"[Attendance] gave me a better grasp of what is involved and the associated time and expense. As a regulator, we only get to see dollars, with no idea of the work involved."*

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- *"Very worthwhile to attend. We see the clean up and costs associated with FMGP sites when utilities file rate cases. This was a good opportunity to see how those monies might be used more effectively and to see what is involved in cleanup activities."*
- *"This type of information is very difficult to get via other methods of information sharing (magazines, books, conferences, etc.). Very helpful seeing the data collected."*
- *"It is very helpful to see the various technologies in action."*
- *"I think it is very important to invite members of the public and locally concerned people to learn about cleanup efforts."*
- *"I'd like to be able to bring a high school class to a session like this. They could see the technologies being used. I appreciate so much the opportunity to attend."*

On the day of the event, we met the *Des Moines Register* reporter and gave him direct access to the scientists and field managers involved with the work. The objectives and technical aspects of the project were accurately reported in the *Des Moines Register*, a state-wide distributed newspaper. Our work was also publicized in *The Probing Times*, Geoprobe System's in-house newsletter that is distributed to consultants, contractors and the regulated community nationwide. An article appeared in the *Iowa Groundwater Association Newsletter*, and resulted in an invitation to speak at the Iowa chapter meeting of that association. We also received an invitation to submit an article to the *Journal of Soil and Water Conservation*. In addition, our ESC Marshalltown project was mentioned in numerous DOE reports and presentations, furthering our objective of increasing awareness.

With the collection of video footage and photos that we had shot during the ESC demonstration, we were able to create hypertext documents and post multimedia descriptions of the ESC work on the Internet's World Wide Web (WWW). Using the suggestions of the IDNR regulator Dr. Johanshir Golchin, and the Iowa Citizens Action Network environmental specialist Julianna Johnston, we also began developing an on-line forum on the WWW to promote a discussion of ESC. A New Jersey video production company shot footage that was used in a promotional video for McLaren/Hart Environmental Engineering. The company shared this footage with the Ames Lab for our use in producing a video about ESC.

Our second objective was to encourage a two-way exchange of information. Evaluation comments indicated that a two-way exchange of information did take place but that more would have been desirable. The causes for the lack of interaction were partly logistical--e.g., running behind schedule which cut into the question and answer time, and not allowing enough time and structure for the tours.

*Ames Expedited Site Characterization - Marshalltown FMGP Site
FINAL Site Report
March 25, 1996*

Some of the feedback we received included:

- *"The on-site tour was very interesting. Each of the speakers took the time to fully answer our questions. The best part was that the speakers were the ones doing the work."*
- *"I would have enjoyed more discussion of the data fusion process...both days I attended there was no question and answer portion of the presentation."*
- *"I felt rushed and missed one of the vendors due to time. Very good information at the ones I did attend though."*
- *"Need more time for demonstrations. Allow more time per station [on tour]. More Ames staff could have been available at the tent for general questions."*

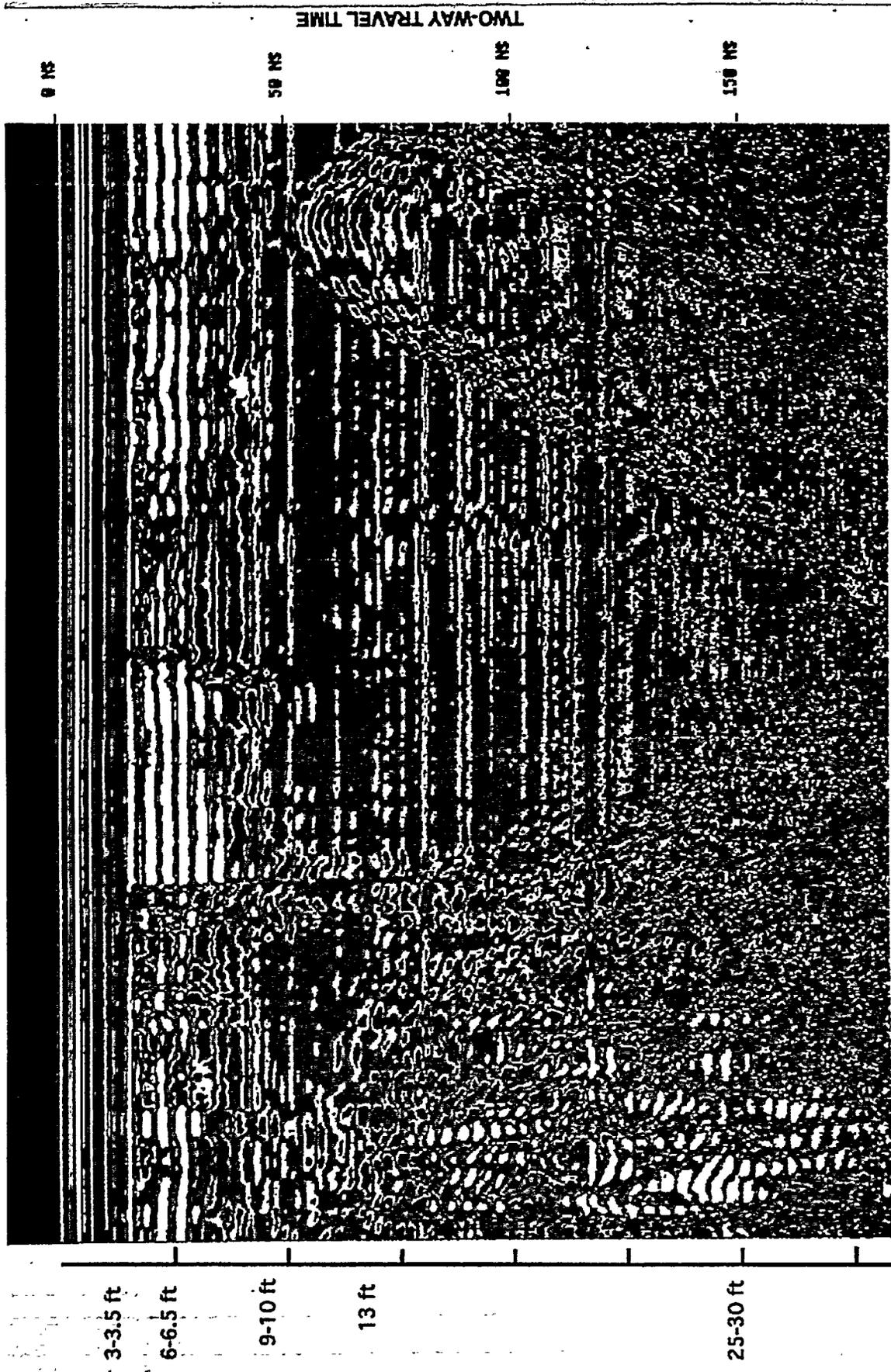
But even with these logistical problems, two-way communication and an exchange of ideas did take place.

These and other comments on the evaluation form provided a very useful mechanism for listening to participants' concerns. Other feedback was obtained through phone calls to attendees after the event. Many of the comments and suggestions have been incorporated into subsequent ESC demonstrations.

4.6.5 Summary

Several factors contributed to the success of the communications effort. One was that IES Utilities' offered their support and cooperation with the public relations/stakeholder involvement effort early on in the project which allowed time for planning. A second, perhaps more important factor was that this support came from IES technical project managers who had a good understanding of, and appreciation for, two-way public relations activities. And a third was that the company had a history of openness with the public and good relationships established with regulators and the media. These factors provided a foundation on which to develop ESC stakeholder activities.

Of those activities, the tours appeared to be one of the most effective means of involving a diverse group of stakeholders and increasing their awareness of the ESC methodology. Allowing participants to go on to the site, to talk directly with the contractors using the technology and discuss the findings demonstrated our commitment to openness and a two-way exchange of ideas.

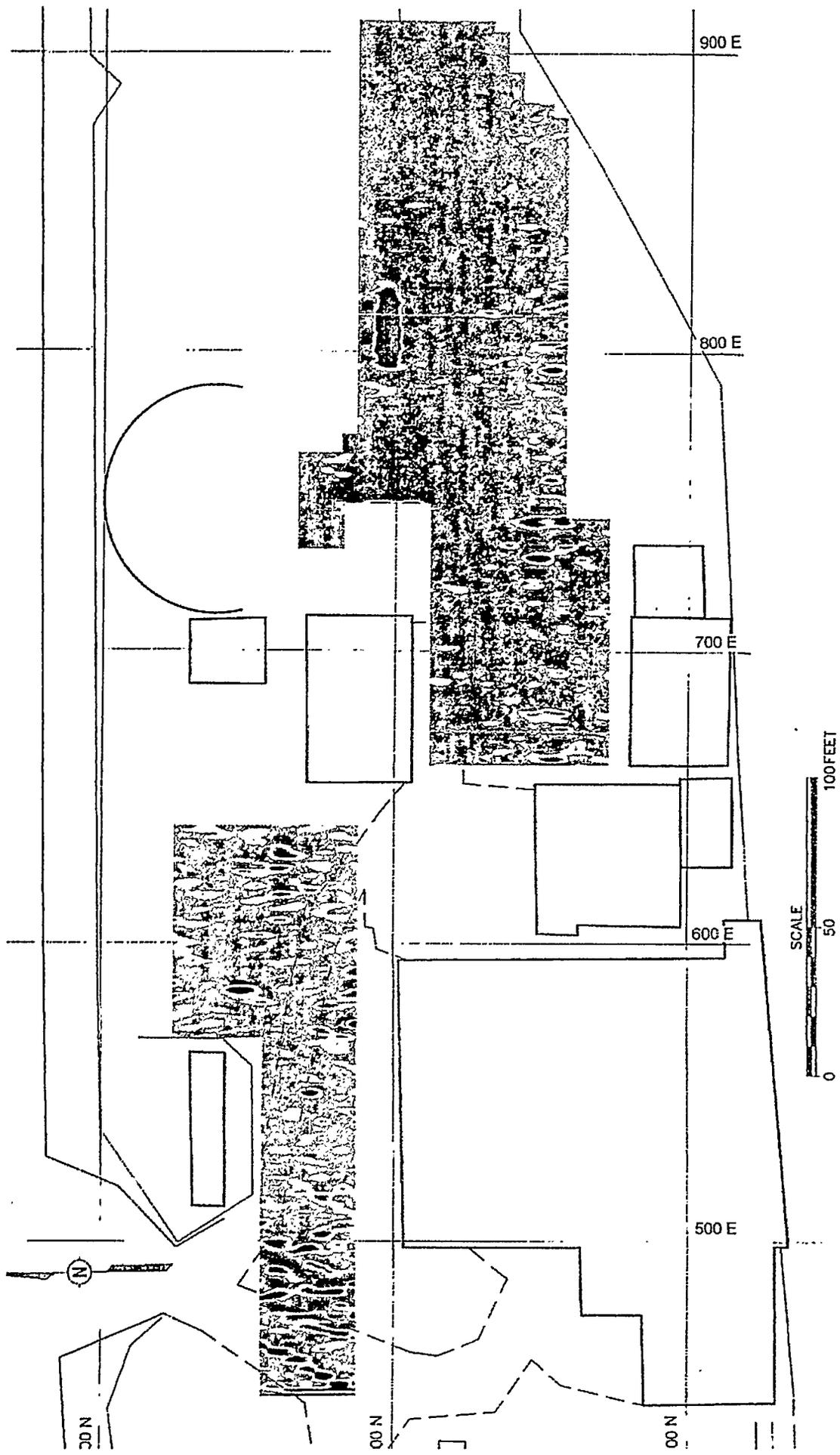


PROFILE 13

NOTE: FOR LOCATION OF PROFILE SEE FIGURE 1

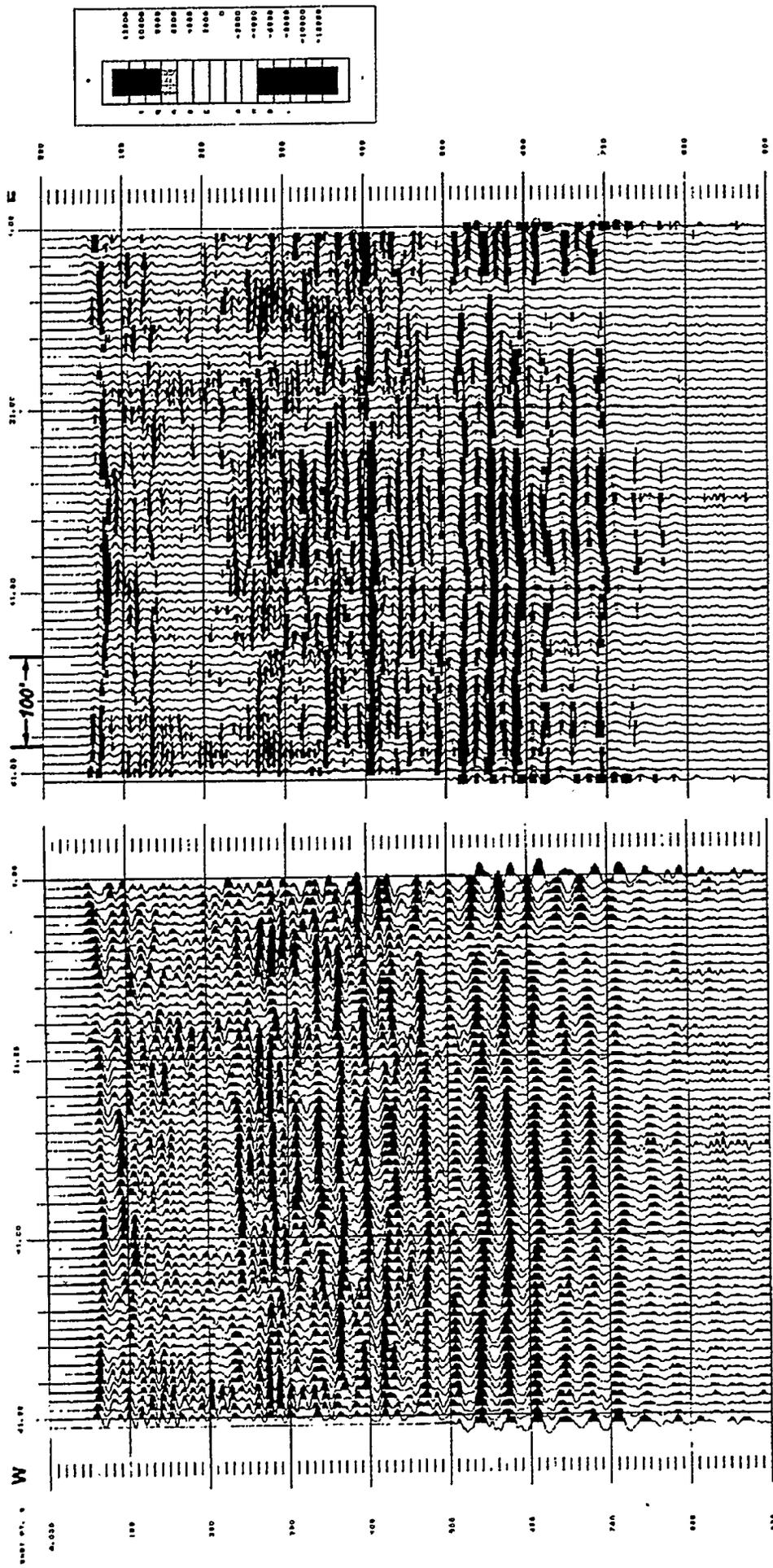
Depths/Time
as reported in text

Figure 4.2 GPR 300 MHz Survey-Profile #13
(from D'Appolonia, 1994)



13 ns Time Slice of Amplified Trace Amplitude

Figure 4.3 GPR 300 MHz Survey -13ns Time Slice
(from D'Appolonia 1994)



NOTE: FOR LOCATION OF PROFILE SEE FIGURE 4.1

Figure 4.4 GPR 100 MHz Survey - CMP Profile (from D'Appolonia 1994)

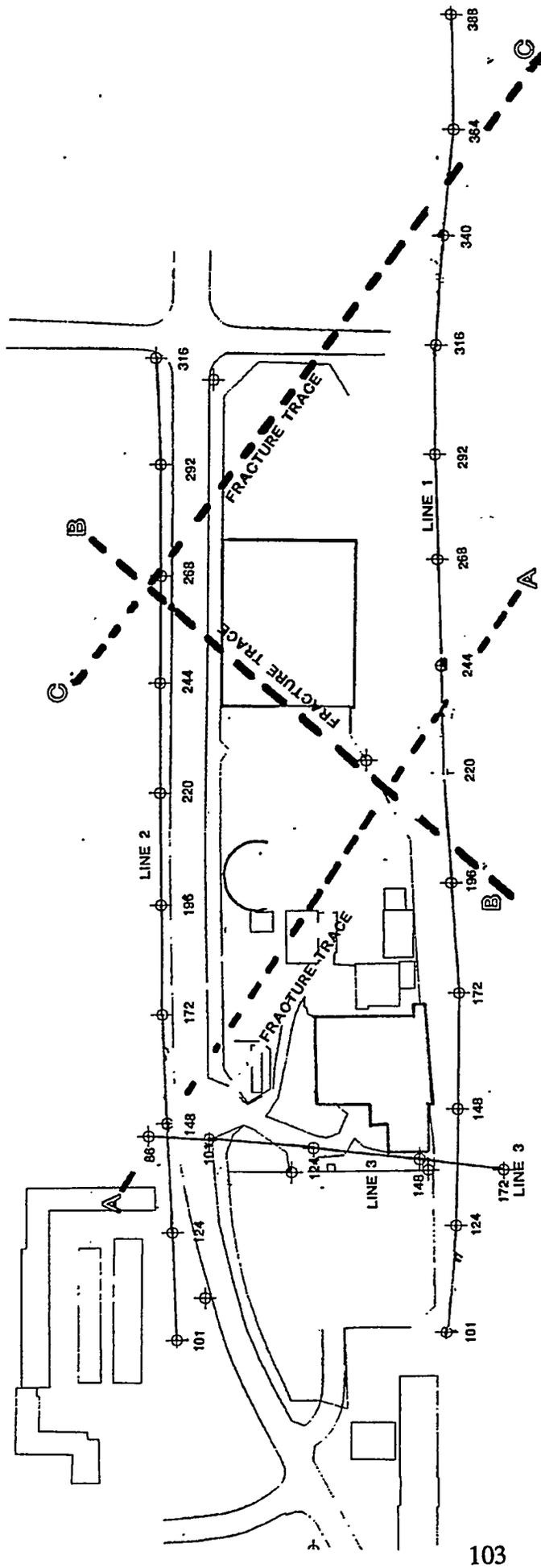


Figure 4.5 Location of Seismic Reflection Lines
(from Resolution Resources, 1994)

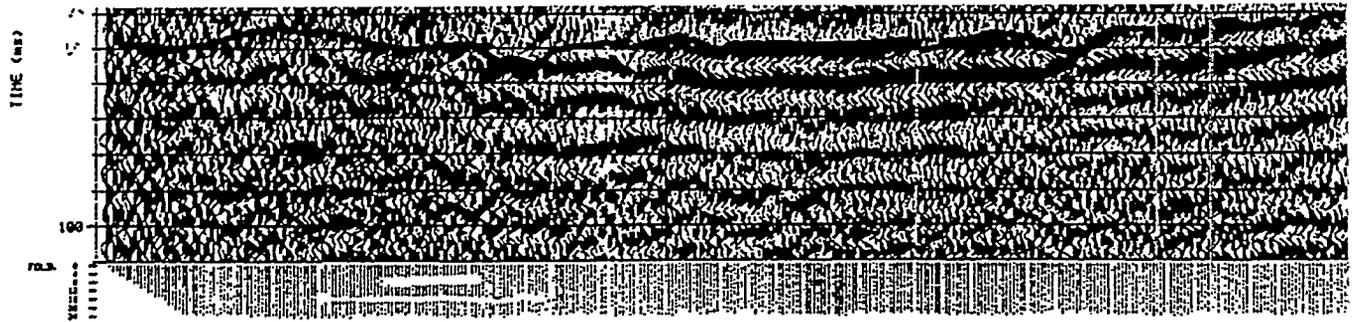


Figure 4.6a

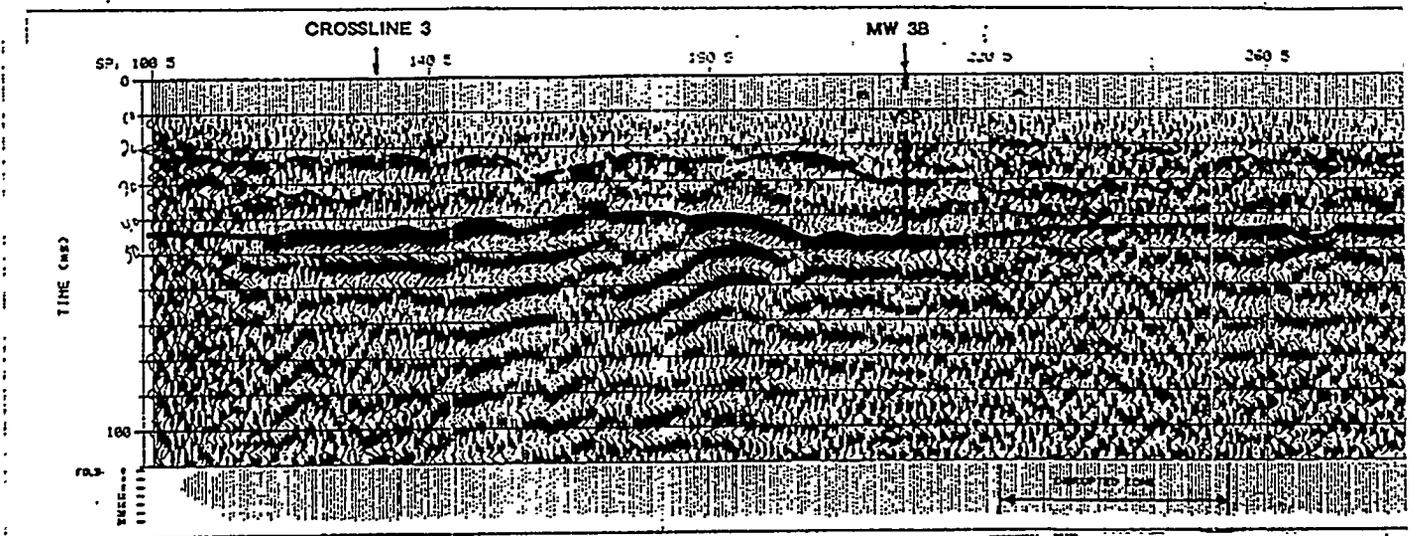
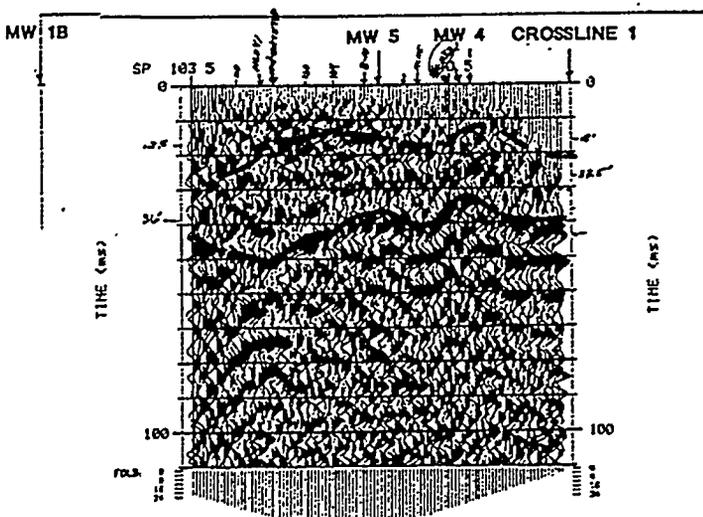


Figure 4.6b



AMES LABORATORY (EXPEDITED SITE CHARACTERIZATION)
 LINE 3 (4894)
 DATA BY RESOLUTION
 PRELIMINARY
 IOWA ELECTRIC MARSHALLTOWN, IOWA
 ACROSS MW-1 TO ACROSS MW-5 TO ACROSS MW-4 TO SEISMIC LINE 1
 NORTH TO SOUTH

RECORDING PARAMETERS
 RECORDED BY: BRIAN E. HENRICE DATE RECORDED: 0-APR-94
 INSTRUMENT: GEOMETRICS R-68 FIELD FILTERS: 70-300 HZ
 SOURCE: 12 LB MHW-4 6 POPS GEOPHONES: RAMM PRODUCTS 48 HZ
 SOURCE INTERVAL: 5.00 FT GROUP INTERVAL: 5.00 FT
 CHANNELS: 48 SAMPLE INTERVAL: 0.25 MS
 SAMPLES/TRACE: 1024 FOLD: 2400 X
 SPECIFIC SPLIT: 229-38-0-36-229

PROCESSING SEQUENCE
 1) IMPORT FIELD RECORDS
 2) CMP SORT
 3) BAND PASS FILTER
 100/20-200/24
 2500 PASSES
 4) NORMAL MOVEOUT
 STRETCH FACTOR: 1.00X
 5) GAIN
 GCE = VIBRO 82 MS
 6) CMP STACK

DISPLAY PARAMETERS
 HORIZONTAL SCALE: 20 MS / IN VERTICAL SCALE: 20 MS / IN / 100
 POLARITY: NORMAL GAIN: GCE = VIBRO 82 MS
 DATE PROCESSED: 21-APR-94

Resolution Resources, Inc.

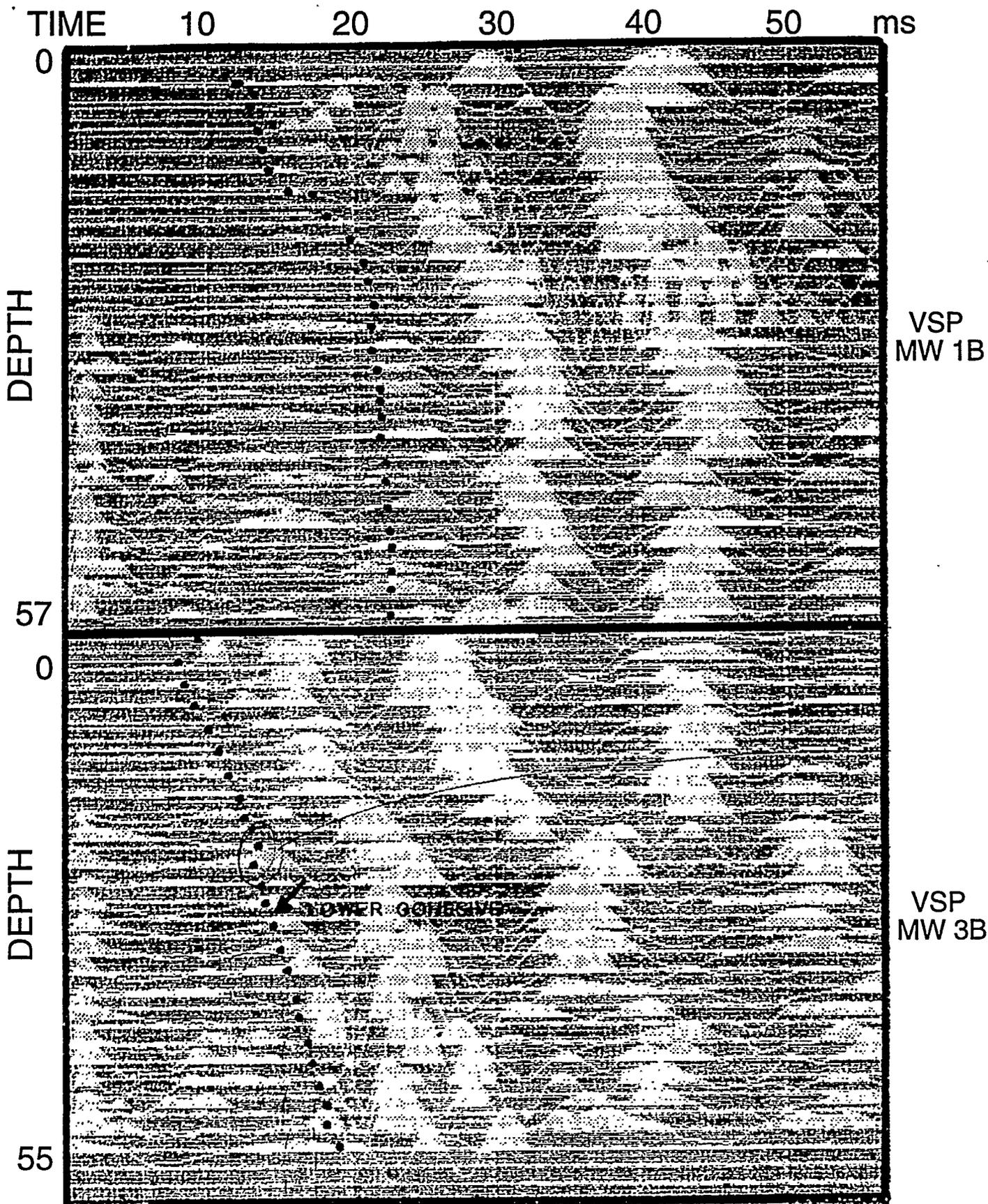


Figure 4.7 Seismic Reflection - Check Shot Survey
(from Resolution Resources, 1994)

LOCATION OF SEISMIC DATA ACQUISITION

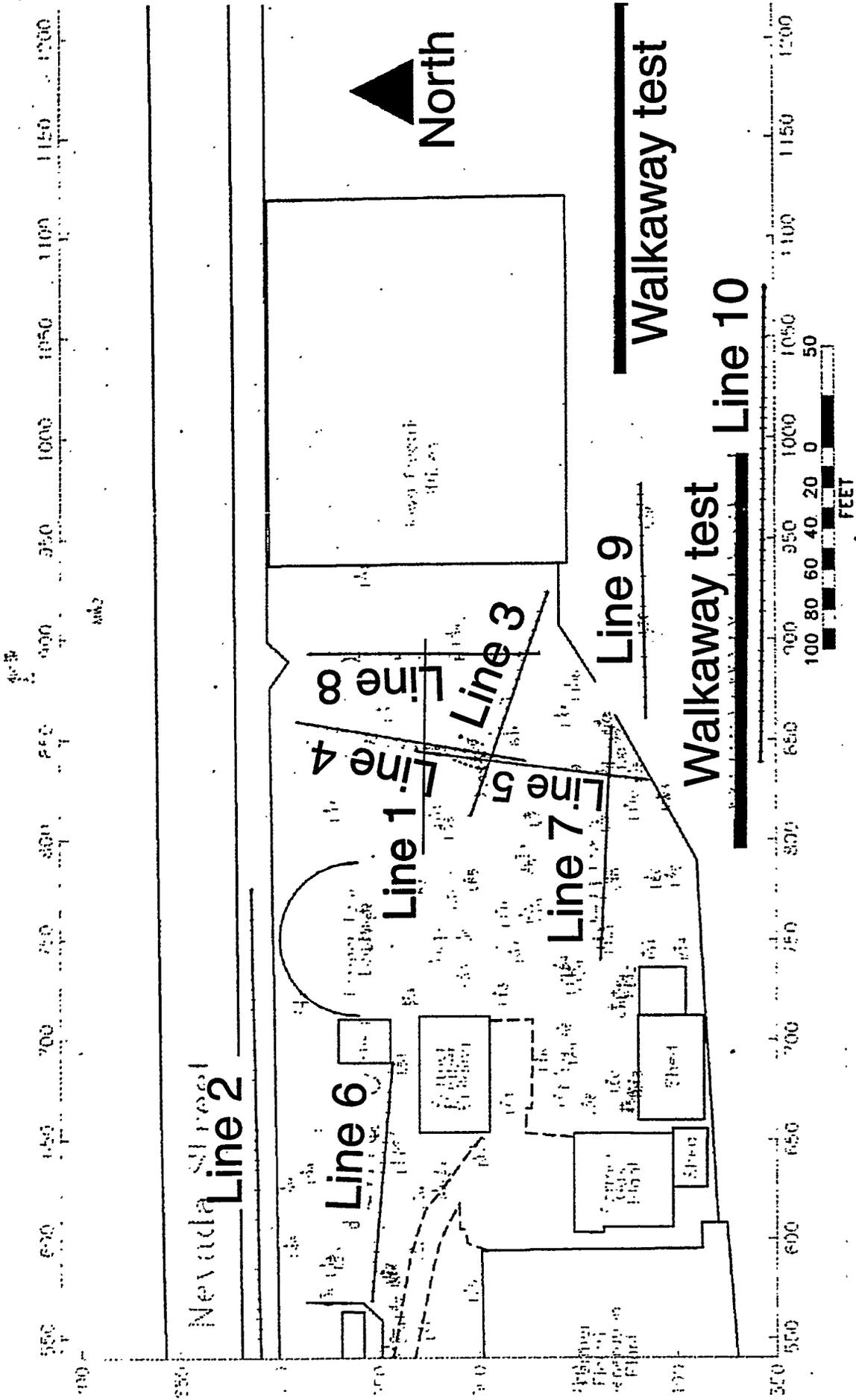


Figure 4.8 Location of Seismic Refraction Lines (from CEES - Blackhawk Geosciences Division)

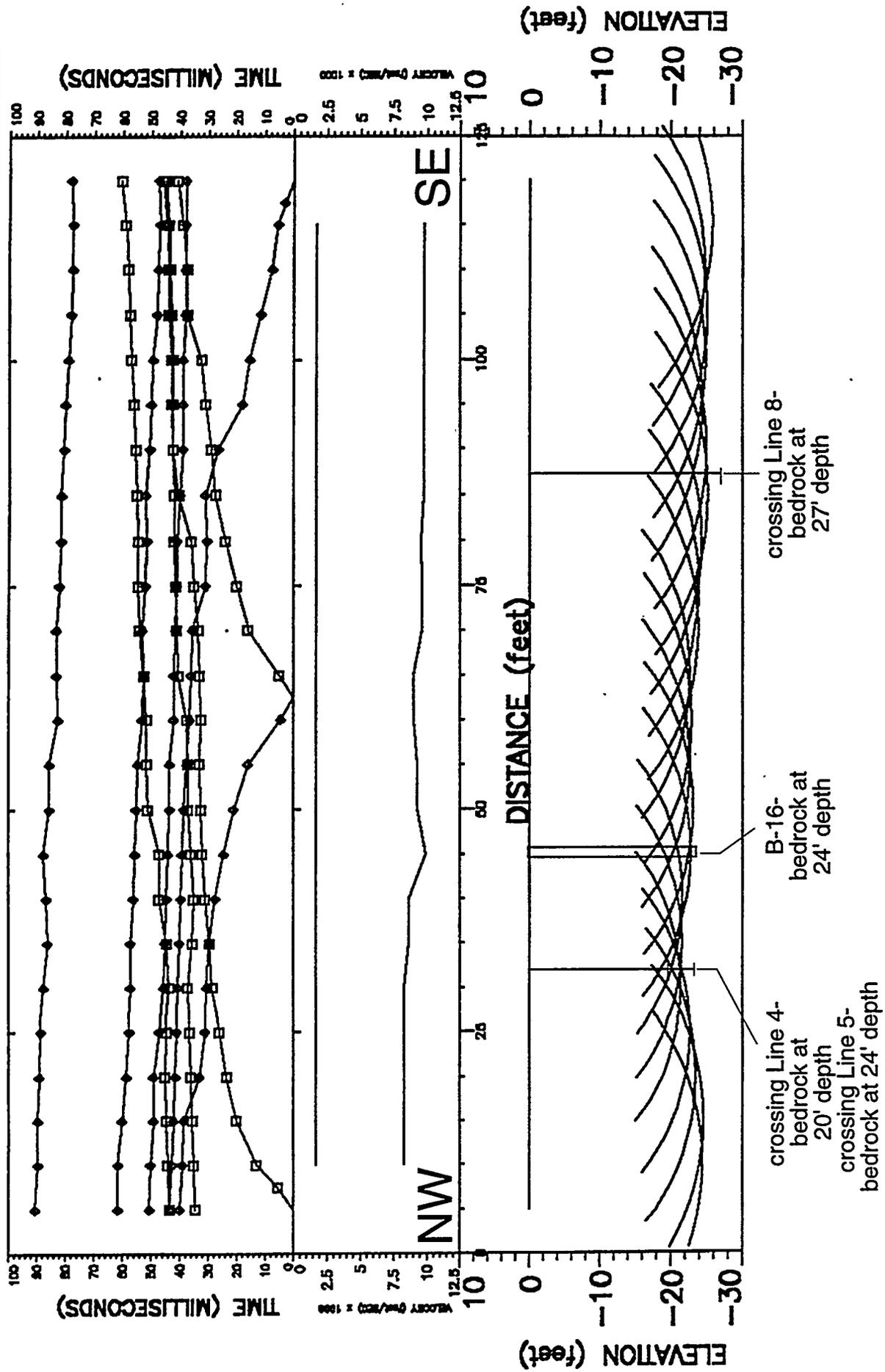


Figure 4.9 Seismic Refraction Survey Line 3
(after CEES - Blackhawk Geosciences Division)

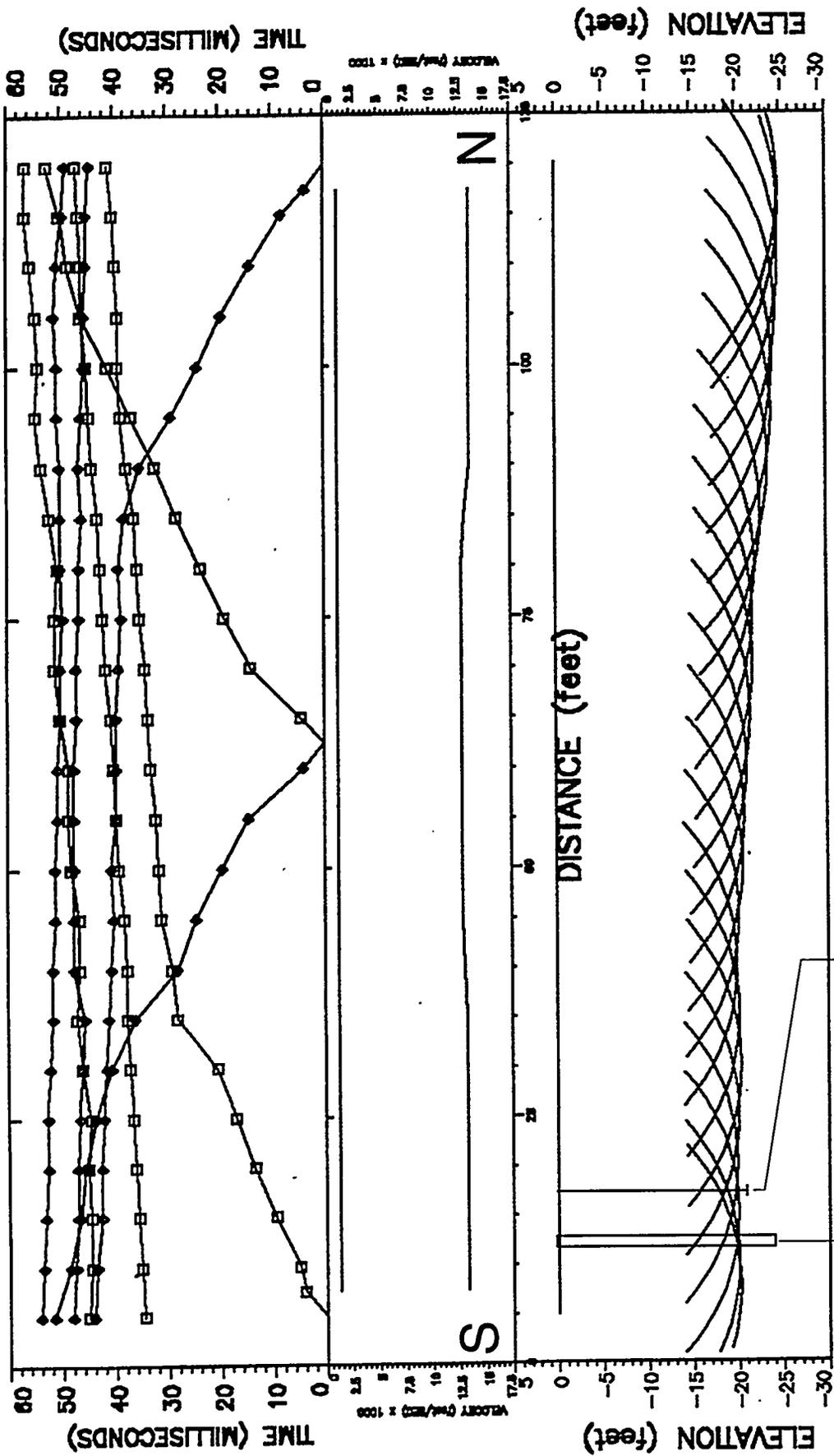


Figure 4.10 Seismic Refraction Survey Line 4
(after CEES - Blackhawk Geosciences Division)

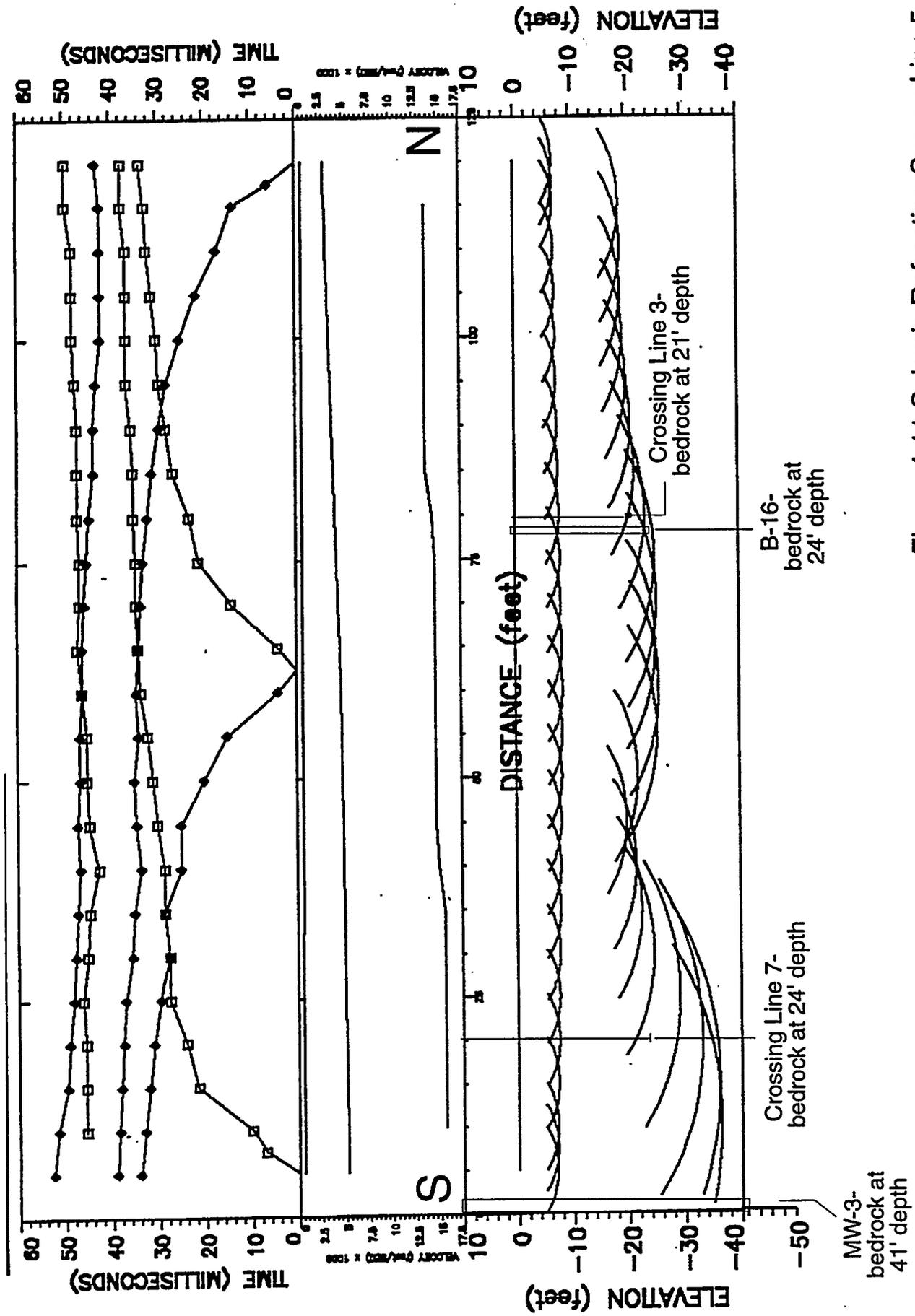


Figure 4.11 Seismic Refraction Survey Line 5 (after CEES - Blackhawk Geosciences Division)

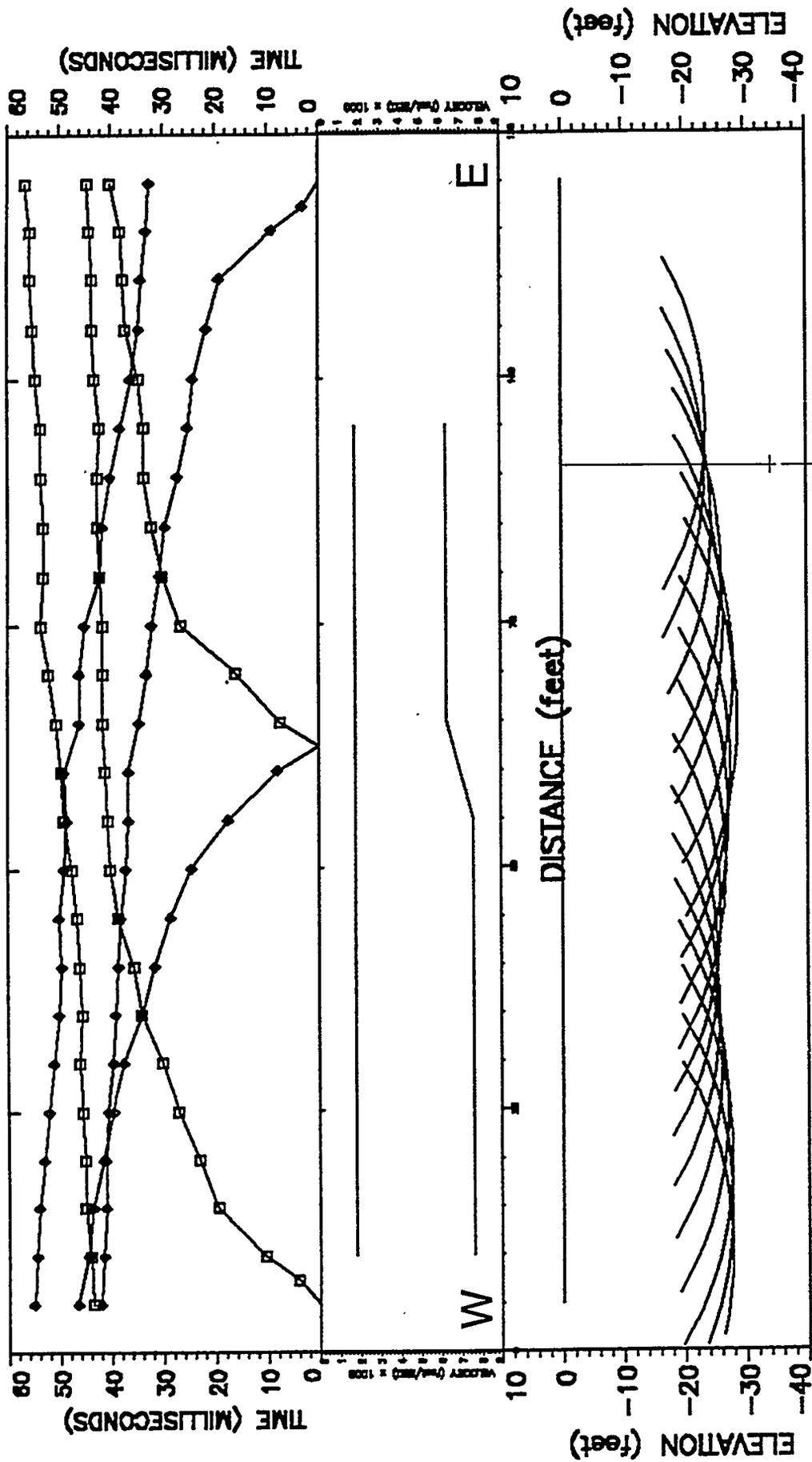


Figure 4.12 Seismic Refraction Survey Line 7
 (after CEES - Blackhawk Geosciences Division)

ELEVATION OF BEDROCK FROM BOREHOLES

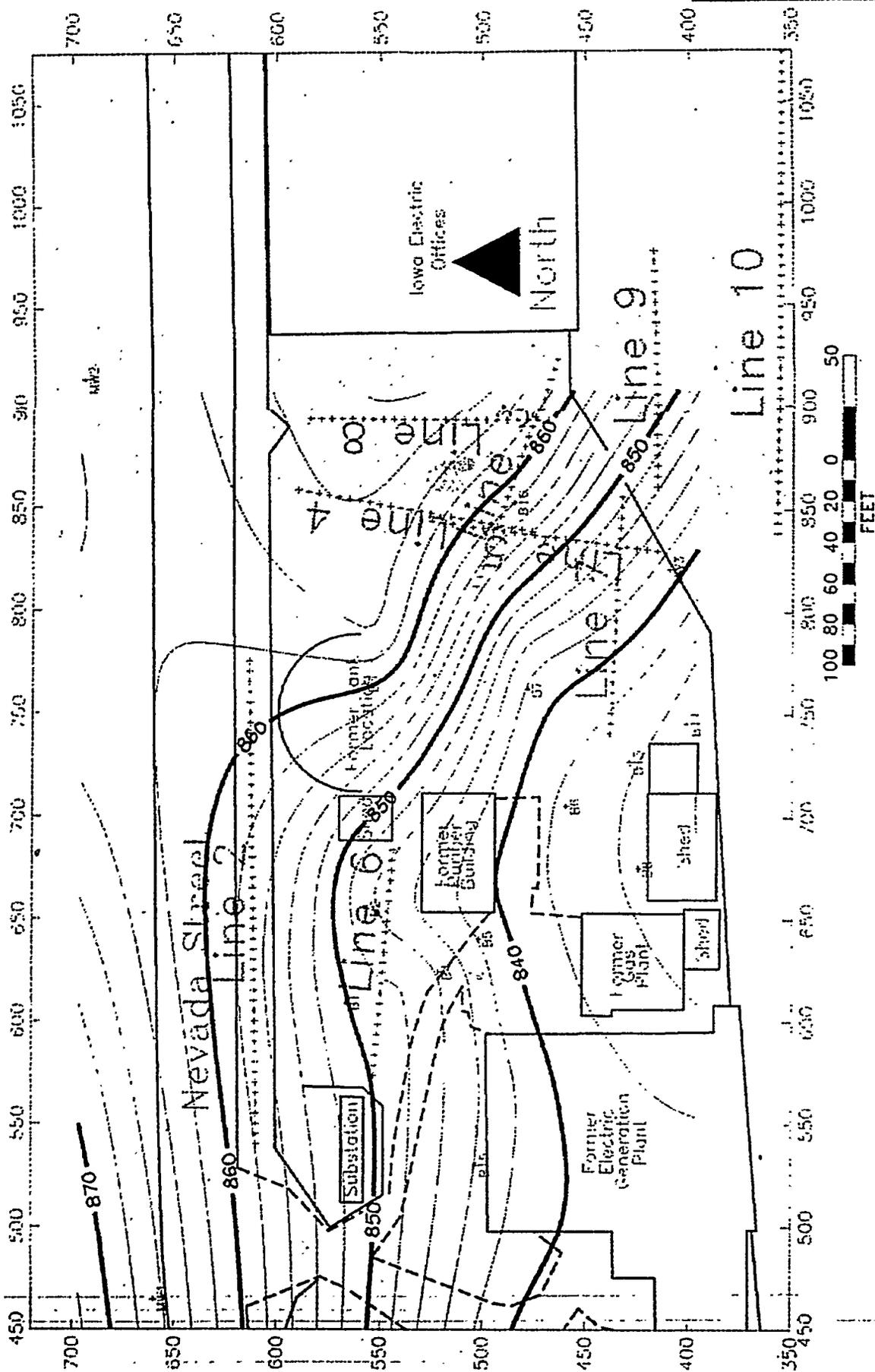


Figure 4.13 Seismic Refraction Survey-Elevation of Bedrock from BWST Boreholes (from CEES - Backhawk Geosciences Division)

ELEVATION OF BEDROCK FROM BOREHOLES AND SEISMIC DATA

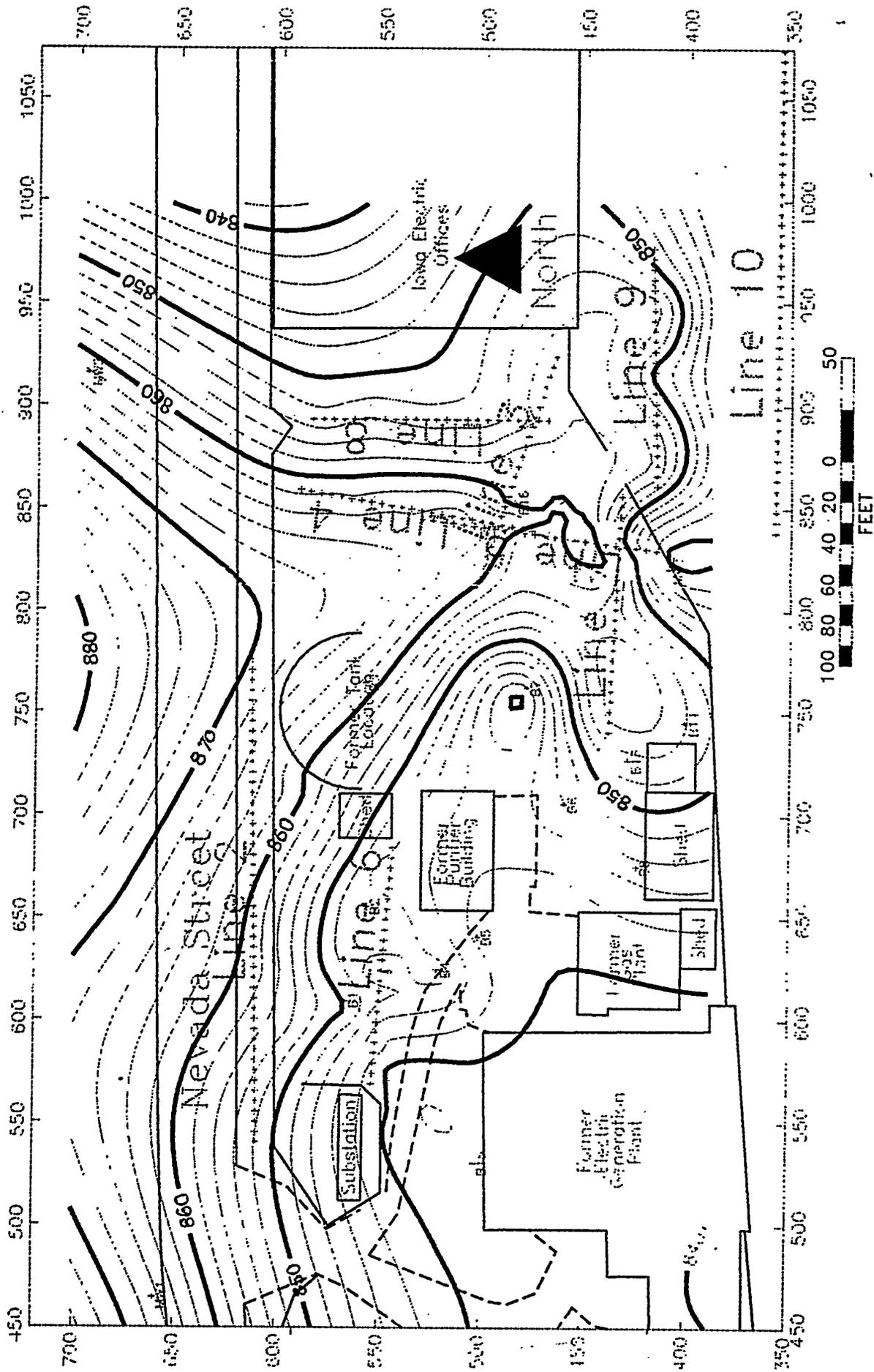


Figure 4.14 Seismic Refraction Survey Elevation of Bedrock from BWST Boreholes and Seismic Refraction Survey Results (from CEES-Blackhawk Geosciences Division)

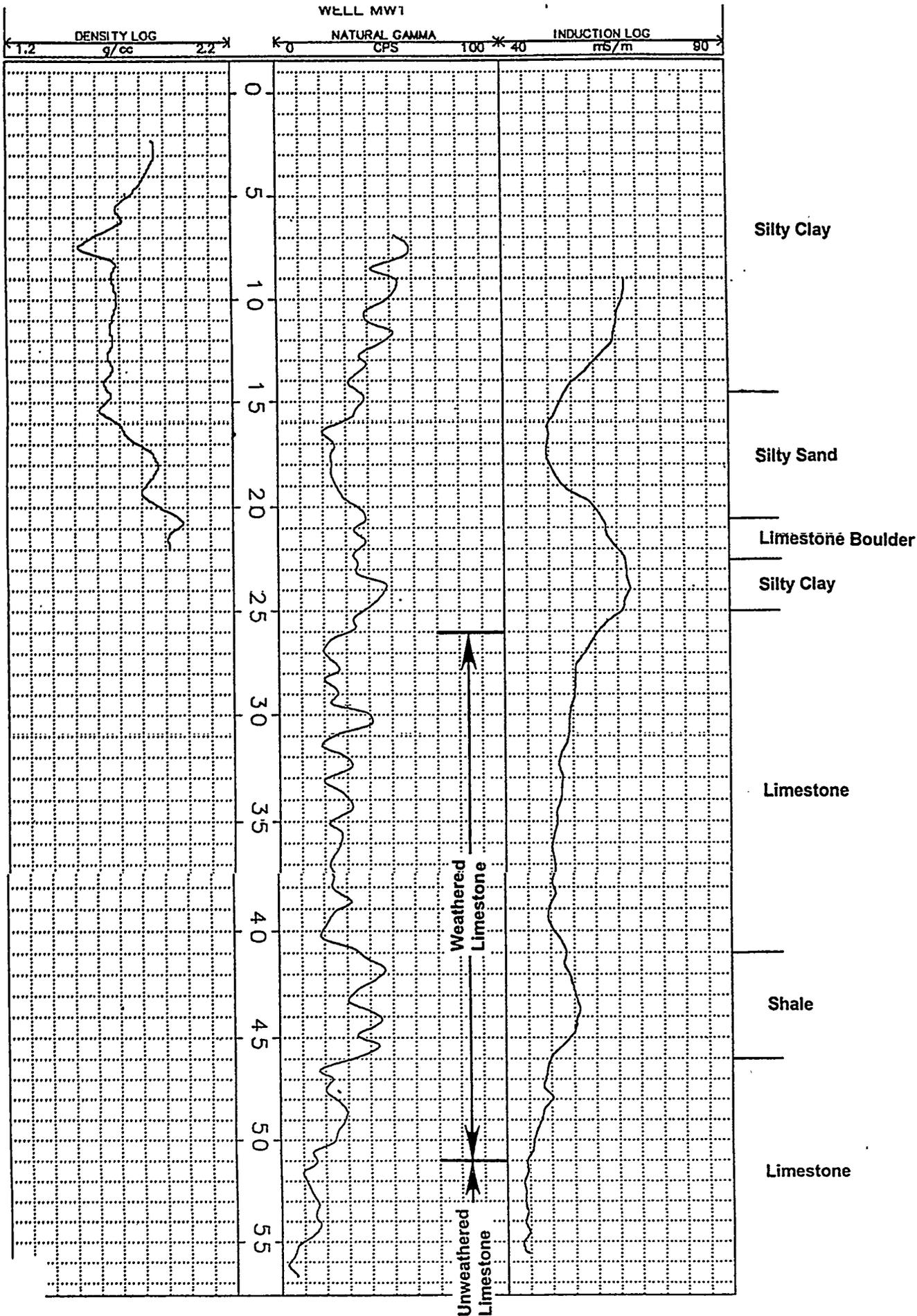


Figure 4.15 Borehole Geophysical Logs-MW1
(from Technos, 1994)

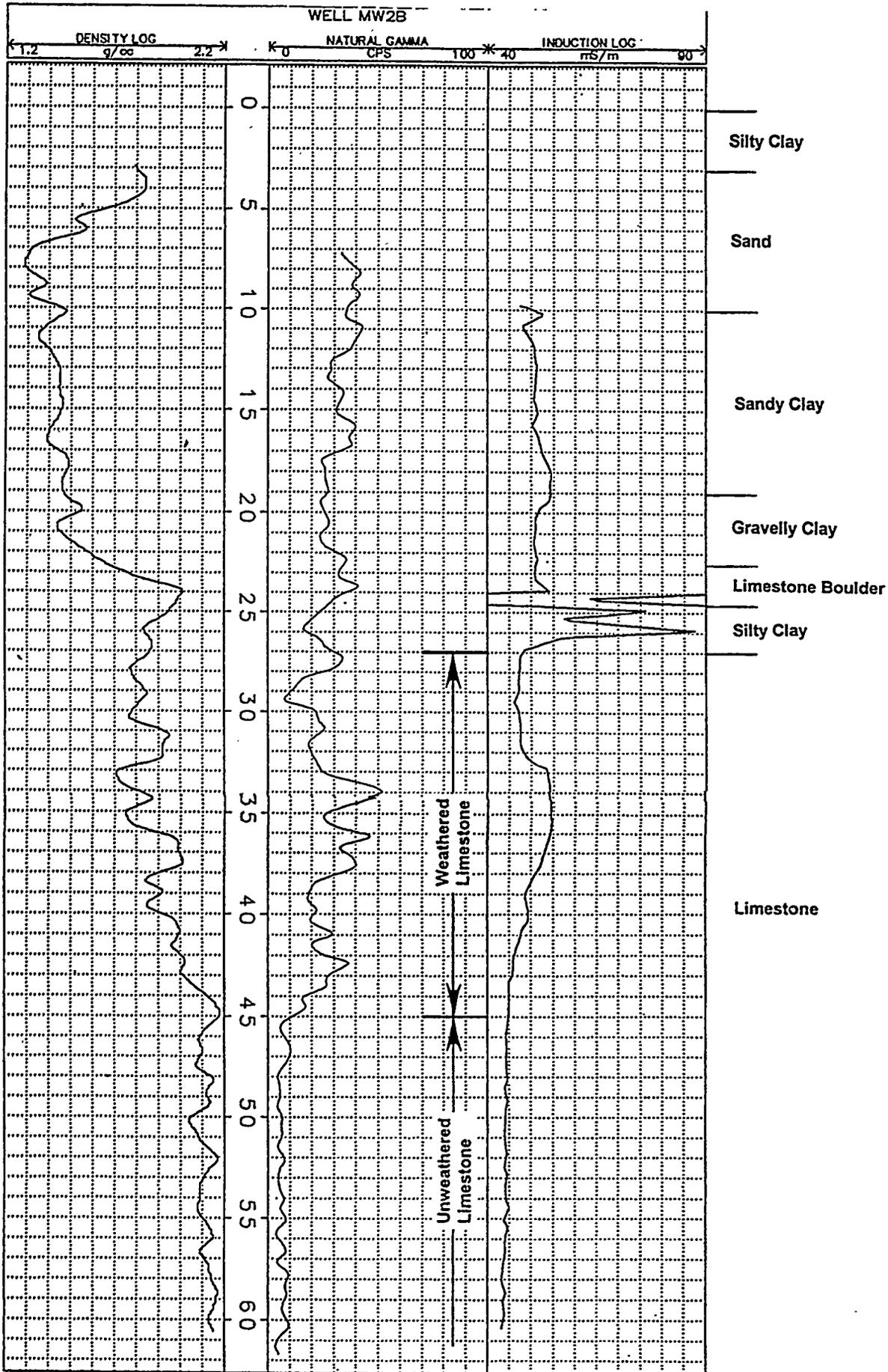


Figure 4.16 Borehole Geophysical Logs-MW2B
(from Technos, 1994)

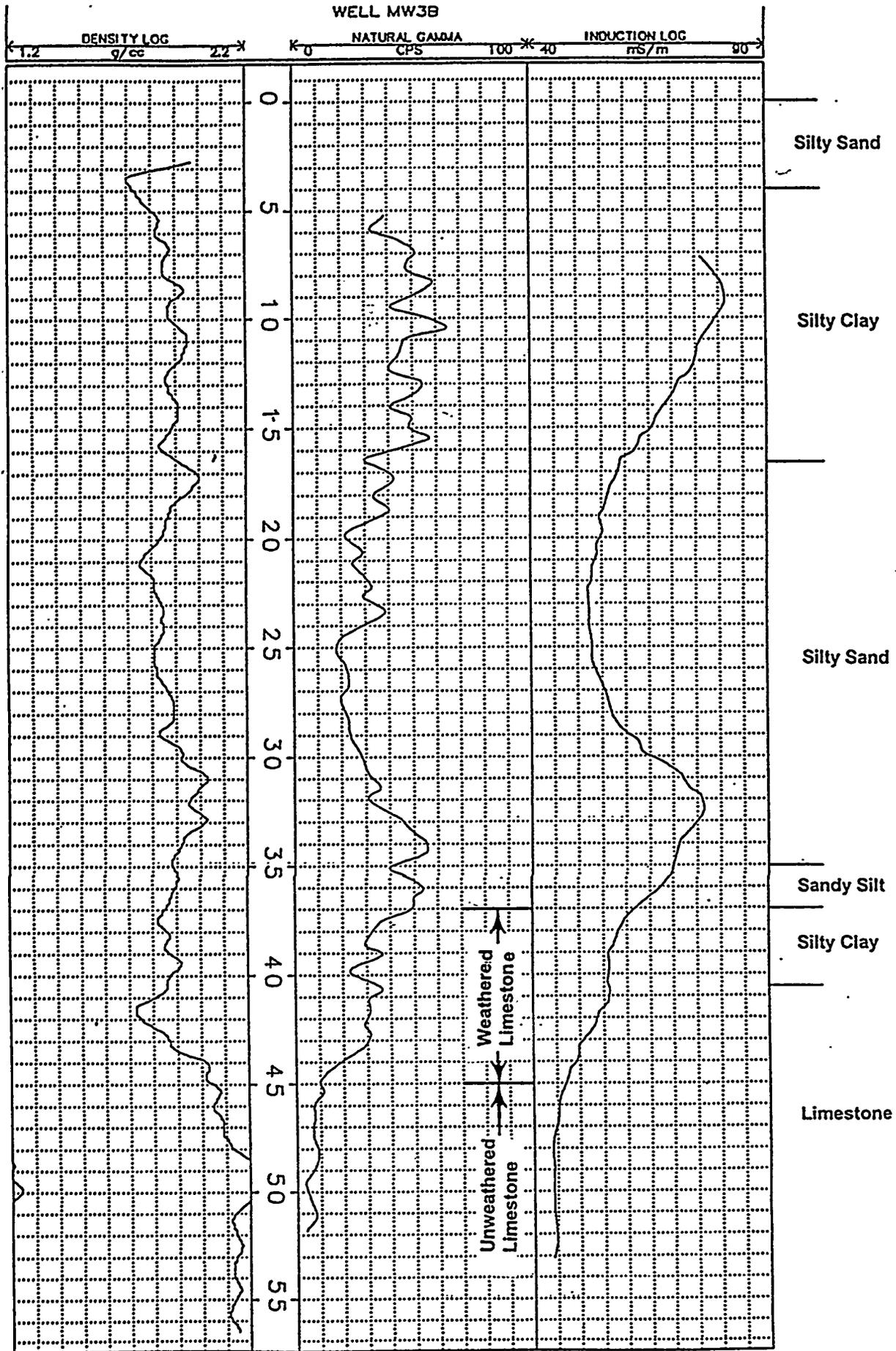


Figure 4.17 Borehole Geophysical Logs-MW3B (from Technos, 1994)

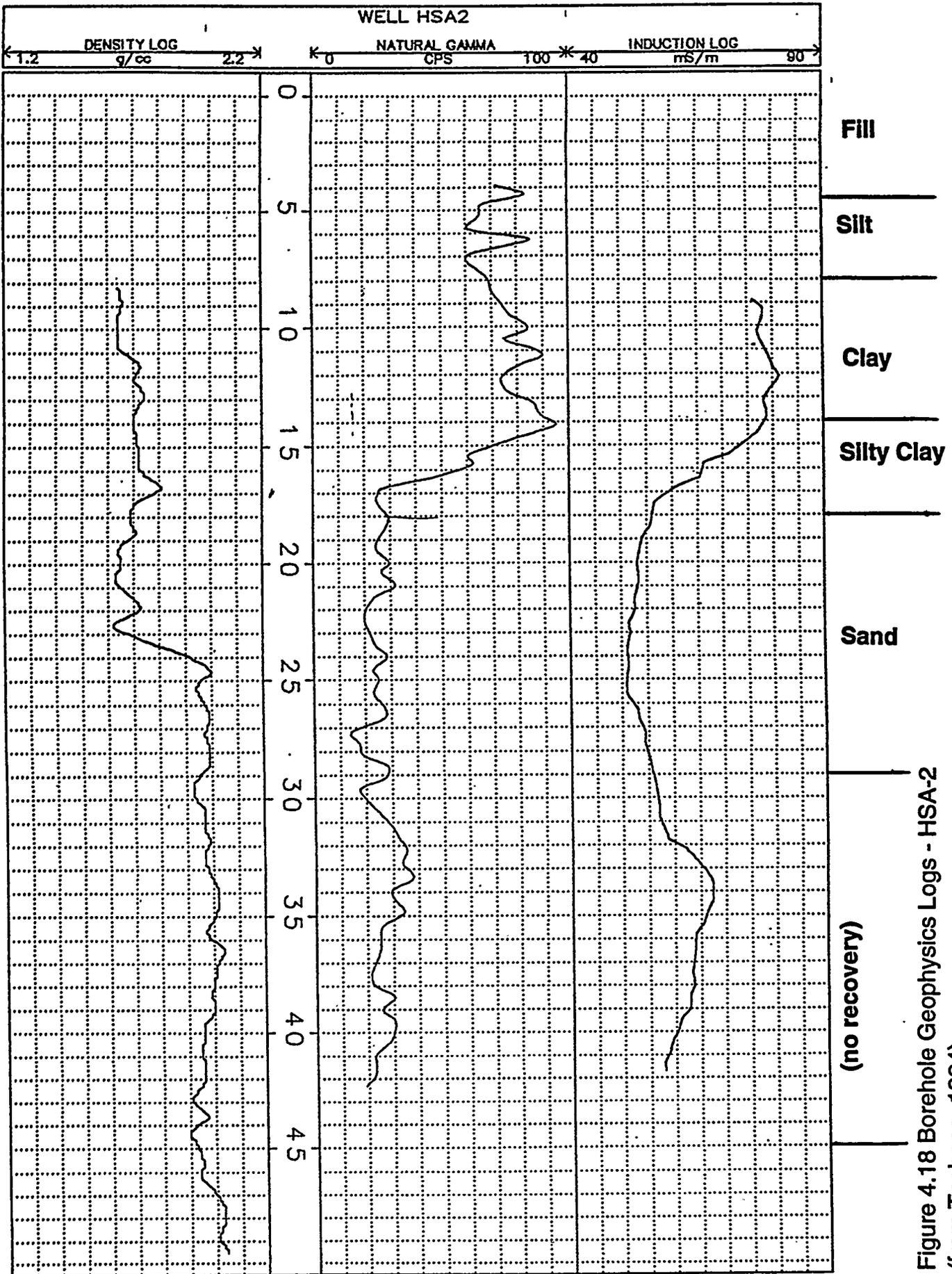


Figure 4.18 Borehole Geophysics Logs - HSA-2
 (from Technos, 1994)

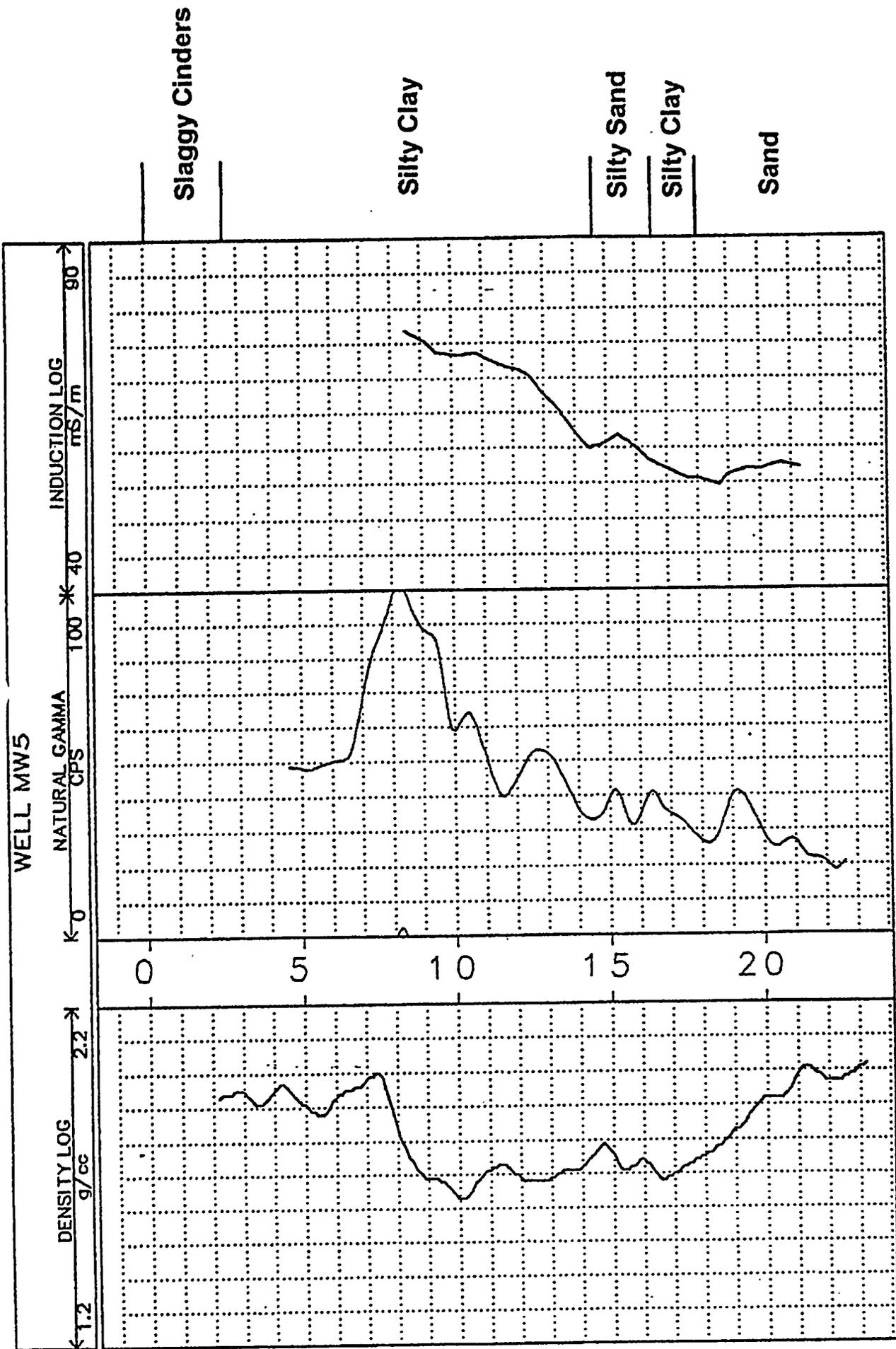


Figure 4.19 Borehole Geophysical Logs -MW5
(from Technos, 1994)

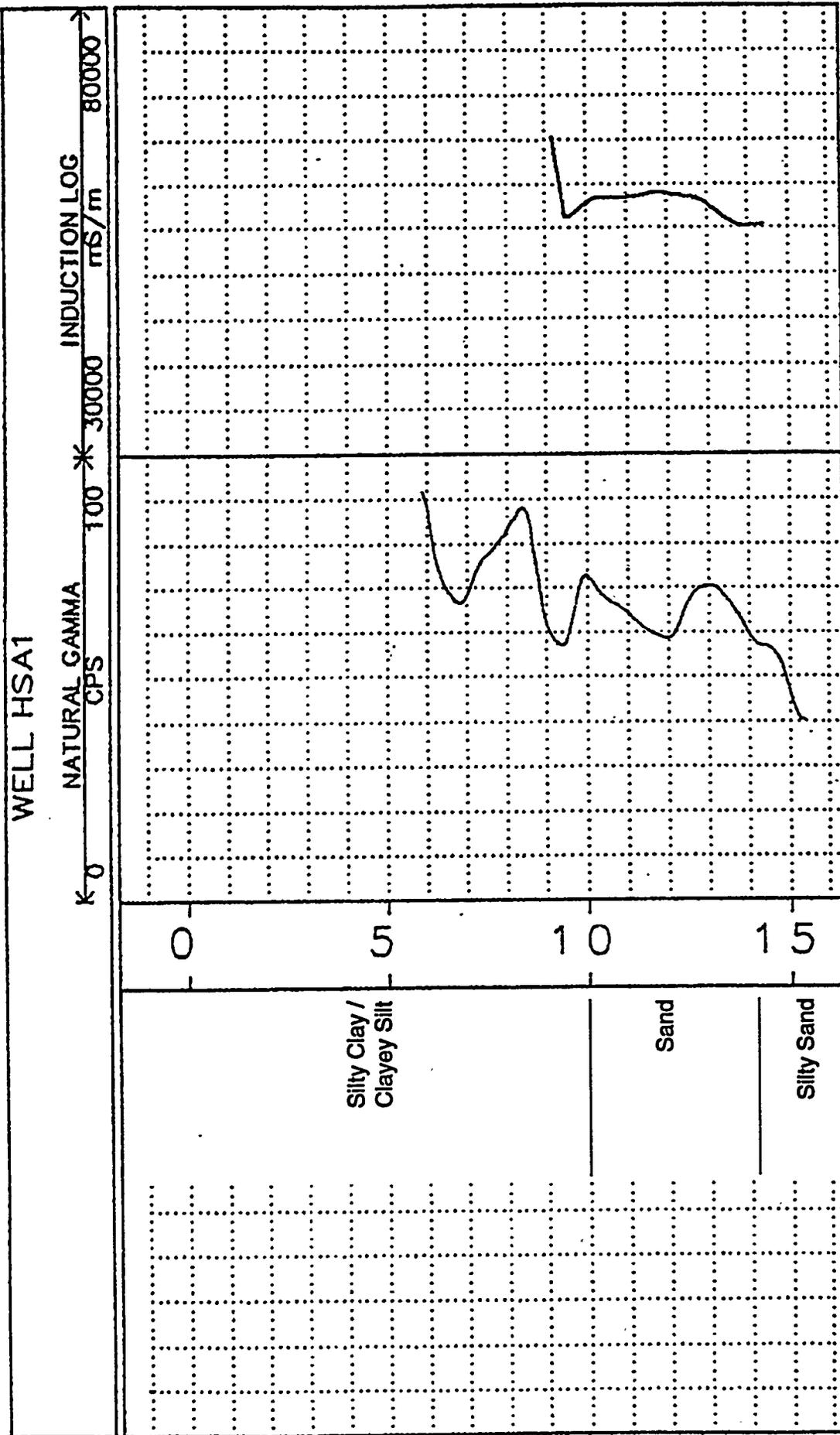
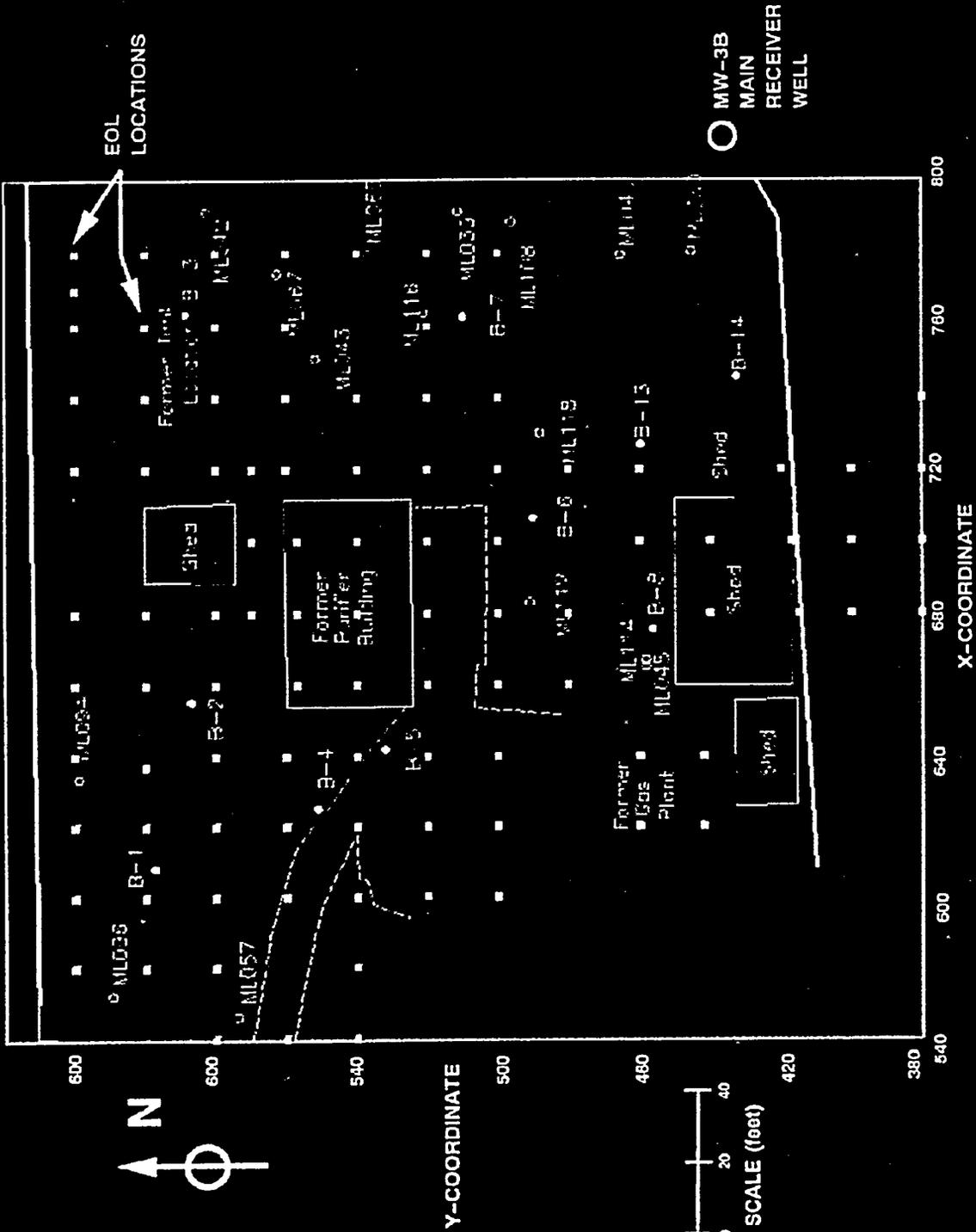


Figure 4.20 Borehole Geophysical Logs - HSA-1 (from Technos, 1994)

Figure 4.21
 Electromagnetic Offset
 Logging - Source and
 Receiver map Locations
 (from GEHM, 1994)



LEGEND:

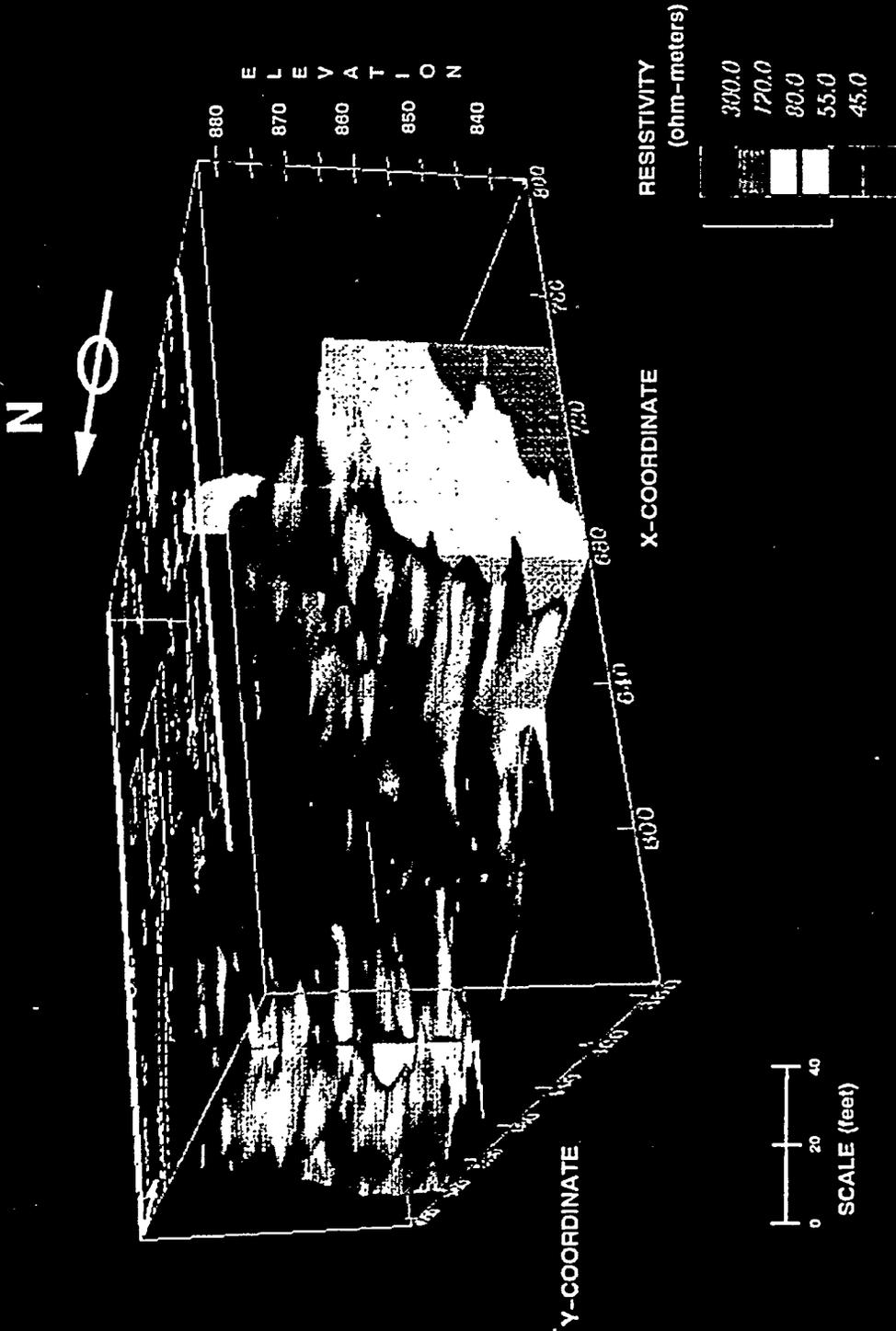
- EM Source Coil (EOL) Locations
- MW-3B EM Receiver Well
- MW-3B Monitor Well
- B-14 Soil Borings
- ML-80 Cone Penetrometer

AMES LABORATORY Project
 Coal Gasification Test Site
 Marshalltown, Iowa

Data Acquired April 1994
 Final Report Submitted July 1994

By The GEHM/Entech Team
 1417 Bingham Road
 Boonville, MO 65223
 816-882-3485

Figure 4.22
 Electromagnetic Offset
 Logging - 3-D Image of
 Resistivity >55 Ohm-
 meters
 (from GEHM, 1994)



LEGEND:

- EM Source Coil (EOL) Locations
- MW-3B EM Receiver Well
- MW-3B Monitor Well
- B-14 Soil Borings
- ML-80 Cone Penetrometer

AMES LABORATORY Project
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 Boonville, MO 65223
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DEPTH TO BEDROCK FROM BOREHOLES AND SEISMIC DATA

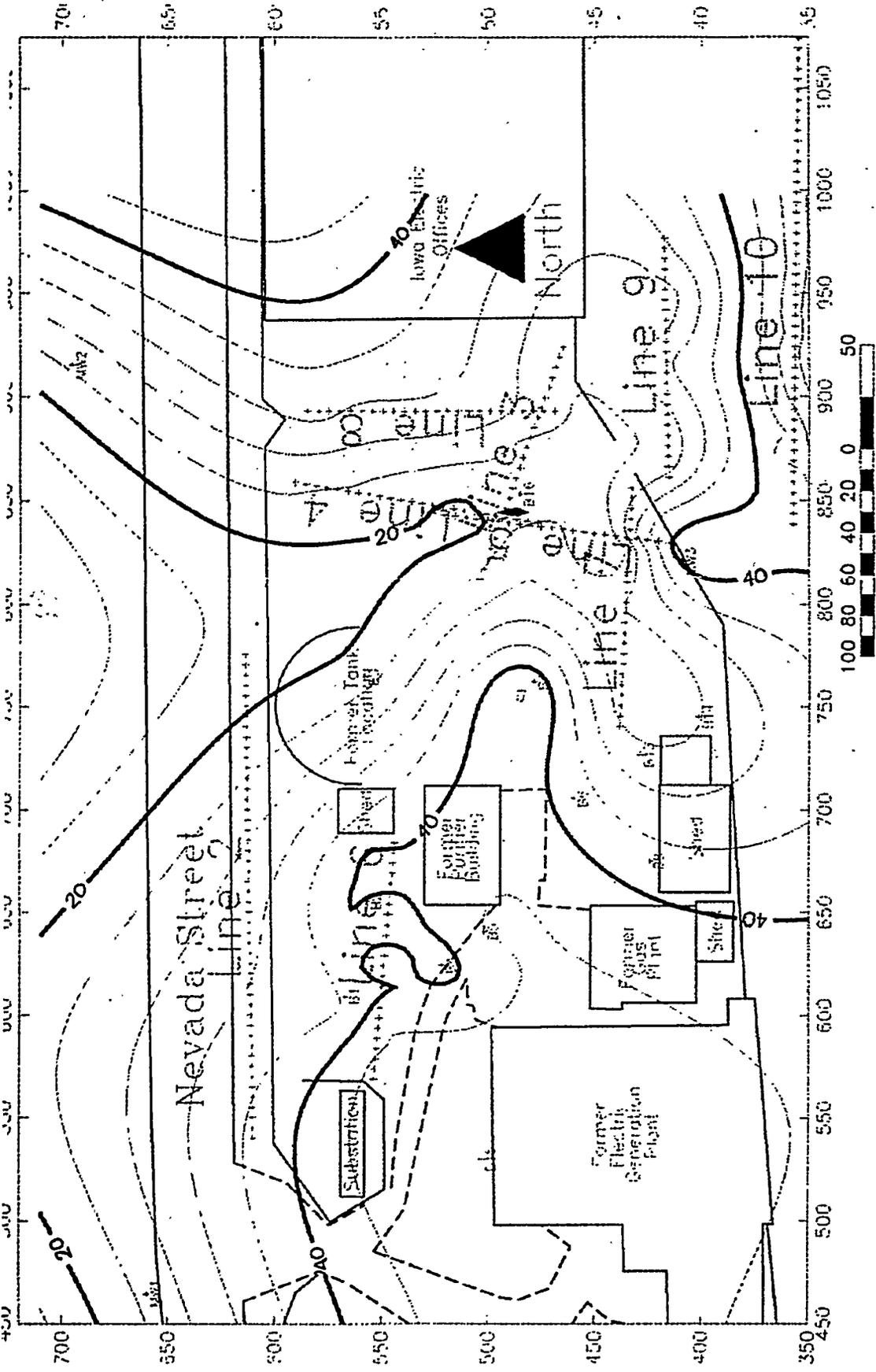


Figure 4.23 Seismic Refraction Survey - Depth to Bedrock from BWST Boreholes and Seismic Refraction Survey Results (from CEES-Blackhawk Geosciences Division)

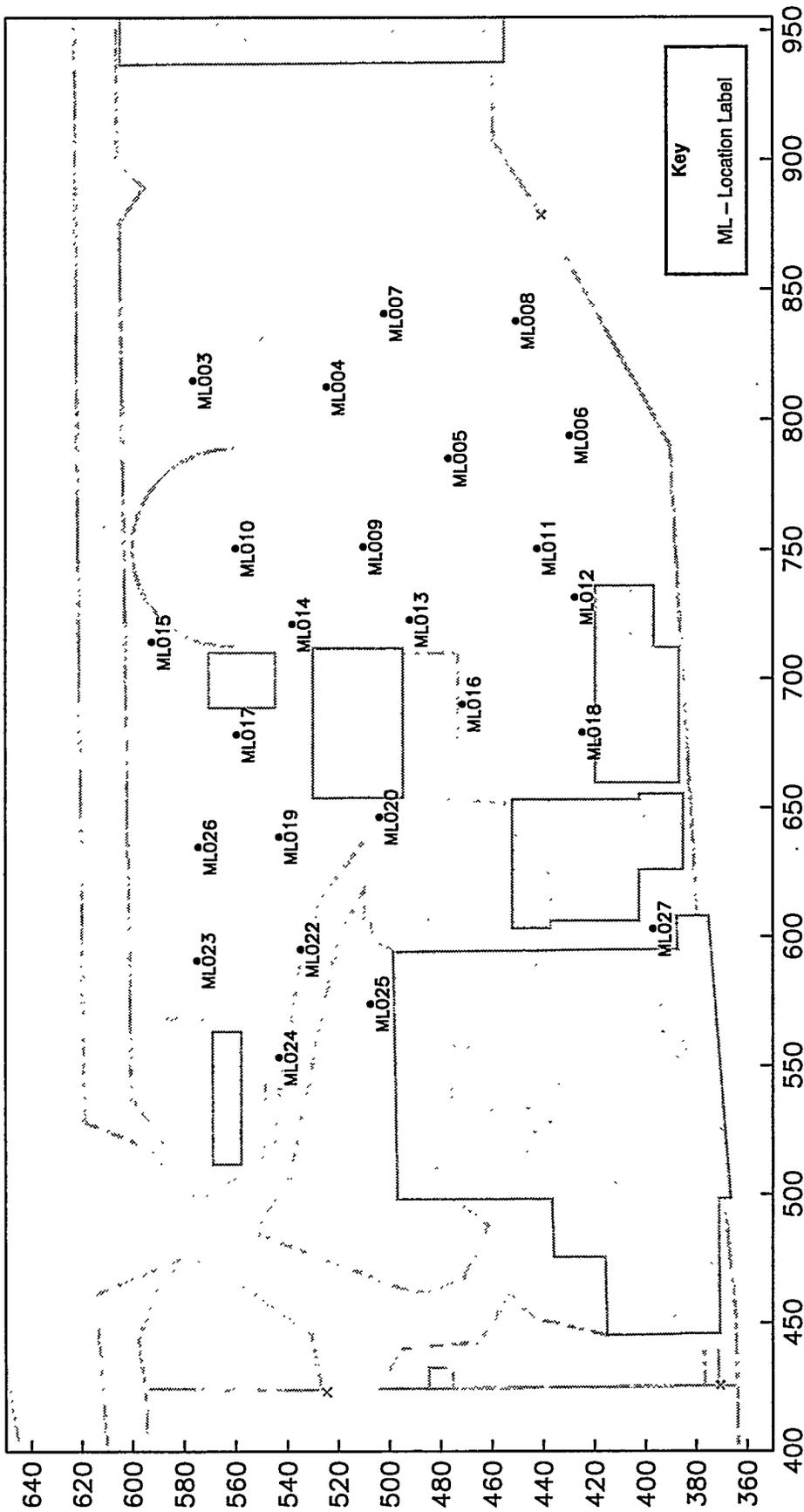


Figure 4.24 ESC Phase I Contaminant Screening Locations

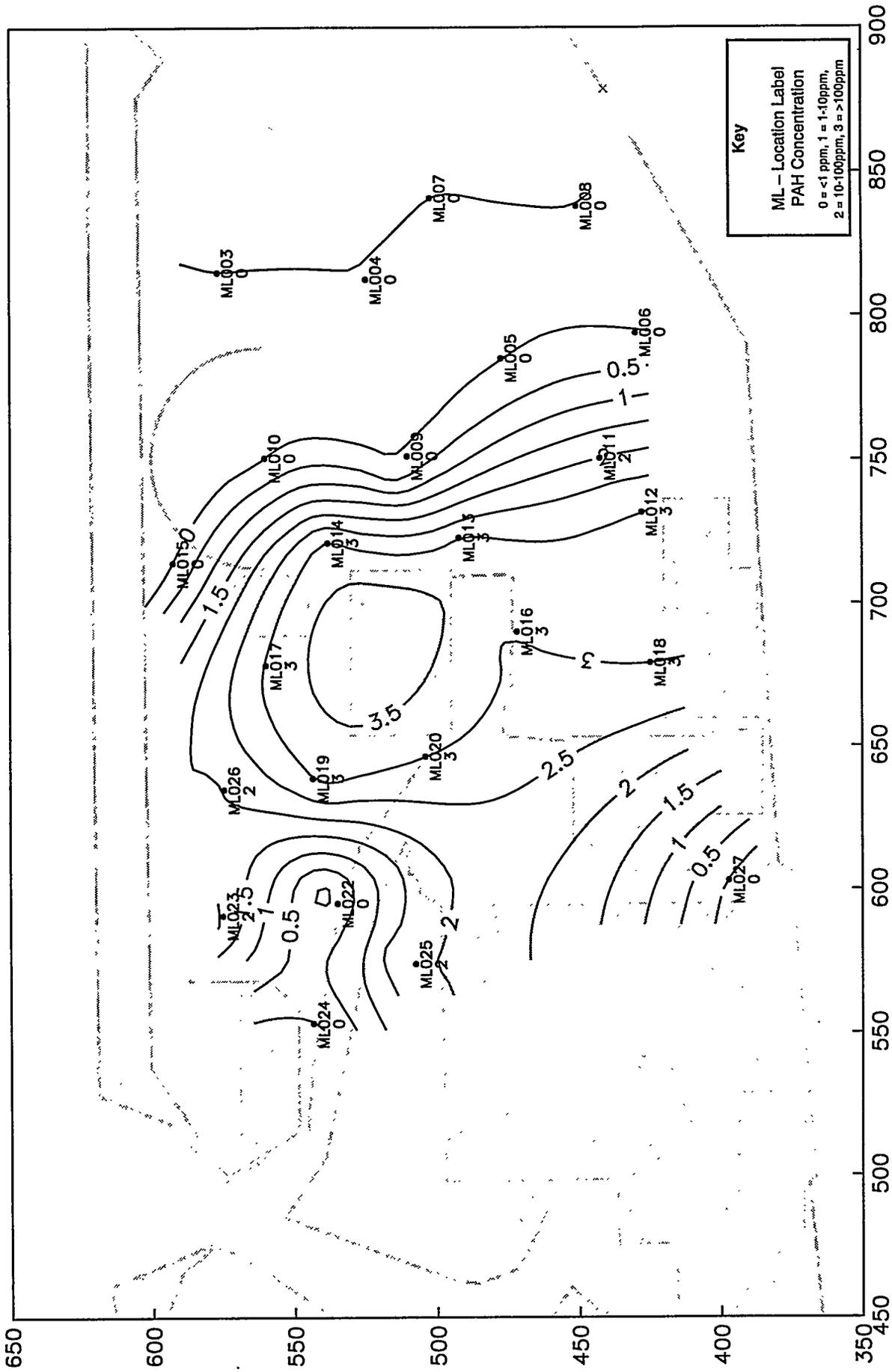


Figure 4.25 IMA Shallow Zone Screening - Ensys

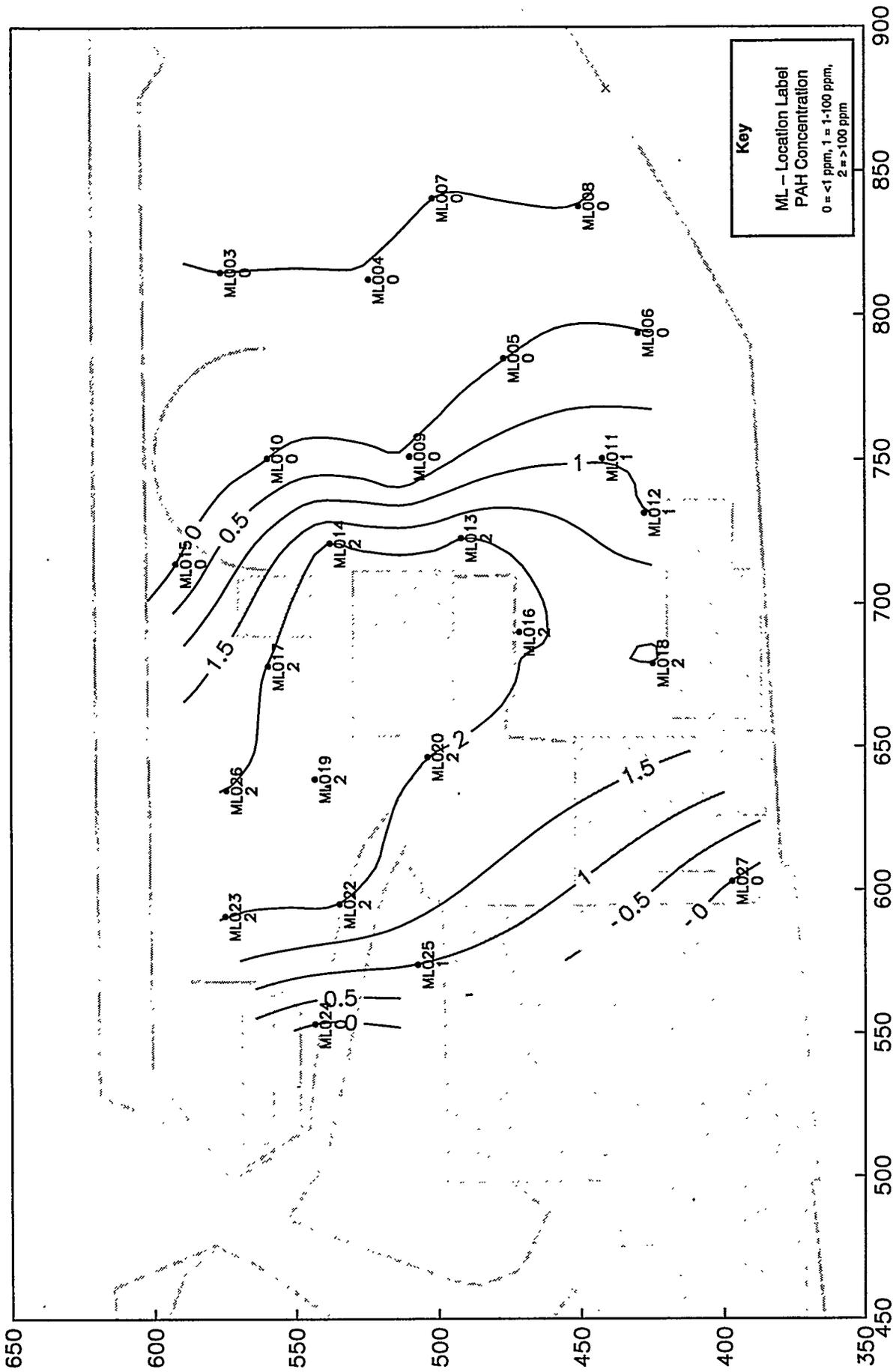


Figure 4.26 IMA Shallow Zone Screening - Millipore

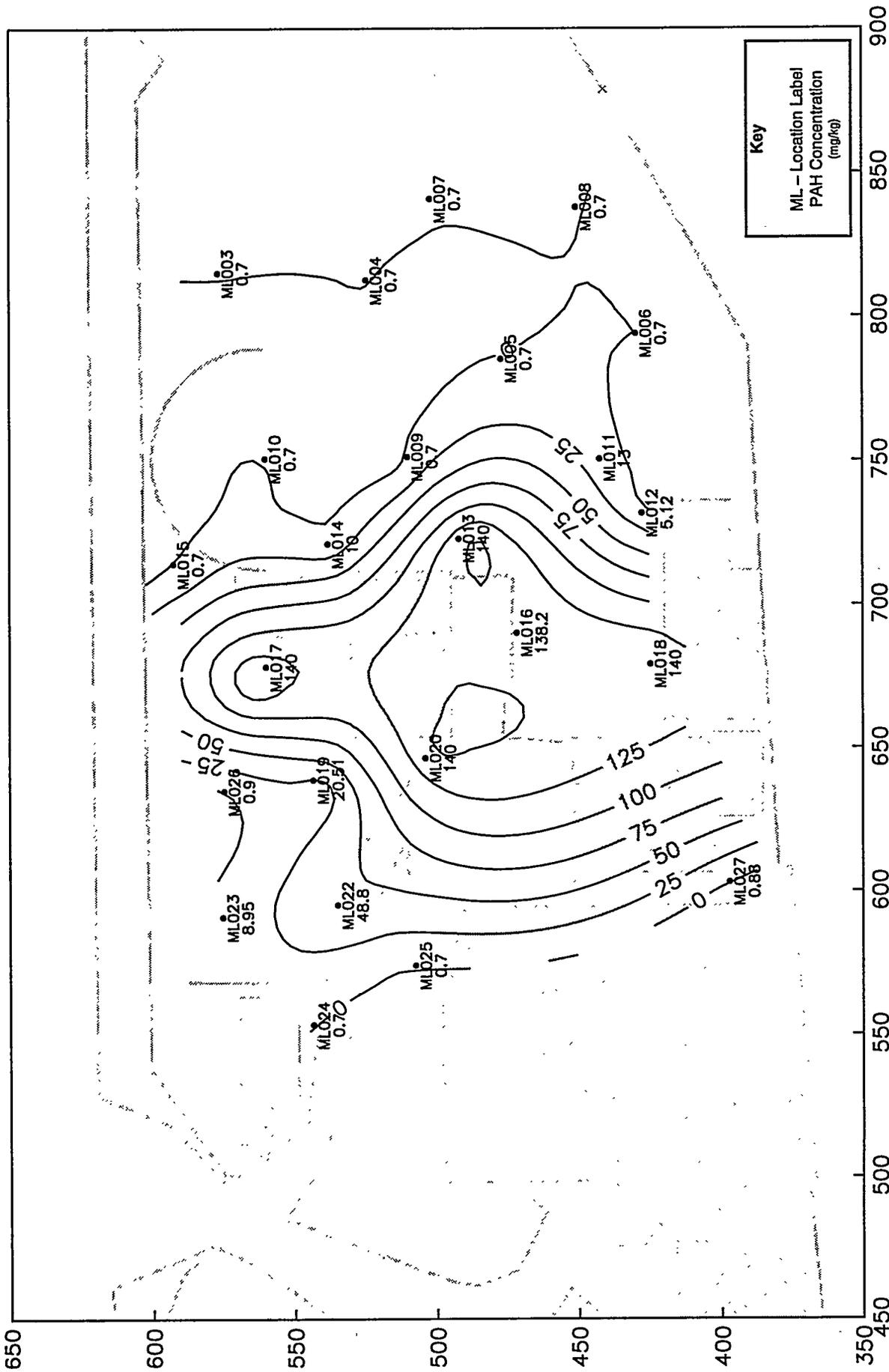


Figure 4.27 IMA Shallow Zone Screening - Quantix

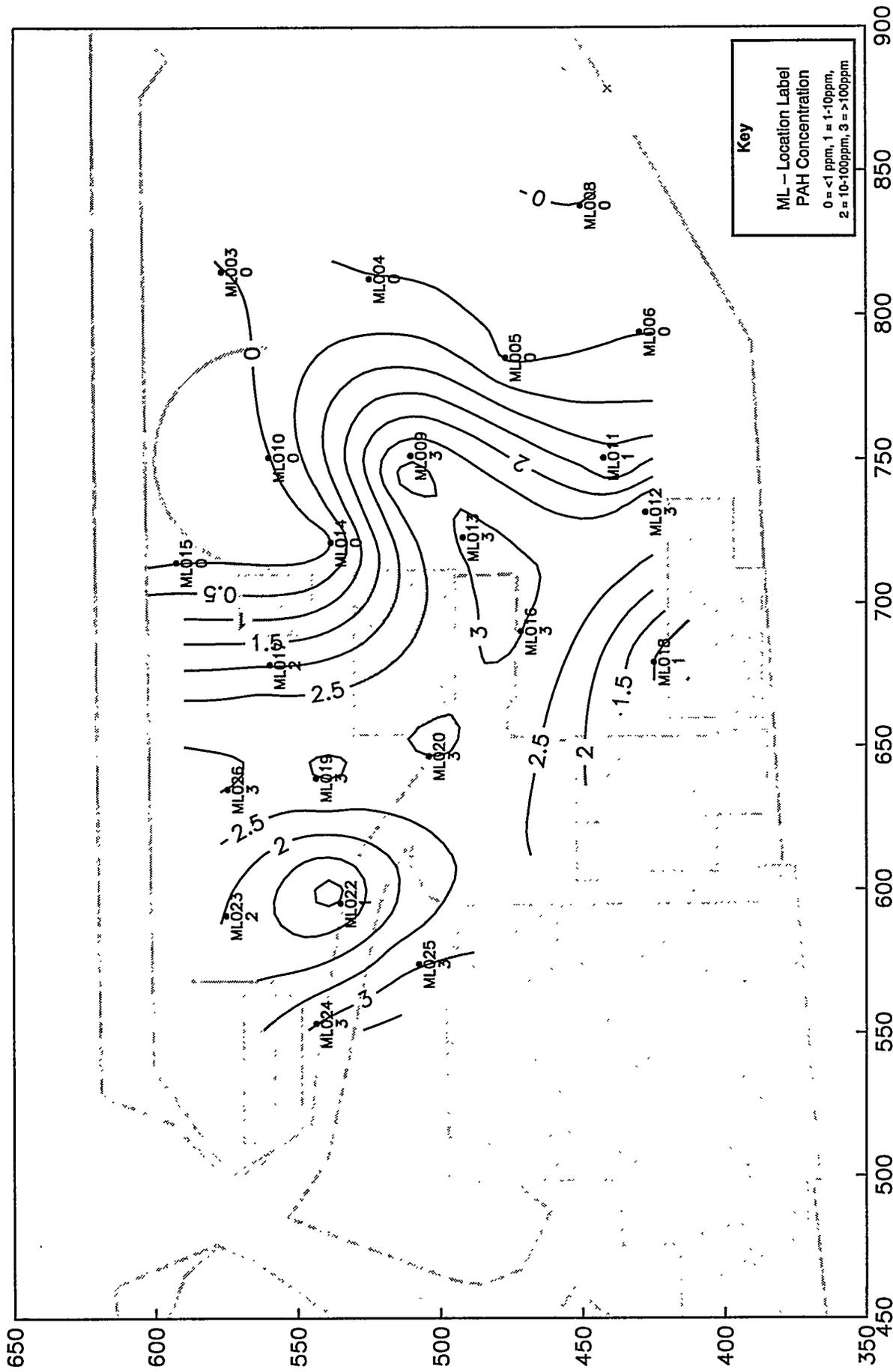


Figure 4.28 IMA Deep Zone Screening - Ensys

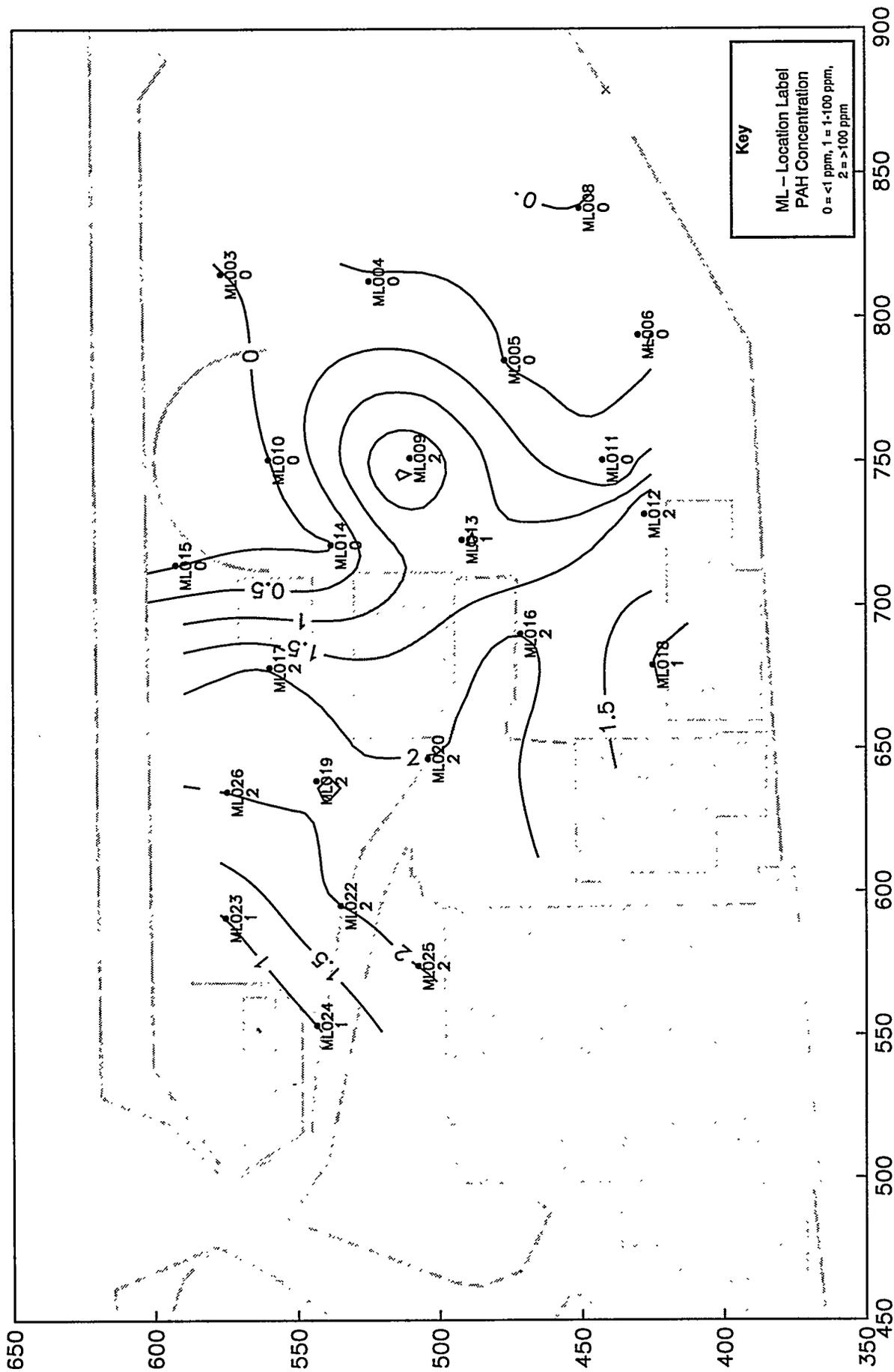


Figure 4.29 IMA Deep Zone Screening - Millipore

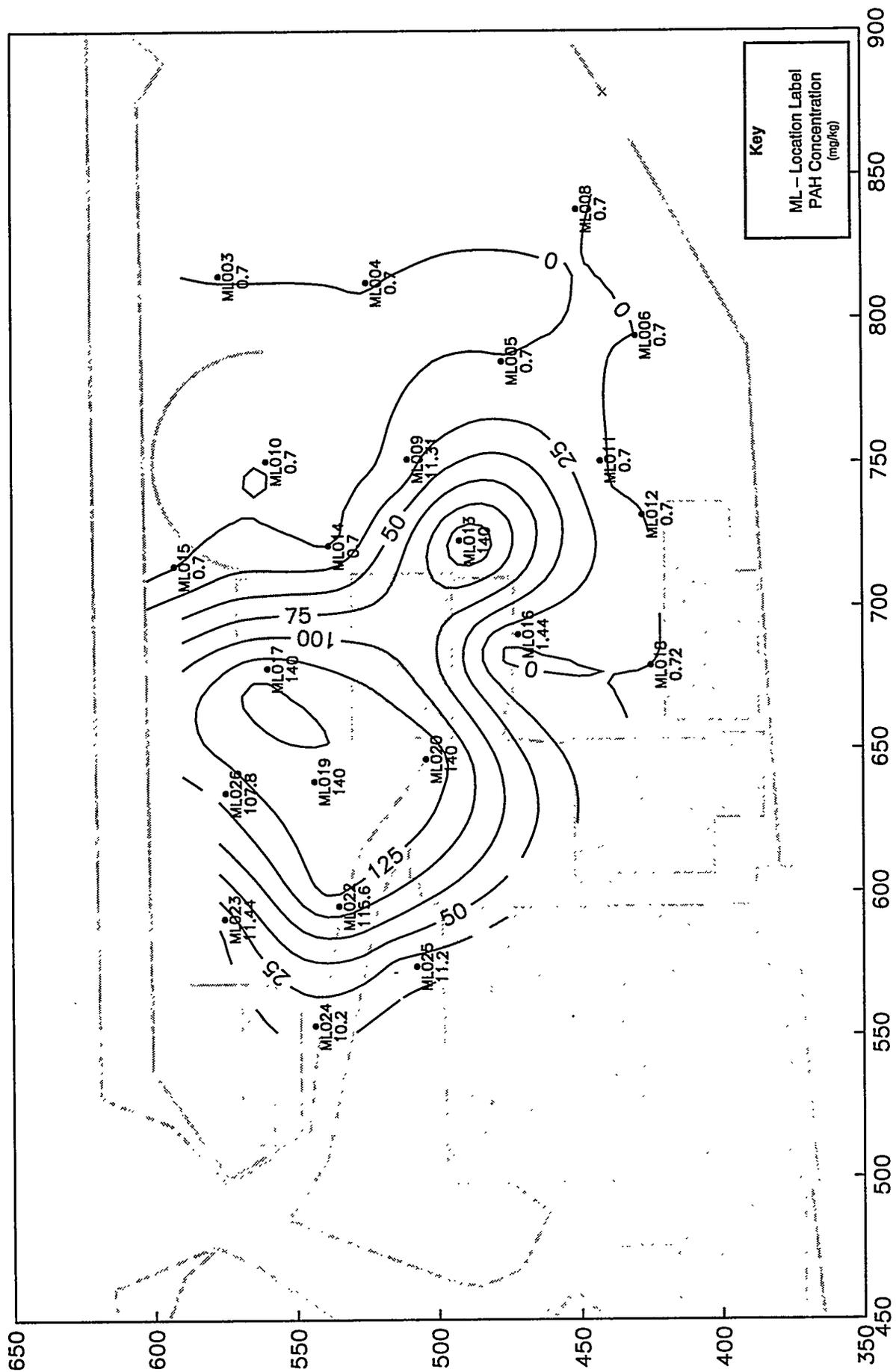


Figure 4.30 IMA Deep Zone Screening - Quantix

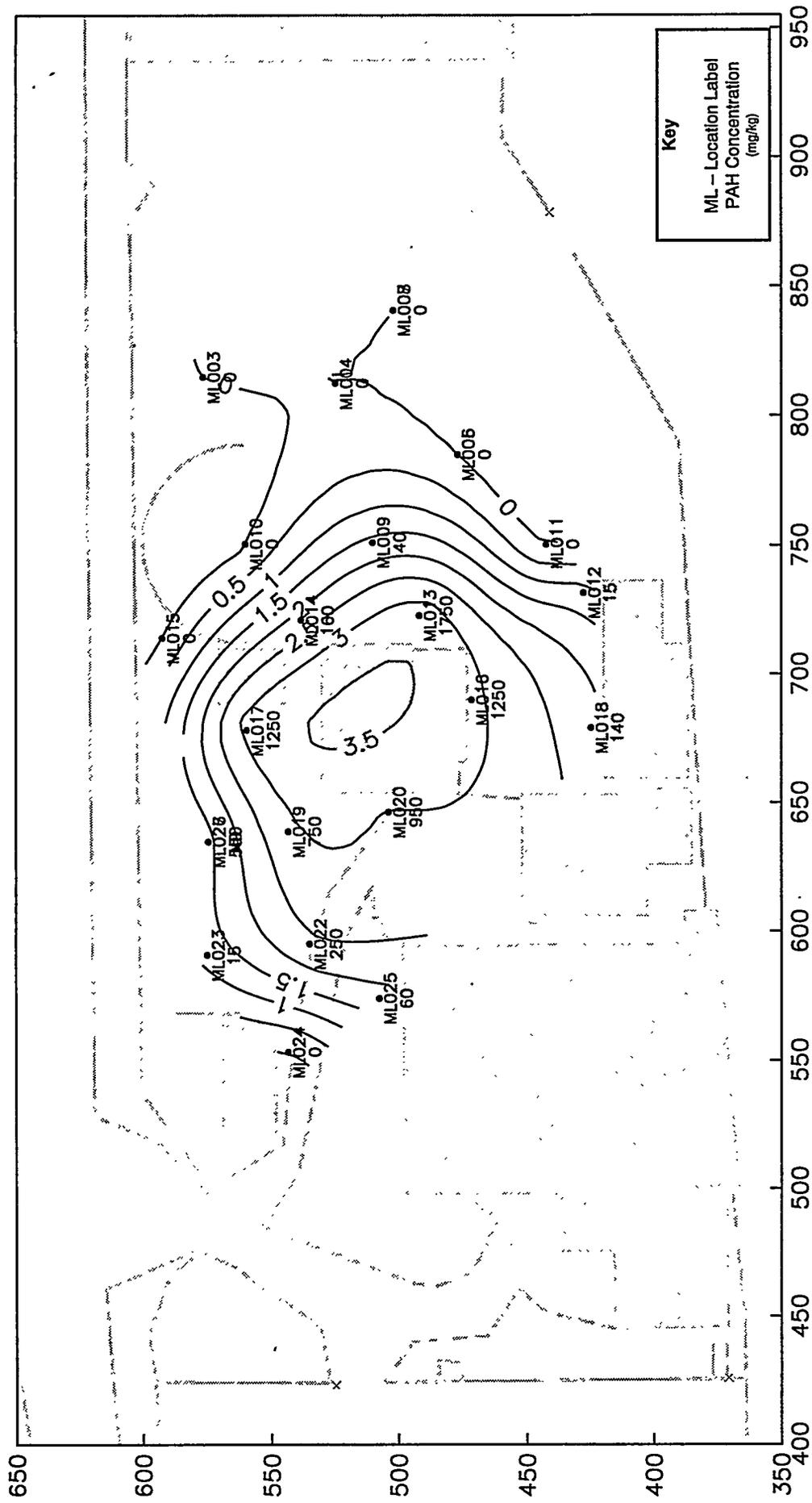


Figure 4.31 Chemiluminescence Shallow Zone Screening

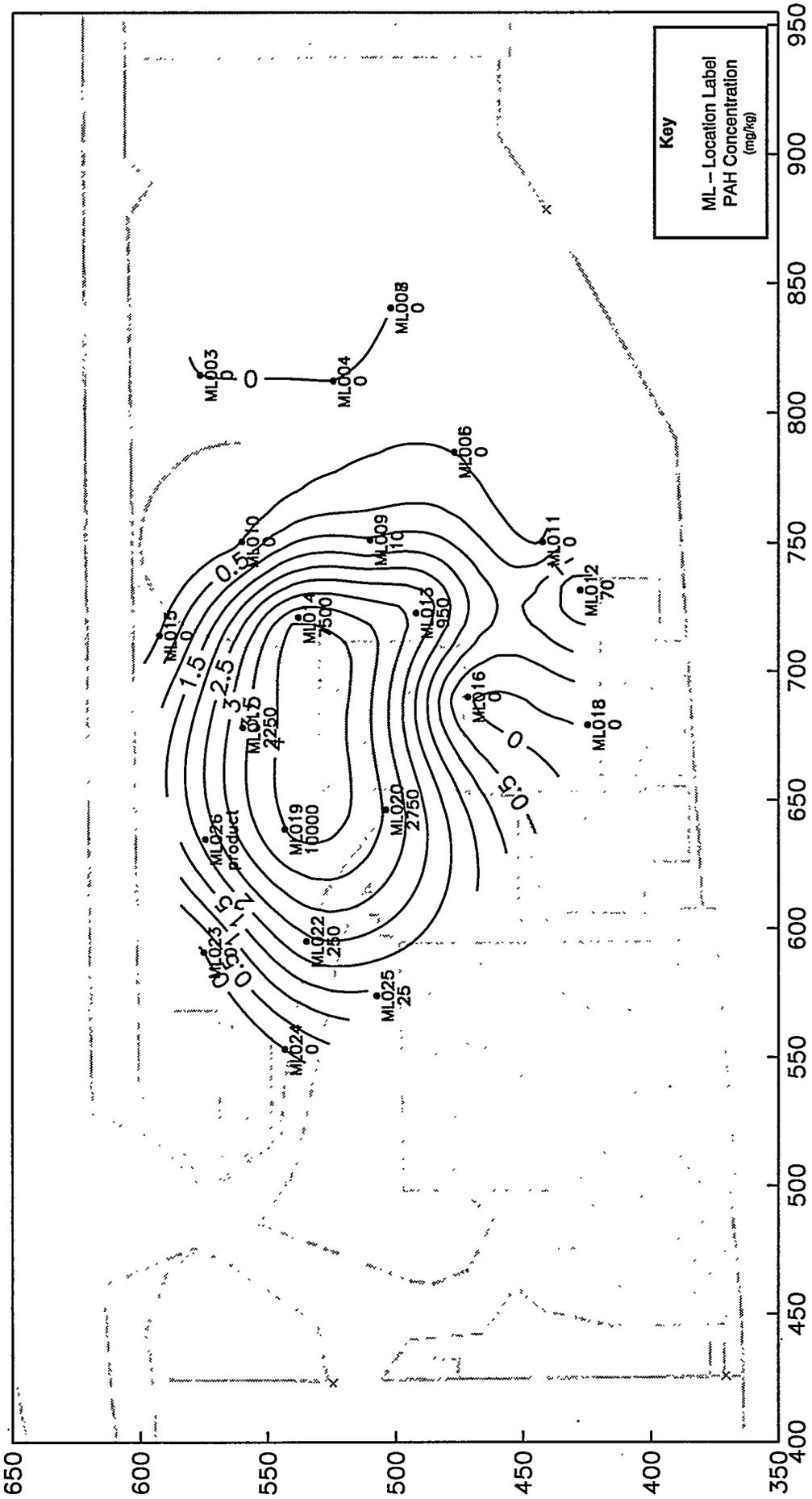


Figure 4.32 Chemiluminescence Deep Zone Screening

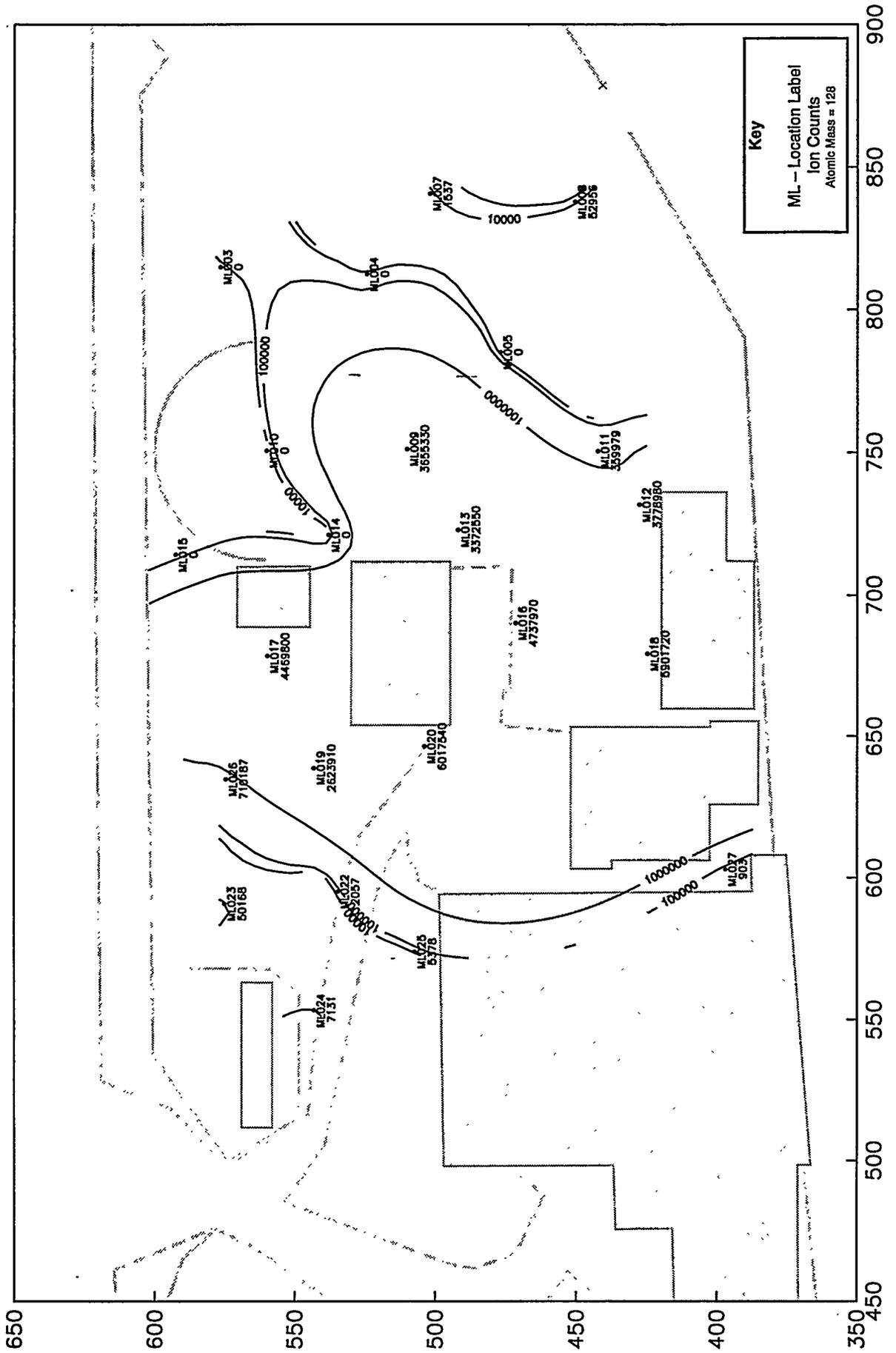


Figure 4.33 Passive Soil Vapor Shallow Zone Screening - Naphthalene

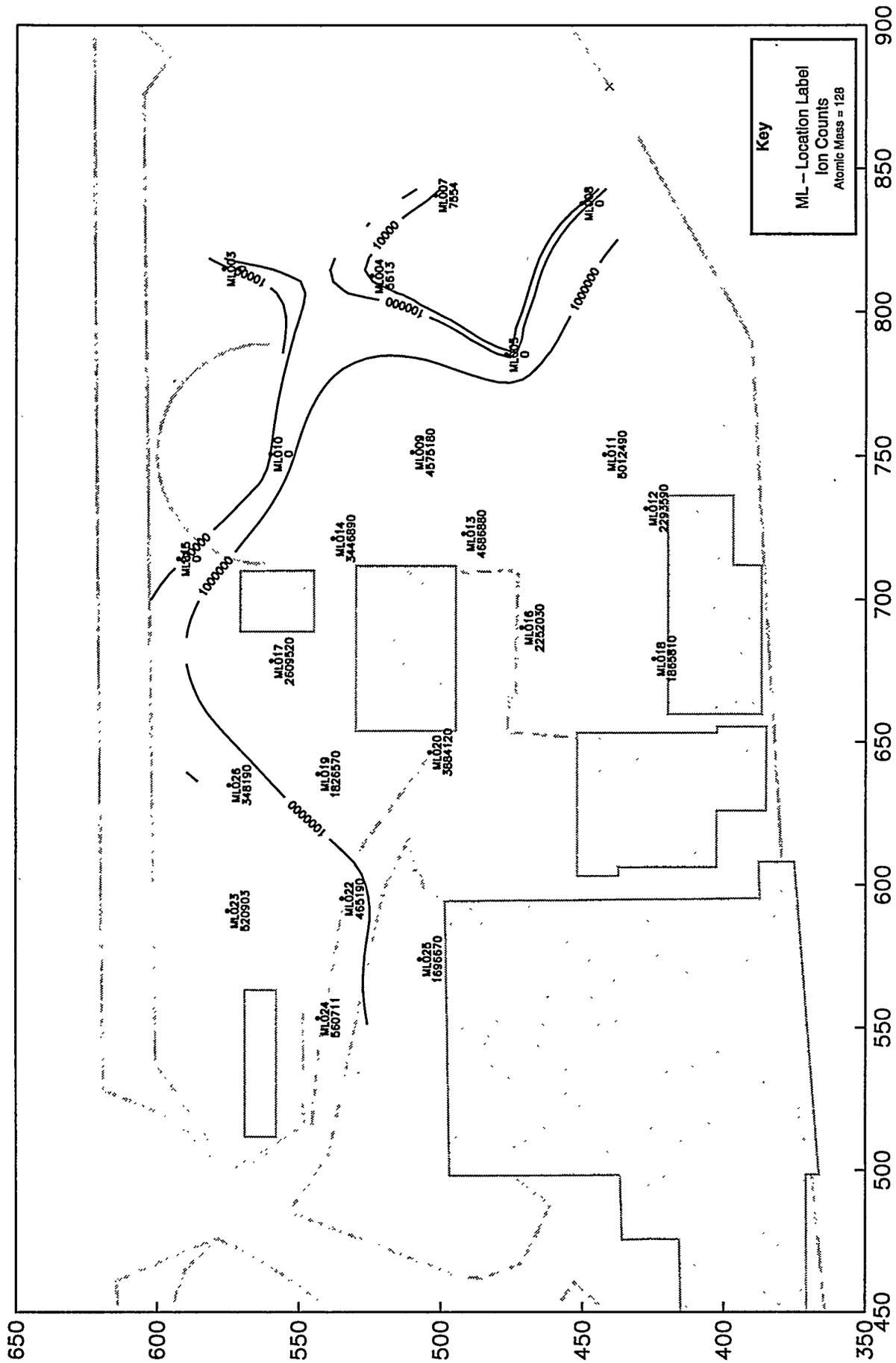


Figure 4.34 Passive Soil Vapor Deep Zone Screening - Naphthalene

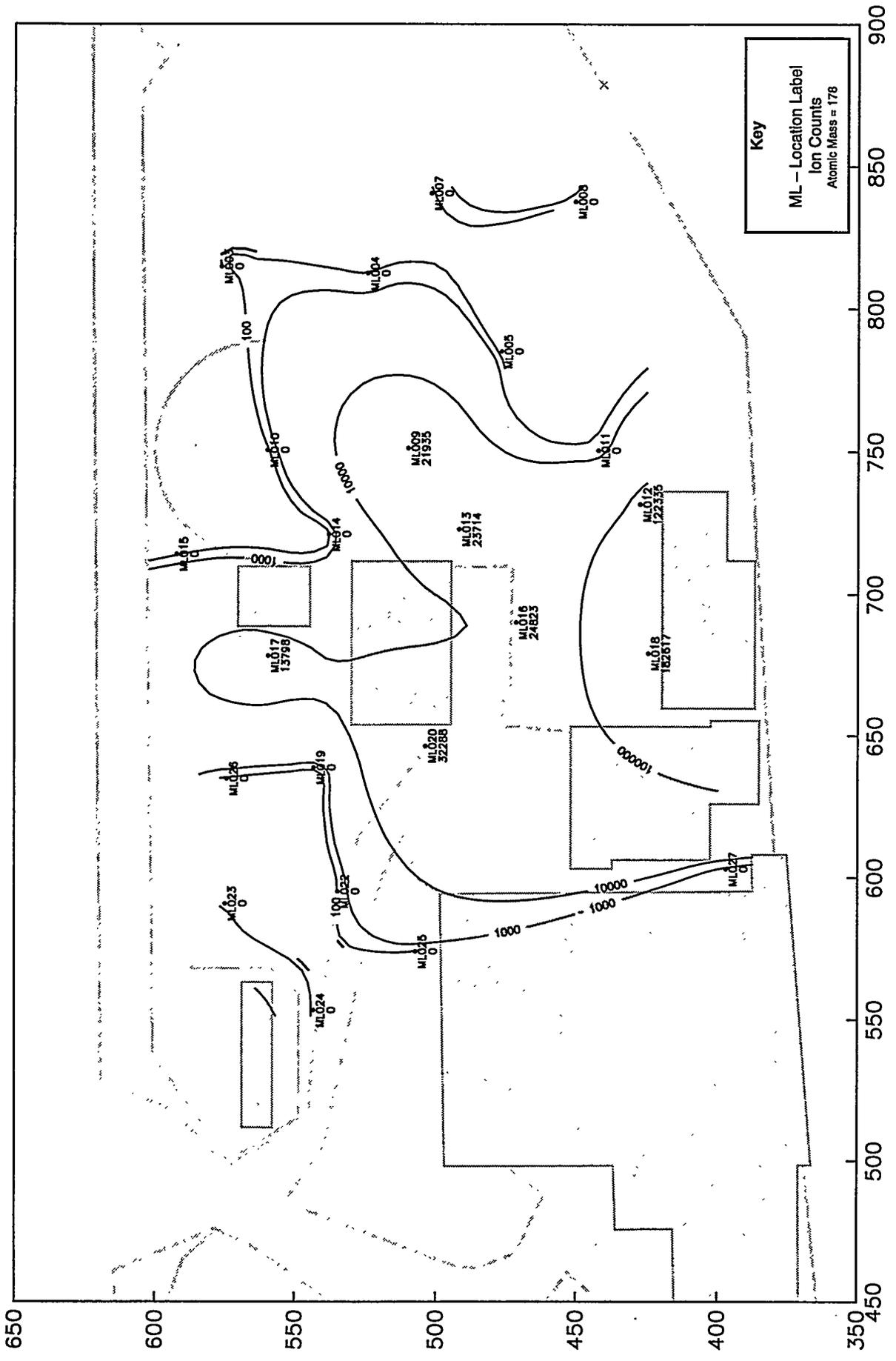


Figure 4.35 Passive Soil Vapor Shallow Zone Screening - Anthracene/Phenanthrene

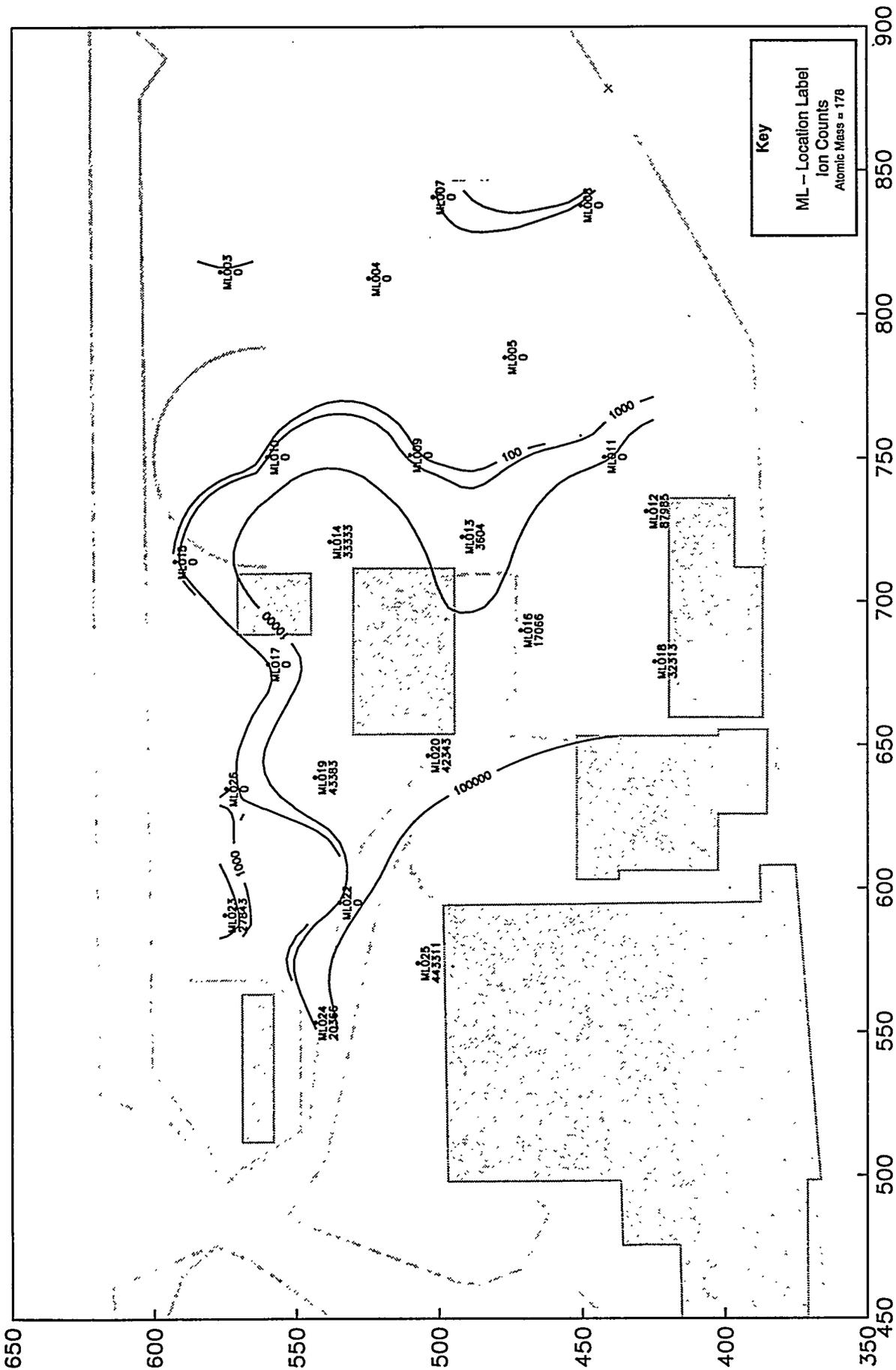


Figure 4.36 Passive Soil Vapor Deep Zone Screening - Anthracene/Phenanthrene

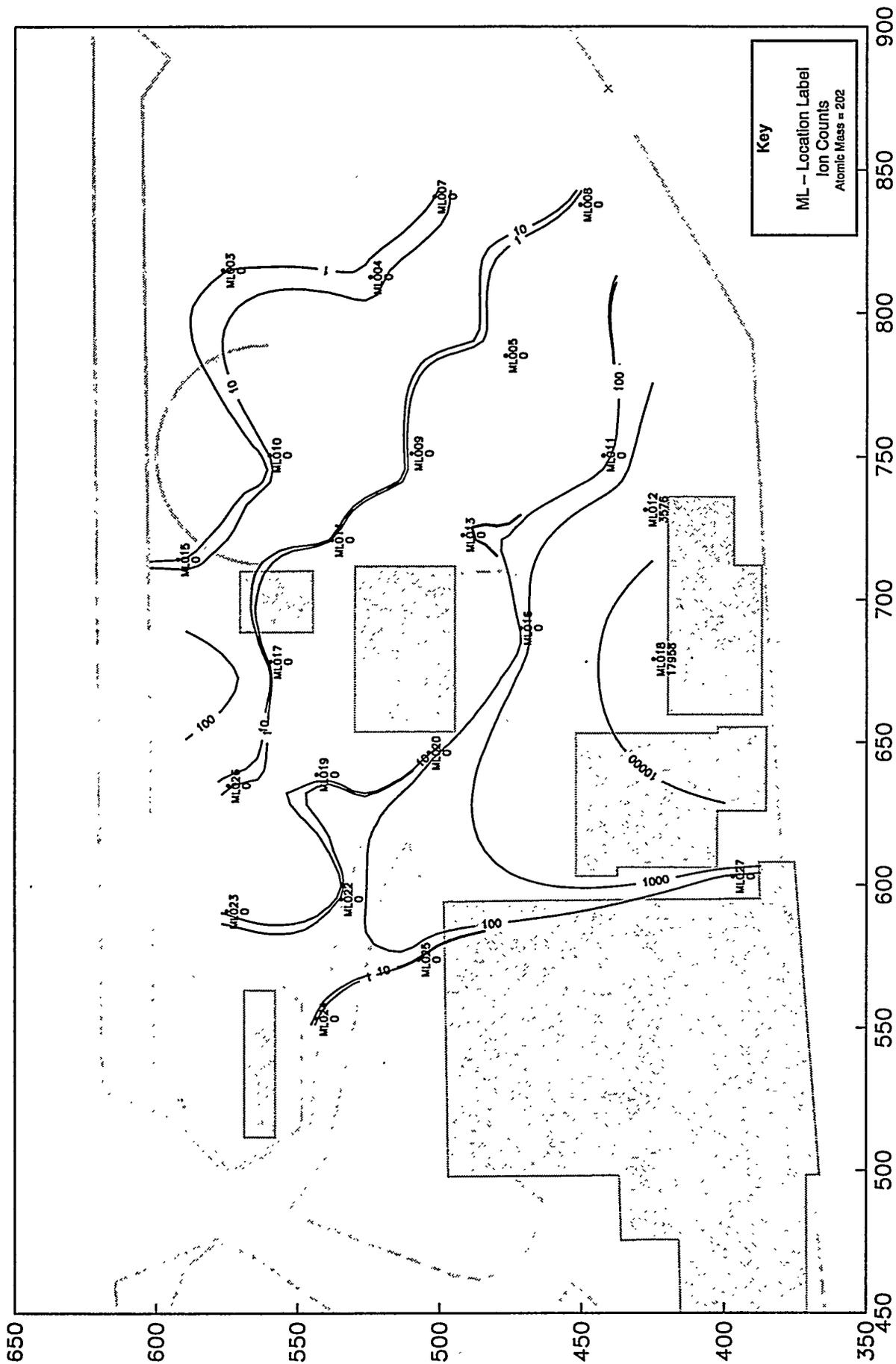


Figure 4.37 Passive Soil Vapor Shallow Zone Screening - Fluoranthene/Pyrene

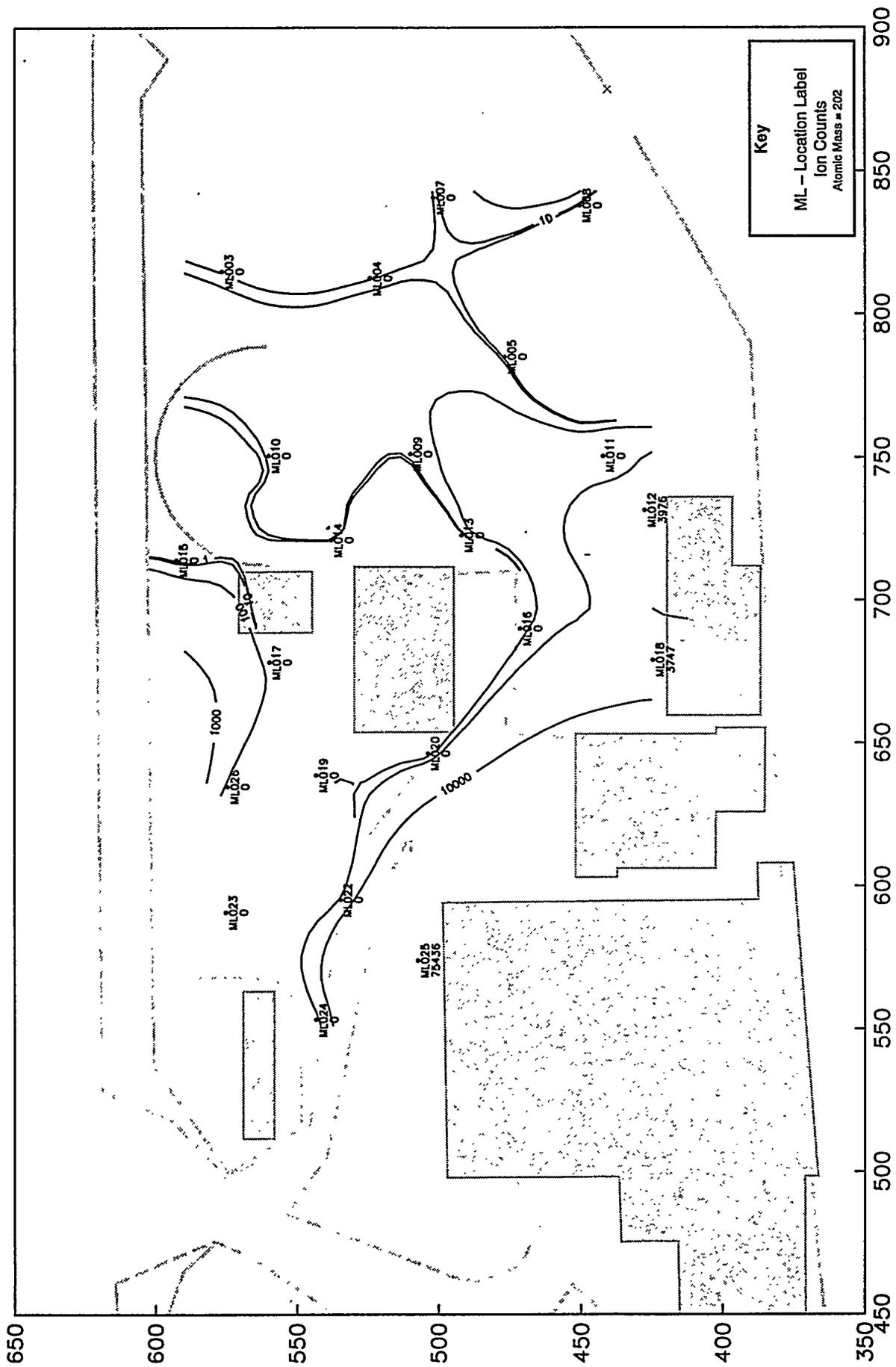


Figure 4.38 Passive Soil Vapor Deep Zone Screening - Fluoranthene/Pyrene

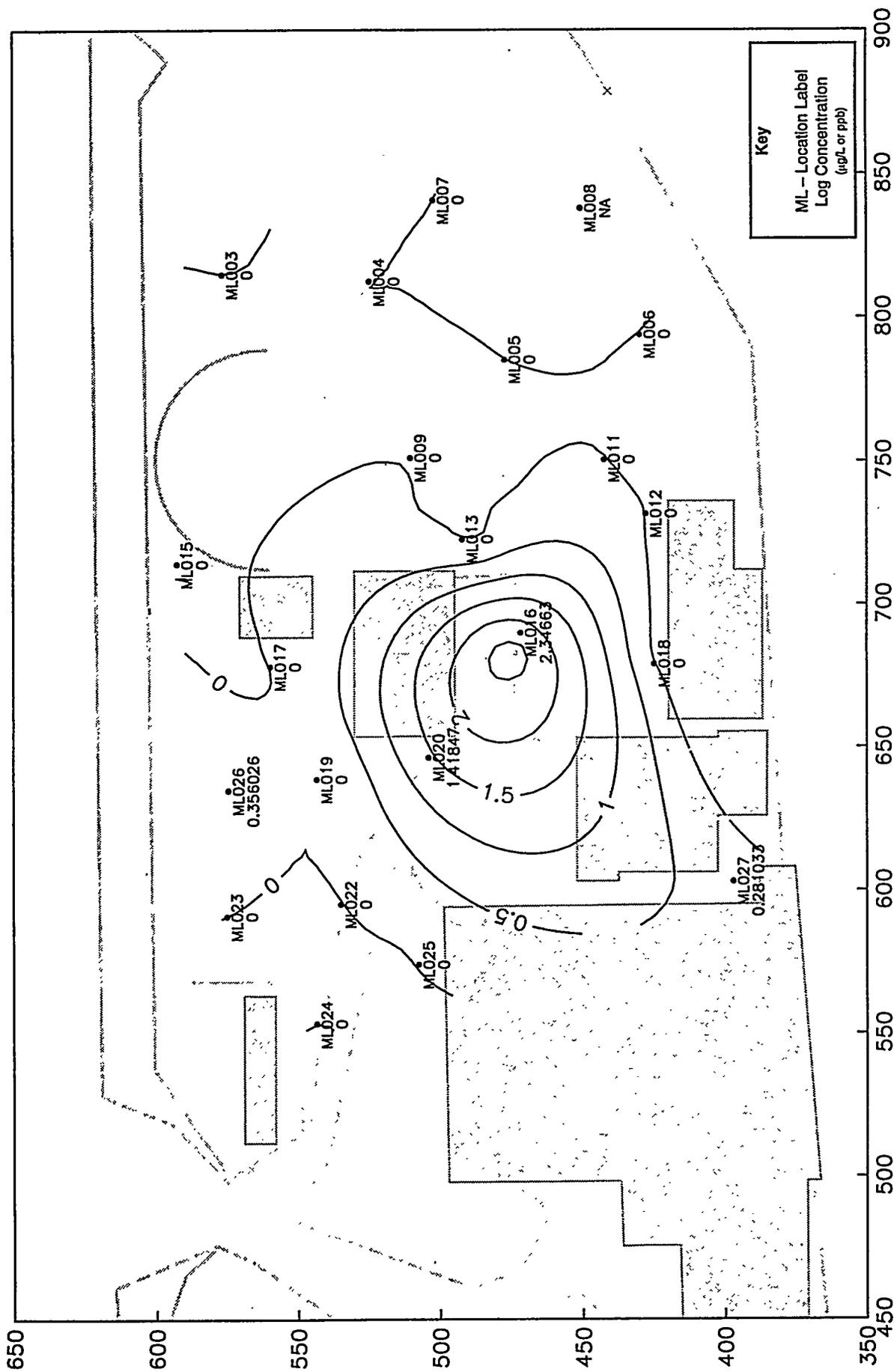


Figure 4.39 Active Soil Vapor Shallow Zone Screening - Naphthalene

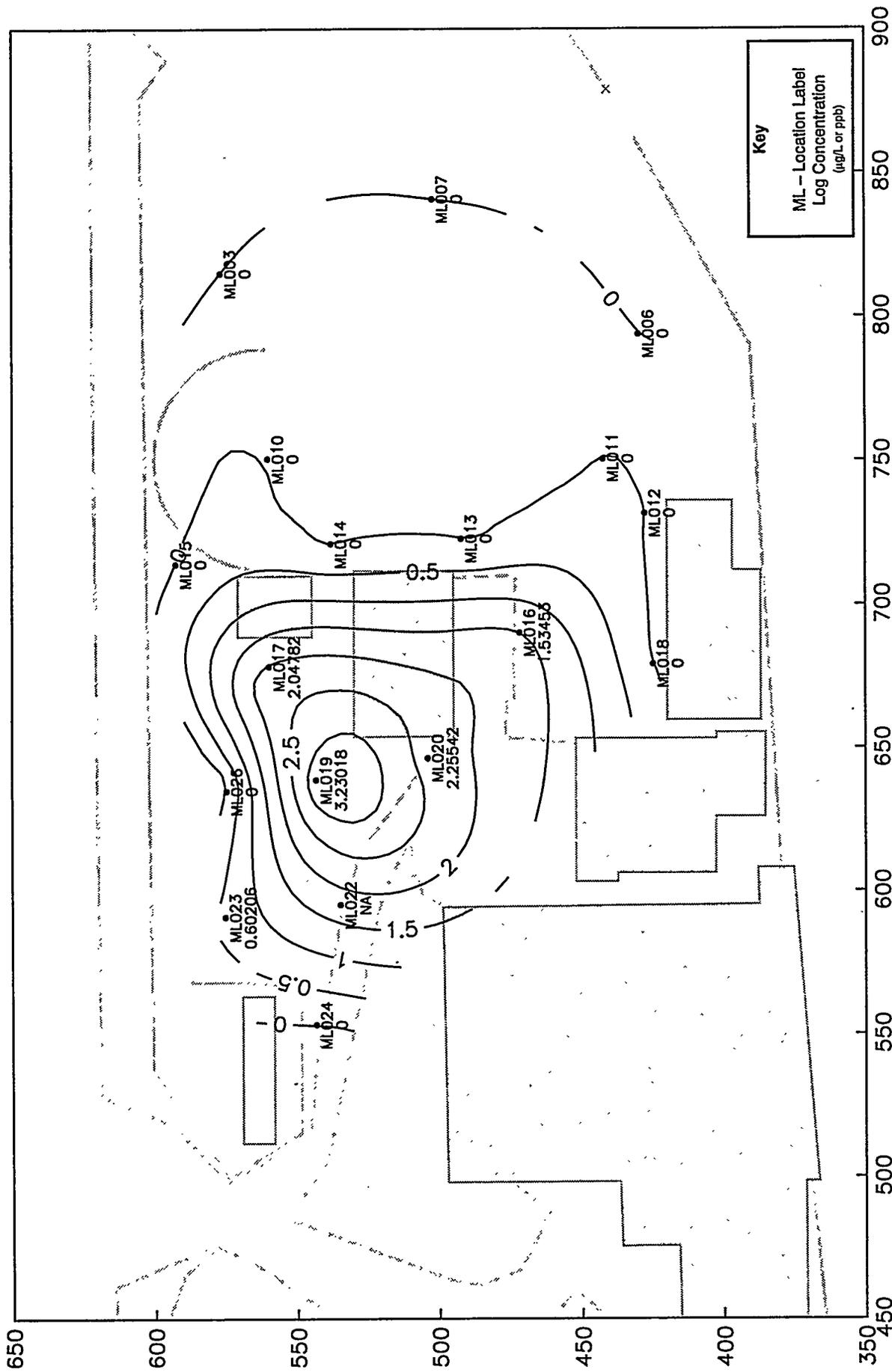
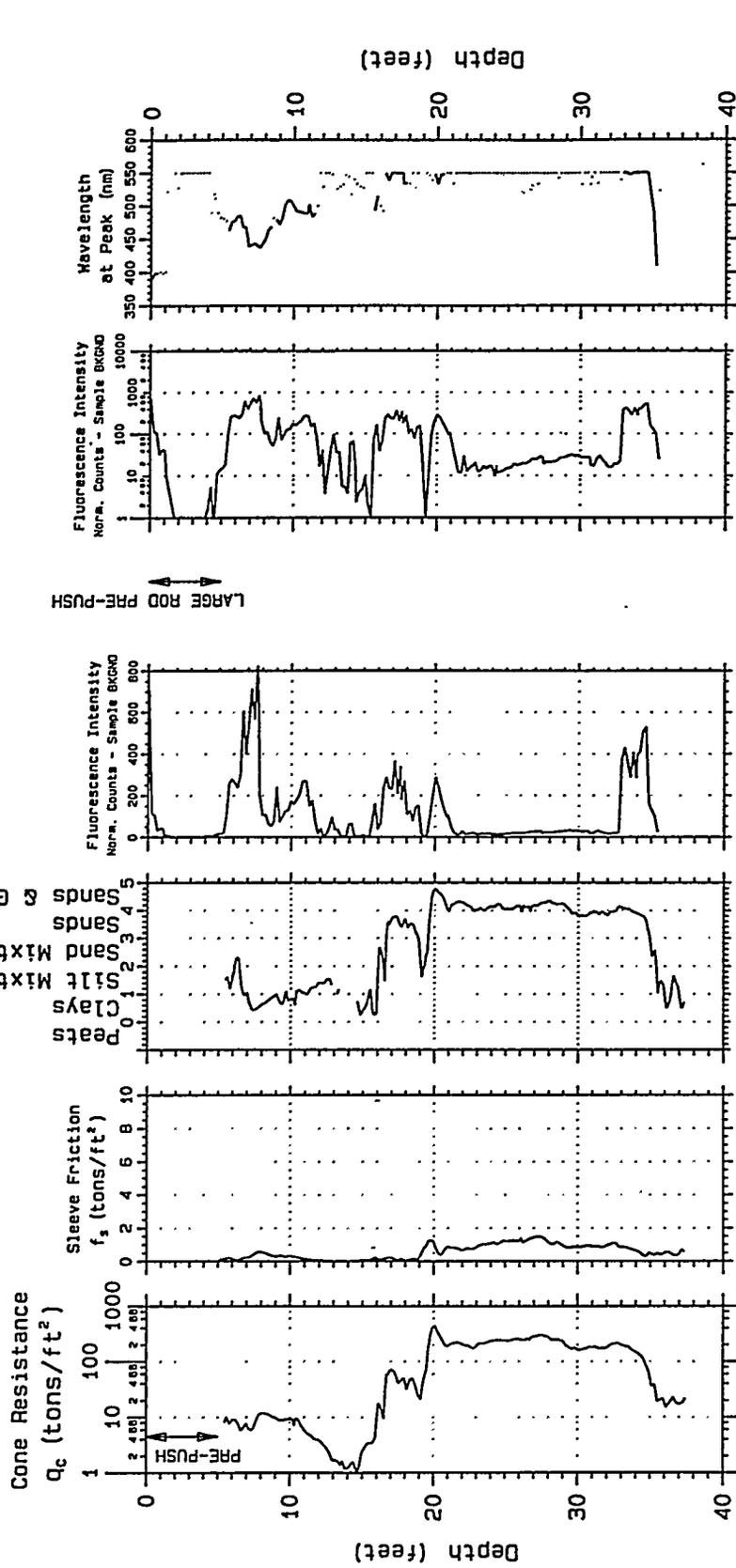


Figure 4.40 Active Soil Vapor Deep Zone Screening - Naphthalene

CPT based SOIL CLASSIFICATION



CPT: 98MT109F
 STATE COORDINATES:
 EASTING (ft.) -1
 NORTHING (ft.) -1

ELEVATION (ft.) 0

Project: Marshalltown

Probe date 05-05-1994

Figure 4.41 CPT Panel Plot for ML-109

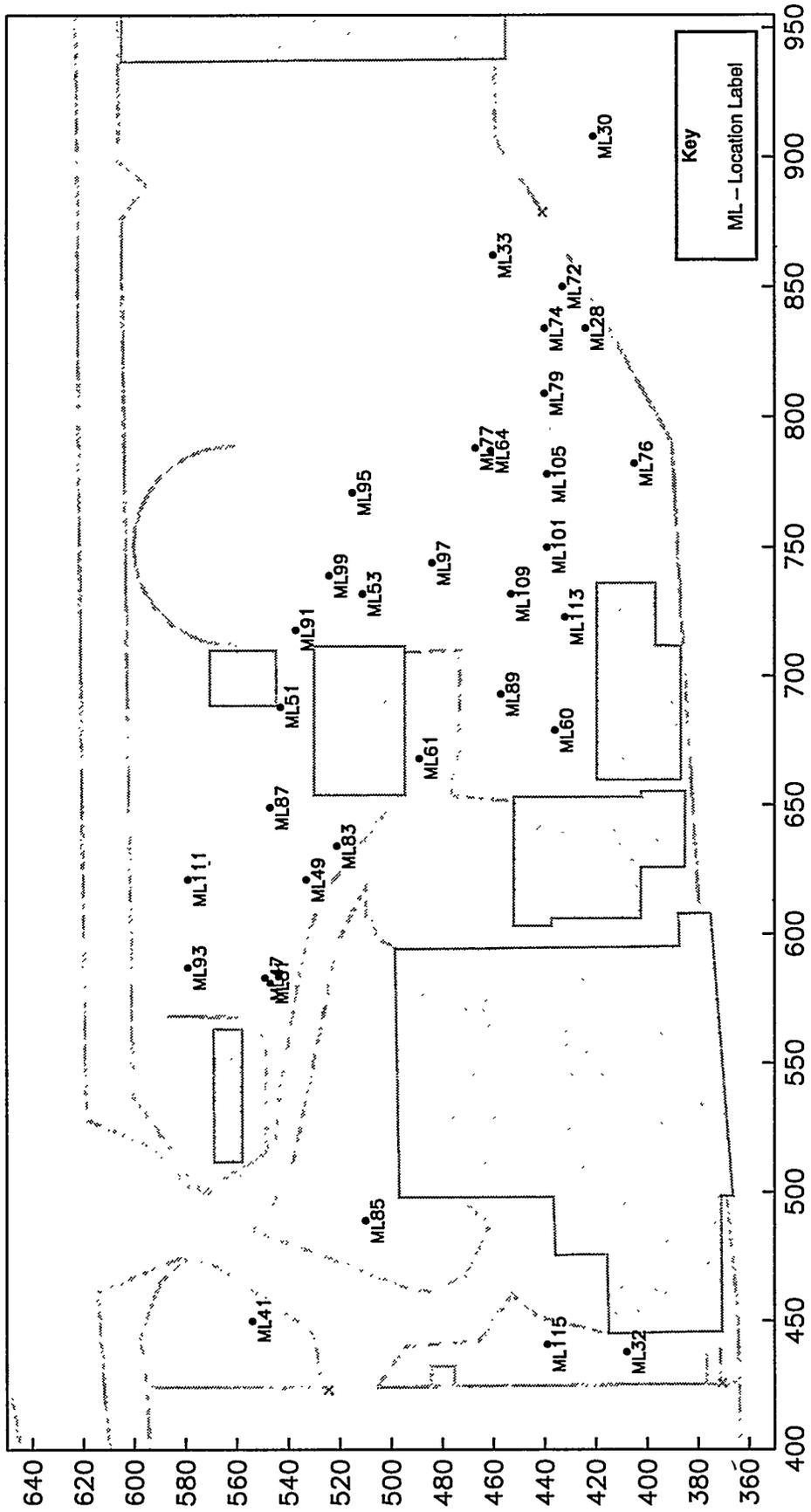
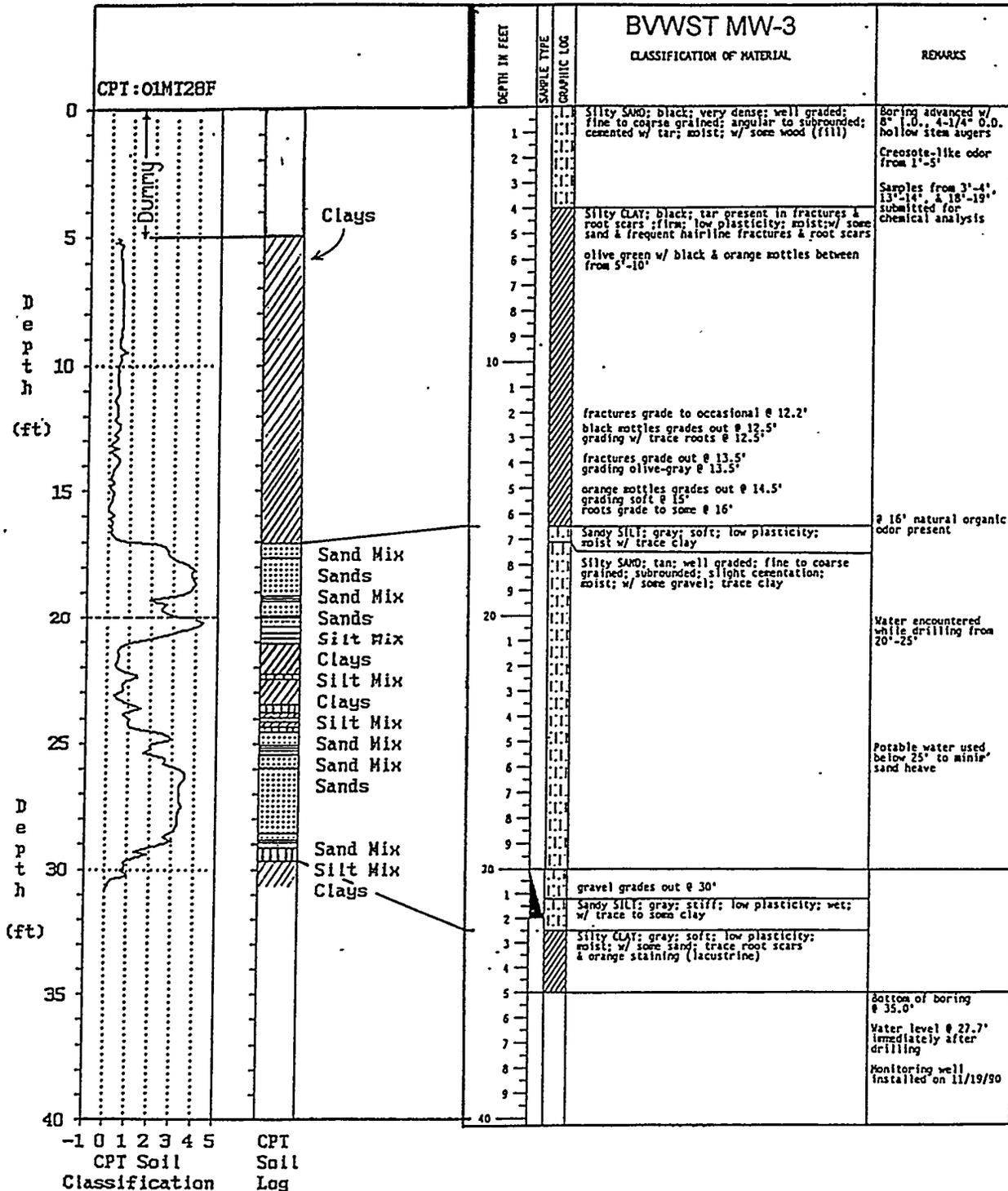


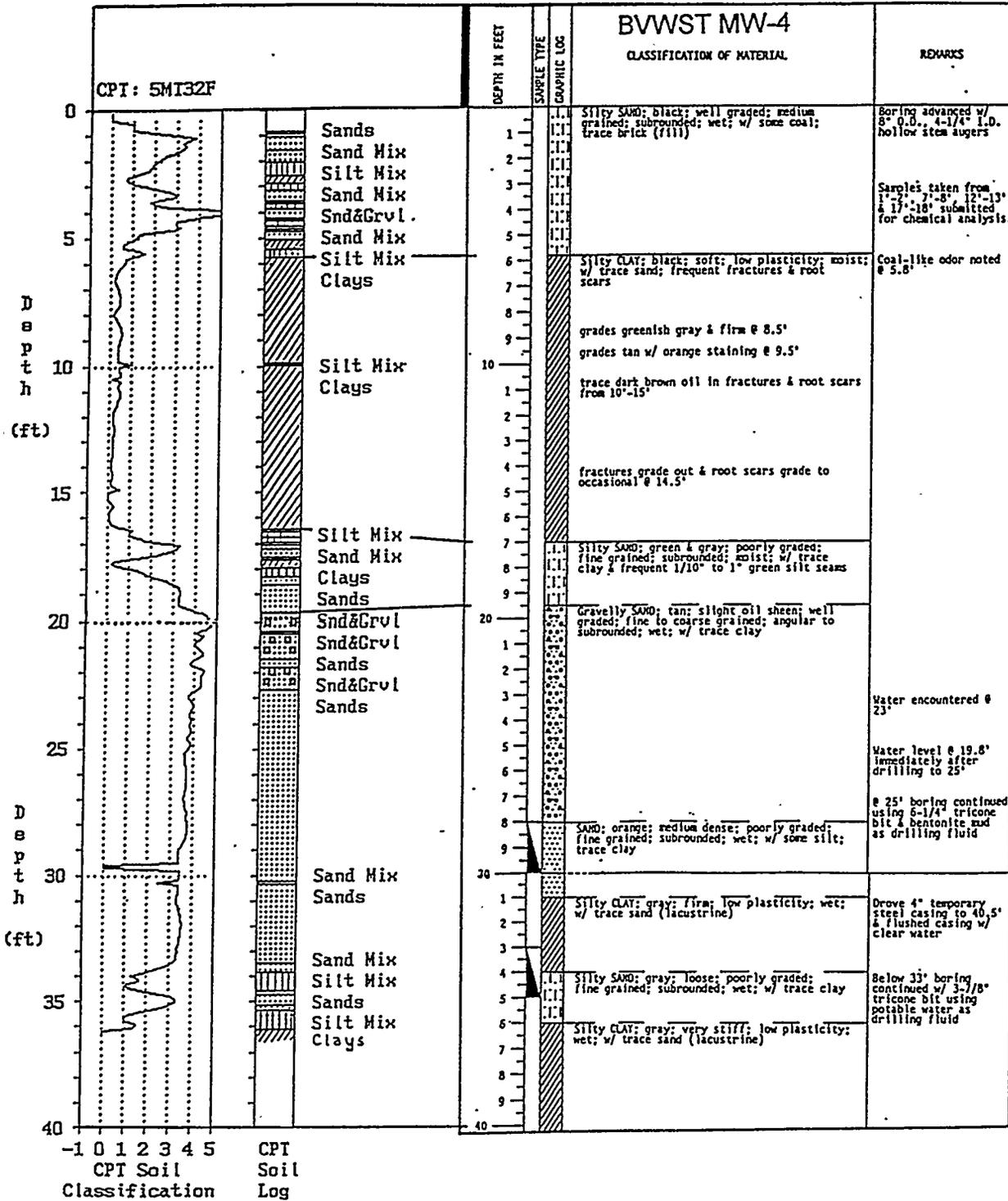
Figure 4.42 CPT Push Locations

Figure 4.43 Comparison of CPT ML-28 Stratigraphic Log with BWST MW-3 Log

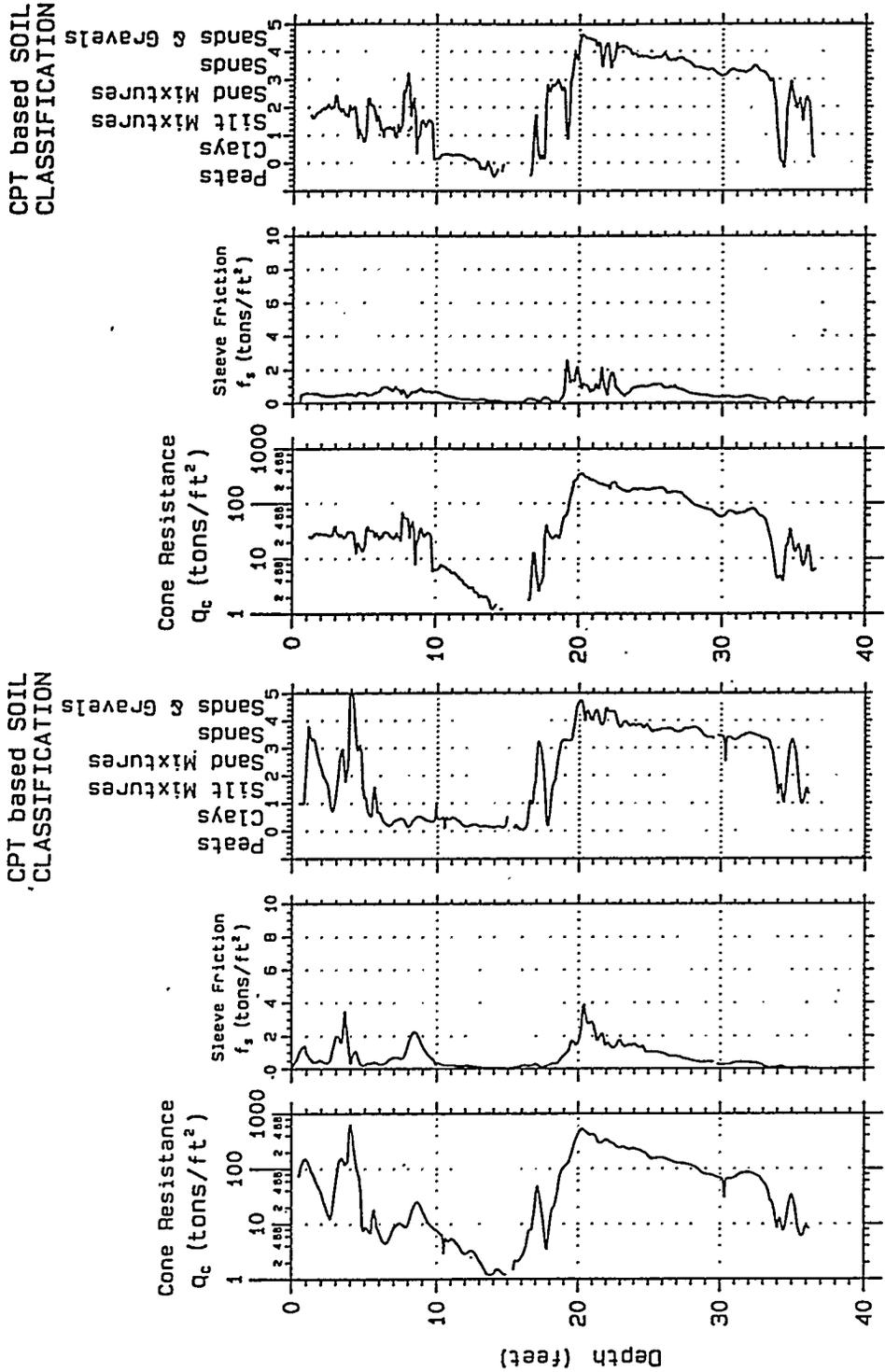


* 0-1=Clays, 1-2=Silt Mixtures, 2-3=Sand Mixtures, 3-4=Sands, 4-5=Sands and gravels.

Figure 4.44 Comparison of CPT ML-32 Stratigraphic Log with BWST MW-4 Log



* 0-1=Clays, 1-2=Silt Mixtures, 2-3=Sand Mixtures, 3-4=Sands, 4-5=Sands and gravels.



ML-32 - LIF

ML-32 - Resistivity

Project: Marshalltown

STATE COORDINATES:
EASTING (ft.) -1
NORTHING (ft.) 0

Probe date 04-26-1994

Figure 4.45 CPT Stratigraphic Repeatability Comparison - ML-32

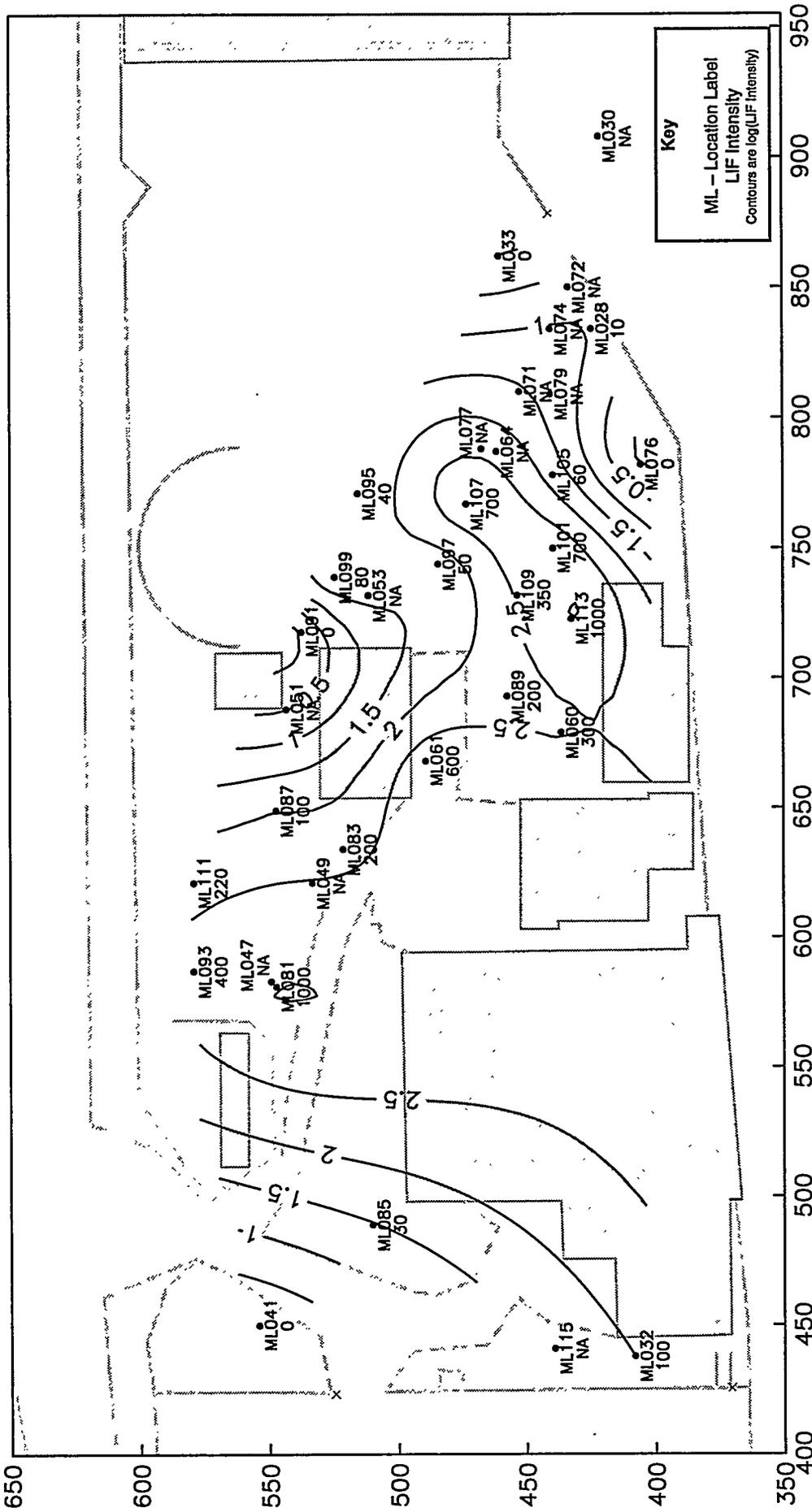


Figure 4.46 CPT LIF Fluorescence Intensity - Stratigraphic Zone 1

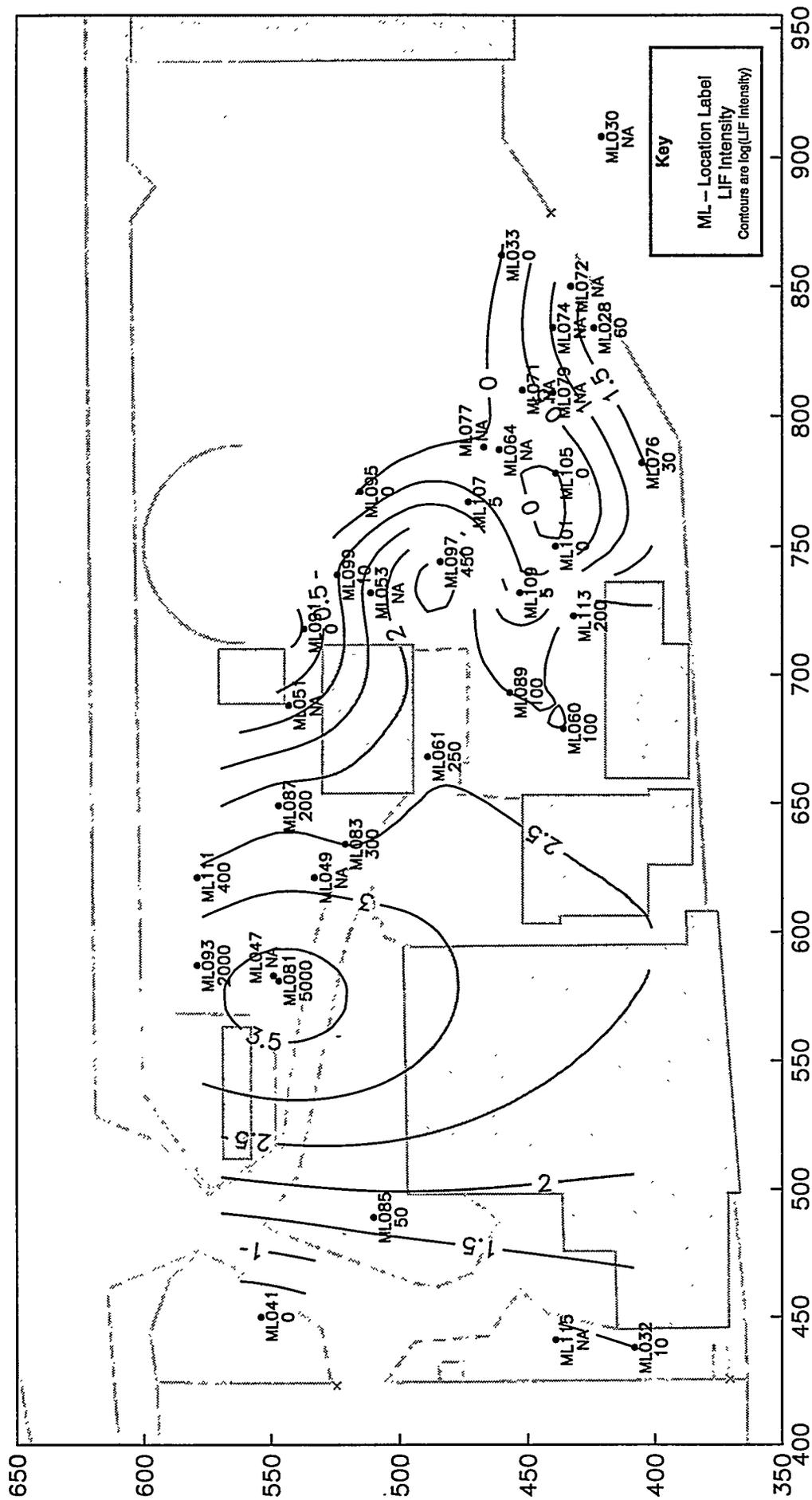


Figure 4.47 CPT LIF Fluorescence Intensity - Stratigraphic Zone 2

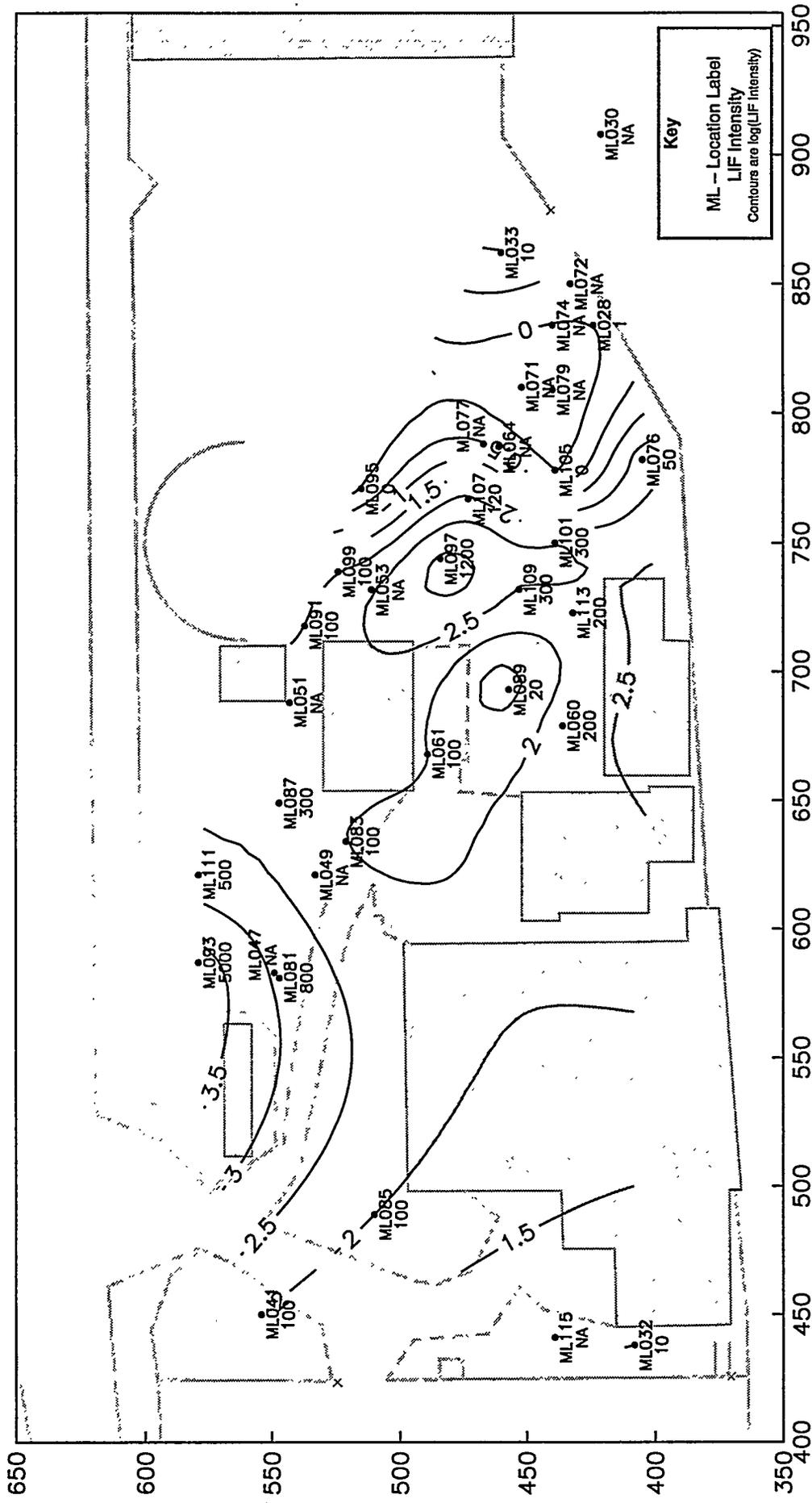


Figure 4.48 CPT LIF Fluorescence Intensity - Stratigraphic Zone 3

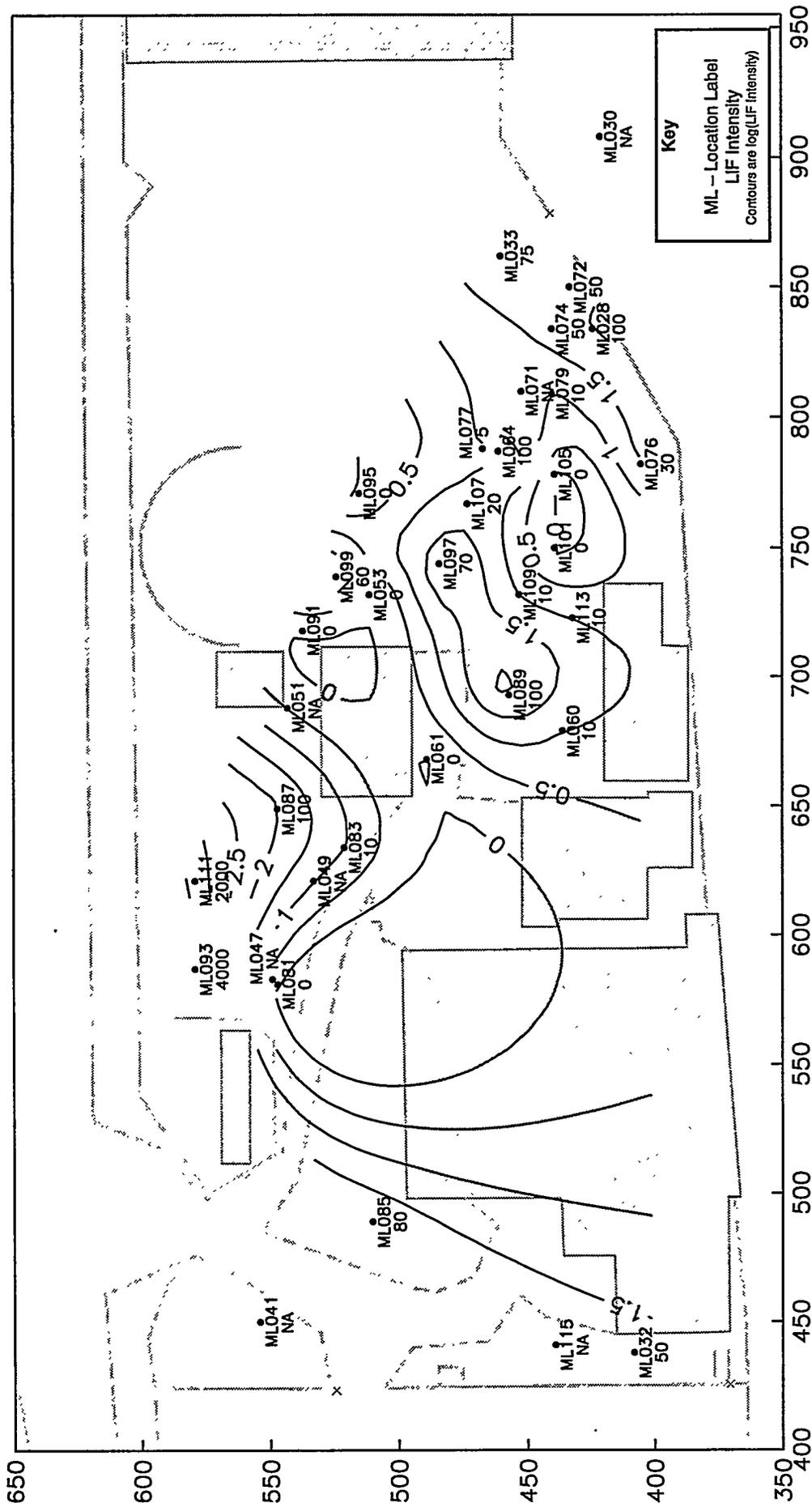


Figure 4.49 CPT LIF Fluorescence Intensity - Stratigraphic Zone 4

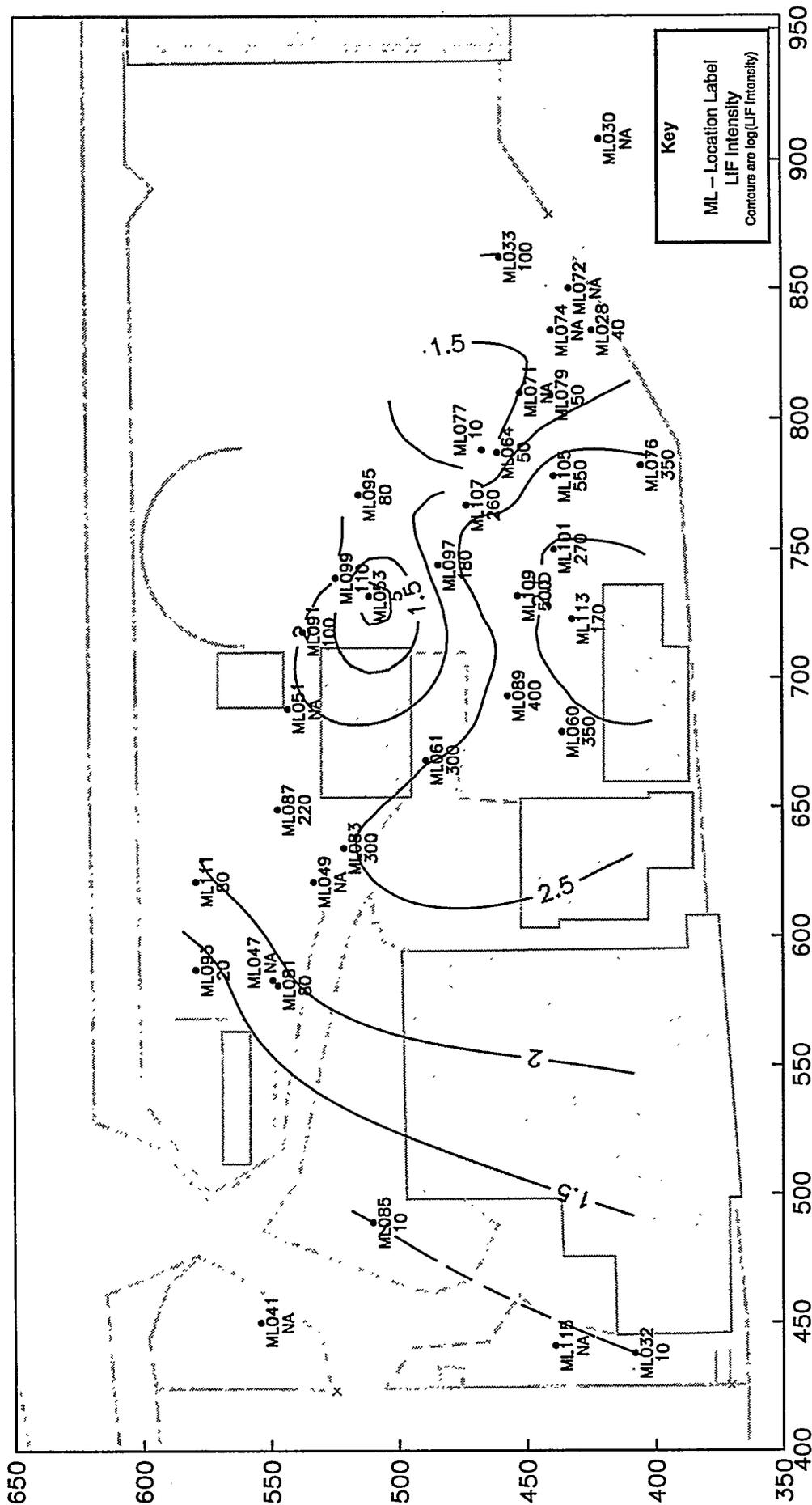


Figure 4.50 CPT LIF Fluorescence Intensity - Stratigraphic Zone 5

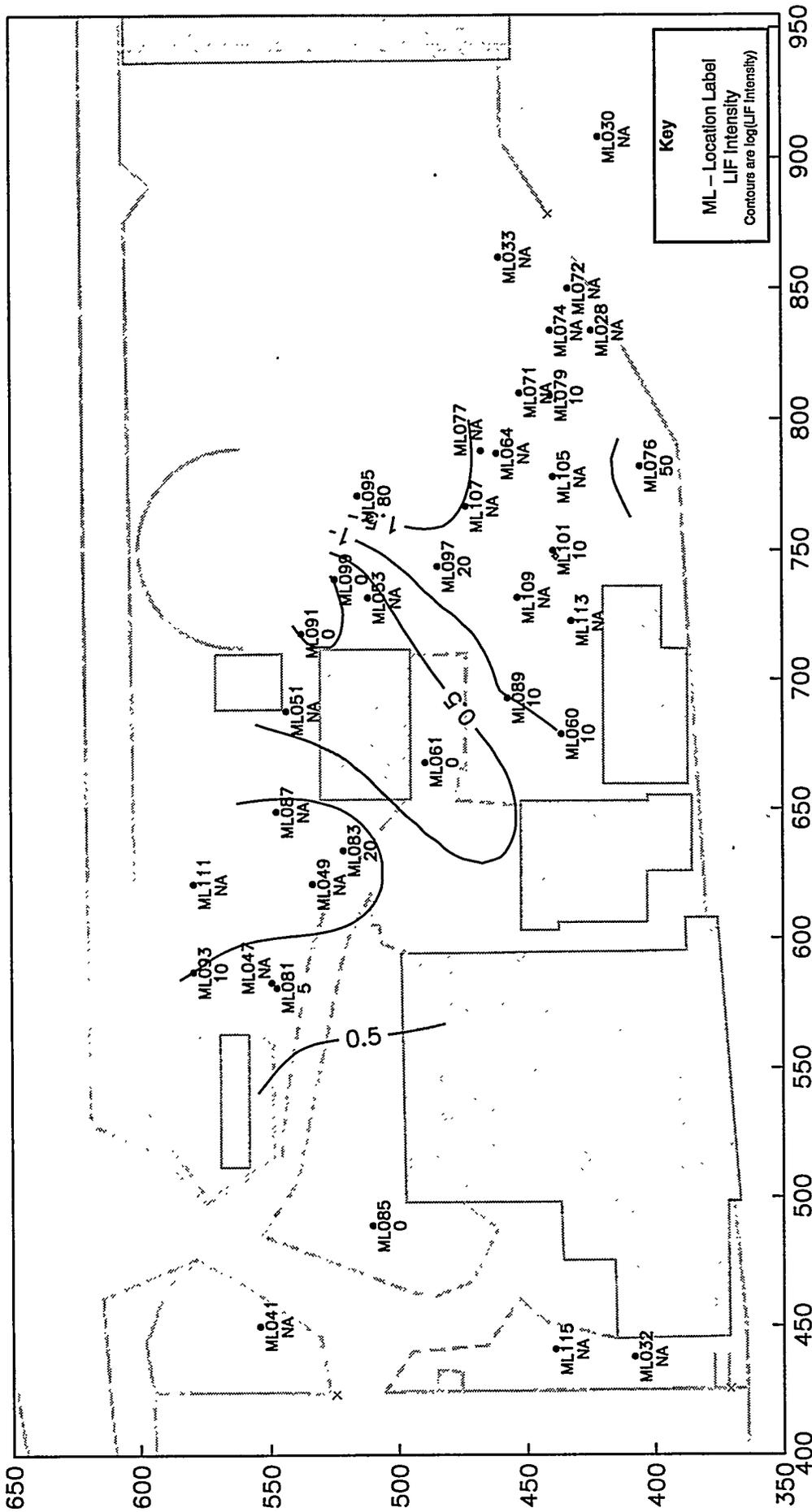


Figure 4.51 CPT LIF Fluorescence Intensity - Stratigraphic Zone 6

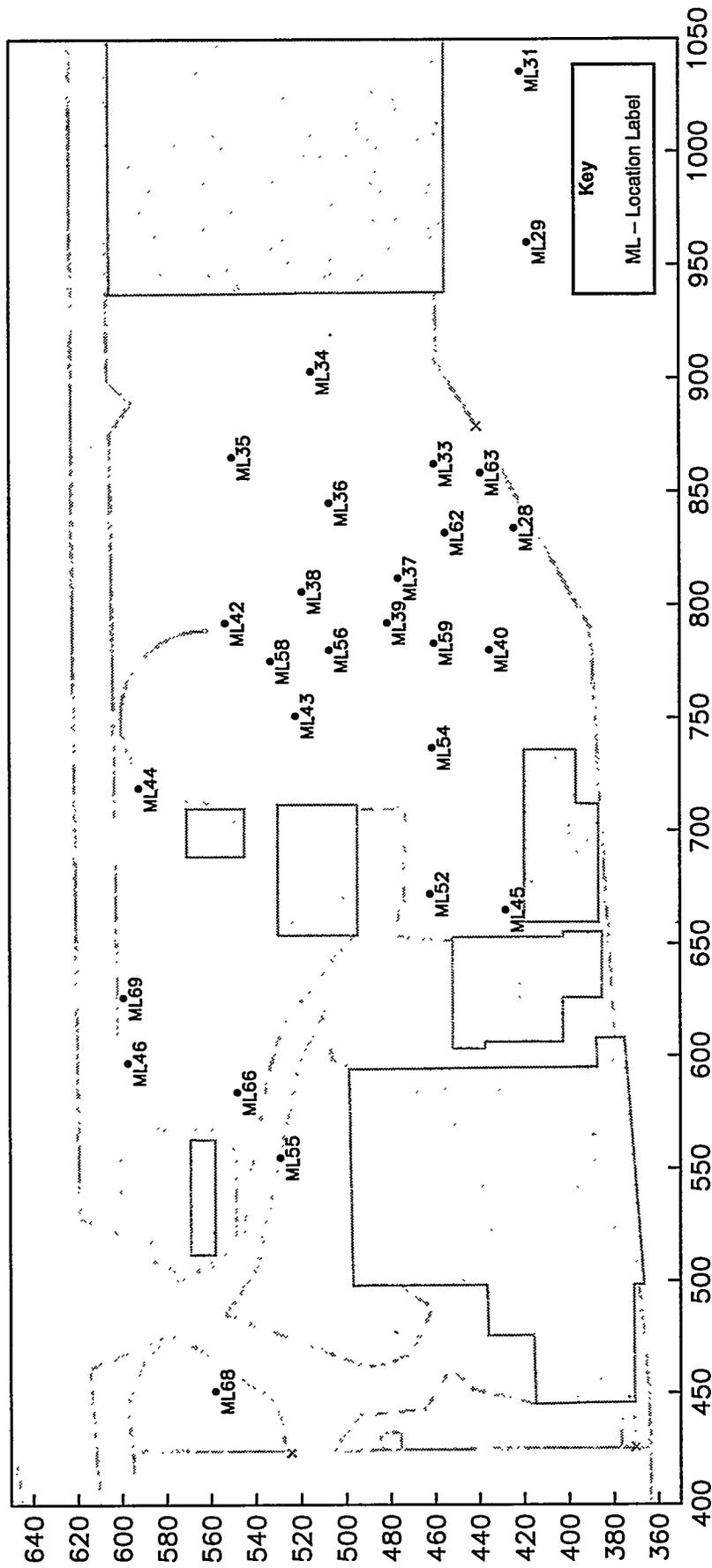


Figure 4.52 Geoprobe Soil Conductivity Push Locations

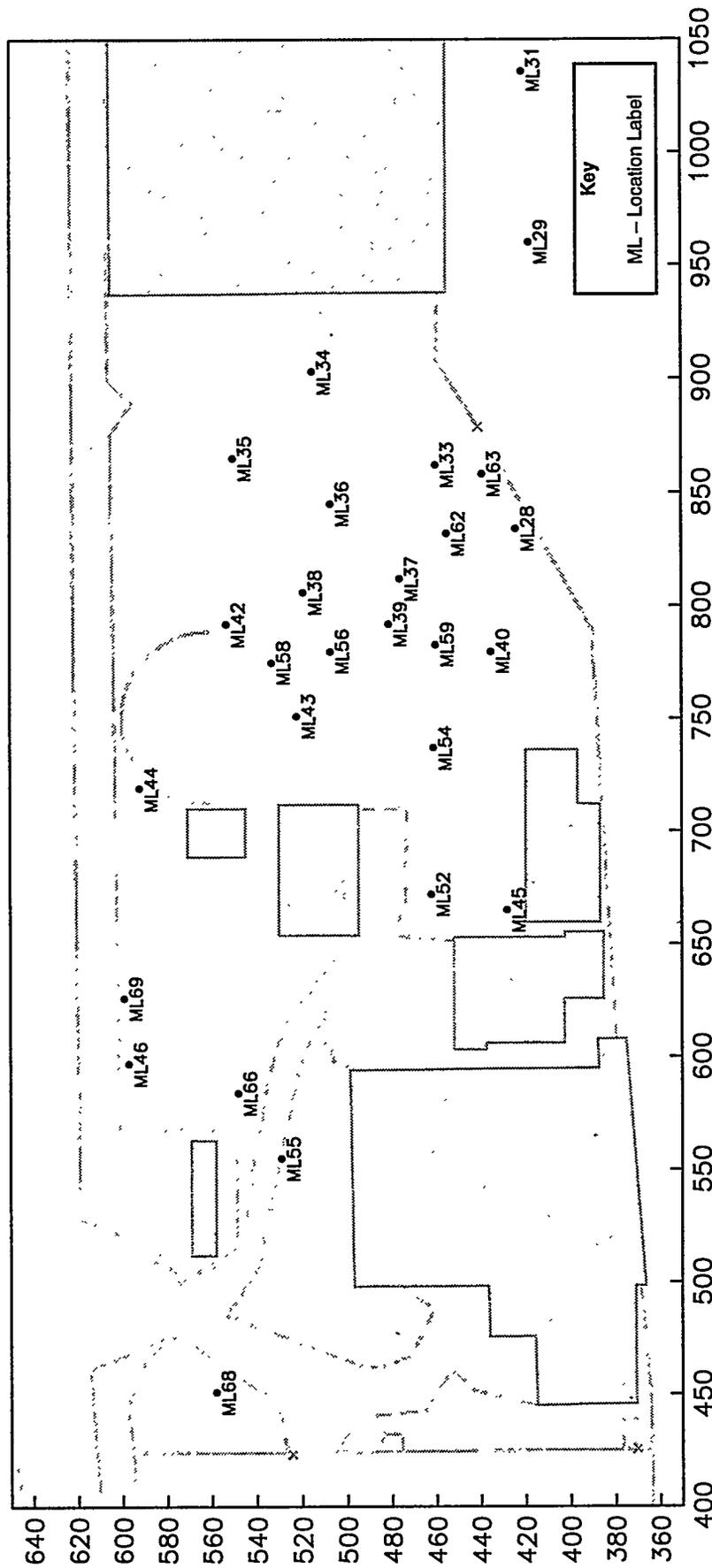
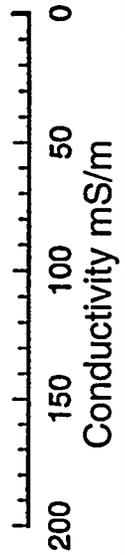
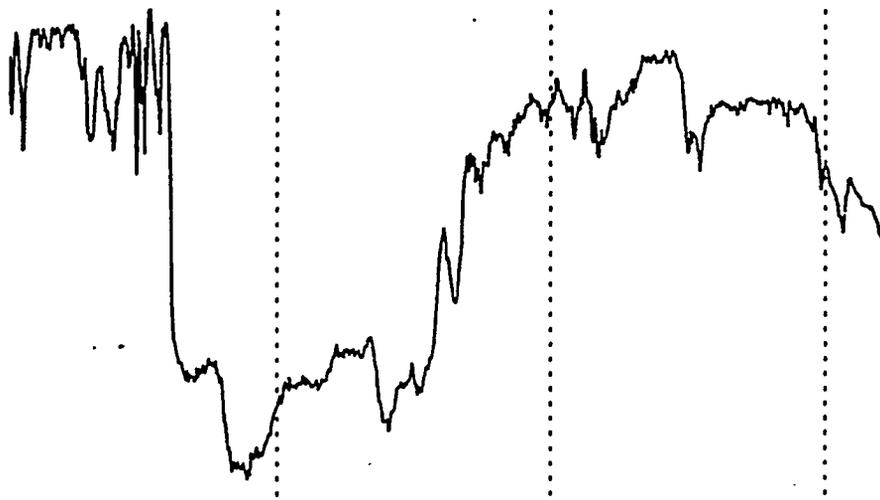


Figure 4.52 Geoprobe Soil Conductivity Push Locations

ML-28 - Soil Conductivity



MW-3A BWST

DEPTH IN FEET	SAMPLE TYPE	CLASSIFICATION OF MATERIAL
0 - 1	GRAVEL	
1 - 2	CLAY	SILTY SAND; black, very dense, well graded; fine to coarse grained; angular to sub-angular; cemented by tar; moist; w/ some wood (fill)
2 - 3	CLAY	
3 - 4	CLAY	
4 - 5	CLAY	SILTY CLAY; black; tar present in fractures & root scars; fine to coarse grained; angular to sub-angular; sand & frequent hairline fractures & root scars from 5'-10' w/ black & orange mottles between
5 - 6	CLAY	
6 - 7	CLAY	
7 - 8	CLAY	
8 - 9	CLAY	
9 - 10	CLAY	
10 - 11	CLAY	fractures grade to occasional @ 12.2'; black w/ trace roots @ 12.5'; fractures, grade out @ 13.5'
11 - 12	CLAY	orange mottling begins out @ 14.5'; roots grade to some @ 16'
12 - 13	CLAY	Silty silt; grey, soft; low plasticity; silty w/ trace clay
13 - 14	CLAY	
14 - 15	CLAY	Silty sand, tan, well graded; fine to coarse grained; angular to sub-angular; moist; w/ some gravel; trace clay
15 - 16	CLAY	
16 - 17	CLAY	
17 - 18	CLAY	
18 - 19	CLAY	
19 - 20	CLAY	
20 - 21	CLAY	
21 - 22	CLAY	
22 - 23	CLAY	
23 - 24	CLAY	
24 - 25	CLAY	
25 - 26	CLAY	
26 - 27	CLAY	
27 - 28	CLAY	
28 - 29	CLAY	
29 - 30	CLAY	gravel grades out @ 30'; silty silt; grey, stiff; low plasticity; moist; w/ trace to some clay
30 - 31	CLAY	
31 - 32	CLAY	Silty clay; grey, soft; low plasticity; moist; w/ some sand; trace root scars & orange staining (lacustrine)
32 - 33	CLAY	
33 - 34	CLAY	

ML-28 - CPT

higher number represents coarser grained soils
Clays → Sand & Gravel

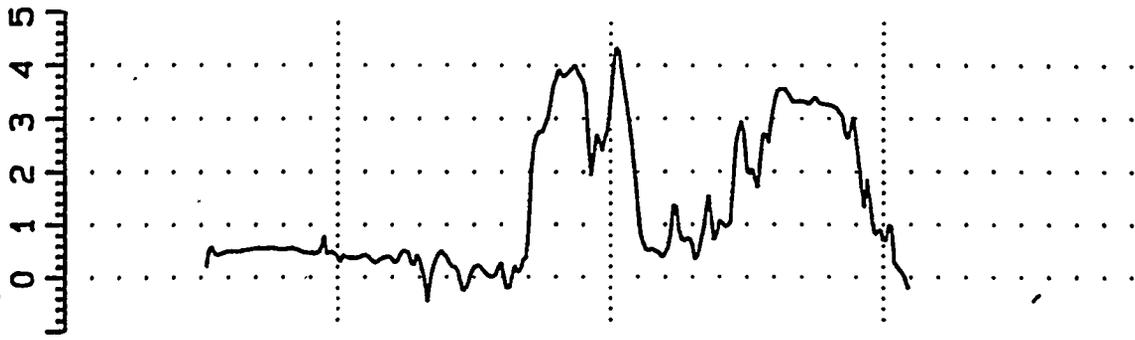
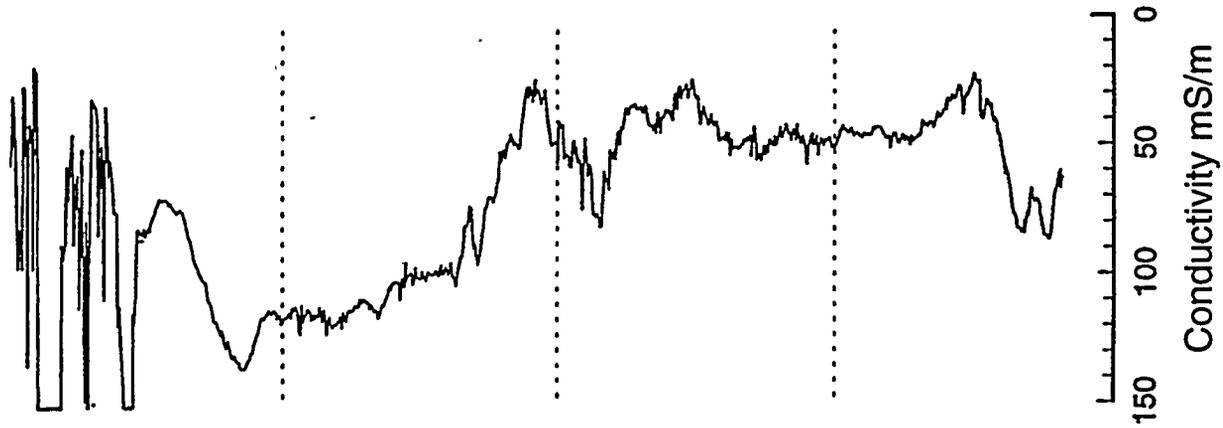


Figure 4.53 Soil Stratigraphic Comparison ML-28 Soil Conductivity vs BWST MW-3A vs CPT ML-28

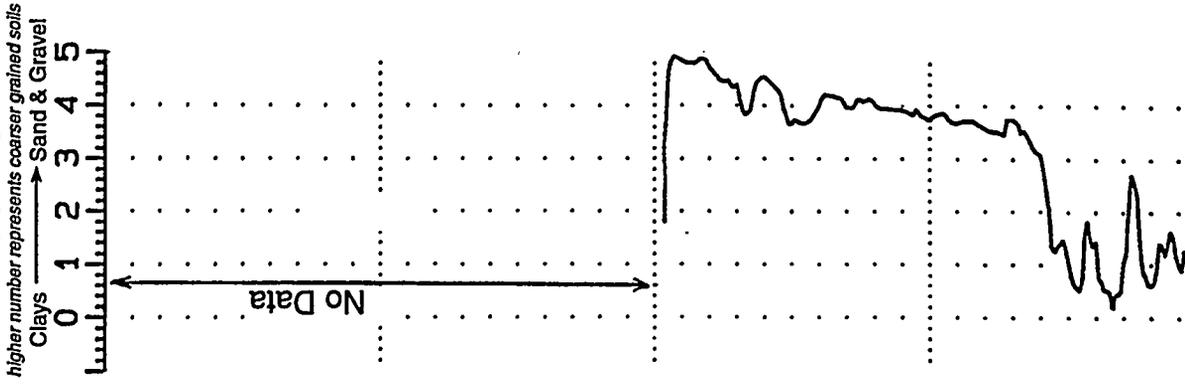
ML-45 - Soil Conductivity



B-8 - BWST

DEPTH IN	SAMPLE TYPE	CLASSIFICATION OR
1	1.1	Silty sand; black, well graded; fine to medium grained; trace oil; coal bed (f111)
2	1.2	
3	1.3	
4	1.4	
5	1.5	
6	1.6	
7	1.7	
8	1.8	Silty clay; black; fine; low plasticity; moist; w/ trace sand grading green & black mottles @ 0.5' grading stiff @ 9'
9	1.9	
10	2.0	grading tan w/ orange mottles w/ frequent black and orange silted root scars @ 10'
11	2.1	
12	2.2	root scars grade to frequent @ 13'
13	2.3	
14	2.4	root scars grade to occasional @ 15'
15	2.5	
16	2.6	frequent 1/2" - 1" sand seams w/ free brown oil grades wet @ 17.5'
17	2.7	
18	2.8	SAND: gray; well graded; fine to coarse Silt; trace clay; to subrounded; wet; w/ some grading black w/ free oil @ 20'
19	2.9	
20	3.0	
21	3.1	
22	3.2	
23	3.3	
24	3.4	
25	3.5	
26	3.6	
27	3.7	
28	3.8	
29	3.9	
30	4.0	Silty sand; tan; medium dense; poorly graded; fine grained; subrounded; wet; w/ trace clay grading black w/ free oil @ 31.5'
31	4.1	
32	4.2	
33	4.3	
34	4.4	
35	4.5	
36	4.6	grading olive green w/ free oil @ 35'
37	4.7	
38	4.8	Silt; olive green; fine; low plasticity; wet; w/ trace sand w/ oil grading gray @ 37'
39	4.9	
40	5.0	

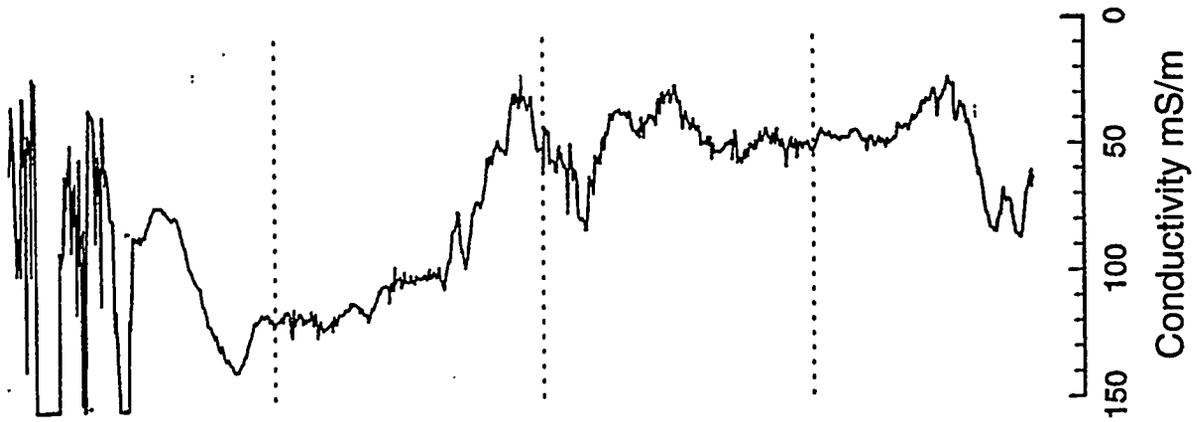
ML-60 - CPT



Conductivity mS/m

Figure 4.54 Soil Conductivity ML-45 vs BVST B-8 vs CPT ML-60

ML-45 - Soil Conductivity



B-8 BWST

DEPTH IN FEET	SAMPLE TYPE	CLASSIFICATION OF MATERIAL
0	GRAVEL LENS	
0 - 8.5		Silty Sand; black; well graded; fine to coarse grained; subrounded to angular; dry; w/some gravel; trace clay, coal & wood (fill)
8.5 - 10		Silty Clay; black; firm; low plasticity; moist; w/trace sand grading green & black mottles @ 8.5' grading silt @ 9'
10 - 13		grading tan w/orange mottles w/frequent black and orange stained root scars @ 10'
13 - 15		root scars grade to frequent @ 13'
15 - 17.5		root scars grade to frequent @ 15'
17.5 - 18		frequent 1/2"-1" sand seams w/free brown oil from 17.5' - 18'
18 - 20		grades wet @ 17.5'
20 - 20		SAND; gray; well graded; fine to coarse grained; angular to subrounded; wet; w/some silt; trace clay
20 - 20		grading black w/free oil @ 20'
20 - 34		
34 - 31.5		Silty SAND; tan; medium dense; poorly graded; fine grained; subrounded; wet; w/trace clay grading black w/free oil @ 31.5'
31.5 - 35		grading olive green w/free oil @ 35'
35 - 40		SILT; olive green; firm; low plasticity; wet; w/some sand & clay grading gray @ 37'

ML-60 - CPT

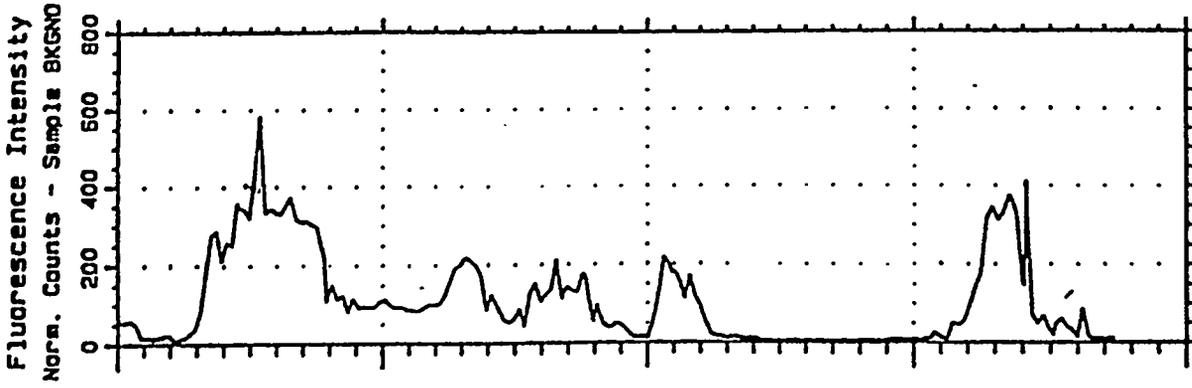


Figure 4.55 Coal Tar Residue Contamination Comparison
Soil conductivity ML-45 vs BWST B-8 vs CPT LIF ML-60

ML-109

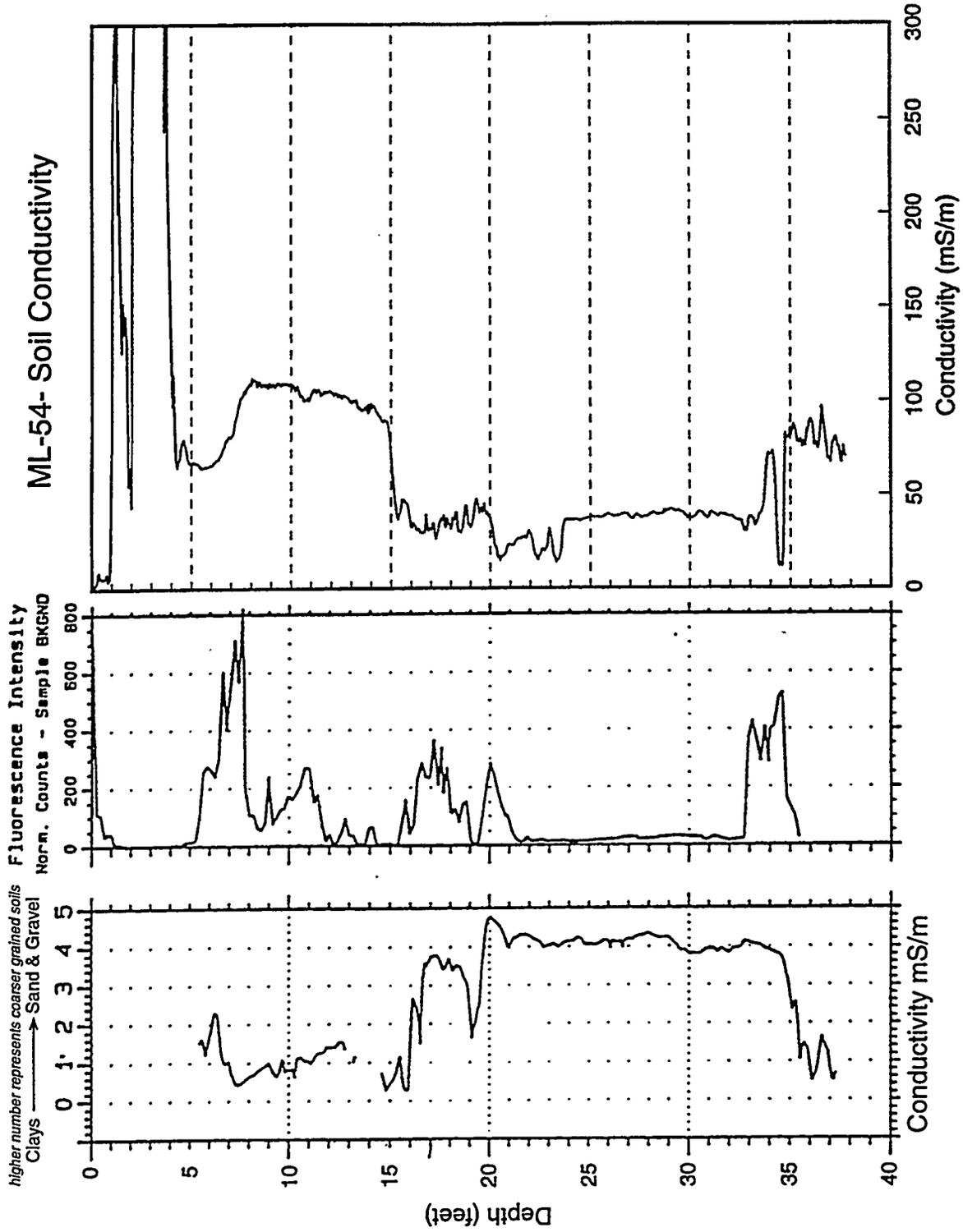


Figure 4.56 Coal Tar Residue Contamination Comparison
CPT LIF ML-109 vs Soil conductivity ML-54

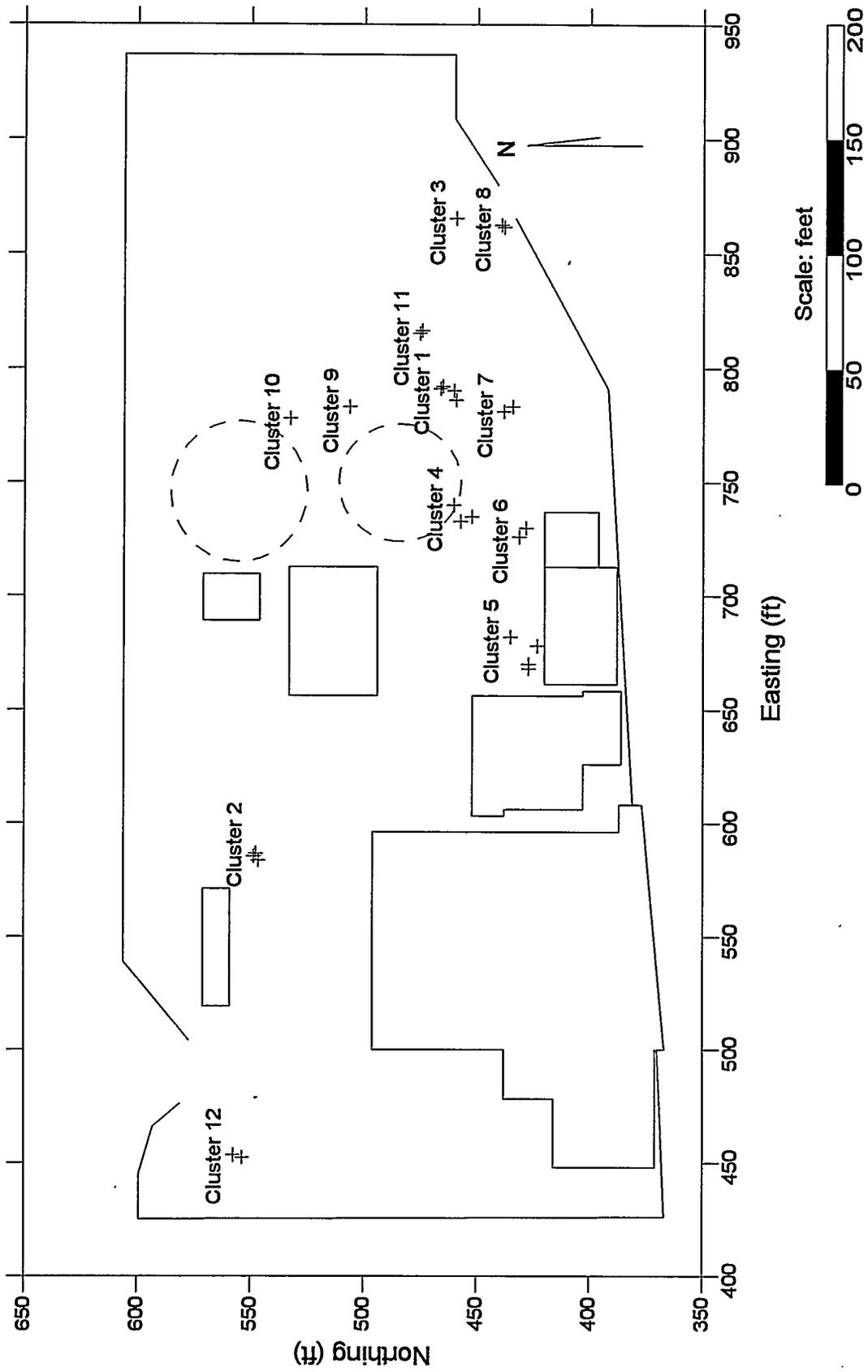


Figure 4.57 Location of Data Clusters Used for Stratigraphic and Contaminant Level Comparisons

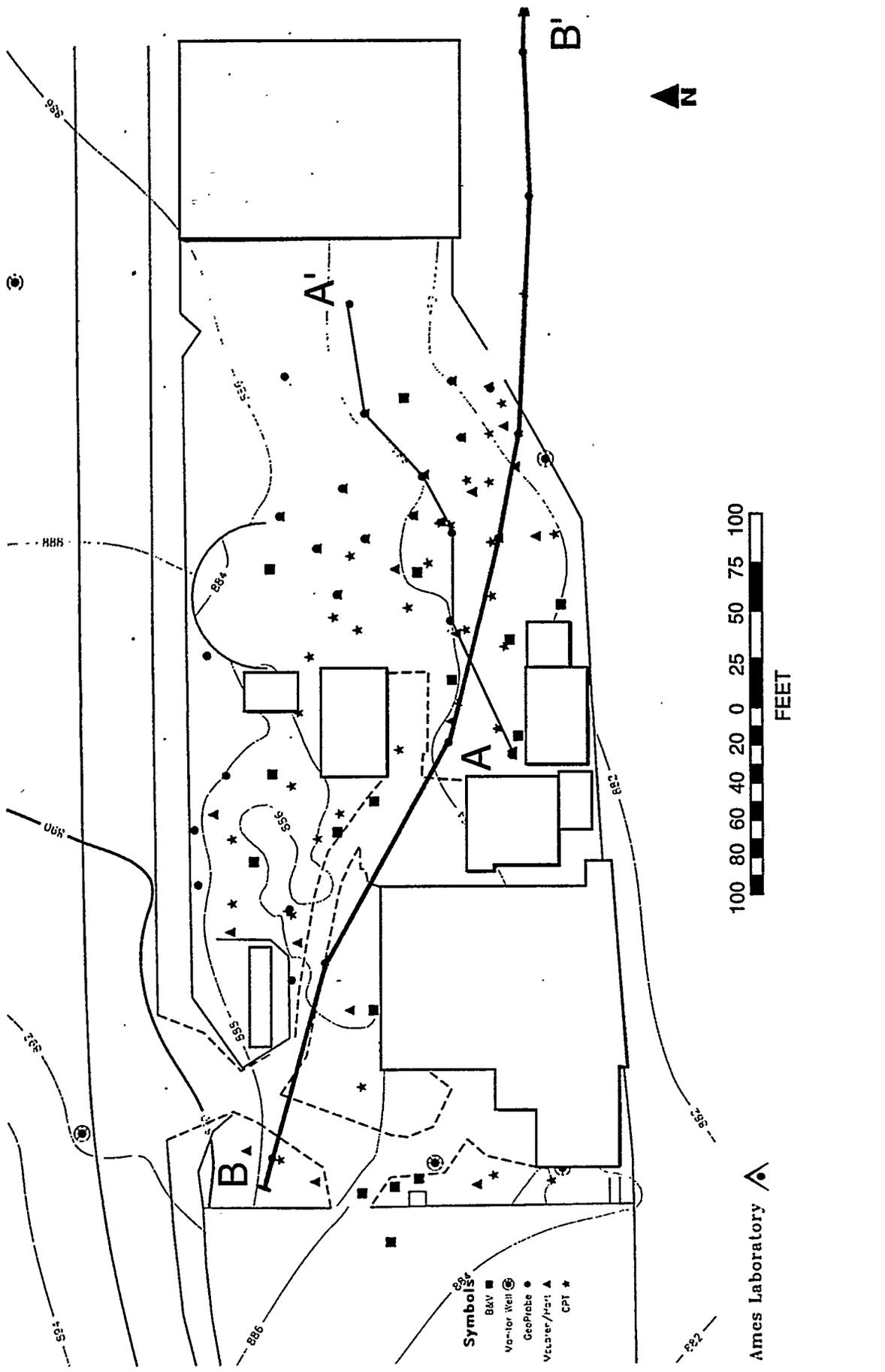


Figure 4.58 Locations of cross sections developed with push technology data

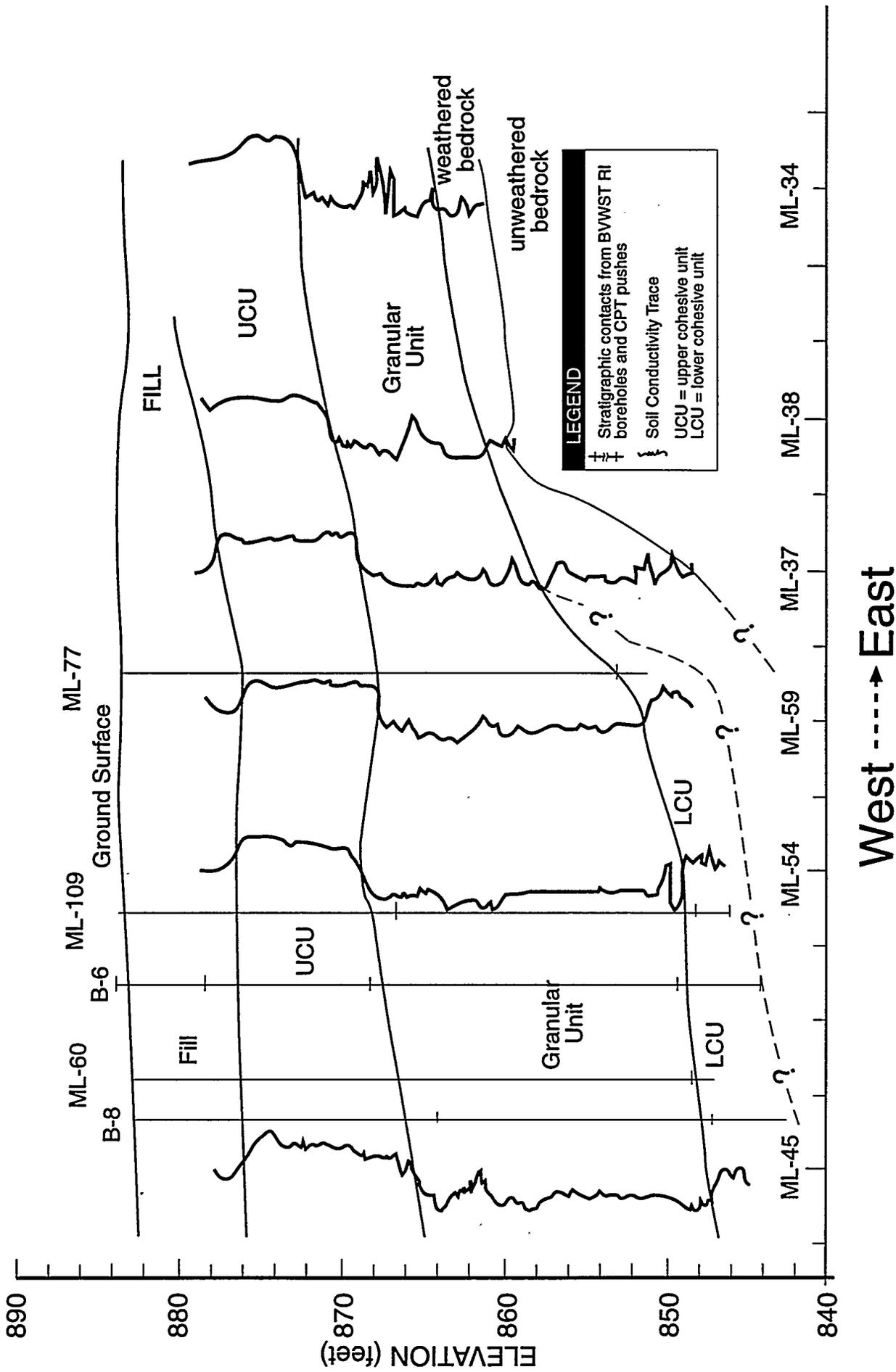


Figure 4.59 Stratigraphic Cross Section AA'
 note: see figure 4.58 for location-section
 drawn using soil conductivity data

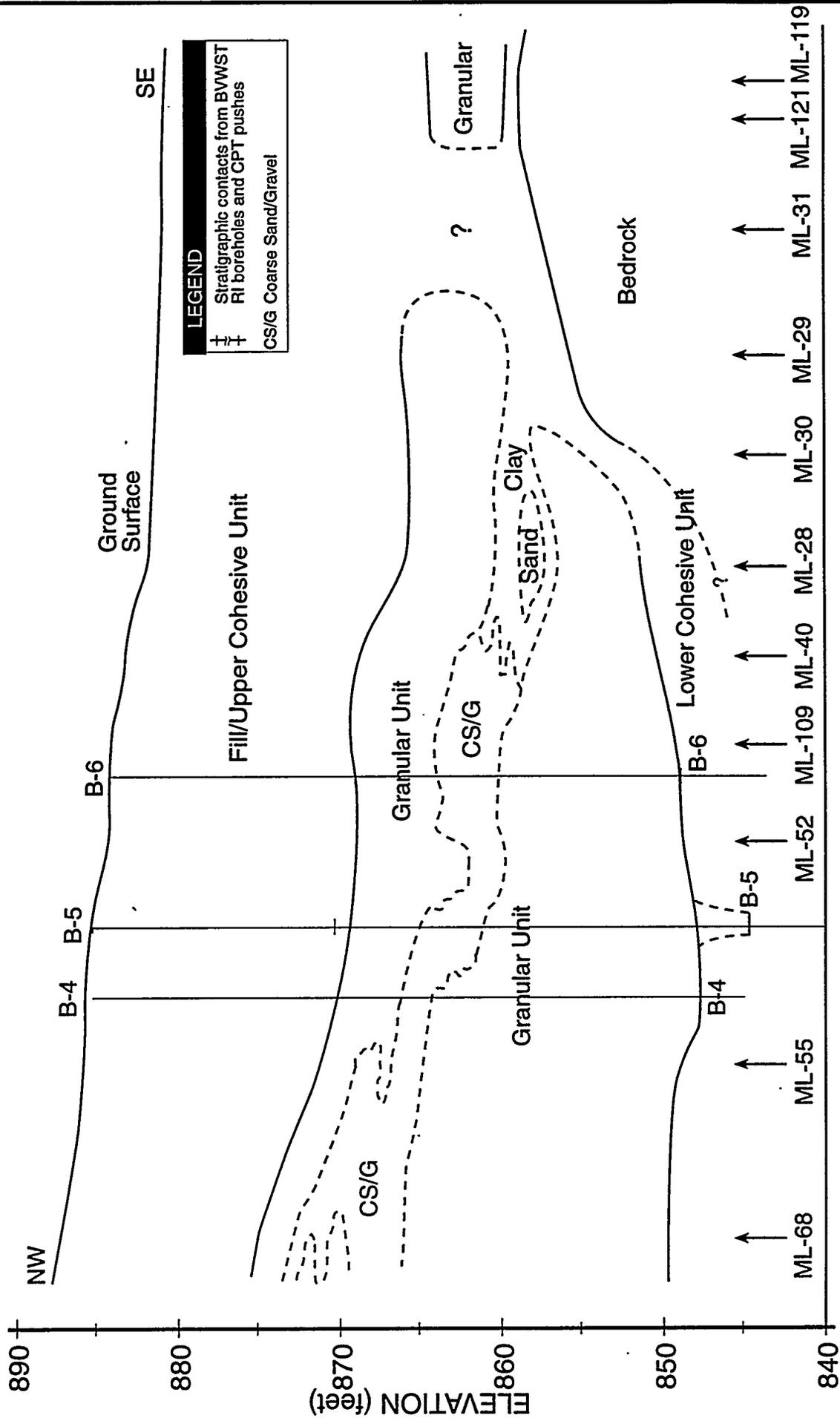


Figure 4.60 Stratigraphic Cross Section BB'
 note: see figure 4.58 for location-section drawn
 using soil conductivity and CPT data

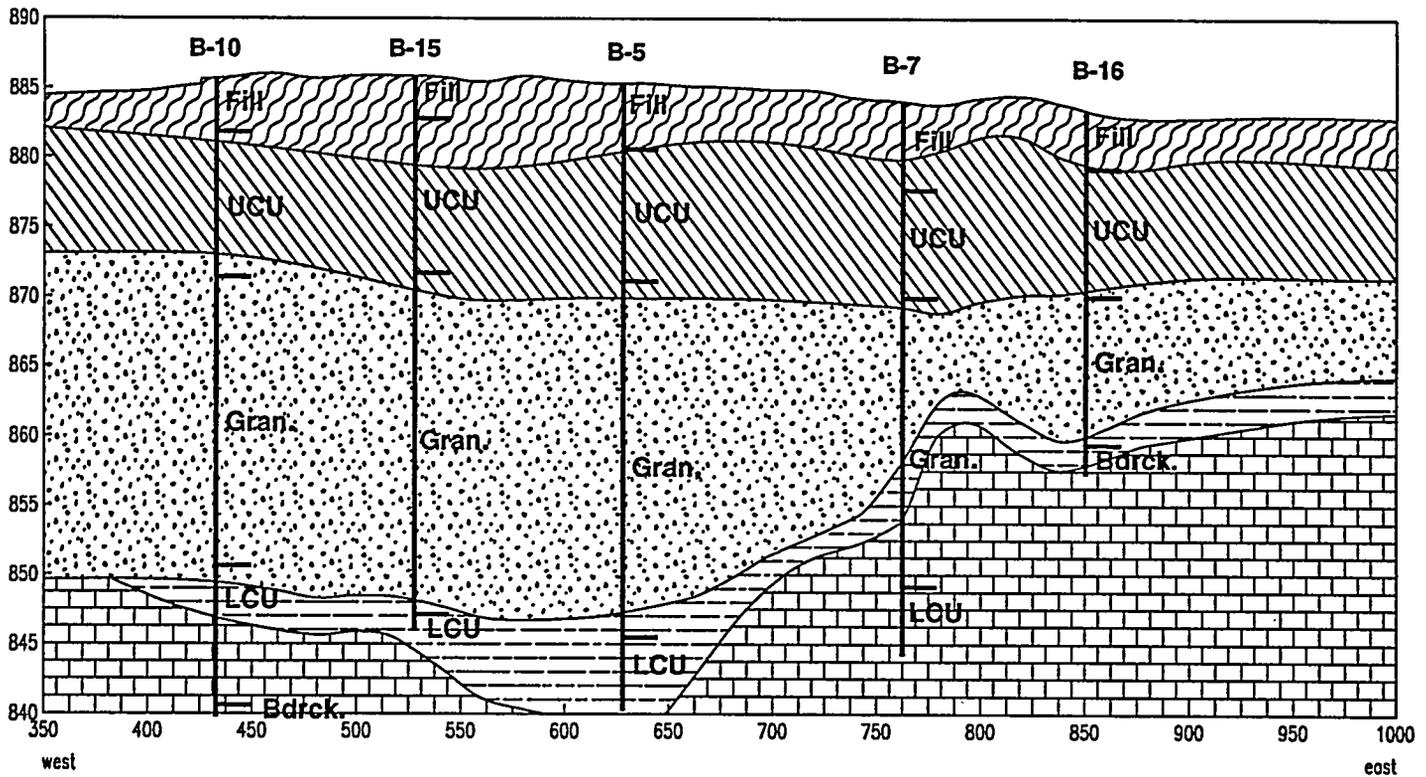
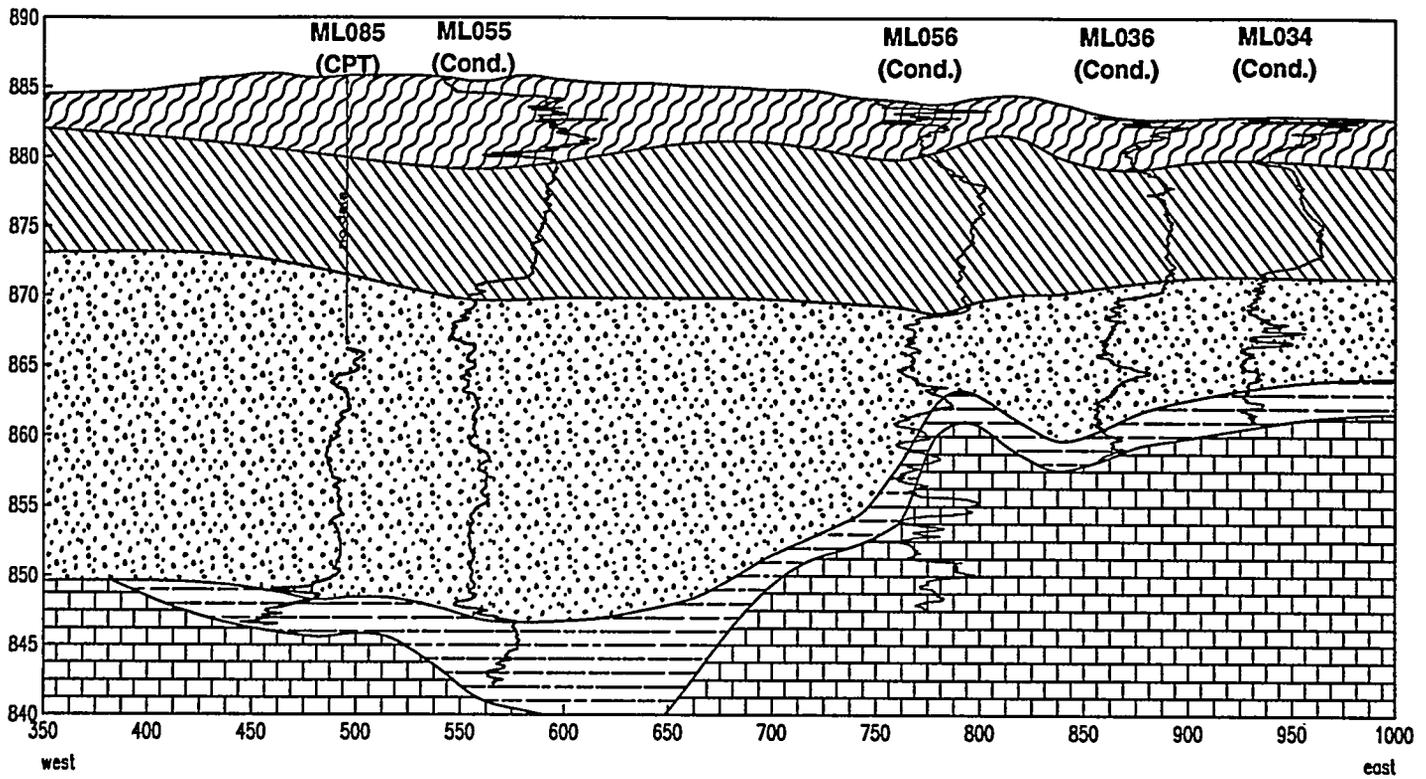


Figure 4.61 EarthVision Stratigraphic Model - East-West Cut at 500 N

(Top - Projected ESC data overlay;
Bottom - Projected BVWST data overlay)

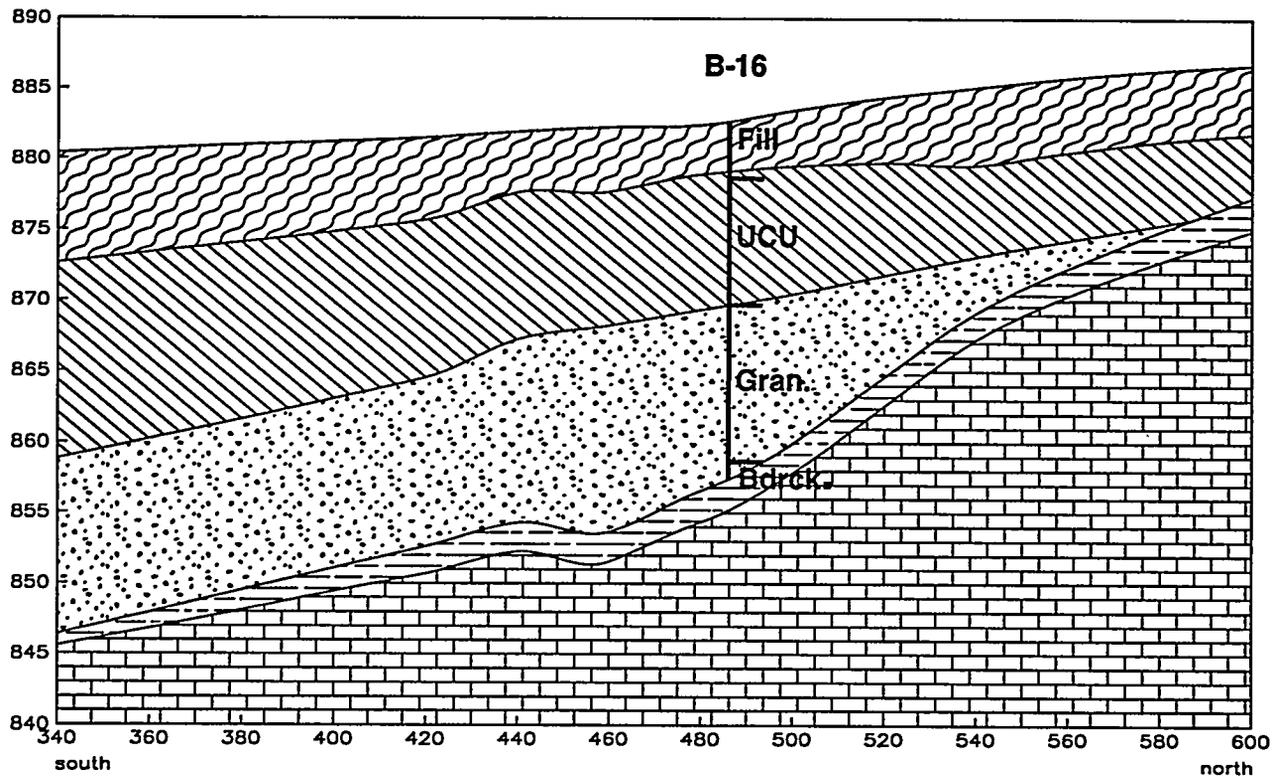
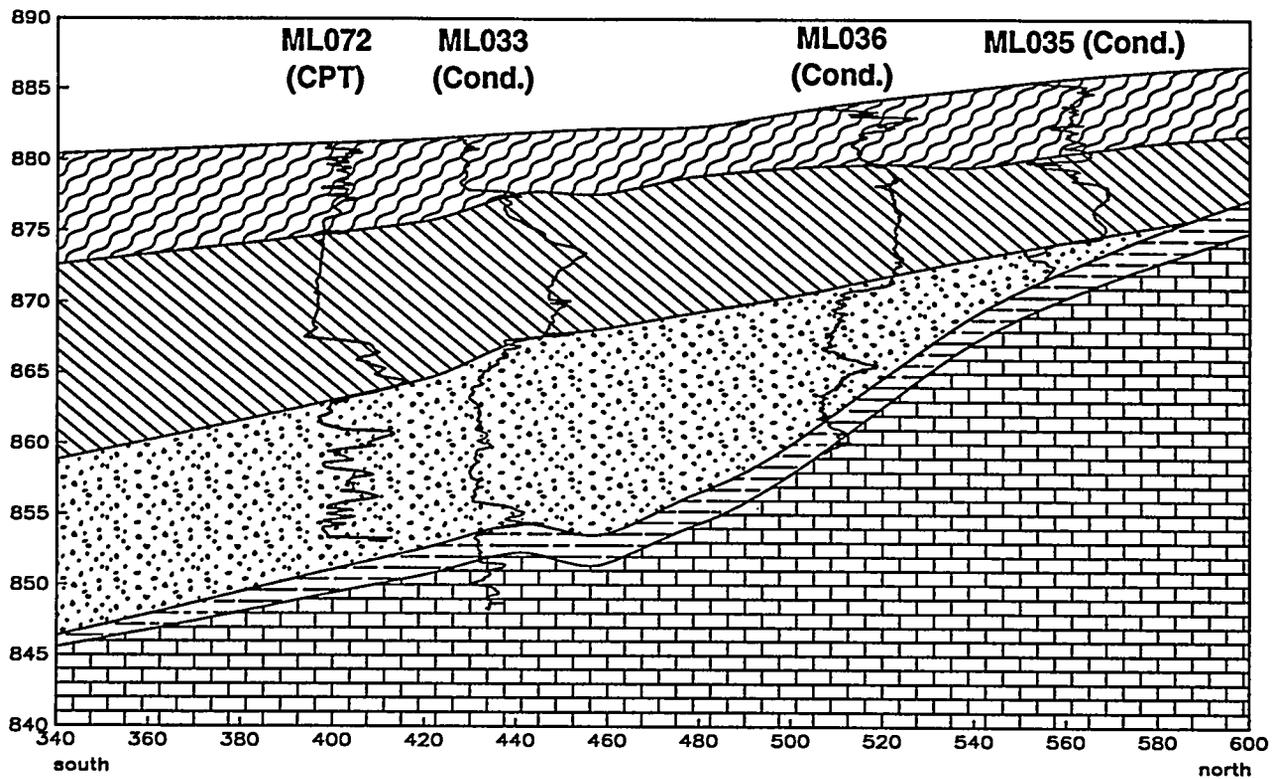


Figure 4.62 EarthVision Stratigraphic Model - North-South Cut at 850 E
 (Top - Projected ESC data overlay;
 Bottom - Projected BVWST data overlay)

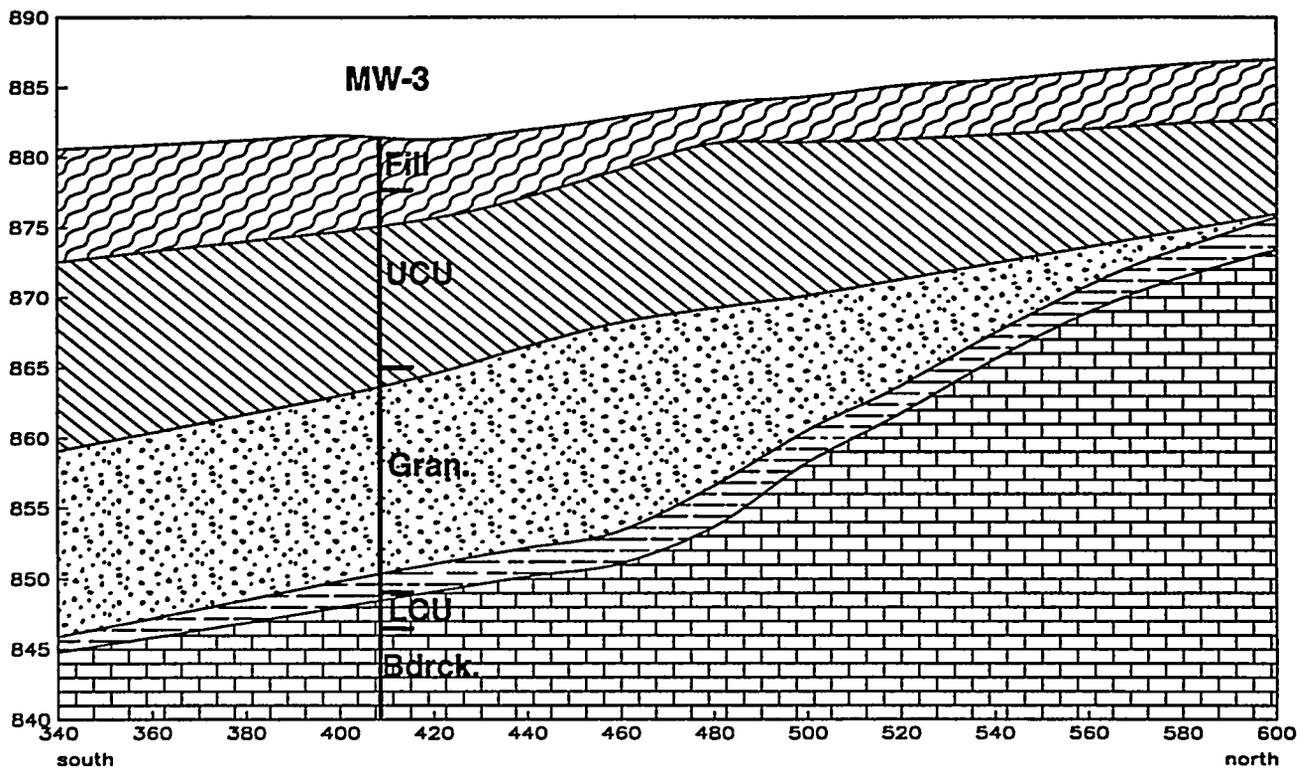
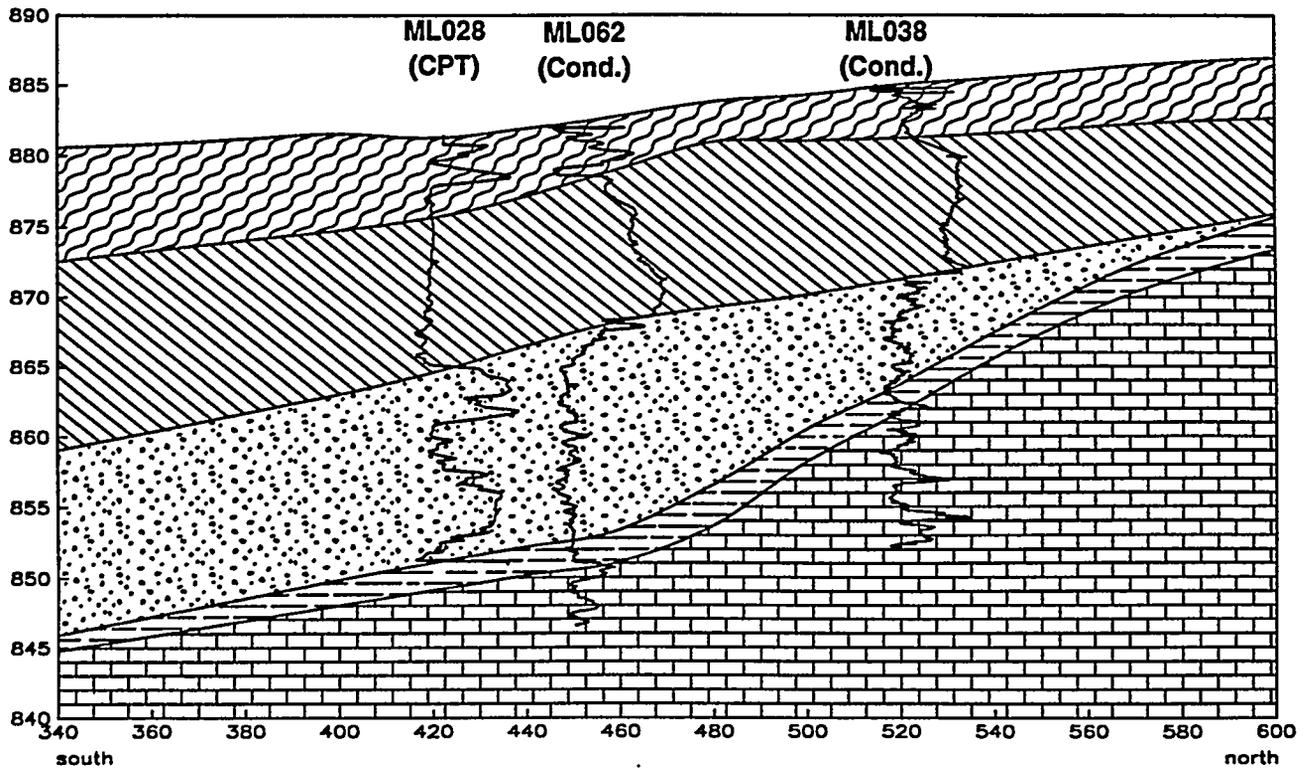


Figure 4.63 EarthVision Stratigraphic Model - North-South Cut at 825 E
 (Top - Projected ESC data overlay;
 Bottom - Projected BVWST data overlay)

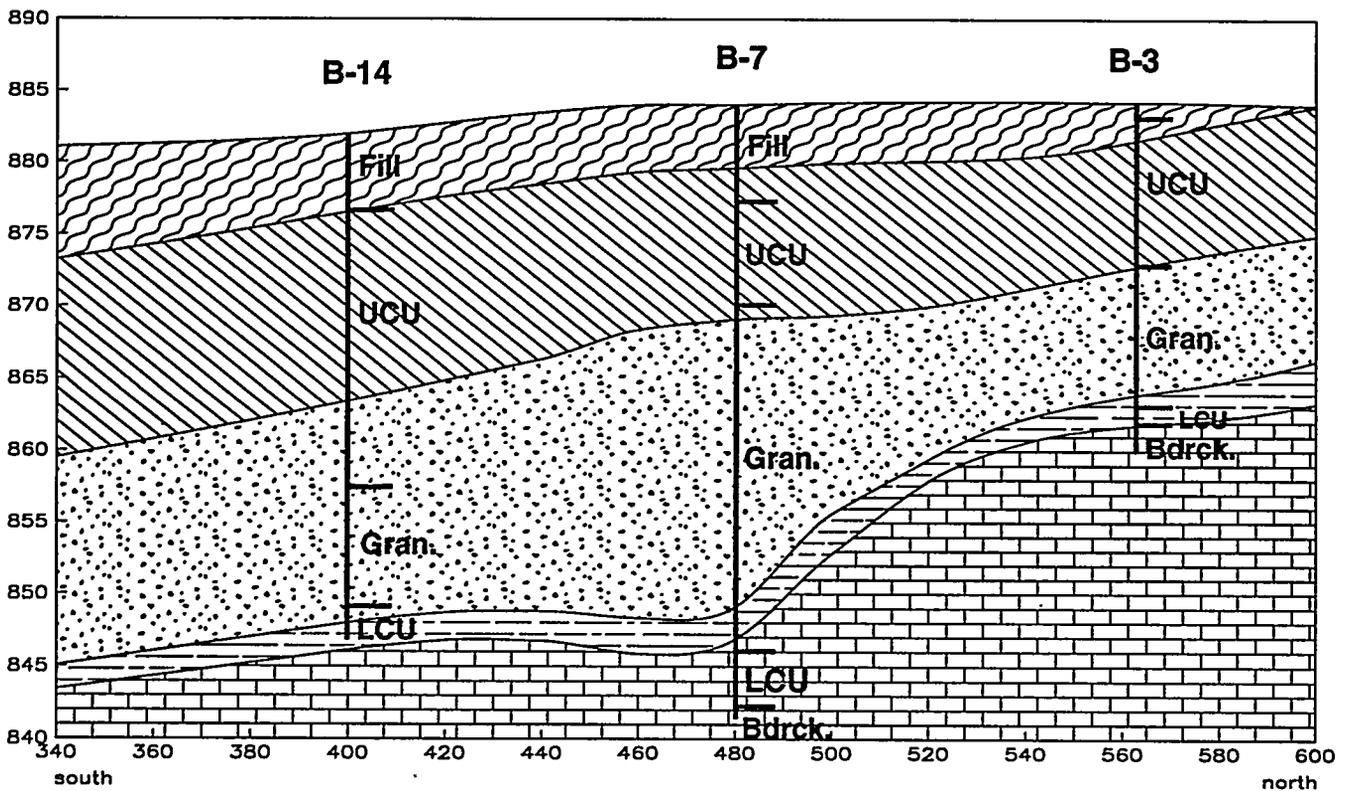
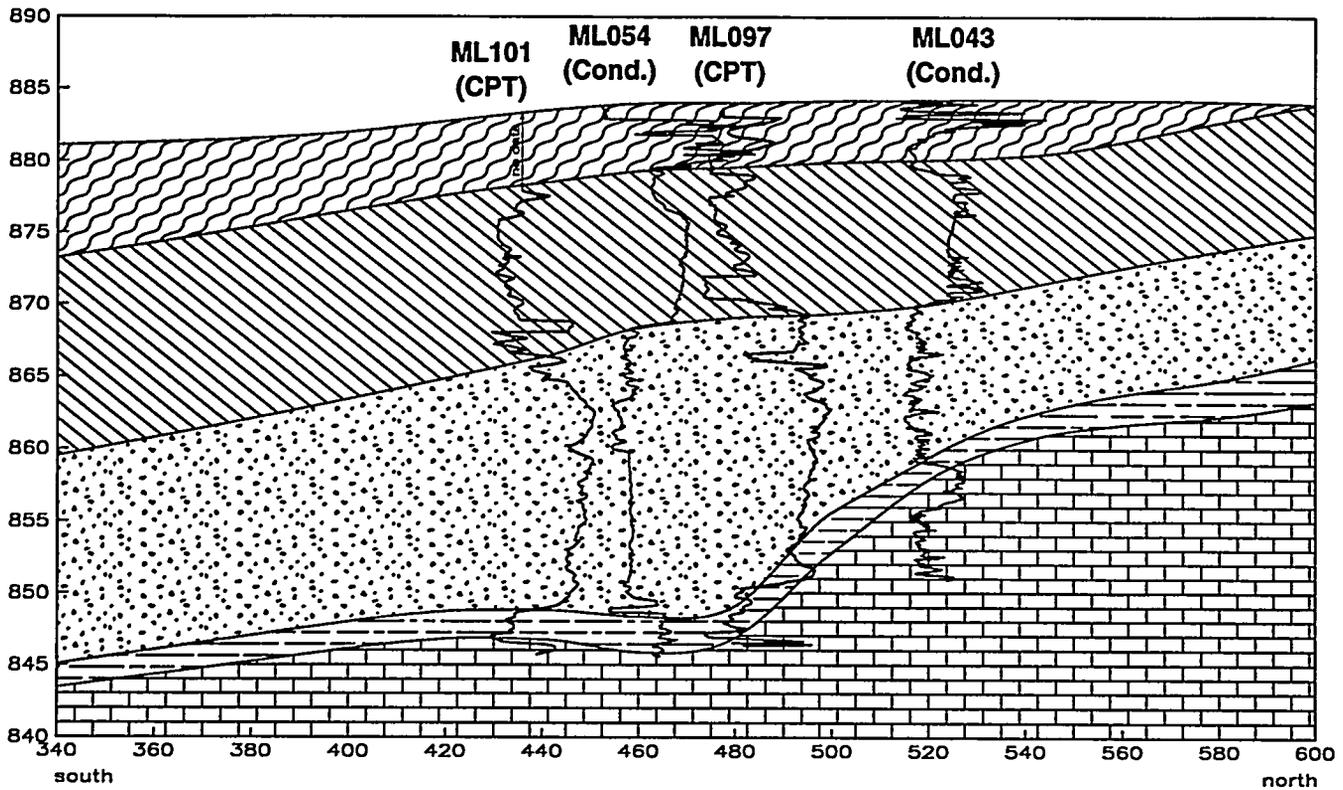


Figure 4.64 EarthVision Stratigraphic Model - North-South Cut at 750 E
 (Top - Projected ESC data overlay;
 Bottom - Projected BVWST data overlay)

Granular Unit/Lower Cohesive Unit Contact Surface Elevation

Day 940426

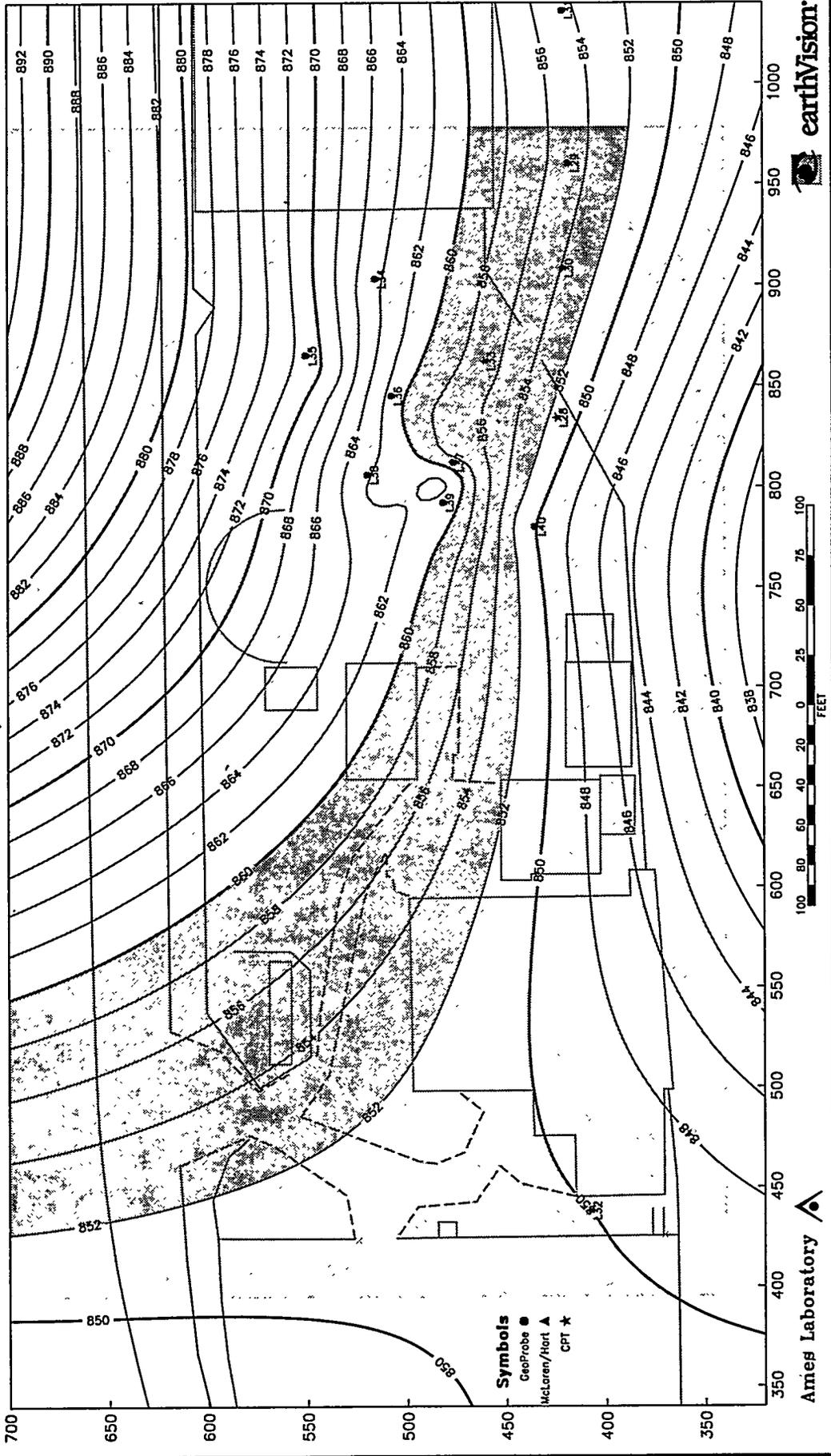


Figure 4.65 Granular Unit/Lower Cohesive Unit Contact - Day 1

Granular Unit/Lower Cohesive Unit Contact Surface Elevation

Day 940427

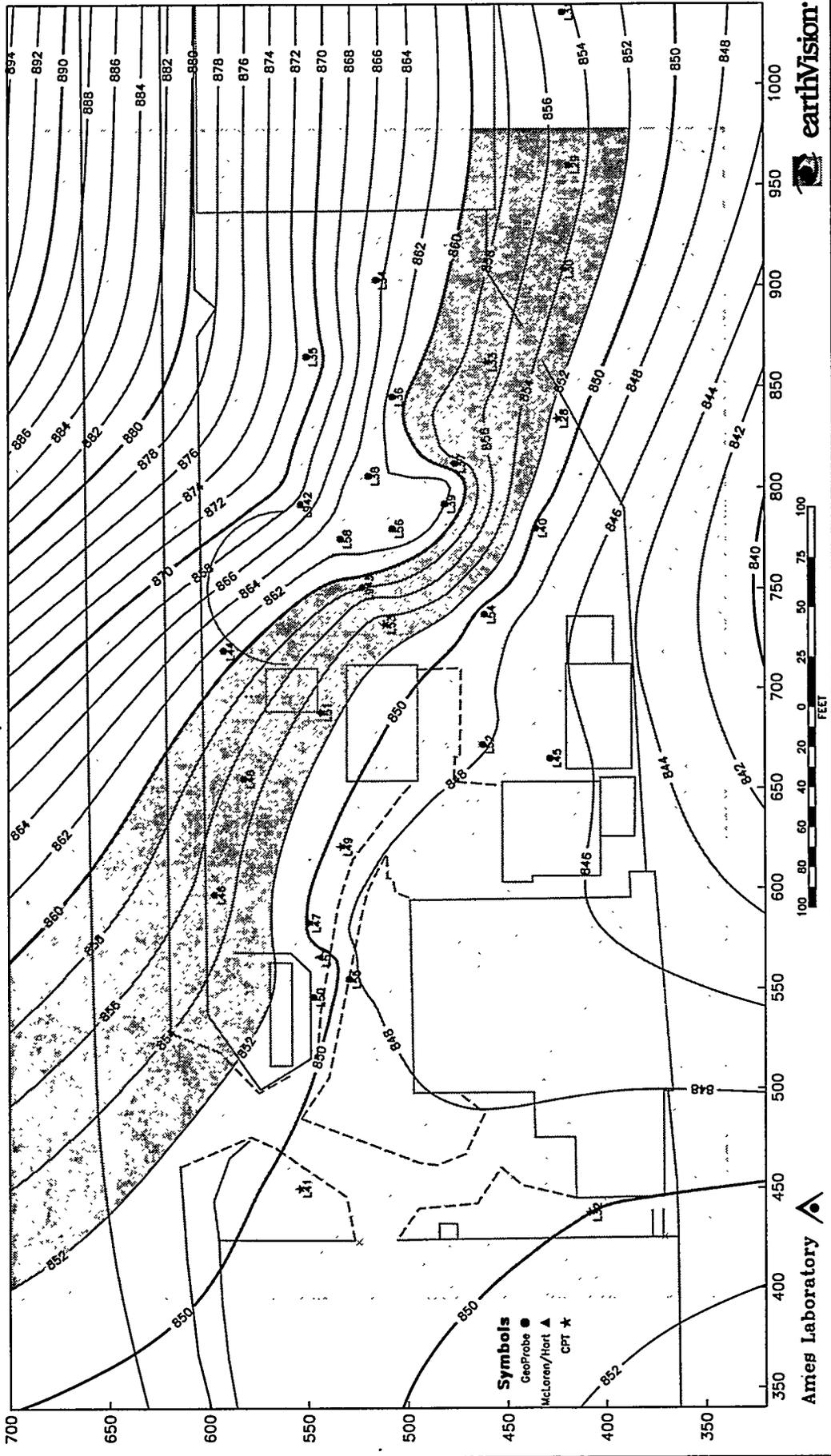


Figure 4.66 Granular Unit/Lower Cohesive Unit Contact - Day 2

Granular Unit/Lower Cohesive Unit Contact Surface Elevation

Doy 940429

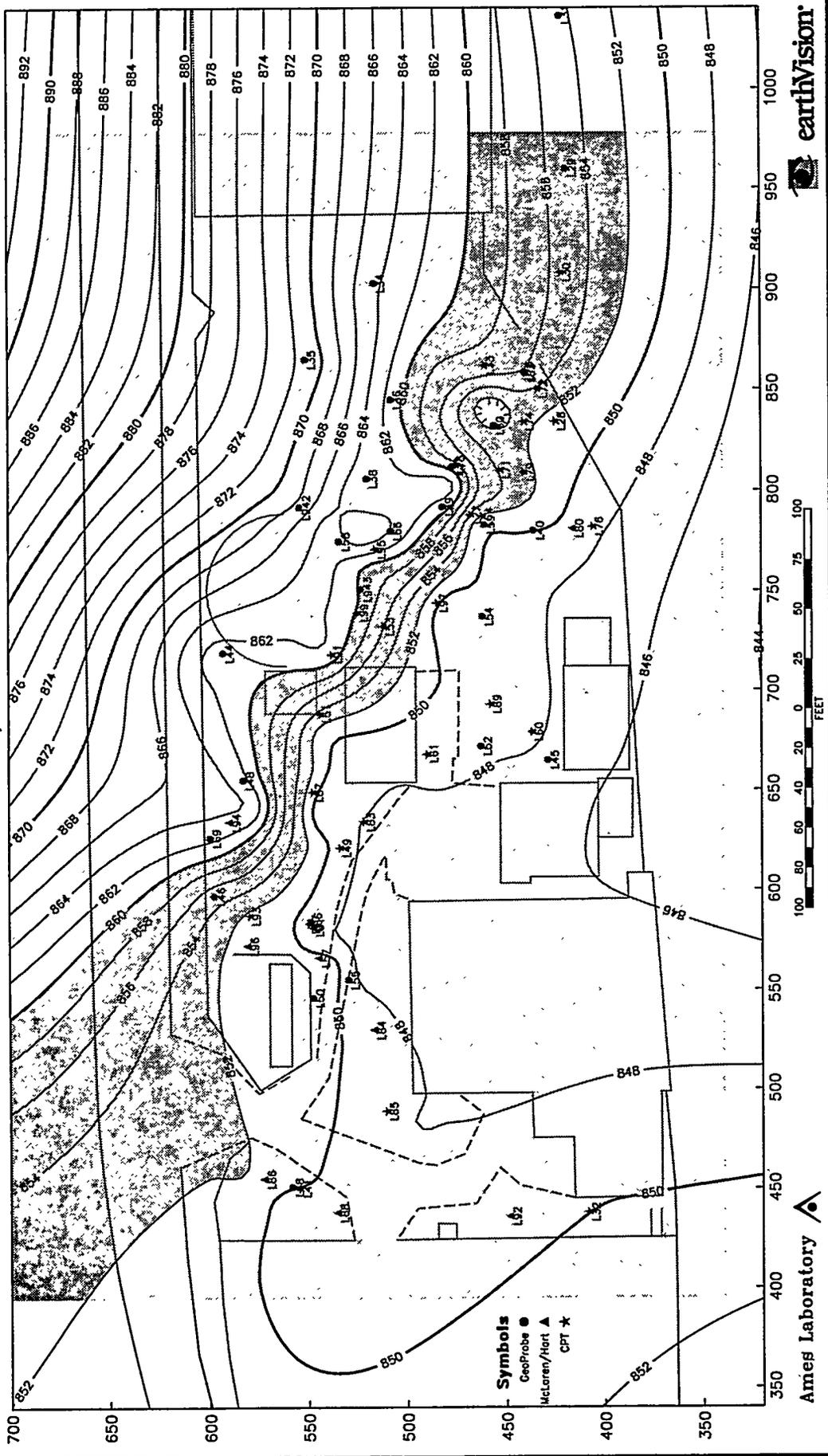


Figure 4.67 Granular Unit/Lower Cohesive Unit Contact - Day 4

Granular Unit/Lower Cohesive Unit Contact Surface Elevation

Day 9/10/30

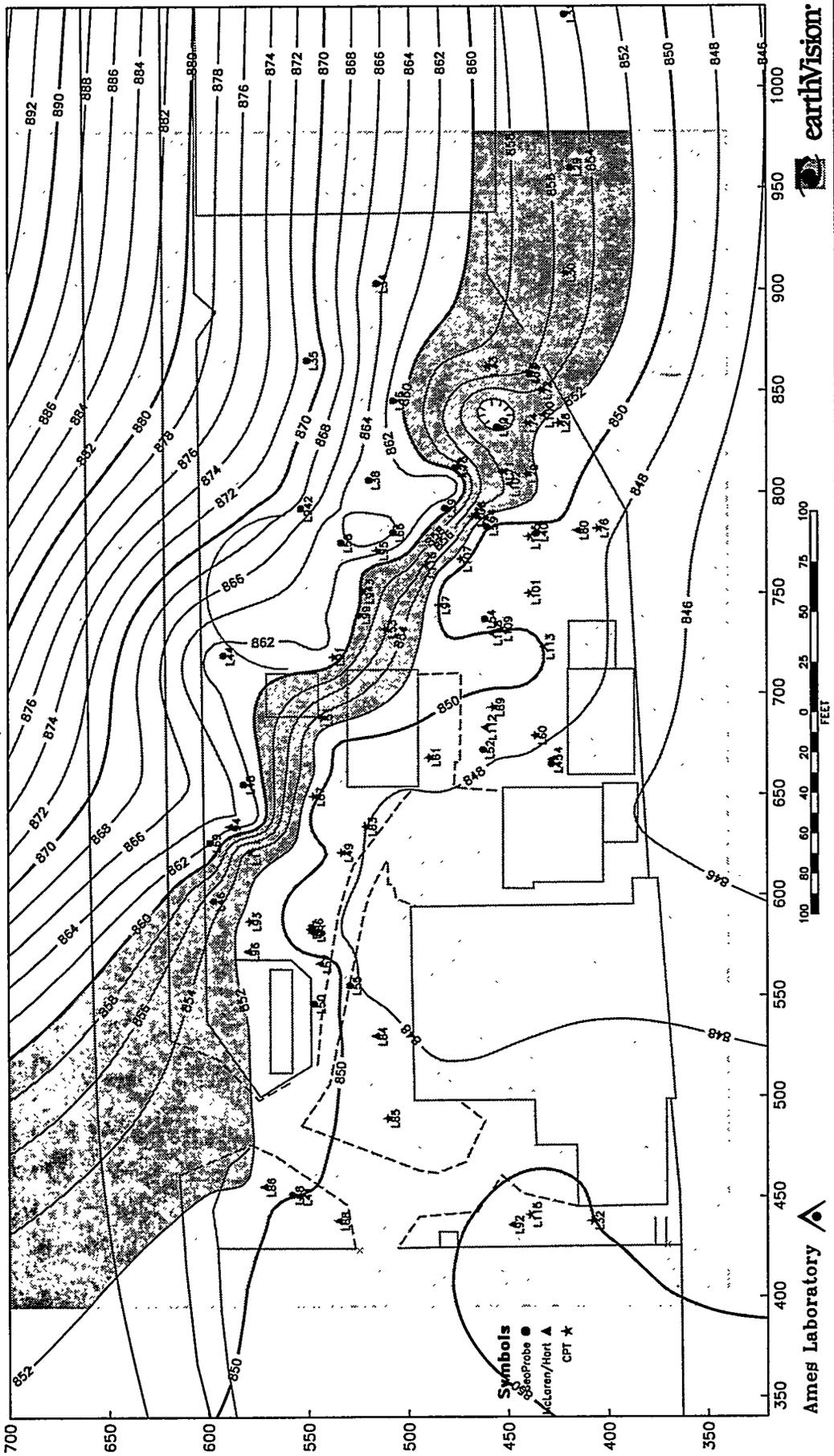


Figure 4.68 Granular Unit/Lower Cohesive Unit Contact - Day 10

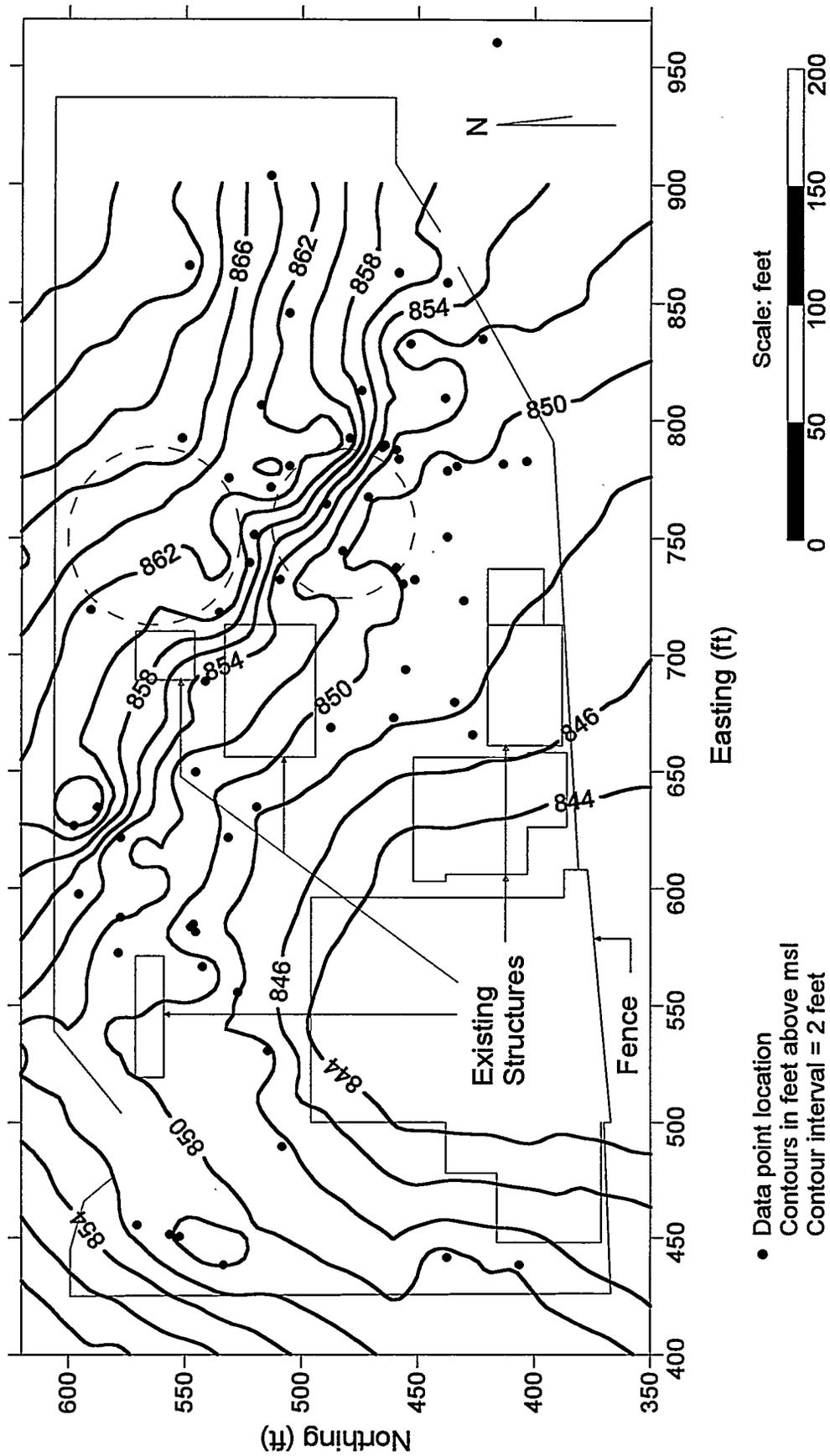
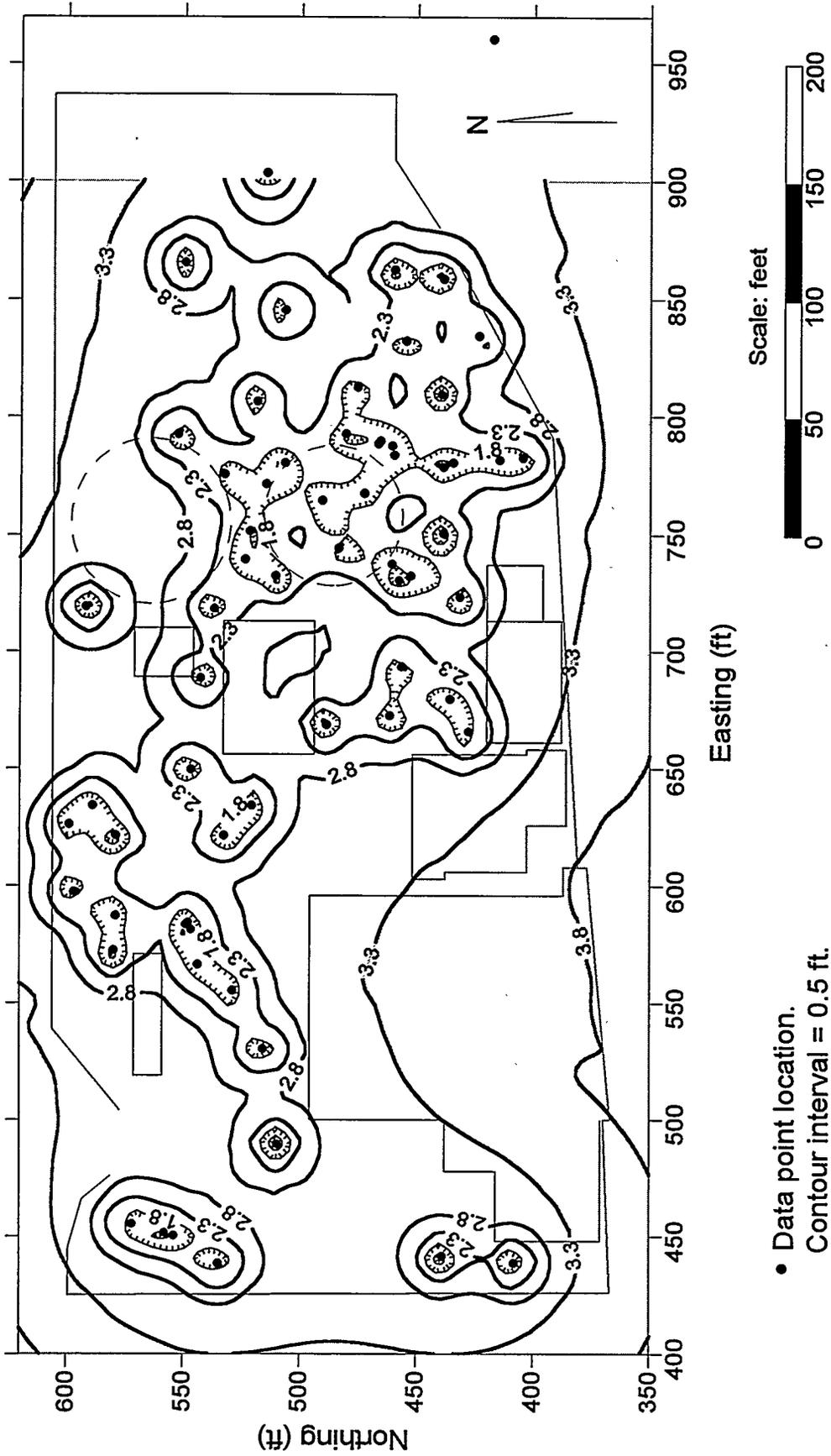


Figure 4.69 Lower Cohesive Unit Surface Elevation Based on Kriged Median Polish Residuals



• Data point location.
 Contour interval = 0.5 ft.

Figure 4.70 Lower Cohesive Unit Surface Elevation Prediction Standard Deviation (feet)

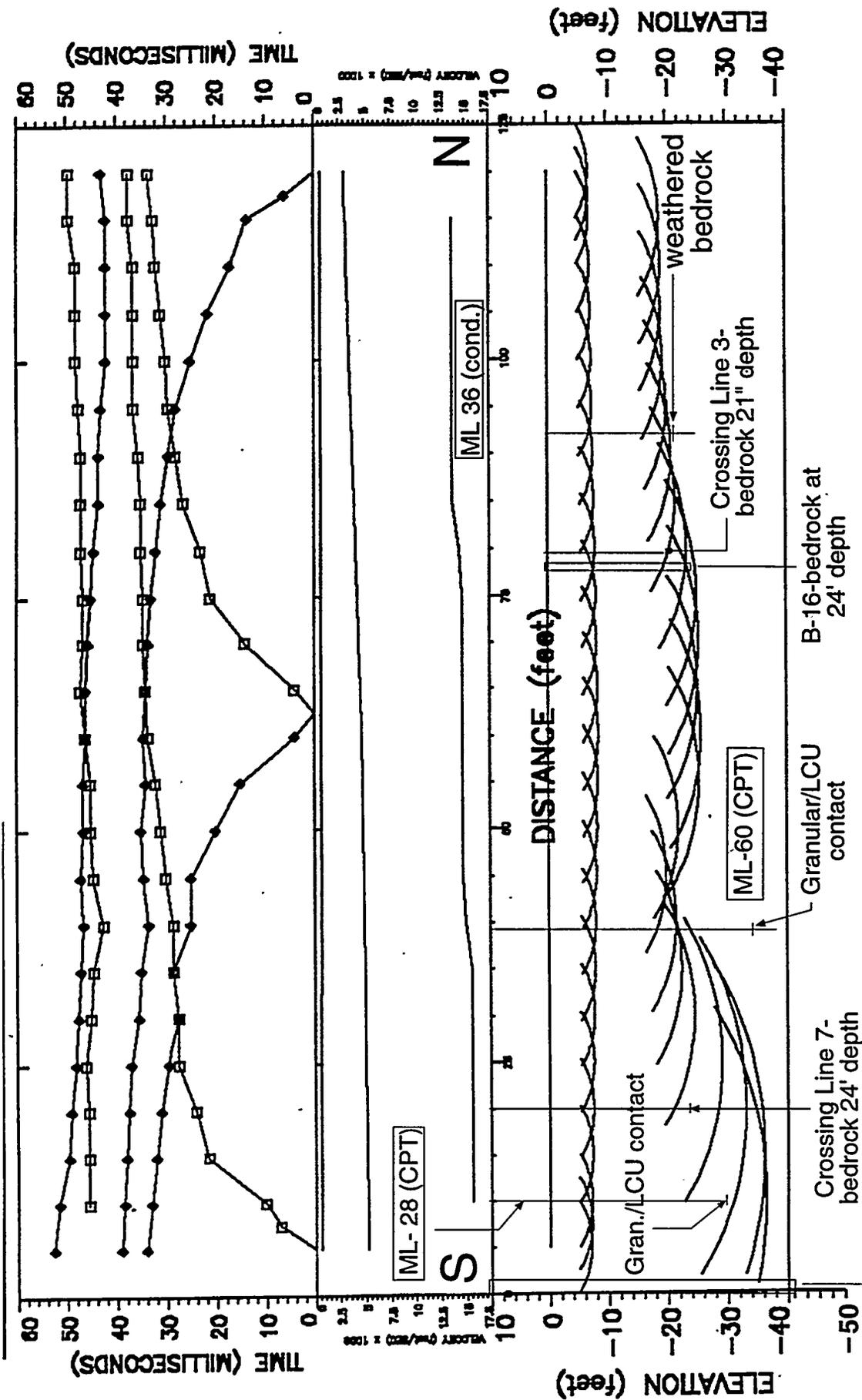


Figure 4.71 Seismic Refraction Survey Line 5 Comparison with Direct Push and Borehole Data (after CEES - Blackhawk Geosciences Division)

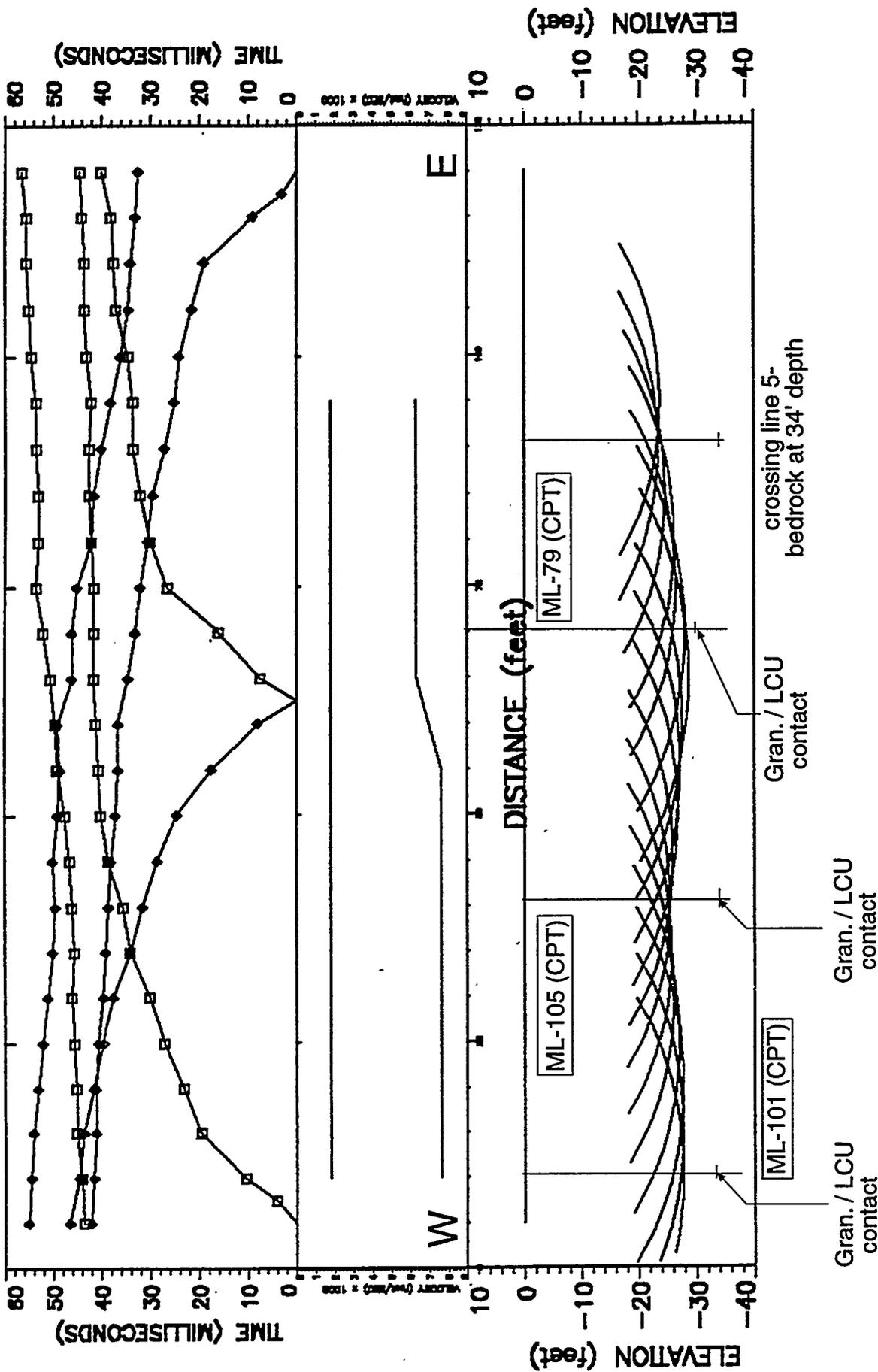


Figure 4.72 Seismic Refraction Survey Line 7
 Comparison with Direct Push Data
 (after CEES - Blackhawk Geosciences Division)

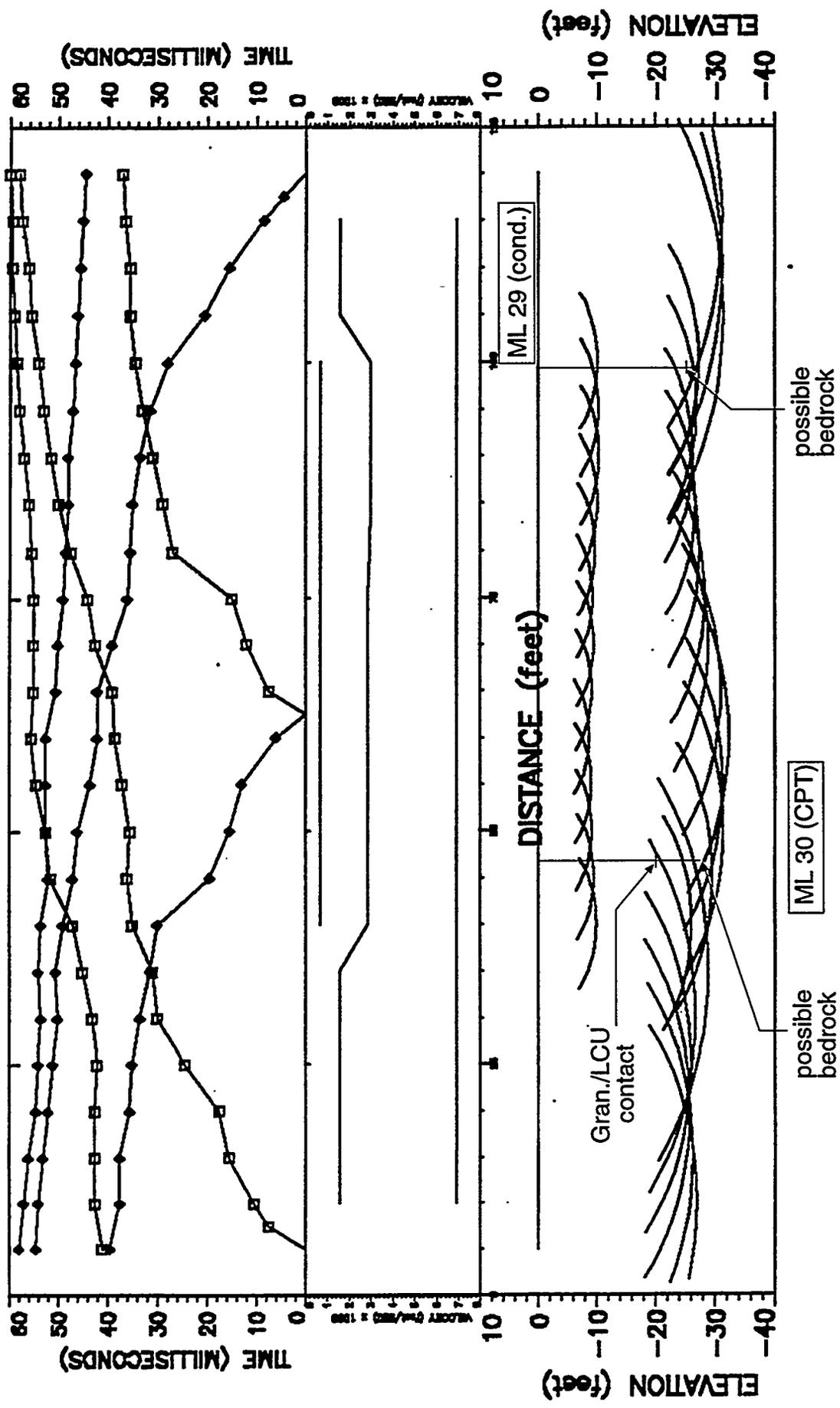


Figure 4.73 Seismic Refraction Survey Line 9
 Comparison with Direct Push Data
 (after CEES - Blackhawk Geosciences Division)

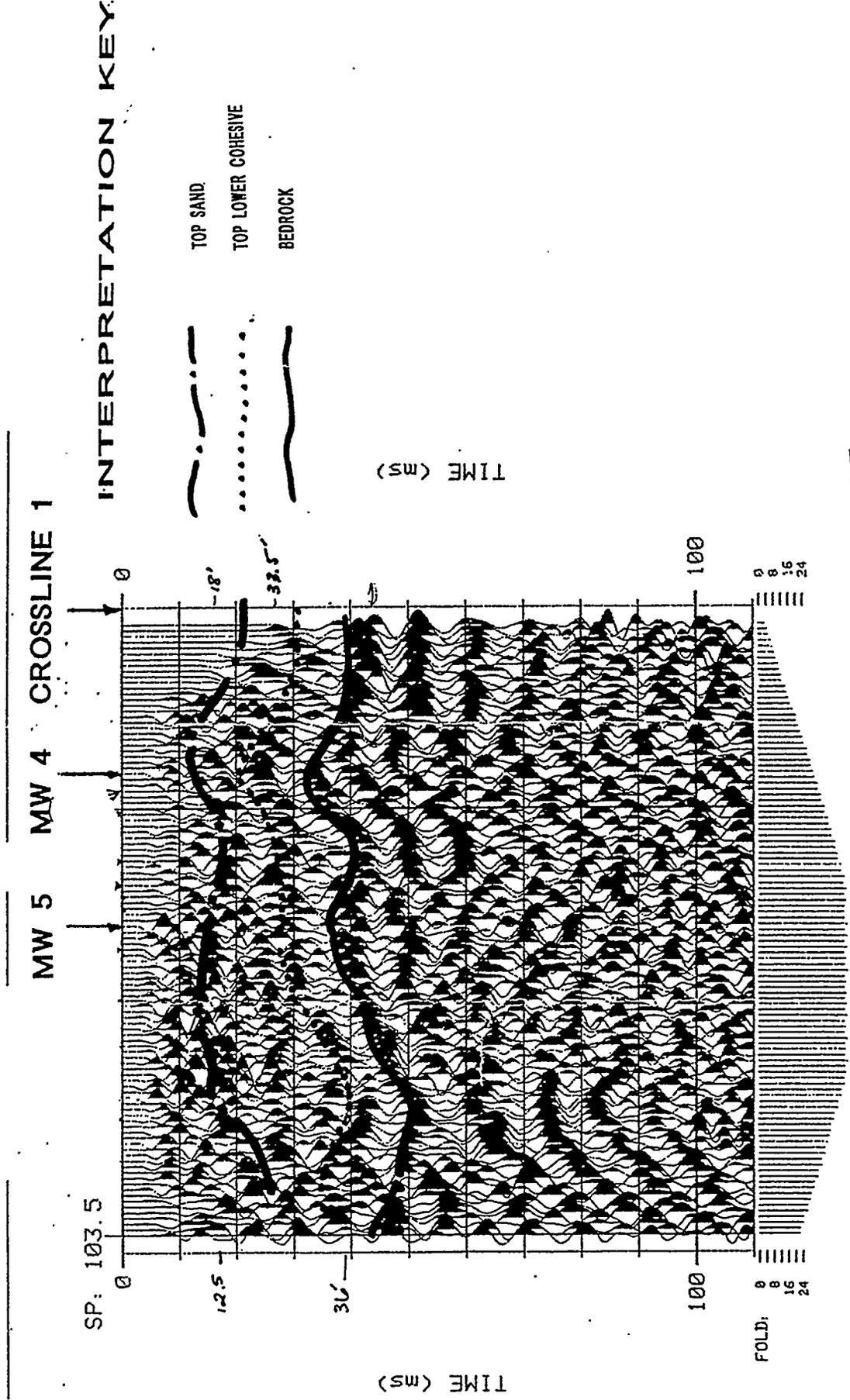


Figure 4.74 Seismic Reflection Survey - West Line Profile

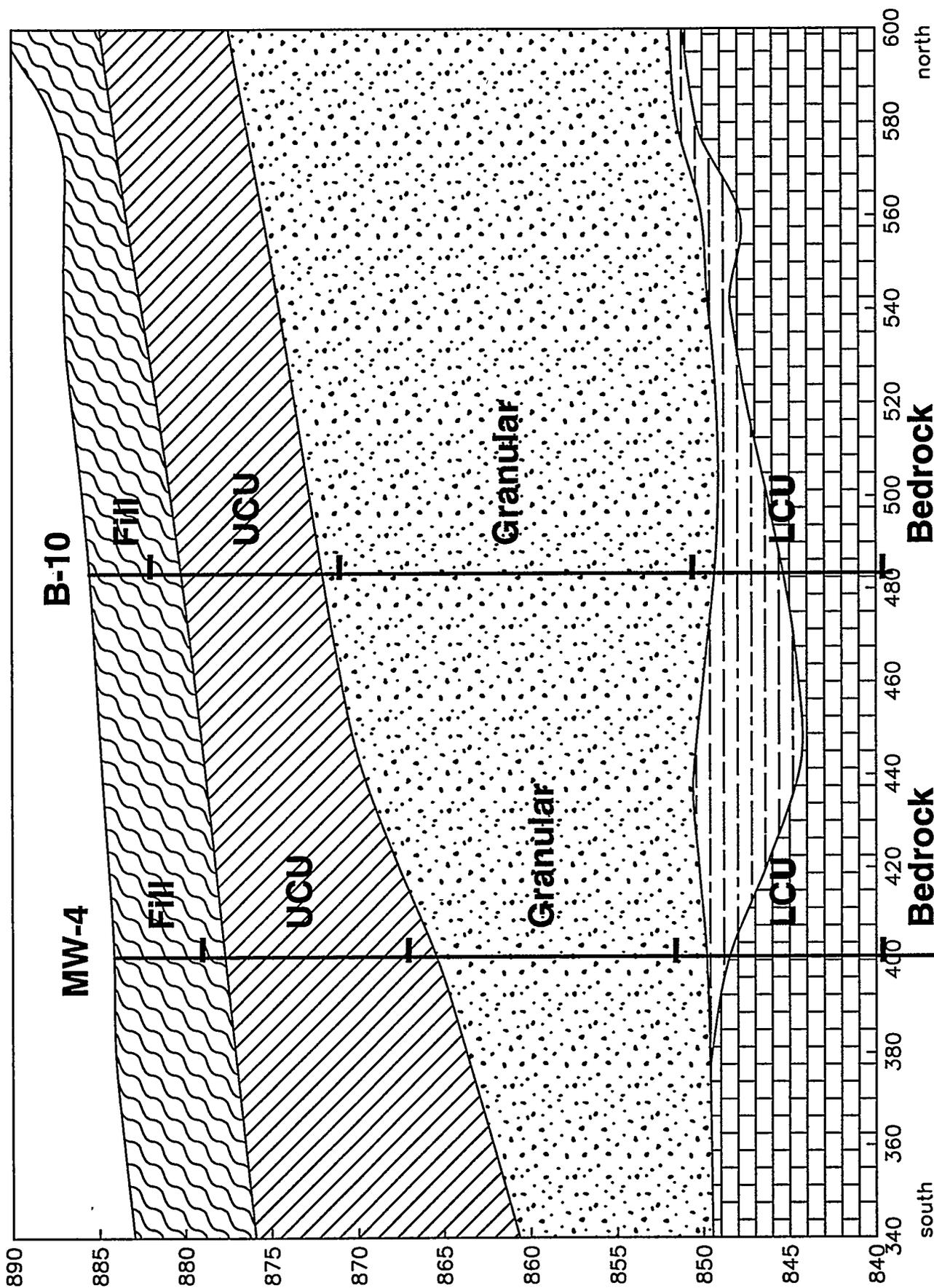


Figure 4.75 Earth Vision Stratigraphic Model - North-South Cut at 450 E

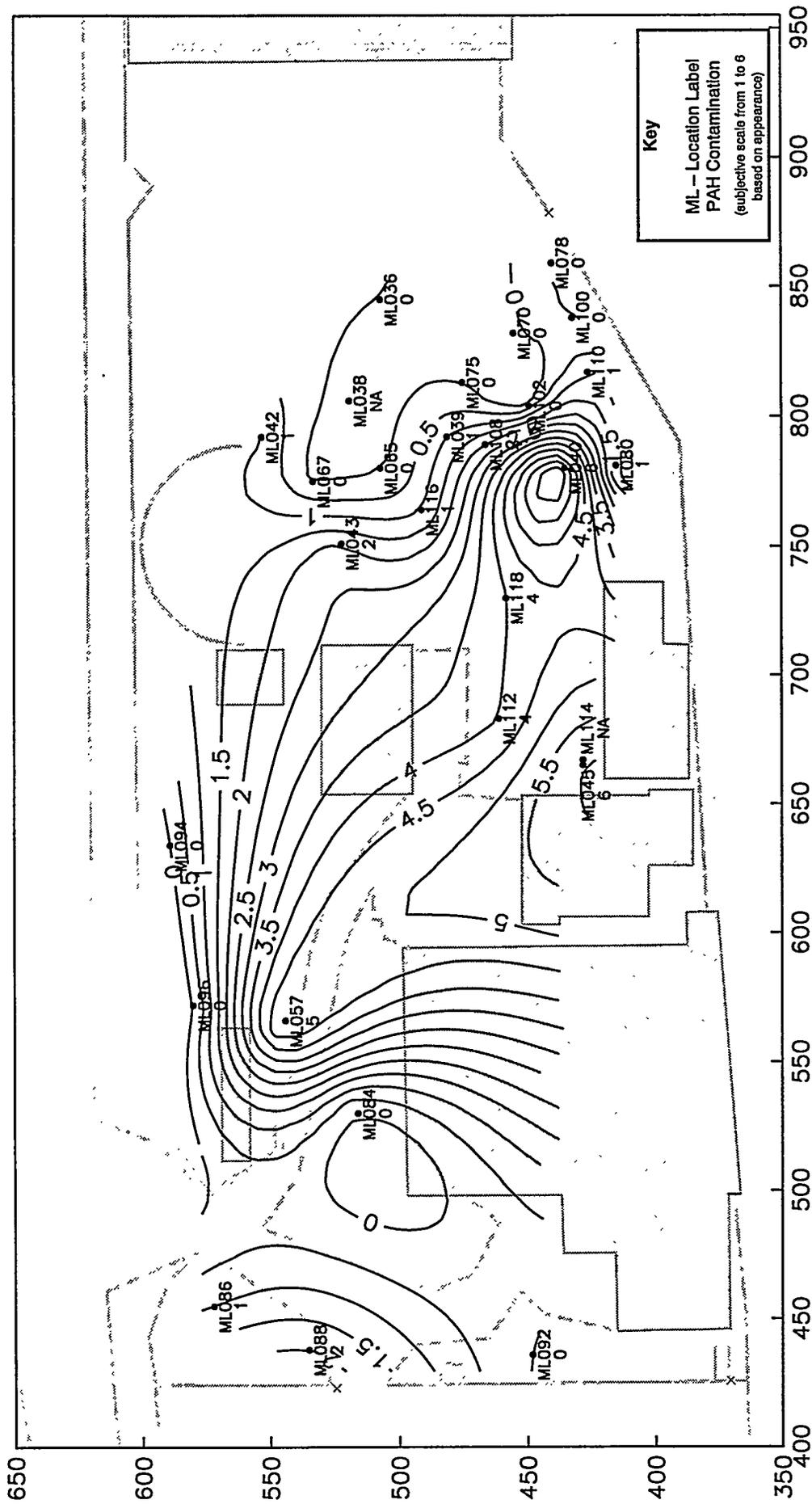


Figure 4.76 McLaren/Hart Samples - Observed Level of PAH Contamination in Soils - Stratigraphic Zone 1

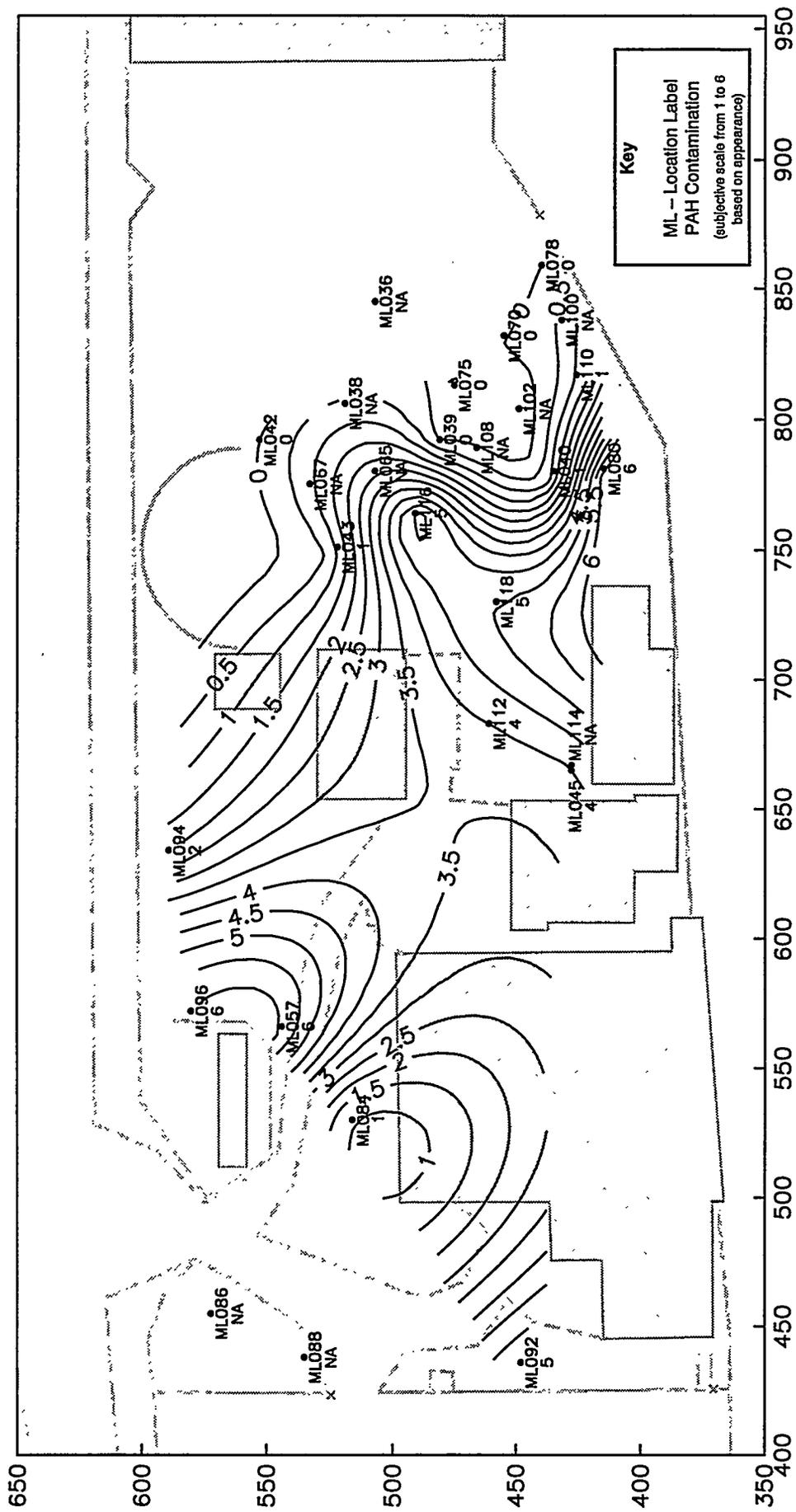


Figure 4.78 McLaren/Hart Samples - Observed Level of PAH Contamination in Soils - Stratigraphic Zone 3

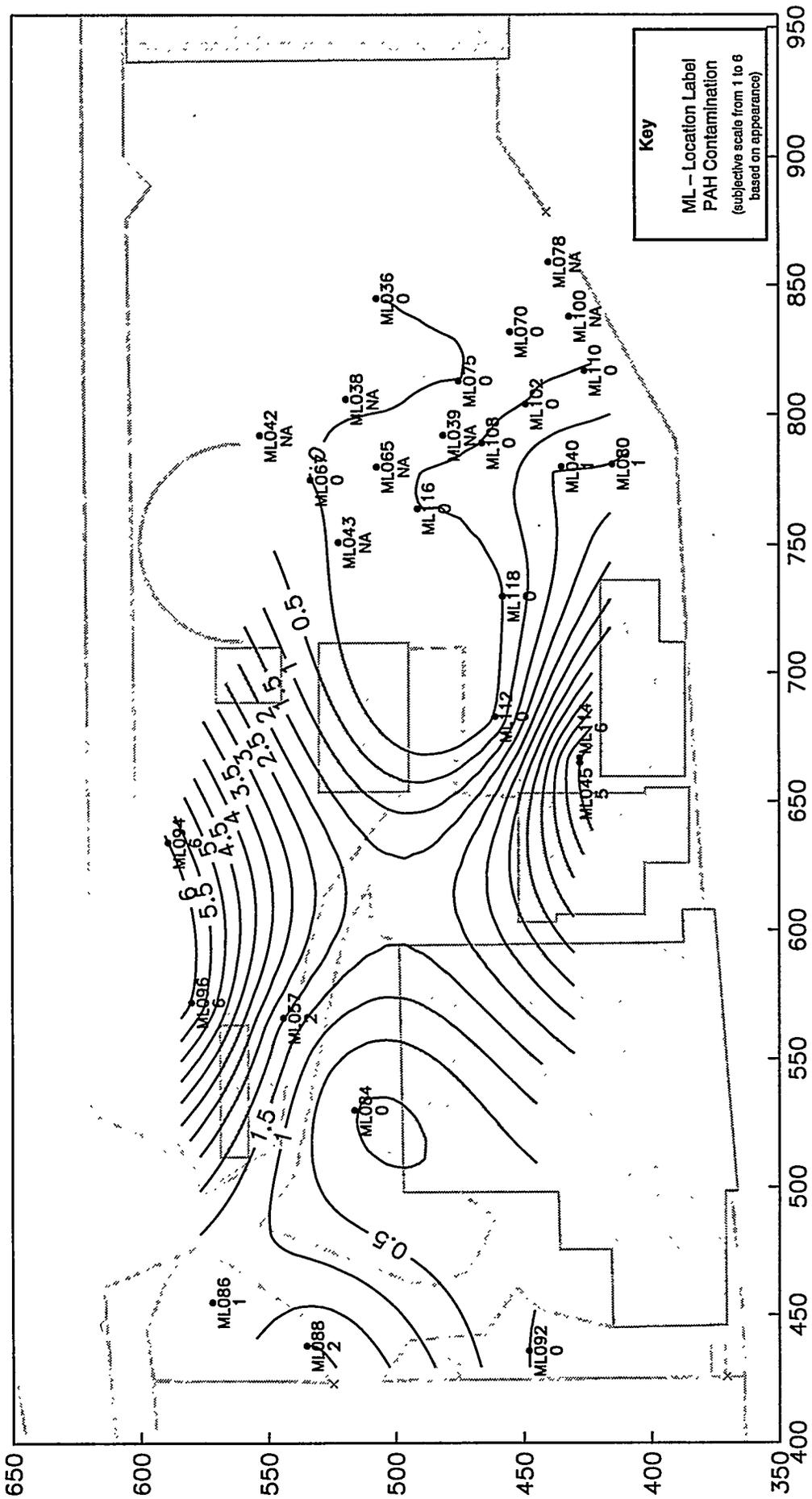


Figure 4.79 McLaren/Hart Samples - Observed Level of PAH Contamination in Soils - Stratigraphic Zone 4

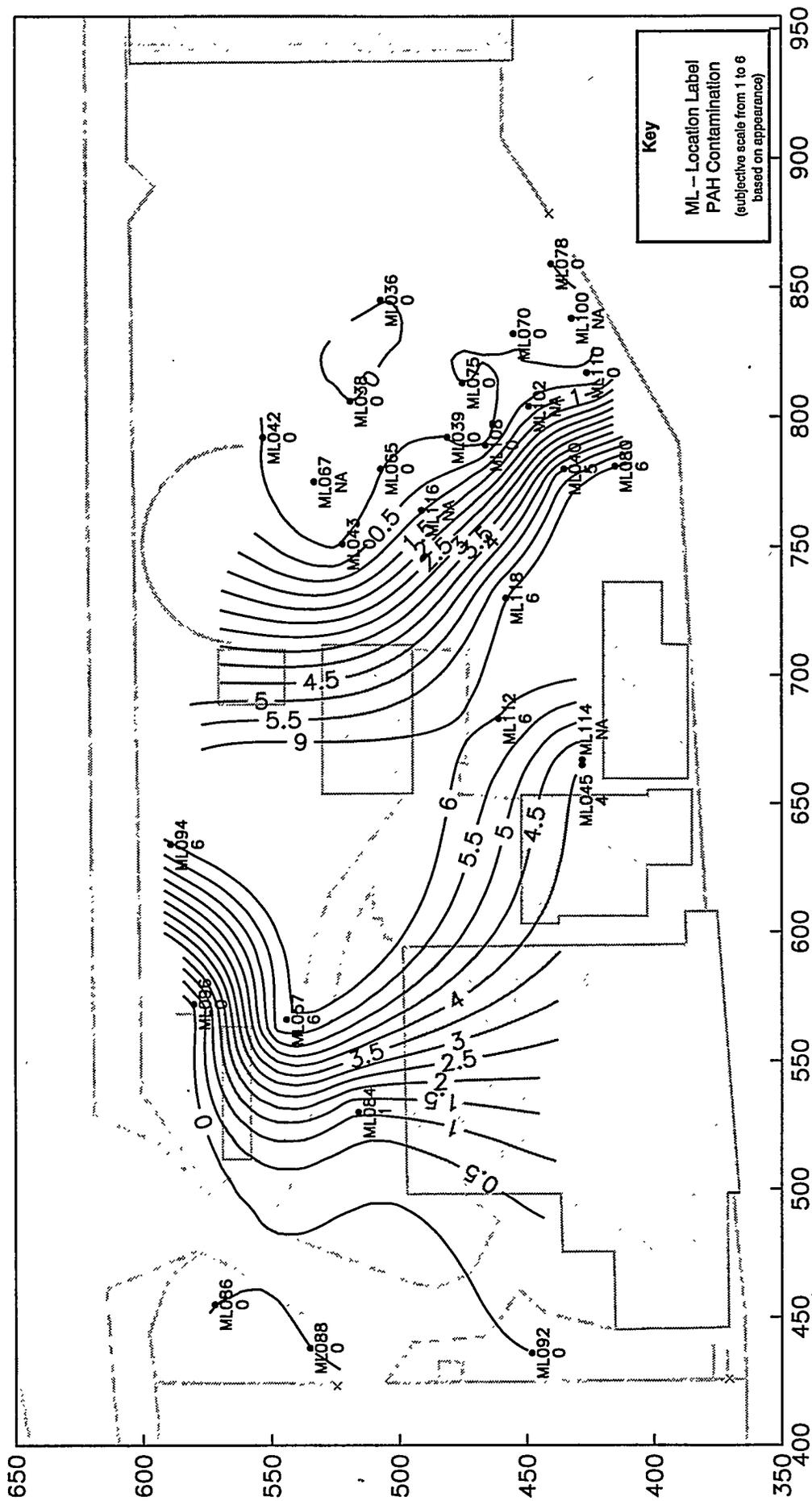


Figure 4.80 McLaren/Hart Samples - Observed Level of PAH Contamination in Soils - Stratigraphic Zone 5

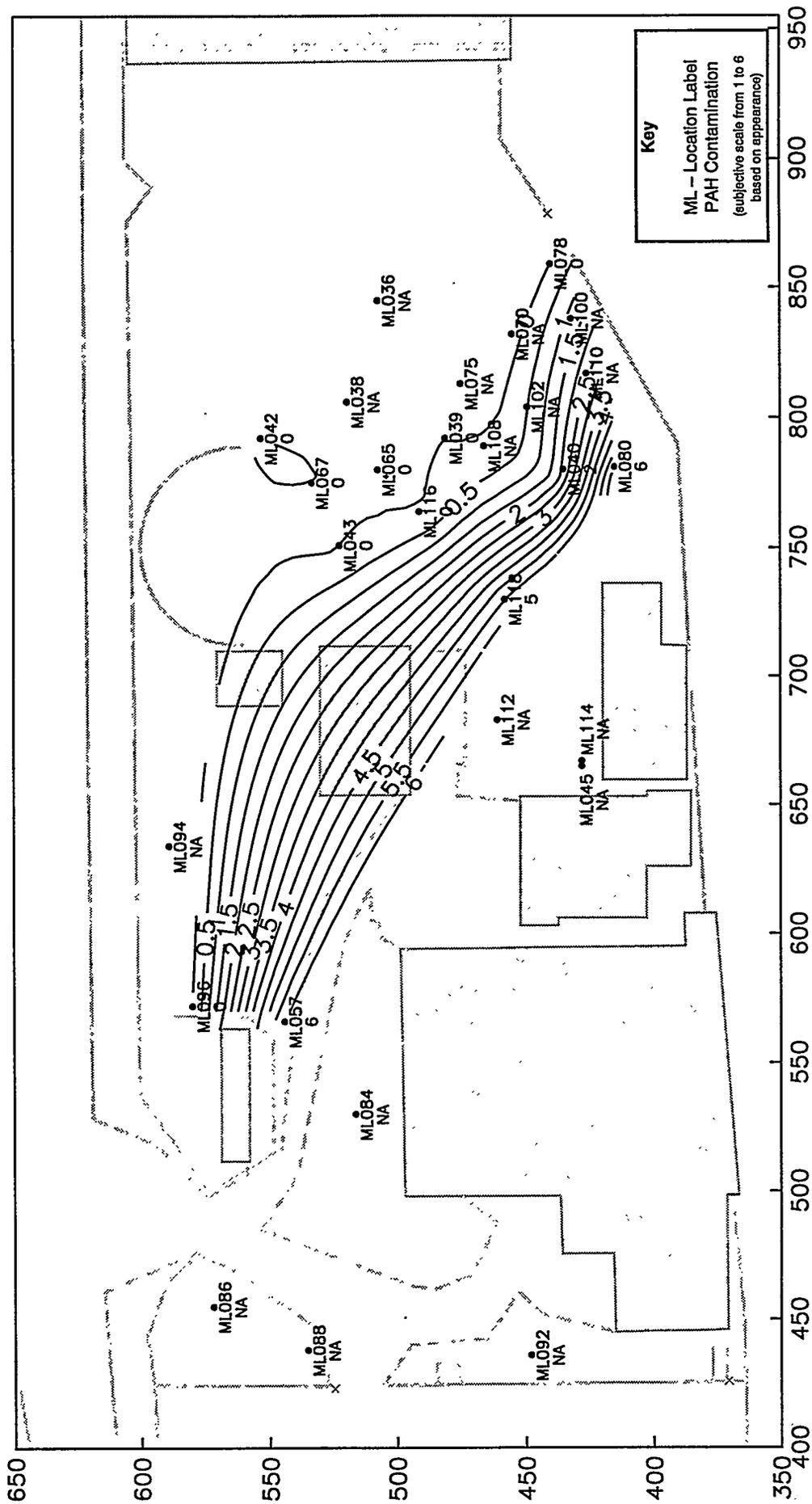


Figure 4.81 McLaren/Hart Samples - Observed Level of PAH Contamination in Soils - Stratigraphic Zone 6

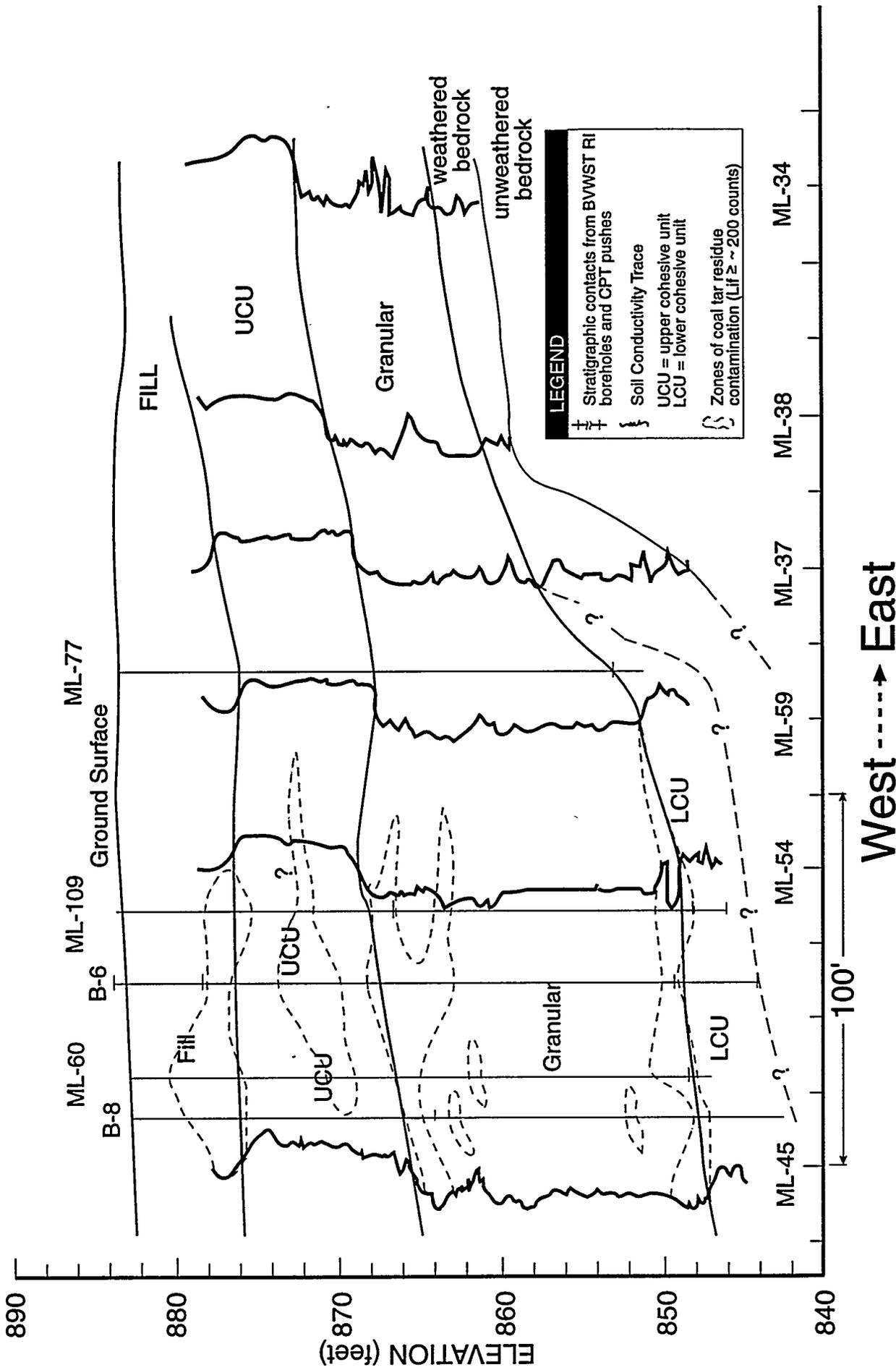


Figure 4.82 Stratigraphic Cross Section AA' showing Zones of Coal Tar Residue Contamination note: see figure 4.58 for location

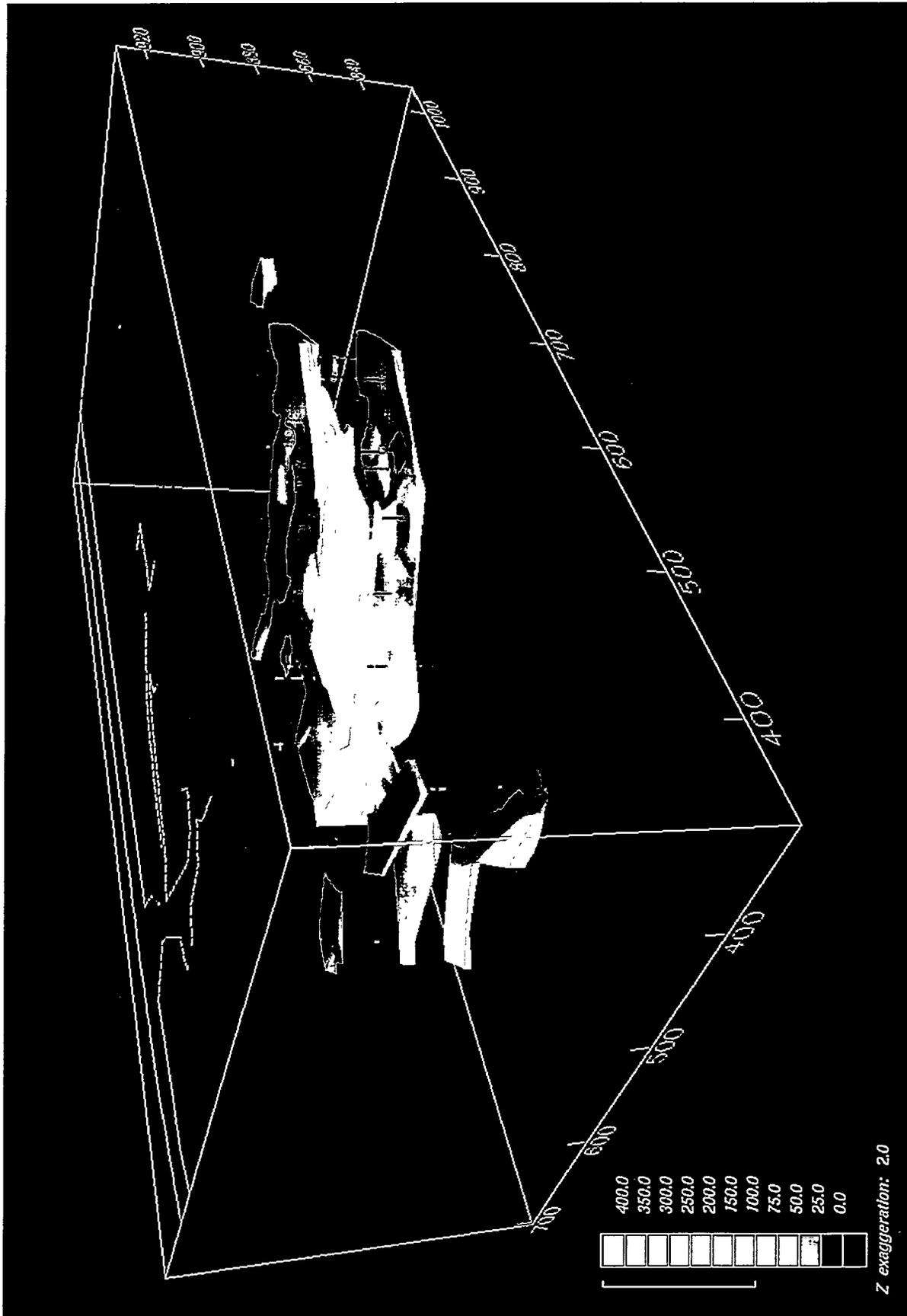


Figure 4.83 Three Dimensional Earth Vision Visualization - LIF Intensity

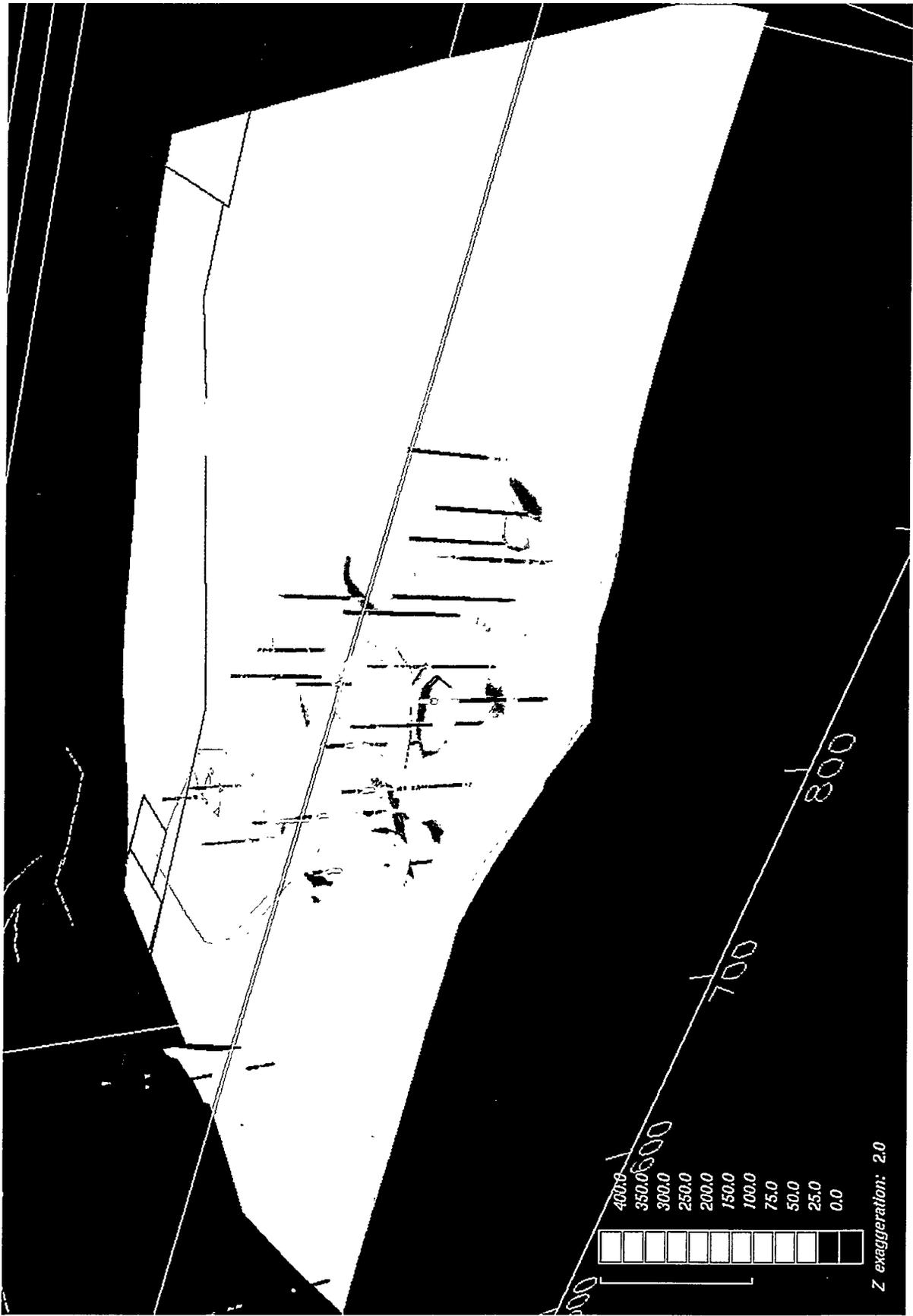


Figure 4.84 Three Dimensional Earth Vision Visualization - Regions with LIF Intensity > 100 Counts

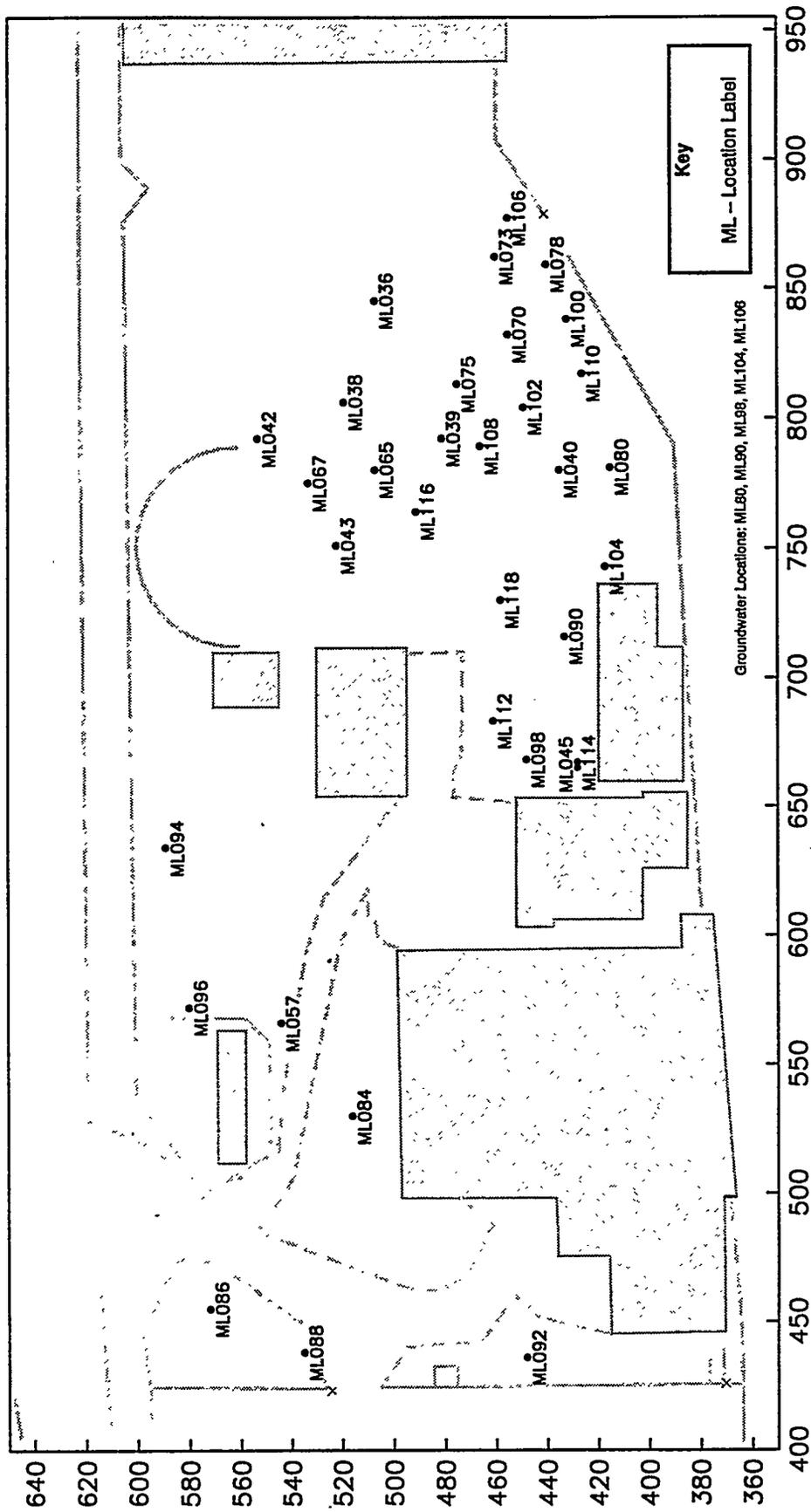


Figure 4.85 McLaren/Hart Soil and Groundwater Sampling Locations

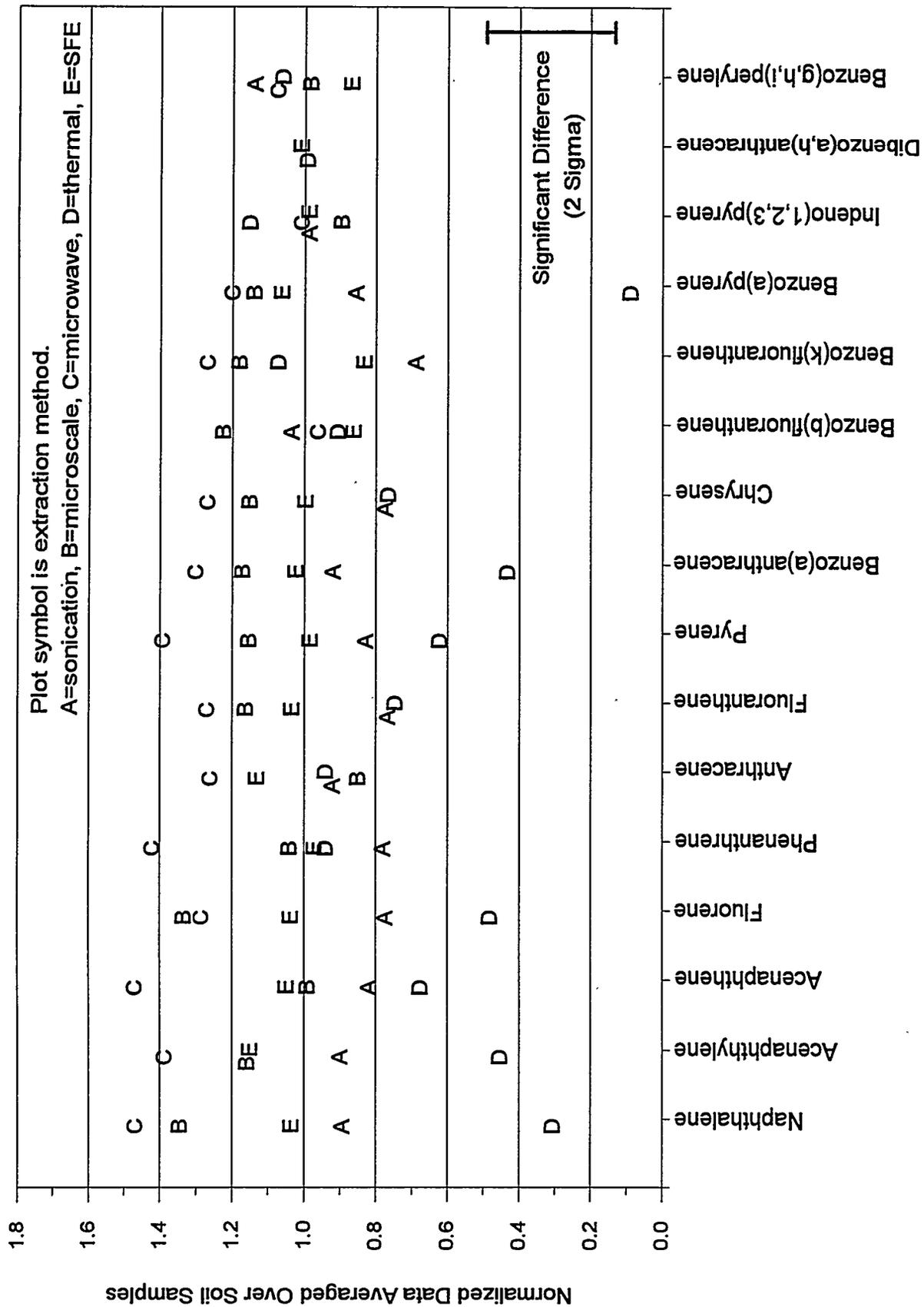


Figure 4.86 Extraction Method Analytical Results - Means of Combined Sandy and Clayey Soil Samples Plotted by Analyte

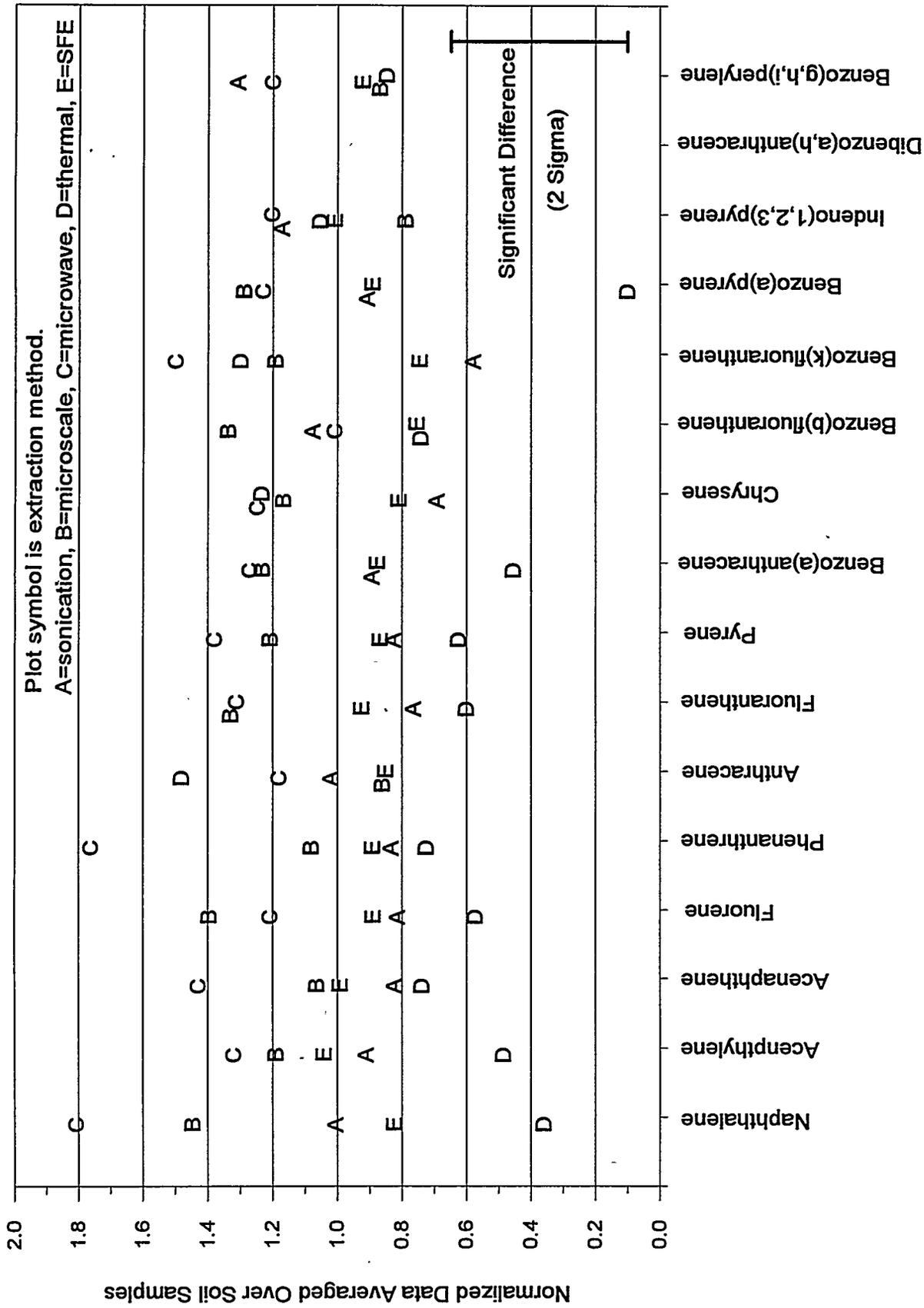


Figure 4.87 Extraction Method Analytical Results - Clayey Soil Sample Means Plotted by Analyte - Data Corrected for Percent Recovery

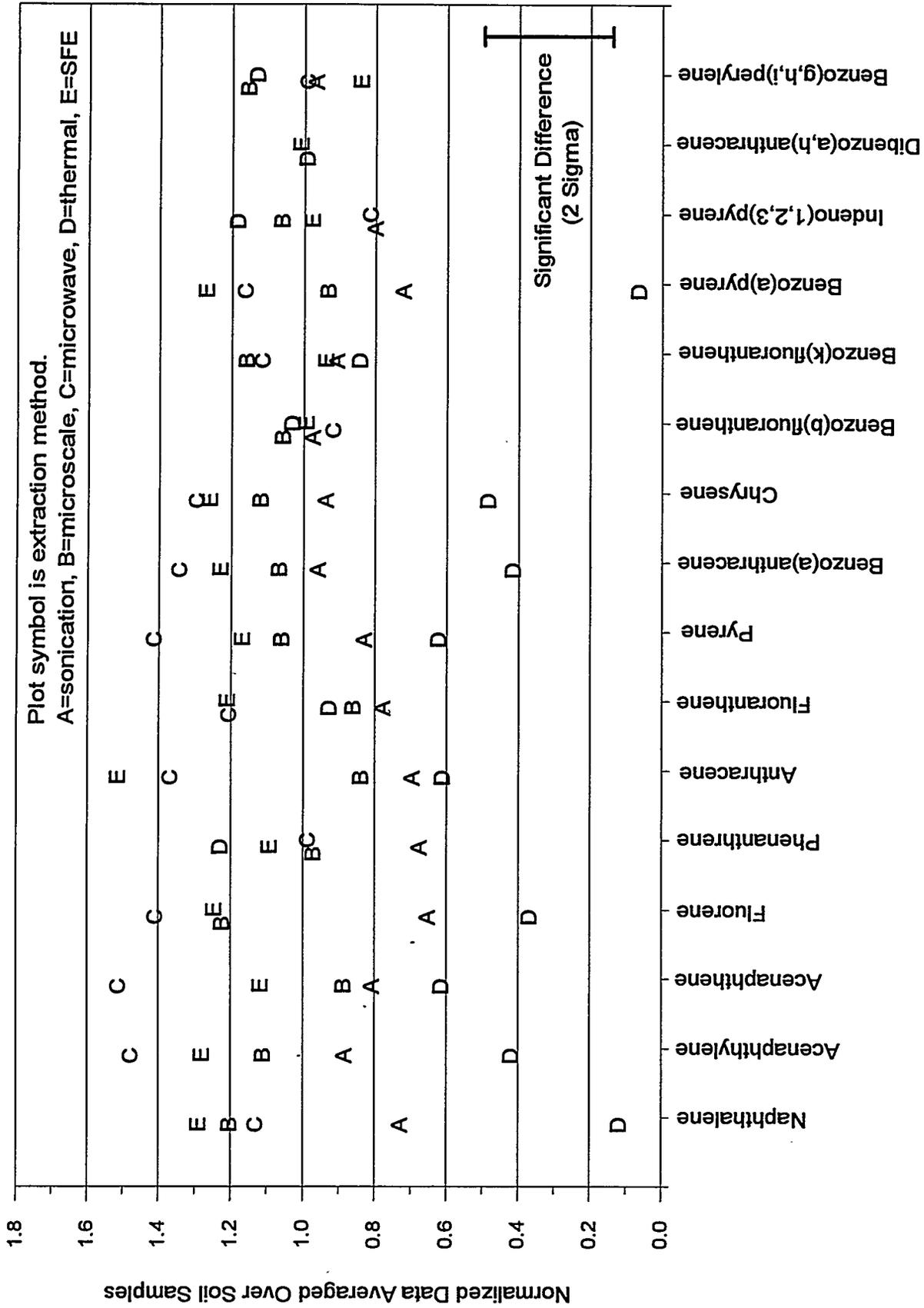


Figure 4.88 Extraction Method Analytical Results - Sandy Soil Sample Means Plotted by Analyte - Data Corrected for Percent Recovery

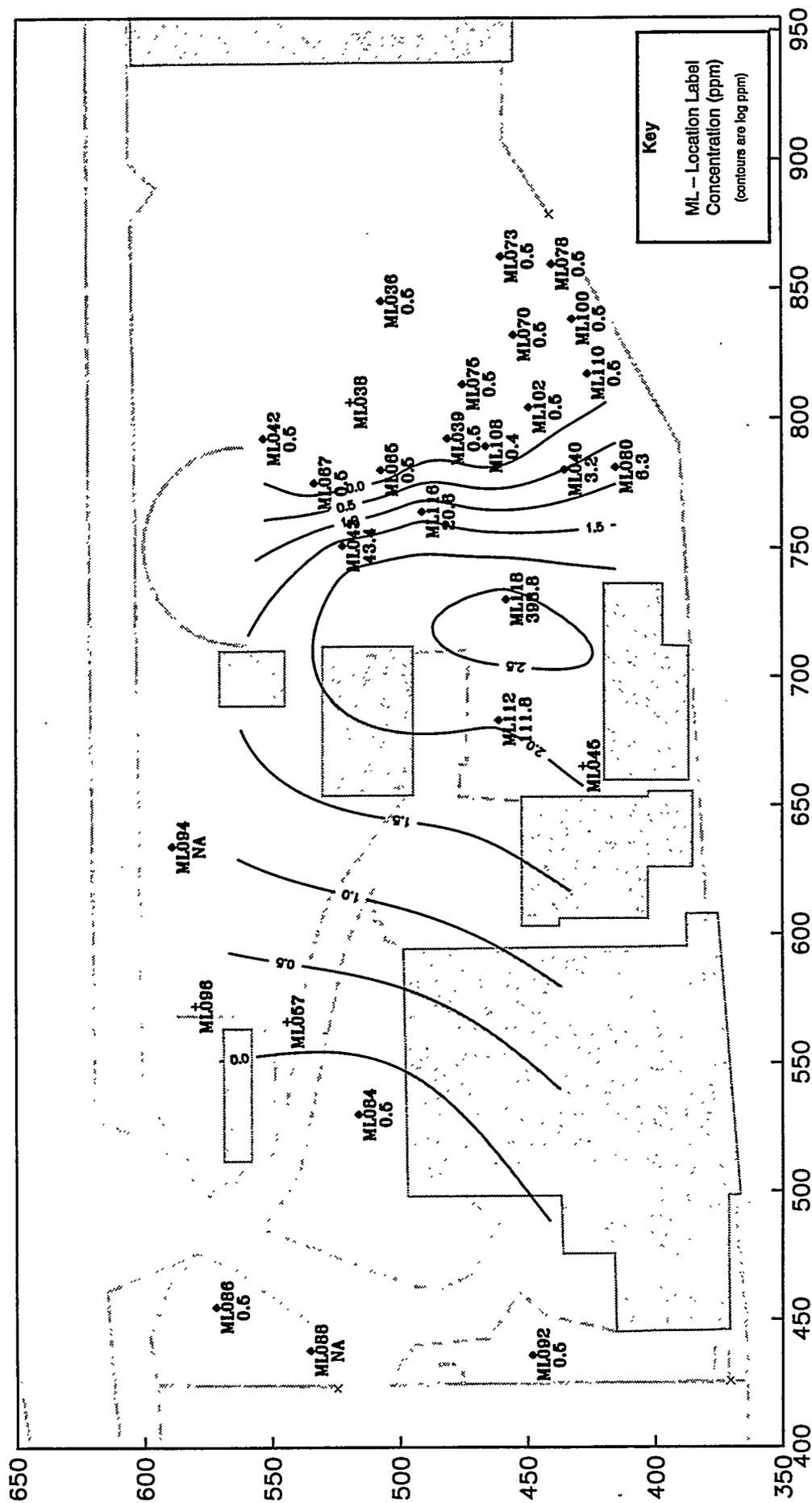


Figure 4.89 McLaren/Hart GC/MS Soil Sample Analysis Results - Naphthalene - Stratigraphic Zone 1

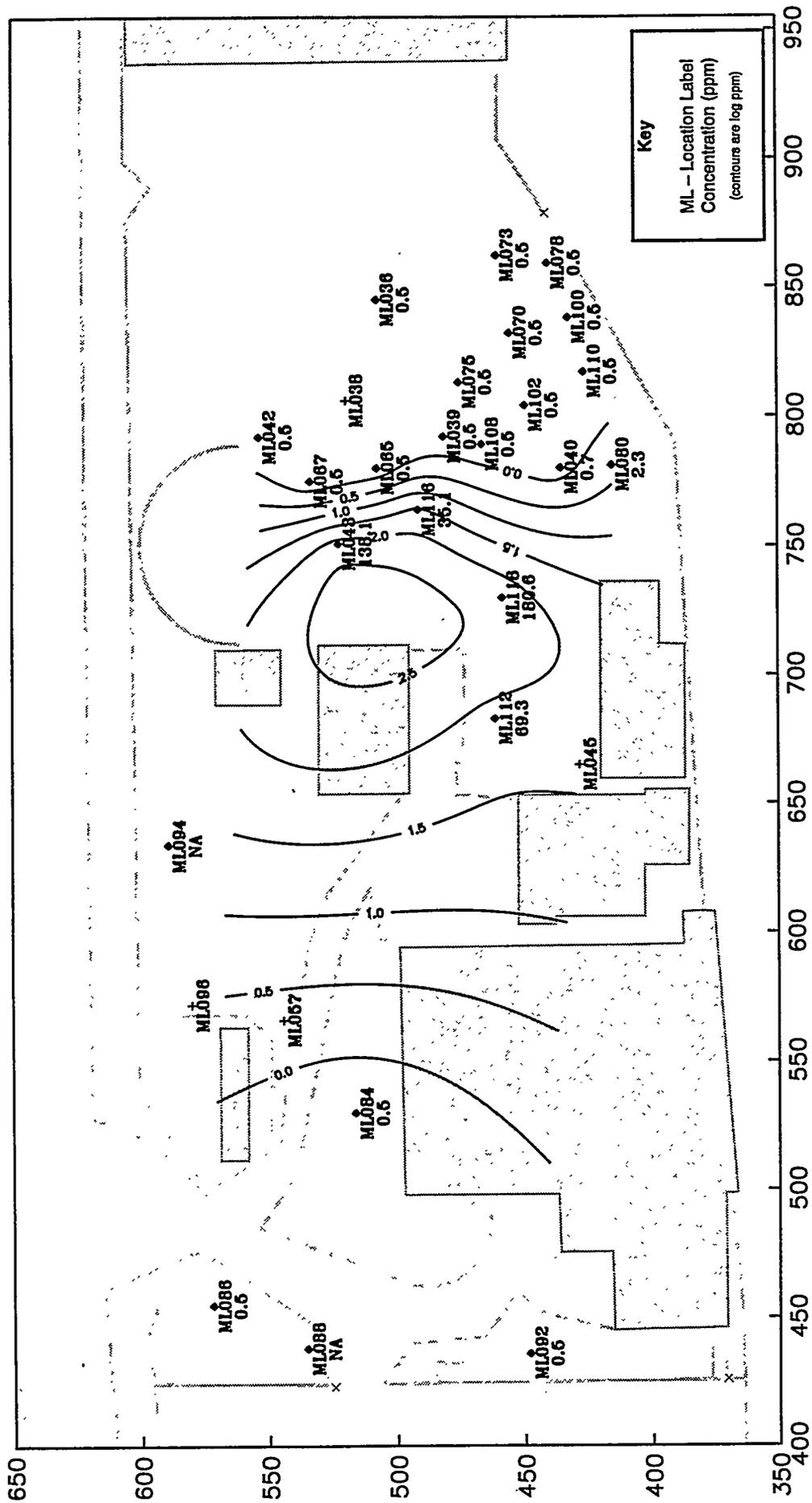


Figure 4.90 McLaren/Hart GC/MS Soil Sample Analysis Results - Phenanthrene - Stratigraphic Zone 1

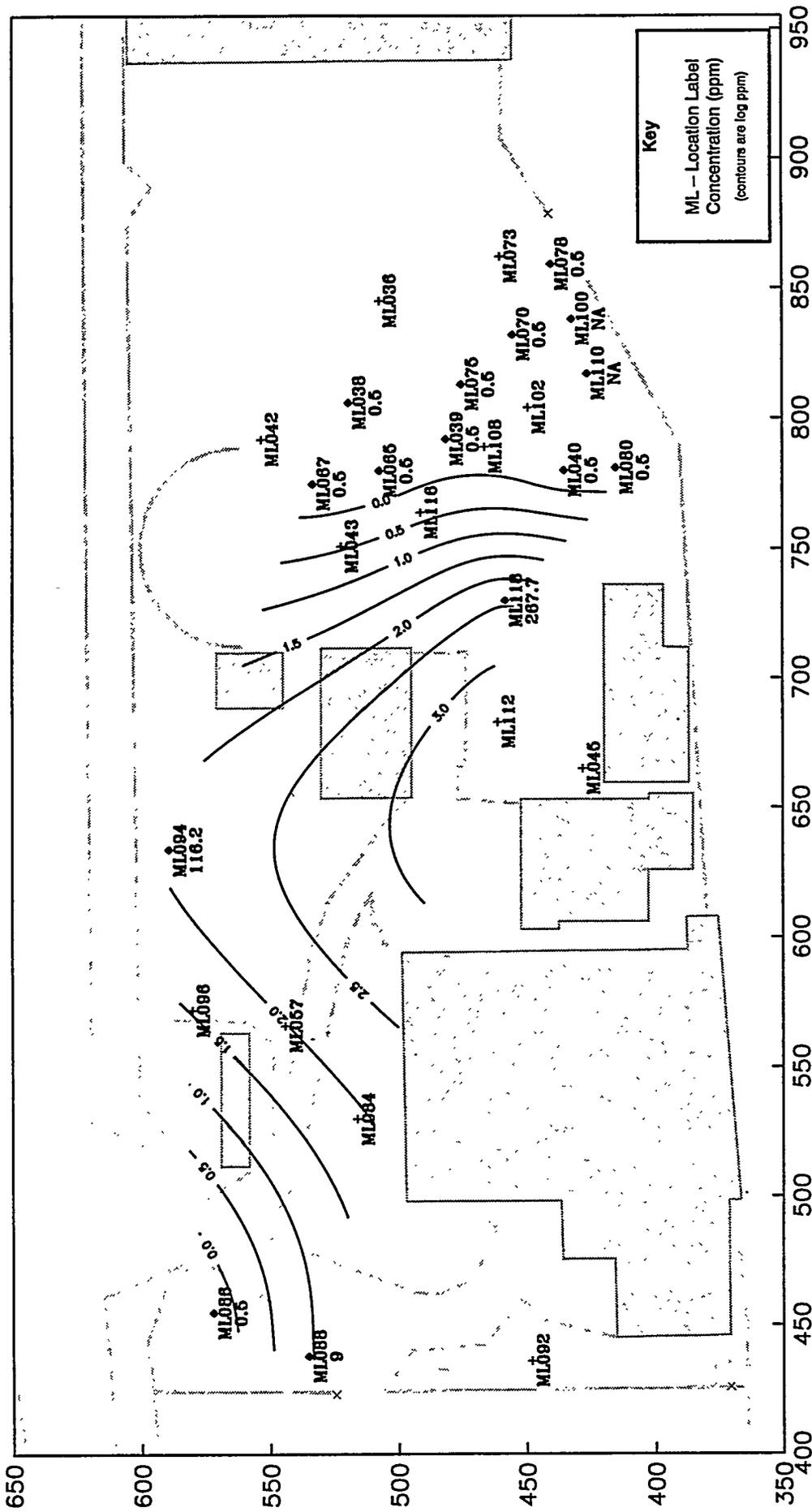


Figure 4.91 McLaren/Hart GC/MS Soil Sample Analysis Results - Naphthalene - Stratigraphic Zone 2

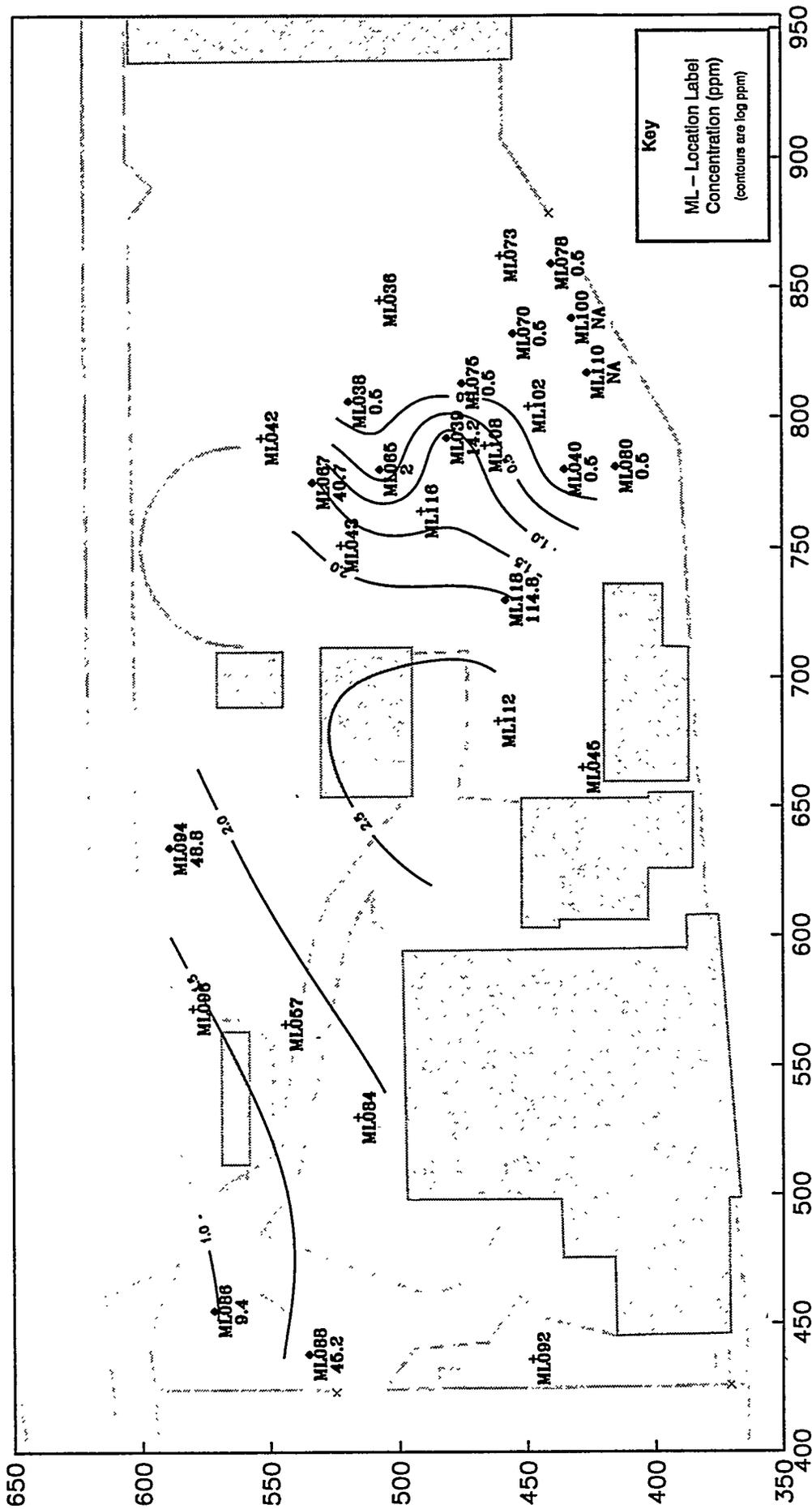


Figure 4.92 McLaren/Hart GC/MS Soil Sample Analysis Results - Phenanthrene - Stratigraphic Zone 2

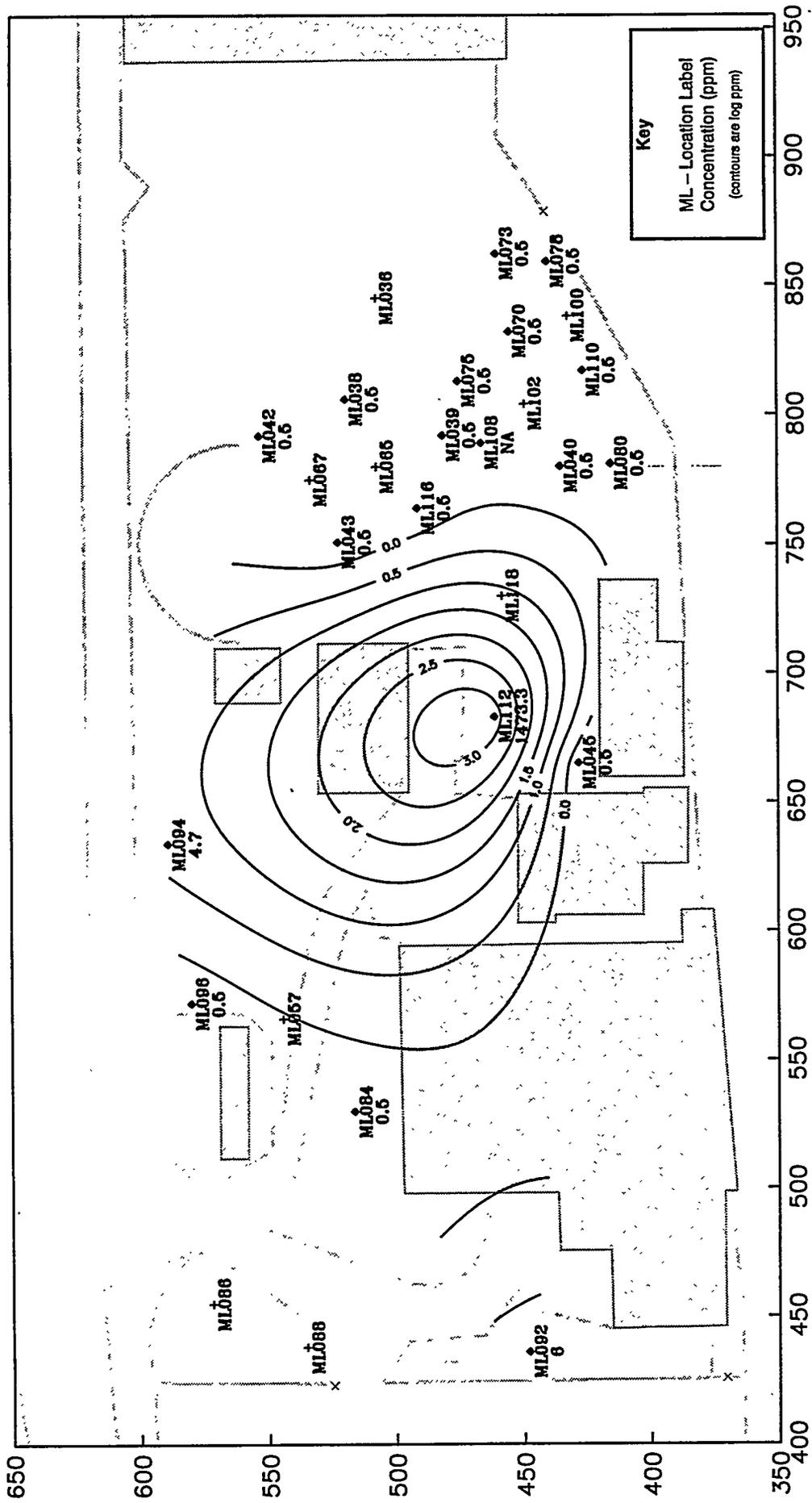


Figure 4.93 McLaren/Hart GC/MS Soil Sample Analysis Results - Naphthalene - Stratigraphic Zone 3

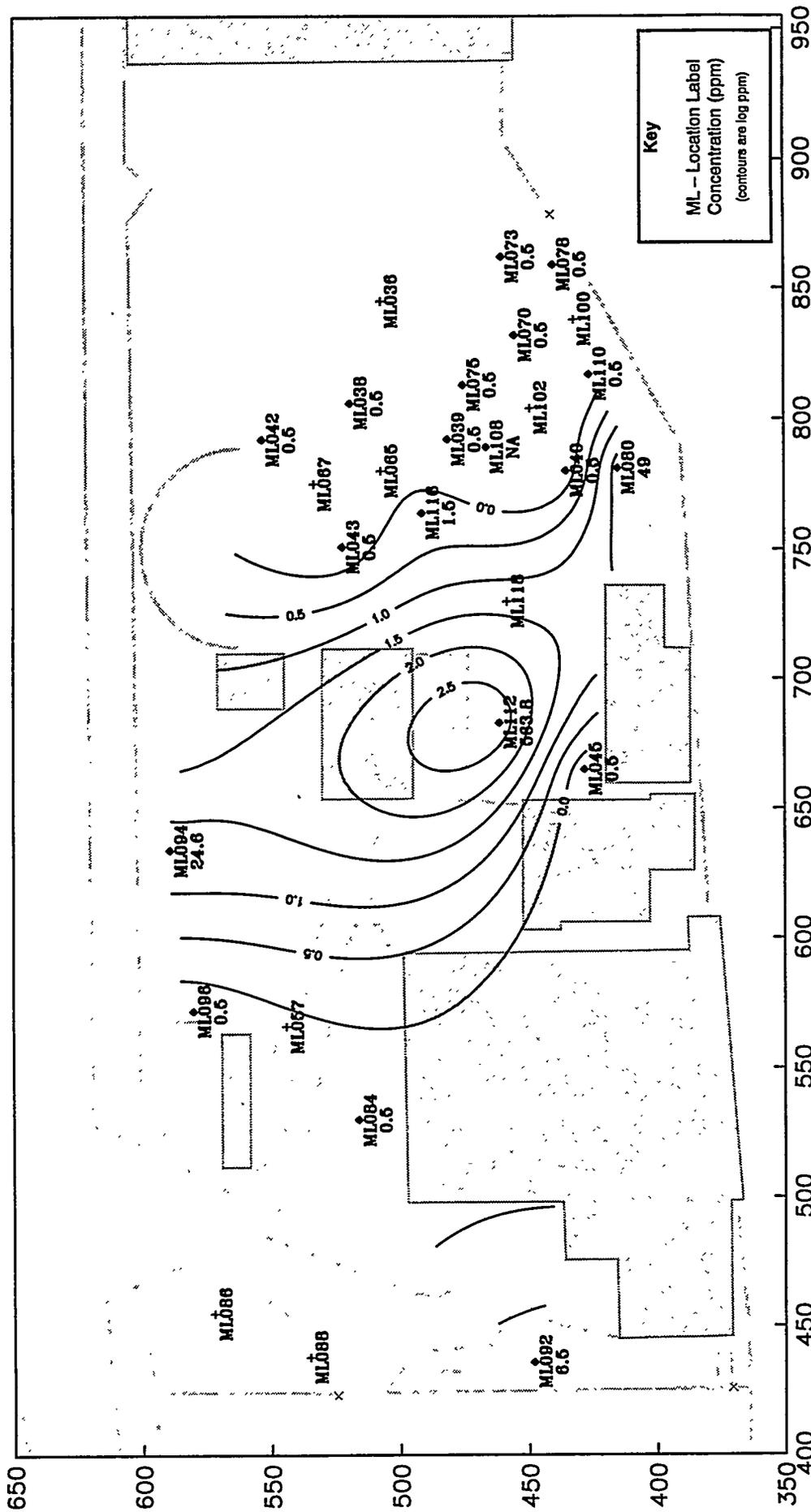


Figure 4.94 McLaren/Hart GC/MS Soil Sample Analysis Results - Phenanthrene - Stratigraphic Zone 3

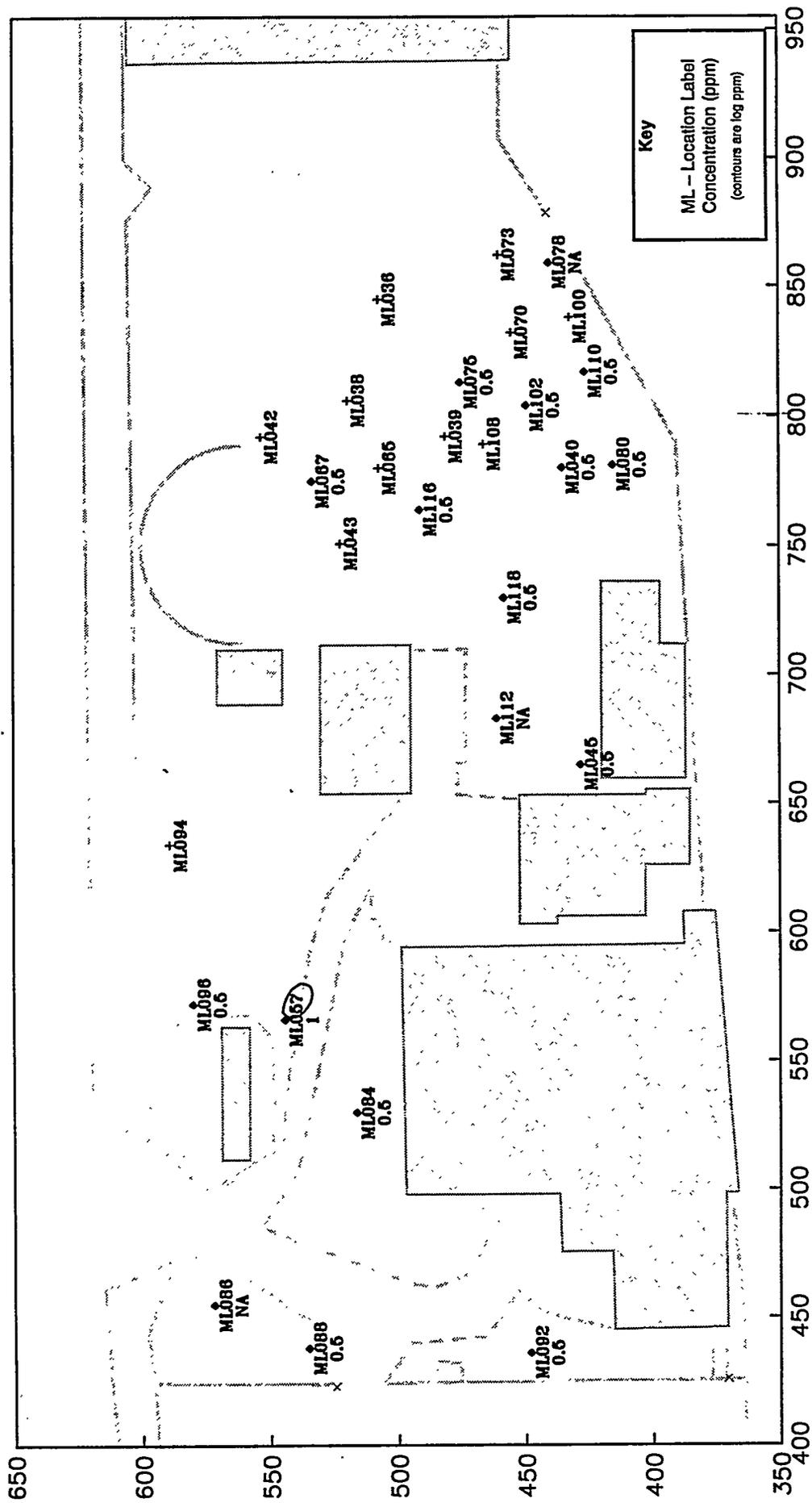


Figure 4.95 McLaren/Hart GC/MS Soil Sample Analysis Results - Naphthalene - Stratigraphic Zone 4

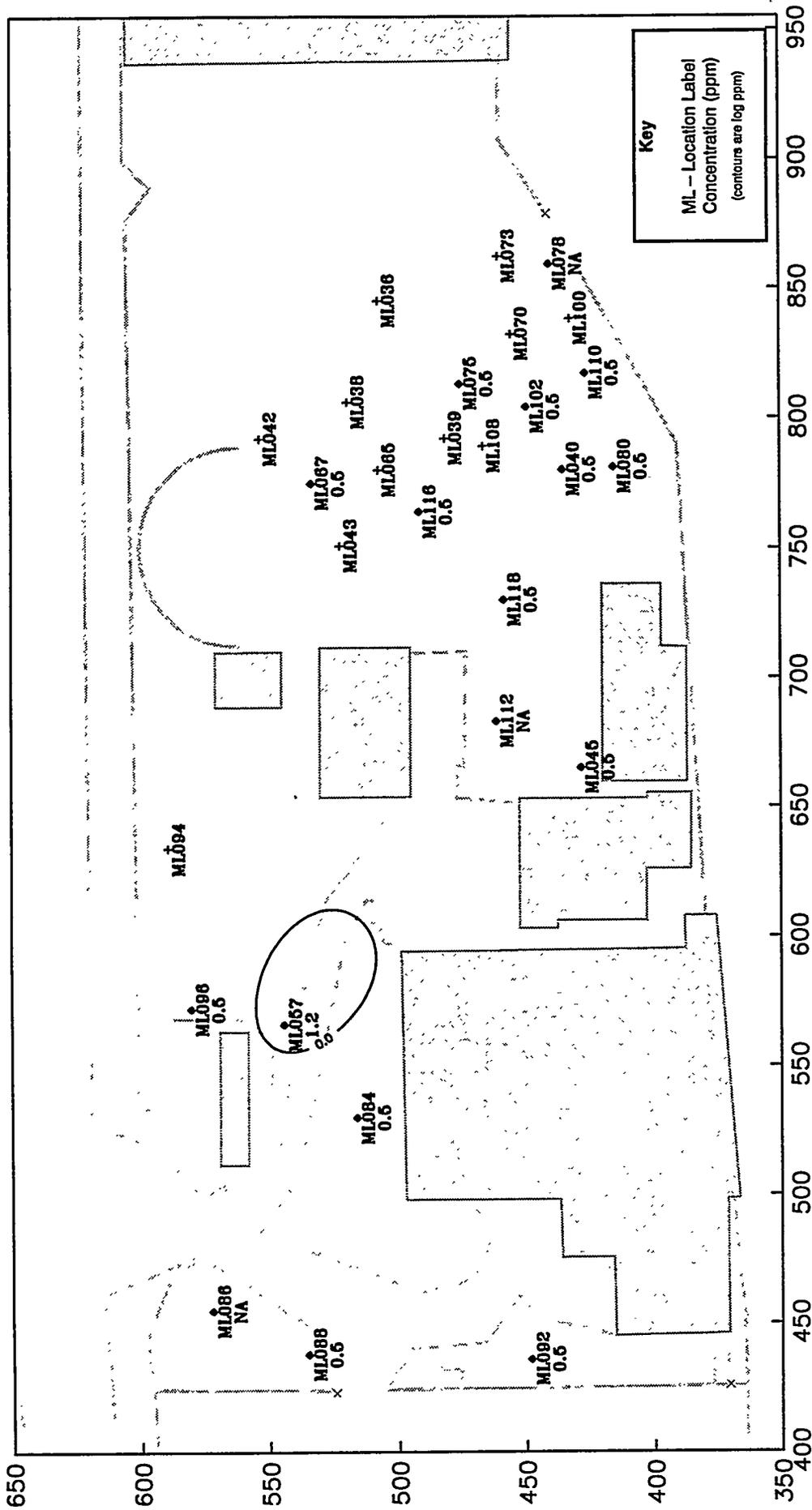


Figure 4.96 McLaren/Hart GC/MS Soil Sample Analysis Results - Phenanthrene - Stratigraphic Zone 4

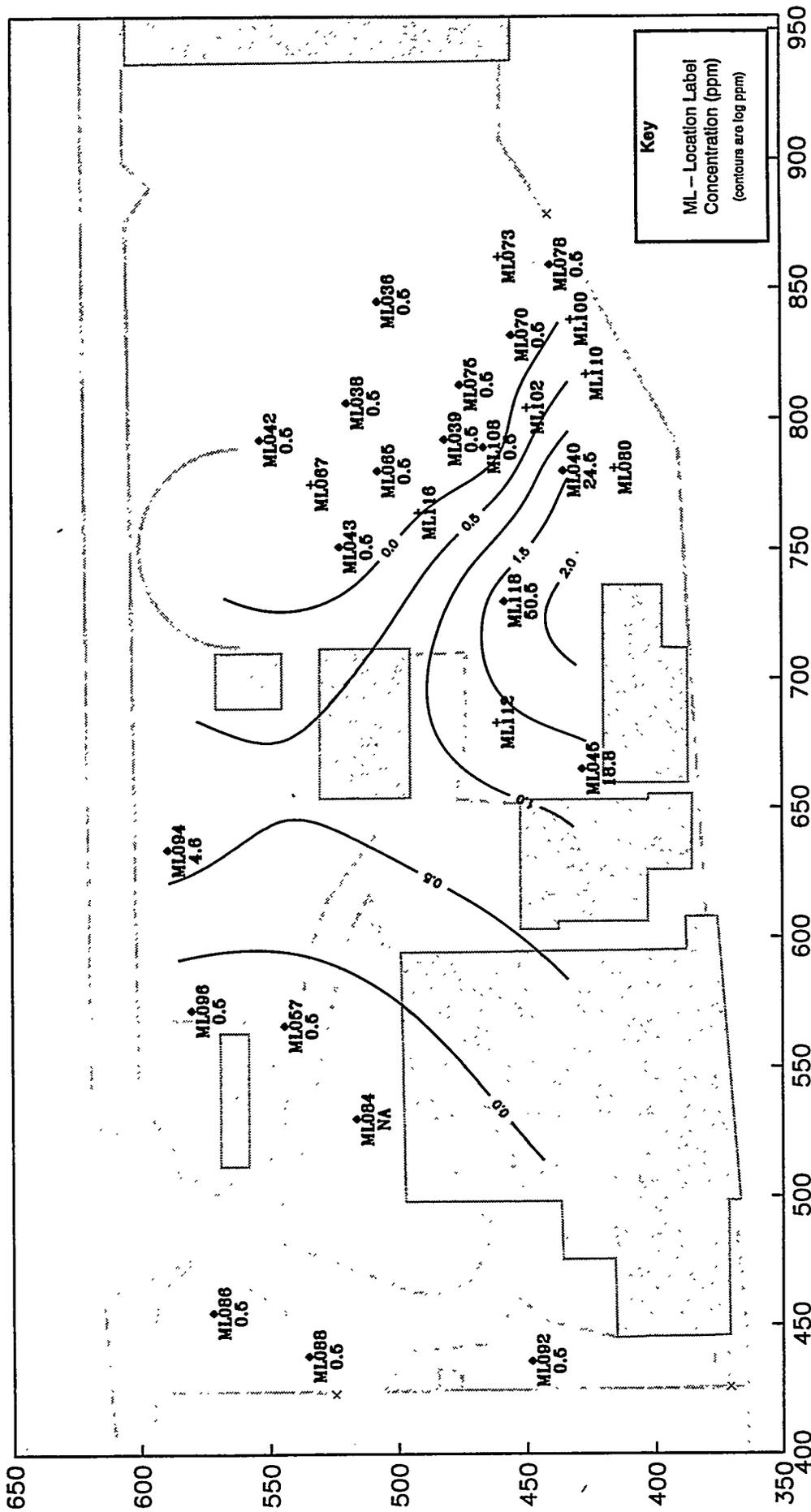


Figure 4.97 McLaren/Hart GC/MS Soil Sample Analysis Results - Naphthalene - Stratigraphic Zone 5

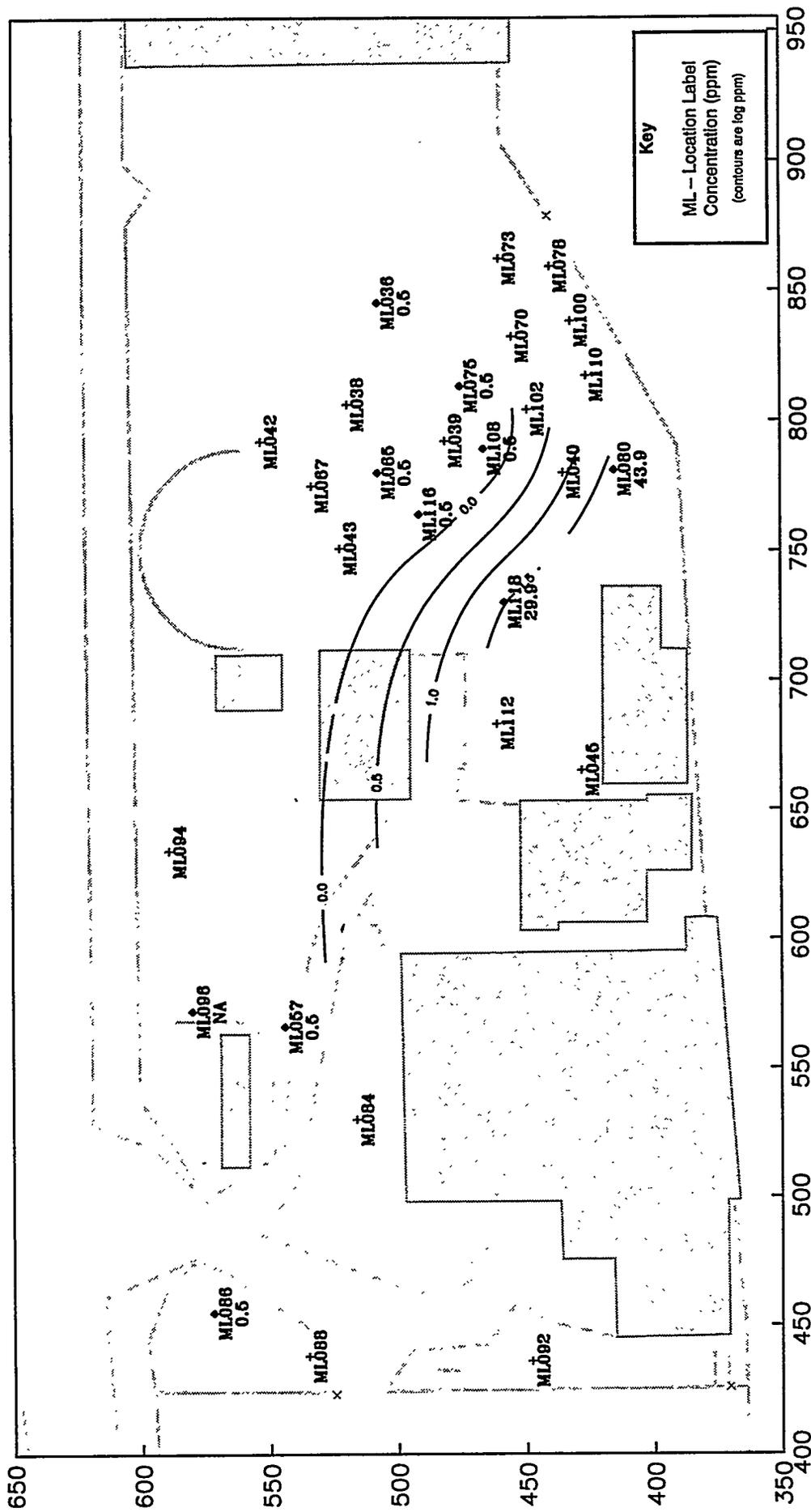


Figure 4.99 McLaren/Hart GC/MS Soil Sample Analysis Results - Naphthalene - Stratigraphic Zone 6

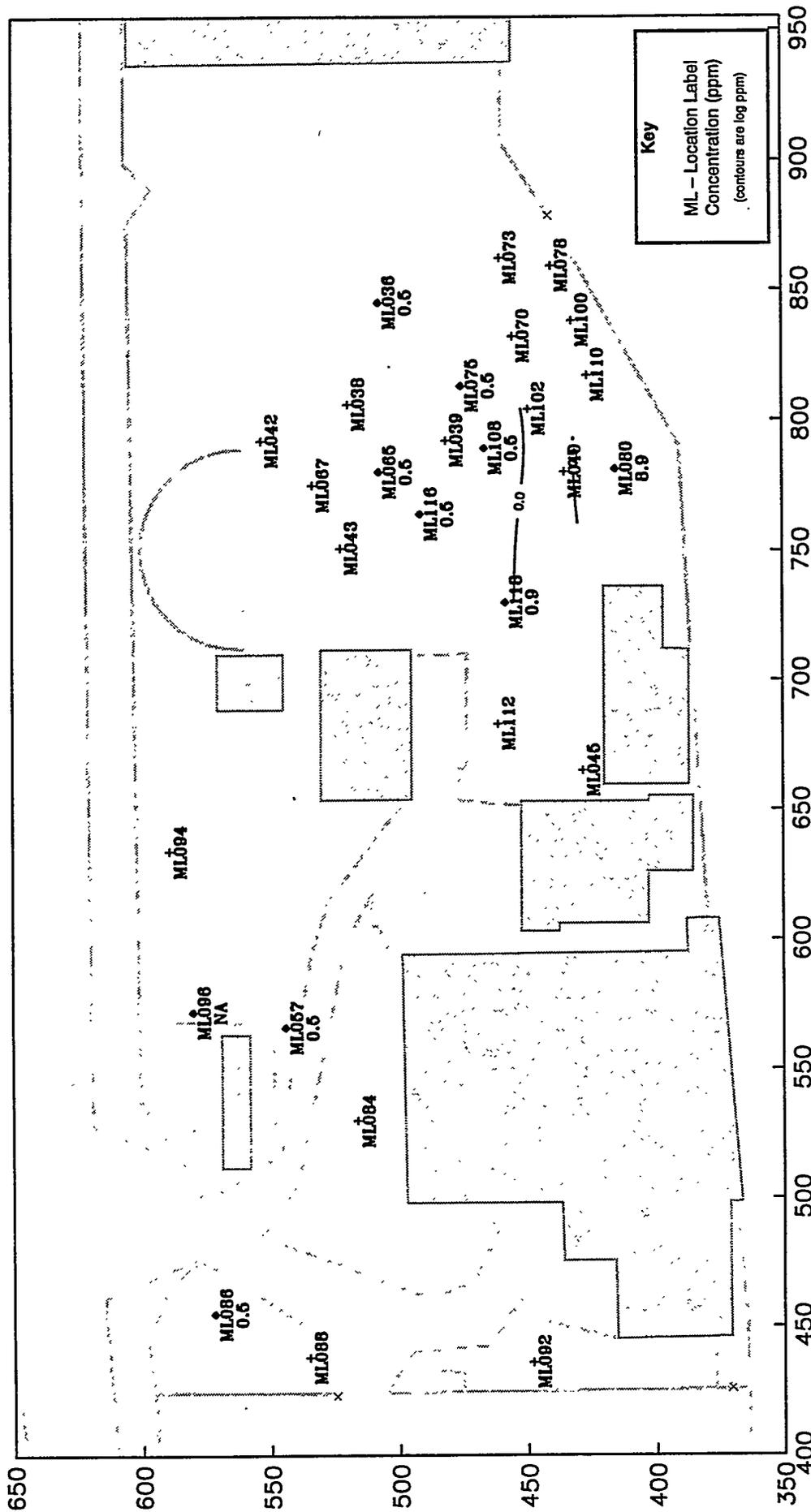


Figure 4.100 McLaren/Hart GC/MS Soil Sample Analysis Results - Phenanthrene - Stratigraphic Zone 6

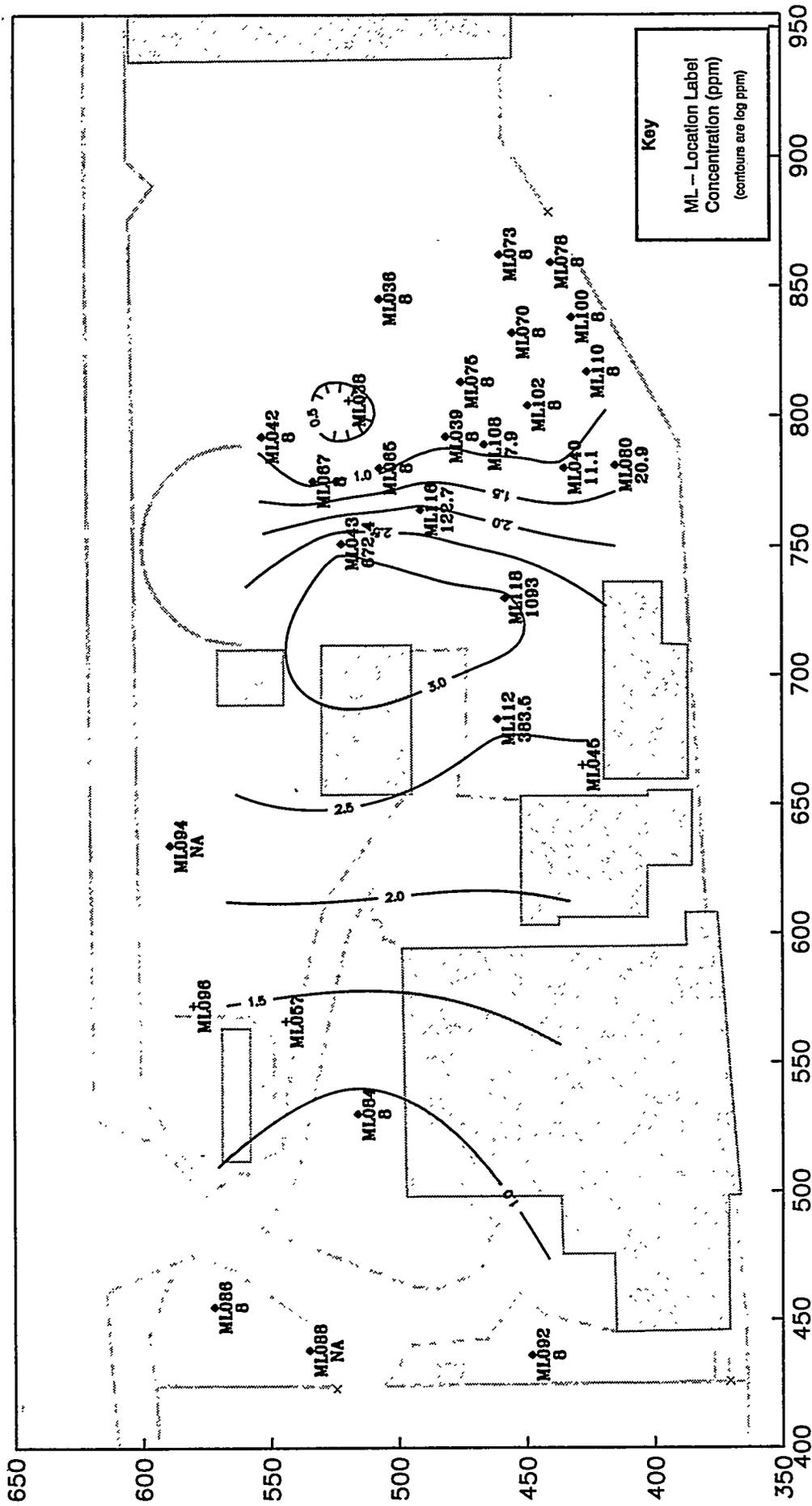


Figure 4.101 McLaren/Hart GC/MS Soil Sample Analysis Results - Total PAH - Stratigraphic Zone 1

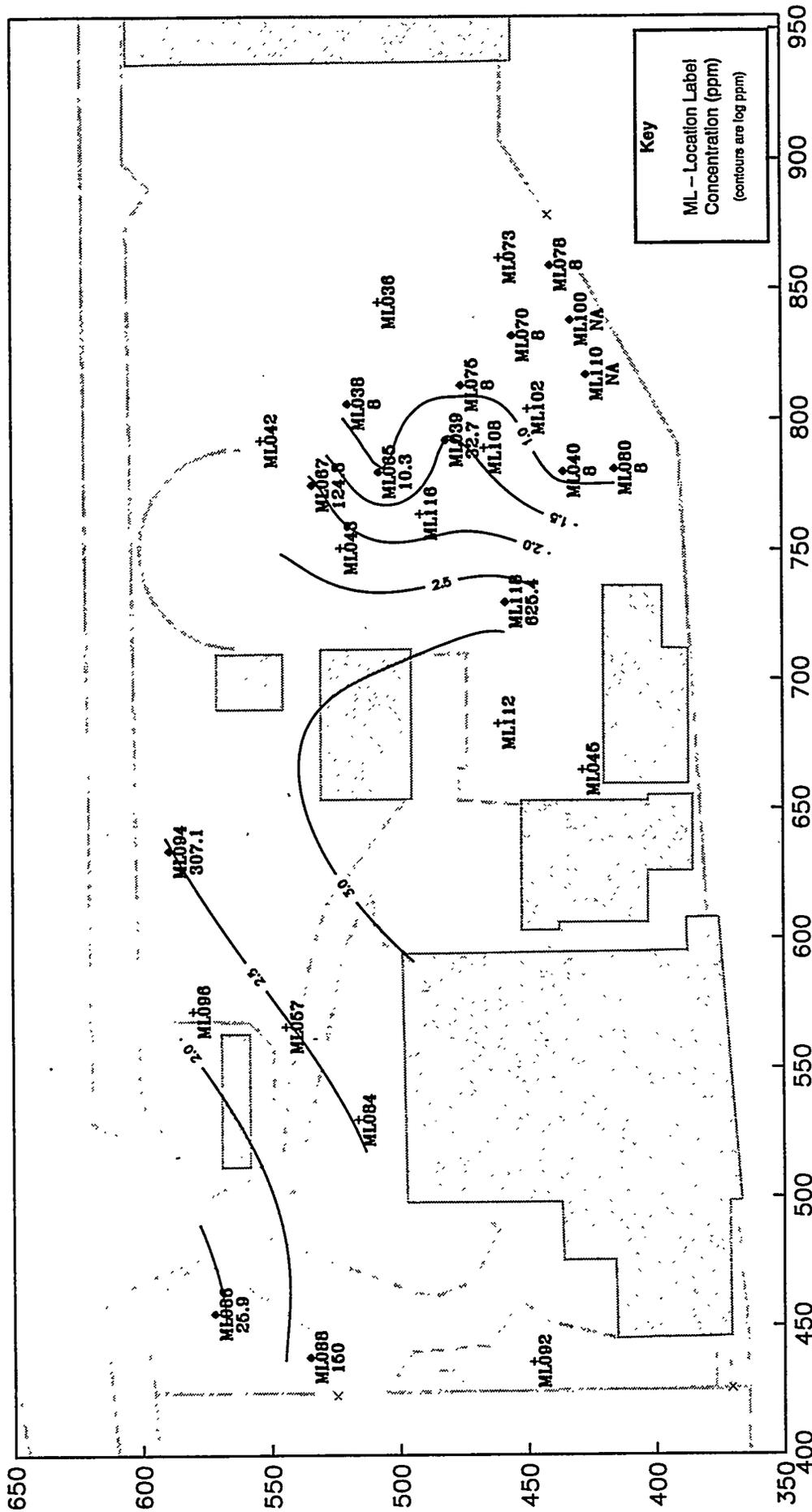


Figure 4.102 McLaren/Hart GC/MS Soil Sample Analysis Results - Total PAH - Stratigraphic Zone 2

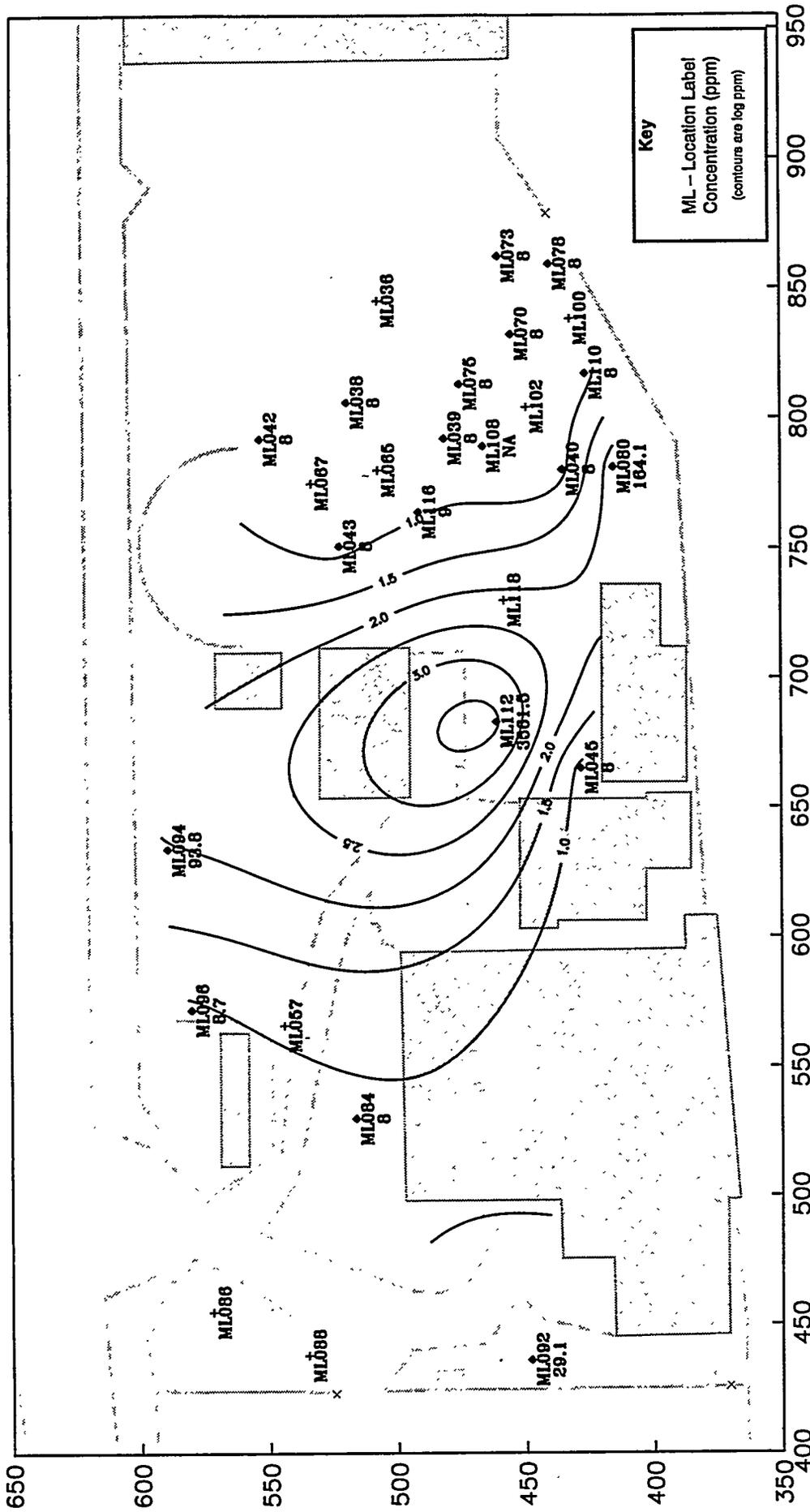


Figure 4.103 McLaren/Hart GC/MS Soil Sample Analysis Results - Total PAH - Stratigraphic Zone 3

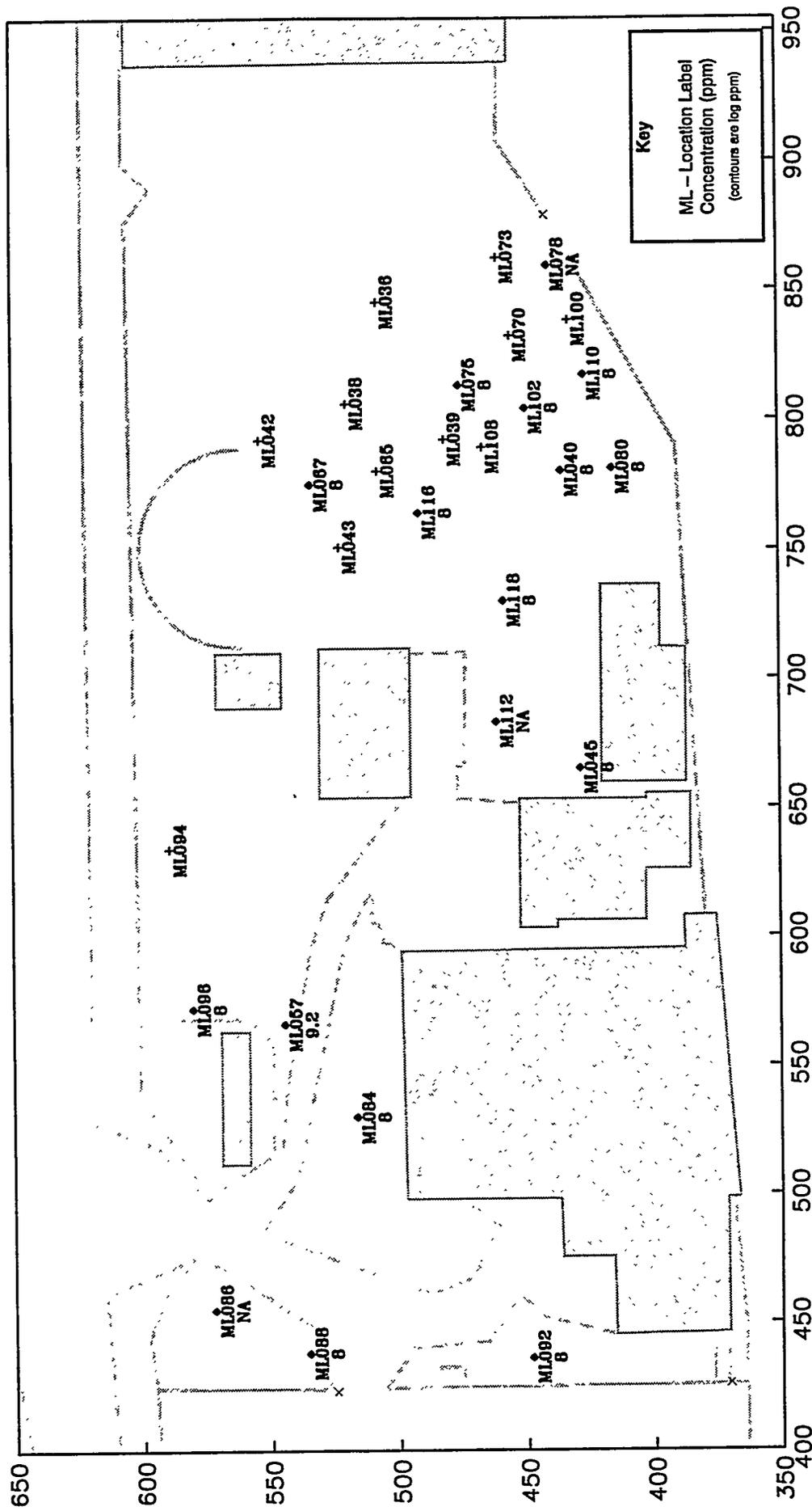


Figure 4.104 McLaren/Hart GC/MS Soil Sample Analysis Results - Total PAH - Stratigraphic Zone 4

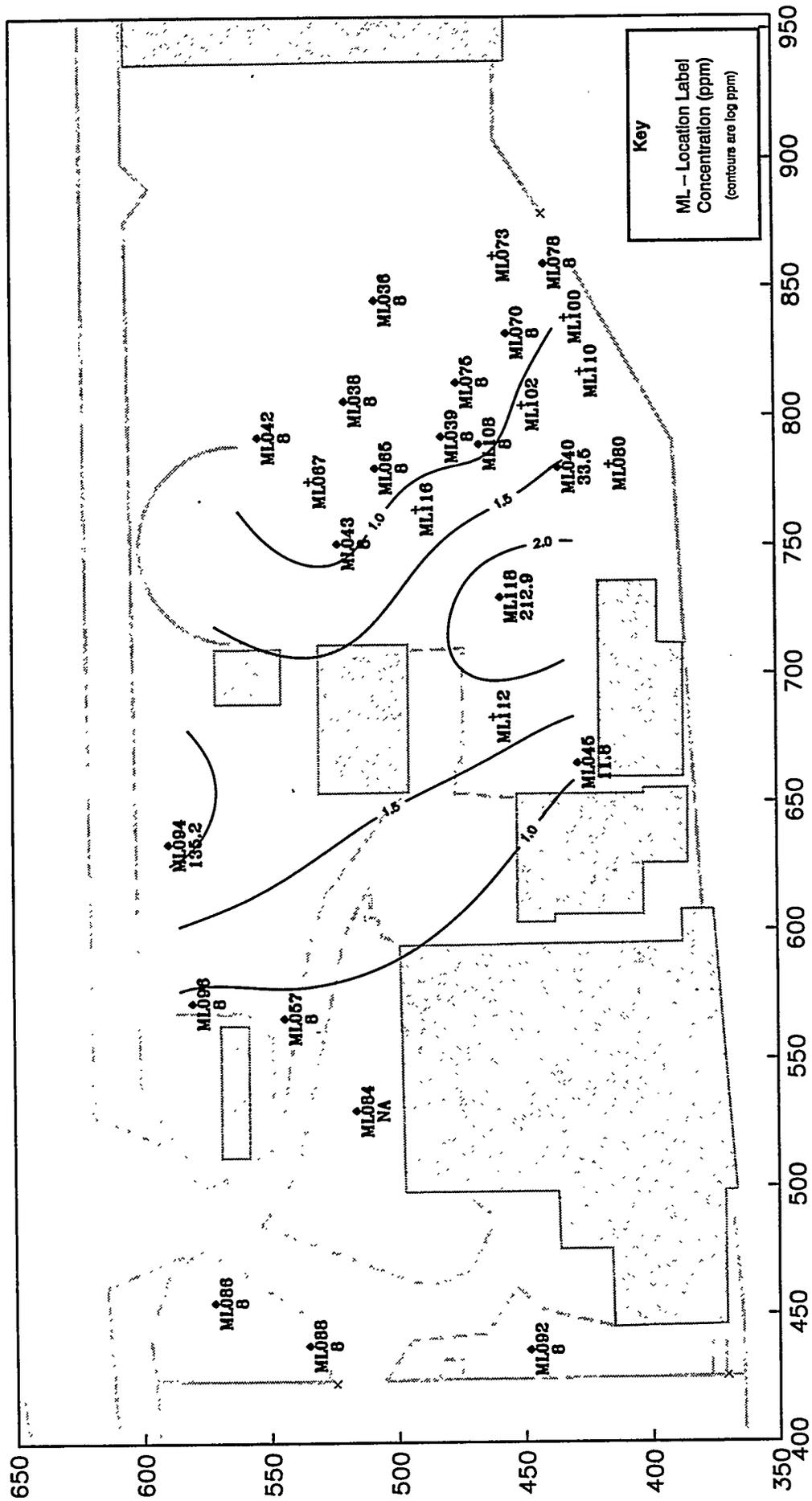


Figure 4.105 McLaren/Hart GC/MS Soil Sample Analysis Results - Total PAH - Stratigraphic Zone 5

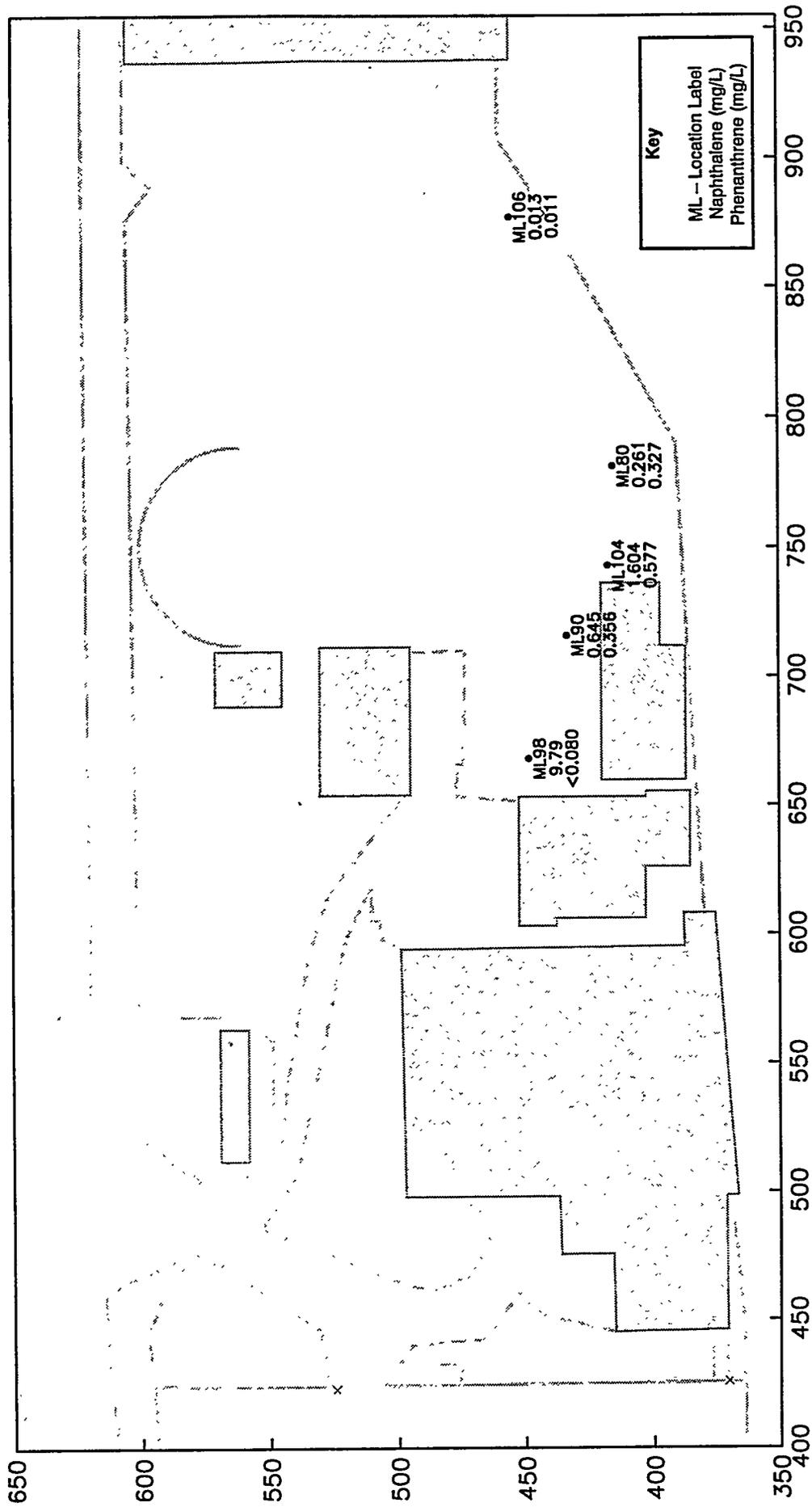


Figure 4.107 McLaren/Hart GC/MS Groundwater Sample Analysis - Naphthalene and Phenanthrene in Shallow Samples

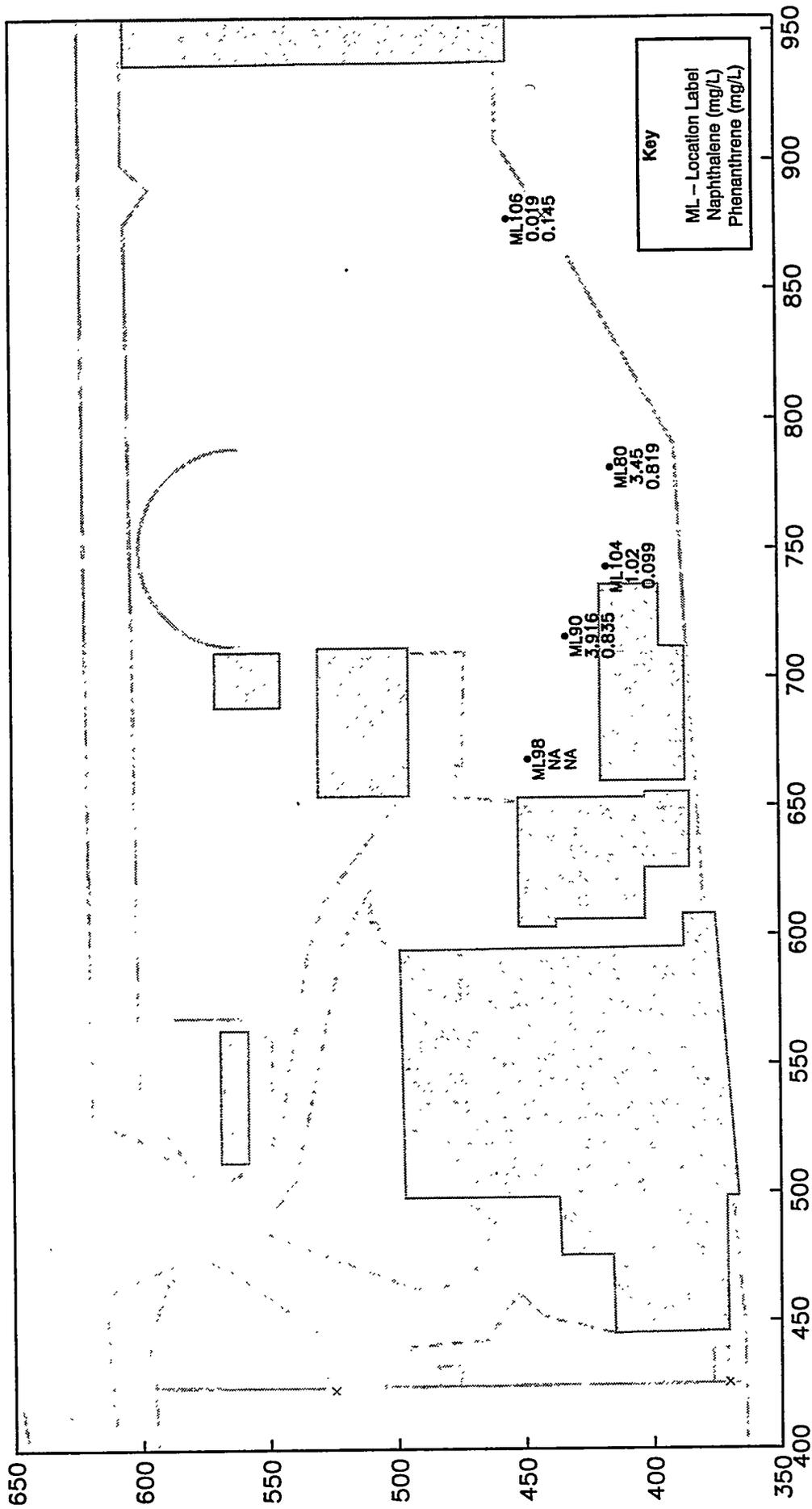


Figure 4.108 McLaren/Hart GC/MS Groundwater Sample Analysis - Naphthalene and Phenanthrene in Deep Samples

TABLE 4.1*

**GPR VELOCITY VS. DEPTH
DERIVED FROM MOVEOUT MEASURED AT
CMP TEST**

Depth (ft)	Two-way travel Time (ns)	Interval Velocity (ns/m two-way travel)	Average Velocity (ns/m two-way travel)
0-6	24.2	13.2	13.2
6-21	104.2	22.7	20.1
21-30	43.8	16	18.8

* From D'Appalonia Environmental Services Inc., 1994

TABLE 4.2**

**APPROXIMATE ELECTRICAL CONDUCTIVITIES, RELATIVE DIELECTRIC CONSTANTS
AND TRAVEL TIMES FOR VARIOUS EARTH MATERIALS**

Material	Approximate Conductivity mS/m	Approximate Relative Dielectric Constant	Two-way Travel Time nanoseconds/meter
Air	0	1	6.6
Fresh Water	10 ⁻¹ -30	81	59
Fresh Water Ice	10 ⁻¹ -10	4	13
Permafrost	10 ⁻² -10	4-11	13-15
Granite	10 ⁻⁶ -1	5.6-8	18.7
Dry Sand	10 ⁻⁴ -1	4-6	13-16
Sand, Saturated (fresh water)	10 ⁻¹ -10 ²	30	36
Silt, Saturated (fresh water)	10-10 ²	10	21
Clay, Saturated (fresh water)	10 ² -10 ⁴	8-25	18.6-23
Average "Dirt"	10 ⁻¹ -10 ²	16	23-30

** Benson et al. (1983)

TABLE 4.3 PHASE 1 CONTAMINANT SCREENING-HPLC ANALYTICAL (EPA METHOD 8130) AND IMMUNOASSAY RESULTS

Analyte	Detection Limit	Results in mg/kg														
		MT-1-G001 ML3-S	MT-1-G002 ML3-D	MT-1-G003 ML4-S	MT-1-G004 ML4-D	MT-1-G005 ML5-S	MT-1-G006 ML5-D	MT-1-G007 ML6-S	MT-1-G008 ML6-D	MT-1-G009 ML7-S	MT-1-G010 ML7-D	MT-1-G011 ML8-S	MT-1-G012 ML8-D	MT-1-G013 ML9-S	MT-1-G014 ML9-D	
Naphthalene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.9	
Acenaphthylene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.1	
Fluorene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.5	
Acenaphthene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.9	
Phenanthrene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.4	
Anthracene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.3	
Fluoranthene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.7	
Pyrene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1	
Crysenene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.5	
Benzo(b)fluoranthene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.3	
Benzo(k)fluoranthene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.3	
Benzo(a)pyrene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.6	
Dibenzo(a,h,i)perylene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.3	
Benzo(g,h,i)perylene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	<0.1	
Indeno(1,2,3-cd)pyrene	0.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.3	
TOTAL PAH's (less naphth.)		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	11.2	
TOTAL PAH's (all 15)		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	13.1	
Percent solids		77.2	88.8	78	85	78	86.7	77.3	86.8	78.1	84.4	75.9	77.3	76.2		
Date collected		4-Apr-94	4-Apr-94	4-Apr-94	4-Apr-94	4-Apr-94	4-Apr-94	4-Apr-94	4-Apr-94	5-Apr-94	5-Apr-94	5-Apr-94	5-Apr-94	5-Apr-94		
IMA screening results		(by weight for Ensys and Millipore; by volume for Quantix) *indicates ambiguous results														
Results are reported in ppm		<1	<1	<1	<1	<1	<1	<1	<1*	<1	<1	<1*	<1	<1	>100	
Ensys:RISC		?	?	?	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	>100	
Millipore/Immunosystems		<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	9.0-13.62	
Quantix																

TABLE 4.3 continued

Results in mg/kg																
MT-1-G015	MT-1-G016	MT-1-G017	MT-1-G018	MT-1-G019	MT-1-G020	MT-1-G021	MT-1-G022	MT-1-G023	MT-1-G024	MT-1-G025	MT-1-G026	MT-1-G027	MT-1-G028	MT-1-G029	MT-1-G030	MT-1-G031
ML10-S	ML10-D	ML11-S	ML11-D	ML12-S	ML12-D	ML14-S	ML14-D	ML13-S	ML13-D	ML17-S	ML17-D	ML19-S	ML19-D	ML18-S	ML18-D	ML16-S
n.a.	n.a.	n.a.	n.a.	52.2	14.5	95.7	n.a.	n.a.	n.a.	57.2	n.a.	n.a.	n.a.	1.2	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	39.9	18	47.1	n.a.	n.a.	n.a.	117	n.a.	n.a.	n.a.	4.9	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	13.4	15.6	8.8	n.a.	n.a.	n.a.	38.8	n.a.	n.a.	n.a.	1.3	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	100	81.9	20.8	n.a.	n.a.	n.a.	131	n.a.	n.a.	n.a.	9	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	32.2	33.9	25.8	n.a.	n.a.	n.a.	50.2	n.a.	n.a.	n.a.	3.3	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	15.2	16.1	9.6	n.a.	n.a.	n.a.	22.3	n.a.	n.a.	n.a.	0.8	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	24.3	28.5	16.4	n.a.	n.a.	n.a.	38.1	n.a.	n.a.	n.a.	1.7	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	72.4	50.8	70.7	n.a.	n.a.	n.a.	102	n.a.	n.a.	n.a.	1.9	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	26.4	30.8	10.6	n.a.	n.a.	n.a.	28.4	n.a.	n.a.	n.a.	1.2	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	8.3	8.5	7.1	n.a.	n.a.	n.a.	15.1	n.a.	n.a.	n.a.	1.6	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	7	7.7	5.8	n.a.	n.a.	n.a.	12.1	n.a.	n.a.	n.a.	0.9	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	7.2	7.3	6.6	n.a.	n.a.	n.a.	12.1	n.a.	n.a.	n.a.	1.4	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	21	15.2	21.4	n.a.	n.a.	n.a.	40	n.a.	n.a.	n.a.	3.3	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	4.6	4.6	2.4	n.a.	n.a.	n.a.	5.1	n.a.	n.a.	n.a.	0.2	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	22.2	22.1	16.4	n.a.	n.a.	n.a.	34.3	n.a.	n.a.	n.a.	2.2	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	394.1	341	269.5	n.a.	n.a.	n.a.	646.5	n.a.	n.a.	n.a.	33.7	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	446.3	355.5	365.2	n.a.	n.a.	n.a.	703.7	n.a.	n.a.	n.a.	34.9	n.a.	n.a.
76.1	85.7	73.8	75.5	79.6	86.7	75.7	77.4	75.8	76.8	73.3	83.8	76.4	n.a.	76.5	77.3	76.7
5-Apr-94	5-Apr-94	5-Apr-94	6-Apr-94	7-Apr-94												

Results are reported in ppm (by weight for Ensys and Millipore; by volume for Quantix)																
*indicates ambiguous results																
<1	<1	10-100	1-10	>100	>100	>100	<1	>100	>100	>100	10-100*	>100	>100	>100	1-10	>100
<1.0	<1.0	1-100	<1.0	>100	>100	>100	<1.0	>100	1-100	>100	>100	>100	>100	>100	1-100	>100
<0.7	<0.7	11->15	<0.7	5.12	<0.7	10	<0.7	>140	>140	>140	>140	13.02-28.0	>140	>140	0.72	136.4-140

TABLE 4.4 PHASE 1 CONTAMINANT SCREENING - HPLC ANALYTICAL AND CHEMILUMINESCENCE RESULTS

Sample	Map Location S = Shallow, D = Deep	Total PAH's in ppm Chemiluminescence	HPLC Analytical (Total PAH's less naphthalene)
MT-1-G001	ML3-S	<10	n.a.
MT-1-G002	ML3-D	<10	n.a.
MT-1-G003	ML4-S	<10	n.a.
MT-1-G004	ML4-D	<10	n.a.
MT-1-G005	ML5-S	<10	n.a.
MT-1-G006	ML5-D	<10	n.a.
MT-1-G007	ML6-S	<10	n.a.
MT-1-G008	ML6-D	<10	n.a.
MT-1-G009	ML7-S	<10	n.a.
MT-1-G010	ML7-D	<10	n.a.
MT-1-G011	ML8-S	<10	n.a.
MT-1-G012	ML8-D	<10	n.a.
MT-1-G013	ML9-S	40	n.a.
MT-1-G014	ML9-D	10	11.2
MT-1-G015	ML10-S	<10	n.a.
MT-1-G016	ML10-D	<10	n.a.
MT-1-G017	ML11-S	<10	n.a.
MT-1-G018	ML11-D	<10	n.a.
MT-1-G019	ML12-S	15	394.1
MT-1-G020	ML12-D	70	341
MT-1-G021	ML14-S	160	269.5
MT-1-G022	ML14-D	7000-8000	n.a.
MT-1-G023	ML13-S	1500-2000	n.a.
MT-1-G024	ML13-D	900-1000	n.a.
MT-1-G025	ML17-S	1000-1500	646.5
MT-1-G026	ML17-D	2000-2500	n.a.
MT-1-G027	ML19-S	700-800	n.a.
MT-1-G028	ML19-D	>10,000	n.a.
MT-1-G029	ML18-S	140	33.7
MT-1-G030	ML18-D	<10	n.a.
MT-1-G031	ML16-S	1000-1500	n.a.
MT-1-G032	ML16-D	<10	n.a.
MT-1-G033	ML15-S	<10	n.a.
MT-1-G034	ML15-D	<10	n.a.
MT-1-G035	ML27-S	<10	n.a.
MT-1-G036	-	-	n.a.
MT-1-G037	ML20-S	900-1000	n.a.
MT-1-G038	ML20-D	2500-3000	n.a.
MT-1-G039	ML26-S	500-600	n.a.
MT-1-G040	ML26-D	free DNAPL	n.a.
MT-1-G041	ML23-S	15	n.a.
MT-1-G042	ML23-D	<10	n.a.
MT-1-G043	ML22-S	250	n.a.
MT-1-G044	ML22-D	250	n.a.
MT-1-G045	ML24-S	<10	n.a.
MT-1-G046	ML24-D	<10	n.a.
MT-1-G047	ML25-S	60	n.a.
MT-1-G048	ML25-D	25	n.a.

TABLE 4.5 PHASE 1 CONTAMINANT SCREENING - PASSIVE SOIL GAS RESULTS

Sample	Map Location S = Shallow, D = Deep	Analyte (all results in 10E6 counts)		
		Naphthalene (a.m.=128)	Anthracene/Phenanthrene (a.m.=178)	Fluoranthene/Pyrene (a.m.=202)
MT-1-G001	ML3-S	ND	ND	ND
MT-1-G002	ML3-D	ND	ND	ND
MT-1-G003	ML4-S	ND	ND	ND
MT-1-G004	ML4-D	0.005613	ND	ND
MT-1-G005	ML5-S	ND	ND	ND
MT-1-G006	ML5-D	ND	ND	ND
MT-1-G007	ML6-S	n.a.	n.a.	n.a.
MT-1-G008	ML6-D	n.a.	n.a.	n.a.
MT-1-G009	ML7-S	0.001537	ND	ND
MT-1-G010	ML7-D	0.007554	ND	ND
MT-1-G011	ML8-S	0.052956	ND	ND
MT-1-G012	ML8-D	ND	ND	ND
MT-1-G013	ML9-S	3.65533	0.021953	ND
MT-1-G014	ML9-D	4.57518	ND	ND
MT-1-G015	ML10-S	ND	ND	ND
MT-1-G016	ML10-D	ND	ND	ND
MT-1-G017	ML11-S	0.359979	ND	ND
MT-1-G018	ML11-D	5.01249	ND	ND
MT-1-G019	ML12-S	3.77898	0.122335	0.003576
MT-1-G020	ML12-D	2.29359	0.087985	0.003976
MT-1-G021	ML14-S	ND	ND	ND
MT-1-G022	ML14-D	3.44689	0.033333	ND
MT-1-G023	ML13-S	3.37255	0.023714	ND
MT-1-G024	ML13-D	4.68688	0.003604	ND
MT-1-G025	ML17-S	4.4698	0.013798	ND
MT-1-G026	ML17-D	2.60952	ND	ND
MT-1-G027	ML19-S	2.62391	ND	ND
MT-1-G028	ML19-D	1.82657	0.043383	ND
MT-1-G029	ML18-S	5.90172	0.182617	0.017958
MT-1-G030	ML18-D	1.86581	0.032313	0.003747
MT-1-G031	ML16-S	4.73797	0.024823	ND
MT-1-G032	ML16-D	2.25203	0.017066	ND
MT-1-G033	ML15-S	ND	ND	ND
MT-1-G034	ML15-D	ND	ND	ND
MT-1-G035	ML27-S	0.000903	ND	ND
MT-1-G036	-	-	-	-
MT-1-G037	ML20-S	6.01754	0.032288	ND
MT-1-G038	ML20-D	3.88412	0.042343	ND
MT-1-G039	ML26-S	0.710187	ND	ND
MT-1-G040	ML26-D	0.34819	ND	ND
MT-1-G041	ML23-S	0.050168	ND	ND
MT-1-G042	ML23-D	0.520903	0.027843	ND
MT-1-G043	ML22-S	0.002057	ND	ND
MT-1-G044	ML22-D	0.46519	ND	ND
MT-1-G045	ML24-S	0.007131	ND	ND
MT-1-G046	ML24-D	0.560711	0.020366	ND
MT-1-G047	ML25-S	0.005378	ND	ND
MT-1-G048	ML25-D	1.69667	0.443311	0.075436

TABLE 4.6 PHASE 1 CONTAMINANT SCREENING - ACTIVE SOIL GAS RESULTS

Sample	Map Location S = Shallow, D = Deep	GC/FID Method					
		Benzene	Toulene	Ethylbenzene	m,p-Xylenes	o-xylene	Napthalene
MT-1-V001	ML3-S	ND	ND	ND	ND	ND	ND
MT-1-V002	ML3-D	ND	ND	ND	ND	ND	ND
MT-1-V003	ML4-S	ND	ND	ND	ND	ND	ND
MT-1-V004	ML4-D	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MT-1-V005	ML5-S	ND	ND	ND	ND	ND	ND
MT-1-V006	ML5-D	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MT-1-V007	ML6-S	ND	ND	ND	ND	ND	ND
MT-1-V008	ML6-D	ND	ND	ND	ND	ND	ND
MT-1-V009	ML7-S	ND	ND	ND	ND	ND	ND
MT-1-V010	ML7-D	ND	ND	ND	ND	ND	ND
MT-1-V011	ML8-S	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MT-1-V012	ML8-D	ND	ND	ND	ND	ND	ND
MT-1-V013	ML9-S	ND	ND	ND	ND	ND	ND
MT-1-V014	ML9-D	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MT-1-V015	ML10-S	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MT-1-V016	ML10-D	ND	ND	ND	ND	ND	ND
MT-1-V017	ML11-S	ND	ND	ND	ND	ND	ND
MT-1-V018	ML11-D	32.128845	11.291580	14.844116	15.113415	8.962986	ND
MT-1-V019	ML12-S	87.901985	30.058519	38.835930	30.026684	18.326065	ND
MT-1-V020	ML12-D	7.286686	4.621140	5.872252	5.545333	ND	ND
MT-1-V021	ML14-S	1.114627	1.192201	ND	ND	ND	ND
MT-1-V022	ML14-D	0.867036	0.656815	ND	ND	ND	ND
MT-1-V023	ML13-S	0.508284	ND	ND	ND	ND	ND
MT-1-V024	ML13-D	0.263760	ND	ND	ND	ND	ND
MT-1-V025	ML17-S	ND	ND	ND	ND	ND	ND
MT-1-V026	ML17-D	32.406437	189.337753	51.765888	238.829361	109.805153	110.641235
MT-1-V027	ML19-S	15.447419	2.840954	7.983398	ND	11.991907	ND
MT-1-V028	ML19-D	124.951363	209.916092	19.891571	144.068634	297.855835	1697.928955
MT-1-V029	ML18-S	1.043859	0.902049	ND	ND	ND	ND
MT-1-V030	ML18-D	ND	ND	ND	ND	ND	ND
MT-1-V031	ML16-S	17.912880	16.999289	184.571533	58.784718	55.972084	221.144943
MT-1-V032	ML16-D	54.406273	70.892494	49.601261	38.358017	23.265814	33.243111
MT-1-V033	ML15-S	ND	ND	ND	ND	ND	ND
MT-1-V034	ML15-D	ND	ND	ND	ND	ND	ND
MT-1-V035	ML27-S	0.230281	ND	ND	ND	ND	0.907483
MT-1-V036	-	-	-	-	-	-	-
MT-1-V037	ML20-S	11.221115	6.981182	49.260754	12.418782	22.069645	25.205538
MT-1-V038	ML20-D	111.492981	229.047714	35.745457	108.202446	98.545418	179.060135
MT-1-V039	ML26-S	ND	2.176346	ND	10.758777	4.500081	1.273942
MT-1-V040	ML26-D	118.070259	309.668213	172.429901	342.930573	394.359253	ND
MT-1-V041	ML23-S	ND	ND	ND	ND	ND	ND
MT-1-V042	ML23-D	31.949976	12.446523	6.208213	14.792828	ND	2.998902
MT-1-V043	ML22-S	6.396442	ND	3.394059	1.939260	1.842153	ND
MT-1-V044CS	ML22-D	513.191284	655.121460	433.833710	308.771027	110.954941	
MT-1-V045	ML24-S	0.829321	ND	ND	ND	ND	ND
MT-1-V046CS	ML24-D	ND	ND	ND	ND	ND	ND
MT-1-V047	ML25-S	ND	ND	ND	ND	ND	ND
MT-1-V048CS	ML25-D	ND	ND	ND	7.543837	ND	7.827275

TABLE 4.6 continued

Sample	Map Location S = Shallow, D = Deep	GC/PID Method					
		Benzene	Toulene	Ethylbenzene	m,p-Xylenes	o-xylene	Naphthalene
MT-1-V001	ML3-S	ND	ND	ND	ND	ND	ND
MT-1-V002	ML3-D	ND	ND	ND	ND	ND	ND
MT-1-V003	ML4-S	ND	ND	ND	ND	ND	ND
MT-1-V004	ML4-D	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MT-1-V005	ML5-S	ND	ND	ND	ND	ND	ND
MT-1-V006	ML5-D	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MT-1-V007	ML6-S	ND	ND	ND	ND	ND	ND
MT-1-V008	ML6-D	ND	ND	ND	ND	ND	ND
MT-1-V009	ML7-S	ND	ND	ND	ND	ND	ND
MT-1-V010	ML7-D	ND	ND	ND	ND	ND	ND
MT-1-V011	ML8-S	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MT-1-V012	ML8-D	ND	ND	ND	ND	ND	ND
MT-1-V013	ML9-S	ND	ND	ND	ND	ND	3.074724
MT-1-V014	ML9-D	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MT-1-V015	ML10-S	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
MT-1-V016	ML10-D	ND	ND	ND	ND	ND	ND
MT-1-V017	ML11-S	0.762419	0.388893	ND	ND	ND	ND
MT-1-V018	ML11-D	42.081406	11.886667	16.486229	16.071447	10.508683	0.948226
MT-1-V019	ML12-S	61.539497	45.550301	42.709007	32.015926	31.759655	0.436001
MT-1-V020	ML12-D	5.224190	4.839434	8.070786	8.349440	5.160131	0.614379
MT-1-V021	ML14-S	1.720358	1.573845	1.773427	1.661087	ND	ND
MT-1-V022	ML14-D	0.944199	0.973644	1.691951	1.553731	ND	ND
MT-1-V023	ML13-S	0.696916	0.524565	1.185306	ND	ND	0.634707
MT-1-V024	ML13-D	0.421216	0.412051	1.035084	ND	ND	ND
MT-1-V025	ML17-S	ND	ND	ND	ND	ND	ND
MT-1-V026	ML17-D	38.792202	202.181534	56.042629	253.712051	120.258537	118.893562
MT-1-V027	ML19-S	18.147797	3.183892	10.937340	6.425730	14.398224	0.476790
MT-1-V028	ML19-D	153.833755	229.549805	22.365625	158.336441	347.819977	1357.087280
MT-1-V029	ML18-S	1.552771	1.174489	ND	ND	ND	ND
MT-1-V030	ML18-D	0.166060	0.176303	ND	ND	ND	ND
MT-1-V031	ML16-S	12.794166	0.197425	175.579727	ND	54.705692	215.517380
MT-1-V032	ML16-D	58.704456	67.421783	47.869938	37.766743	24.987623	32.456169
MT-1-V033	ML15-S	ND	ND	ND	ND	ND	ND
MT-1-V034	ML15-D	ND	ND	ND	ND	ND	ND
MT-1-V035	ML27-S	0.259059	ND	ND	ND	ND	1.036475
MT-1-V036	-	-	-	-	-	-	-
MT-1-V037	ML20-S	11.654924	8.977472	68.481377	32.538208	23.819075	27.987640
MT-1-V038	ML20-D	157.798843	248.118134	40.769600	124.510078	127.324875	192.626328
MT-1-V039	ML26-S	ND	2.018552	ND	0.569878	ND	2.300092
MT-1-V040	ML26-D	154.387711	317.272400	6.795660	326.882874	451.848389	3.326771
MT-1-V041	ML23-S	0.181321	ND	ND	ND	ND	ND
MT-1-V042	ML23-D	10.988695	2.228972	22.420876	10.019212	9.833989	1.089709
MT-1-V043	ML22-S	9.492801	ND	5.466444	2.701645	4.599745	1.019308
MT-1-V044CS	ML22-D	237.062820	588.789856	435.934601	305.007874	117.603355	7.800683
MT-1-V045	ML24-S	0.936194	ND	0.447682	0.421743	ND	0.191397
MT-1-V046CS	ML24-D	ND	0.420658	ND	2.737419	ND	0.207056
MT-1-V047	ML25-S	ND	ND	ND	ND	ND	ND
MT-1-V048CS	ML25-D	1.758627	0.405296	0.217005	0.348230	ND	0.975272

TABLE 4.7

CPT LIF DATA FOR
 SOIL SAMPLES HELD AGAINST THE SAPPHIRE WINDOW VS
 SPLIT SAMPLE LABORATORY TRPH

Sample ID	Sample Depth (ft.)	EPA 418.1 Analysis (mg/kg)	Peak Fluorescence Intensity (counts)	Peak Wavelength (nm)	Visual Soil Classification
97-1	4.5	<25	164	400	clay
101-2	12.5	<25	141	400	clay
111-1	12.4	232	123	400	clay
81-2	8.0	1920	1072	468	clay
60-1	5.5	2334	605	467	clay
97-2	10.6	5646	1052	496	clay
101-1	6.5	8178	1595	475	clay
60-5	33.5	23600	530	540	clay
111-2	14.2	3542	424	533	mix
97-4	25.5	<25	154	400	sand
105-2	8.0	<25	139	400	sand
60-2	13.0	505	125	400	sand
97-5	32.1	597	124	400	sand
105-1	4.2	668	240	400	sand
101-3	21.5	716	188	400	sand/gravel
81-1	3.0	5849	275	400	sand
97-3	14.5	7006	911	506	sand
111-3	21.0	8831	322	488	sand
81-3	14.5	14122	6186	425	sand

TABLE 4.8

PANEL PLOT CPT LIF INTENSITY
VS
LABORATORY ANALYSIS OF ADJACENT SOIL SAMPLES

Sample ID	Sample Depth (ft.)	EPA 418.1 Analysis (mg/kg)	Panel Plot Peak Fluorescence Intensity (counts)	Dummy Pre-push	Visual Soil Classification
97-1	4.5	<25	10	*	clay
101-2	12.5	<25	0		clay
111-1	12.4	232	400		clay
81-2	8.0	1920	700	*	clay
60-1	5.5	2334	400	*	clay
97-2	10.6	5646	300		clay
101-1	6.5	8178	650		clay
60-5	33.5	23600	380		clay
111-2	14.2	3542	550		mix
97-4	25.5	<25	75		sand
105-2	8.0	<25	0		sand
60-2	13.0	505	200	*	sand
97-5	32.1	597	150		sand
105-1	4.2	668	100	*	sand
101-3	21.5	716	250		sand/gravel
81-1	3.0	5849	75	*	sand
97-3	14.5	7006	1200		sand
111-3	21.0	8831	2500		sand
81-3	14.5	14122	6000	*	sand

* Indicates fluorescence reading was taken in dummy probe pre-push area.

TABLE 4.9

CPT LIF INTENSITIES WITHIN STRATIGRAPHIC ZONES

Map	X	Y	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Pre-push*
Location	(ft.)	(ft.)							
ML28	834	424	10	60	1	100	40	NA	-
ML30	908	421	NA	NA	NA	NA	NA	NA	-
ML32	438	408	100	10	10	50	10	NA	-
ML33	862	460	0	0	10	75	100	NA	-
ML41	450	554	0	0	100	NA	NA	NA	-
ML53	732	511	NA	NA	NA	0	5	NA	20'LR
ML60	679	436	300	100	200	10	350	10	20'LR
ML61	668	489	600	250	100	0	300	0	20'SR
ML64	787	461	NA	NA	NA	100	50	NA	20'LR
ML72	850	433	NA	NA	NA	50	NA	NA	21'SR
ML74	834	440	NA	NA	NA	50	NA	NA	21'SR
ML76	782	405	0	30	50	30	350	50	20'SR
ML77	788	467	NA	NA	NA	5	10	NA	20'SR
ML79	809	440	NA	NA	NA	10	50	10	20'SR
ML81	581	547	1000	5000	800	0	80	5	20'SR
ML83	634	521	200	300	100	10	300	20	20'SR
ML85	489	510	30	50	100	80	10	0	20'SR
ML87	649	547	100	200	300	100	220	NA	20'LR
ML89	693	457	200	100	20	100	400	10	20'LR
ML91	718	537	0	0	100	0	100	0	20'LR
ML93	587	579	400	2000	5000	4000	20	10	5'LR
ML95	771	515	40	0	0	0	80	80	5'LR
ML97	744	484	50	450	1200	70	180	20	5'LR
ML99	739	524	80	10	100	60	110	0	7'LR
ML101	750	439	700	0	300	0	270	10	5'LR
ML105	778	439	60	0	0	0	550	NA	5'LR
ML107	767	473	700	5	120	20	260	NA	5'LR
ML109	732	453	350	5	300	10	500	NA	5'LR
ML111	621	579	220	400	500	2000	80	NA	5'LR
ML113	723	432	1000	200	200	10	170	NA	5'LR

* Depth LR= Large Rod, SR= Small Rod

TABLE 4.10

COMPARISON OF GEOPROBE CONDUCTIVITY DIPS WITH MCLAREN/HART AND CPT LOGS

Geoprobe Location ID	Conductivity Dip Depths (ft.)	Possible Explanation	Source	Source Distance from Geoprobe (ft.)
L028	21.25	Gravel at 20 ft, LIF near 10*	CPT L028	2
	23-24.5	LIF about 100 at 22 to 23 ft.		
L033	16&17	Gravel at 16 to 17 ft. (LIF < 25)	CPT L033	2
	21 to 25	LIF about 50 to 100 at 20 to 24 ft.		
L037	23.5 & 25 to 27	Gravel plentiful, (no odor) from 23 to 25 ft.	MLH L075	2
L040	6	LIF peaks to 400 at 5 to 6 ft.	CPT L105	5
	19.5	Possible gravel at 17.5 ft. (LIF < 10)		
	32 to 33	LIF > 400 from 32 to 35.5 ft.		
L043	16	LIF near 100 from 14 to 15 ft.	CPT L099	13
	18.5 to 19	Gravel from 18 to 20 ft. and LIF > 50 from 18 to 23 ft.		
	20.5	LIF near 100 from 20 to 22 ft.		
	22 to 23	LIF > 50 from 22 to 23 ft.		
L045	22.5 to 23	Gravelly sand with free product from 22 to 24 ft.	MLH L114	2
L052	4.5 to 7	Strong odor, black but no sheen from 6 to 8 ft.	MLH L112	12
	15.5 & 18.5	Strong odor, product visible from 16 to 17 ft.		
	32 to 34.5	Free phase product from 32 to 34 ft.		
L054	4 to 7	LIF > 200 from 5.5 to 8 ft.	CPT L109	10
		Strong odor with product from 6 to 7 ft.	MLH L118	8
	15	Odor with product from 14 to 16 ft.		
	20.5, 22.5 & 23.5	Gravel from 20 to 23 ft. LIF > 200 from 16 to 18 ft. LIF about 300 at 20 ft.	CPT L109	
		Gravel from 22 to 24 ft.	MLH L118	
	34.5	LIF > 200 from 33 to 35 ft.	CPT L109	
		Free product from 32 to 34 ft. Strong odor, possible product from 34 to 36 ft.	MLH L118	
L055	5	Black soil with strong odor from 5 to 7 ft.	MLH 057	19
	12 to 14	Free product from 12 to 14 ft.		
	19	Strong odor, gravel from 18 to 20 ft.		
	25	Slight odor, no product 24 to 26 ft.		
	36	Product from 34 to 36 ft.		

* LIF intensity units are counts.

TABLE 4.10 (continued)

COMPARISON OF GEOPROBE CONDUCTIVITY DIPS WITH MCLAREN/HART AND CPT LOGS

Geoprobe Location ID	Conductivity Dip Depths (ft.)	Possible Explanation	Source	Source Distance from Geoprobe (ft.)
L056	19	Trace gravel, no product mentioned, from 18 to 20 ft.	MLH L065	2
	24 to 25	Gravel, no product mentioned, from 24 to 26 ft.		
L058	10 to 11	Slight odor at 11 to 13 ft.	MLH L067	2
L059	5 to 7	Odor, no visible product	MLH L108	9
	21	Gravel, no odor from 19 to 21 ft. Gravel at 20 ft. LIF near 100* from 20 to 24 ft.		
	23 to 24.5	Gravel from 24 to 27 ft. LIF near 100 from 20 to 24 ft.		
L062	18 to 20	Trace gravel, no odor, 18 to 20 ft.	MLH L070	2
	31	Gravel, no odor, 30 to 32 ft.		
L063	18 to 19	Gravel, no odor, 18 to 20 ft.	MLH L078	2
	24	Trace gravel, no odor, 25 to 27 ft.		
L066	17 & 18	LIF > 1000 from 11 to 18 ft.	CPT L081	4
	20.5	LIF about 800 at 20.5 ft. Gravel at 20 to 21.5 ft.		
	25.5 & 26	Possible gravel from 24 to 25 ft.		
	36	LIF about 100 from 34 to 36 ft.		
L069	18.5 & 21.5	Free product, some gravel from 19 to 21 ft.	MLH L94	14
	24.5 & 26 to 27	Strong odor, free product, from 25 to 27 ft.		

* LIF intensity units are counts.

TABLE 4.11 SOIL CLASSIFICATION COMPARISONS BY SELECTED SAMPLE LOCATION CLUSTERS.

Cluster 1				
Location	L77	L64	L59	L108
(X,Y) (ft.)	788,467	781,461	783,460	789,466
Source	CPT	CPT	Soil Cond.	McLaren/Hart
Depth (ft.)				
6 to 8			clay	silt with clay
19 to 20			sand	silty sand with gravel
20 to 21	silt and clay	sand and silt	sand	silty sand with gravel
26 to 28	sand	sand with gravel	sand/silt?	sand
30 to 31	silt	sand	sand/silt?	sand
31 to 32	silt	sand and clayey silt	sand/silt?	clayey silt

Cluster 2			
Location	L47	L81	L66
(X,Y) (ft.)	583,549	581,547	584,548
Source	CPT	CPT	Soil Cond.
Depth (ft.)			
20 to 21	sand with gravel	sand with gravel	sand
21 to 36	sand	sand	sand
36 to 39		silt with clay	clay

Cluster 3			
Location	L33	L33	L73
(X,Y) (ft.)	862,460	862,460	862,460
Source	CPT LIF	CPT Resistivity	McLaren/Hart
Depth (ft.)			
0 to 4	silt mix	silt mix	
4 to 6	silt mix	clay	silt with clay
6 to 7	silt mix	clay	
8 to 10	clay	clay	clay
10 to 13	clay	clay	
13 to 14	clay	clay	silt with sand
14 to 15	sand mix	sand/silt mix	silt with sand
15 to 17	sand mix with gravel	sand/silt mix	

Cluster 4			
Location	L54	L109	L118
(X,Y) (ft.)	737,461	732,453	730,458
Source	Soil Cond.	CPT	McLaren/Hart
Depth (ft.)			
5 to 7	silt/sand	silt mix	silty clay
7 to 14	clay	clay with silt mix	
14 to 15	clay	clay with silt mix	silty clay
15 to 16	sand	clay with silt mix	silty clay
16 to 20	sand	sand with silt mix	
20 to 22	sand with gravel	sand with gravel	
22 to 24	sand with gravel	sand with gravel	sand
24 to 26	sand	sand with gravel	sand
26 to 30	sand	sand with gravel	sand with silt
30 to 34	sand	sand with gravel	sand
34 to 36	silt/clay	silt with clay	silty clay

TABLE 4.11 CONTINUED

Cluster 5				
Location	L45	L60	L114	B8
(X,Y) (ft.)	665,428	679,436	667,428	675,424
Source	McLaren/Hart	CPT	McLaren/Hart	BVWST
Depth (ft.)				
6 to 7	silty clay			silty sand
7 to 8	silty clay			silty clay
17 to 19	silty sand			silty clay
20 to 22		sand with gravel		sand
22 to 24		sand with gravel	sand with gravel	sand
24 to 26	sand	sand		sand
26 to 27		sand		sand
27 to 30		sand		silty sand
30 to 32	silt and sand	sand		silty sand
32 to 34		sand		silty sand
34 to 35		silt mix with clay		silty sand
35 to 36	sand and silt	silt mix with clay		silty sand
36 to 37	sand and silt	silt mix with clay		silt with clay
37 to 39		silt mix with clay		silt with clay

Cluster 6		
Location	L113	B13
(X,Y) (ft.)	723,432	727,429
Source	CPT	BVWST
Depth (ft.)		
6 to 16.5	clay with silt mix	silty clay
16.5 to 18	silt mix	silty clay
18 to 19	sand	silty clay
19 to 25	sand with gravel	sand
25 to 28	sand with gravel	silty sand, some gravel
28 to 33	sand	silty sand, some gravel
33 to 35	clay	silty sand
36.5 to 40		silty clay

Cluster 7		
Location	L40	L105
(X,Y) (ft.)	780,435	778,439
Source	McLaren/Hart	CPT
Depth (ft.)		
6 to 8	silt over clay	silt over clay
16 to 18	silty clay	clay, silt and sand
26 to 28	sand	sand
31 to 33	sand	sand with gravel
33 to 35	silt and sand	sand over silt

Cluster 8		
Location	L78	L63
(X,Y) (ft.)	859,440	858,439
Source	McLaren/Hart	Soil Cond.
Depth (ft.)		
4 to 6	silt with clay	silt ?
9 to 11	clay with silt	clay
13 to 15	clay with silt	clay over silt
18 to 20	sand with gravel	sand with gravel
25 to 27	sand and gravel over clay	sand over silt/clay

TABLE 4.11 CONTINUED

Cluster 9		
Location	L65	L56
(X,Y) (ft.)	780,507	780,507
Source	McLaren/Hart	Soil Cond.
Depth (ft.)		
4 to 6	silt with clay	silt ?
12 to 14	silty clay	clay
18 to 20	sand on silt with clay	sand
24 to 26	silt with gravel on clay	silt/sand with clay ?

Cluster 10		
Location	L67	L58
(X,Y) (ft.)	775,533	775,533
Source	McLaren/Hart	Soil Cond.
Depth (ft.)		
4 to 6	silt with clay	clay over silt ?
11 to 13	clay with silt	clay over silt ?
16 to 18	sand with silt	sand with silt
21 to 23	silt/sand/gravel on clay	sand over clay

Cluster 11		
Location	L75	L37
(X,Y) (ft.)	813,475	812,476
Source	McLaren/Hart	Soil Cond.
Depth (ft.)		
5 to 7	silt with clay	sand over clay ?
10 to 12	clay with silt	clay
14 to 16	clay over silt	clay over silt
19 to 21	silt with sand and clay	sand
23 to 25	silt	sand and silt

Cluster 12		
Location	L41	L68
(X,Y) (ft.)	450,554	451,558
Source	CPT	Soil Cond.
Depth (ft.)		
5 to 12.5	clay	silt over clay
12.5 to 16.5	sand	sand with gravel
19 to 21	sand with gravel	sand with gravel
21 to 36.5	sand	sand
37	clay	silt/clay ?

TABLE 4.12 DEPTHS OF STRATIGRAPHIC CONTACTS FROM DIRECT PUSH TECHNOLOGIES

Map Location	Source	X (ft.)	Y (ft.)	Topo.	fill-ucu	ucu-gran	gran-lcu	lcu-bed
L1	I	931.75	560.57	885.29				
L3	I	814.83	576.47	886.67				
L4	I	812.4	524.41	885.15				
L5	I	785.02	476.94	883.48				
L7	I	840.63	501.91	884.02				
L9	I	751.16	510.02	884.56				
L10	I	750.6	559.96	884.86				
L11	I	750.39	442.33	883.99				
L12	I	731.66	427.6	882.55				
L13	I	722.9	491.92	884.65				
L14	I	721.16	537.99	884.91				
L15	I	714.18	592.35	888.57				
L16	I	689.99	471.51	884.5				
L17	I	678.24	559.63	888.07				
L18	I	679.07	424.69	883.3				
L19	I	638.71	543.24	886.42				
L20	I	646.34	503.82	885.52				
L22	I	595.1	534.75	886.14				
L23	I	590.79	575.02	886.02				
L24	I	553.31	543.28	886.45				
L25	I	573.97	507.37	885.79				
L26	I	634.79	574.47	886.02				
L28	GC	834	424	881.5	6	17	30	32
L29	G	960	418	881	4	17	26	27
L30	C	908	421	881.2	ND	16	ND	ND
L31	G	1036	421	880.5	4	16	26	27
L32	C	438	408	884	6	18	34	35
L33	GC	862	460	882	5	14	25	27
L34	G	903	515	883.5	3	11	19	22
L35	G	865	550	885.1	6	11	13.5	15.5
L36	GM	845	507	883.7	4	13	22.5	45.5
L37	G	812	476	884	3	15	26	29
L38	GM	806	519	884.5	2	13.5	22.5	24.5
L39	GM	792	481	884.1	4	15	21.5	23.5
L40	GM	780	435	883	5	16	33	35
L41	C	450	554	886.5	ND	ND	37	39.5
L42	GM	792	553	885.5	3	13	18	20
L43	GM	751	522	884.2	4	14	25.5	27.5
L44	G	719	592	887.2	3	13	26	29
L45	GM	665	428	883	5	18	36	38
L46	G	597	597	889	5	15	34	36
L47	C	583	549	886	ND	ND	36.5	38
L48	G	655	582	888	ND	ND	ND	ND
L49	C	621	533	886	ND	ND	32.5	34

TABLE 4.12 continued

Map Location	Source	X (ft.)	Y (ft.)	Topo.	fill-ucu	ucu-gran	gran-icu	icu-bed
L50	G	546	547	886	ND	ND	ND	ND
L51	C	688	543	885.5	ND	ND	32.5	34
L52	G	672	462	883.2	3	15	35	38
L53	C	732	511	884.5	ND	ND	31.7	ND
L54	G	737	461	884	4	15	34.5	37.5
L55	G	555	529	885	5	14	36.5	41
L56	G	780	507	883.9	3.5	15	20	22
L57	M	566	544	886	ND	ND	35	37
L58	G	775	533	884.2	5.5	13	21.5	23.5
L59	G	783	460	883.5	6.5	15.5	32.5	33
L60	C	679	436	883	ND	ND	34.5	36
L61	C	668	489	885	ND	ND	36	38
L62	G	832	455	882.5	4	14.5	32	34
L63	G	858	439	882	4	14.5	26.2	28.2
L64	C	787	461	883.5	ND	ND	31.5	34
L65	M	780	507	883.9	ND	ND	20	22
L66	G	584	548	886	5	13	36.7	38
L68	G	451	558	887.3	4	12	37	39
L69	G	626	599	889.2	5	17	27	29
L70	M	832	455	882.5	ND	ND	ND	ND
L71	C	810	452	882.5	ND	ND	ND	ND
L72	C	850	452	881.5	ND	ND	ND	ND
L73	M	862	460	882	ND	ND	ND	ND
L74	C	834	440	882.5	ND	ND	ND	ND
L75	M	813	475	884	ND	ND	ND	ND
L76	C	782	405	882	ND	ND	33.5	35.5
L77	C	788	467	884	ND	ND	31	33
L78	M	859	440	882	ND	ND	ND	ND
L79	C	809	440	882.5	ND	ND	29.5	31.5
L80	M	781	415	882.4	NA	NA	33	35
L81	C	581	547	885.5	ND	ND	37.5	39.5
L83	C	634	521	885.2	ND	ND	37	50
L84	M	530	516	886	NA	NA	37	39
L85	C	489	510	886	ND	ND	37.5	39.5
L86	M	455	572	887.5	ND	ND	36	37
L87	C	649	547	886	ND	ND	36	38
L88	M	438	535	886.5	ND	ND	37	38
L89	C	693	457	883.3	ND	ND	34	37
L90	W	716	433	883.2	ND	ND	ND	ND
L91	C	718	537	884.9	ND	ND	24	26
L92	M	436	448	885	ND	ND	ND	ND
L93	C	587	579	886.5	ND	13	34.5	36.5
L94	M	634	589	887.5	ND	ND	23	25
L95	C	771	515	884.2	ND	15	20	22

TABLE 4.12 continued

Map Location	Source	X (ft.)	Y (ft.)	Topo.	fill-ucu	ucu-gran	gran-lcu	lcu-bed
L96	M	572	580	886.7	ND	ND	36	38
L97	C	744	484	884	ND	15	34	36
L98	W	668	448	883.2	ND	ND	ND	ND
L99	C	739	524	884.2	ND	14	23	25
L100	M	838	432	881.5	ND	ND	ND	ND
L101	C	750	439	883	ND	17	34	36
L102	M	804	449	883	ND	ND	ND	ND
L103	C	ND	ND	-	-	-	-	-
L104	W	743	417	882.5	ND	ND	ND	ND
L105	C	778	439	883.1	ND	ND	34.5	36.5
L106	W	877	455	881.6	ND	ND	ND	ND
L107	C	767	473	884	ND	15	33.5	35.5
L108	M	789	466	883.8	ND	ND	31	33
L109	C	732	453	883.5	ND	17	35.5	37.5
L111	C	621	579	886	ND	14	32.5	34.5
L112	M	683	461	883.6	ND	ND	ND	ND
L113	C	723	432	883.2	ND	18	33	35
L114	M	667	428	882.8	ND	ND	ND	ND
L115	C	441	439	884.8	ND	15	34	40
L116	M	764	491	884	ND	ND	28	32
L117	ND	ND	ND	-	-	-	-	-
L118	M	730	458	883.6	ND	ND	33	35

Topo = topographic elevation

ucu = upper cohesive unit

lcu = lower cohesive unit

gran = granular soil

bed = bedrock

Sources:

I = Phase 1

G = Geoprobe soil conductivity

C = CPT

M = McLaren/Hart - soil sample

W = McLaren/Hart - groundwater sample

TABLE 4.13
COMPARISON OF KRIGED LCU SURFACE ELEVATIONS WITH LCU SURFACE
ELEVATIONS FROM BVWST BOREHOLE LOGS

BVWST Boring (ft.)	X (ft.)	Y (ft.)	Kriging Results		BVWST Surface Elevation (ft. a. msl)	Krig-BVWST Difference (ft.)	Z-score *	Note
			LCU Surface Elevation (ft. above msl)	Prediction Std. Dev. (ft.)				
B1	609.10	567.10	852.20	2.67	851.30	0.90	0.34	-
B2	655.40	557.10	853.20	2.38	846.60	6.60	2.78	hole?
B3	764.40	558.30	865.00	3.02	862.50	2.40	0.81	-
B4	624.50	522.10	848.10	1.90	847.90	0.20	0.11	-
B5	640.60	502.30	847.30	2.86	845.20	2.10	0.73	1
B6	705.60	460.10	849.60	2.48	848.90	0.80	0.30	-
B7	762.30	478.80	851.90	1.70	845.40	6.50	3.85	hole ?
B8	675.10	424.50	847.60	2.08	846.80	0.80	0.40	-
B9	435.10	492.10	849.90	3.12	-	-	-	-
B10	439.30	479.10	849.80	3.10	850.60	-0.80	-0.26	-
B11	431.80	509.60	849.10	3.20	-	-	-	-
B12	405.50	494.40	852.10	3.38	-	-	-	-
B13	726.80	429.10	850.00	1.66	845.80	4.20	2.53	hole ?
B14	745.50	401.50	848.50	3.08	849.50	-1.00	-0.32	-
B15	530.10	503.10	846.70	2.51	847.30	-0.60	-0.24	-
B16	853.00	485.70	858.60	2.88	858.40	0.30	0.09	2
MW1A	464.70	660.00	855.90	4.18	869.20	-13.30	-3.18	extrap, 3
MW2B	915.40	695.50	880.10	4.31	876.90	3.20	0.75	extrap
MW3A	820.90	409.60	851.00	2.85	849.00	2.00	0.71	-
MW4	440.00	402.10	849.40	1.89	853.30	-3.90	-2.06	-
MW5	447.90	470.50	848.70	3.06	-	-	-	-

1 depth to LCU not clear from BVWST log, 40,43 ft. bgs (40 ft. used here)

2 depth to bedrock assumed, LCU not encountered on BVWST log

3 depth to LCU not clear on BVWST, 20.5 to 22.5 ft. bgs (22.5 ft. used here)

extrap = extrapolation significantly outside of data bounds

* z-score = (Krig-BVWST)/(Prediction Std. Dev.)

Notes:

Kriging results based on median polish residuals fit to the CPT and Geoprobe Conductivity.

Geoprobe soil sampling data is compared to the BVWST data for LCU surface elevation.

This analysis provides an independent measure of the uncertainty in the model of the LCU

surface elevation and is useful for comparison of the Kriging results.

Conclusions:

a) The BVWST data suggest lower LCU surface elevations for 12 of the 17 comparisons. Neglecting the extrapolated data, this leaves 4 out of 15 BVWST greater than the predicted value, which is an unusual, but not highly unlikely event.

b) The z-scores should be approximately normally distributed with mean zero and a standard deviation of one if the modeling matches the Kriging prediction theory. With the exception of the extrapolated point MW1 and borings B2, B7, and B13 the z-scores are in good agreement with the prediction theory. This suggests that the prediction standard deviation plot is reasonably accurate. The outlying points B2, B7 and B13 indicate that either the BVWST data happened to hit depressions in the surface, or the predicted standard deviation is too small.

c) The big deviation at MW1A highlights the danger of extrapolation.

TABLE 4.14 SOIL PAH CONTAMINATION COMPARISONS BY SELECTED SAMPLE LOCATION CLUSTERS.

Cluster 1				
Location	L77	L64	L59	L108
(X,Y) (ft.)	788,467	781,461	783,460	789,466
Source	CPT LIF (COUNTS)	CPT	Soil Cond.	McLaren/Hart
Depth (ft.)				
6 to 8	50	50	conductivity low 5 to 7 ft.	odor, no visible product
19 to 20	10	50	conductivity low 18 to 20 ft.	no odor
20 to 21	10	100	obvious conduc. dip at 21 ft.	no odor
23 to 24	10	100	obvious conductivity dip	
26 to 28	10	50	no PAH signal	no odor
30 to 32	10	50	no PAH signal	no odor

Cluster 2		
Location	L81	L66
(X,Y) (ft.)	581,547	584,548
Source	CPT LIF (counts)	Soil Cond.
Depth (ft.)		
6 to 21	>200	conduc. dips 14 to 19 ft.
7 to 9	>400	no PAH signal
11 to 18	>1000	conduc. dips 14 to 19 ft.
35 to 36	100	slight conduc. dip

Cluster 3		
Location	L33	L73
(X,Y) (ft.)	862,460	862,460
Source	CPT LIF (counts)	McLaren/Hart
Depth (ft.)		
4 to 6	10	no odor mentioned
8 to 10	0	no odor mentioned
13 to 15	0	no odor

Cluster 4			
Location	L54	L109	L118
(X,Y) (ft.)	737,461	732,453	730,458
Source	Soil Cond.	CPT LIF (counts)	McLaren/Hart
Depth (ft.)			
5 to 7	conduc. is low	>200	strong odor, product
7 to 14	conduc. is high	100 to 200	
14 to 15	no clear signal	10	odor
15 to 16	no clear signal	50	odor and product
16 to 20	no clear signal	200 from 16 to 19 ft.	
20 to 22	conduc. dip at 20.5 ft.	100	
22 to 24	conductivity dips	10	no odor
24 to 30	no PAH signal	10	no odor
30 to 34	no PAH signal	10	slight odor, product
34 to 36	conduc. dip at 34.5 ft.	400	slight odor, product

TABLE 4.14 CONTINUED

Cluster 5				
Location	L45	L60	L114	B8
(X,Y) (ft.)	665,428	679,436	667,428	675,424
Source	McLaren/Hart	CPT LIF (counts)	McLaren/Hart	BVWST
Depth (ft.)				
6 to 7	free product	300		coal and wood fill ?
7 to 8	free product	300		tarry odor
17 to 19	free product	100		tarry odor, free brown oil
20 to 22		150		black free oil at 20 ft.
22 to 24		10	product	
24 to 26	no contaminant mentioned	10		
30 to 32	free product	50 (300 from 32 to 34 ft.)		black free oil
35 to 36	sheen and odor	50		
36 to 37	sheen and odor	50		

Cluster 6		
Location	L113	B13
(X,Y) (ft.)	723,432	727,429
Source	CPT LIF (counts)	BVWST
Depth (ft.)		
2 to 7.5	400 at 3 to 4 ft, >400 at 5 to 8 ft.	black tarry free oil
7.5 to 31	irregular trace, < 100	no contaminant mentioned
31 to 33	100 to 200	tarry oil, oil sheen

Cluster 7		
Location	L40	L105
(X,Y) (ft.)	780,435	778,439
Source	McLaren/Hart	CPT LIF (counts)
Depth (ft.)		
6 to 8	black, strong odor	> 200 at 5 to 6 ft. otherwise about 10
16 to 18	black, mild odor	10
20 to 22	no odor	10
26 to 28	slight odor	10
31 to 33	free product	> 400 at 32 to 34
33 to 35	odor, no product	LIF stops at 34 ft.

Cluster 8		
Location	L78	L63
(X,Y) (ft.)	859,440	858,439
Source	McLaren/Hart	Soil Cond.
Depth (ft.)		
4 to 6	brown to black, no odor	unclear signal
9 to 11	no odor	no PAH signal
13 to 15	no odor	no PAH signal
18 to 20	no odor	slight conduc. dip
25 to 27	no odor	no PAH signal

TABLE 4.14 CONTINUED

Cluster 9		
Location	L65	L56
(X,Y) (ft.)	780,507	780,507
Source	McLaren/Hart	Soil Cond.
Depth (ft.)		
4 to 6	no odor	no PAH signal
12 to 14	possible product in isolated zone	no clear signal, possible conductivity dip
18 to 20	no contaminant mentioned	no clear signal
24 to 26	no contaminant mentioned	no clear signal

Cluster 10		
Location	L67	L58
(X,Y) (ft.)	775,533	775,533
Source	McLaren/Hart	Soil Cond.
Depth (ft.)		
4 to 6	no odor	no PAH signal
11 to 13	slight odor ?	no PAH signal
16 to 18	no contaminant mentioned	no PAH signal
21 to 23	no contaminant mentioned	no PAH signal

Cluster 11		
Location	L75	L37
(X,Y) (ft.)	813,475	812,476
Source	McLaren/Hart	Soil Cond.
Depth (ft.)		
5 to 7	black crumbly soil	no PAH signal
10 to 12	no contaminant mentioned	no PAH signal
14 to 16	no odor	no PAH signal
19 to 21	no odor	no PAH signal
23 to 25	no odor	no PAH signal

Cluster 12		
Location	L41	L68
(X,Y) (ft.)	450,554	451,558
Source	CPT LIF (counts)	Soil Cond.
Depth (ft.)		
12 to 21	200 from 12 to 14 zero from 14 to 17 CPT LIF ends at 17	several conductivity dips from 13 to 21

TABLE 4.15 MCLAREN HART SOIL SAMPLES -OBSERVED LEVEL OF PAH CONTAMINATION BY STRATIGRAPHIC ZONE

Map Location	X (ft.)	Y (ft.)	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
ML36	845	507	0	0	NA	0	0	NA
ML38	806	519	NA	0	NA	NA	0	NA
ML39	792	481	1	2	0	NA	0	0
ML40	780	435	6	NA	1	1	5	2
ML42	792	553	1	NA	0	NA	0	0
ML43	751	522	2	2	1	NA	0	0
ML45	665	428	6	NA	4	5	4	NA
ML57	566	544	5	6	6	2	6	6
ML65	780	507	0	2	NA	NA	0	0
ML67	775	533	0	1	NA	0	NA	0
ML70	832	455	0	0	0	0	0	NA
ML75	813	475	0	0	0	0	0	NA
ML78	859	440	0	0	0	NA	0	0
ML80	781	415	1	0	6	1	6	6
ML84	530	516	0	NA	1	0	1	NA
ML86	455	572	1	6	NA	1	0	NA
ML88	438	535	2	5	NA	2	0	NA
ML92	436	448	0	NA	5	0	0	NA
ML94	634	589	0	2	2	6	6	NA
ML96	572	580	0	6	6	6	0	0
ML100	838	432	0	0	NA	NA	NA	NA
ML102	804	449	0	NA	NA	0	NA	NA
ML108	789	466	2	NA	NA	0	0	NA
ML110	817	426	1	1	1	0	0	NA
ML112	683	461	4	NA	4	0	6	NA
ML114	667	428	NA	NA	NA	6	NA	NA
ML116	764	491	1	NA	5	0	NA	0
ML118	730	458	4	2	5	0	6	5

Note:

<u>Observed Level Of PAH Contamination</u>	<u>Designation</u>
Free Product	6
Product Sheen	5
Discoloration	4
Strong Odor	3
Mild Odor	2
Slight Odor	1
No Odor	0

TABLE 4.16 MCLAREN/HART SOIL SAMPLE ATTRIBUTES

Map Location	Depth (ft.)	Soil Type	Zone	Extraction Methods	Recovery (feet)	Odor	Detects
36	5	c	1	a,b,c,d,e	full	y	0
36	12	c	1	a,b,c,d,e	1.3	y	0
36	18	c	6	a,b,c,d,e	1.7	y	0
36	23	c/s	7	a,b,c,d,e	full	y	0
38	12.5	c	2	a,b,c,d,e	full	y	0
38	23	r/s	5	a,b,c,d,e	1.5	y	0
39	9	c	1	a,b,c,d,e	full	15ppm	1
39	13	c	2	a,b,c,d,e	1.5	y	2
39	17	s	3	a,b,c,d,e	1.75	y	0
39	22	r	5	a,b,c,d,e	1.75	y	0
40	7.7	c	1	a,b,c,d,e	full	9ppm	2
40	17	c	2	a,b,c,d,e	1.5	y	0
40	21	s	3	a,b,c,d,e	1.7	y	0
40	27	s	4	a,b,c,d,e		30ppm	1
40	34.5	s	5	a,b,c,d,e	1.5	200ppm	5
43	5	c	1	a,b,c,d,e	1.6	y	2
43	16	s	3	a, d,e	1.4	y	1
43	25	gravel	7	a, d,e	0.9	y	0
42	4	silt	1	a, c,d,e	1.8	y	1
42	14	s	3	a, c,d,e	1.3	y	0
42	19	c,s	5	a	1.2	y	0
45	18.2	s	3	a, c,d,e	1.6	y	0
45	25	s	4	a,b,c,d,e	1.6	10ppm	0
45	35.5	s	5	a	1.8	20ppm	4
45	36.5	s	5	a, c,d,e	1.8	2ppm	4
57	19	s	4	a, d,e	1.55	y	2
57	25	s	4	a, d,e	1.65	y	1
57	34.5	s		a, d,e	1.8	y	0
57	35.7	c	6	a, d,e	1.8	y	@34.2=60 ppm
65	5	c	1	a, d,e	1.6	y	0
65	13	c	2	a,b, d,e	1	3ppm	4
65	18.5	s	5	a, d,e	1.6	y	0
65	19.5	c	6	a, d,e	1.6	y	0
65	25	si,c	7	a, d,e	1.6	y	0
67	5	c	1	a, d,e		y	0
67	12	c	2	a,b,c,d,e	1	30ppm	1
67	17	s	4	a, d,e	1.6	y	0
67	22	gravel	7	a, d,e	1.5	y	0
70	5	c	1	a, d,e	1.9	y	0
70	11	c	1	a, e	1.4	y	0
70	14	c	2	a	1.95	y	0
70	19	s	3	a	1.7	y	0
70	30.5	s, gravel	5	a	1.1	y	0

TABLE 4.16 continued

Map Location	Depth (ft.)	Soil Type	Zone	Extraction Methods	Recovery (feet)	Odor	Detects
73	5	c	1	a, c	1.7	y	0
73	9	c	1	c,d	1	y	0
73	14	sl,s3		a,b,c,d,e	1.6	y	0
75	6	c	1	c,d	2	y	0
75	11	c	1	c,d	1.3	y	0
75	14.5	c	2	c,d	1.8	y	0
75	15.5	s	3	c,d	1.8	y	0
75	20	sl,r	4	c,d	1.2	y	0
75	23.5	sl,r	6	c, e	1.6	y	0
75	24.5	c	6	c, e	1.6	y	0
78	5	c	1	e	1.85	y	0
78	10	c	1	e	1.1	y	0
78	14	c	2	e	1.41	y	0
78	19.5	s	3	a	1.6	y	0
78	20	c	4	d	1.6	y	0
78	26	c,s	5	e	1.2	y	0
80	6	c	1	a, d,e	1.85	10ppm	1
80	9	c	1	d	1.9	y	1
80	14	c	2	a,b, d,e	1.5	y	0
80	19	s	3	a,b,c,d,e	1.6	70ppm	6
80	29	s	4	e	1.85	y	1
80	33.5	c	6	a,b,c,d	1.7	70ppm	2
80	36	c	6	a,b,c,d,e	2	30ppm	5
84	6	c	1	a	1.9	y	0
84	13.5	s	3	e	1.55	y	1
84	25	s	4	a	2	y	0
84	36	s	5	d	1.85	y	1
86	5	c	1	e	1.9	y	1
86	10.5	c	2	a,b	1.75	y	1
86	20	s	4	d	1.4	y	1
86	35.5	s	5	e	1.4	y	0
86	36.5	c	6	a	1.4	y	0
88	5	c	1	d	1.9	y	2
88	11	c	2	a,b,c,d,e	1.65	10ppm	2
88	20	s	4	e	1.65	y	2
88	36	s	5	a	1.3	y	0
92	8	c	1	d,e	1.9	y	0
92	17	c,s	3	c, e	1.6	y	3
92	25	s	4	a, d,e	2	10ppm	0
92	33	s	5	a	1.4	y	0
94	6	c	1	d	1.5	y	0
94	13	c,s	2	a,b,c,d,e	1.8	300ppm	3
94	20	s	3	a,b,c,d,e	1.7	40ppm	5

TABLE 4.16 continued

Map Location	Depth (ft.)	Soil Type	Zone	Extraction Methods	Recovery (feet)	Odor	Detects
94	26	s	5	a,b,c,d,e	1.4	90ppm	6
96	13.5	s	3	a, d,e	1.4	5ppm	3
96	24.5	s	4	e	1.55	y	0
96	30	s	4	a	1.5	y	0
96	34.5	s	5	e	1.8	y	0
96	35.5	c	6	d	1.8	y	0
100	9	c	1	a	1.9	y	0
100	15	c	2	d	1.3	4ppm	0
102	8	c	1	e	1.85	y	0
102	16	s	4	a	1.7	y	0
108	7	c	1	a,b, d,e	1.45	y	2
108	20	s	3	d	1.2	y	0
108	27	s	5	a,b, d,e	2	y	0
108	31	s,c	6	e	1.8	y	0
110	9	c	1	a	1.6	y	1
110	16	c,s	3	d	1.35	y	1
110	19	s	3	e	1.6	y	0
110	23	s	4	a	0.9	y	0
112	7	c	1	a,b, d,e	1.9	140ppm	3
112	16.5	s	3	a,b, d,e	1.6	1700ppm	6
112	17.5	s	3	a, e	1.6	70ppm	2
112	26	s	4	d	2	30ppm	0
116	10.5	c	1	a,b, d,e	1.8	60ppm	3
116	11.5	c	1	a, d,e	1.8	10ppm	1
116	16	s	3	a, e	1.6	2ppm	1
116	21	s	4	d	1.65	2ppm	0
116	25	s	4	a,b, d,e	1.8	2ppm	0
116	31	c	6	a, d,e	1.2	9ppm	0
118	6.1	c	1	a,b, d,e	1.6	600ppm	3
118	15	s	2	a,b, d	1.4	500ppm	5
118	23	s	4	d	1.55	3ppm	0
118	25	s	4	???	1.8	y	0
118	27	s	4	a	1.9	y	0
118	29	s	4	d	1.9	3ppm	0
118	31	s	5	a,b, d,e	1.2	50ppm	5
118	34.5	c	6	a,b, d,e	1.7	35ppm	5
118	35.5	c	6	a,b, d,e	1.7	35ppm	4

TABLE 4.17 MCLAREN/HART SAMPLES USED FOR EXTRACTION METHOD COMPARISONS.

Map Location	McLaren/Hart Sample ID	X (ft.)	Y (ft.)	Sample Depth (ft. bgs**)		Soil Type
				from	to	
ML39	MT-2-G9	792	481	12	14	clayey
ML40	MT-2-G17.9	780	435	34	35	sandy
ML43	MT-2-G18	751	522	4	6	clayey
ML67*	MT-2-G40	775	533	11	13	clayey
ML80	MT-2-G65	781	415	18	20	sandy
ML88	MT-2-G78	438	535	10	12	clayey***
ML94	MT-2-G86	634	589	12	14	clayey***
ML94	MT-2-G87	634	589	19	21	sandy
ML94	MT-2-G88	634	589	25	27	sandy***
ML112	MT-2-G106	683	461	6	8	clayey
ML112	MT-2-G107.1	683	461	16	17.2	sandy
ML116*	MT-2-G111.1	764	491	10	11	clayey
ML118	MT-2-G116.2	730	458	5.5	606	clayey
ML118	MT-2-G117.1	730	458	14	15.4	clayey
ML118	MT-2-G122.1	730	458	30	31.2	sandy

* sample not included in the September 1994 report.

** ft. bgs = feet below ground surface.

*** soil type classification changed from the September 1994 report: from "silty clay" (MT-2-G78) and "clayey sand" (MT-2-G86, predominantly clayey according to the McLaren/Hart logbook) to "clayey" and from "silty sand" (MT-2-G88) to "sandy."

TABLE 4.18 MCLAREN/HART SOIL SAMPLE ANALYSIS- AVERAGE PERCENT RECOVERY BY EXTRACTION METHOD AND ANALYTE.

Analyte	Analyte Code	Average Percent Recovery by Extraction Method				
		A Sonication	B Microscale	C Microwave	D* Thermal	E** SFE
Naphthalene	N	89	120	122	100	85
Acenaphthylene	AL	93	120	120	100	86
Acenaphthene	AT	92	118	120	100	86
Fluorene	F	99	120	122	100	86
Phenanthrene	PH	100	145	124	100	88
Anthracene	A	97	142	130	100	90
Fluoranthene	FT	102	141	126	100	88
Pyrene	PY	101	150	110	100	86
Benzo(a)anthracene	BA	98	131	115	100	86
Chrysene	C	97	134	115	100	87
Benzo(b)fluoranthene	BF	105	101	121	100	97
Benzo(k)fluoranthene	KF	105	107	119	100	84
Benzo(a)pyrene	BP	103	99	118	100	89
Indeno(1,2,3,cd)pyrene	IP	94	108	129	100	85
Dibenzo(a,h)anthracene	AA	91	96	124	100	89
Benzo(g,h,i)perylene	GP	81	87	126	100	91

* No percent recovery data available; 100% was assumed, i.e., no data adjustment was made.

** Supercritical fluid extraction, SFE

TABLE 4.19 SUMMARY STATISTICS OVER SOIL SAMPLES WITHIN ANALYTE/METHOD SUBGROUPS

Analyte	Analyte Molecular Weight	Statistic*	Method				
			A Sonication	B Microscale	C Microwave	D Thermal	E SFE
Naphthalene	128	Mean	0.89	1.34	1.47	0.31	1.03
		s	0.41	0.53	0.48	0.24	0.4
		n	10	12	6	9	11
Acenaphthylene	152	Mean	0.9	1.16	1.39	0.45	1.15
		s	0.36	0.39	0.61	0.22	0.34
		n	9	13	7	10	11
Acenaphthene	154	Mean	0.82	0.99	1.47	0.68	1.05
		s	0.32	0.33	0.26	0.25	0.34
		n	7	12	6	6	11
Fluorene	166	Mean	0.77	1.33	1.28	0.48	1.04
		s	0.3	0.47	0.46	0.29	0.43
		n	12	14	8	9	12
Phenanthrene	178	Mean	0.78	1.04	1.42	0.94	0.97
		s	0.27	0.51	0.74	0.54	0.37
		n	14	14	9	14	13
Anthracene	178	Mean	0.92	0.85	1.26	0.94	1.13
		s	0.65	0.51	0.5	0.93	0.6
		n	10	14	7	8	12
Fluoranthene	202	Mean	0.77	1.16	1.27	0.75	1.03
		s	0.24	0.54	0.39	0.42	0.35
		n	11	14	8	9	13
Pyrene	202	Mean	0.83	1.15	1.39	0.62	0.98
		s	0.31	0.37	0.3	0.22	0.35
		n	14	14	8	7	13
Benzo(a)anthracene	228	Mean	0.92	1.17	1.3	0.43	1.02
		s	0.41	0.39	0.26	0.2	0.41
		n	10	14	7	7	12
Chrysene	228	Mean	0.77	1.15	1.27	0.76	1
		s	0.27	0.44	0.23	0.87	0.45
		n	9	14	7	8	12
Benzo(b)fluoranthene	252	Mean	1.03	1.22	0.96	0.91	0.86
		s	0.4	0.44	0.5	0.38	0.35
		n	5	10	6	7	11
Benzo(k)fluoranthene	252	Mean	0.69	1.18	1.27	1.07	0.83
		s	0.21	0.52	0.36	1	0.38
		n	6	11	5	6	11
Benzo(a)pyrene	252	Mean	0.85	1.14	1.2	0.09	1.06
		s	0.53	0.51	0.41	0.04	0.35
		n	7	12	7	3	11
Indeno(1,2,3,cd)pyrene	276	Mean	0.99	0.9	1.01	1.15	0.99
		s	0.26	0.4	0.3	0.41	0.2
		n	2	5	4	4	6
Dibenzo(a,h)anthracene	278	Mean				0.99	1.01
		s					
		n	0	0	0	1	1
Benzo(g,h,i)perylene	276	Mean	1.14	0.98	1.07	1.06	0.87
		s	0.24	0.3	0.21	0.17	0.24
		n	2	5	5	4	6

*s= standard deviation, n= number of observations.

TABLE 4.20 SANDY VS. CLAYEY SOIL SAMPLE COMPARISONS FOR ALL DATA

Method	Clayey			Sandy			Mean Tests	Variance Tests
	Mean	s	n	Mean	s	n	p-value	p-value
A, Sonication	0.86	0.41	84	0.81	0.22	44	0.833	0.006
B, Microscale	1.19	0.51	11	1.04	0.33	67	0.032	0.003
C, Microwave	1.34	0.53	55	1.21	0.27	45	0.277	0.000
D, Thermal	0.70	0.66	55	0.72	0.42	57	0.191	0.671
E, SEF	0.88	0.40	92	1.17	0.29	74	0.000	0.000

s= standard deviation, n= number of observations.

TABLE 4.21 SUMMARY OF METHOD DETECTION LIMIT DATA BY EXTRACTION METHOD.

Analyte	A, n=7 Sonication		B, n=7 Microscale		C, n=7 Microwave		D, n=7 Thermal		E, n=6 SFE	
	X	s	X	s	X	s	X	s	X	s
Naphthalene	7.95	1.2	11.54	0.56	6.93	0.25	10.40	5.6	7.40	1.9
Acenaphthylene	8.15	1.6	12.23	0.75	7.22	0.15	24.60	9	7.76	3.2
Acenaphthene	8.35	1.4	12.03	0.71	7.19	0.18	12.60	6.6	8.70	2.3
Fluorene	8.91	1.6	11.95	0.73	7.21	0.1	16.90	5.2	8.74	2.3
Phenanthrene	9.06	1.5	14.02	0.69	7.25	0.5	27.20	18.6	9.09	2.2
Anthracene	8.82	1.7	14.87	0.75	7.15	0.38	17.40	3.2	9.20	2.5
Fluoranthene	9.63	1.4	13.55	0.41	7.06	0.29	19.90	3	9.06	2.2
Pyrene	9.61	2	16.12	2.3	7.14	0.26	19.90	3.2	8.45	2.1
Benzo(a)anthracene	9.67	1.9	13.50	0.75	6.99	0.23	19.70	4.3	8.46	2.1
Chrysene	10.06	1.7	14.21	1.2	7.11	0.29	20.60	2.6	8.65	2.2
Benzo(b)fluoranthene	8.69	2.1	9.10	0.6	7.00	0.18	20.90	4.7	10.20	3
Benzo(k)fluoranthene	9.61	2.3	9.73	0.48	7.43	0.25	16.50	4.8	11.08	3
Benzo(a)pyrene	8.94	1.8	9.18	0.6	6.73	0.2	22.30	3.1	8.53	2.7
Indeno(1,2,3,cd)pyrene	9.59	0.9	8.50	2.1	7.16	0.2	26.20	9.1	9.70	2.7
Dibenzo(a,h)anthracene	9.14	1.2	7.74	1.1	6.64	0.27	24.30	7.6	9.69	2.6
Benzo(g,h,i)perylene	9.28	1.3	8.23	1.5	6.63	0.16	27.80	9.1	9.47	2.3
Average	9.09	1.6	11.66	0.95	7.05	0.24	20.45	6.23	9.01	2.46
Std. error of avg.	0.41		0.27		0.07		1.80		0.62	

TABLE 4.22 SUMMARY OF METHOD DETECTION LIMITS DEVELOPED ON SITE (mg/kg)

Analyte	A Sonication	B Microscale	C Microwave	D Thermal	E SFE
Naphthalene	3.8	1.8	0.79	17.60	6.40
Acenaphthylene	5.0	2.4	0.47	28.30	10.80
Acenaphthene	4.4	2.2	0.57	20.70	7.70
Fluorene	5.0	2.3	0.31	16.30	7.70
Phenanthrene	4.7	2.2	1.60	58.40	7.40
Anthracene	5.3	2.4	1.20	10.00	8.40
Fluoranthene	4.4	1.3	0.91	9.40	7.40
Pyrene	6.3	7.2	0.82	10.00	7.10
Benzo(a)anthracene	6.0	2.4	0.72	13.50	7.10
Chrysene	5.3	3.8	0.75	8.20	7.40
Benzo(b)fluoranthene	6.6	1.9	0.57	14.80	10.00
Benzo(k)fluoranthene	7.2	1.5	0.79	15.10	10.00
Benzo(a)pyrene	5.6	1.9	0.63	9.70	9.10
Indeno(1,2,3,cd)pyrene	2.8	6.6	0.63	28.60	9.10
Dibenzo(a,h)anthracene	3.8	3.4	0.85	23.90	8.70
Benzo(g,h,i)perylene	4.1	4.7	0.50	28.60	7.70

TABLE 4.23 RELATIVE ERROR (%) CALCULATED FROM AVERAGES BY ANALYTE FOR EACH METHOD.

Extraction Method	MDL Study	Clayey Soil	Sandy Soil	Clayey and Sandy Samples Combined
A, Sonication	18	50	30	44
B, Microscale	8.1	44	33	40
C, Microwave	3.4	42	17	35
D, Thermal	30	94	42	73
E, SFE	27	49	22	39

TABLE 4.24 SUMMARY OF METHOD BIAS AND PRECISION STATISTICAL TESTS.

Comparison/Test	Conclusions: Based on	
	All available data	38 subsets with >ND data for all five methods
Method Bias, overall	D<A<E=B<C*	D<A=B<E=C
Method Precision, overall	D=B<A, no other differences	A=B=C=D=E
Method Bias Clayey vs Sandy soil means	A: clayey = sandy B: clayey = sandy C: clayey = sandy D: clayey = sandy E: clayey < sandy	A: clayey > sandy B: clayey > sandy C: clayey = sandy D: clayey < sandy E: clayey = sandy
Method Precision Clayey vs Sandy soil standard deviations Note: low standard deviation implies high precision	A: σ sandy < σ clayey B: σ sandy < σ clayey C: σ sandy < σ clayey D: σ sandy = σ (<***)clayey E: σ sandy < σ clayey	A: σ sandy = σ clayey B: σ sandy = σ clayey C: σ sandy < σ clayey D: σ sandy = σ clayey E: σ sandy < σ clayey
Analyte Means vs. MW, ** combined samples	D increases with increasing MW C decreases with increasing MW	No analyses performed
Analyte Means vs. MW, ** clayey samples	No changes with increasing MW	
Analyte Means vs. MW, ** sandy samples	D increases with increasing MW E and C decrease with increasing MW	

* A = Sonication, B = Microscale, C = Microwave, D = Thermal and E = SFE

** Based on a linear regression of analyte mean on molecular weight (MW)

*** The F-Test indicates "<" but the nonparametric test indicates "=".

TABLE 4.25 MCLAREN/HART GROUNDWATER SAMPLE RESULTS

ML	Depth	Compound		Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene
		Matrix	WATER									
		Conc:mg/l										
Sample Name												
80	19'-21'	GW001-DL	0.261	0.151	0.030 J	0.079 J	0.327	0.123	0.174	0.152	0.086	
80	30'-32'	GW002-DL	3.450	0.464 J	<0.080	0.317 J	0.819	0.376 J	0.448 J	0.340 J	0.190 J	
90	23'	GW003-DL	0.645	0.090	0.032 J	0.094	0.356	0.098 J	0.154 J	0.148 J	0.067 J	
90	33'	GW004-DL	3.916	0.710 J	0.088 J	0.305 J	0.835	0.244 J	0.251 J	0.300 J	0.134 J	
98	24'-26'	GW005-UNFIL.T-DL	9.790	0.624 J	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080
98	24'-26'	GW005-FIL.T-DL	6.112	0.348 J	ND	ND	ND	ND	ND	ND	ND	ND
104	21'-23'	GW007-DL	1.604	0.321 J	<0.080	0.200 J	0.577 J	0.115 J	0.179 J	0.252 J	0.102 J	
104	30'-32'	GW008-DL	1.020	0.108 J	<0.020	0.031 J	0.099 J	0.035 J	0.057 J	0.053 J	0.026 J	
106	22'-24'	GW009	0.019 J	0.004 J	ND	0.005 J	0.145	0.005 J	0.011 J	0.010 J	0.005 J	
106	16'-18'	GW010	0.013 J	ND	ND	ND	0.011 J	0.020 J	0.010 J	0.007 J	<0.004	
		Solubility(mg/l)*	30	3.93	3.47	1.69	1	0.045	0.24	0.135	0.012	

Qualifiers:

ND = No detection of this target analyte at or above the MDL.

MDL = 4.0 ug/l

DL = Dilution required to bring target analyte concentration within linear and or qualifier range.

J = Estimated value outside the instrument's linear range.

* at 25 degrees centigrade

TABLE 4.25 MCLAREN/HART GROUNDWATER SAMPLE RESULTS (continued)

ML	Depth	Sample Name	Conc:mg/l		Chrysene		Benzo(b)fluoranthene		Benzo(k)fluoranthene		Benzo(a)pyrene		Indeno(1,2,3-cd)pyrene		Dibenzo(a,h)anthracene		Benzo(e,h,i)perylene	
			Matrix	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER
80	19'-21'	GW001-DL		0.077 J	0.049 J	0.066 J	0.065 J	0.033 J	0.012 J	0.027 J								
80	30'-32'	GW002-DL		0.180 J	<0.080	<0.080	0.126 J	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080
90	23'	GW003-DL		0.059 J	0.031	0.038	0.051	0.032	ND	0.028								
90	33'	GW004-DL		0.122 J	<0.080	<0.080	0.083 J	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080
98	24'-26'	GW005-UNFILT-DL		<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080
98	24'-26'	GW005-FILT-DL		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
104	21'-23'	GW007-DL		<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080
104	30'-32'	GW008-DL		0.025 J	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
106	22'-24'	GW009		0.005 J	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
106	16'-18'	GW010		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Solubility(mg/l)*		0.0018	0.014	0.00055	0.0039	0.062	0.005	0.00026								

Qualifiers:

ND = No detection of this target analyte at or above the MDL.

MDL = 4.0 ug/l

DL = Dilution required to bring target analyte concentration within linear and or qualifier range.

J = Estimated value outside the instrument's linear range.

* at 25 degrees centigrade

5.0 SUMMARY AND CONCLUSIONS

5.1 Introduction

Ames Laboratory of the U.S. DOE undertook a project sponsored by its Office of Technology Development (OTD) in the Environmental Management (EM) program to promote the adoption of ESC and its associated technologies. The goals of the project are to seek out and develop better, safer, faster, cheaper technologies and approaches to solving DOE environmental problems, to improve the basis for analyzing site characterization data, to compare the various analytical technologies, and to encourage stakeholder participation in the environmental arena. The ESC methodology incorporates on-site decision making that facilitates the use of dynamic work plans, allowing site characterizations to be completed in a single continuous effort rather than in a protracted, iterative manner. It has been demonstrated that characterizations can be streamlined and made more efficient without compromising data quality. Two fundamental precepts of the ESC method are, first, the use of both on-site quantitative analytical and multiple geological characterization technologies to minimize the need to perform massive intrusive sampling and time consuming off-site laboratory analysis and, second, the use of on-site decision making to significantly reduce the probability of returning to the site to fill data gaps. As a result, the traditional multi-phase sequence of sampling-analysis-planning-sampling-analysis-etc., becomes compressed into a single integrated effort.

In many situations, ESC may be executed in two steps or phases. The first can be described as a focusing phase, in which a direction for the execution, or at least initiation, of the detailed quantitative investigation (Phase II) is planned. Phase I may involve paring down an extensive list of possible contaminants to a short list of target analytes, and/or it may involve identification of the area(s) in which to focus or begin a detailed characterization. In many situations, Phase I has been previously accomplished through work conducted in preliminary site assessments, scoping investigations, or review of historical records.

Several categories of effort can be applied to Phase I, depending on site-specific factors, regulatory considerations, and the existing data set. These categories include:

- Preliminary sampling and quantitative analysis to identify contaminants of concern. This is applicable at sites where multiple wastes or products may have been released and a target list has not been developed.
- Qualitative chemical analysis to identify gross dimensions of the contaminated areas, identify contaminant media, and to qualitatively identify analytes for Phase II.

- Geologic characterization from principally non-intrusive methods (e.g., geophysical surveys) to build a conceptual model of the subsurface from which, with knowledge of contaminant properties, likely contaminant migration pathways can be assessed.

ESC Phase II involves the process of confirming and further developing the site geological model with the application of more intrusive technologies than Phase I and gathering detailed quantitative data regarding the nature and extent of contaminants in the relevant media, which might be called the chemical site model. The data collection plan is designed and continually updated to maximize efficiency by effectively eliminating unneeded sampling. Samples are usually collected by rapid methods which produce minimal disturbance and analyzed in on-site, mobile laboratories instrumented to strictly comply with regulator-approved methods (e.g., U.S.-EPA SW-846) traditionally performed in off-site laboratories. Data generated by the mobile laboratories is verified on site and integrated into the conceptual site model on a daily basis, allowing for real-time interpretation.

ESC was first developed and executed by a group at Argonne National Laboratory on a landfill site in New Mexico. Since then the Argonne group has conducted ESC projects at sites in Texas and on several sites in the central U.S. During its first year, the Ames ESC Project mission was to evaluate and promote both IT and SOPT environmental characterization technologies within the ESC framework of real-time data evaluation and a dynamic work plan. Work at the first site, described in this report, was performed as a demonstration outside of the regulatory compliance domain. With the assistance of the Iowa Department of Natural Resources, a FMGP site in Marshalltown, Iowa, was identified as a suitable subject site for the Ames ESC demonstration.

The summary and conclusions of the Marshalltown FMGP ESC investigation focus on an evaluation of the applicability, effectiveness and reliability of both the SOPT and IT fielded at the site in the broad categories of geological/stratigraphic characterization, detection of the nature, distribution and extent of contamination and on-site data integration. In addition, the lessons learned from the Marshalltown ESC demonstration, including significant contributions from this investigation to the advancement of the application of the ESC process in general, are elucidated.

5.2 Geological/Stratigraphic Characterization

The site is situated within a glacial drift terrain on the edge of the floodplain of a minor stream. The ground surface is flat to gently sloping, with approximately 10 feet of relief across the site. The BVWST RI report provided a significant amount of stratigraphic information with which to plan the Ames ESC demonstration. The report indicated that the depth to limestone bedrock at the site varies from about 25 feet in the northern part of the site to about 45 feet in the southwestern part of the site. Overlying the bedrock is a sequence of alluvial and

*Ames Expedited Site Characterization - Marshalltown FMGP Site
FINAL Site Report
March 25, 1996*

glacial/lacustrine soils generally characterized by the sequence cohesive over granular over cohesive. The soils were in turn overlain by a heterogeneous dense/hard fill.

Geophysical survey techniques including GPR, seismic reflection and refraction, EOL and borehole logging were fielded at the site primarily to define the surface of the bedrock. Secondary objectives were to provide soil stratigraphic information and information regarding the distribution of PAH contamination. Geophysical survey techniques are considered to be the primary component in the early phase of the ESC process. In this case, the geophysical survey techniques were required to operate under very difficult site conditions. Cultural interferences such as noise from the railroad tracks and from activities within the site, overhead power lines, buildings and surface metallic objects and site stratigraphic conditions such as the heterogeneous upper dense/hard fill unit and the uneven, weathered bedrock surface all contributed to the difficulties. In addition to the geophysical survey techniques, two minimally intrusive geophysical/geotechnical techniques, CPT and soil conductivity logging, were fielded primarily to define the soil stratigraphy and, in particular, the surface topography of the LCU as the DNAPL coal tar residue could tend to pool on and flow along this stratigraphic contact. The CPT unit was equipped with a LIF sensor designed to detect petroleum, oil and lubricant contaminants in the subsurface; the CPT thus played a dual characterization role.

Results of the geophysical surveying were compared with both the BVWST data and with the minimally intrusive data collected as a part of this investigation. After these comparisons were made, it appears that only the SOPT borehole logging provided useful, reliable information. The 300 MHz GPR survey data provided some information on the locations of shallow foundations and services/utilities, but this was not an important aspect of this project. Significant above ground reflectors are apparent in the traces. The processing of the data in a three-dimensional format and the production of time slices through the model, which is an IT associated with this work, shows promise. A significant portion of the data set, however, was not used in generating the three-dimensional model because of software limitations. More appropriate software and computing capabilities should be considered for future endeavors.

The dense/hard upper fill layer and the highly electrically conductive upper cohesive unit are believed to have restricted the depth of penetration of the 100 MHz surveying equipment. The contractor provided profiles in terms of nanoseconds only on the vertical scale; it was left up to ESC personnel to try and interpret depths in feet. Potential variations in velocities could create errors in the depths to contacts on the order of 5 to 10 feet. Moreover, the bedrock surface inferred from the 100 MHz profile did not compare well qualitatively with the general topography of the bedrock surface interpreted from intrusive technologies.

The seismic refraction data was acquired using good techniques and was presented in a clear and concise manner in the contractor's report. Comparisons were generally quite good with the existing BVWST data (which they had at the time of their data interpretation) but comparisons

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with the minimally intrusive data indicated that their interpreted bedrock depth contours could be in error by as much as 13 feet; 5 to 10 foot disagreements were frequent. The seismic reflection contractor, as with the GPR contractor, provided uninterpreted seismic profiles with milliseconds on the vertical scale. Their velocity interpretations were unclear, including the application of a "static correction" between two lines, thus making the data virtually impossible to interpret in a quantitative sense by Ames ESC personnel. Qualitative comparisons with minimally intrusive data indicate that their interpretation of the depth to bedrock is in error on the order of 10 feet in places. Moreover, seismic reflection trials carried out by the seismic refraction contractor with a similar sledge hammer source indicated that no clear reflections were apparent. Trials with an IT vibratory source also did not produce any clear reflecting events.

The IT EOL results indicated a large high resistivity anomaly was present in the central part of the site where contamination was believed to be the highest. When the resistivity values determined for this anomaly were compared with representative resistivity values calculated from the borehole geophysical logging and the soil conductivity probe results, it was noted that the EOL resistivities were significantly higher than those detected by either of the other technologies - the borehole geophysical conductivities and soil conductivity probe values are similar. The EOL resistivity anomaly remains without a rational explanation or correlation with other technologies. The fact that the transmitter loop was deployed within a few feet of vehicles, chain link fences, stacks of steel piping and even within a steel shed and the fact that only one receiver well was used probably detracted from the accuracy of the results.

As noted above, the SOPT borehole geophysics may be considered the only reliable information generated from the suite of geophysical surveying technologies fielded. These data proved useful in defining the transition from weathered to unweathered limestone and also provided useful information for correlation with other geophysical data, such as the soil conductivity probe and the EOL surveying data. This information also could have been useful in assessing the depth of penetration of the GPR, but was not used for this purpose at this site. (The GPR contractor is the same contractor who carried out the borehole geophysics.) On the down side, however, the borehole geophysical logging required previously drilled boreholes with wells installed and thus did not provide much additional stratigraphic information, beyond that mentioned above. Moreover, the conductivity responses from the borehole conductivity logging in particular did not produce either as sharp a stratigraphic contact or the ranges of conductivity values produced by the soil conductivity probe. This is probably due to the fact that the soil conductivity probe is in direct contact with the soil and is measuring the bulk conductivity of a relatively small volume of soil whereas the borehole conductivity measurements, in order to avoid measuring the conductivity of the well materials, need to be made farther out into the stratigraphic units and thus measure the bulk conductivity of a much greater volume of material.

It is clear that at the Marshalltown FMGP site the interpretation of the bedrock surface from the geophysical survey techniques is tenuous and can be in error by as much as 10 to 15 feet when

compared with data from intrusive technologies. The negative impact of the cultural interferences and relatively difficult stratigraphic conditions, coupled with uninterpreted data being submitted by some contractors, make evaluation of the techniques very difficult. All the techniques, however, point to the fact that the bedrock surface is weathered, uneven and highly variable.

The SCAPS CPT unit and the Geoprobe soil conductivity probe provided very useful and reliable stratigraphic data. Side-by-side comparisons of the direct push technology logs with BVWST borehole logs indicated stratigraphic correspondence of the unit contacts generally within about one to two feet. The CPT is basically a stand-alone stratigraphic logging tool, requiring limited on-site calibration while stratigraphic interpretation from the soil conductivity probe requires a higher level of calibration. The soil conductivity probe could be regarded as having a role of filling in stratigraphic information between two locations with known stratigraphic profiles. The major unit stratigraphic contacts were generally easily picked off of both the CPT and soil conductivity logs and used to generate a database for an EarthVision three-dimensional site stratigraphic model. When sections from this site stratigraphic model were compared with nearby BVWST borehole logs, correlation of stratigraphic units was generally within about one to two feet. It should be noted, however, that the BVWST data tended to produce a slightly deeper granular unit/LCU contact than the direct push data. This could be the result of differing interpretations of the often transitional lower contact or also could be due to inherent stratigraphic variability over relatively small distances. It should be noted that both the CPT and soil conductivity probe produce continuous logs and significantly more stratigraphic detail than can be obtained through auger borehole logging. This level of detail can be important for DNAPL fate and transport considerations.

Several difficulties experienced with the direct push technologies are as follows: the heterogeneous upper fill layer created problems for penetration of both the CPT and the soil conductivity probes; neither technology could reliably indicate the surface of the bedrock; and, probe breakage was a problem if large gravel or cobble sizes or the bedrock surface was unexpectedly encountered. The Geoprobe soil conductivity unit had the advantages of better mobility and more rapid production than the CPT; however, the CPT had the advantages of being more stand alone in terms of stratigraphic logging, provided more direct contaminant screening data and also had more push capacity than the Geoprobe. Hollow stem augering or a similar technology is probably the only means by which the surface of the bedrock may be reliably determined at this site.

5.3 Contaminant Detection

Based on the previous BVWST site characterization work, the lateral and vertical distribution of the dissolved PAHs and residual non-aqueous phase liquid contamination was estimated.

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Assessment of the nature and distribution of the PAH contaminants was carried out using three types of technologies: Phase I screening technologies involving three commercially available IT immunoassay (IMA) kits, an IT CL system and SOPT active and IT passive soil gas measurements; Phase II screening involving IT CPT LIF and IT Geoprobe soil conductivity measurements; and, Phase II quantitative chemical analysis of soil samples using five different on-site extraction methods coupled with GC/MS instruments. For the purpose of developing and assessing the site contamination model, the soil stratigraphy was subdivided into six zones based on the site soil stratigraphy. The six zones defined are as follows:

- middle and bottom of upper cohesive unit (termed zones 1 and 2 respectively),
- top, middle and bottom of granular unit (termed zones 3, 4 and 5 respectively), and
- top of LCU (termed zone 6).

The Phase I suite of contaminant screening technologies were applied in an effort to evaluate their ability to identify the approximate boundaries of the organically contaminated area. A triangular 24-point, 50 foot grid was designed to overlap suspected contaminated and uncontaminated areas. At each grid node, Geoprobe equipment was used to collect one shallow (4 to 5 feet deep) and one deep (10 to 15 feet deep) soil sample - these depths correspond to zones 1 and 2, and in places zone 3, as described above. Duplicates from soil core samples were analyzed by all three IMA techniques; in addition, the pore fluids were extracted from an additional duplicate sample and analyzed using the CL system. Since this step in the characterization process was conducted to simulate a screening-level interpretation of the distribution of contaminants, soil collected in the sample tubes was not homogenized. In addition, a soil vapor sample was drawn at each sampling level and analyzed using a field gas chromatograph housed in a Geoprobe vehicle. Finally, a soil gas collector containing two or three adsorption elements in a resealable glass container was placed in a pre-cleaned copper tube in each probe hole at the approximate soil sampling depths to passively adsorb organic compounds in soil vapors over a period of a week.

The data from the three IMA analyses indicated that the presence or absence of detectable PAHs for each vendor's data correlates fairly well with either of the other two. Furthermore, each of the three shallow and deep data sets agree very well with each other on the location and shape of the PAH contamination distribution. The deep data sets places the centroid of the plume further west than the shallow data, consistent with the depth dependent results from other analytical techniques used. When compared to the limited off-site analysis set, the relative degree of agreement within each of the three IMA results are good. Better agreement and fewer false negatives were produced by IMA techniques using gravimetric measurement of soil rather than the volumetric measurements.

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The CL analysis involved a proprietary organic liquid phase extraction from the soil sample and addition of chemicals to bring about luminescence of PAH compounds in the extract. This method required independent laboratory analysis of samples from the same media to develop a calibration curve. Results were reported as total PAH and did not correlate well with other methods used. Moreover, the method requires significantly more calibration, sample preparation and handling than the other screening methods.

Passive soil vapor samplers were analyzed off site by thermal desorption and direct mass spectrometer (MS) analysis. Results are thus reported in ion counts of three different molecular masses. The passive collectors provided the advantage of detecting some of the less volatile PAHs not detectable with active soil gas techniques. The shallow data for all three molecular masses agree well with each other. Little of the heavier PAHs compounds were found in the deeper data set, and as expected, lighter molecular weight appears to correspond to higher volatility and concentration in soil gas.

Active soil gas measurements for aromatic hydrocarbons and naphthalene were made by drawing a vacuum on the probe hole, capturing the effluent vapor stream, and injecting it into the GC. Detection of naphthalene was facilitated by heating the vapor sample prior to injection. Results from both photoionization and flame ionization detectors were recorded for aromatic hydrocarbons and naphthalene. Good agreement between the two detectors was found. Concentration differences between the two depths were small and consistent with a more extensive eastern component of the shallow plume.

Overall, the results of the Phase I contaminant screening technologies generally compare well with the BVWST results for stratigraphic zones 1, 2 and 3. The plumes are generally centered around the former purifier building and extend down toward the storage shed at the southern end of the site. Analytical results for BVWST boreholes B-02, B-04, B-05 and B-06 generally indicated the highest levels of PAH contamination. Analytical results for boreholes B-08, B-13 and B-14 indicated that the top two stratigraphic zones in the southcentral part of the site also contained PAH contaminants. The gravimetric IMA results and the passive gas results for the deep screening zone indicated significant PAH contamination in this region; the other screening techniques have partially detected it (CL) or completely missed it (active gas). A significant finding of the Phase I contaminant screening study was that PAH contamination existed further to the west than it would appear from the BVWST data. In particular, the BVWST analytical data for B-15 from zone 2, corresponding to the deep screening tests, indicate no PAH contamination (the analytical results for samples from this depth range gave non detects). The deep zone IMA results and passive gas results, in particular, exhibit significant levels of PAH contamination at ML-24 and ML-25, indicating that the plume could in fact extend farther to the west.

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Phase II contaminant screening was performed using the SCAPS LIF sensor system and interpreting dips in the Geoprobe soil conductivity profiles. Chemical analysis of soil samples collected adjacent to LIF "hits" indicated that while the LIF sensor data could not be considered as quantitative, the LIF sensor could reliably detect regions of low, medium or high contamination in a qualitative sense. In addition, comparisons of LIF data with olfactory/visual contamination descriptions from nearby BVWST boreholes and MLH sampling locations provided further support for the efficacy of the LIF data.

Average LIF intensities for each of the six stratigraphic zones were interpreted from the LIF panel plots. Contour plots for each zone gave an excellent indication of the distribution of contaminants at the site. In the upper four zones the most significant feature is the heavily contaminated zone in the northwest portion of the site, just to the east of the substation. The general trend of the contaminated region is still, however, from the northwest to the southeast through the central part of the site. Relatively high LIF readings were also noted in the region of ML-97 (off the SE corner of the former purifier building) in the upper four zones. The main plume for zone 5 (base of the granular unit) extends from just west of the former purifier building to the southern portion of the site; elevated LIF readings near the southern site boundary indicate that contamination has most likely moved off the site in this zone. Significant hits were only observed at two locations in zone 6 (top of the LCU).

Many of the panel plots showed elevated fluorescence intensity values within the upper cohesive unit and within the upper and lower portions of the granular unit. Examination of the LIF panel plots revealed that elevated fluorescence intensity levels commonly occurred in the two to four feet of sandy soil immediately overlying the top of the LCU indicating a pooling of DNAPL on the LCU. When LIF measurements were taken in the top of the LCU, the fluorescence intensity reading typically dropped to near zero. This indicates that the LCU is tending to retard the downward migration of the DNAPL contamination at these locations.

Although the BVWST borehole B-1 indicates some fairly significant contamination in zone 3 in the northwest part of the site, the CPT LIF data suggest that this area of the site is more heavily contaminated than is indicated by the BVWST data alone. Moreover, the CPT LIF results in this region tend to confirm the hits in the deep zone by the IMA and the passive gas naphthalene tests - the deep zone for these tests approximately corresponds to zone 2. The CPT LIF responses in the southern part of the site agree both with the BVWST data and the IMA and passive soil gas screening data for the deep zone. In addition, the lobe centered at ML-97 in the LIF data is captured very nicely by the deep IMA screening data, which has this lobe centered on ML-9 some 4 feet to the south of ML-97. No evidence of this lobe appears in the shallow IMA data. The passive soil gas data for the shallow and deep zones, especially for naphthalene, shows this feature as well. Only shallow GC/PID naphthalene shows this feature while no evidence for it appears in any of the CL data. The relatively low but persistent LIF hits at ML-33 on the eastern

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side of the site are not confirmed by any other measurements of the PAH concentration in this region.

When correlated with olfactory/visual or LIF data, the Geoprobe soil conductivity logs could be used to interpret zones of PAH contamination. Zones of heavy coal tar residue contamination showed up as distinctive dips on the conductivity trace. Thus, while the soil conductivity probe data can not be considered stand-alone, it can be used to enhance the detail of the site contamination model between more definitive data locations. Another source of data which should not be overlooked is the olfactory/visual comments from the sample logs. A logarithmic-type scale ranging from zero (essentially no contamination) to six (essentially free product) has been developed which can quite clearly distinguish heavily contaminated zones from lightly or non-contaminated zones. These type of plots have been developed for both the BVWST and MLH descriptions and correlate very well with and provide support for the more quantitative data.

In terms of contaminant screening, the CPT LIF may be considered the most direct qualitative methodology for indicating regions of PAH contamination. The LIF responses have been corroborated by side-by-side sampling with chemical analyses, by correspondence with nearby BVWST logs and indirectly by the soil conductivity logs. The CPT LIF contaminant screening program has indicated the extent of the heavily contaminated zone in the northwestern part of the site near the substation and also highlighted the extent of coal tar residue contamination which is sitting on the LCU.

Phase II quantitative plume delineation efforts were planned and implemented based on the results of the BVWST RI report, contaminant screening data collected in Phase I and Phase II, and the updated site geologic model. The primary technology evaluation function of this part of Phase II was the comparison and assessment of five on-site extraction methods (both SOPT and IT) for PAHs in soil. In terms of the site characterization goal of this project, samples would ordinarily be selected outside the expected plume area followed by moving toward the suspected plume with the intent of using the low quantitation limits of the GC/MSs to map the action limits of the plume. This approach, however, would lead to a large number of ND samples which could not be used for the technology evaluation task. In the end, as a result of lower than expected sample analysis throughput and the realization that very few samples would be available for the extraction method comparison task, modifications were made to the sampling and analysis plan so that only samples judged to be contaminated were sent to all five extraction methods for quantitative analysis. Consequently, only the eastern edge of the plume was well defined by the quantitative methodologies.

Soil core samples for this effort were collected with minimal subsurface disturbance using a Geoprobe system. A total of 127 samples were run through one or more of the five extraction methods and analyzed by one of three identical GC/MS systems. The extraction methods used

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included three organic solvent-based methods (sonication, microscale, microwave-enhanced extraction) plus thermal desorption and SFE. Sonication extraction is a SOPT while all the others are ITs. To acquire matrix-specific MDLs, a soil sample was spiked with 10 mg/kg of each of the sixteen targeted PAHs, homogenized and split into 35 subsamples. Analyses for each of the 16 analytes were run seven times (six for SFE) using each of the five extraction methods. In addition, a series of percent recovery tests were carried out to examine the relative extraction efficiency of the different methods. These data were generated by testing five or six samples in duplicate (two for microwave) spiked with 50 mg/kg of each of the PAH compounds.

The evaluation of the on-site extraction methods was complicated by the fact that the data set being used was unbalanced (i.e., unequal representation in the data set between soil types, analytes or extraction methods), there were still a significant number of ND results in the data set and two basic soil type matrices (sandy and clayey soils) were present. Given these limitations, the method bias comparisons clearly indicate that the thermal extraction efficiency is less than (lower mean, negative bias) the sonication extraction efficiency which is less than the microwave extraction efficiency (higher mean, positive bias). The microscale and SFE extraction methods generally give intermediate results. There is no definitive indication that any extraction method is more precise overall, although there is a tendency for the method precision for the thermal and microscale extraction methods to be significantly less than the precision for the sonication method on the basis of all the available data. On the basis of all the available data, the clayey soil analytical results show greater variation than the sandy soil results indicating greater precision with sandy samples for all but the thermal extraction method. The 38 subsets of this data, whereby all methods gave a greater than ND determination, indicate that only the microwave and SFE methods show greater variation with clayey than with sandy soils, while the other methods show no variation differences between soil types.

The MDL study performed on site indicates that the MDL is greater than 1.0 mg/kg for all extraction methods except the microscale method. The relative errors based on the field data generally indicate poorer analytical precision than is indicated by the MDL data. The MDL study data sets are small and were collected over a relatively short time frame during which the on-site procedures were being established. The MDL data indicate that the microwave method shows a negative bias while the thermal method shows a large positive bias; these results conflict with biases indicated by the field data for both the thermal and microwave methods.

In summary, within the inherent limitations of these analyses, we found low thermal extraction results with high relative error and high microwave extraction results with low relative error, while the absolute value of the bias for both of these methods appears to decrease with increasing analyte molecular weight. A significant finding of the study was the potential for inconsistencies in procedures and results to arise, even within the strict adherence to SW-846 methods.

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Due to the areal distribution of the sampling locations, as noted above, and the fact that heavily contaminated samples were systematically excluded from quantitative PAH analysis, the quantitative data generated on site adds little to further the development of the site contamination model. This data does, however, confirm the eastern edge of the contaminated area as defined by the Phase I and Phase II screening technologies and also correlates well, in places, with the quantitative BVWST data. A key issue is that while the screening tools have been able to define the areas of contamination much more clearly, they do so only in a qualitative sense. Quantitative data like the MLH data presented in this report are required for regulatory decision making.

In terms of analysis of the limited number of groundwater samples collected, it may be noted that PAH compounds were detected above the IDNR standards in every one of the groundwater samples analyzed. Due to the distance of the sampling locations from BVWST monitoring wells and the different groundwater sampling collection procedures, direct comparison of these results with the BVWST results is not possible. It is apparent, however, that the concentrations given in the central part of the plume are significantly higher than any concentrations recorded by BVWST.

5.4 Data Integration

EarthVision was used for integration and visualization of the data on a daily basis and it was extremely useful in assessing the status of the site geological and contamination models and in planning the next day's sampling locations. Data handling, analysis and visualization could be improved with a more flexible database arrangement and also with the inclusion of geostatistical capabilities such as kriging and quantitative uncertainty analysis.

5.5 Lessons Learned

In making the conclusions noted above and detailing the lessons learned from this investigation, it must be kept in mind that a primary goal of the Ames ESC project at Marshalltown was to compare and evaluate SOPT and ITs; the goal was not to carry out a full ESC style characterization of the site. In this context, in terms of geological characterization technologies, a lesson learned from this investigation is that while geophysical survey techniques are an integral part of the ESC process, all techniques may not be appropriate for all sites. In this case, the difficult stratigraphic conditions and significant cultural interferences, along with, in some cases poor data collection and analysis/reporting procedures, led to significant error and uncertainty in the geophysical survey results and severely limited their useful application. The potential limitations of the methods being proposed need to be carefully considered on a site

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specific basis. Future endeavors also need to insist on receiving fully interpreted data from the contractors in terms of stratigraphy and depths to major geologic contacts.

Information regarding the location of the phreatic surface and hydraulic heads and gradients was lacking in this investigation and tends to, in general, play somewhat of a secondary role in the ESC process as currently defined. An understanding of the site groundwater conditions is essential to the development of a realistic conceptual model of contaminant transport and thus to the preliminary evaluation of potential remedial schemes. Part of the difficulty is that traditional regulatory-accepted groundwater sampling requires monitoring wells while the selection of monitoring well locations is one of the end products of an ESC investigation. Progress in this regard could be made with the further development and regulatory acceptance of groundwater data from samples collected using direct push and probing tools. There is still the difficulty, however, of assessing the temporal variations of groundwater conditions. An ESC investigation, by design, is meant to be initiated and completed in the shortest possible time; this approach is not conducive to assessing the temporal variation of groundwater conditions. The use of temporary, direct-push-technology-installed wells for continued collection of data during the analysis/reporting stage is one potential alternative which could be built into ESC procedures.

The application, versatility and the high quality of data from direct push technologies was demonstrated and proven at this site. The SCAPS CPT demonstrated the reliability and efficiency of both the stratigraphic logging capabilities and LIF sensing capabilities in developing the site stratigraphic model and delineating areas of PAH contamination. The capabilities of the Geoprobe soil conductivity system were also proven. It had more maneuverability than the CPT and was also more operationally efficient. With proper calibration, it can be reliably used to fill in stratigraphic data between two locations with known stratigraphic profiles. In addition, again with proper calibration and verification, it can be used to enhance the site contamination model. Both direct push technologies have the capability to provide much more detailed stratigraphic information than conventional auger boring, which is important when considering contaminant fate and transport. On the down side, both direct push technologies had difficulties detecting weathered bedrock, and unexpected bedrock or large gravel/cobbles resulted in broken probes. More rugged equipment for getting through upper heterogeneous fill layers, which could be present on many developed sites, could be considered.

There was a great deal of sampling in the east and northeast areas of the site. Once it was established that contamination in this area was low or nonexistent, this sampling activity should have been shifted west to where higher levels of contamination were detected. The eastern boundary of the contaminant plume was defined with relatively high accuracy, however, there is a large uncertainty regarding the location of the western boundary of the plume. This is due in large part to several large buildings in the southwest corner of the site; however, it may have been possible to obtain several more samples at selected locations adjacent to these buildings. Probably the most useful additional data could be obtained from sampling just south of the site

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adjacent to the railroad tracks, if this were possible. As one of the primary objectives of the Ames Laboratory ESC project was to collect enough data to allow direct comparison of SOPT and ITs, this does not impact on the success of project. It would have been extremely useful, however, to have quantitatively assessed the level of uncertainty in both the stratigraphic and contaminant distribution models on a daily basis with the use of geostatistical tools.

Lastly, this study indicates the potential for significant variation of chemical analysis results for PAHs in soils, even when following regulatory approved SW-846 procedures. The uncertainty and potential variability associated with soil matrix effects, sample selection, preparation and extraction procedures far outweigh inaccuracies in the chemical analysis methodologies themselves. The Phase I and Phase II screening results, including the olfactory/visual data, give a far better picture of the distribution and extent of contamination than the quantitative analysis results. Technologies such as CPT LIF give a continuous profile of contamination at a specific location and the results are largely operator independent. The promotion of these technologies to regulatory acceptance would fit the goals of this project in developing better, safer, faster and cheaper site characterization technologies. The quantitative analysis technologies could perhaps be limited to confirmation of the ranges of contamination measured by screening type analyses. The ranges could tie into both action levels and the evaluation/selection of potential remedial schemes.

6.0 ACKNOWLEDGMENTS

The value of this demonstration has been enhanced by the efforts of many people. As principal investigator (PI) I take full responsibility for any of its failures and declare that its successes are owed exclusively to the following people.

First are the members of the Ames Laboratory ESC Team: Dave Wonder, hydrogeologist, whose experience and judgment was simply invaluable, Connie Bailey, communications specialist, whose insights on how to meet stakeholder needs are unique to the DOE complex, Joel Prail, computer engineer, whose willingness to explore new ways to use data management tools was vital and finally Beth Weiser, information & logistics coordinator, whose creativity, insight and energy were so effective and infectious. Jo Holland and Kathy Petersen, project secretaries, performed beautifully under conditions often characterized by uncertainty and urgency.

Support from Assistant Professor Bruce Kjartanson of the Civil Engineering Department at Iowa State University ranged from being the major author of this report to field and off-site analysis of the direct push technologies. His insights were greatly valued as were those of his PhD student Greg Stenback, whose statistical expertise was crucial for this report. Greg Junk served as analytical advisor to the PI and his expertise was very helpful in planning for the analytical program of this demonstration. A debt of gratitude goes to Bill Haas for several reasons but most importantly for identifying McLaren/Hart as a company having experience with many aspects of ESC in the private sector.

Steve Gelb, national director of field analytical services for McLaren/Hart, offered critical guidance and generous support on project strategies as well as the implementation of the field sampling and analysis program. Another major contributor was Johanshir Golchin, environmental engineer of the Iowa Department of Natural Resources, who took an active, personal interest in the implementation of this demonstration. Without his generous assistance our schedule would not have been met. Dean Hargens of IES Industries was a model of a site manager willing to try something new that could result in significant savings in the characterization the FMGP sites currently owned by IES. He and his staff provided effective and timely support to for the myriad needs of an ESC demonstration with its new ways of doing business.

Tom Noble and Jim Corones provided an opportunity for this PI to lead the project on very little evidence of his ability to do so. Such faith and courage is often absent in a program and nearly always goes unrecognized. I trust that this acknowledgment helps in a small way to repay their extraordinary support.

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Finally, none of this work could have occurred without the vision and unwavering support of Caroline Purdy, DOE headquarters program manager. Her management style serves as a model for all to emulate and her considerable efforts are cheerfully and gratefully acknowledged.

Ames Laboratory is operated for the U.S.-DOE by Iowa State University under Contract No. W-7405-ENG-82 and is a member of ISU's Institute for Physical Research and Technology. This report was prepared as a deliverable on the project "Ames Laboratory Expedited Site Characterization Demonstrations," Technical Task Plan CH1-3-10-05, as part of the Characterization, Monitoring, and Technology Crosscutting Program in the OTD within the DOE's EM program.

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**APPENDIX A: STRATIGRAPHIC LOGS FOR BOREHOLES HSA-1 AND
 HSA-2**



FIELD BOREHOLE LOG

BOREHOLE No.

HSA-1

PROJECT NAME: MARSHALLTOWN FMGP ESC
LOCATION: MARSHALLTOWN, IA
DRILLING CO.: LAYNE-WESTERN
DRILLING METHOD: HOLLOW-STEM AUGER
DRILLING PARTY: C. MOORE & L. PORTER
GEOLOGIST: D. WONDER

DATE COMPLETED: 04/01/94
TOTAL DEPTH: 16 FEET
GROUND ELEV.: 885.29 FT. ASL
LOCATION: 931.75E, 560.57N
(local)
SHEET: 1 **OF:** 1

DEPTH (ft.)	RECOVERY	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	WELL CONSTRUCTION
0.0 5.0 10.0 15.0 20.0 25.0		<p>SILTY CLAY: Dk. brown, plastic, silty clay w/ coal fragments; firm; dry.</p> <p>.....</p> <p>SILTY CLAY: Yellowish-brown, firm, silty clay; dry.</p> <p>.....</p> <p>CLAYEY SILT: Brown, soft, clayey silt w/ coarse sand; visibly moist @ 9 ft.</p> <p>.....</p> <p>SAND: Lt. brown to yellow silty to clayey med. grained sand; well sorted; cohesive to granular; moist.</p> <p>.....</p> <p>SILTY SAND: Med. grained silty sand grading to gravelly clayey sand; gravel is rounded to angular, fluvial in origin; saturated.</p>		<p>Flush cover</p> <p>Med. granular bentonite</p> <p>2" I.D. Sch. 40 PVC Casing (no screen)</p> <p>Borehole Diam. ~10"</p>



FIELD BOREHOLE LOG

BOREHOLE No.

HSA-2

PROJECT NAME: MARSHALLTOWN FMGP ESC
 LOCATION: MARSHALLTOWN, IA
 DRILLING CO.: LAYNE-WESTERN
 DRILLING METHOD: HOLLOW-STEM AUGER
 DRILLING PARTY: C. MOORE & L. PORTER
 GEOLOGIST: D. WONDER

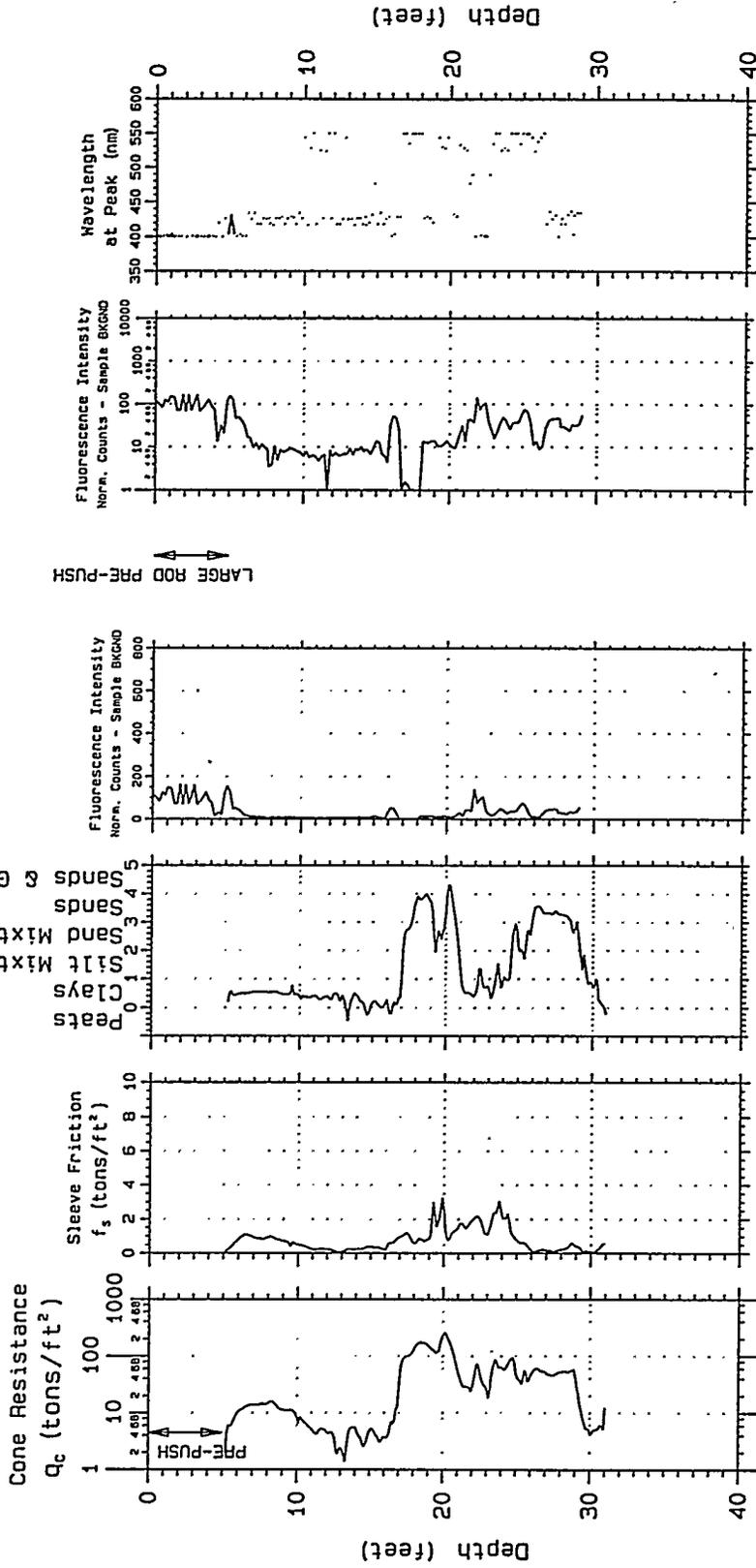
DATE COMPLETED: 04/01/94
 TOTAL DEPTH: 45 FEET
 GROUND ELEV.: 883 FT. ASL (est.)
 LOCATION: 314E, 382N (est.)
 (local)
 SHEET: 2 OF: 2

DEPTH (ft.)	RECOVERY	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	WELL CONSTRUCTION
25.0 30.0 35.0 40.0 45.0 50.0	NO CORES TAKEN 29-45 FEET	<p>SAND: Yellow-brown, well sorted, fine to med. grained sand; little clay or silt.</p> <p>.....</p> <p>Sand heaving occurred upon removal of 24-29 ft. core. Switched to augering with coring. Augers pulled and bottom plate installed.</p> <p>Auger cuttings indicated sediments below 29 feet were saturated silty sand, fine to med. grained, liquified.</p> <p>Very firm surface with only slight auger chattered encountered at 45 feet. No evidence of cohesive material in auger cuttings.</p>		<p>Filter Sand (Morie Co. #9942)</p> <p>2" I.D. Sch. 40 PVC Casing (no screen)</p> <p>Borehole Diam. ~10"</p>

Ames Expedited Site Characterization - Marshalltown FMGP Site
DRAFT Site Report
October 19, 1995

APPENDIX B: PANEL PLOTS FOR CPT PUSHES

CPT based SOIL CLASSIFICATION

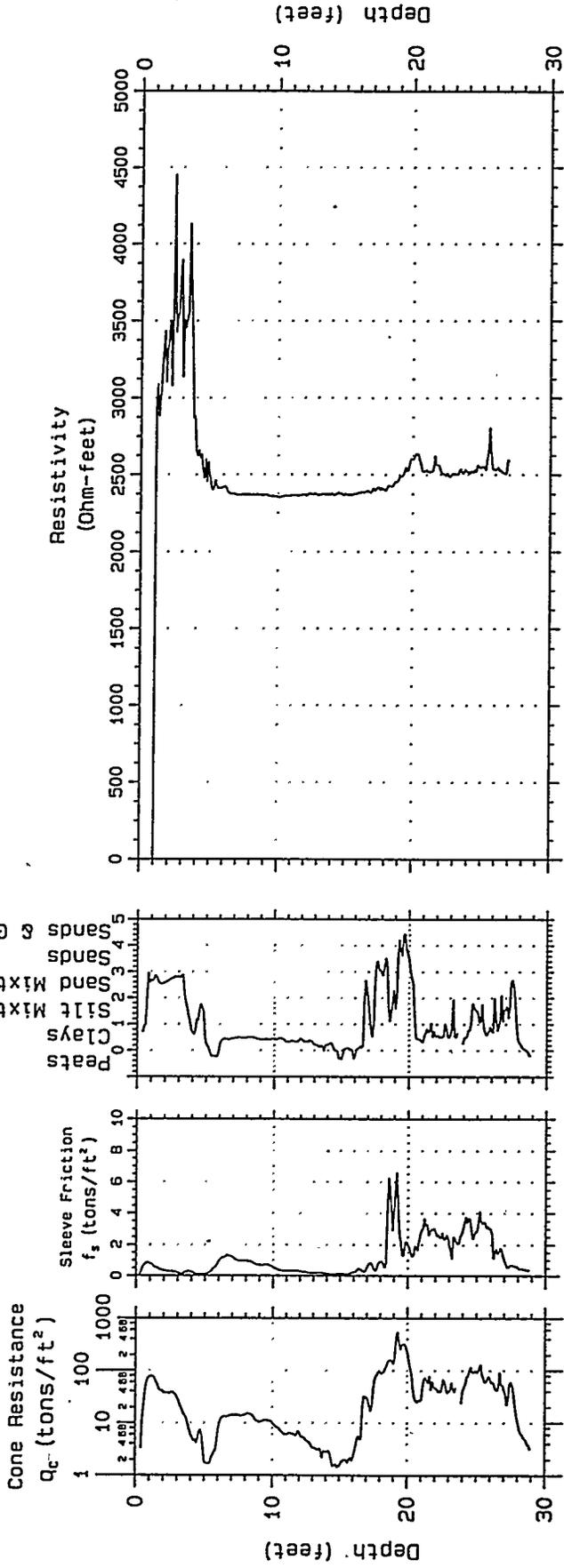


Project: Marshall Town <NEW>

CPT: 01MT28F
 STATE COORDINATES:
 EASTING (ft.) -1
 NORTHING (ft.) -1
 ELEVATION (ft.) 0

Probe date 04-26-1994

CPT based SOIL CLASSIFICATION

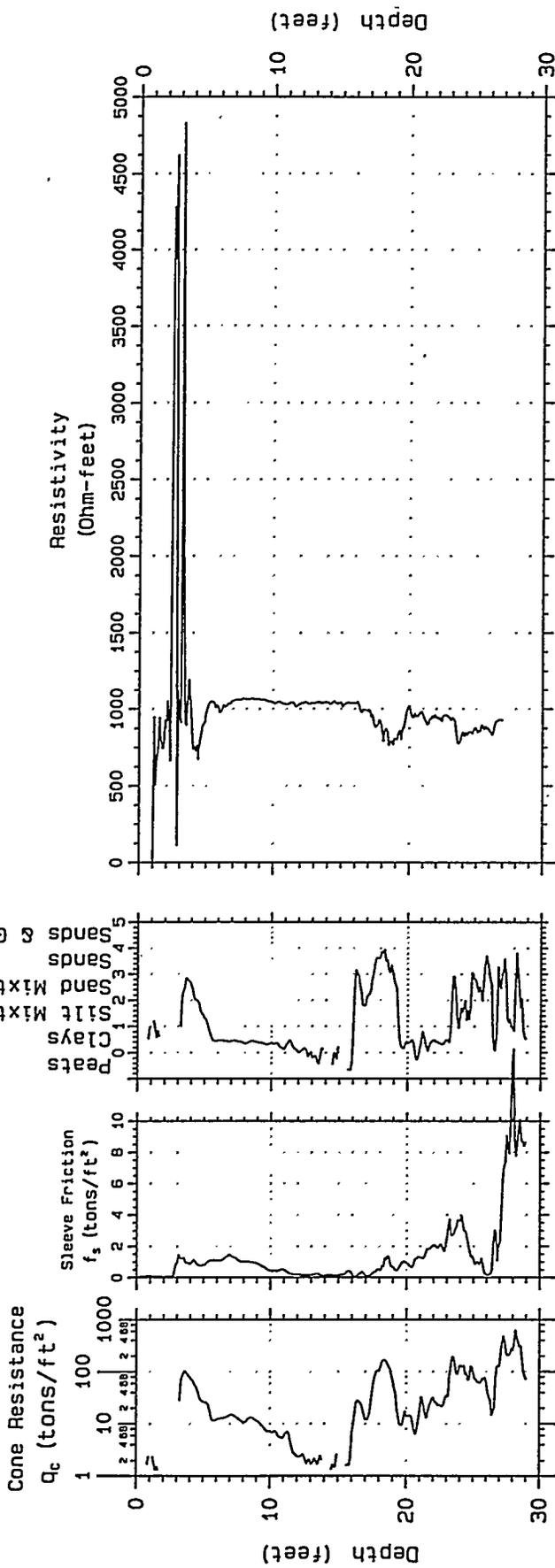


CPT: 2MT28R
 STATE COORDINATES:
 EASTING (ft.) 0
 NORTHING (ft.) 0
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-26-1994

CPT based SOIL CLASSIFICATION

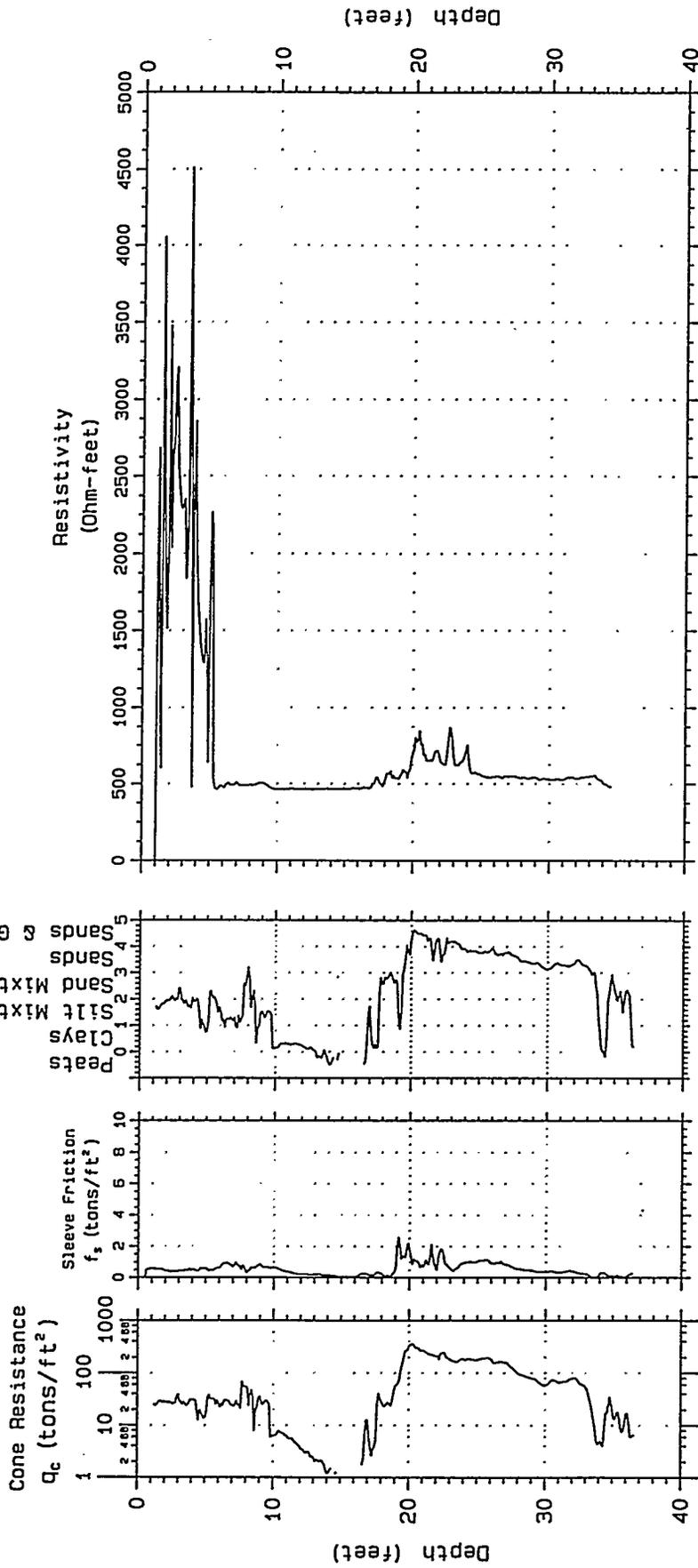


CPT: 3MT30R
 STATE COORDINATES:
 EASTING (ft.) 0
 NORTHING (ft.) 0
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-26-1994

CPT based SOIL CLASSIFICATION

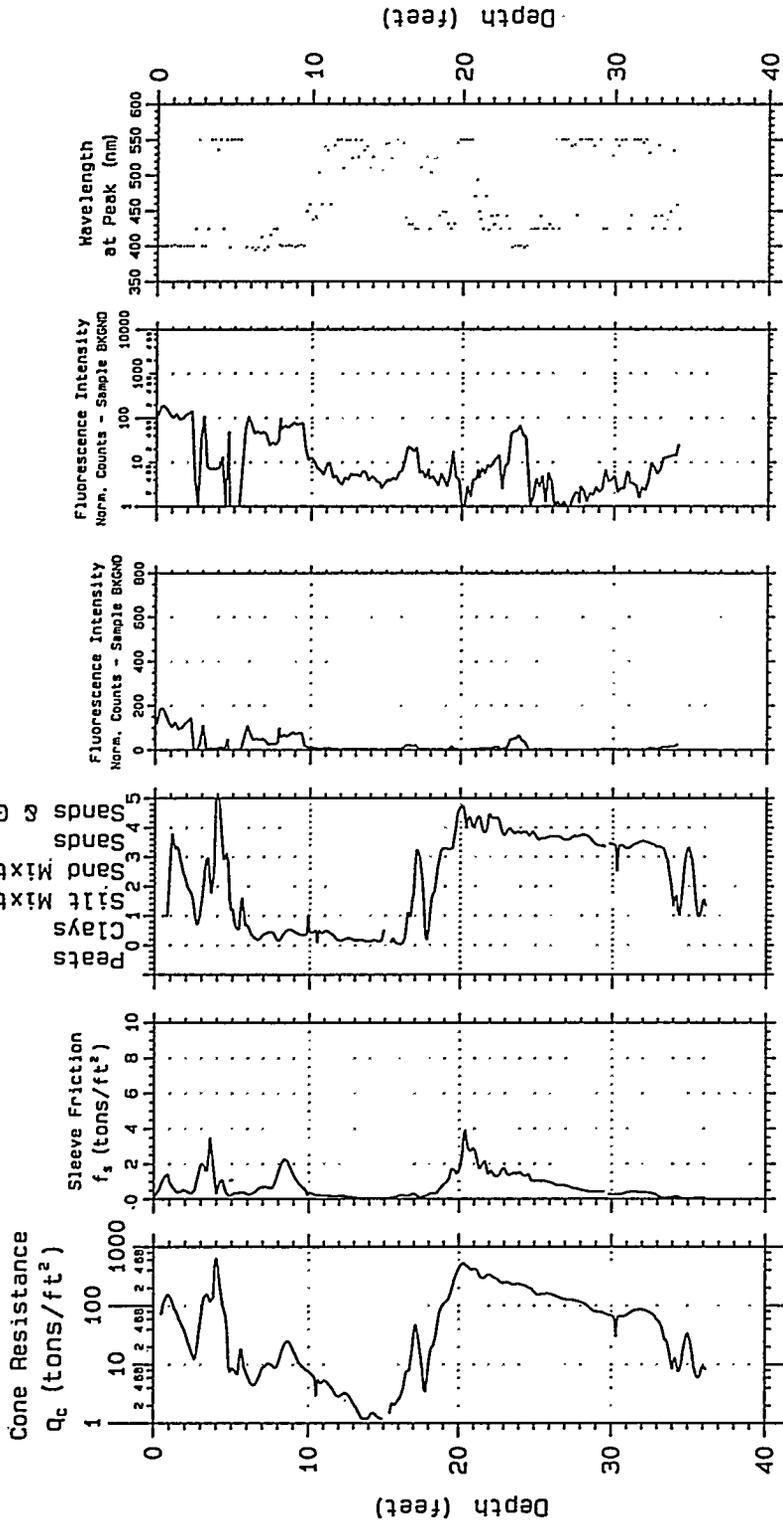


CPT: 4MT32R
 STATE COORDINATES:
 EASTING (ft.) 0
 NORTHING (ft.) 0
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-26-1994

CPT based SOIL CLASSIFICATION



CPT: 5MT32F
STATE COORDINATES:

EASTING (ft.)

-1

NORTHING (ft.)

-1

ELEVATION (ft.)

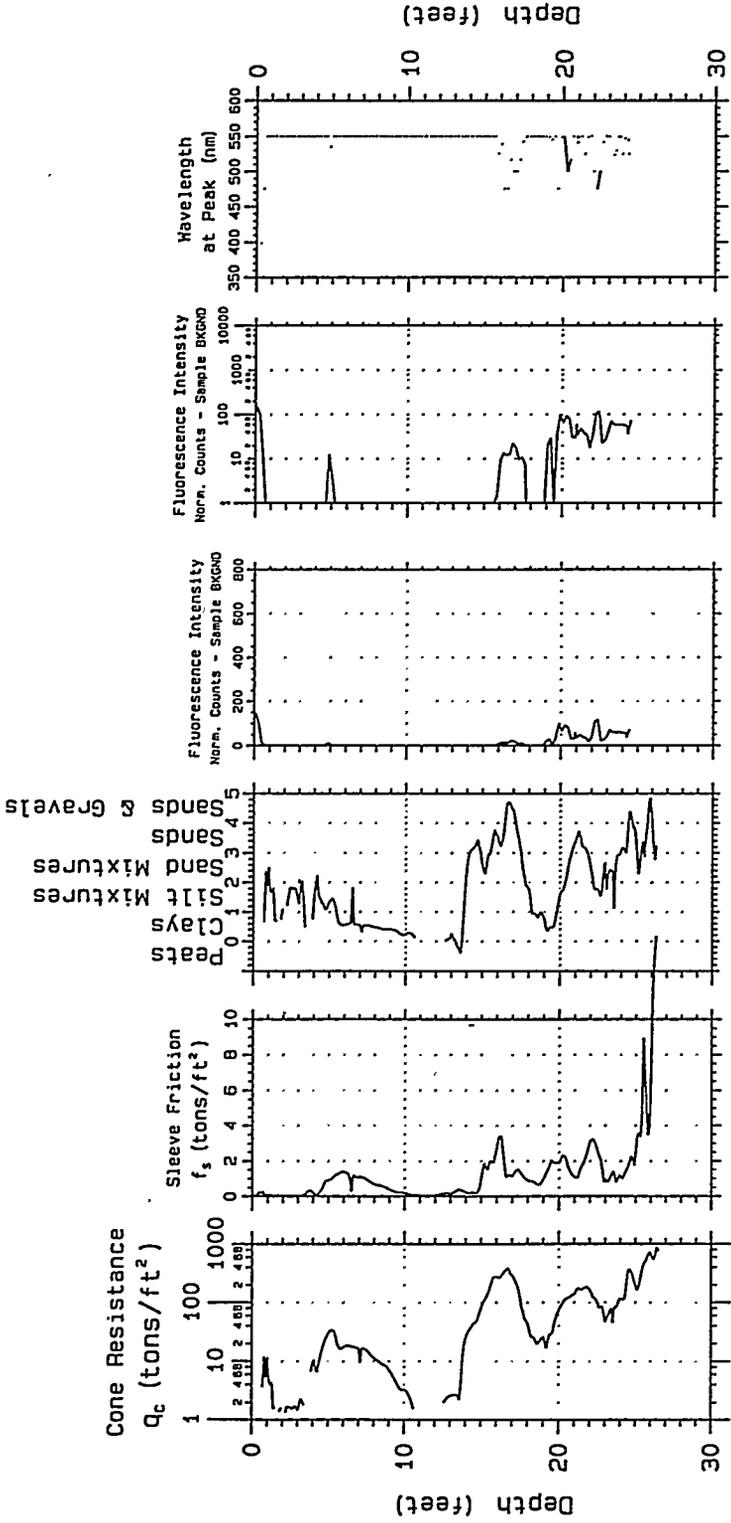
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Project: Marshalltown

Probe date

04-26-1994

CPT based SOIL CLASSIFICATION



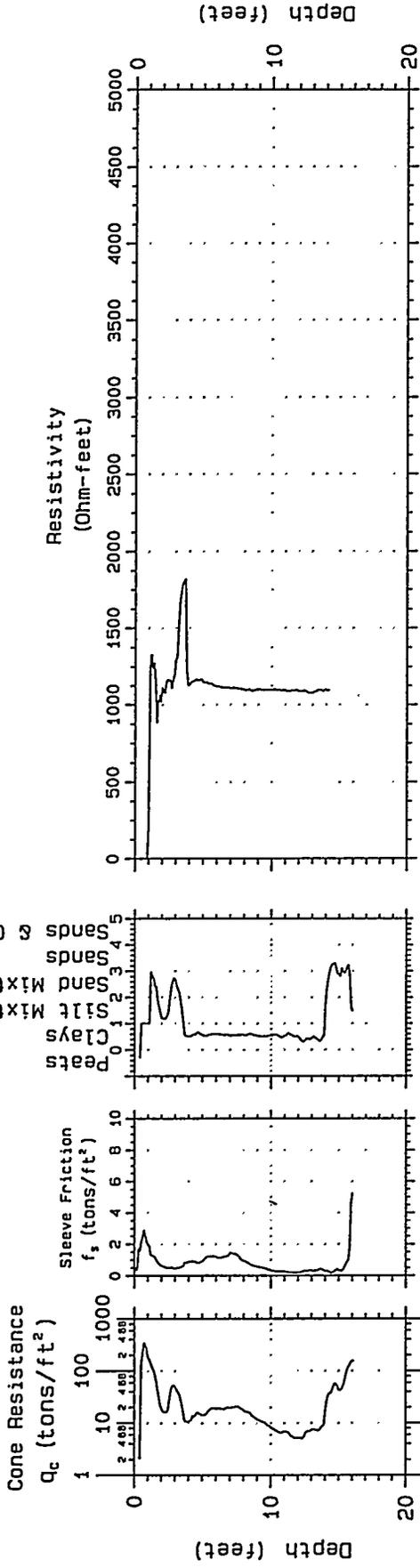
CPT: 6MT33F
 STATE COORDINATES:
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 NORTHING (ft.) -1

ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-26-1994

CPT based SOIL CLASSIFICATION

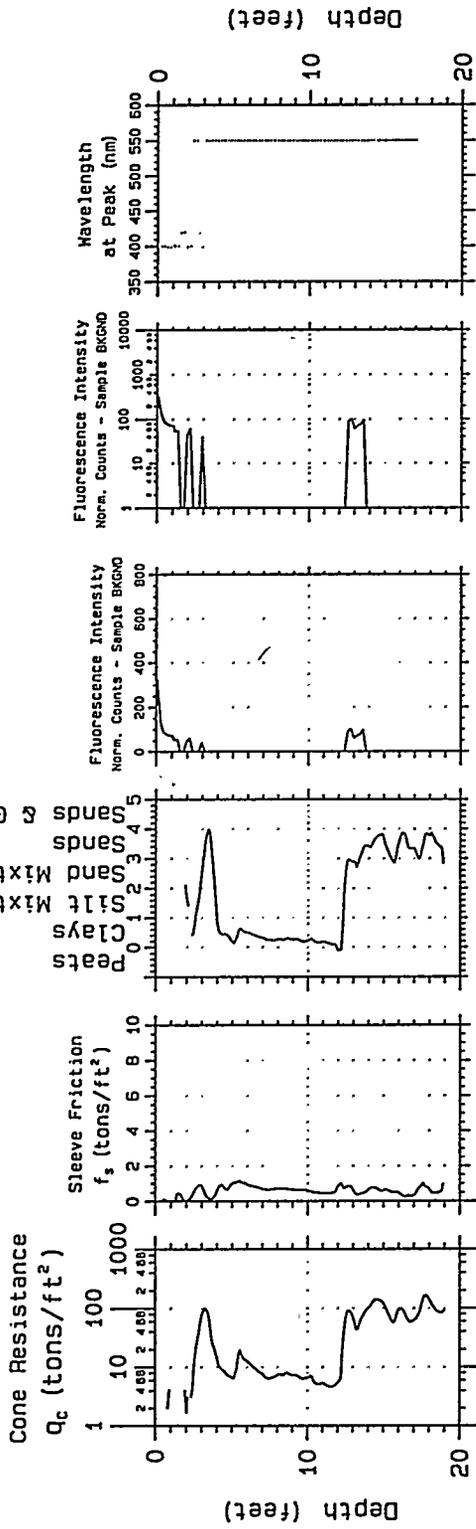


CPT: 7MT33R
 STATE COORDINATES:
 EASTING (ft.) 0
 NORTHING (ft.) 0
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-27-1994

CPT based SOIL CLASSIFICATION

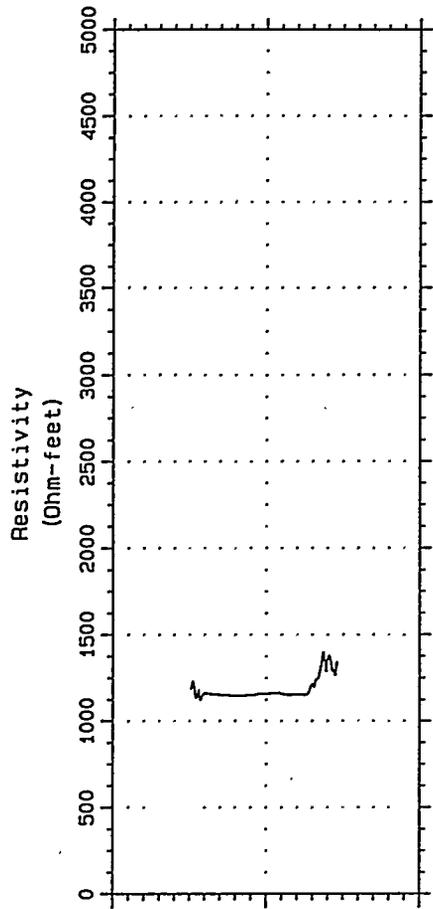
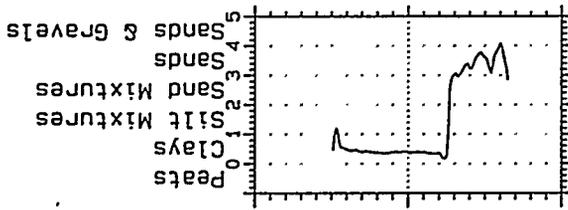
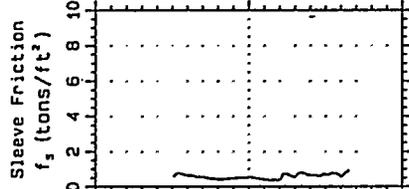
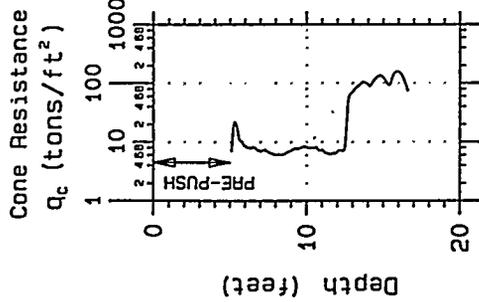


CPT: BMT41F
 STATE COORDINATES:
 EASTING (ft.) -1
 NORTHING (ft.) -1

Project: Marshalltown
 ELEVATION (ft.) 0

Probe date 04-27-1994

CPT based SOIL CLASSIFICATION



CPT: 11MT41R
STATE COORDINATES:

EASTING (ft.) 0

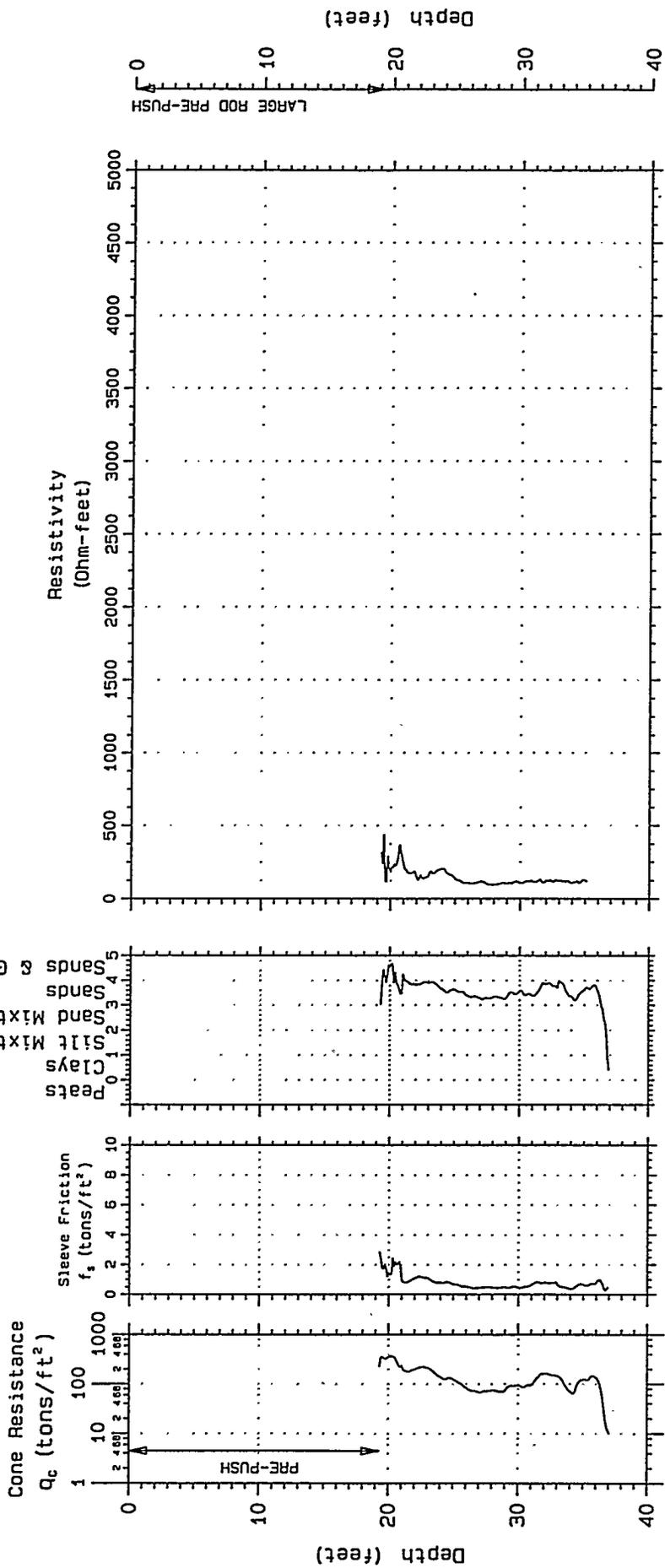
NORTHING (ft.) 0

ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-28-1994

CPT based SOIL CLASSIFICATION

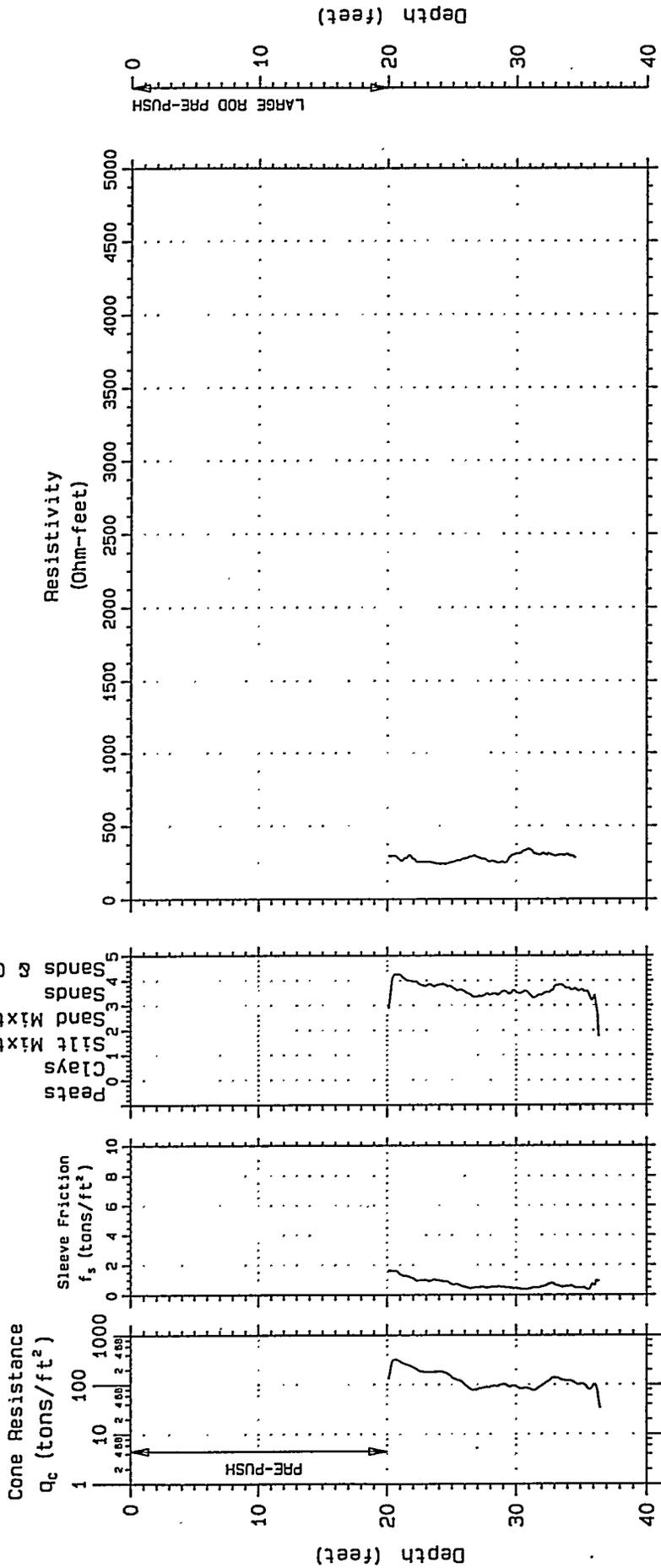


CPT: 13MT41R
 STATE COORDINATES:
 EASTING (ft.) 0
 NORTHING (ft.) 0
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-28-1994

CPT based SOIL CLASSIFICATION

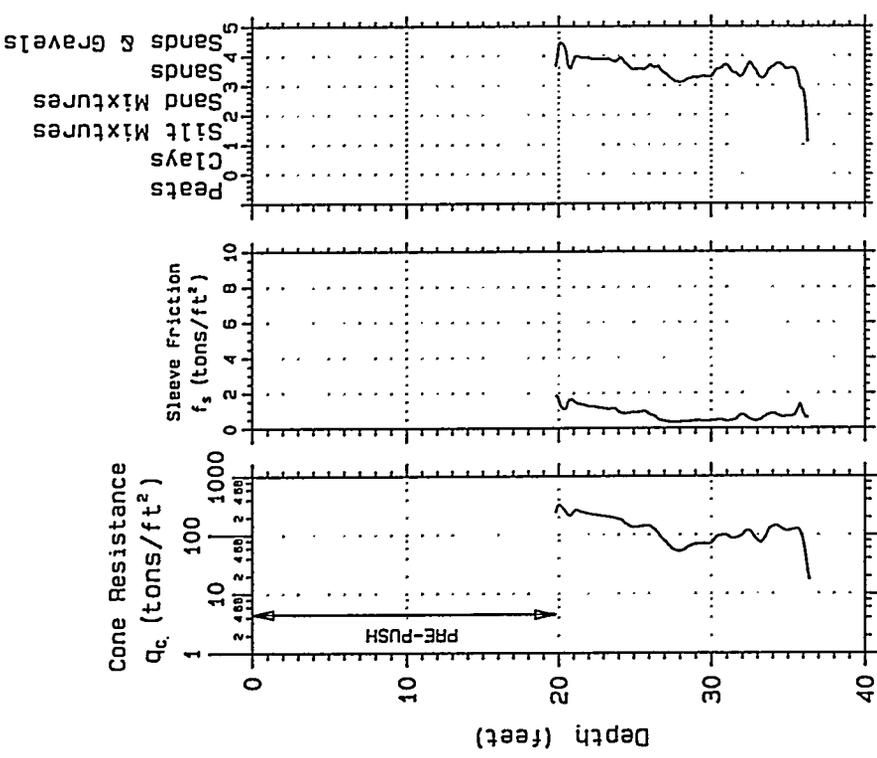


CPT: 15MT47R
 STATE COORDINATES:
 EASTING (ft.) 0
 NORTHING (ft.) 0
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-28-1994

CPT based SOIL CLASSIFICATION



CPT: 17MT49R
STATE COORDINATES:

EASTING (ft.) 0

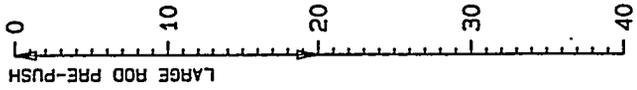
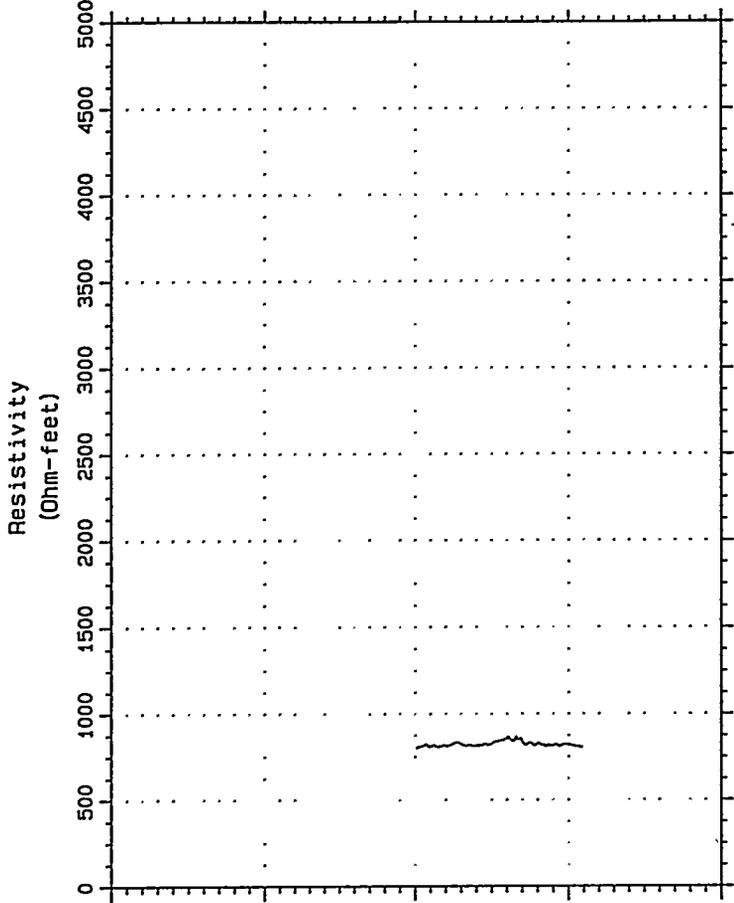
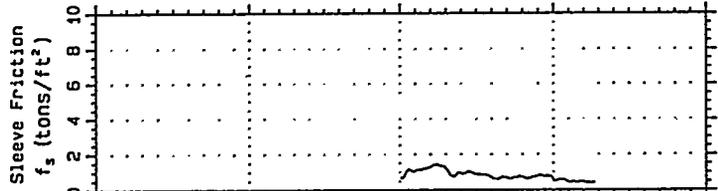
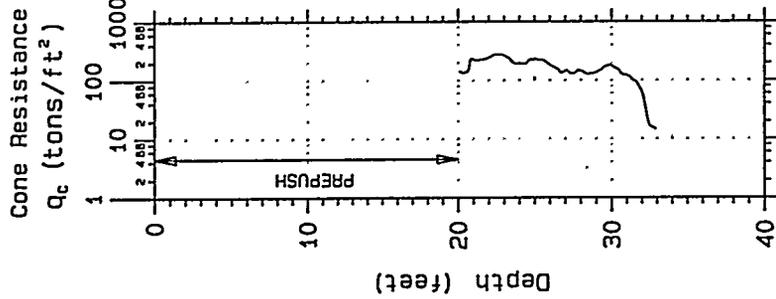
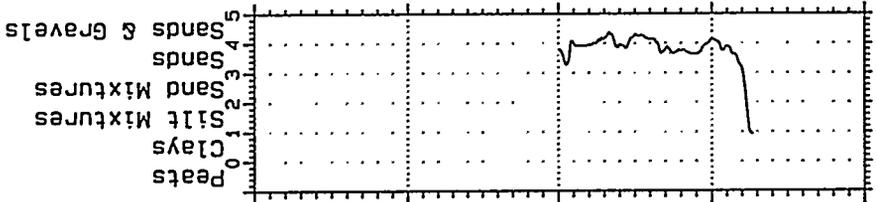
NORTHING (ft.) 0

ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-28-1994

CPT based SOIL CLASSIFICATION

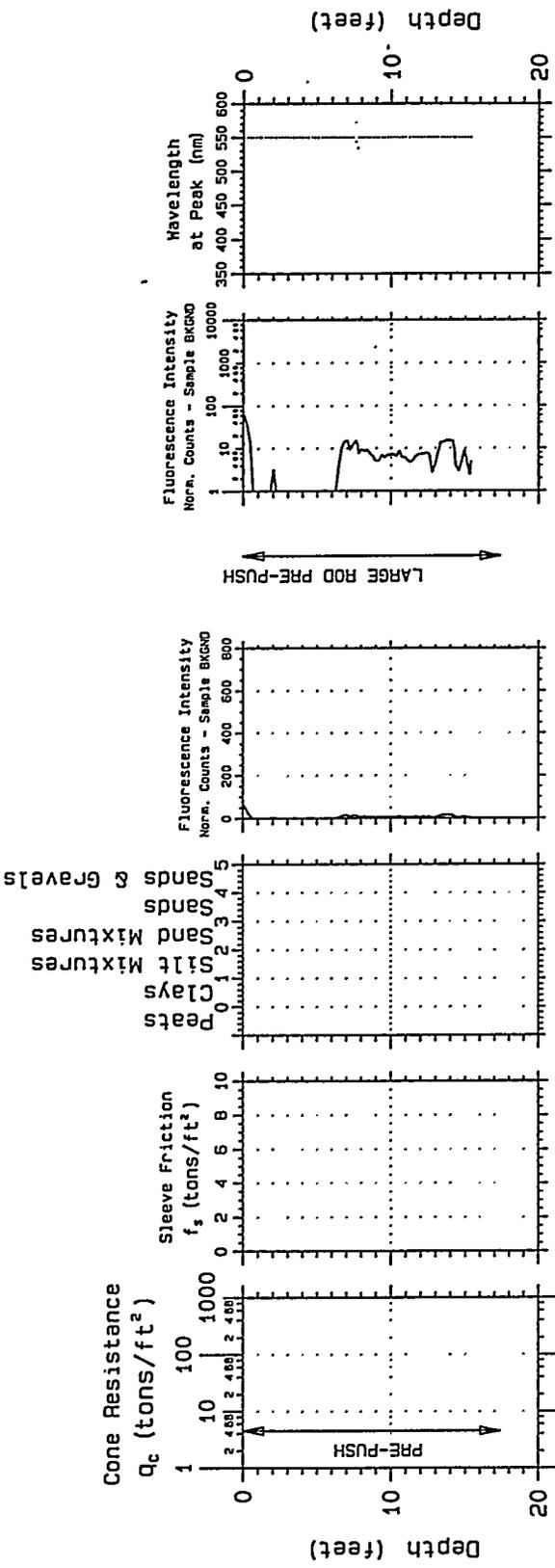


CPT: 26MT51R
 STATE COORDINATES:
 EASTING (ft.) 0
 NORTHING (ft.) 0
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-28-1994

CPT based SOIL CLASSIFICATION

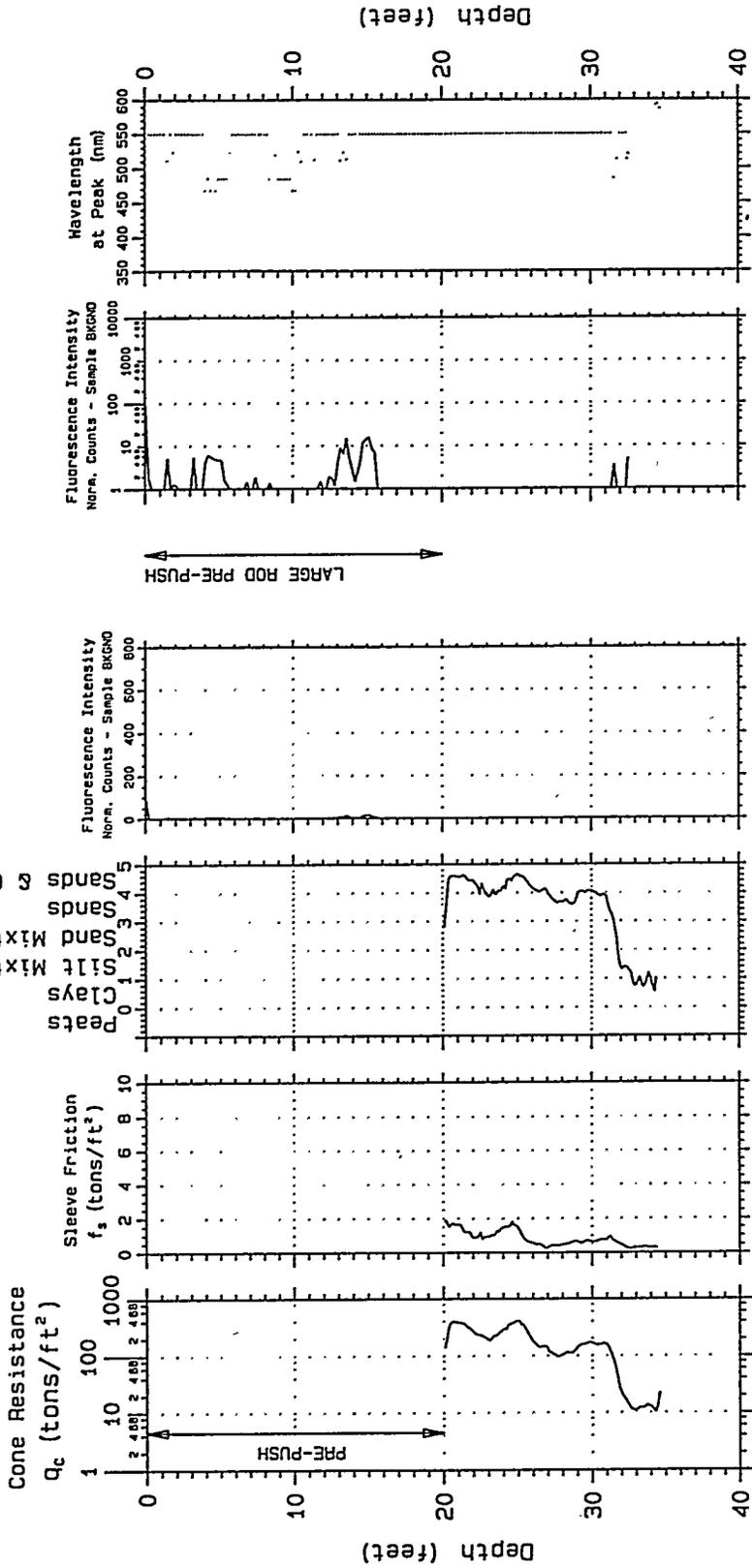


CPT: 28MT53F
 STATE COORDINATES:
 EASTING (ft.) -1
 NORTHING (ft.) -1
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-29-1994

CPT based SOIL CLASSIFICATION



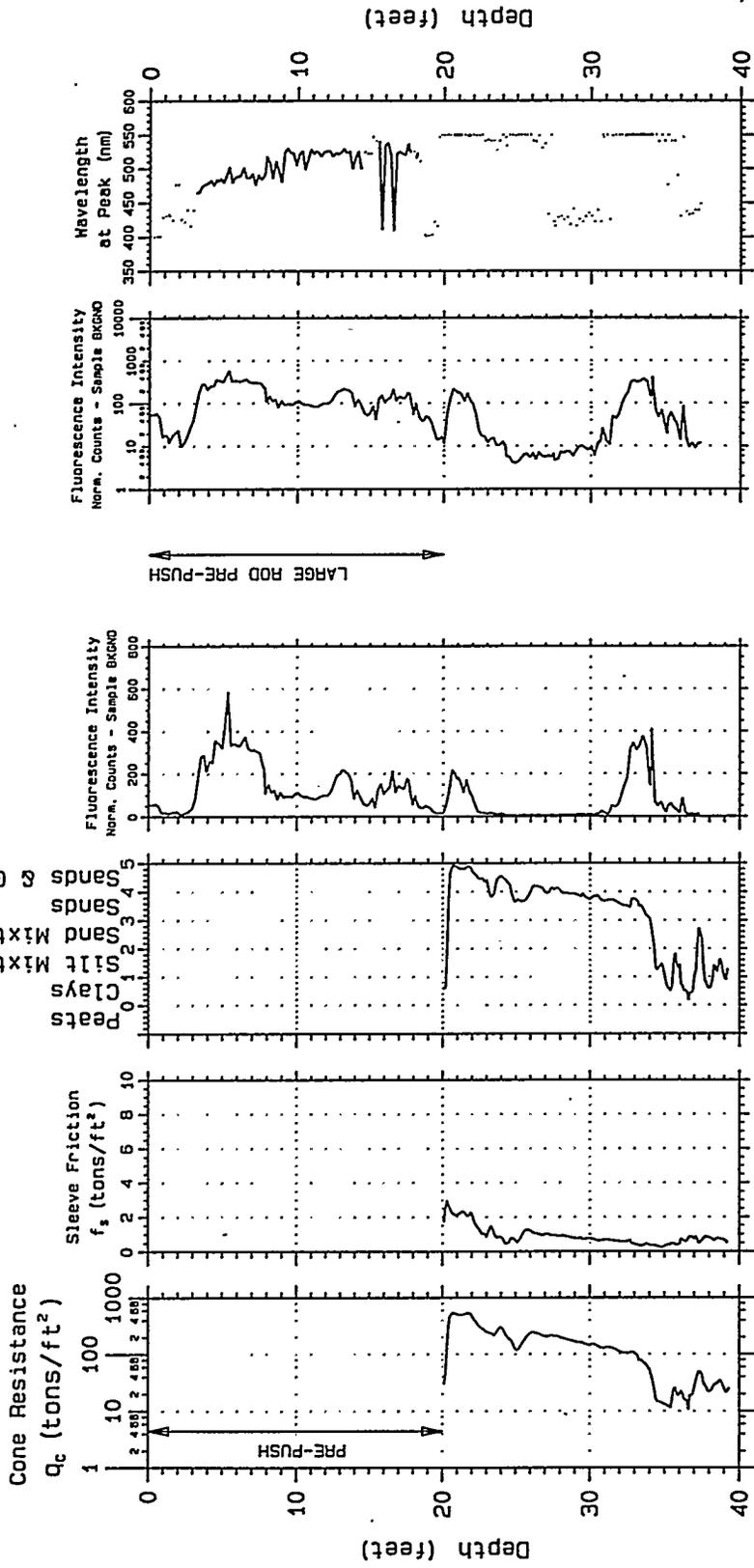
CPT: 30MT53F
 STATE COORDINATES:
 EASTING (ft.) -1
 NORTHING (ft.) -1

ELEVATION (ft.) 0

Project: Marshalltown

Probe date 04-29-1994

CPT based SOIL CLASSIFICATION



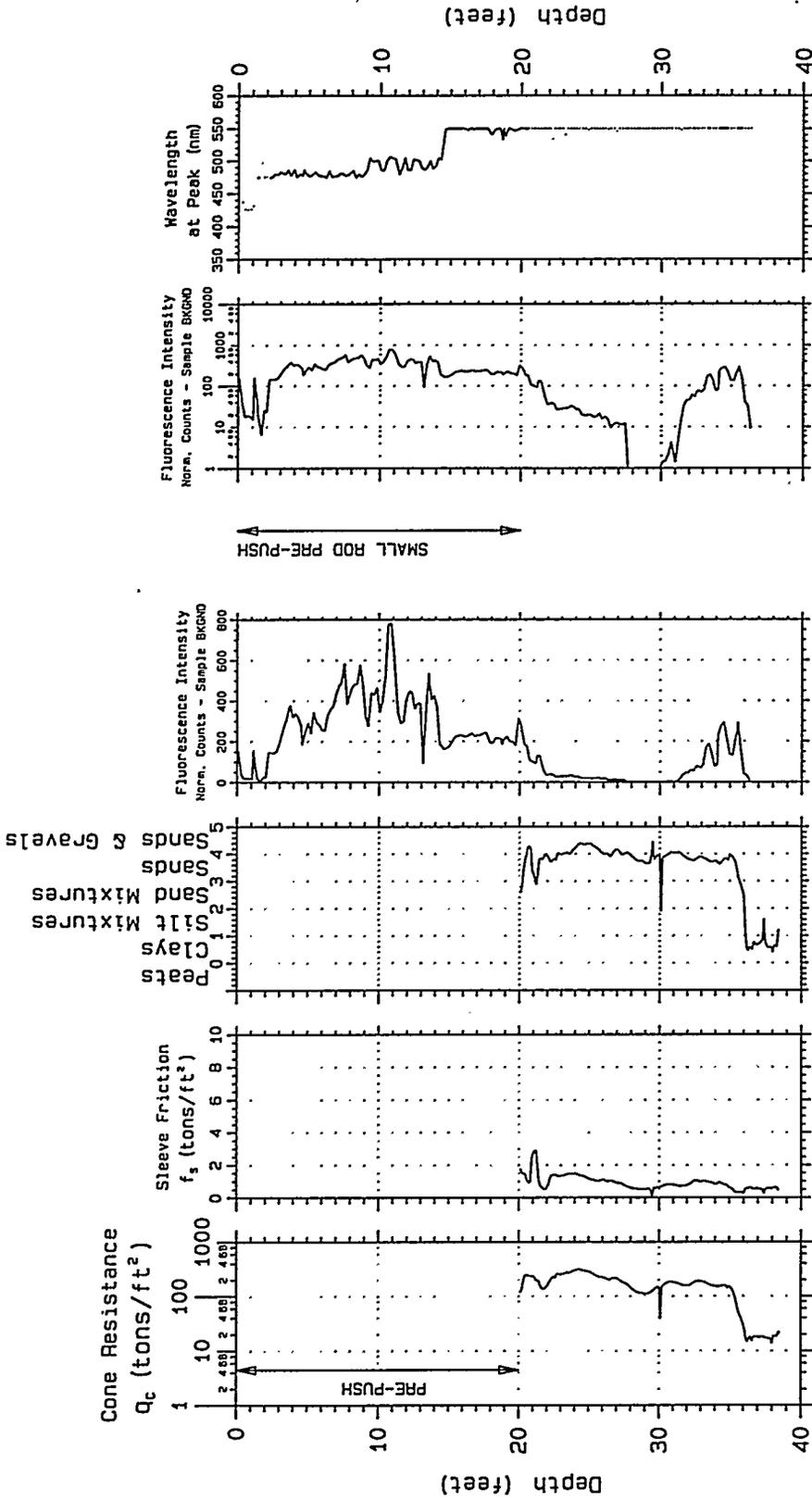
CPT: 33MT60F
 STATE COORDINATES:
 EASTING (ft.)
 -1

NORTHING (ft.)
 -1
 ELEVATION (ft.)
 0

Project: Marshalltown

Probe date 04-29-1994

CPT based SOIL CLASSIFICATION



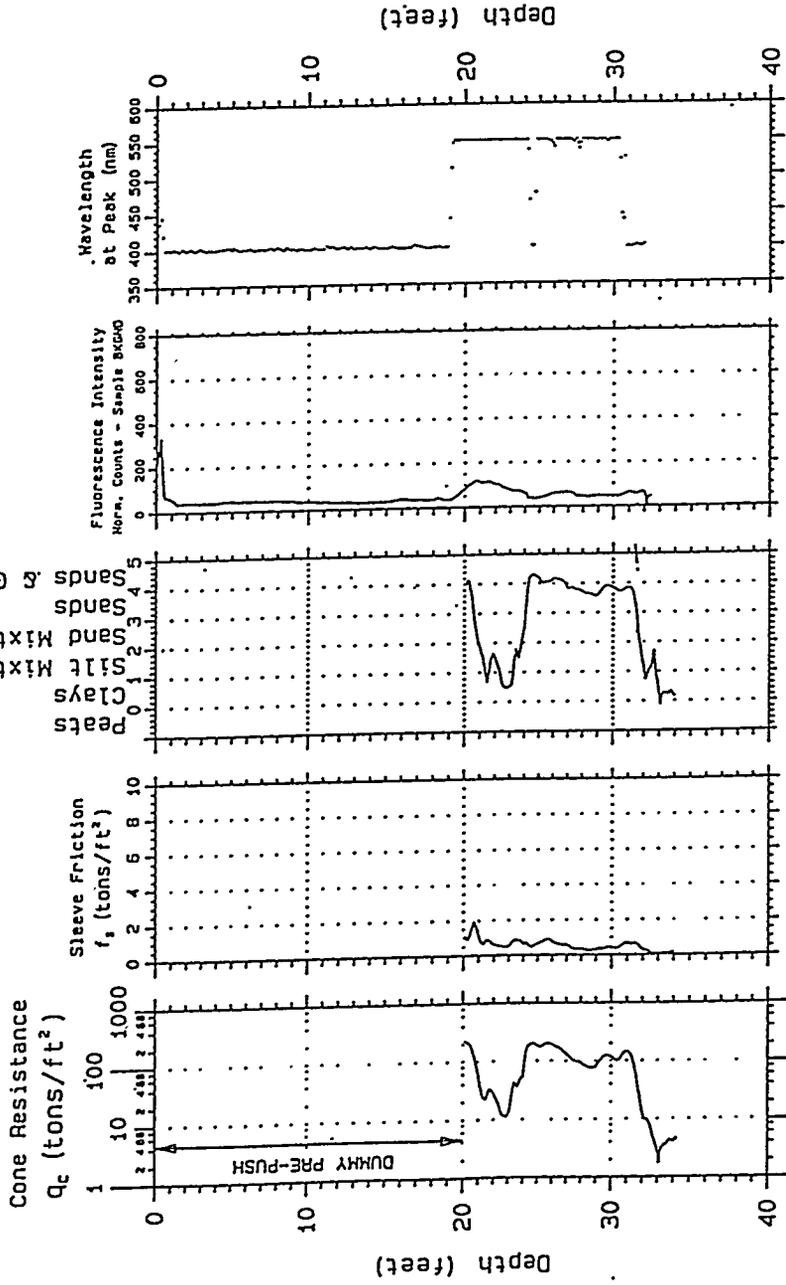
CPT: 35MT61F
 STATE COORDINATES:
 EASTING (ft.)

NORTHING (ft.) ELEVATION (ft.)
 -1 0

Project: Marshalltown

Probe date 04-29-1994

CPT based SOIL CLASSIFICATION

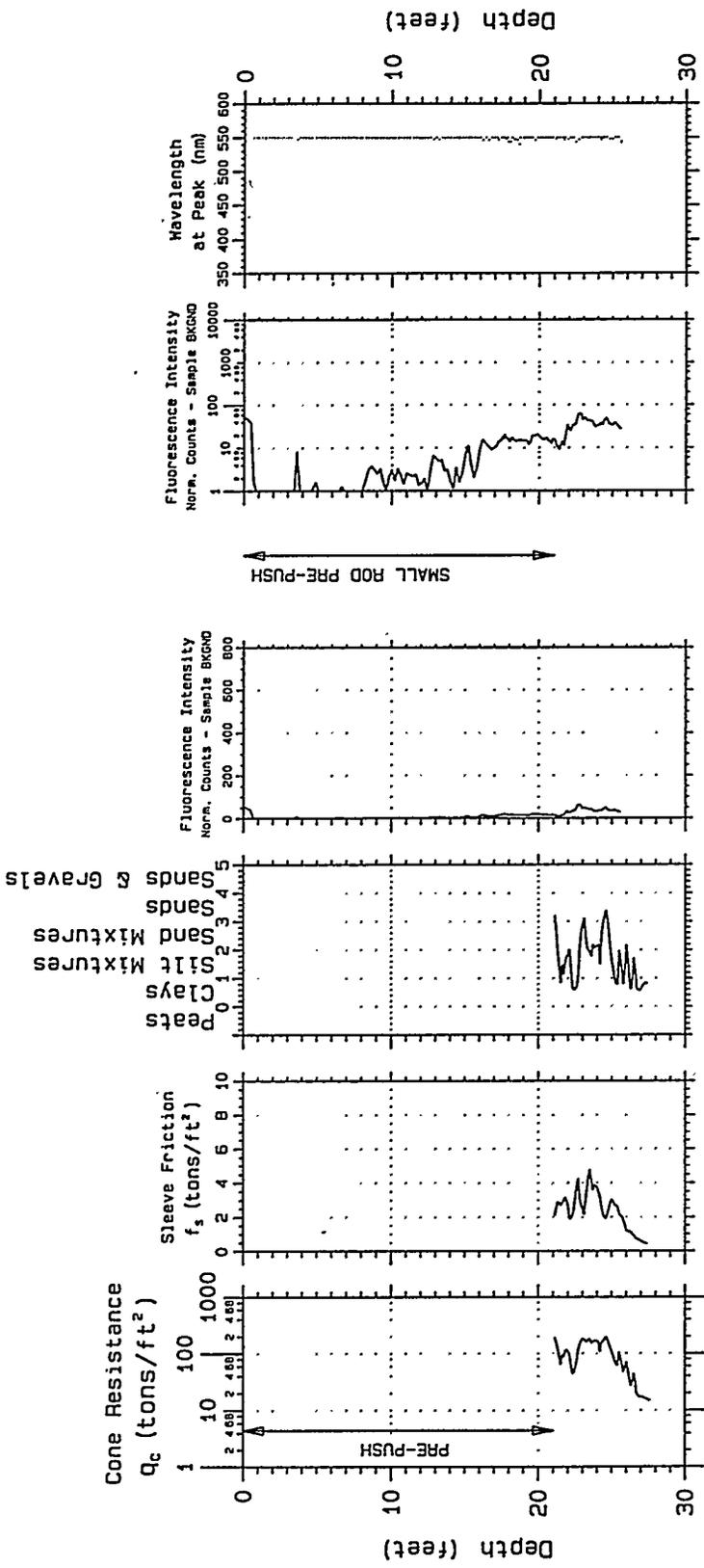


Project: Marshall Town

CPT: 37M164F
STATE COORDINATES:

EASTING (ft.) NORTHING (ft.) ELEVATION (ft.)
-1 -1 -1

CPT based SOIL CLASSIFICATION

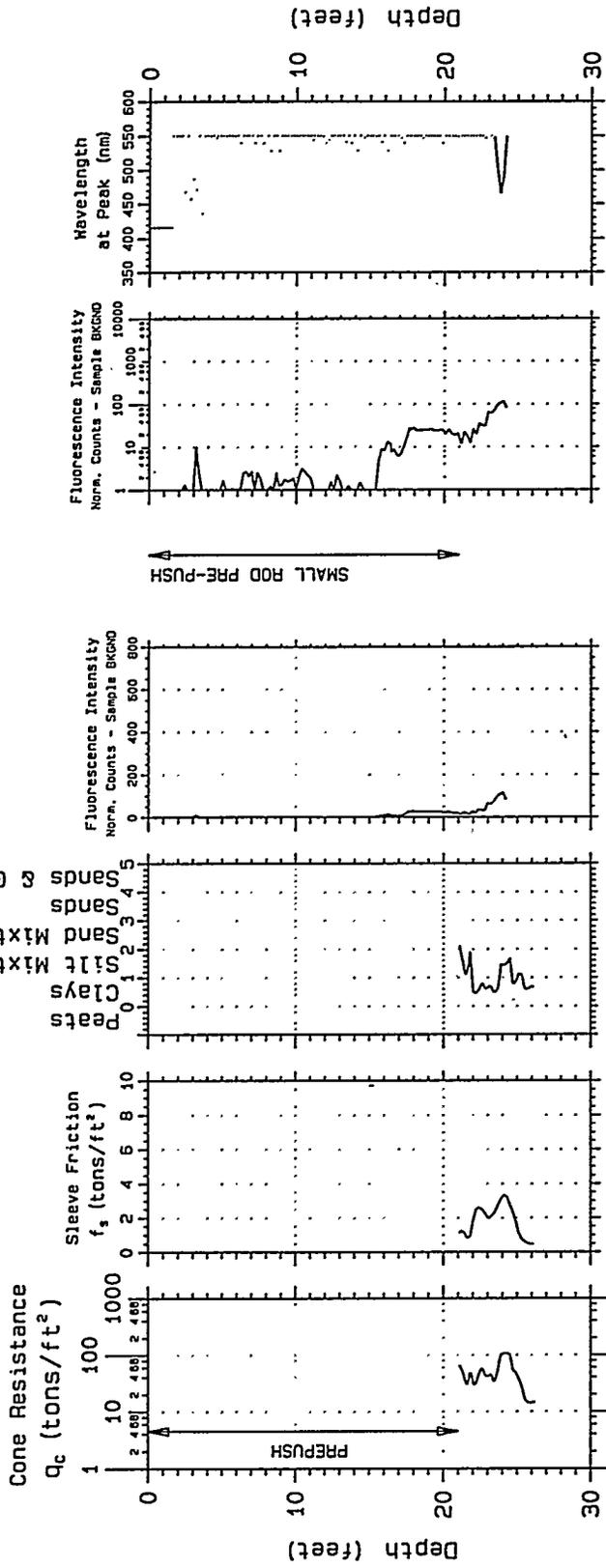


CPT: 41MT72F
 STATE COORDINATES:
 EASTING (ft.) NORTHING (ft.) ELEVATION (ft.)
 -1 -1 0

Project: Marshalltown

Probe date 04-30-1994

CPT based SOIL CLASSIFICATION



CPT: 43MT74F
 STATE COORDINATES:

EASTING (ft.)

-1

Project: Marshalltown

NORTHING (ft.)

-1

ELEVATION (ft.)

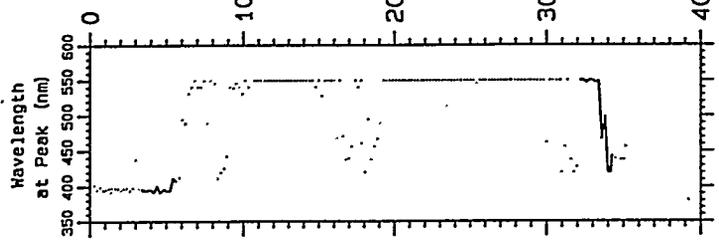
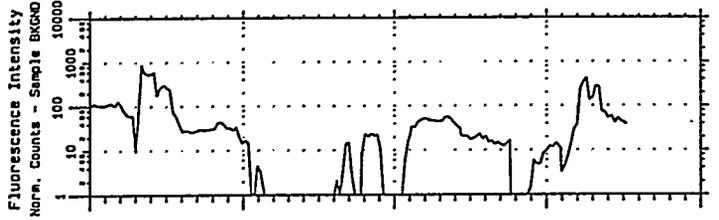
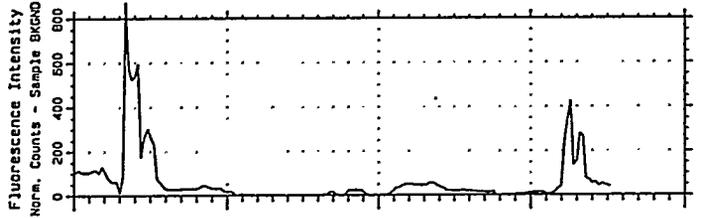
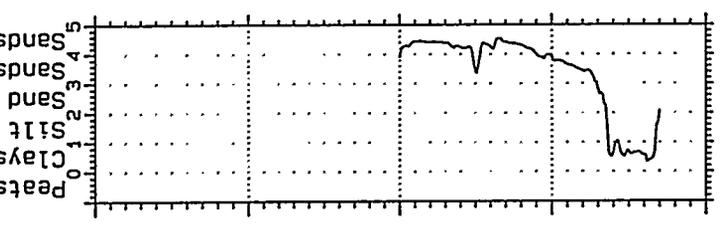
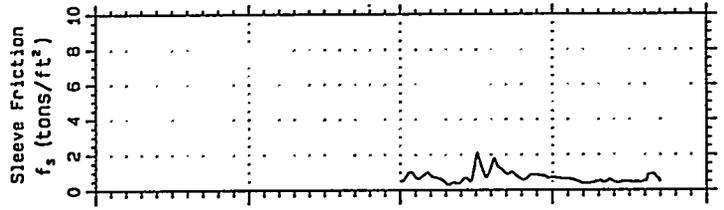
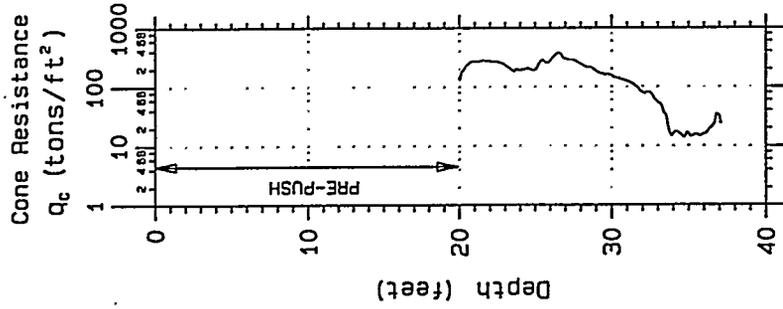
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Probe date

04-30-1994

CPT based SOIL CLASSIFICATION

0 Silts
1 Silts and Clays
2 Silts and Mixtures
3 Silts and Sands
4 Silts and Sands & Gravels
5 Sands & Gravels



SMALL ROD PRE-PUSH

Depth (feet)

CPT: 45MT76F
STATE COORDINATES:

EASTING (ft.)

-1

NORTHING (ft.)

-1

ELEVATION (ft.)

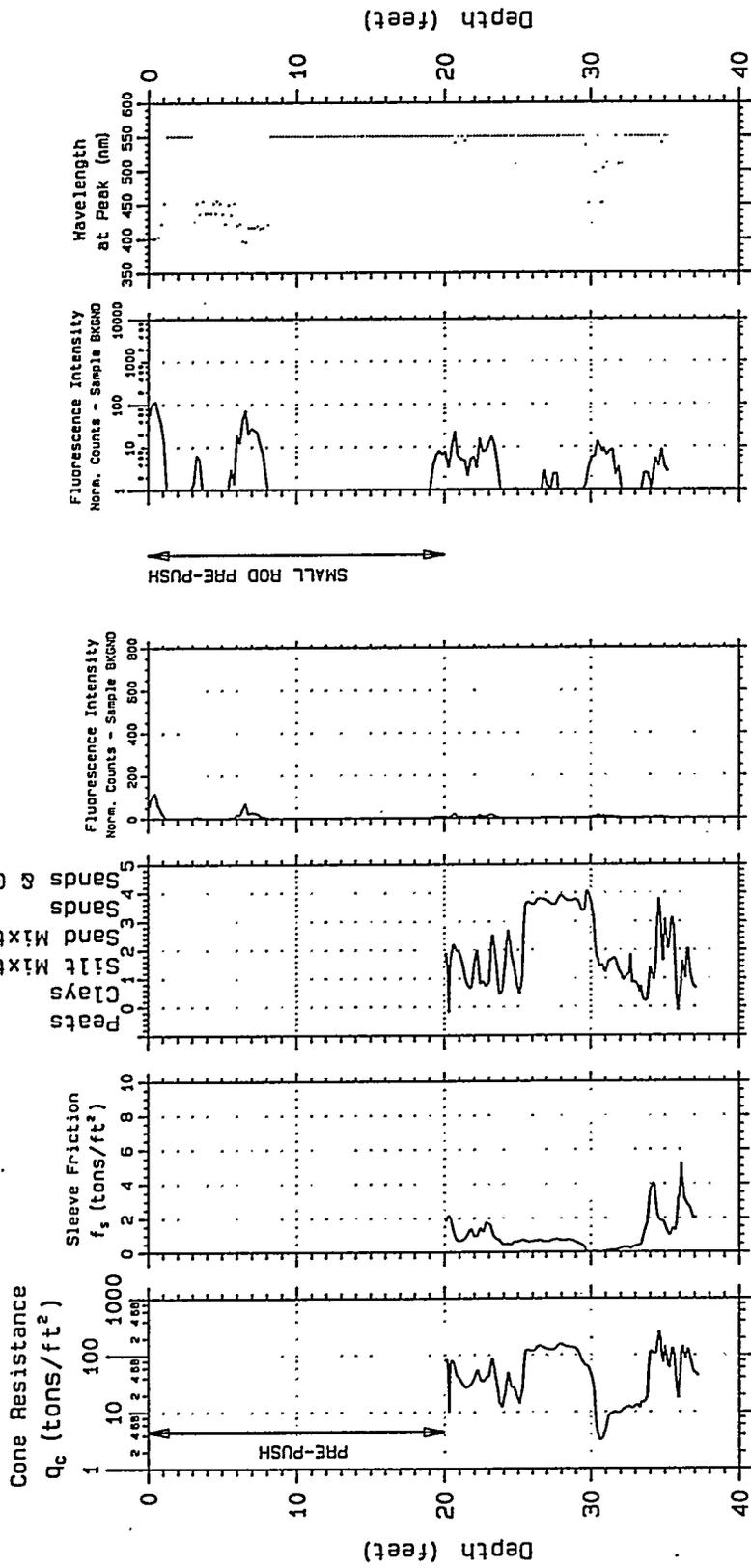
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Project: Marshalltown

Probe date

04-30-1994

CPT based SOIL CLASSIFICATION



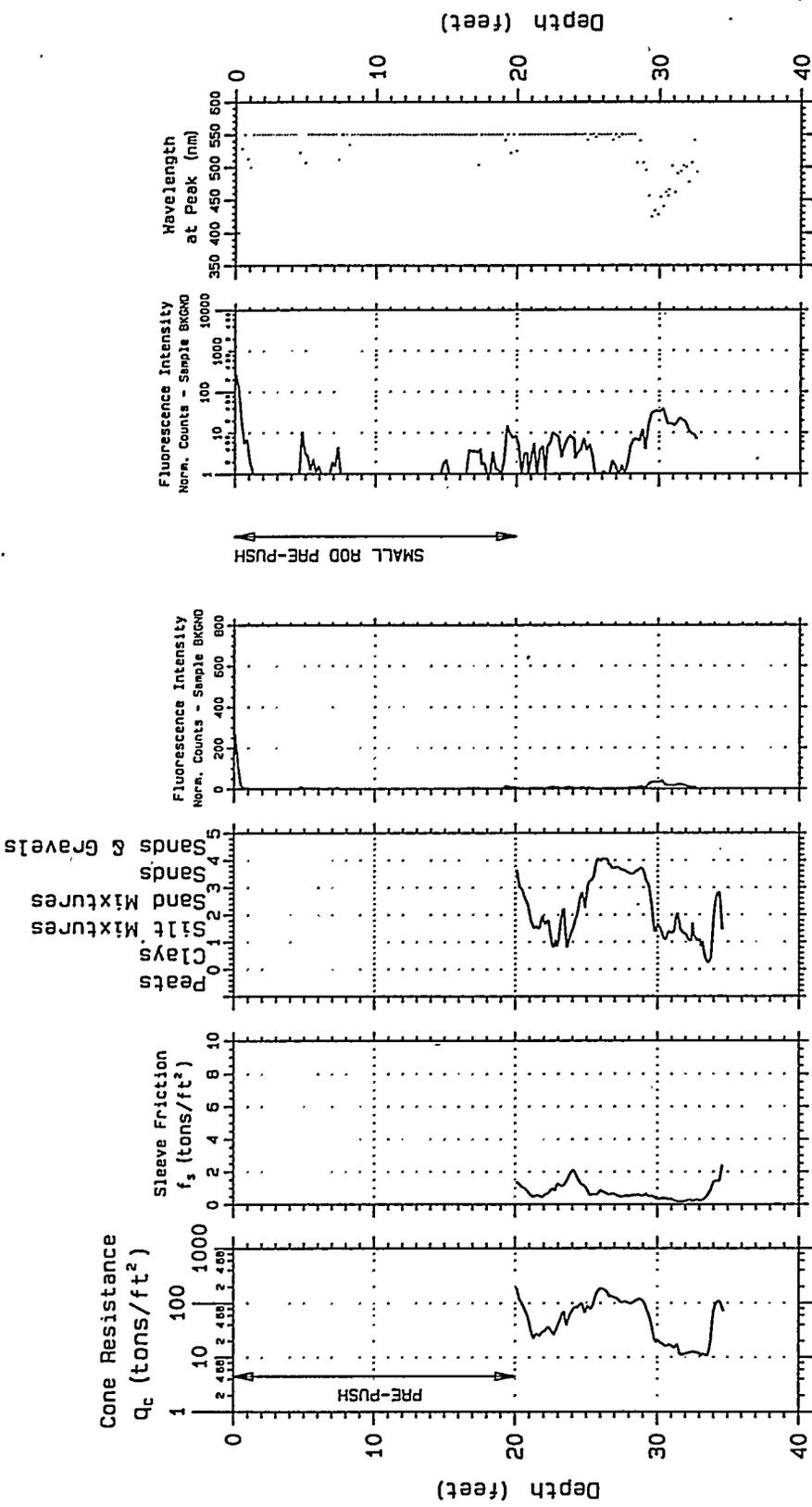
CPT: 47MT77F
 STATE COORDINATES:
 EASTING (ft.)
 -1

NORTHING (ft.)
 0
 ELEVATION (ft.)
 -1

Project: Marshalltown

Probe date 04-30-1994

CPT based SOIL CLASSIFICATION

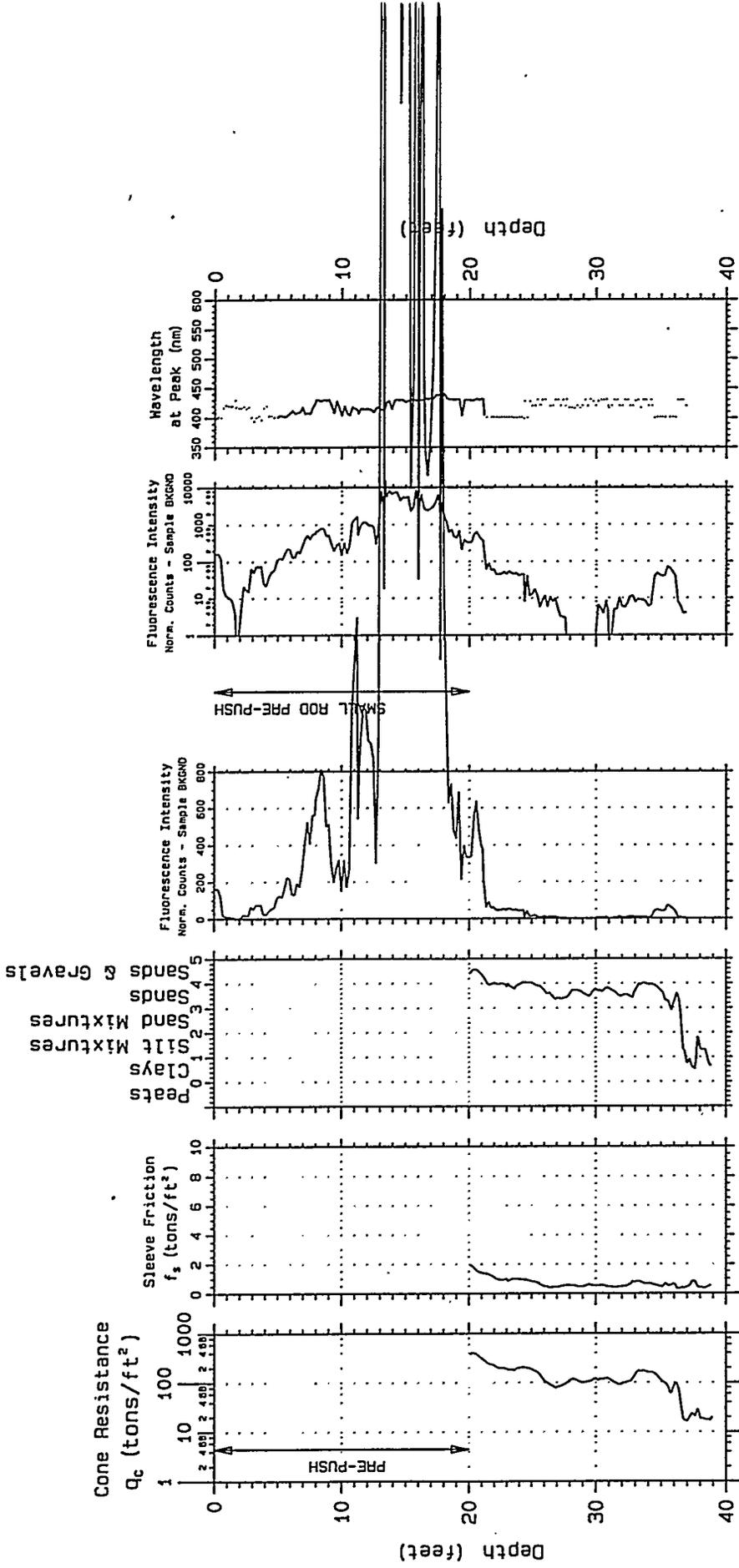


CPT: 49MT79F
 STATE COORDINATES:
 EASTING (ft.) -1
 NORTHING (ft.) -1
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 05-01-1994

CPT based SOIL CLASSIFICATION



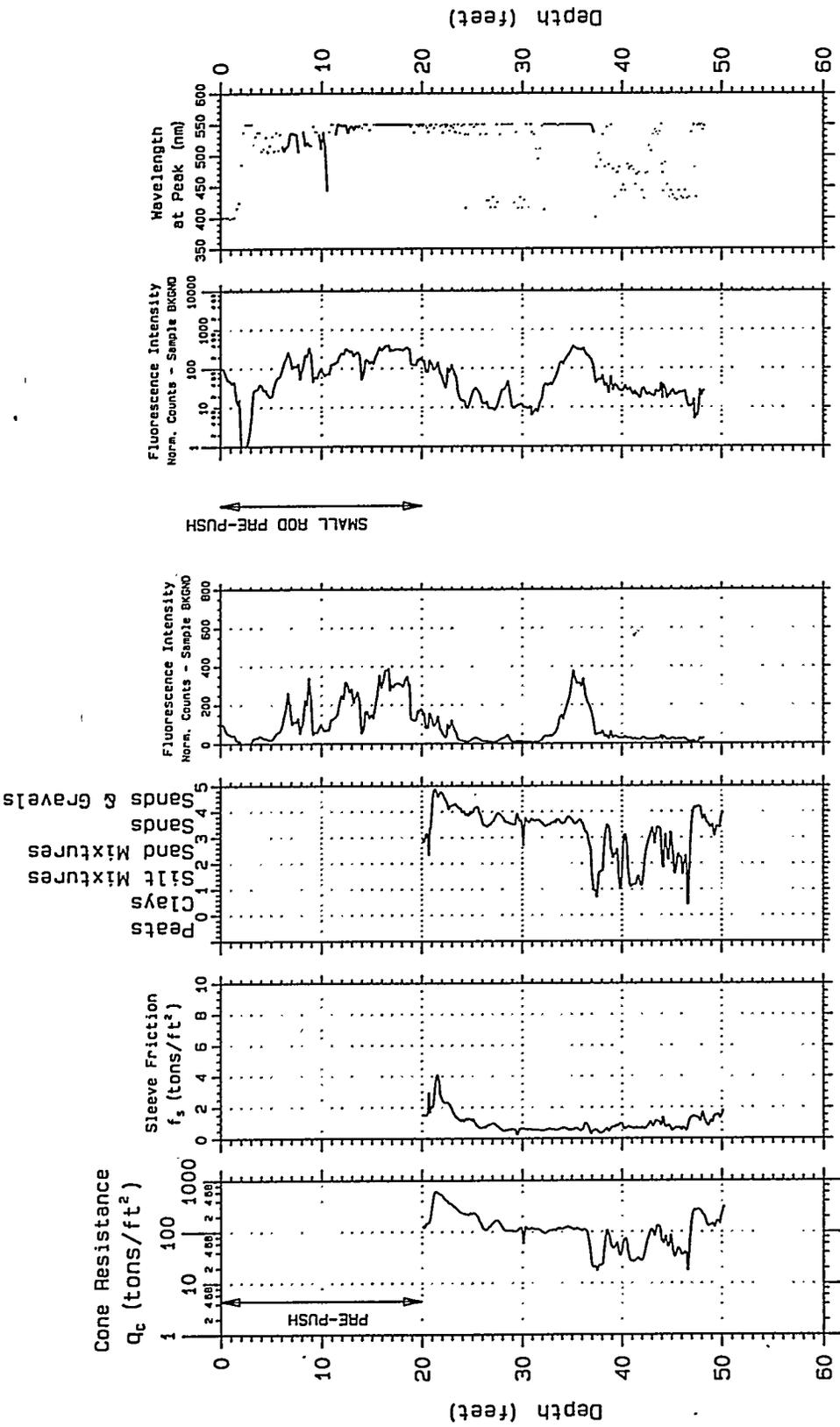
CPT: 52MT81F
 STATE COORDINATES:
 EASTING (ft.)

Project: Marshalltown

NORTHING (ft.) ELEVATION (ft.)
 -1 0

Probe date 05-01-1994

CPT based SOIL CLASSIFICATION

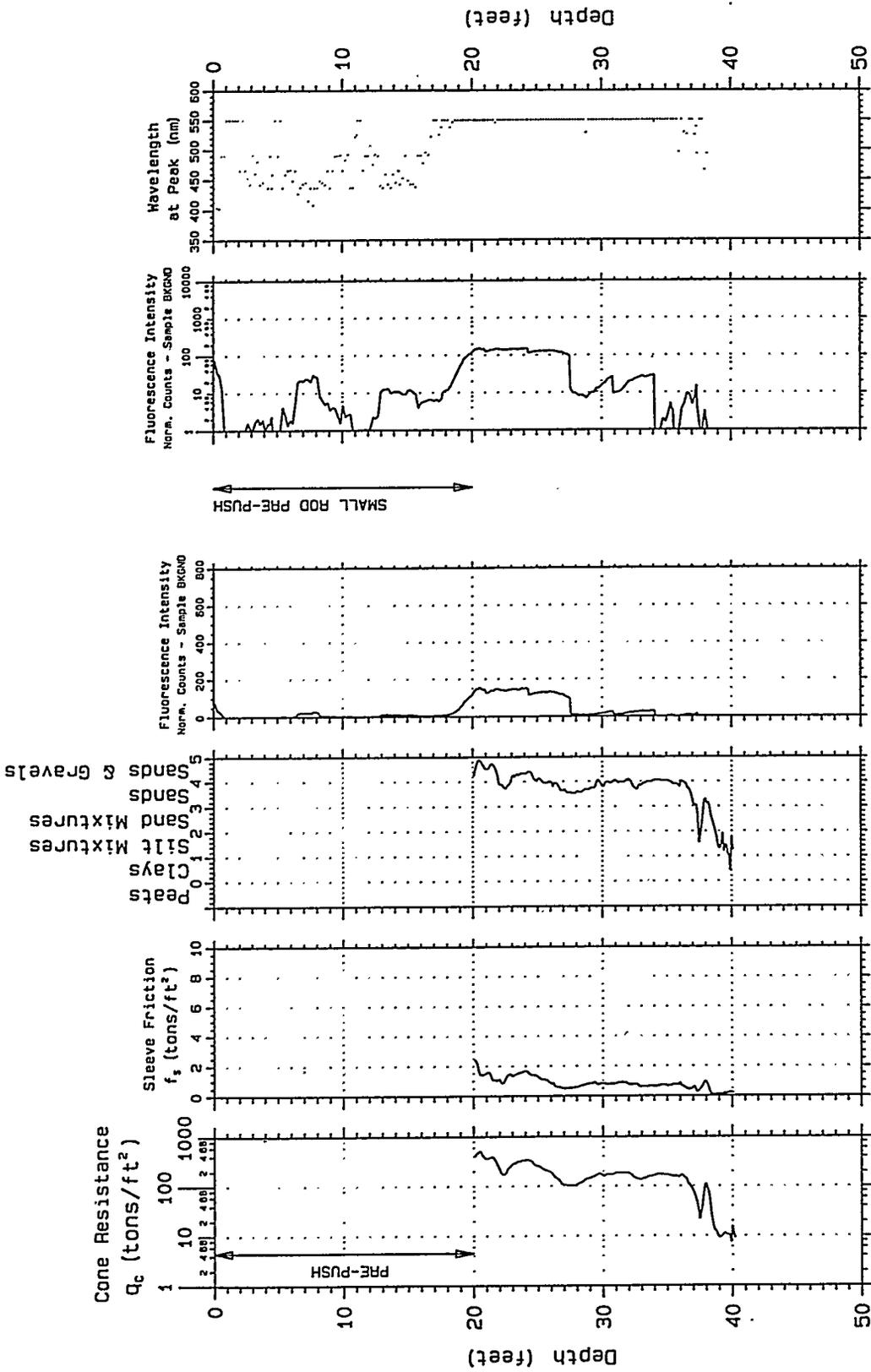


CPT: 54MT83F
 STATE COORDINATES:
 EASTING (ft.) -1
 NORTHING (ft.) -1
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 05-01-1994

CPT based SOIL CLASSIFICATION



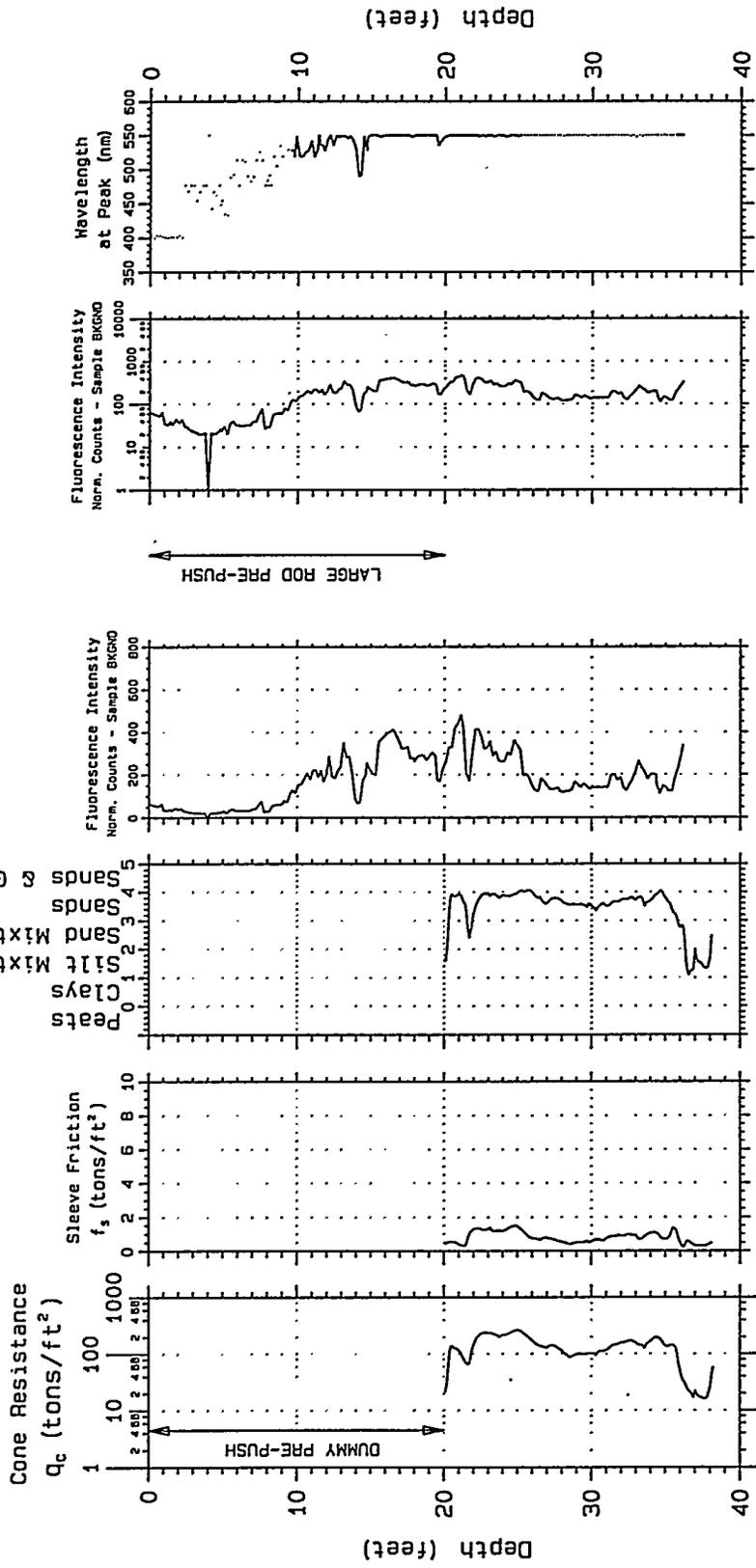
CPT: 56MT85F
STATE COORDINATES:

EASTING (ft.) NORTHING (ft.) ELEVATION (ft.)
-1 -1 0

Project: Marshalltown

Probe date 05-01-1994

CPT based SOIL CLASSIFICATION



CPT: 59MT87F
STATE COORDINATES:

EASTING (ft.)

-1

NORTHING (ft.)

-1

ELEVATION (ft.)

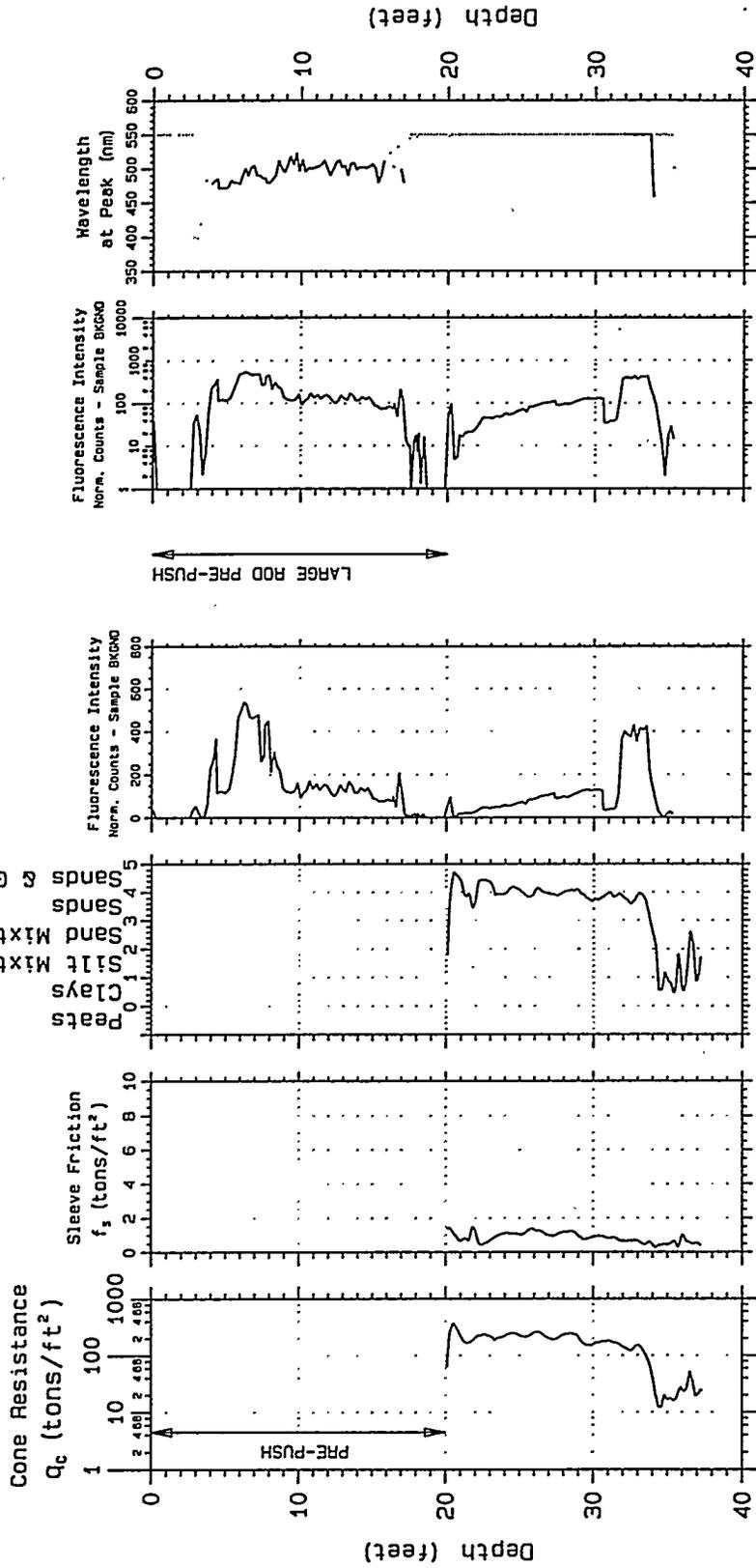
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Project: Marshalltown

Probe date

05-02-1994

CPT based SOIL CLASSIFICATION

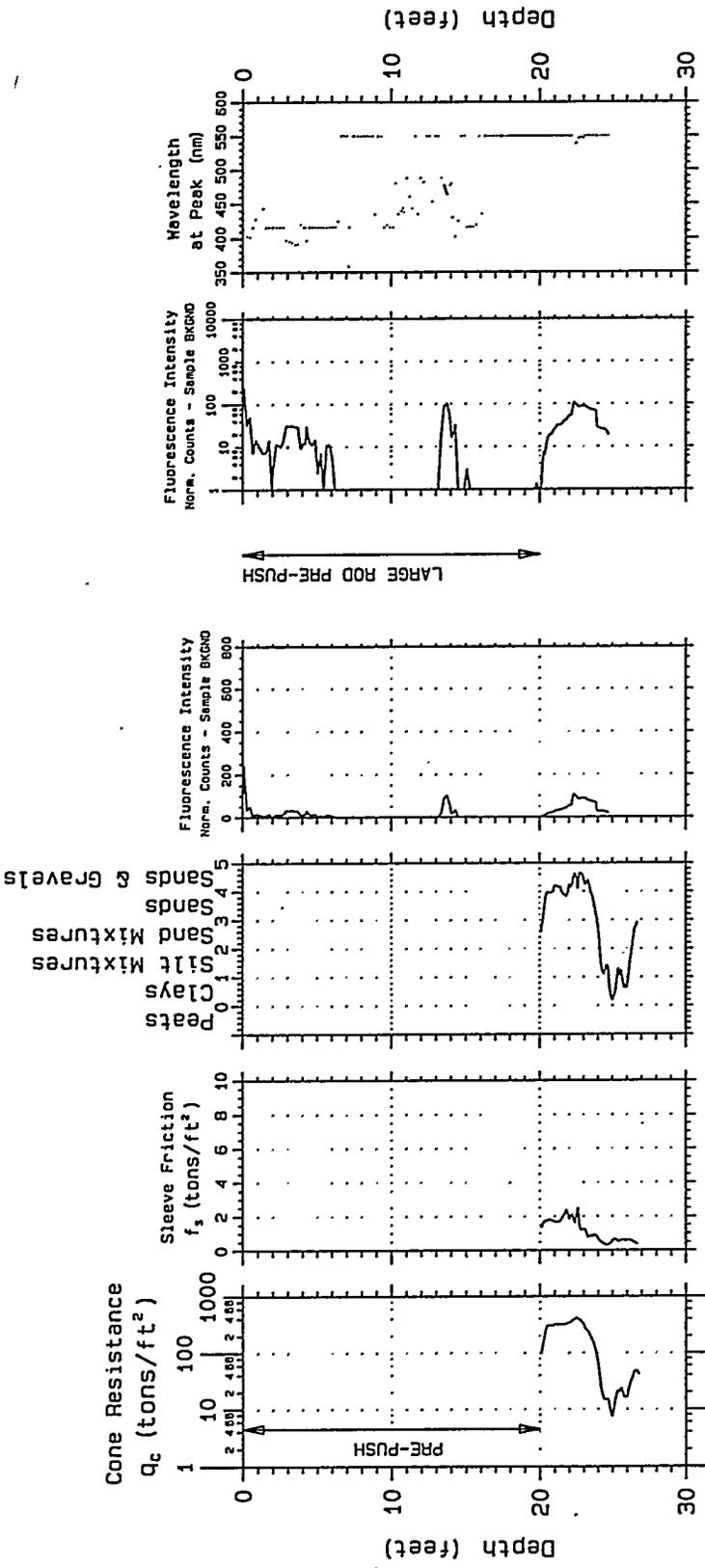


CPT: 61MT89F
 STATE COORDINATES:
 EASTING (ft.) -1
 NORTHING (ft.) -1

Project: Marshalltown
 ELEVATION (ft.) 0

Probe date 05-02-1994

CPT based SOIL CLASSIFICATION

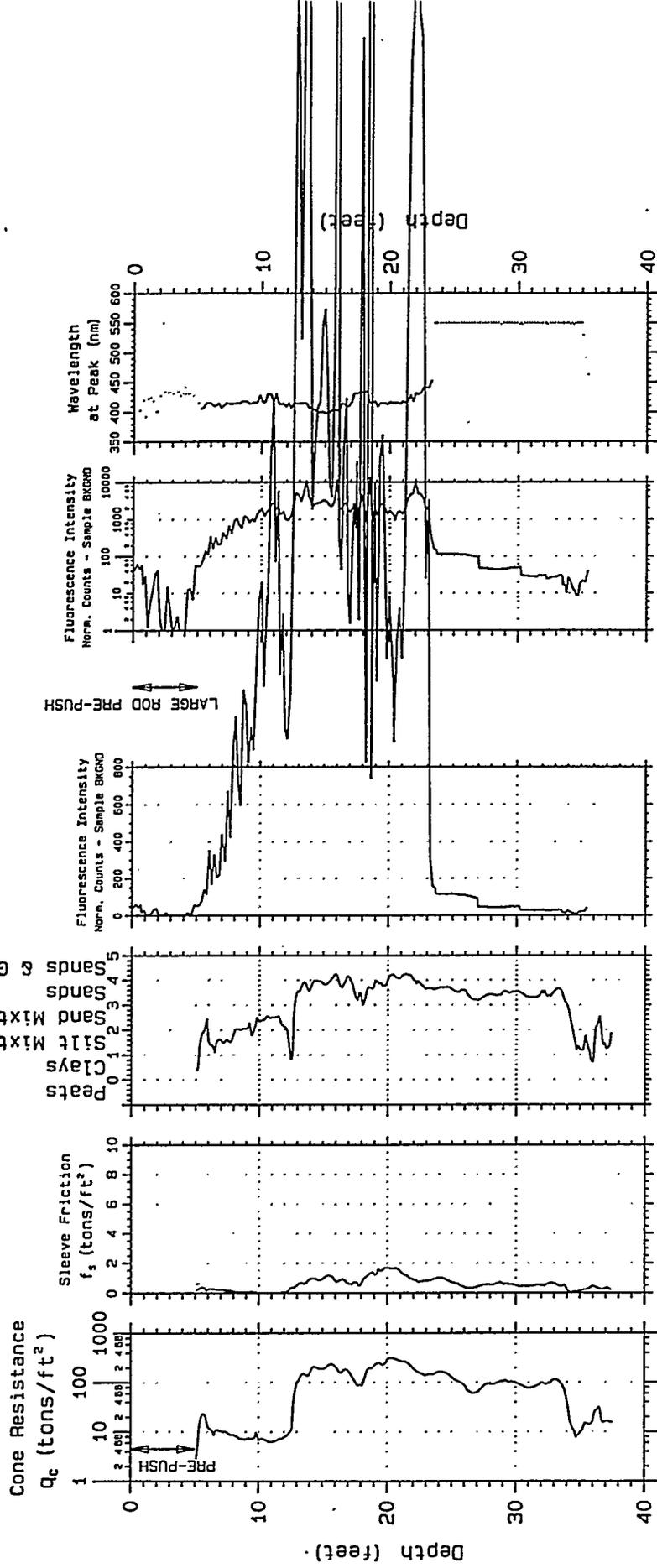


CPT: 63MT91F
 STATE COORDINATES:
 EASTING (ft.) -1
 NORTHING (ft.) -1
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 05-02-1994

CPT based SOIL CLASSIFICATION



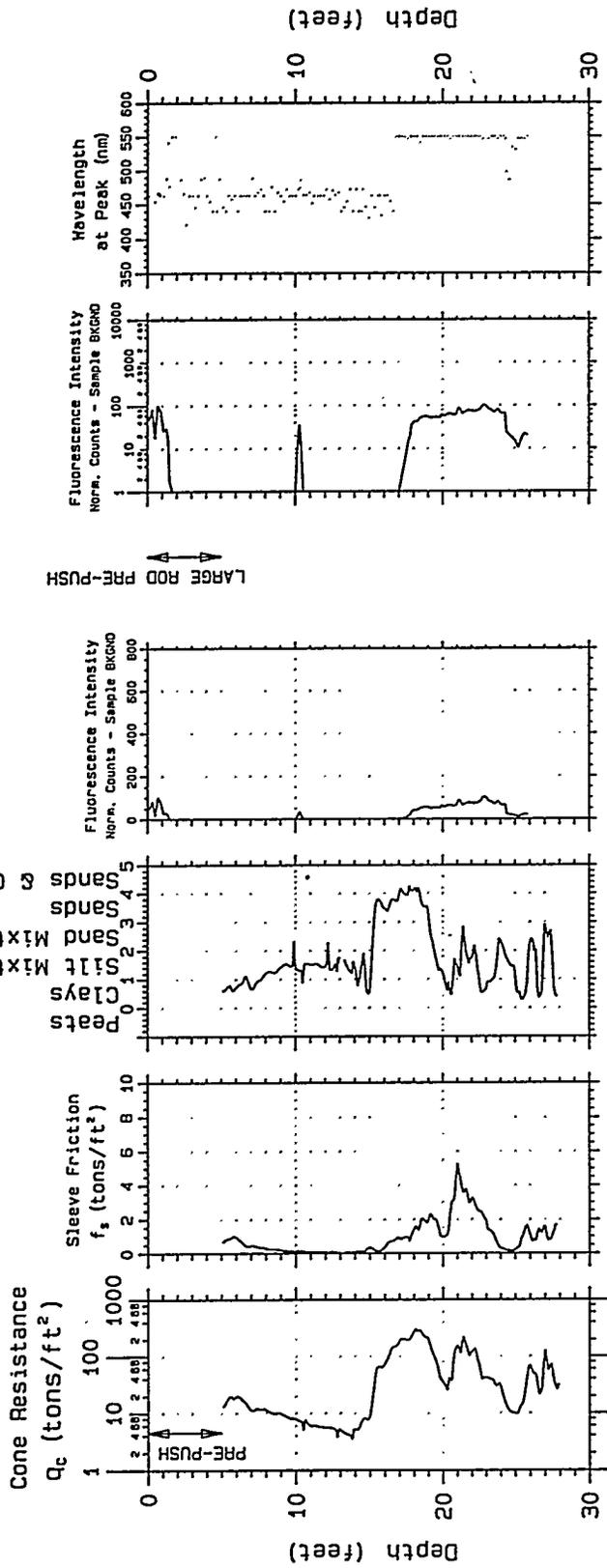
CPT: 65MT93F
 STATE COORDINATES:
 EASTING (ft.)
 -1

NORTHING (ft.)
 0
 ELEVATION (ft.)
 -1

Project: Marshalltown

Probe date 05-03-1994

CPT based SOIL CLASSIFICATION



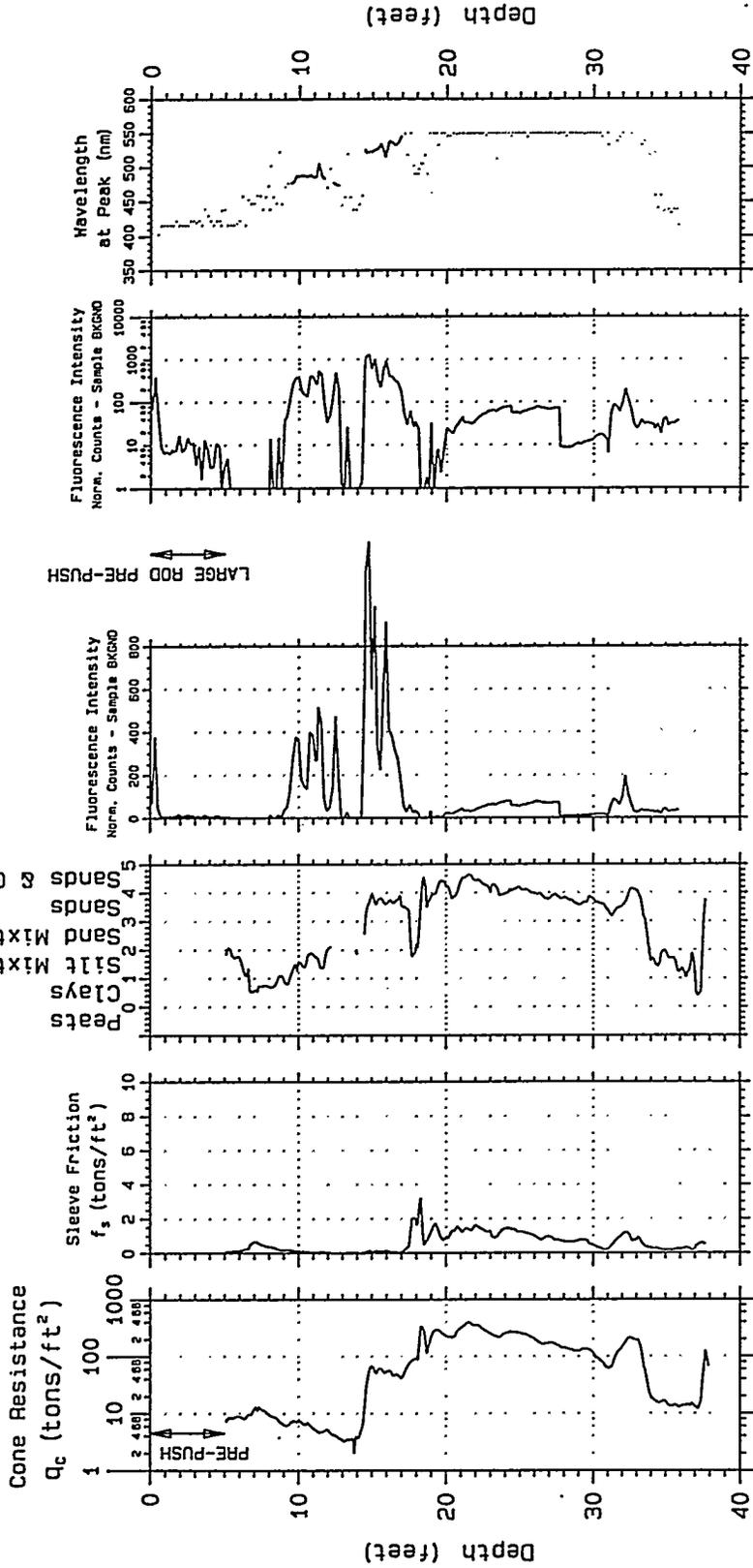
CPT: 67MT95F
 STATE COORDINATES:
 EASTING (ft.)

Project: Marshalltown

NORTHING (ft.)

ELEVATION (ft.) 0
 Probe date 05-03-1994

CPT based SOIL CLASSIFICATION



Project: Marshalltown <NEW>

CPT: 73MT97F
STATE COORDINATES:

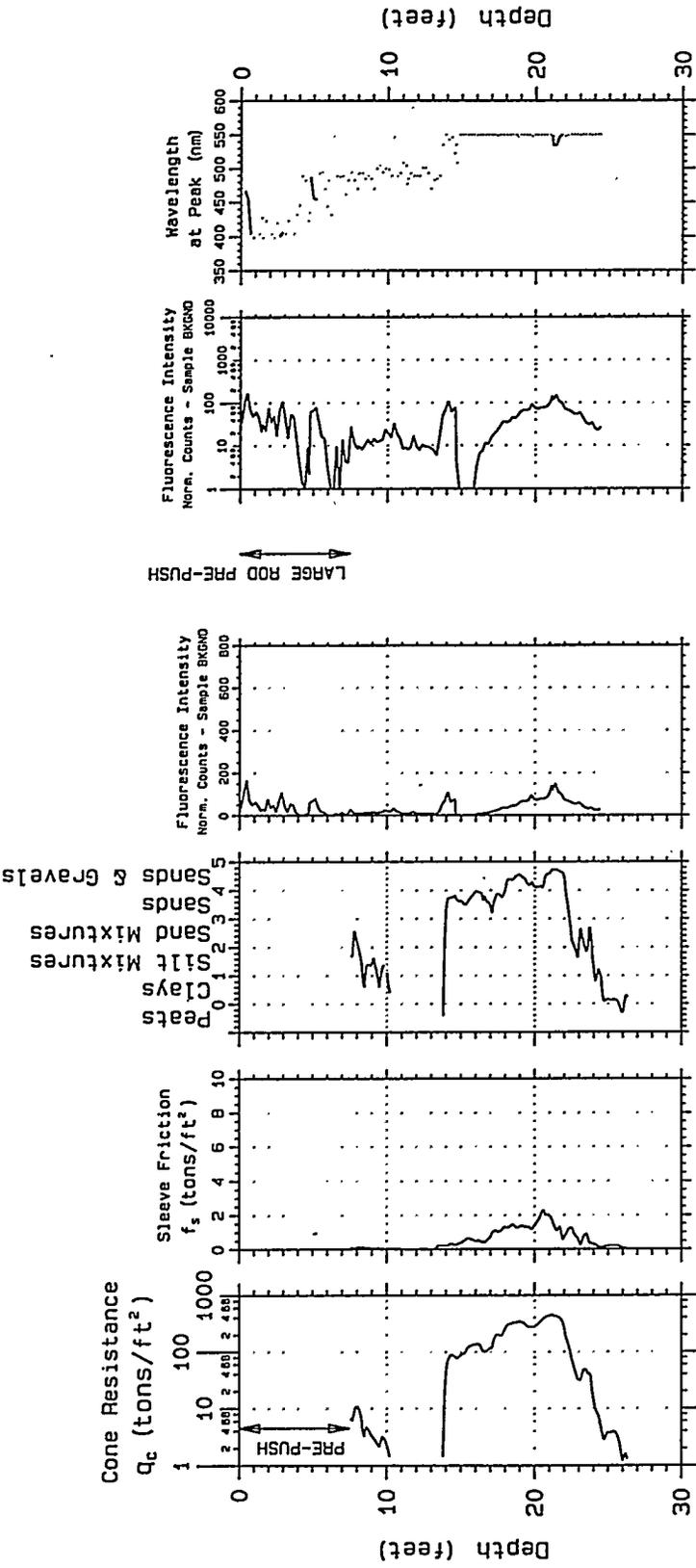
EASTING (ft.) NORTHING (ft.) ELEVATION (ft.)

0 0 05-03-1994

-1

-1

CPT based SOIL CLASSIFICATION



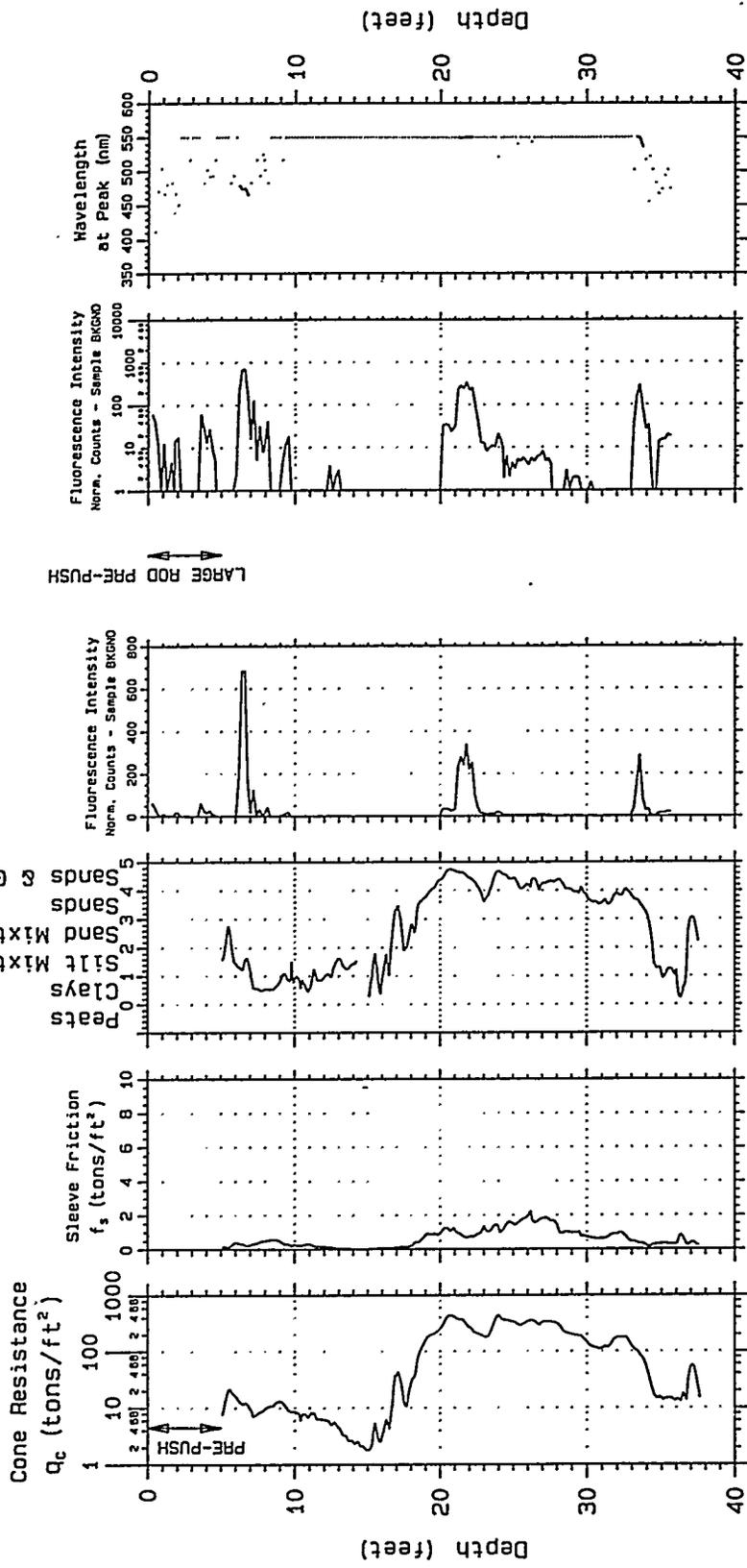
CPT: 81MT99F
 STATE COORDINATES:
 EASTING (ft.)
 -1

Project: Marshalltown

NORTHING (ft.)
 -1
 ELEVATION (ft.)
 0

Probe date 05-04-1994

CPT based SOIL CLASSIFICATION



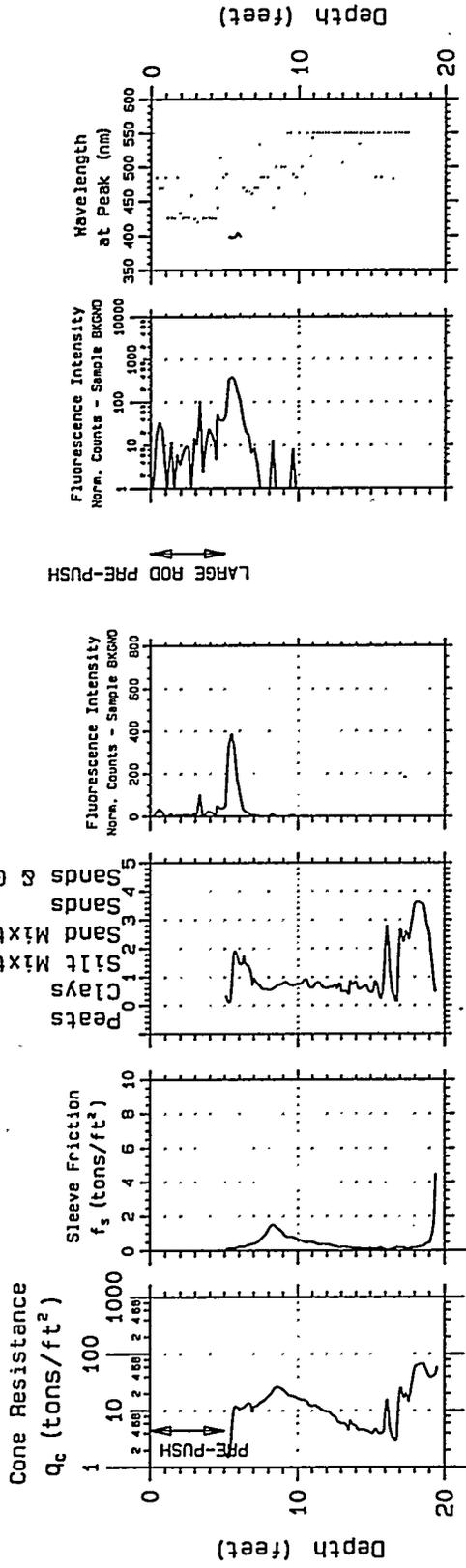
CPT: 83MT101F
 STATE COORDINATES:
 EASTING (ft.)
 -1

Project: Marshalltown

NORTHING (ft.)
 -1
 ELEVATION (ft.)
 0

Probe date 05-04-1994

CPT based SOIL CLASSIFICATION



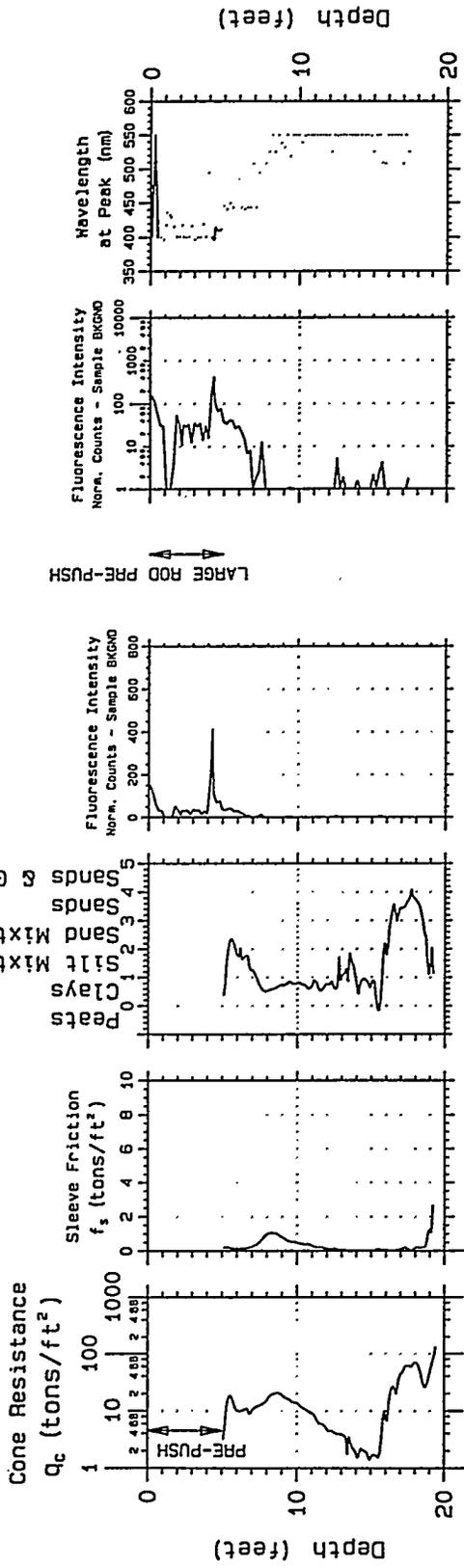
CPT: 90MT105F
 STATE COORDINATES:
 EASTING (ft.)
 -1

NORTHING (ft.)
 -1
 ELEVATION (ft.)
 0

Project: Marshalltown

Probe date 05-04-1994

CPT based SOIL CLASSIFICATION



CPT: 92MT105F
STATE COORDINATES:

EASTING (ft.)

-1

NORTHING (ft.)

-1

ELEVATION (ft.)

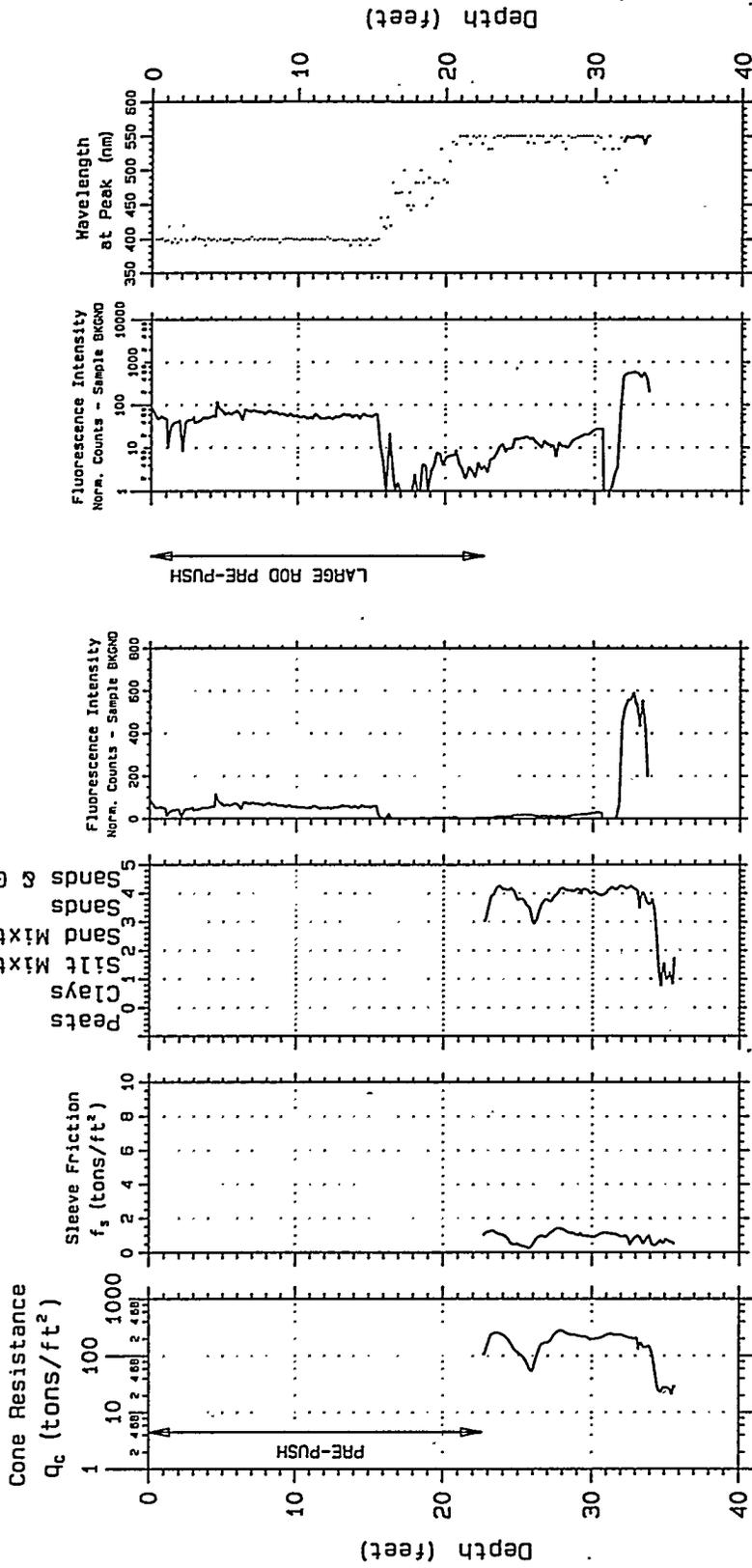
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Project: Marshalltown

Probe date

05-04-1994

CPT based SOIL CLASSIFICATION



CPT: 96MT105F
STATE COORDINATES:

EASTING (ft.) NORTHING (ft.) ELEVATION (ft.)

-1

-1

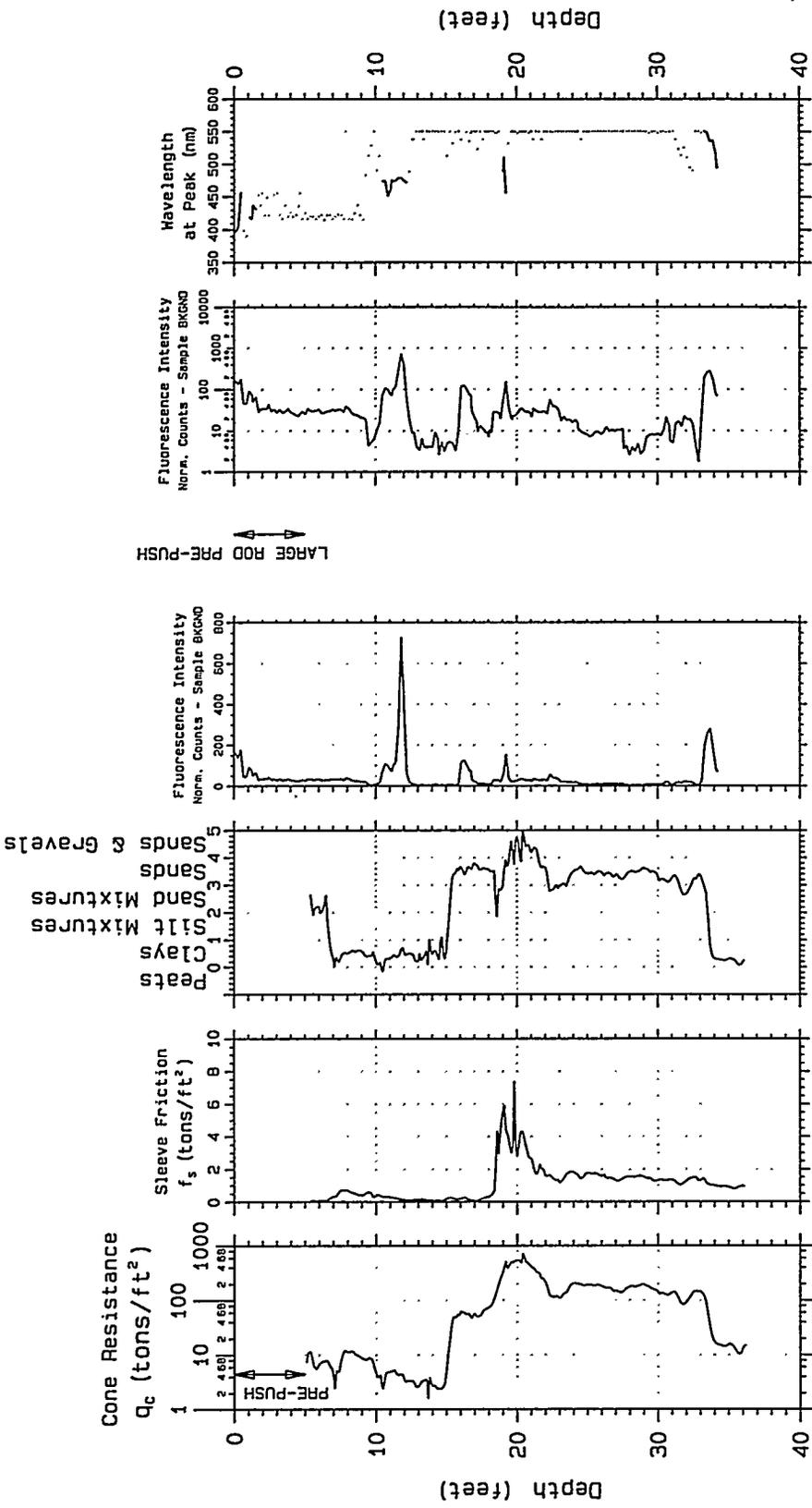
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Project: Marshalltown

Probe date

05-05-1994

CPT based SOIL CLASSIFICATION



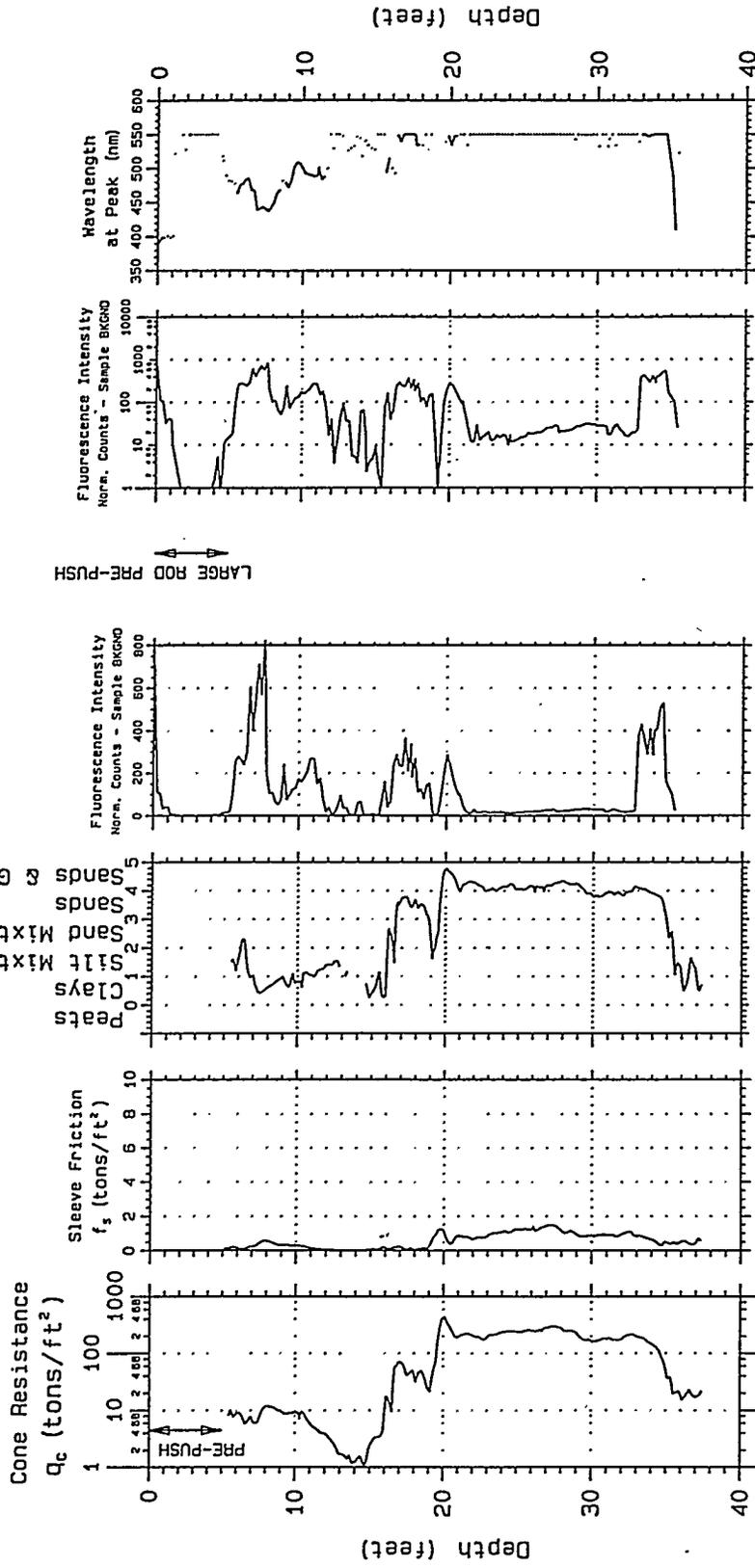
CPT: 102M107F
 STATE COORDINATES:
 EASTING (ft.)

Project: Marshalltown

NORTHING (ft.) ELEVATION (ft.)
 -1 0

Probe date 05-05-1994

CPT based SOIL CLASSIFICATION



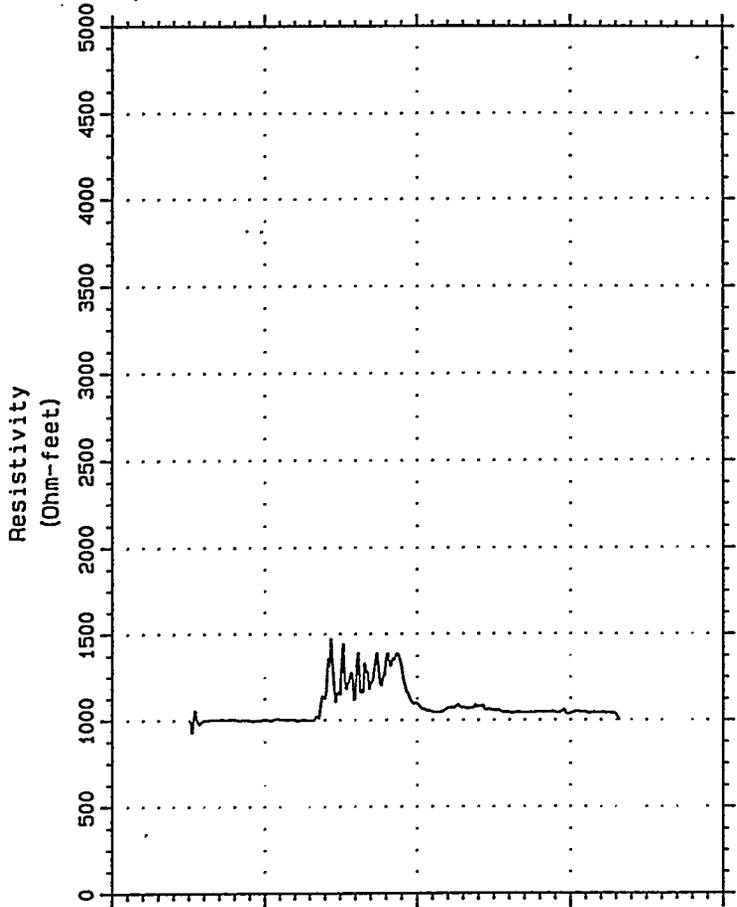
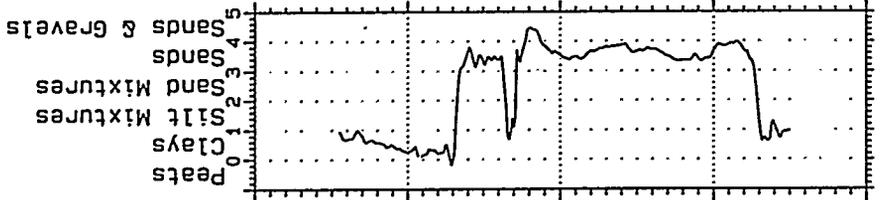
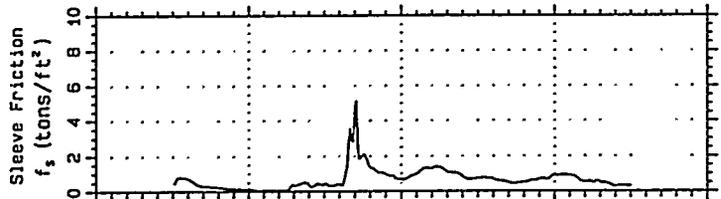
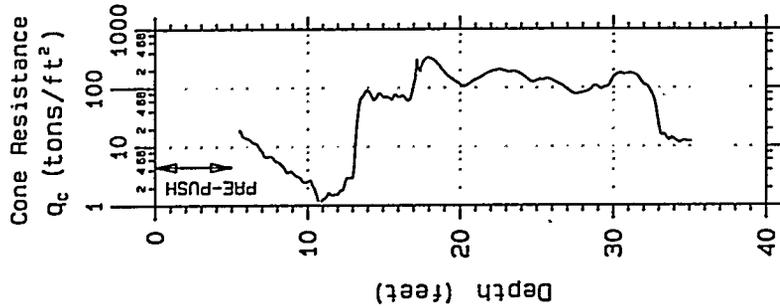
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 STATE COORDINATES:
 EASTING (ft.) -1
 NORTHING (ft.) -1

ELEVATION (ft.) 0

Project: Marshalltown

Probe date 05-05-1994

CPT based SOIL CLASSIFICATION



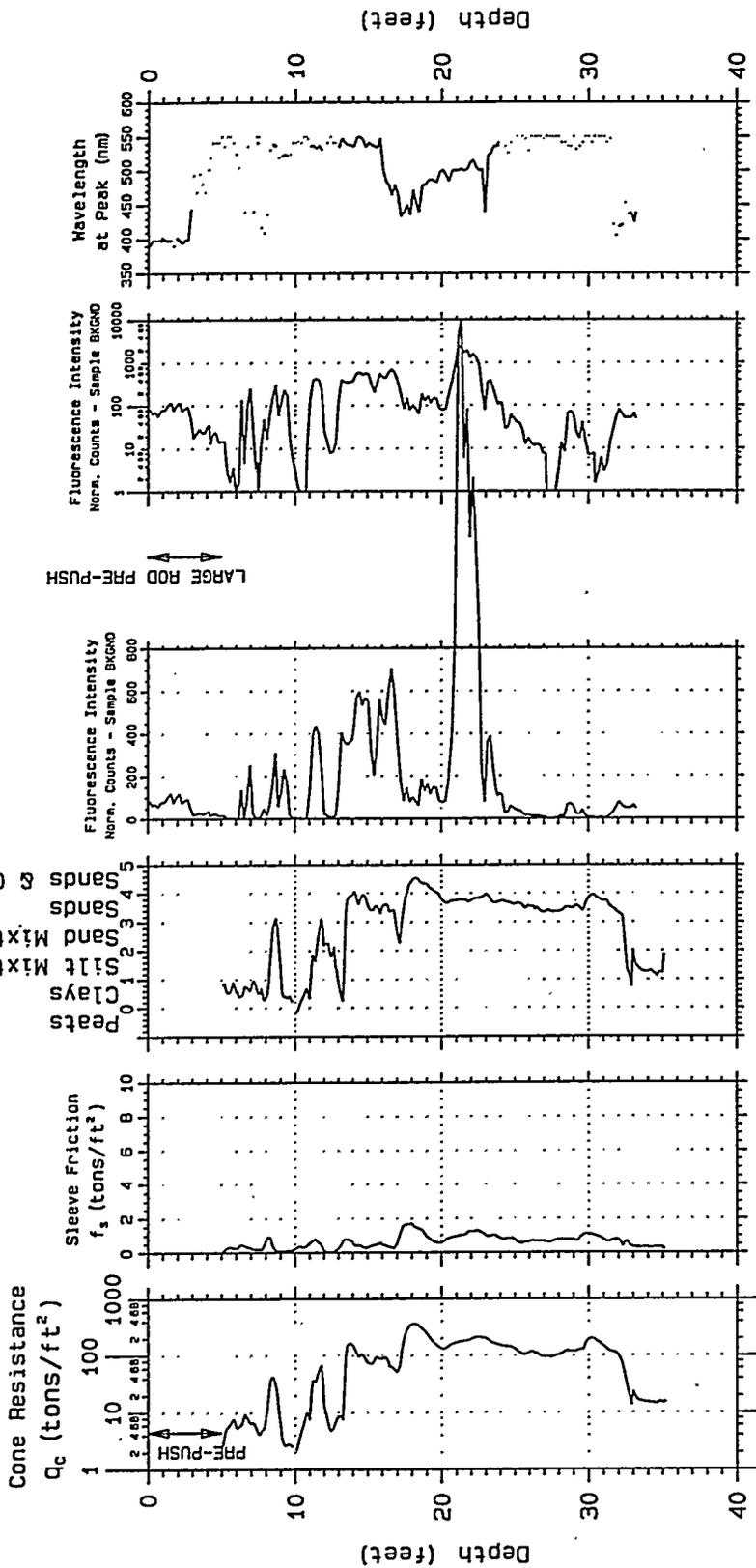
LARGE ROD PRE-PUSH

CPT: 106M111R
 STATE COORDINATES:
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 NORTHING (ft.) 0
 ELEVATION (ft.) 0

Project: Marshalltown

Probe date 05-05-1994

CPT based SOIL CLASSIFICATION



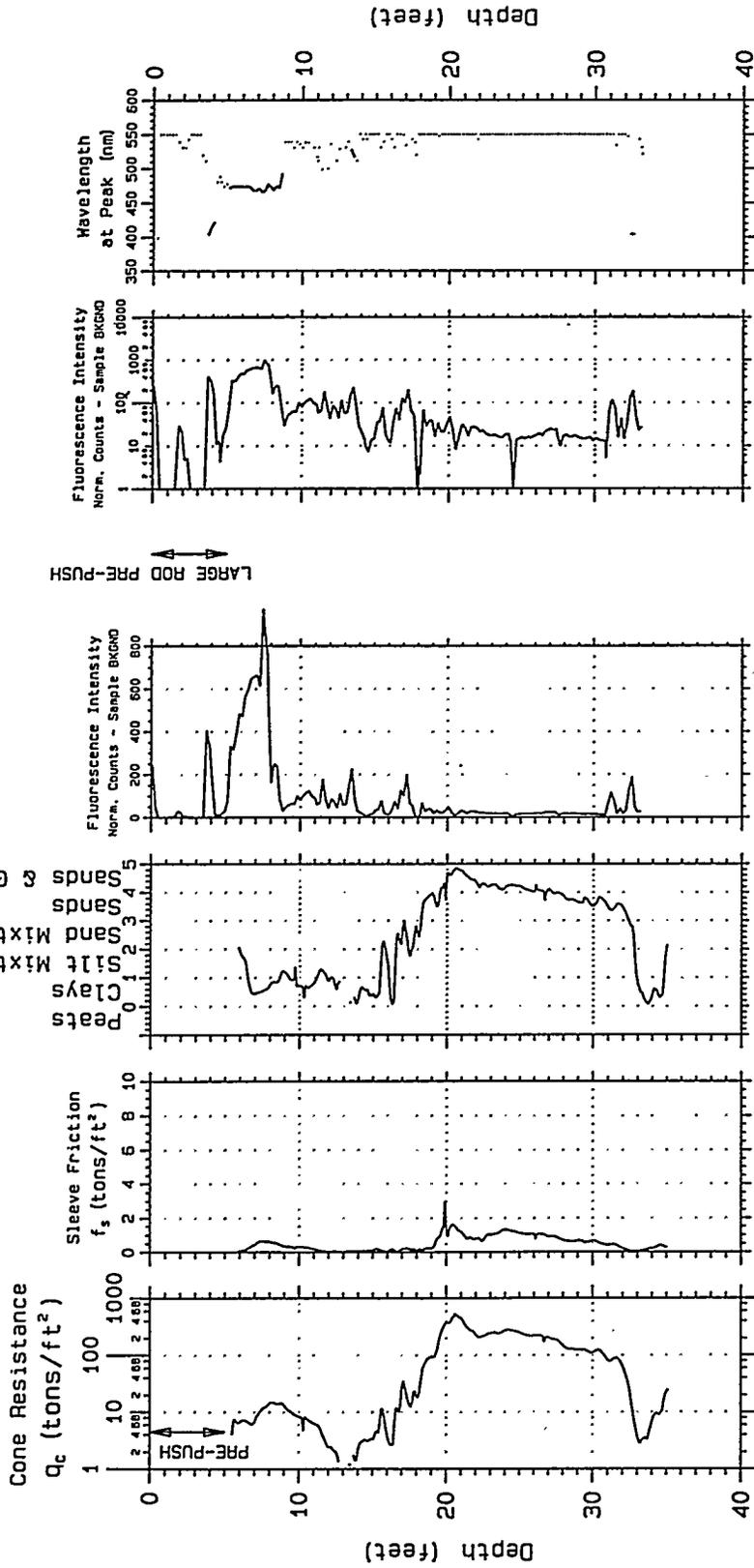
CPT: 104M111F
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 NORTHING (ft.) 0

ELEVATION (ft.) 0

Project: Marshalltown

Probe date 05-05-1994

CPT based SOIL CLASSIFICATION



CPT: 100M113F

STATE COORDINATES:

EASTING (ft.)

NORTHING (ft.)

ELEVATION (ft.)

-1

-1

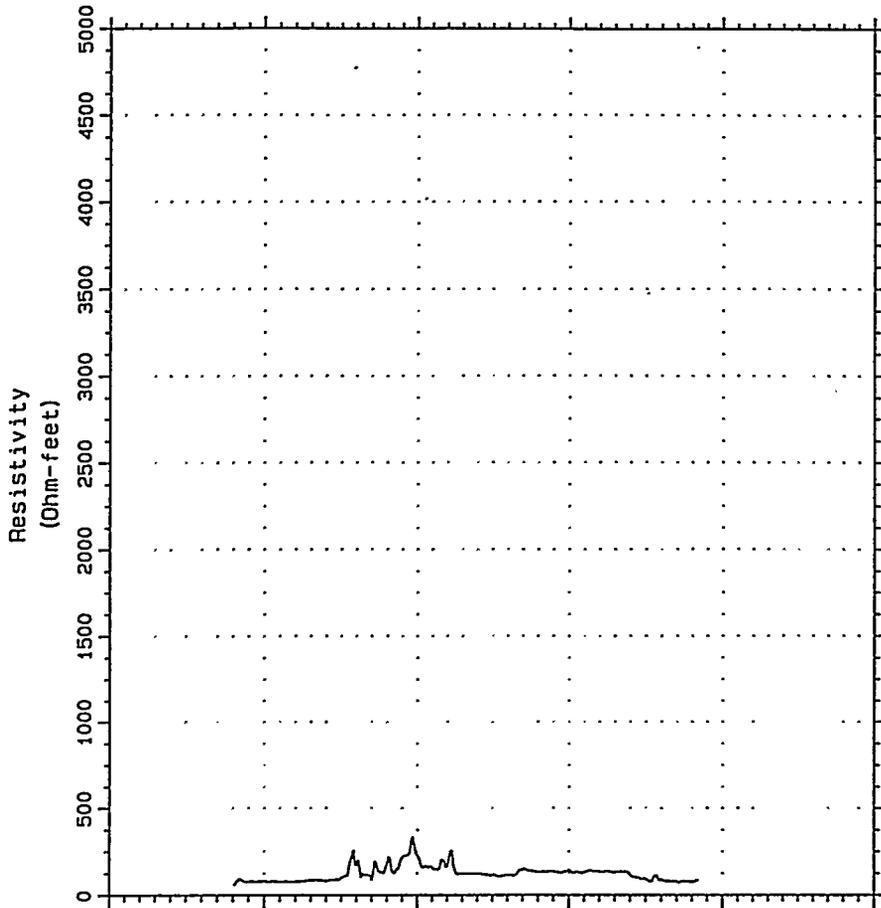
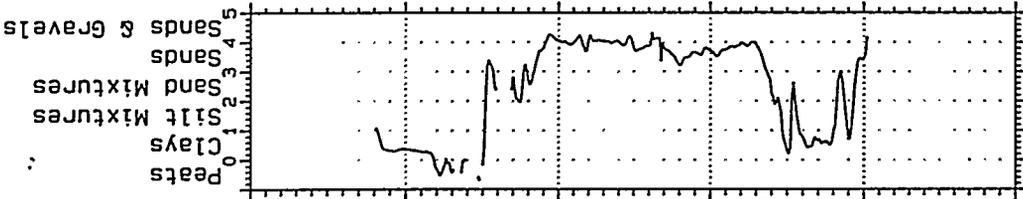
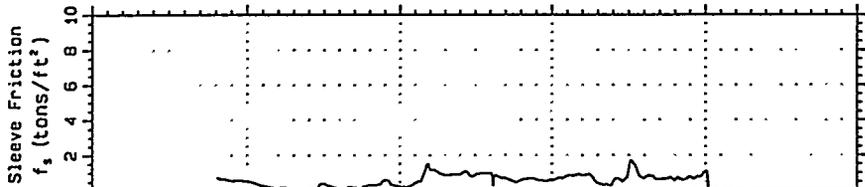
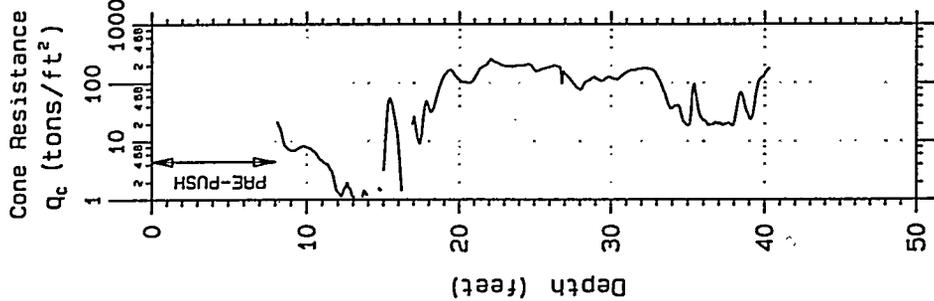
0

Project: Marshalltown

Probe date

05-05-1994

CPT based SOIL CLASSIFICATION



Depth (feet) 0 10 20 30 40 50
LARGE ROD PRE-PUSH

CPT: 108M115R

Project: Marshalltown

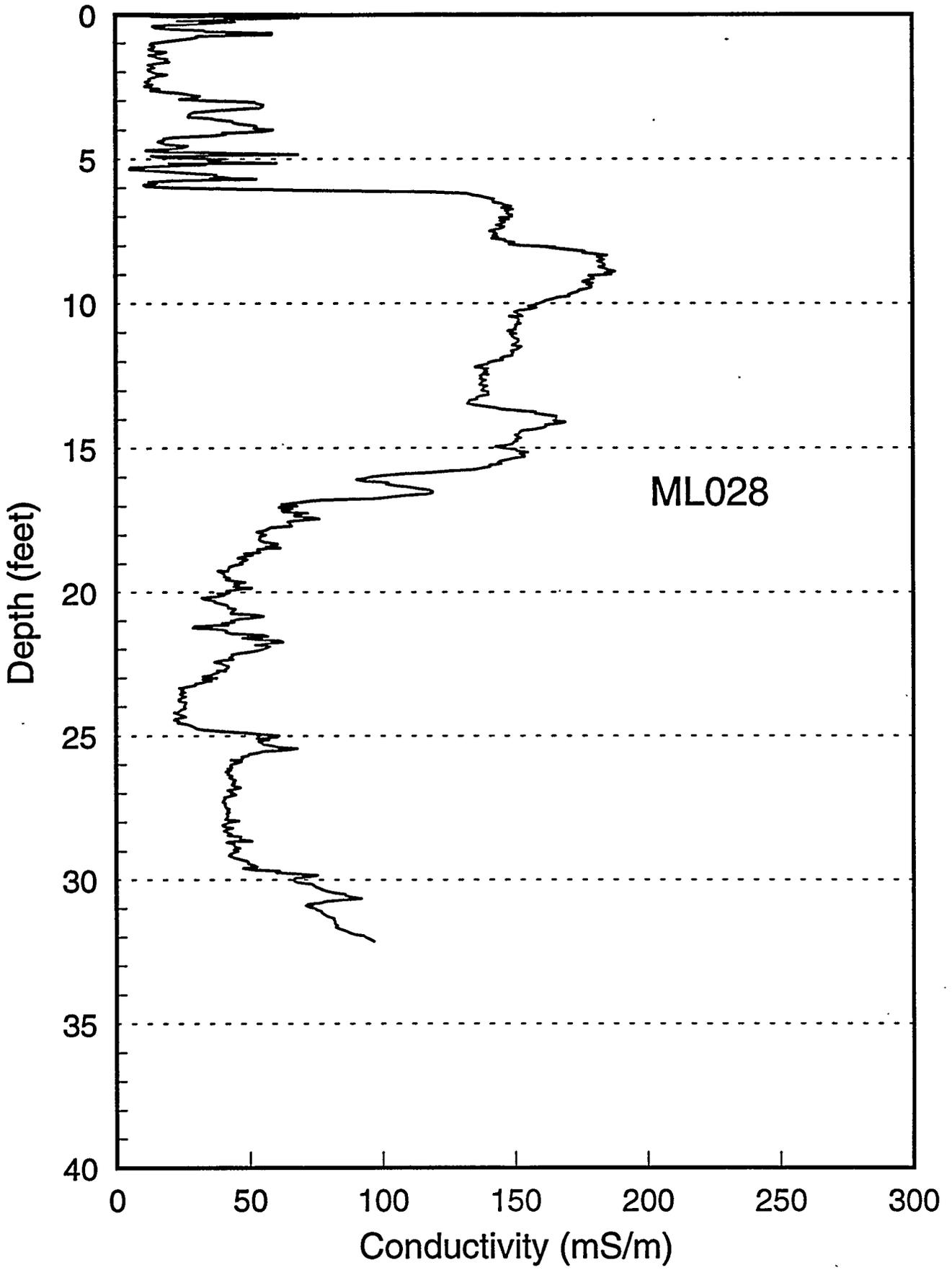
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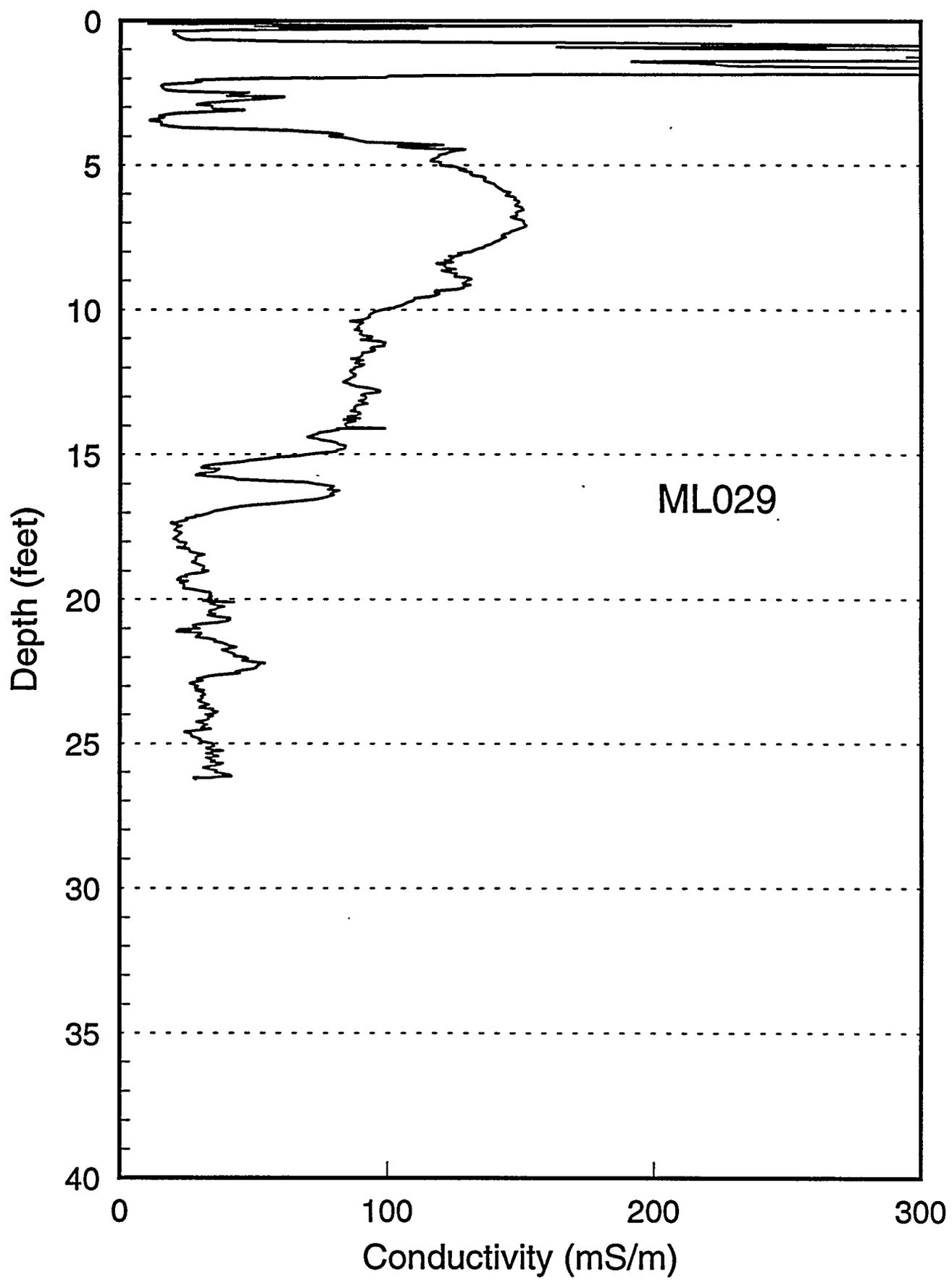
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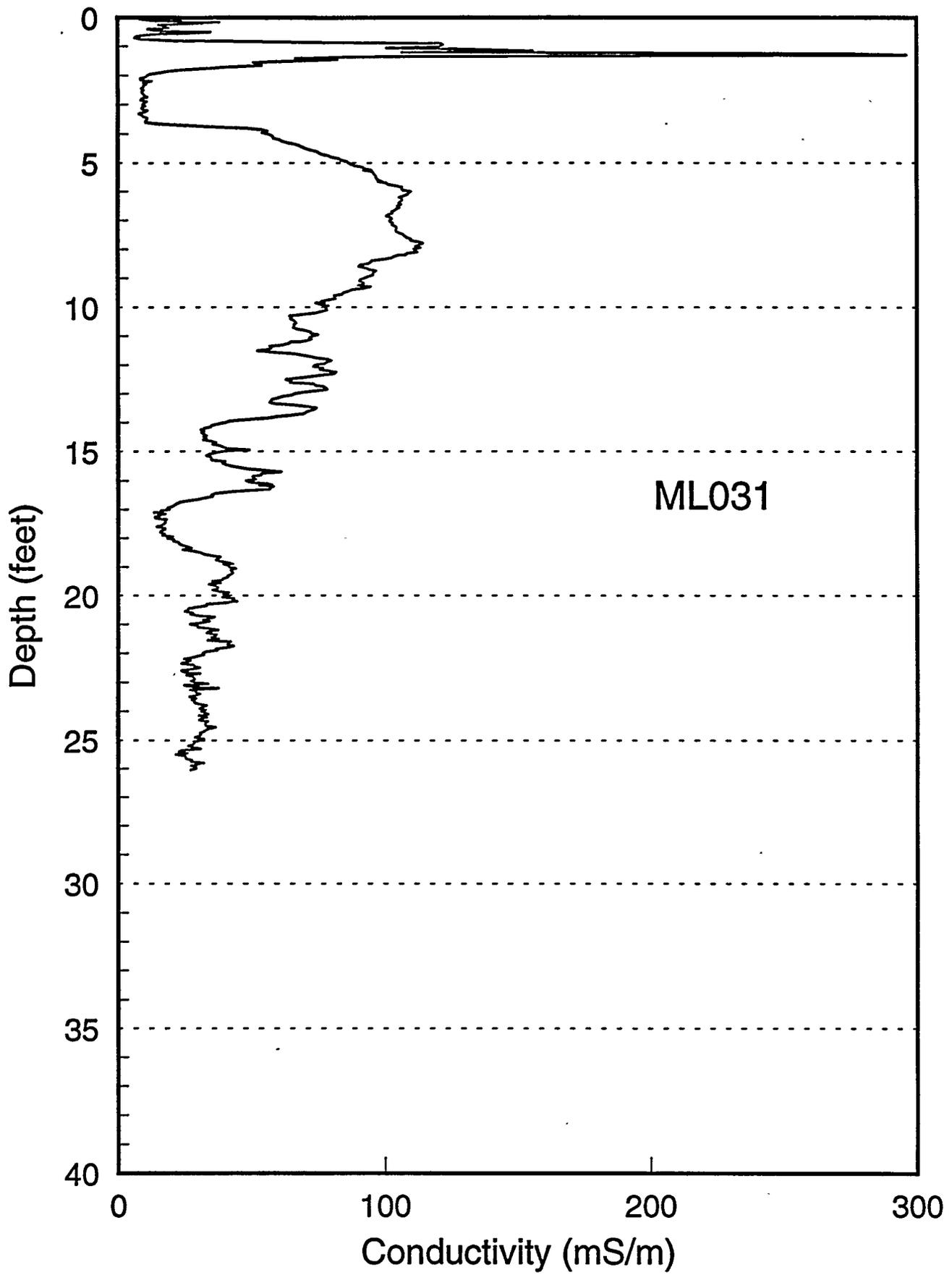
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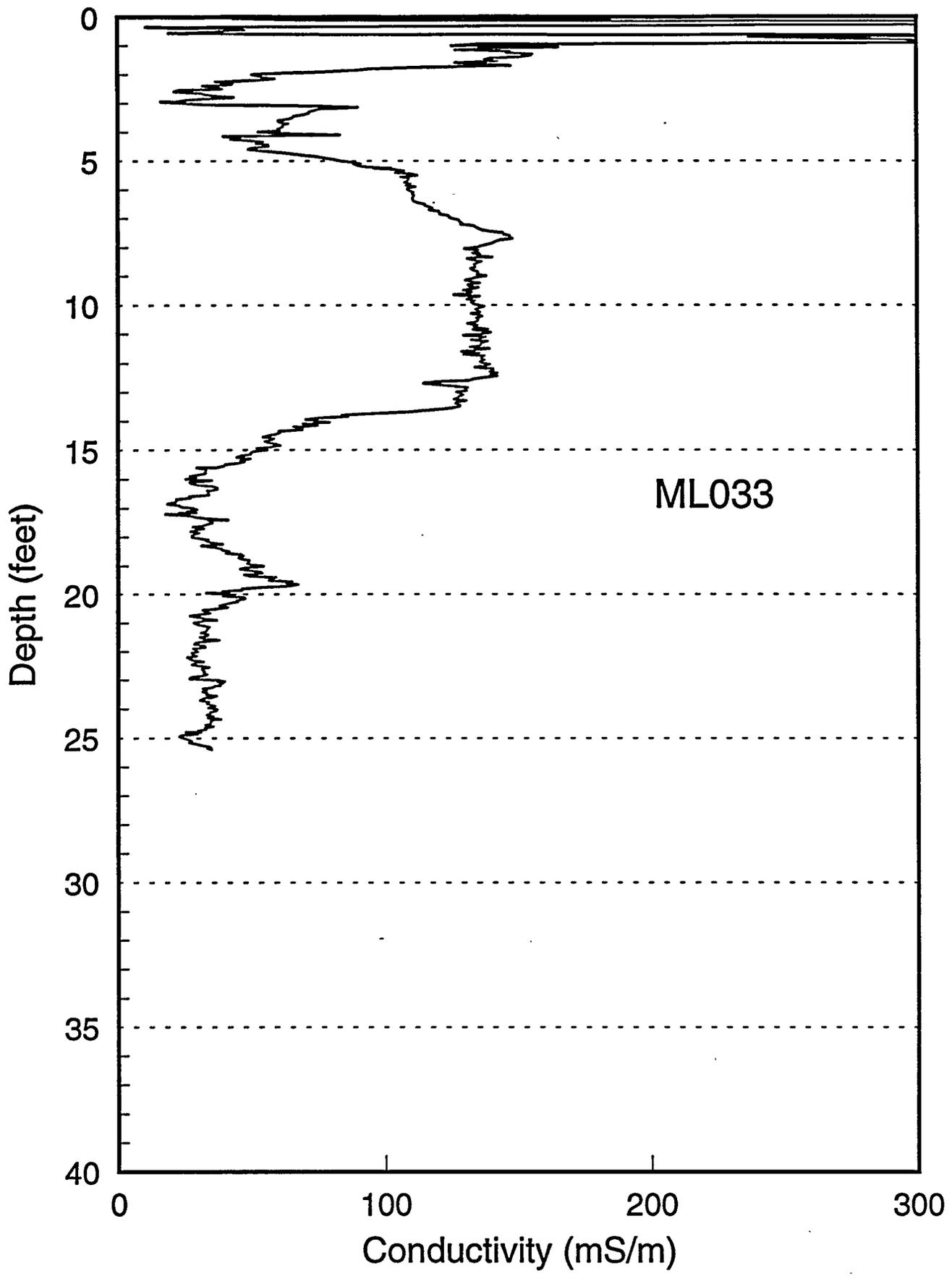
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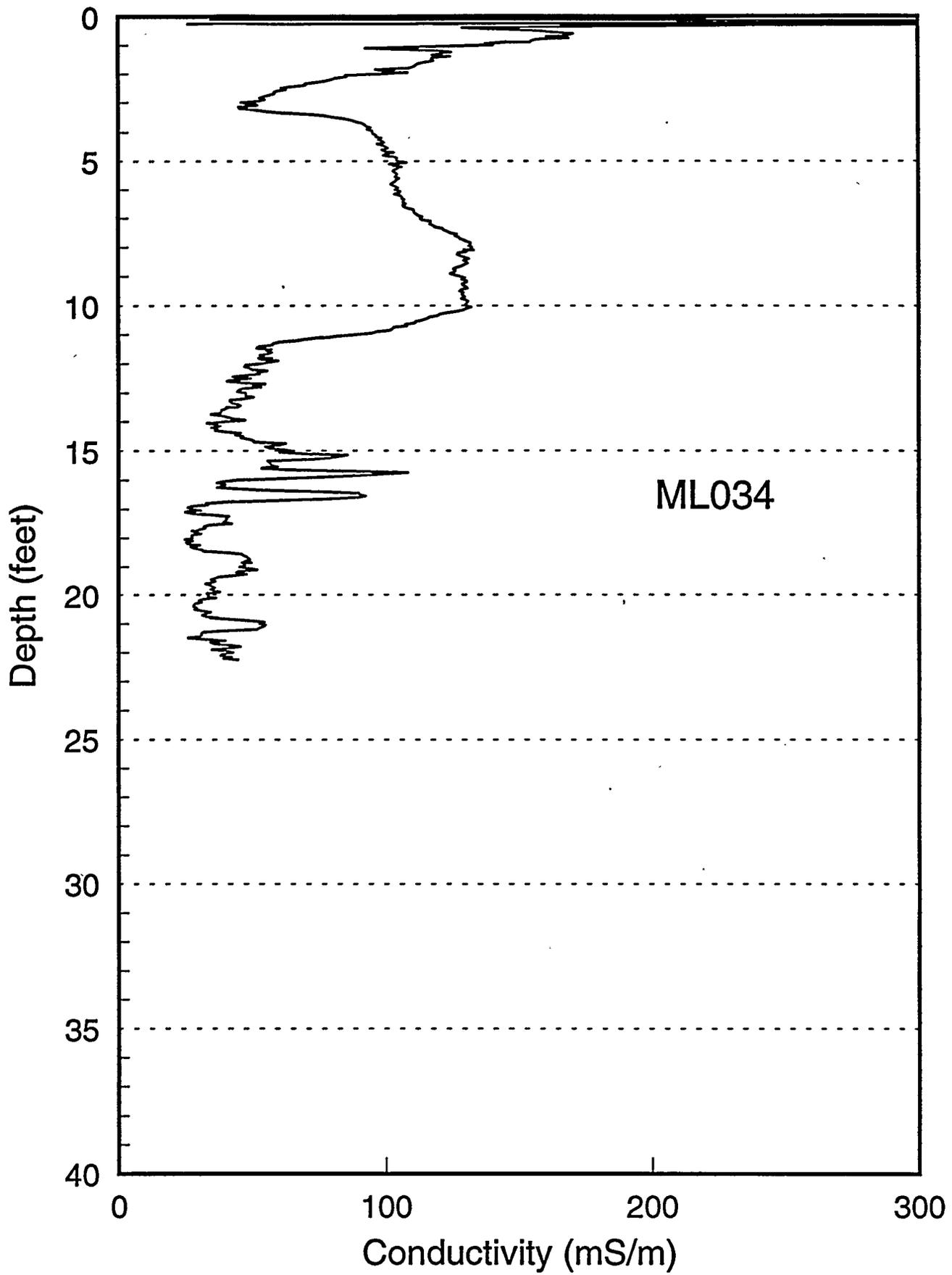
**APPENDIX C: CONDUCTIVITY PROFILES -- CONDUCTIVITY VERSUS
 DEPTH LOGS**

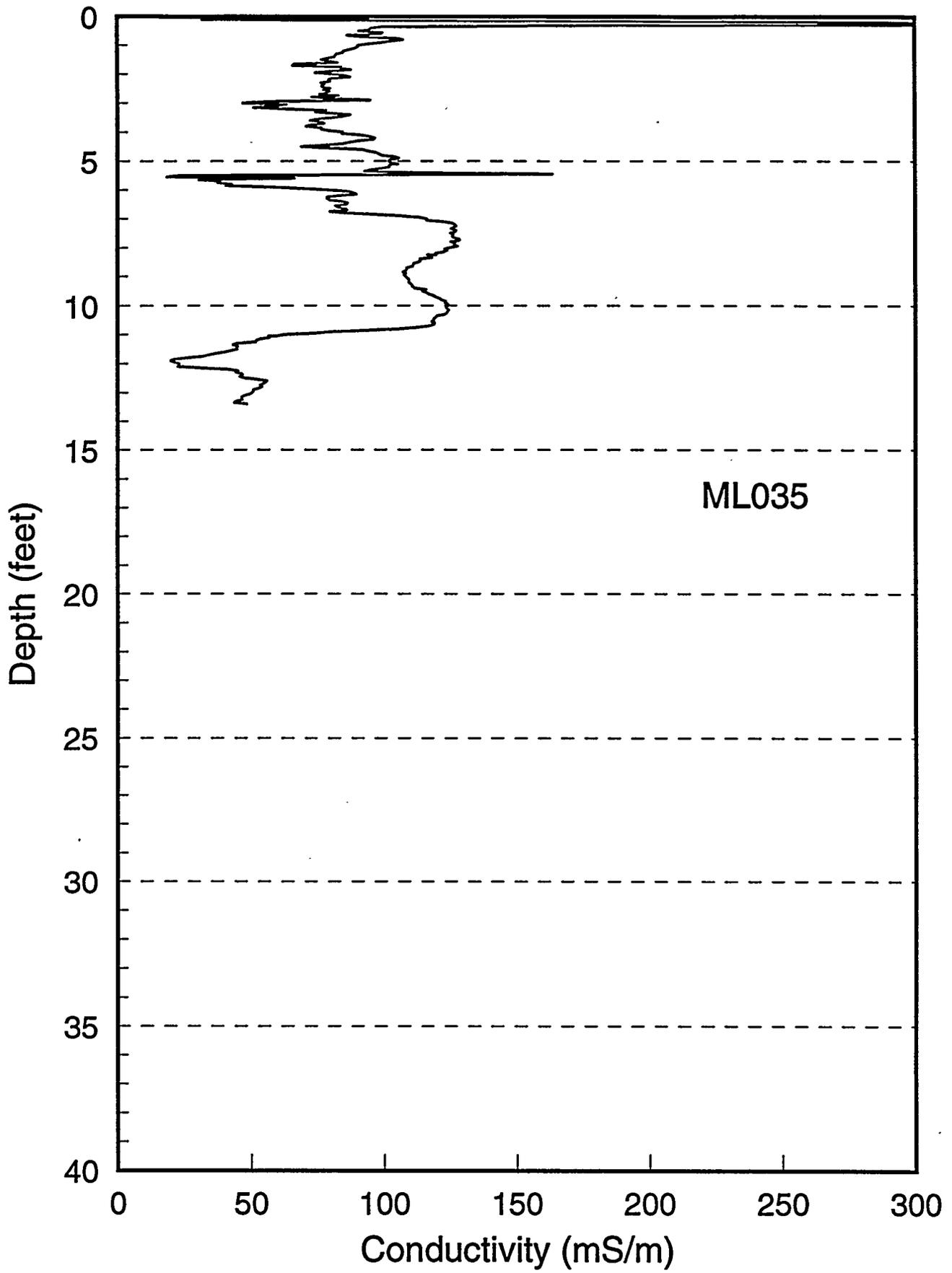


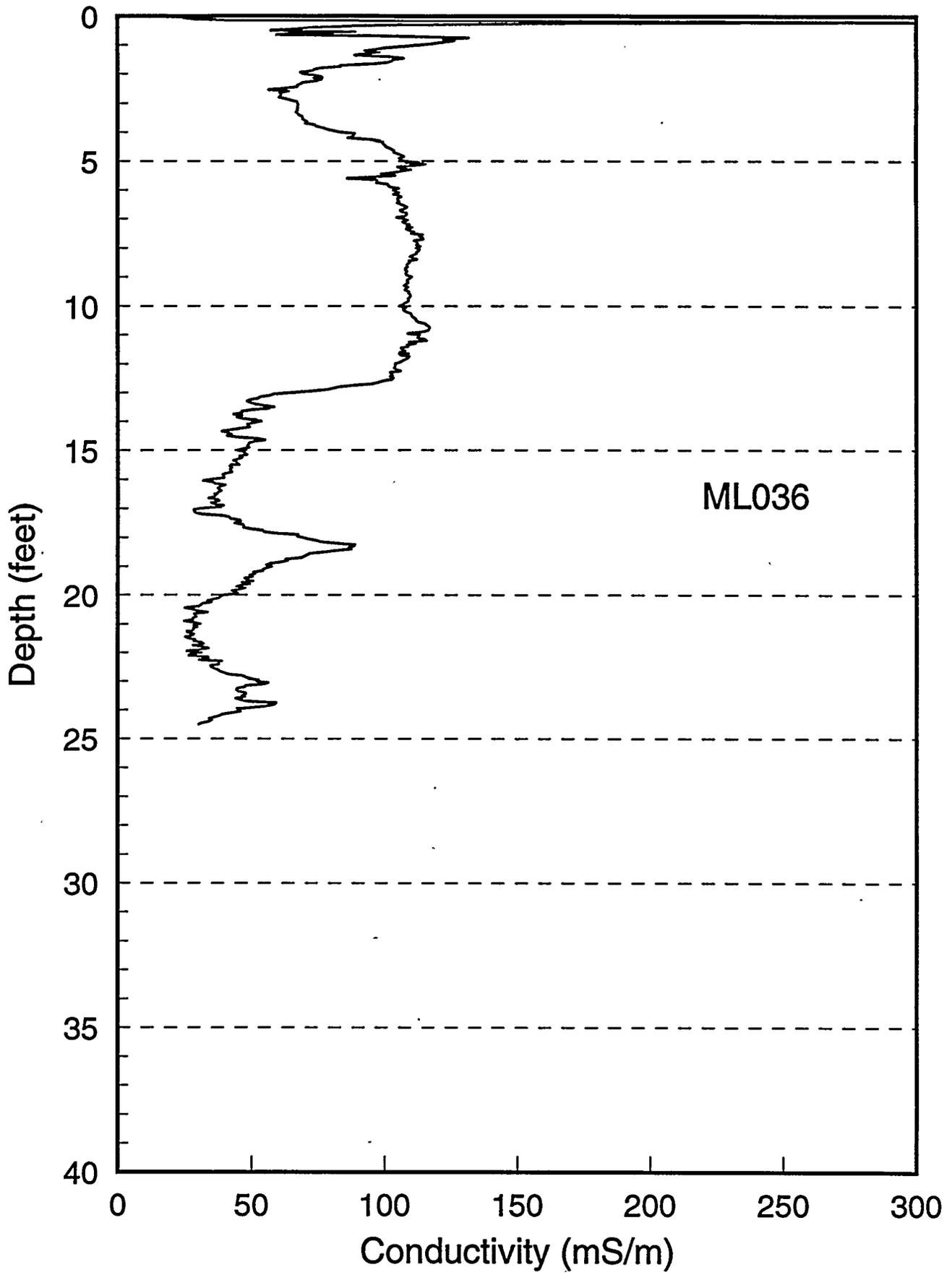


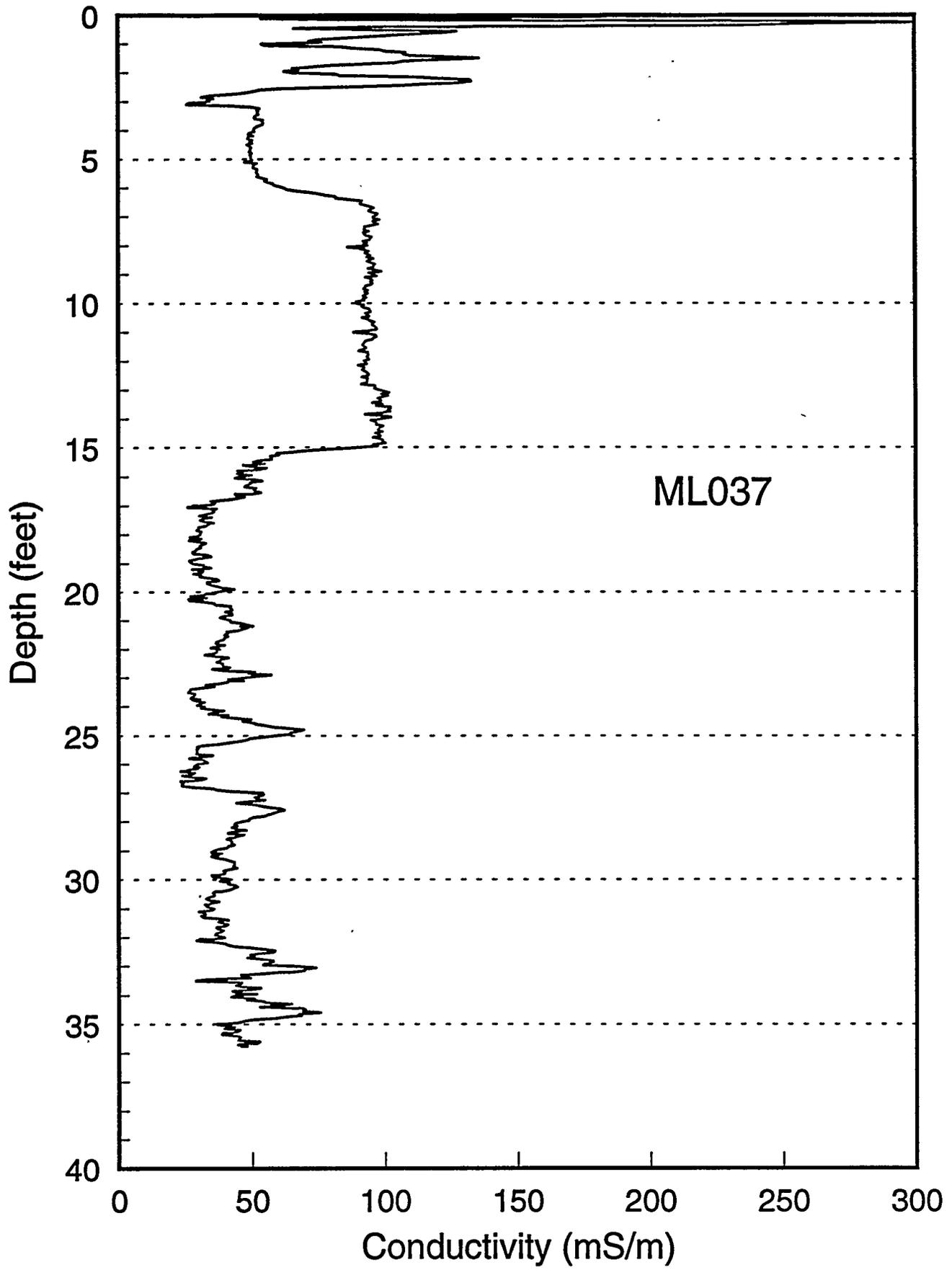


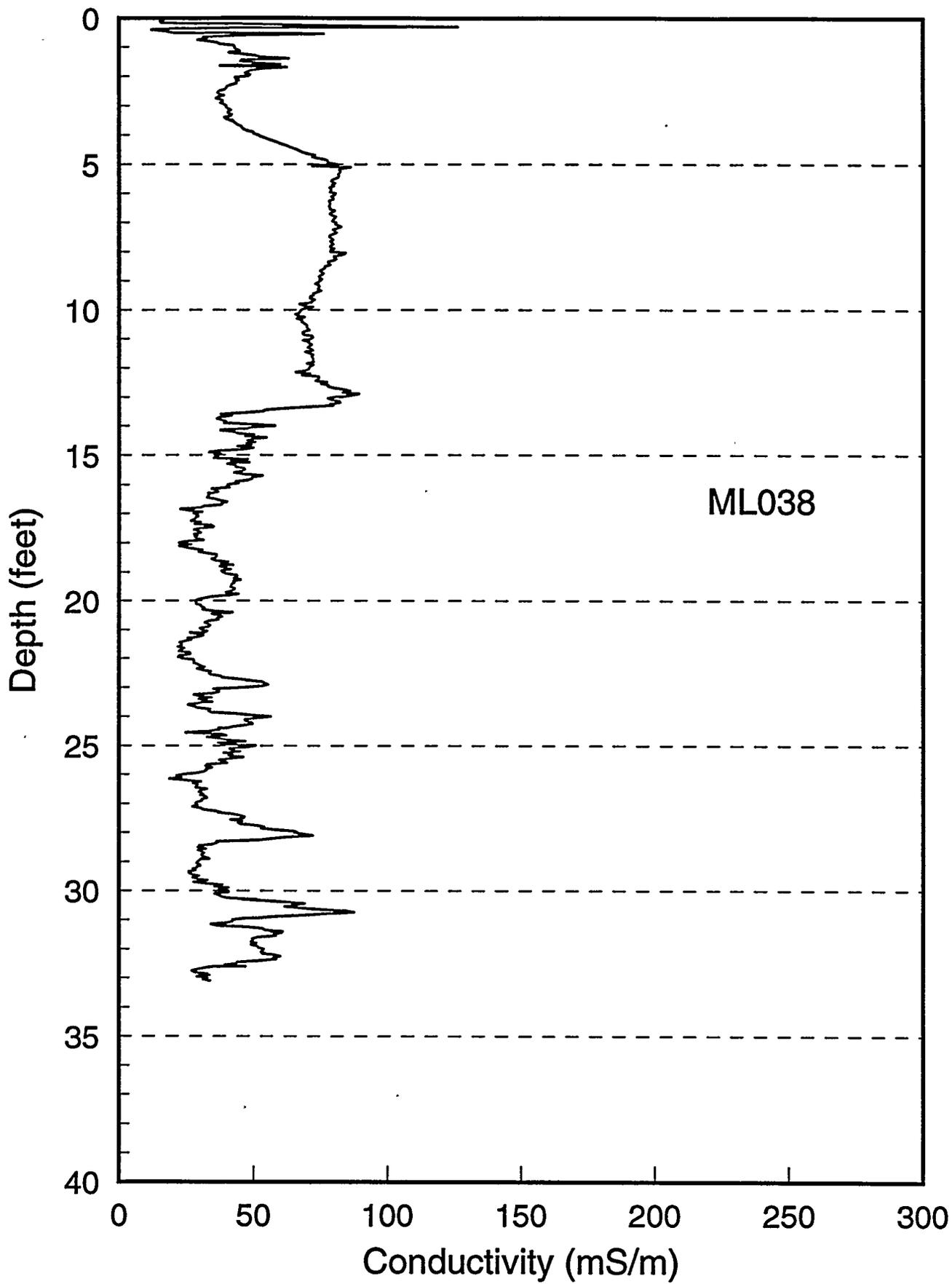


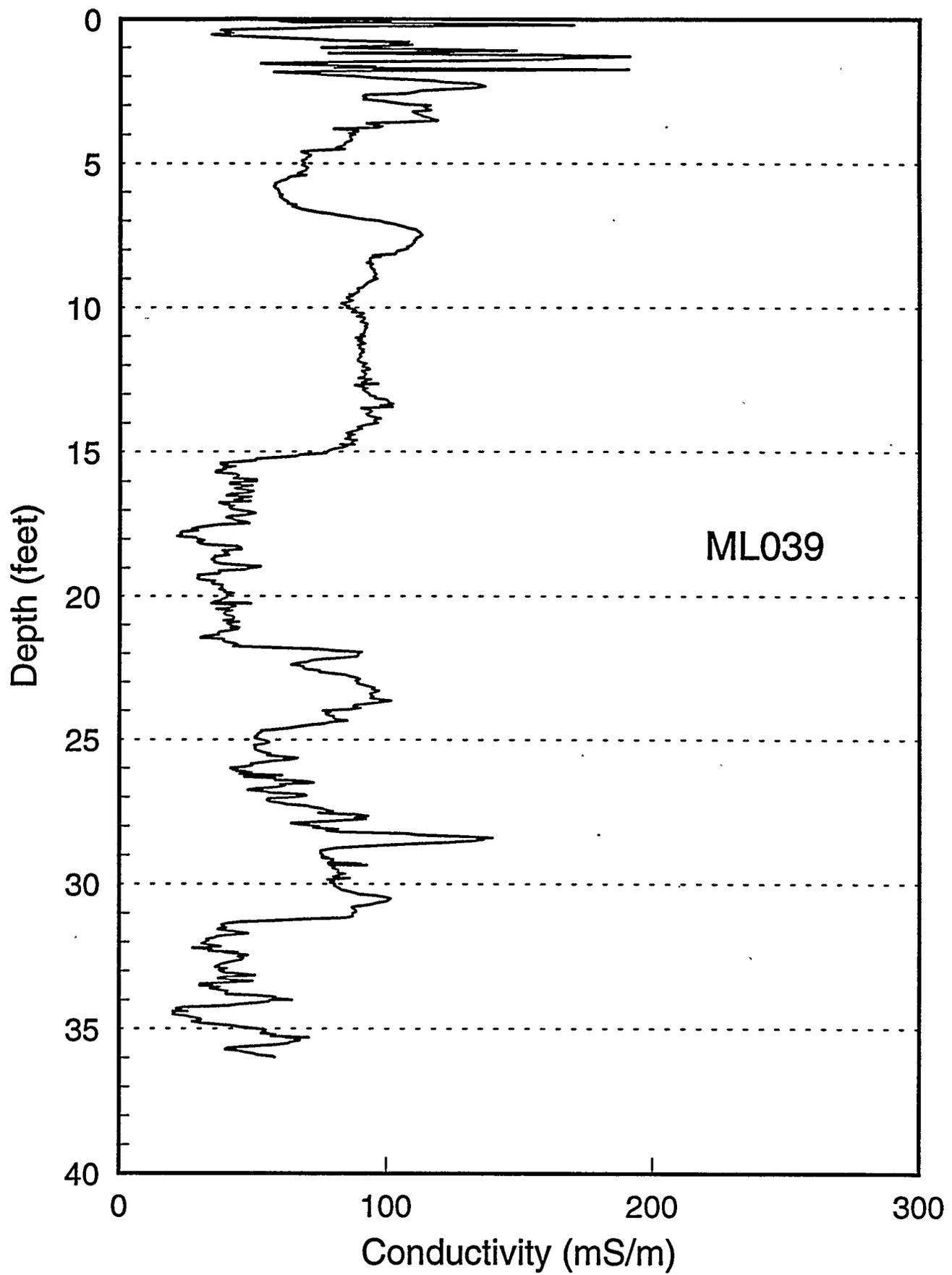


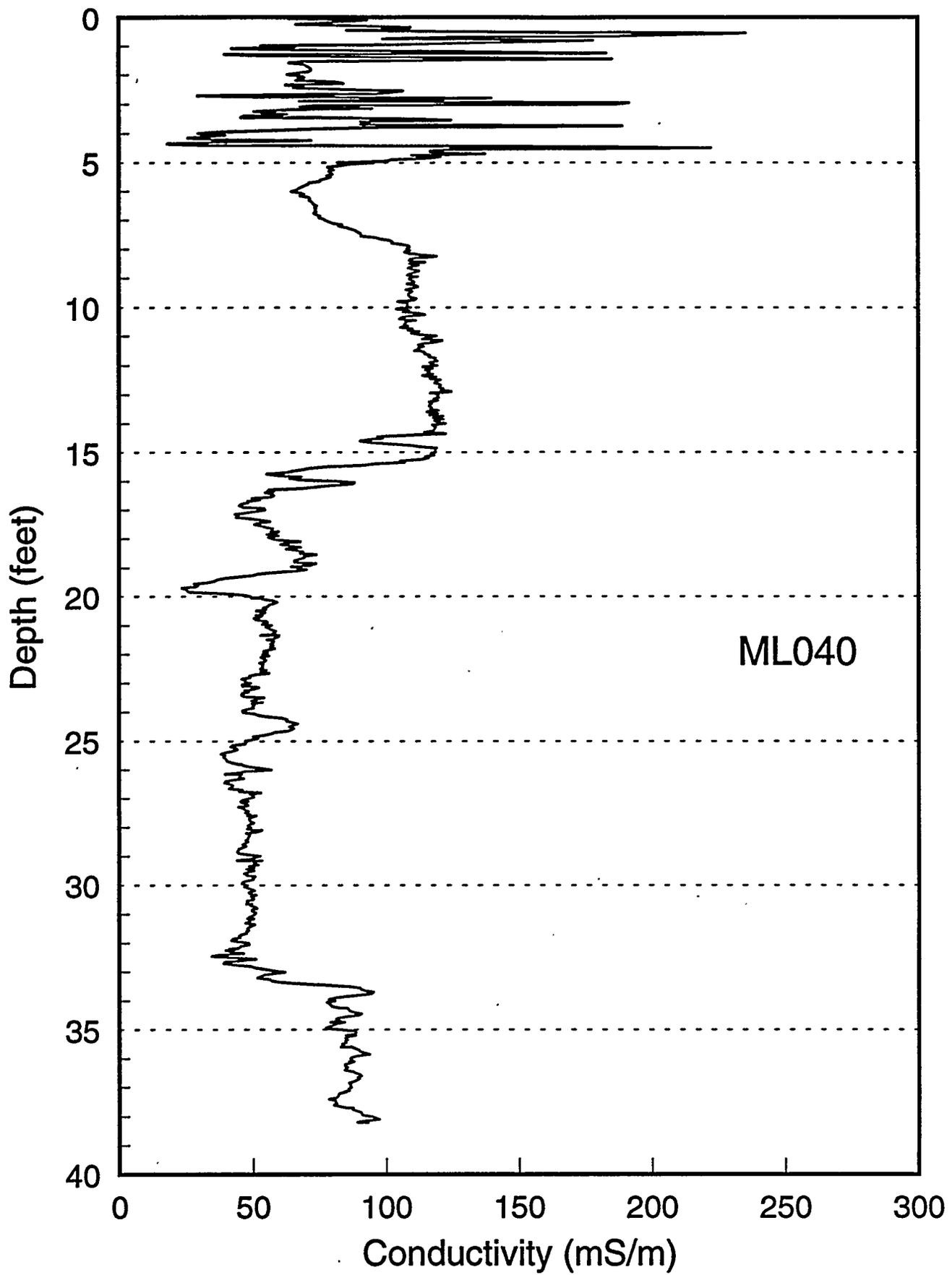


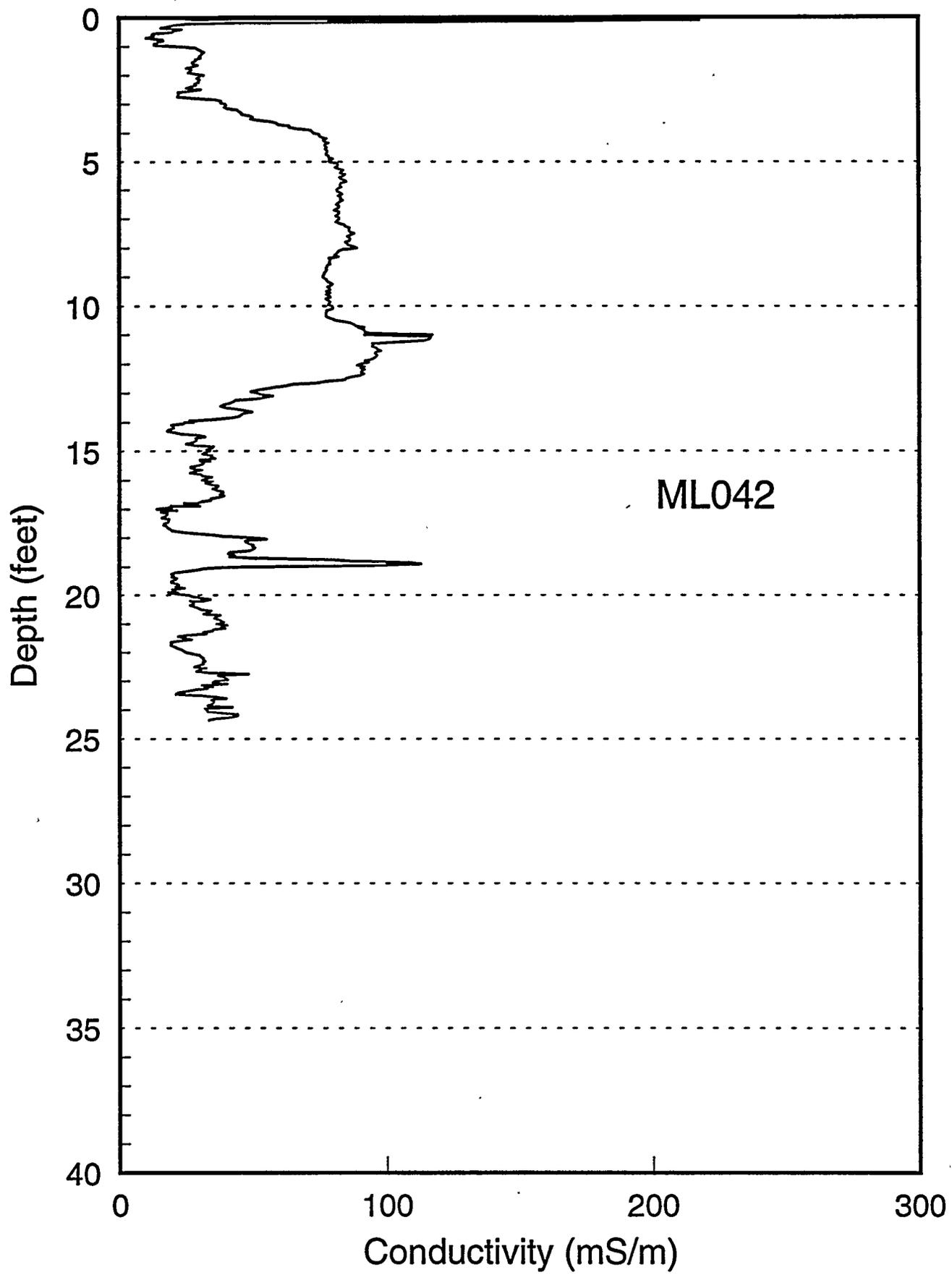


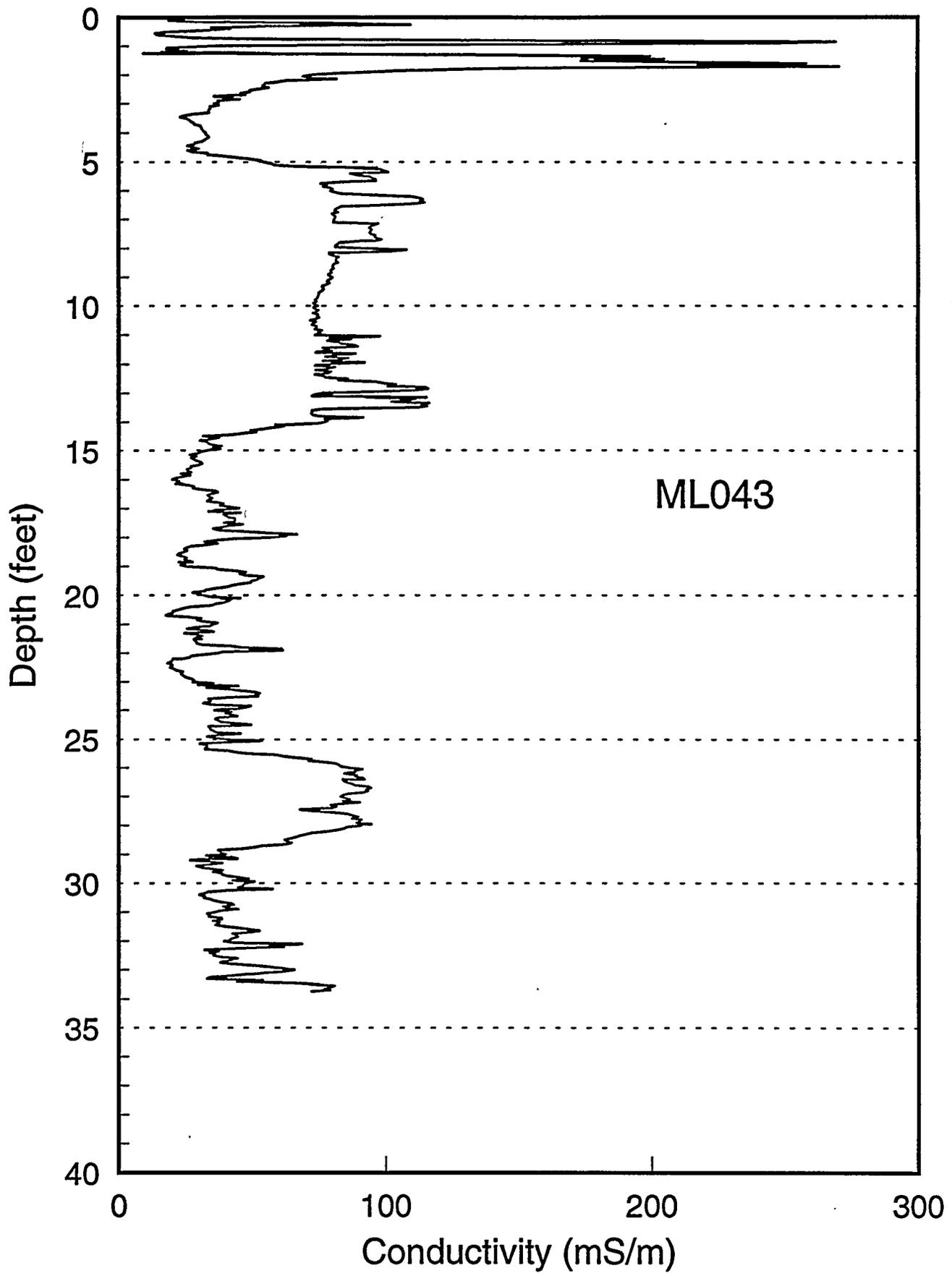


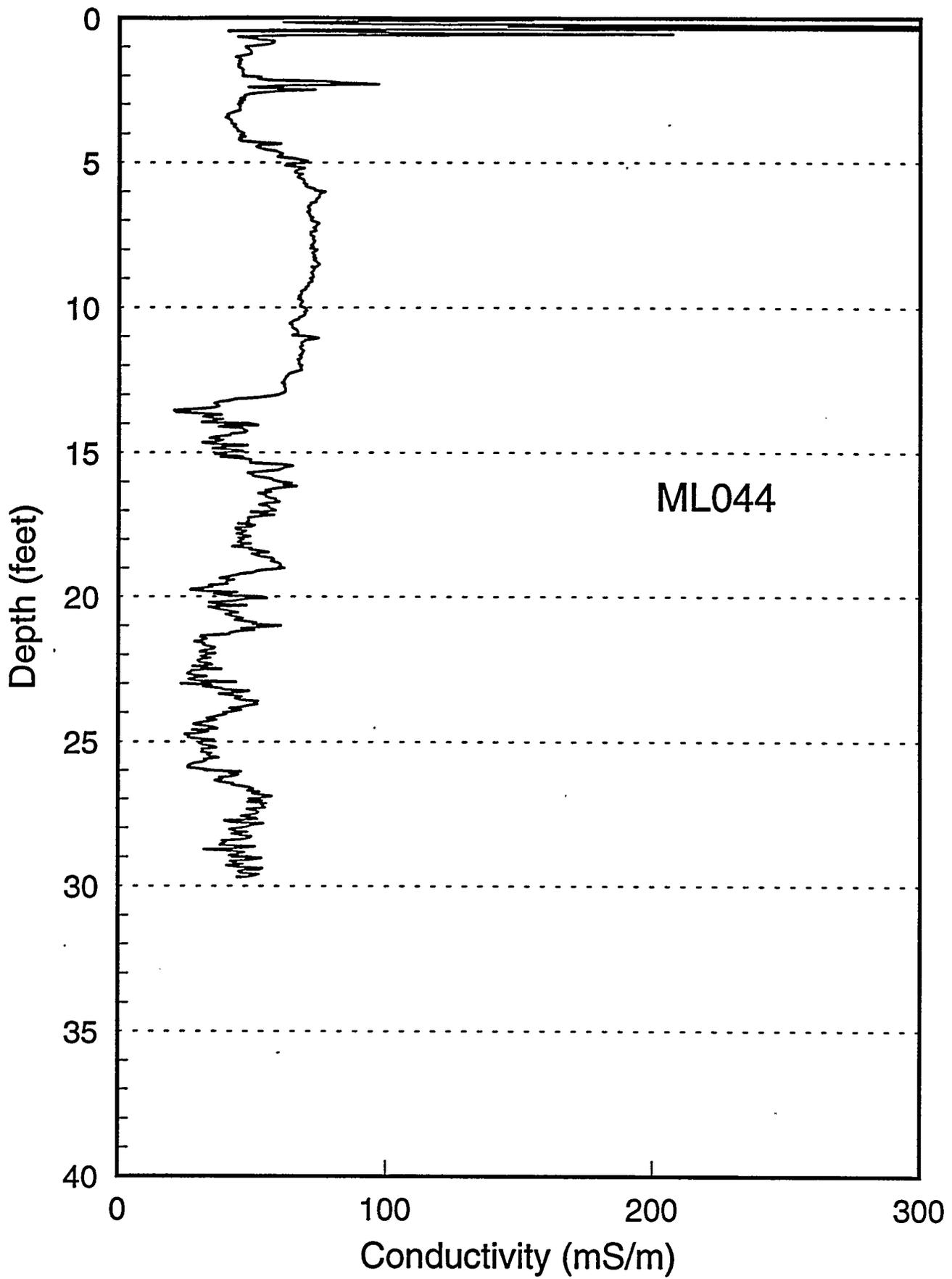


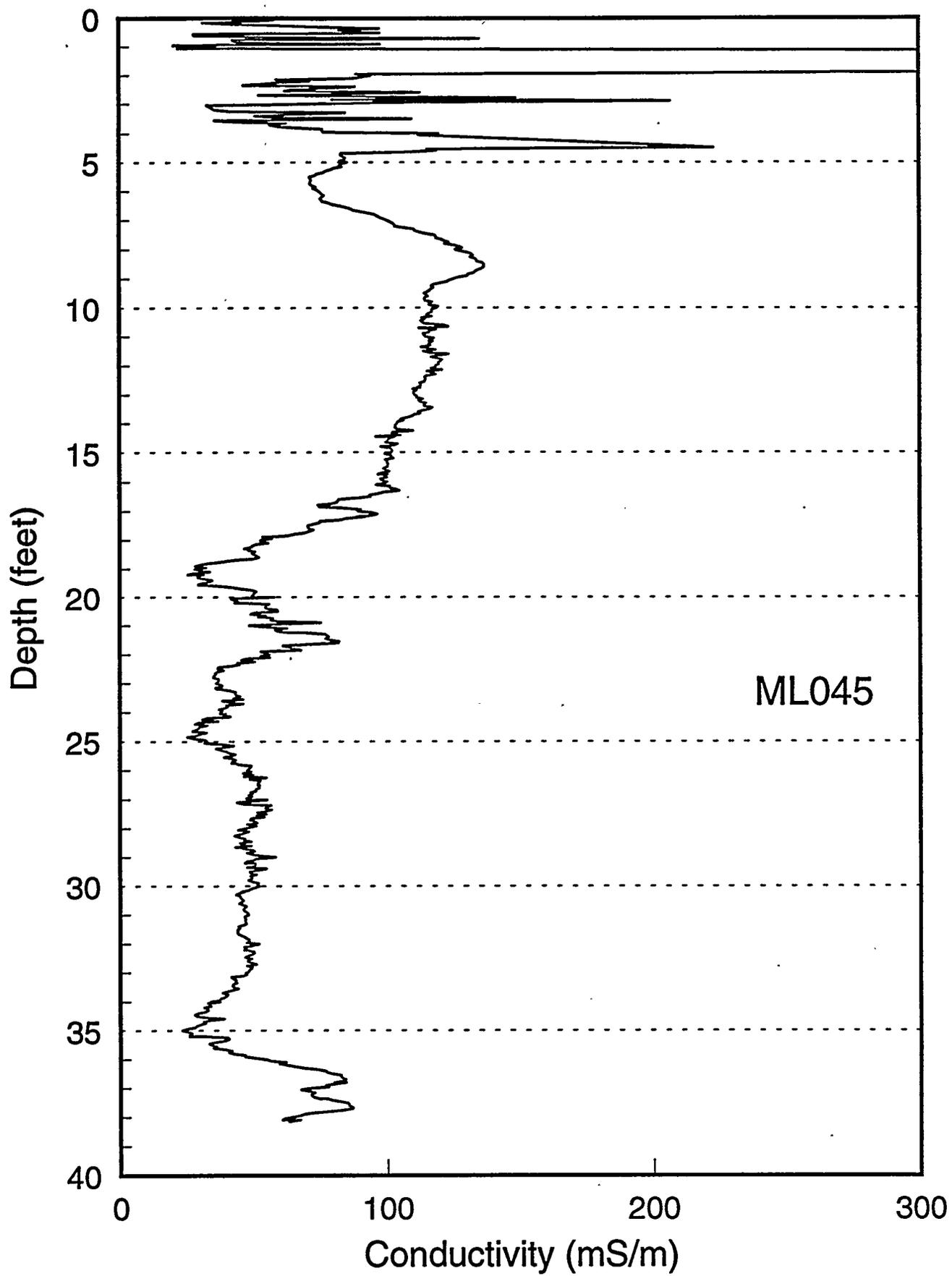


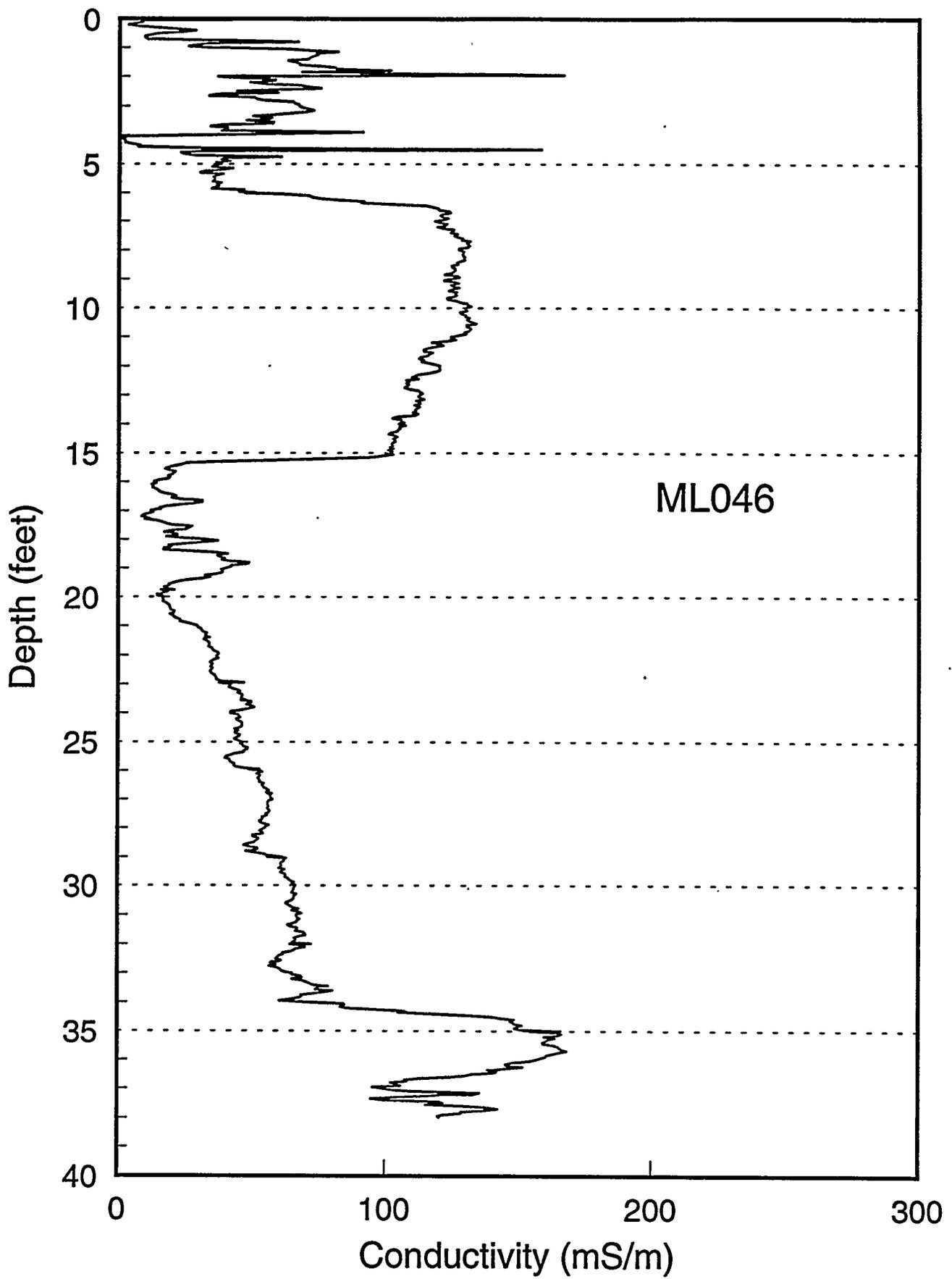


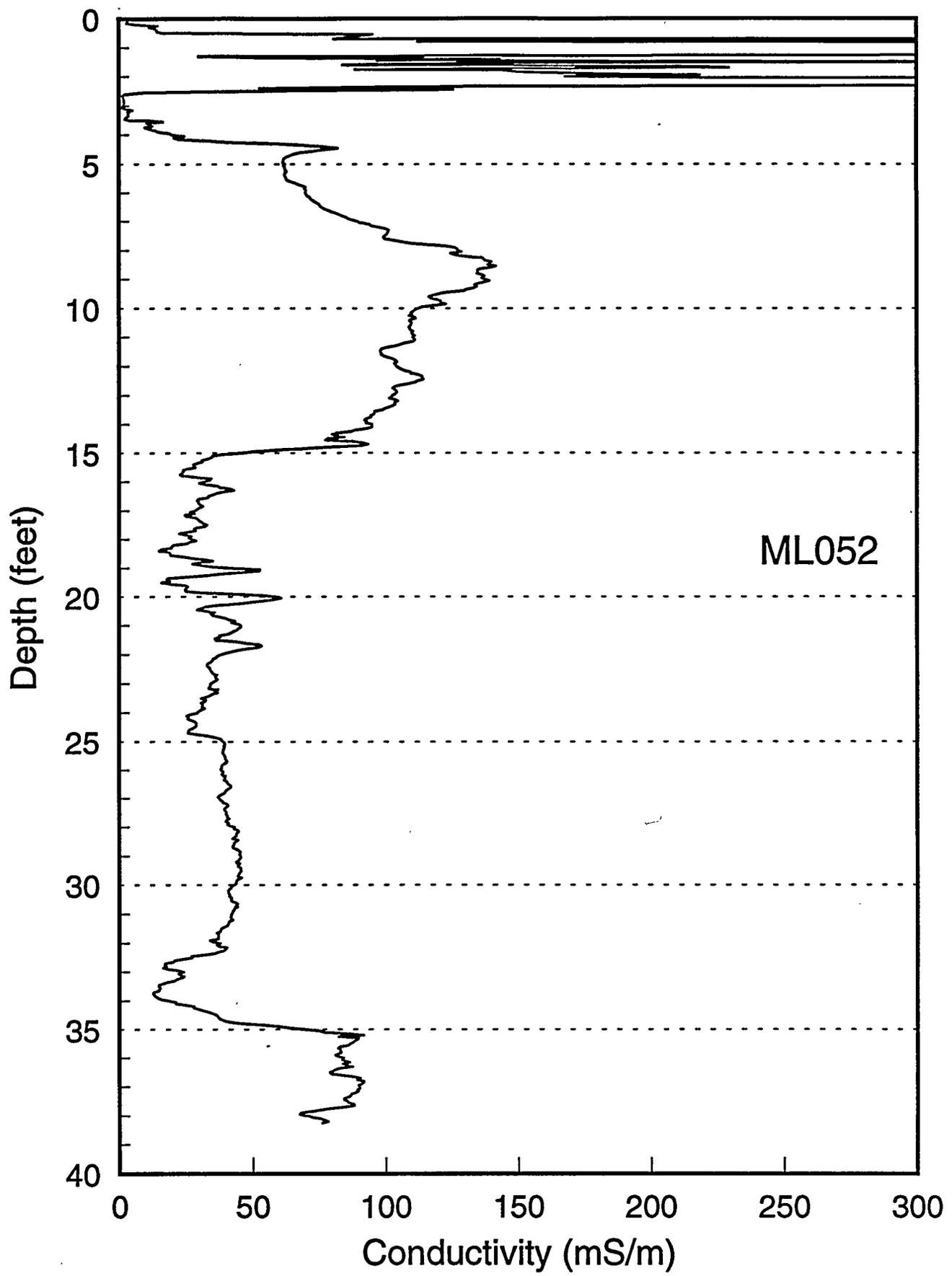


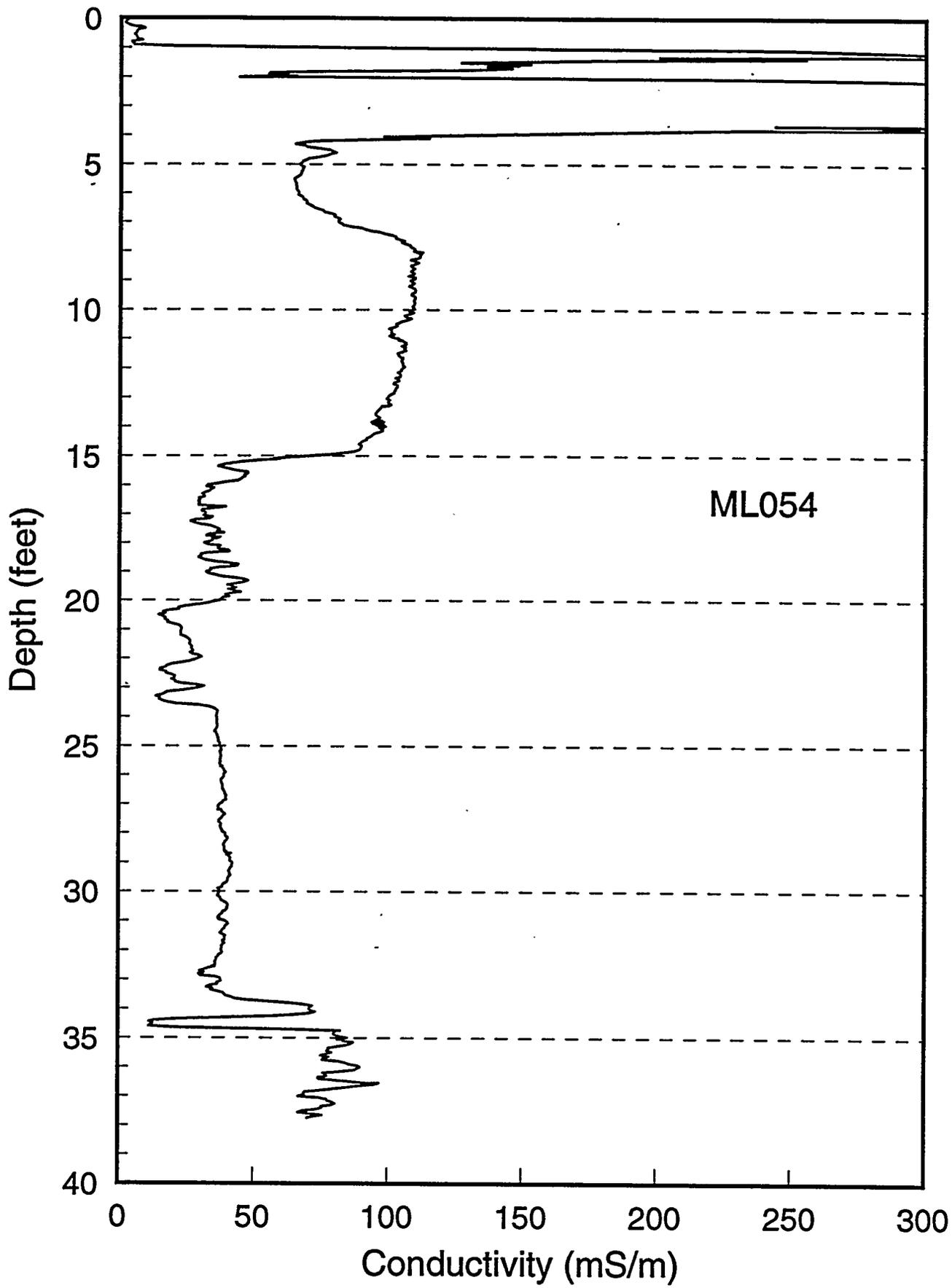


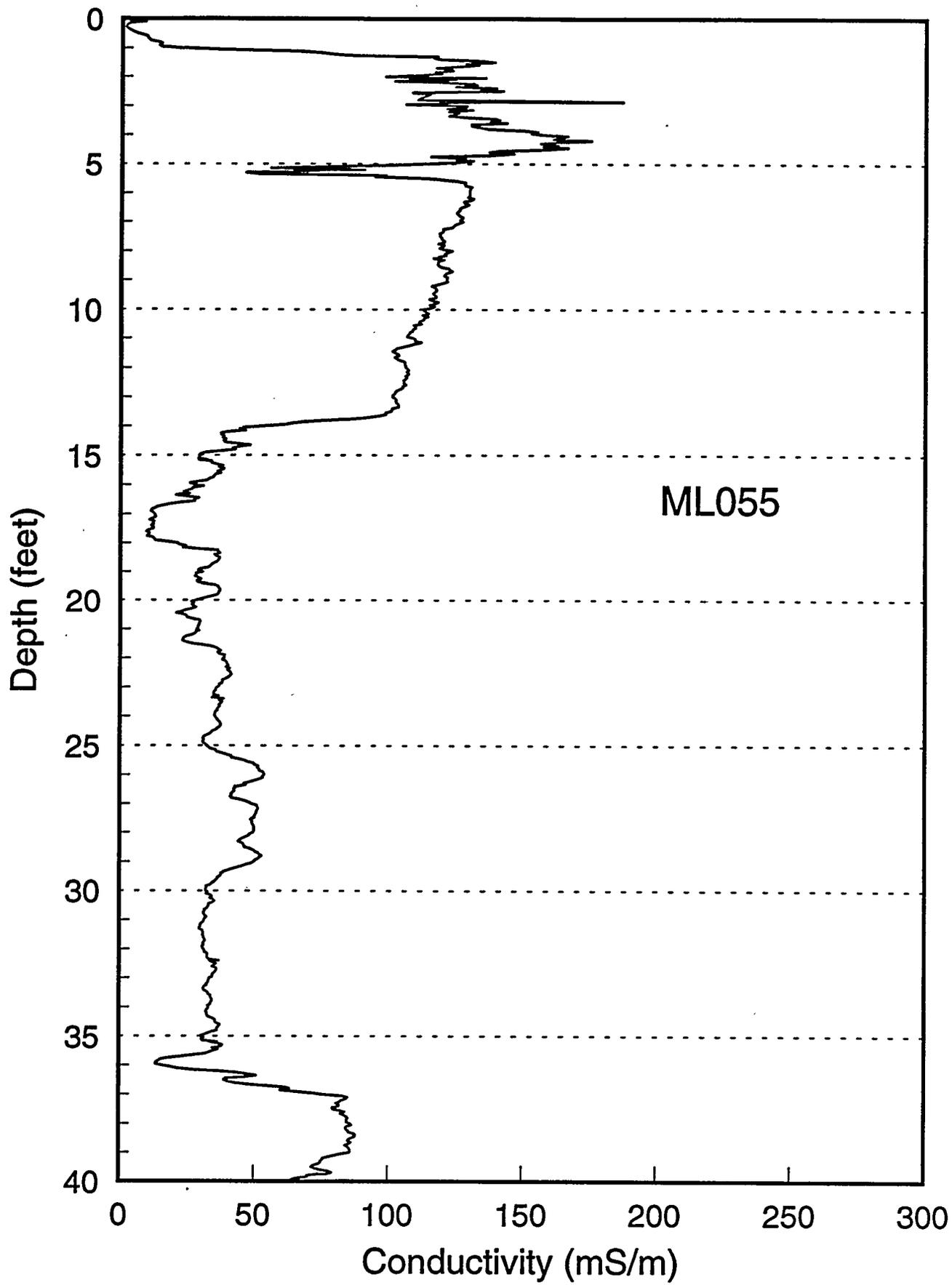


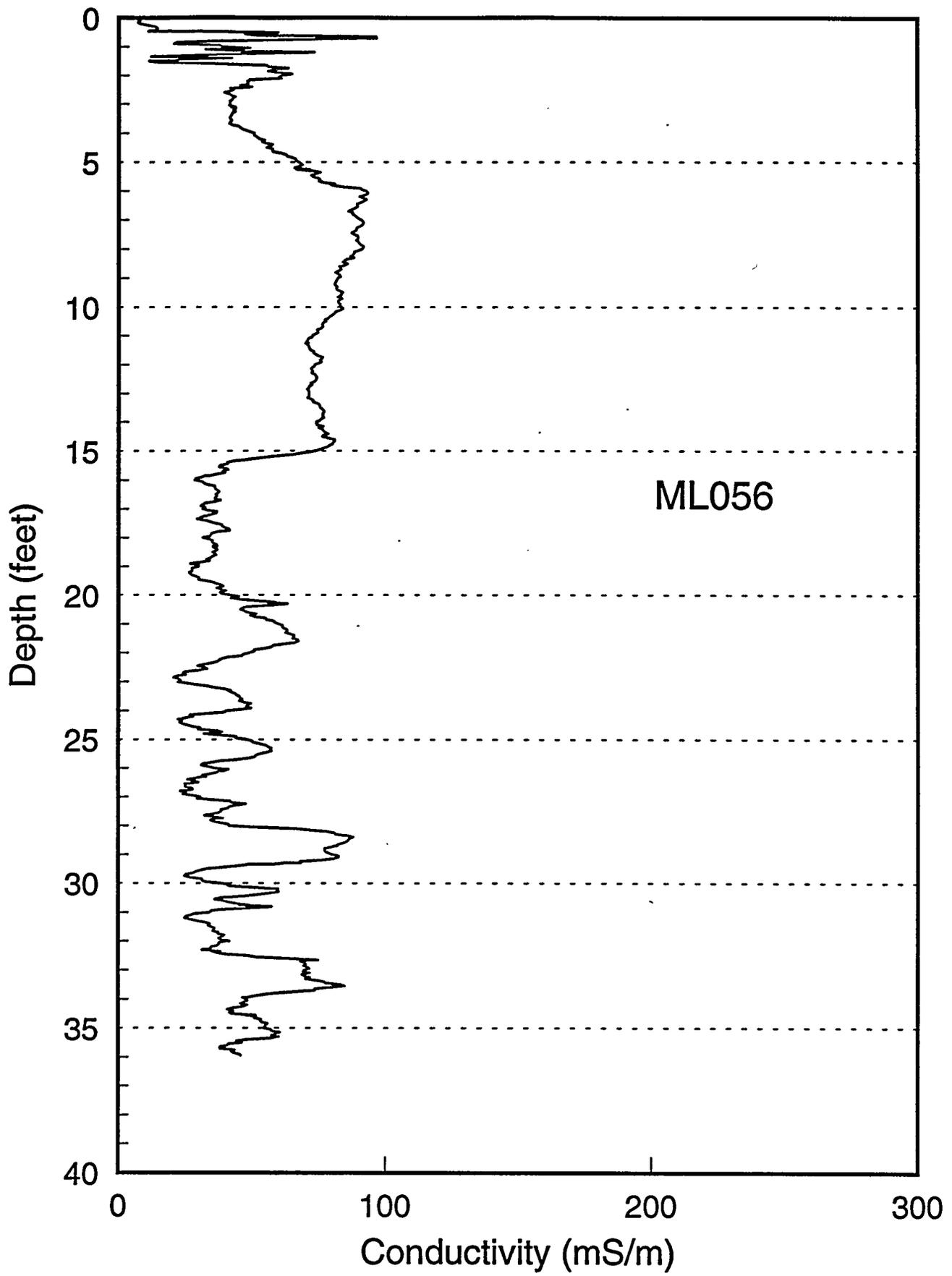


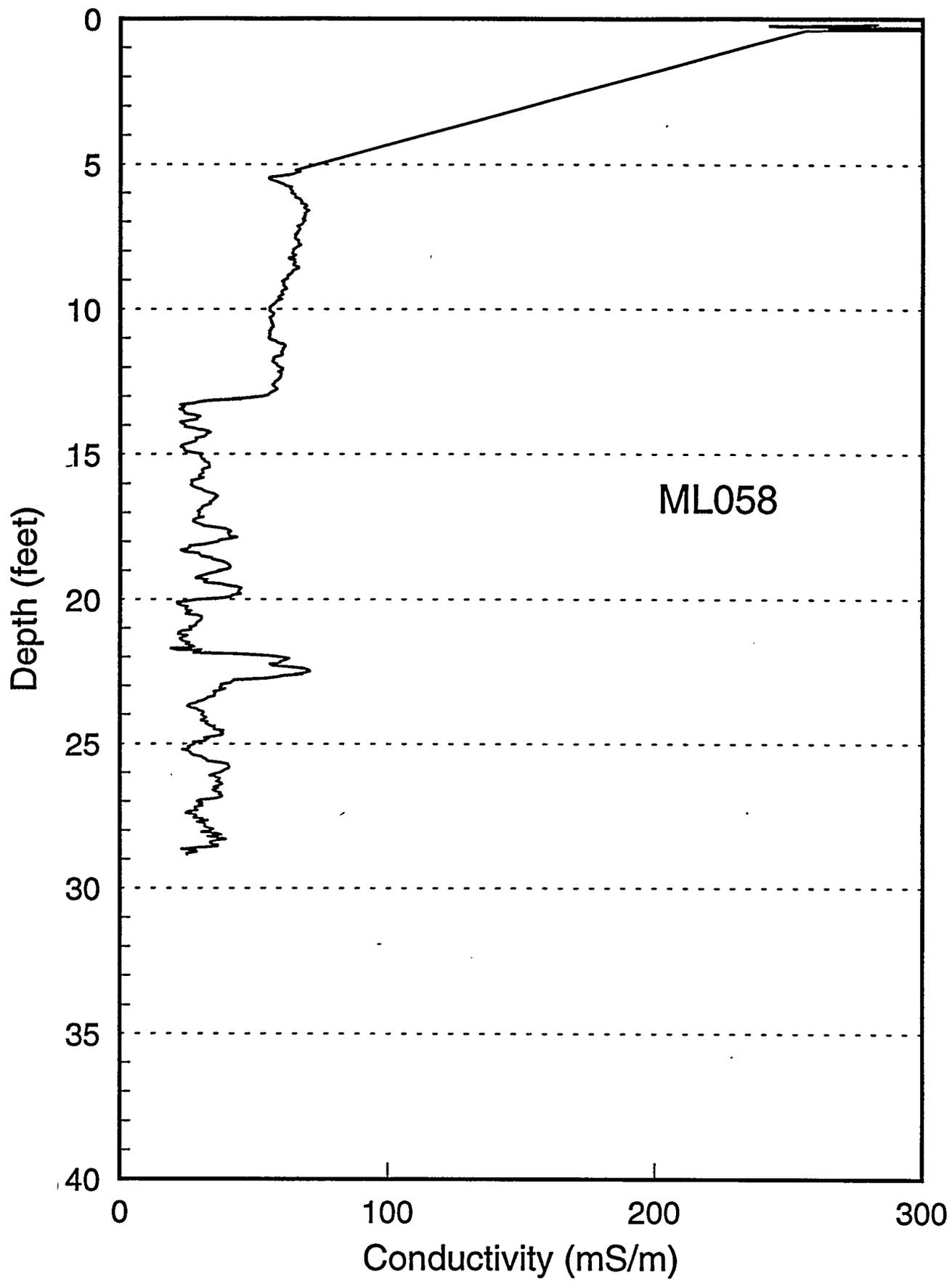


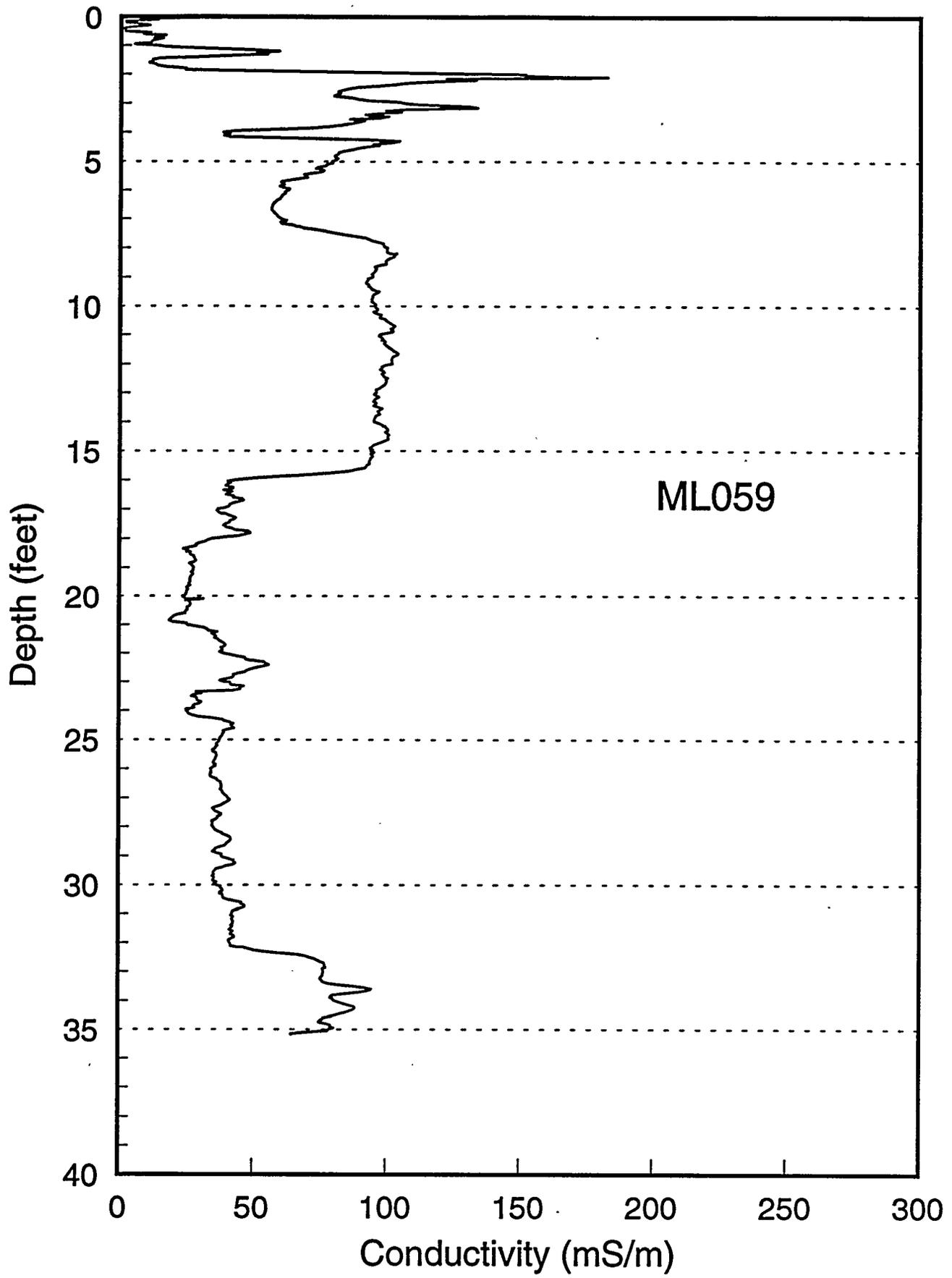


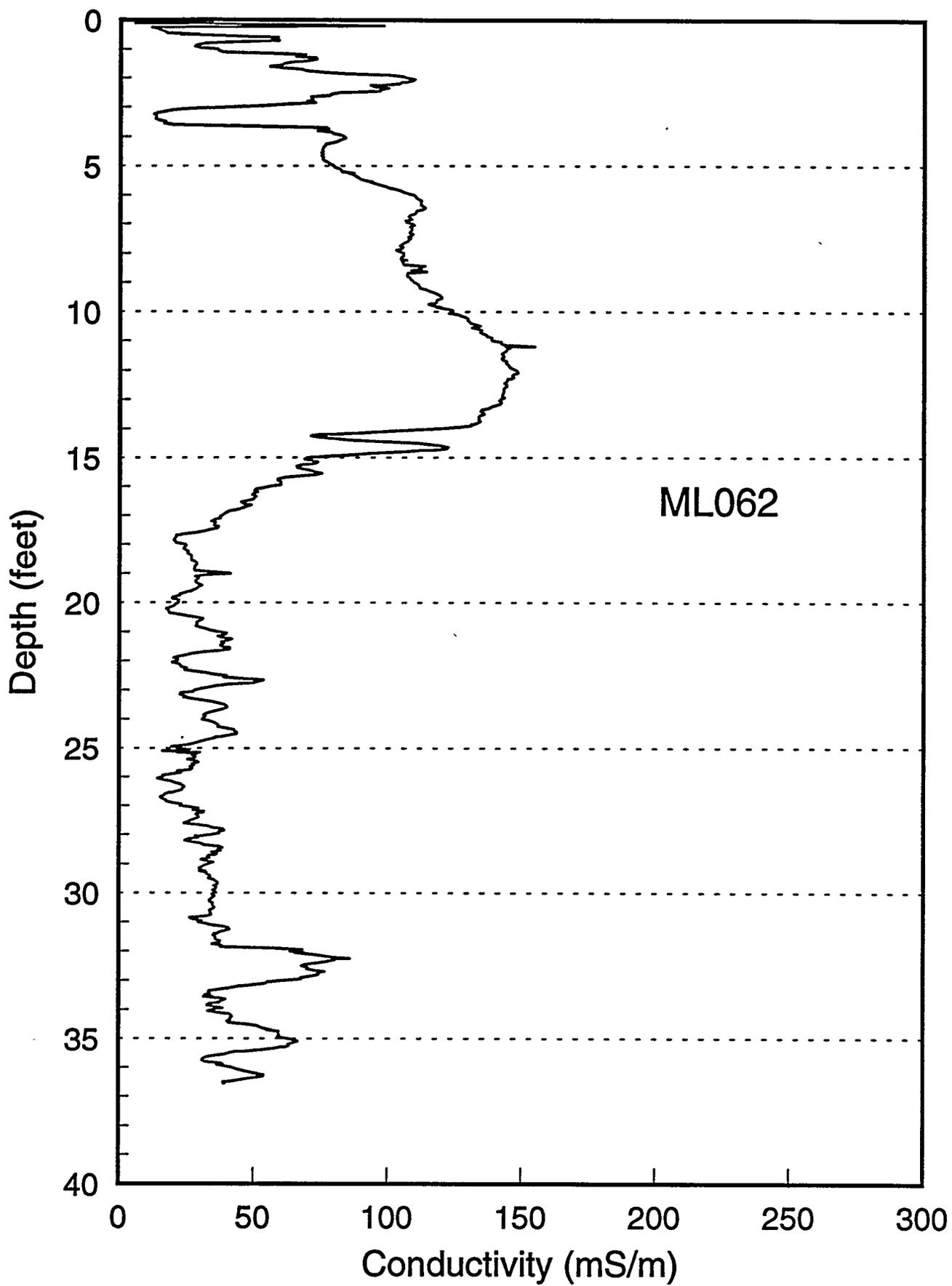


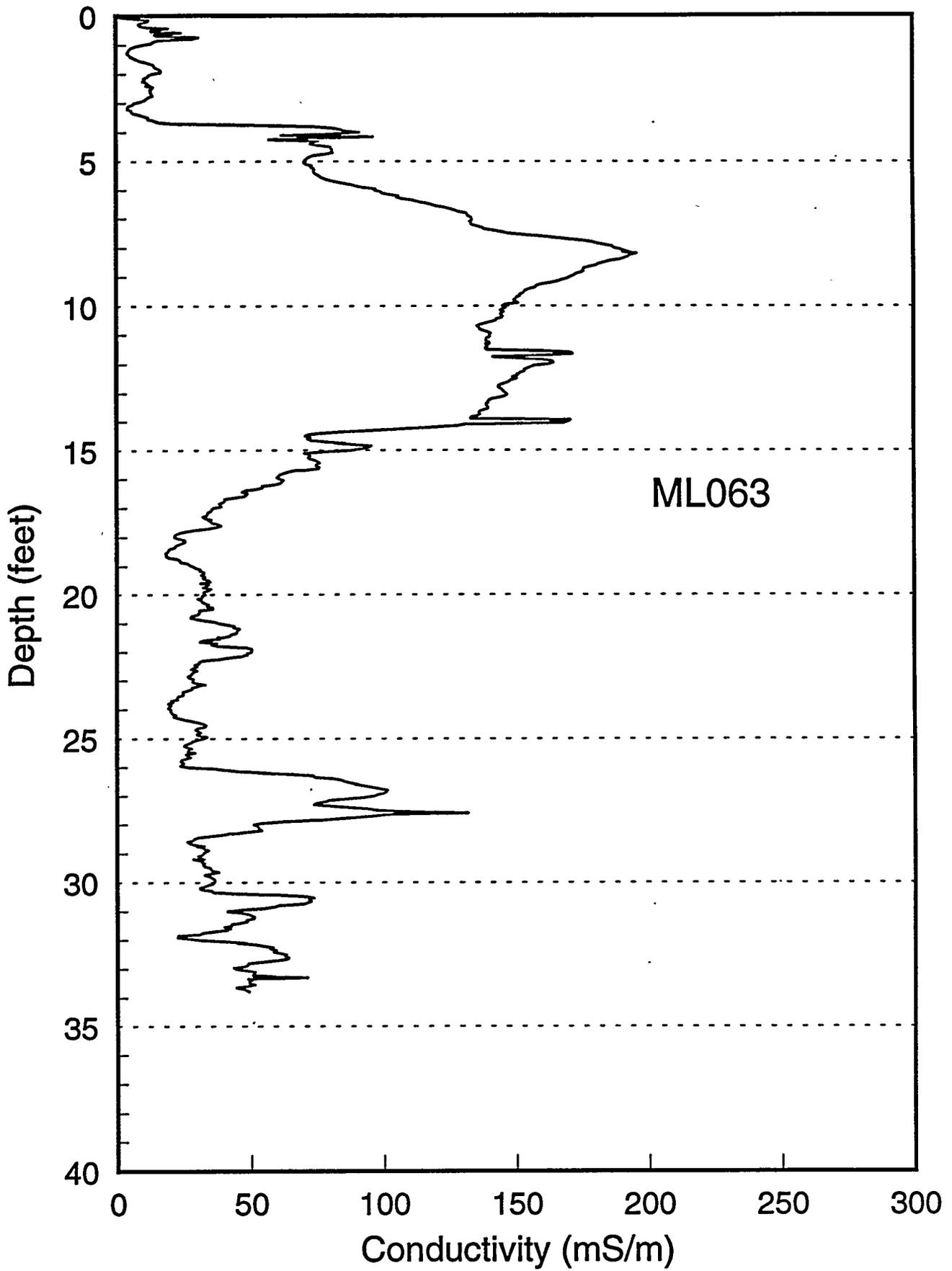


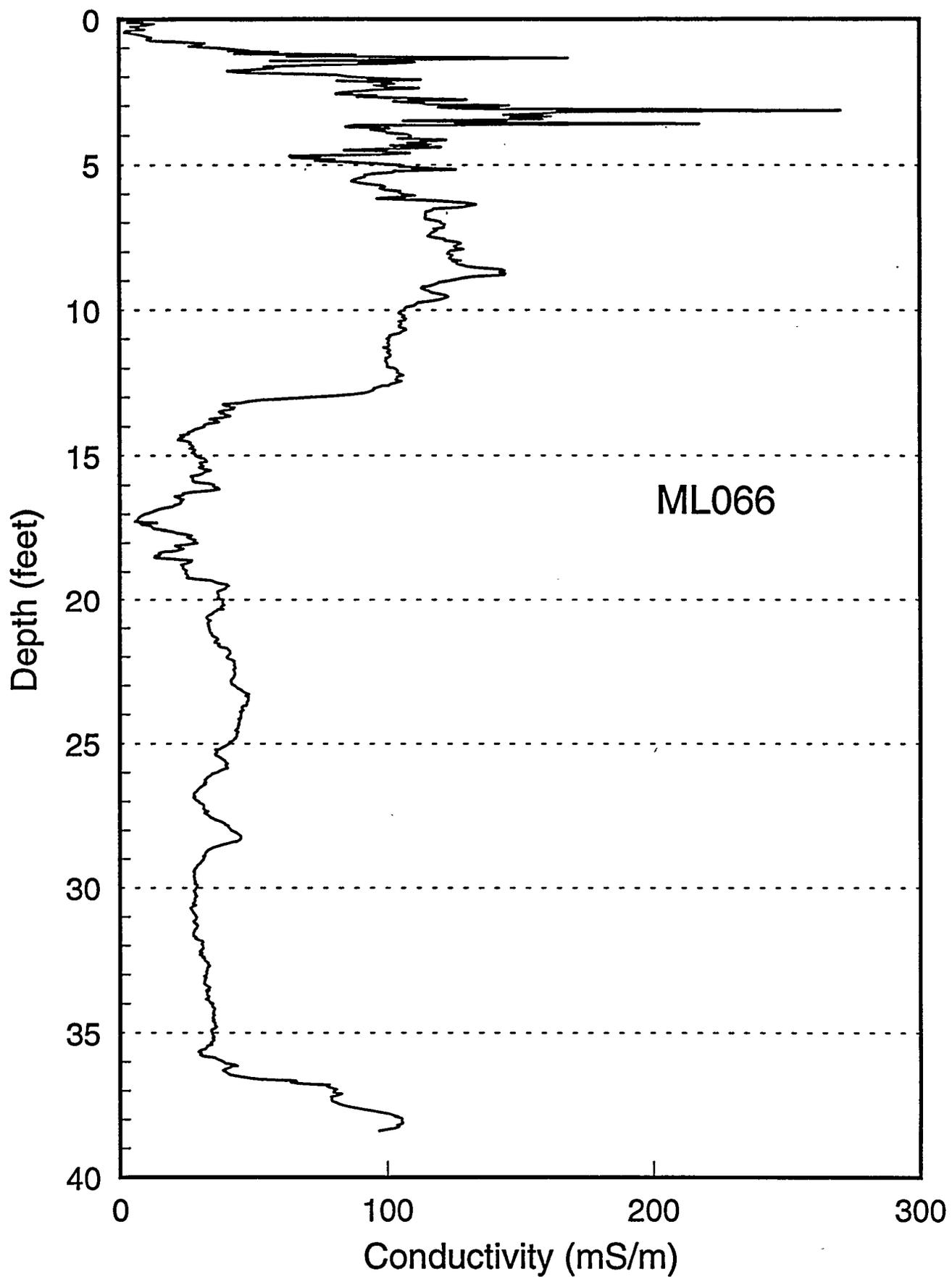


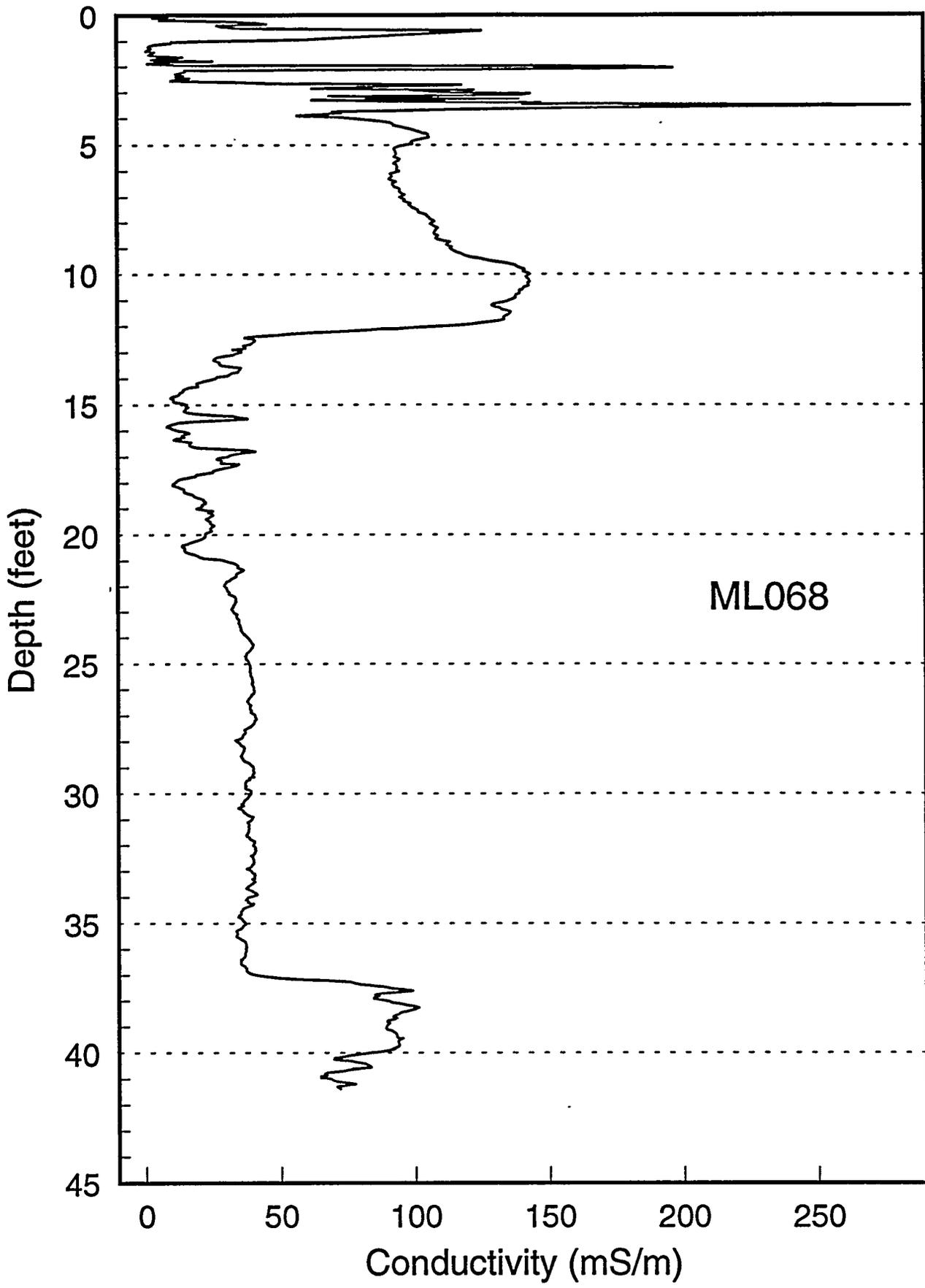


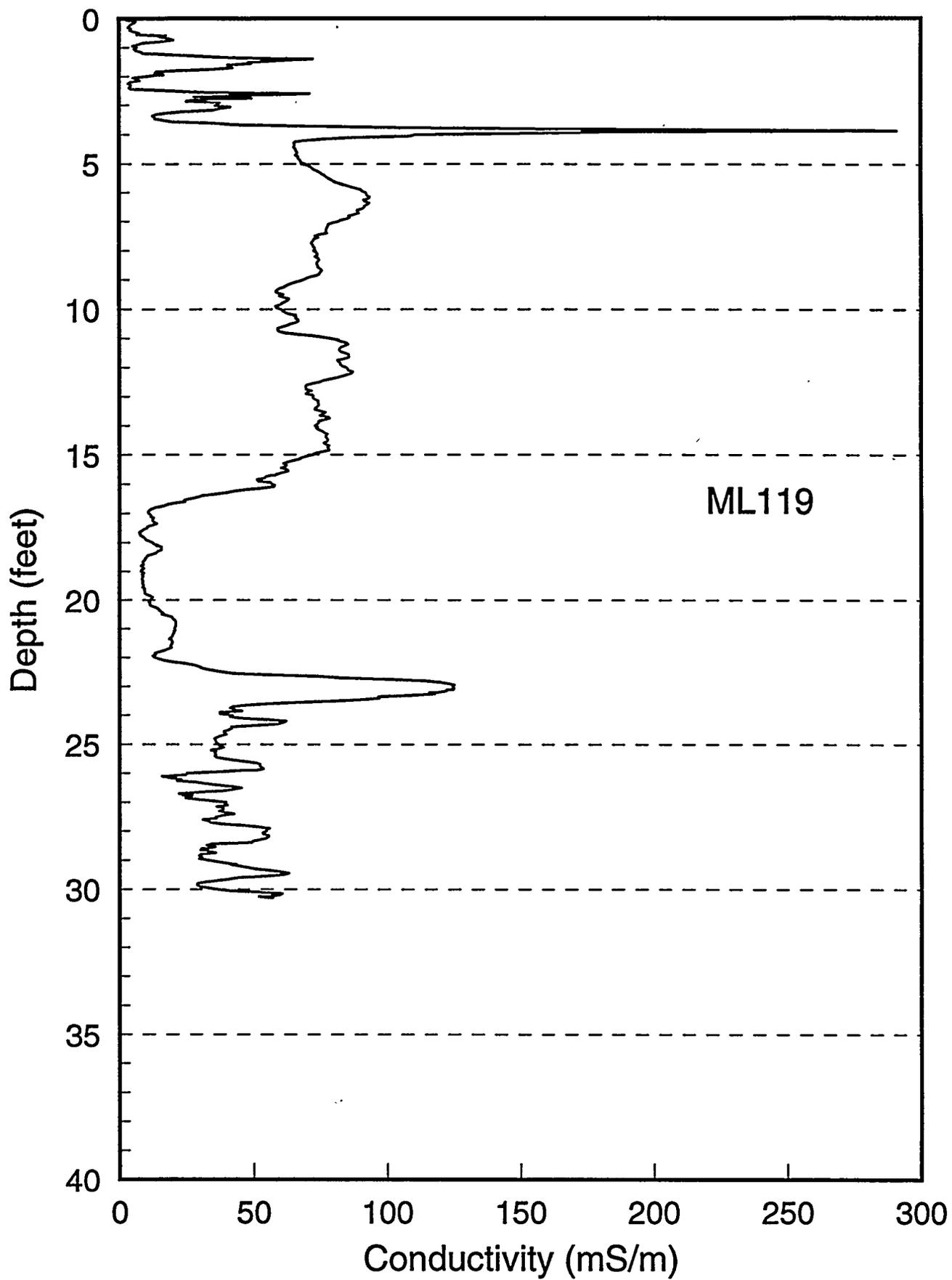


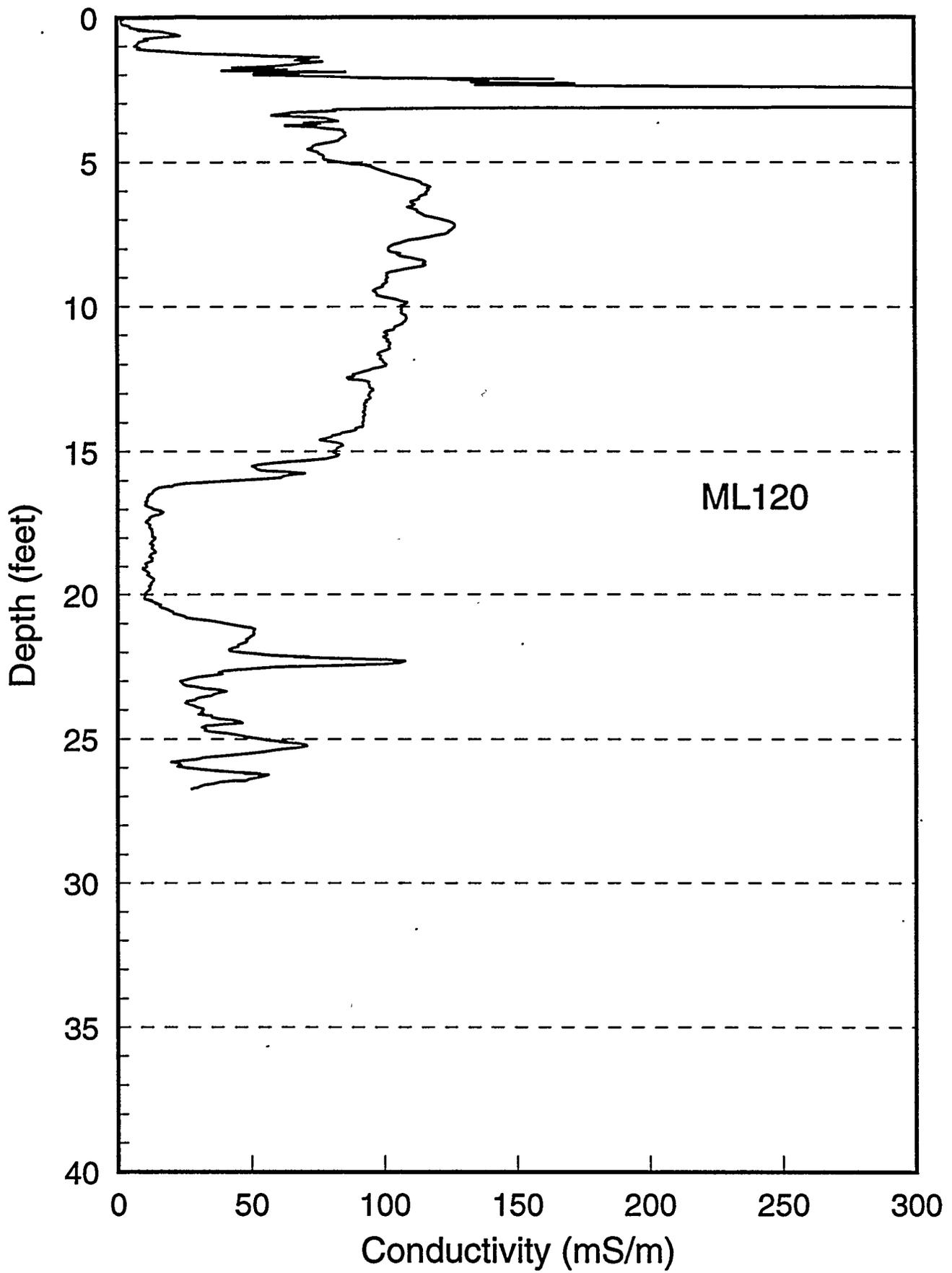


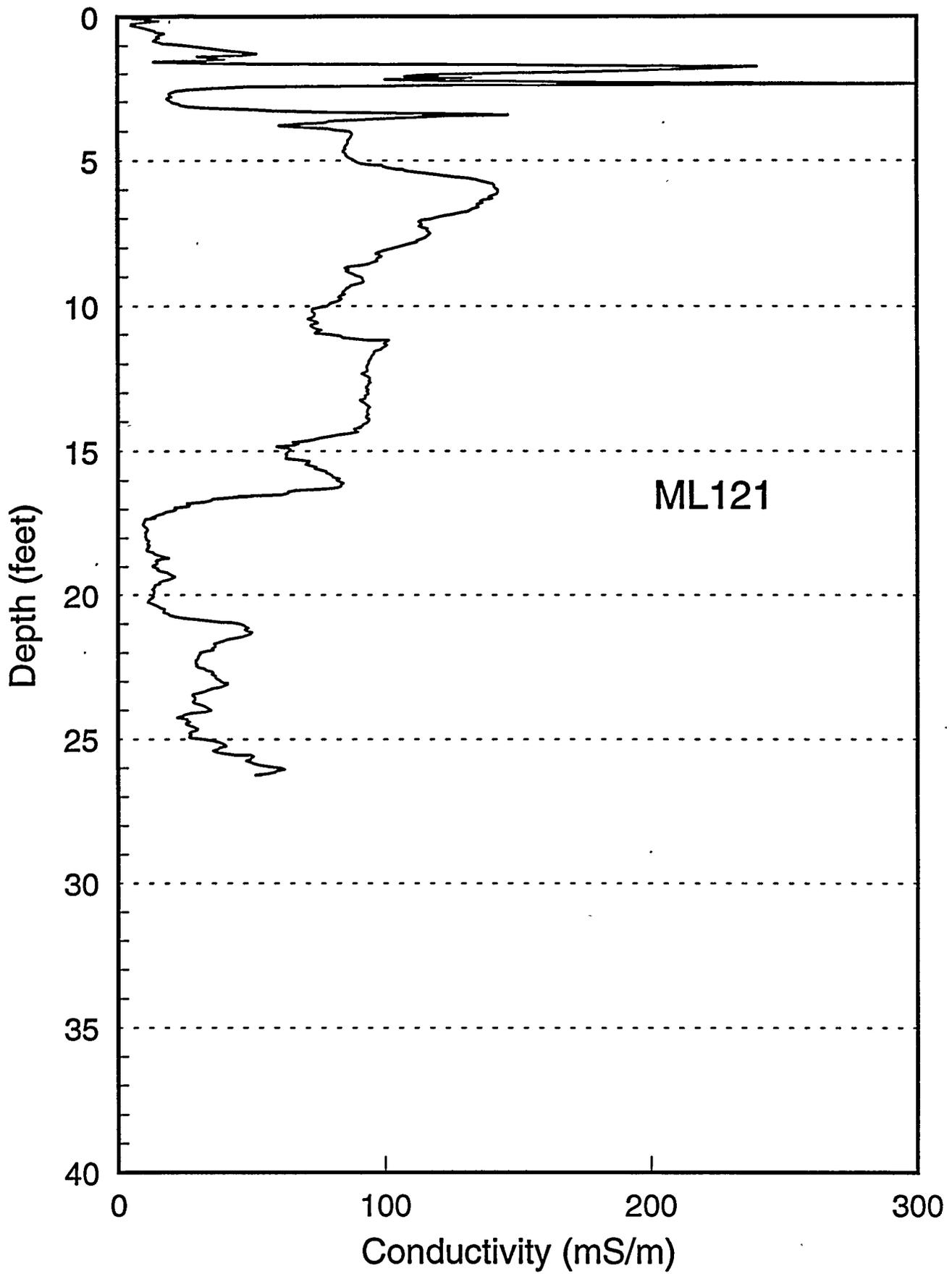












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**APPENDIX D: ANALYTICAL RESULTS OF EACH SAMPLE FOR THE 16
PAHS**

GCMS Data

		Sample Source Information										PAH										Summary	
		Point Location of Sample																					
		Strat Zone																					
Well-ID	SampleID	X	Y	Z	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo[a]anthracene	Crysene	Benzo[b]fluoranthene	Benzo[k]fluoranthene	Benzo[e]pyrene	Indeno[1,2,3-cd]perylene	Dibenz[a,h]anthracene	Benzo[ghi]perylene	Total PAH	Total Carcinogenic PAH	
MT-2-G006.2	Avg	806.0	519.0	871.5	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	A	ML038	'MT-2-G006.2'	806.0	519.0	871.5	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	B	ML038	'MT-2-G007'	806.0	519.0	862.5	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	C	ML038	'MT-2-G007'	806.0	519.0	862.5	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	D	ML038	'MT-2-G007'	806.0	519.0	862.5	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	E	ML038	'MT-2-G007'	806.0	519.0	862.5	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	Avg	ML038	'MT-2-G007'	806.0	519.0	862.5	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	A	ML039	'MT-2-G008'	792.0	481.0	876.1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	B	ML039	'MT-2-G008'	792.0	481.0	876.1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	C	ML039	'MT-2-G008'	792.0	481.0	876.1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	D	ML039	'MT-2-G008'	792.0	481.0	876.1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	E	ML039	'MT-2-G008'	792.0	481.0	876.1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	Avg	ML039	'MT-2-G008'	792.0	481.0	876.1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	A	ML039	'MT-2-G009'	792.0	481.0	872.1	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	22.1	4.8
	B	ML039	'MT-2-G009'	792.0	481.0	872.1	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	29.3	9.7
	C	ML039	'MT-2-G009'	792.0	481.0	872.1	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	29.3	9.7
	D	ML039	'MT-2-G009'	792.0	481.0	872.1	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	29.3	9.7
	E	ML039	'MT-2-G009'	792.0	481.0	872.1	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	29.3	9.7
	Avg	ML039	'MT-2-G009'	792.0	481.0	872.1	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	29.3	9.7
	A	ML039	'MT-2-G010'	792.0	481.0	868.1	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	B	ML039	'MT-2-G010'	792.0	481.0	868.1	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	C	ML039	'MT-2-G010'	792.0	481.0	868.1	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	D	ML039	'MT-2-G010'	792.0	481.0	868.1	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	E	ML039	'MT-2-G010'	792.0	481.0	868.1	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	Avg	ML039	'MT-2-G010'	792.0	481.0	868.1	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	A	ML039	'MT-2-G011'	792.0	481.0	863.1	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	B	ML039	'MT-2-G011'	792.0	481.0	863.1	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	C	ML039	'MT-2-G011'	792.0	481.0	863.1	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	D	ML039	'MT-2-G011'	792.0	481.0	863.1	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	E	ML039	'MT-2-G011'	792.0	481.0	863.1	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	Avg	ML039	'MT-2-G011'	792.0	481.0	863.1	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	A	ML040	'MT-2-G012.3'	780.0	435.0	875.5	1	2.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	11.1	3.5
	B	ML040	'MT-2-G012.3'	780.0	435.0	875.5	1	9.6	0.5	1.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	9.6	3.5
	C	ML040	'MT-2-G012.3'	780.0	435.0	875.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	D	ML040	'MT-2-G012.3'	780.0	435.0	875.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	E	ML040	'MT-2-G012.3'	780.0	435.0	875.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	Avg	ML040	'MT-2-G012.3'	780.0	435.0	875.5	1	3.2	0.5	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	11.1	3.5
	A	ML040	'MT-2-G013'	780.0	435.0	867.0	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	B	ML040	'MT-2-G013'	780.0	435.0	867.0	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	C	ML040	'MT-2-G013'	780.0	435.0	867.0	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	D	ML040	'MT-2-G013'	780.0	435.0	867.0	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	E	ML040	'MT-2-G013'	780.0	435.0	867.0	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	Avg	ML040	'MT-2-G013'	780.0	435.0	867.0	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	A	ML040	'MT-2-G014'	780.0	435.0	863.0	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	B	ML040	'MT-2-G014'	780.0	435.0	863.0	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	C	ML040	'MT-2-G014'	780.0	435.0	863.0	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	D	ML040	'MT-2-G014'	780.0	435.0	863.0	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5

GCMS Data

		Sample Source Information					PAH											Summary					
		Point Location of Sample					Cardiogenic											Total Carcho genic PAH					
WellID	SampleID	X	Y	Z	Strat Zone	Naphth alene	Acenap thylene	Acenap thylene	Fluorene	Phenanthrene	Anthracene	Fluoran thene	Pyrene	Benzo(a)anthracene	Crysene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(a)pyrene	Indeno(1,2,3-cd)pyrene	Dibenz(a,h)anthracene	Benzo(g,h,i)perylene	Total Carcho genic PAH	
D	ML042	792.0	553.0	867.5	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
E	ML042	792.0	553.0	867.5	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
Avg	ML042	792.0	553.0	867.5	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
A	ML045	685.0	428.0	864.6	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
B	ML045	685.0	428.0	864.6	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
C	ML045	685.0	428.0	864.6	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
D	ML045	685.0	428.0	864.6	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
E	ML045	685.0	428.0	864.6	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
Avg	ML045	685.0	428.0	864.6	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
A	ML045	685.0	428.0	859.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
B	ML045	685.0	428.0	859.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
C	ML045	685.0	428.0	859.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
D	ML045	685.0	428.0	859.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
E	ML045	685.0	428.0	859.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
Avg	ML045	685.0	428.0	859.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
A	ML045	685.0	428.0	848.0	5	5.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	13.4
B	ML045	685.0	428.0	848.0	5	7.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	15.4
C	ML045	685.0	428.0	848.0	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
D	ML045	685.0	428.0	848.0	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
E	ML045	685.0	428.0	848.0	5	3.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	10.6
Avg	ML045	685.0	428.0	848.0	5	4.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	11.8
A	ML045	685.0	428.0	846.7	5	18.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	18.8
B	ML045	685.0	428.0	846.7	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
C	ML045	685.0	428.0	846.7	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
D	ML045	685.0	428.0	846.7	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
E	ML045	685.0	428.0	846.7	5	18.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	18.8
Avg	ML045	685.0	428.0	846.7	5	18.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	18.8
A	ML057	566.0	544.0	868.0	4	0.5	0.5	0.5	0.5	1.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.6
B	ML057	566.0	544.0	868.0	4	0.5	0.5	0.5	0.5	2.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	10.4
C	ML057	566.0	544.0	868.0	4	1.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
D	ML057	566.0	544.0	868.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
E	ML057	566.0	544.0	868.0	4	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.5
Avg	ML057	566.0	544.0	868.0	4	1.0	0.5	0.5	0.5	1.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	9.2
A	ML057	566.0	544.0	862.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
B	ML057	566.0	544.0	862.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
C	ML057	566.0	544.0	862.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
D	ML057	566.0	544.0	862.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
E	ML057	566.0	544.0	862.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
Avg	ML057	566.0	544.0	862.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
A	ML057	566.0	544.0	852.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
B	ML057	566.0	544.0	852.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
C	ML057	566.0	544.0	852.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
D	ML057	566.0	544.0	852.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
E	ML057	566.0	544.0	852.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
Avg	ML057	566.0	544.0	852.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
A	ML057	566.0	544.0	852.0	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0
B	ML057	566.0	544.0	852.0	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0

GCMS Data

		Sample Source Information					PAH										Summary									
Well-ID	SampleID	Point Location of Sample					Strat Zone	Naphthalene	Acenaphthylene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Carcinogenic					Total Carcinogenic PAH	Total Carcinogenic PAH					
		X	Y	Z											Benzo(a)anthracene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(a)pyrene	Indeno(1,2,3-cd)pyrene			Dibenz(a,h)anthracene	Benzo(ghi)perylene			
MT-2-G034.1	ML057	568.0	544.0	852.0	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML057	568.0	544.0	852.0	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML057	568.0	544.0	852.0	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
Avg	ML057	566.0	544.0	850.7	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
MT-2-G034.3	ML057	568.0	544.0	850.7	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML057	568.0	544.0	850.7	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML057	566.0	544.0	850.7	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
Avg	ML057	566.0	544.0	850.7	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
MT-2-G035	ML065	780.0	507.0	879.9	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML065	780.0	507.0	879.9	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML065	780.0	507.0	879.9	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
Avg	ML065	780.0	507.0	879.9	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
MT-2-G036	ML065	780.0	507.0	871.9	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML065	780.0	507.0	871.9	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML065	780.0	507.0	871.9	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
Avg	ML065	780.0	507.0	871.9	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
MT-2-G037.1	ML065	780.0	507.0	865.9	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML065	780.0	507.0	865.9	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML065	780.0	507.0	865.9	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
Avg	ML065	780.0	507.0	865.9	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
MT-2-G037.2	ML065	780.0	507.0	864.9	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML065	780.0	507.0	864.9	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML065	780.0	507.0	864.9	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
Avg	ML065	780.0	507.0	864.9	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
MT-2-G038	ML065	780.0	507.0	859.9	7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML065	780.0	507.0	859.9	7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML065	780.0	507.0	859.9	7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
Avg	ML065	775.0	533.0	880.2	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
MT-2-G039	ML067	775.0	533.0	880.2	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML067	775.0	533.0	880.2	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
	ML067	775.0	533.0	880.2	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
Avg	ML067	775.0	533.0	880.2	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0
MT-2-G040	ML067	775.0	533.0	873.2	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0

GCMS Data

Sample Source Information										PAH										Summary		
WellID	SampleID	Point Location of Sample			Strat Zone	Naphthalene	Acenaphthylene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzofluoranthene	Crysenene	Benzofluoranthene	Benzofluoranthene	Indeno(1,2,3-cd)pyrene	Dibenz(a,h)anthracene	Benzofluoranthene	Total Carcinogenic PAH	Total Carcinogenic PAH	
		X	Y	Z																		
MT-2-G093.1	ML096	MT-2-G093.1'	572.0	580.0	852.7	5															0.0	0.0
	ML095	MT-2-G093.1'	572.0	580.0	852.7	5															0.0	0.0
	ML096	MT-2-G093.1'	572.0	580.0	852.7	5															0.0	0.0
	ML095	MT-2-G093.1'	572.0	580.0	852.7	5															0.0	0.0
	ML096	MT-2-G093.1'	572.0	580.0	852.7	5															0.0	0.0
	ML095	MT-2-G093.1'	572.0	580.0	852.7	5															0.0	0.0
	ML096	MT-2-G093.2'	572.0	580.0	852.0	6															0.0	0.0
	ML095	MT-2-G093.2'	572.0	580.0	852.0	6															0.0	0.0
	ML096	MT-2-G093.2'	572.0	580.0	852.0	6															0.0	0.0
	ML095	MT-2-G093.2'	572.0	580.0	852.0	6															0.0	0.0
	ML096	MT-2-G093.2'	572.0	580.0	852.0	6															0.0	0.0
	ML095	MT-2-G093.2'	572.0	580.0	852.0	6															0.0	0.0
	ML096	MT-2-G094'	838.0	432.0	873.5	1															0.0	0.0
	ML095	MT-2-G094'	838.0	432.0	873.5	1															0.0	0.0
	ML096	MT-2-G094'	838.0	432.0	873.5	1															0.0	0.0
	ML095	MT-2-G094'	838.0	432.0	873.5	1															0.0	0.0
	ML096	MT-2-G094'	838.0	432.0	873.5	1															0.0	0.0
	ML095	MT-2-G094'	838.0	432.0	873.5	1															0.0	0.0
	ML096	MT-2-G095'	838.0	432.0	867.5	2															0.0	0.0
	ML095	MT-2-G095'	838.0	432.0	867.5	2															0.0	0.0
	ML096	MT-2-G095'	838.0	432.0	867.5	2															0.0	0.0
	ML095	MT-2-G095'	838.0	432.0	867.5	2															0.0	0.0
	ML096	MT-2-G095'	838.0	432.0	867.5	2															0.0	0.0
	ML095	MT-2-G095'	838.0	432.0	867.5	2															0.0	0.0
	ML096	MT-2-G096'	804.0	449.0	876.0	1															0.0	0.0
	ML095	MT-2-G096'	804.0	449.0	876.0	1															0.0	0.0
	ML096	MT-2-G096'	804.0	449.0	876.0	1															0.0	0.0
	ML095	MT-2-G096'	804.0	449.0	876.0	1															0.0	0.0
	ML096	MT-2-G096'	804.0	449.0	876.0	1															0.0	0.0
	ML095	MT-2-G096'	804.0	449.0	876.0	1															0.0	0.0
	ML096	MT-2-G097'	804.0	449.0	868.0	4															0.0	0.0
	ML095	MT-2-G097'	804.0	449.0	868.0	4															0.0	0.0
	ML096	MT-2-G097'	804.0	449.0	868.0	4															0.0	0.0
	ML095	MT-2-G097'	804.0	449.0	868.0	4															0.0	0.0
	ML096	MT-2-G097'	804.0	449.0	868.0	4															0.0	0.0
	ML095	MT-2-G098'	789.0	466.0	877.8	1															0.0	0.0
	ML096	MT-2-G098'	789.0	466.0	877.8	1															0.0	0.0
	ML095	MT-2-G098'	789.0	466.0	877.8	1															0.0	0.0
	ML096	MT-2-G098'	789.0	466.0	877.8	1															0.0	0.0
	ML095	MT-2-G098'	789.0	466.0	877.8	1															0.0	0.0
	ML096	MT-2-G098'	789.0	466.0	877.8	1															0.0	0.0
	ML095	MT-2-G099'	789.0	466.0	864.8	3															0.0	0.0
	ML096	MT-2-G099'	789.0	466.0	864.8	3															0.0	0.0
	ML095	MT-2-G099'	789.0	466.0	864.8	3															0.0	0.0
	ML096	MT-2-G099'	789.0	466.0	864.8	3															0.0	0.0
	ML095	MT-2-G099'	789.0	466.0	864.8	3															0.0	0.0
	ML096	MT-2-G099'	789.0	466.0	864.8	3															0.0	0.0

GCMS Data

Sample Source Information				PAH												Summary							
Well-ID	SampleID	Point Location of Sample			Strat Zone	Naphthalene	Acenaphthylene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Carcinogenic					Total Carcinogenic PAH					
		X	Y	Z									Benzo(a)anthracene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(e)pyrene	Indeno(1,2,3-cd)pyrene	Dibenz(a,h)anthracene	Benzo(a)ghioperylene	Total PAH	Total Carcinogenic PAH		
MT-2-G099	ML108	'MT-2-G099'	789.0	466.0	864.8	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	
MT-2-G100	A	ML108	'MT-2-G100'	789.0	466.0	857.8	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	B	ML108	'MT-2-G100'	789.0	466.0	857.8	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	C	ML108	'MT-2-G100'	789.0	466.0	857.8	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	D	ML108	'MT-2-G100'	789.0	466.0	857.8	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	E	ML108	'MT-2-G100'	789.0	466.0	857.8	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MT-2-G101	A	ML108	'MT-2-G101'	789.0	466.0	853.8	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	B	ML108	'MT-2-G101'	789.0	466.0	853.8	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	C	ML108	'MT-2-G101'	789.0	466.0	853.8	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	D	ML108	'MT-2-G101'	789.0	466.0	853.8	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	E	ML108	'MT-2-G101'	789.0	466.0	853.8	6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MT-2-G102	A	ML110	'MT-2-G102'	817.0	426.0	873.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	B	ML110	'MT-2-G102'	817.0	426.0	873.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	C	ML110	'MT-2-G102'	817.0	426.0	873.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	D	ML110	'MT-2-G102'	817.0	426.0	873.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	E	ML110	'MT-2-G102'	817.0	426.0	873.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MT-2-G103	A	ML110	'MT-2-G103'	817.0	426.0	866.5	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	B	ML110	'MT-2-G103'	817.0	426.0	866.5	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	C	ML110	'MT-2-G103'	817.0	426.0	866.5	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	D	ML110	'MT-2-G103'	817.0	426.0	866.5	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	E	ML110	'MT-2-G103'	817.0	426.0	866.5	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MT-2-G104	A	ML110	'MT-2-G104'	817.0	426.0	863.5	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	B	ML110	'MT-2-G104'	817.0	426.0	863.5	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	C	ML110	'MT-2-G104'	817.0	426.0	863.5	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	D	ML110	'MT-2-G104'	817.0	426.0	863.5	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	E	ML110	'MT-2-G104'	817.0	426.0	863.5	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MT-2-G105	A	ML110	'MT-2-G105'	817.0	426.0	859.5	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	B	ML110	'MT-2-G105'	817.0	426.0	859.5	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	C	ML110	'MT-2-G105'	817.0	426.0	859.5	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	D	ML110	'MT-2-G105'	817.0	426.0	859.5	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	E	ML110	'MT-2-G105'	817.0	426.0	859.5	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MT-2-G106	A	ML112	'MT-2-G106'	683.0	461.0	877.6	1	87.1	16.1	17.3	51.9	14.1	17.1	24.4	13.4	13.2	8.0	9.2	8.1	3.6	3.5	228.1	0.0
	B	ML112	'MT-2-G106'	683.0	461.0	877.6	1	140.0	10.7	25.5	78.7	21.8	23.9	38.5	19.9	19.9	4.2	5.3	4.1	4.5	0.5	4.6	0.5
	C	ML112	'MT-2-G106'	683.0	461.0	877.6	1	57.3	8.0	16.6	116.0	20.2	20.7	19.9	4.2	5.3	4.1	4.5	0.5	4.6	0.5	3.4	309.8
	D	ML112	'MT-2-G106'	683.0	461.0	877.6	1	108.2	14.5	32.5	77.2	29.9	28.9	36.3	14.3	13.0	7.0	9.8	13.0	4.4	4.4	4.2	424.8
	E	ML112	'MT-2-G106'	683.0	461.0	877.6	1	111.8	12.6	25.1	69.3	22.0	23.3	33.1	13.8	13.1	7.5	9.5	10.5	4.0	3.9	383.5	
MT-2-G107.1	A	ML112	'MT-2-G107.1'	683.0	461.0	867.6	3	815.2	143.2	272.6	74.0	124.0	124.0	124.0	121.6	126.1	73.3	86.7	65.3	32.1	0.5	32.6	4781.4
	B	ML112	'MT-2-G107.1'	683.0	461.0	867.6	3	1982.0	362.9	59.7	241.3	777.7	229.2	239.9	351.1	121.6	126.1	73.3	86.7	65.3	32.1	0.5	32.6
	C	ML112	'MT-2-G107.1'	683.0	461.0	867.6	3	85.9	34.1	28.4	59.5	194.0	74.0	0.5	24.3	25.0	0.5	41.7	2.5	12.9	5.3	30.3	
	D	ML112	'MT-2-G107.1'	683.0	461.0	867.6	3	85.9	34.1	28.4	59.5	194.0	74.0	0.5	24.3	25.0	0.5	41.7	2.5	12.9	5.3	30.3	

GCMs Data

		Sample Source Information										PAH										Summary		
Well-ID	SampleID	Point Location of Sample			Strat Zone	Naphthalene	Acenaphthylene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Carcinogenic					Dibenzofuran	Total Carcinogenic PAH					
		X	Y	Z									Benzo(a)anthracene	Crysene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(e)pyrene			Indeno(1,2,3-cd)pyrene	Benzo(a)pyrene	Benzo(g)hchrysenene	Total Carcinogenic PAH	
MT-2-G107.1	ML112	683.0	461.0	867.6	3	1622.3	190.0	35.8	108.7	641.1	249.8	255.7	119.4	50.6	50.2	35.8	19.8	44.0	44.0	13.7	4.8	12.3	3453.9	218.9
	Avg	683.0	461.0	867.6	3	1473.3	232.0	47.2	175.0	563.8	239.5	247.7	198.2	86.1	88.1	54.6	53.3	54.7	54.7	22.9	2.7	22.5	3561.5	362.2
	A	683.0	461.0	866.4	3	62.0	14.6		11.0	30.8	30.9		12.8										0.0	0.0
	B	683.0	461.0	866.4	3																		0.0	0.0
	C	683.0	461.0	866.4	3																		0.0	0.0
	D	683.0	461.0	866.4	3																		0.0	0.0
	E	683.0	461.0	866.4	3	563.3	15.0	2.2	9.1	21.6	8.4	7.3	8.6	3.5	3.6	2.1	2.3	3.5	3.5	1.3	0.5	1.2	148.6	16.9
	Avg	683.0	461.0	866.4	3	59.1	14.8	2.2	10.0	26.2	19.6	7.3	10.7	3.6	3.6	2.1	2.3	3.5	3.5	1.3	0.5	1.2	168.1	16.9
	A	683.0	461.0	858.6	4																		0.0	0.0
	B	683.0	461.0	858.6	4																		0.0	0.0
	C	683.0	461.0	858.6	4																		0.0	0.0
	D	683.0	461.0	858.6	4																		0.0	0.0
	E	683.0	461.0	858.6	4																		0.0	0.0
	Avg	683.0	461.0	858.6	4	13.9	4.7	4.0	6.4	24.1	5.5	6.4	7.9	5.9	6.9	3.6	4.3	5.9	5.9	17.6	17.6	4.3	169.6	20.7
	A	764.0	491.0	874.0	1	32.2			12.6	52.6	12.3	12.3											0.0	0.0
	B	764.0	491.0	874.0	1																		0.0	0.0
	C	764.0	491.0	874.0	1																		0.0	0.0
	D	764.0	491.0	874.0	1	6.4	1.3	0.5	0.5	19.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	34.0	3.5
	E	764.0	491.0	874.0	1	15.8	3.8	3.2	10.3	26.7	9.1	8.6	8.7	3.4	3.6	1.7	2.0	2.6	2.6	0.5	0.5	0.5	102.7	14.2
	Avg	764.0	491.0	874.0	1	20.6	4.3	3.6	9.8	35.1	9.0	9.3	11.4	4.7	5.2	2.6	3.2	2.6	2.6	0.5	0.5	0.5	122.7	19.2
	A	764.0	491.0	872.8	1	9.0	0.5	0.5	0.5	3.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	21.5	3.5
	B	764.0	491.0	872.8	1																		0.0	0.0
	C	764.0	491.0	872.8	1																		0.0	0.0
	D	764.0	491.0	872.8	1	0.5	0.5	0.5	0.5	2.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	9.9	3.5
	E	764.0	491.0	872.8	1	8.2	0.5	0.5	0.5	4.2	0.5	0.5	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	19.9	3.5
	Avg	764.0	491.0	872.8	1	8.6	0.5	0.5	0.5	3.6	1.7	0.5	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	20.7	3.5
	A	764.0	491.0	869.0	3	0.5	0.5	0.5	0.5	1.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	9.3	3.5
	B	764.0	491.0	869.0	3																		0.0	0.0
	C	764.0	491.0	869.0	3																		0.0	0.0
	D	764.0	491.0	869.0	3																		0.0	0.0
	E	764.0	491.0	869.0	3	0.5	0.5	0.5	0.5	1.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.7	3.5
	Avg	764.0	491.0	869.0	3	0.5	0.5	0.5	0.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	9.0	3.5
	A	764.0	491.0	864.0	4																		0.0	0.0
	B	764.0	491.0	864.0	4																		0.0	0.0
	C	764.0	491.0	864.0	4																		0.0	0.0
	D	764.0	491.0	864.0	4	0.5	0.5	0.5	0.5	1.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.7	3.5
	E	764.0	491.0	864.0	4																		0.0	0.0
	Avg	764.0	491.0	864.0	4	0.5	0.5	0.5	0.5	1.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.7	3.5
	A	764.0	491.0	860.0	4																		0.0	0.0
	B	764.0	491.0	860.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	C	764.0	491.0	860.0	4																		0.0	0.0
	D	764.0	491.0	860.0	4	0.5	0.5	0.5	0.5	1.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	9.4	3.5
	E	764.0	491.0	860.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	Avg	764.0	491.0	860.0	4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.0	3.5
	A	764.0	491.0	854.0	6																		0.0	0.0
	B	764.0	491.0	854.0	6																		0.0	0.0
	C	764.0	491.0	854.0	6																		0.0	0.0

GCMS Data

Well-ID	SampleID	Sample Source Information						PAH											Summary						
		Point Location of Sample			Strat Zone	Naphthalene	Acenaphthylene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene	Carcinogenic			Dibenzofuran	Total Carcinogenic PAH							
		X	Y	Z										Crysenene	Benzo(b)fluoranthene	Benzo(k)fluoranthene			Benzo(a)pyrene	Indeno(1,2,3-cd)pyrene	Benzo(e)pyrene	Benzo(a)ghioperylene	Total Carcinogenic PAH		
C	ML118	MT-2-G124.1'	730.0	458.0	849.6	6	1.3	0.5	0.5	3.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0		
D	ML118	MT-2-G124.1'	730.0	458.0	849.6	6	5.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	12.2	3.5	
E	ML118	MT-2-G124.1'	730.0	458.0	849.6	6	7.5	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	12.5	3.5	
Avg	ML118	MT-2-G124.1'	730.0	458.0	849.6	6	4.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	15.8	3.5	
A	ML118	MT-2-G124.2'	730.0	458.0	848.9	6	31.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	38.8	3.5
B	ML118	MT-2-G124.2'	730.0	458.0	848.9	6	29.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	36.8	3.5
C	ML118	MT-2-G124.2'	730.0	458.0	848.9	6	4.2	0.5	0.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	
D	ML118	MT-2-G124.2'	730.0	458.0	848.9	6	29.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	15.7	3.5
E	ML118	MT-2-G124.2'	730.0	458.0	848.9	6	29.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	36.7	3.5
Avg	ML118	MT-2-G124.2'	730.0	458.0	848.9	6	29.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	37.4	3.5

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APPENDIX E: CONTRACTORS AND CONSULTANTS

Mobile Analytical Services and Equipment:

McLaren/Hart Environmental
25 Independence Boulevard
Warren, NJ 07059
908/627-8162

PACE, Inc.
1710 Douglas Drive North
Minneapolis, MN 55422
612/544-5543

CEM Corporation
3100 Smith Farm Road
P. O. Box 200
Matthews, NC 28106-200
913/492-2006

Field screening technologies:

ENSYS
P. O. Box 14063
Research Triangle Park, NY 27709
919/941-5509 Ext129

Millipore Corporation
80 Ashby Road
Bedford, MA 01730
800/722-5996 Ext 8654

Quantix Systems
2611 Branch Pike
Cinnaminson, NJ 08077
609/829-0110

Northeast Research Institute (NERI)
390 Farmington Avenue, Suite A100
Farmington, CT 06032
203/677-9666

Global Environmental
5311 Spring Canyon Trail
Rapid City, SD 57 702-9176
605/342-5311

Golder Federal
4104 148th Avenue North
Redmond, WA 98052
206/883-0777

MTI Analytical Institute
41762 Christy Street
Fremont, CA 94538
510/490-0901 Ext 242

U.S. Army Corps of Engineers
Kansas City District
700 Federal Building
601 E. 12th
Kansas City, MO 64106-2896
816/426-3553

Geophysical surveys:

Resolution Resources
9501 Ferris Road
Springport, MI 49284
517/857-3939

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Coleman Research Corporation
Blackhawk Geosciences Division
301 Commercial Road,
Suite B
Golden, CO 80401
301/621-8600

GEHM Corporation
1417 Bingham Road
P. O. Box 65
Boonville, MO 65233
816/882-3485

D'Appolonia Environmental Services
One Monroeville Center
Suite 500
Monroeville, PA 15146
303/248-6424

Drilling services:

Layne-Western
25450 Highway 275
Valley, NE 68064
402/359-2042

Health and safety oversight:

Layne Safety & Environmental Health
Sciences
1900 Shawnee Mission Parkway
Shawnee Mission, KS 66201
913/677-6852

Stratigraphic characterization services:

Geoprobe Systems, Inc.
605 Barney
Salina, KS 67401
913/825-1842

U.S. Army Corps of Engineers
Kansas City District
700 Federal Building
601 E. 12th
Kansas City, MO 64106-2896
816/426-3553

2-D and 3-D data visualization:

Dynamic Graphics, Inc.
1015 Atlantic Avenue
Alameda, CA 94501
510/522-0700

Off-site laboratory analysis:

Keystone Laboratories
501 West 3rd Street North
Newton, IA 50208
800/858-5227

Field management support:

Knightly Environmental, Inc.
P. O. Box 15104
Lenexa, KS 66285
913/888-1985

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Geophysics consultant:

Technos, Inc.
3333 Northwest 21st Street
Miami, FL 33142
305/634-4507

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APPENDIX F: STAKEHOLDER LIST

New and State-of-the-Practice Technology Providers

DOE national labs, technology transfer officers and environmental groups/programs)
Army Corps of Engineers
Companies responding to the ESC Request for Proposals
Personal contacts made by ESC project managers
University technology development centers
DOE EM-50 managers

Technology Users - Customers of ESC

DOE EM-30 points of contacts
DOE EM-40 managers
Iowa Utility Association (includes utilities who are privately owned but whose stock is public)
Iowa Association of Municipal Utilities (government owned-e.g., Ames Municipal Utilities, Cedar Falls, Muscatine)
EPRI (Electric Power Research Institute)
Gas Research Institute (GRI) members
EEI (Edison Electric Institute)
IGT (Institute of Gas Technology)
Environmental managers of utilities in the U. S. (from EEI database)
Iowa Department of Transportation
Chicago Northwestern Railroad (borders the site)

City Government

Ames Chamber of Commerce
Marshalltown Mayor and Chamber of Commerce
Iowa League of Municipalities members
National League of Municipalities members

Regulators

Iowa State Association of Counties (includes County Board of Supervisors who make decisions on FMGPs)
Division directors of EPA staff nationwide
Neighboring (regional) state environmental protection departments
Iowa Department of Natural Resources
Iowa Department of Health & Human Services
Iowa Utility Board
Iowa Office of Consumer Advocate

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Media and Trade Press

Hazmat World
Environmental Protection Magazine
Environmental Science and Technology
KDHO, 2 radio stations in Marshalltown
Marshalltown Times Republican newspaper
Des Moines Register
The Daily Tribune (Ames)
WHO TV
WOI TV
Omaha World Herald
Newsletters that reach utilities -- (Utility Environment Report,
Electric Utility Week, Electric Power Daily)
Users of the Washington State Energy Office's electronic bulletin board
[3000 users (United States and International) includes consultants working
with utilities]
DOE publications/newsletters

Associations and Societies

Iowa Petroleum Council
Soil and Water Conservation Society
Iowa Engineering Society (includes Consulting Engineers Council of Iowa)
Iowa Geologic Society
Iowa Geologic Survey Bureau
Petroleum Marketers of Iowa
National Association of Engineering Geologists
Kansas City Region of AEG
National Groundwater Association
Iowa Groundwater Association
Iowa Association of Business and Industry
Environmental Professionals of Iowa
Air and Waste Management Association
American Society for Testing of Materials
Association of engineering firms practicing in the geosciences
Hazardous Waste Action Coalition
National Registry of Environmental Professionals

Educators

Iowa High School Science Educators
AEA (Area Education Agency)
College Placement Council Newsletter
Iowa Community Colleges (e.g., Kirkwood)
Department heads of the science departments at Iowa State University, University of Iowa,
University of Northern Iowa

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Iowa point of contacts for DOE EM's PETE program

Iowa Legislators

Ralph Rosenberg and others on environmental committee

Other governments

Sac and Fox Tribe

Public Interest Groups and other citizens

Iowa Citizens for Community Improvement

Iowa Citizen Action Network

Businesses located adjacent to the site

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APPENDIX G: ATTENDEES AT THE VISITORS' DAYS

ESC Attendees List for May 2

Shiv Ambardar
Seneca Environmental Services
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(515)292-3464

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Allwaste/Northcentral
305 21st Street
Camanche, IA 52730
(319)243-7951

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91 Pinnacle Road West
Holtwood, PA 17532
(717)284-5225

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Montgomery Watson
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Des Moines, IA 50322-7938
(515)253-0830

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Iowa Utilities Board
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(515)281-5979

Perry Morris
Kirkwood Community College
6301 Kirkwood Blvd
Cedar Rapids, IA 52341
(319)398-5678

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P.O. Box 657-T
610 S. 12th Avenue
Marshalltown, IA 50158
(515)753-5566

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10881 Lowell
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4009 W. 49th St.
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(605)361-6000

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4-2845

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Marshalltown, IA 50158

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Iowa City, IA 52242
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Julianna Johnston
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124 1/2 E. Washington St.
Iowa City, IA 52240
(319)354-8116

Amanda Clark
Ames Laboratory
ASC II
Iowa State University
Ames, IA 50011
4-7338

Fred Fitter
Groundwater Service & Supply
2701 SE Convenience Blvd.
Ankeny, IA 50021
(515)964-0304

Greg Junk
Ames Laboratory
108 Spedding
Iowa State University
Ames, IA 50011
4-9488

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Marshalltown, IA 50158
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Walsh Environmental
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Omaha, NE 68114
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4-6773

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CPB - 342
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Larry Shi
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(515)233-0000

ESC Attendees List for May 3

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900 East Grand
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(515)281-8925

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Columbia, IL 62236
(618)281-7173

Ying Yan
Iowa Office of Consumer Advocate
Office of Utilities
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Des Moines, IA 50319
(515)281-5984

ESC Attendees List for May 4

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1740 W. Rebel Road
Palmdale, CA 93551
(805)273-8592

Tom Albertson
Iowa-Illinois Gas and Electric Company
206 E. 2nd Street
Davenport, IA 52801
(319)326-7384

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Coleman Energy and Enviro. Systems
301 Commercial Road, Ste B
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Curt Clowe
Woodward-Clyde Consultants
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Kevin Cornwell
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Jack Cummings
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Janet Estep
PACE, Incorporated
1710 Douglas Drive North
Minneapolis, MN 55422
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John Haas
Iowa Dept. of Transportation
800 Lincolnway
Bureau of Management
Ames, IA 50010
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Bart Hoekstra
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Gary K. Hubbard
Unisys Environmental Systems
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M/S U1F 15
St. Paul, MN 55164-0525
(612)456-3721

Dan Huffaker
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West Des Moines, IA 50265
(515)221-9823

Robin Husman
Seneca Environmental Services
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APPENDIX H: ABBREVIATIONS AND ACRONYMS

A/P	Anthracene/phenanthrene
ASL	Above sea level
BVWST	Black and Veatch Waste Science and Technology
CDP	Common depth point
CL	Chemiluminescence
CLP	Contract laboratory program
CMP	Common midpoint
CPT	Cone penetration testing
DNAPL	Denser-than-water non-aqueous phase liquid
DOE	U. S. Department of Energy
E&E	Ecology and Environmental
EM	Environmental Management
EOL	Electromagnetic offset logging
ESC	Expedited Site Characterization
F/P	Fluoranthene/pyrene
FMGP	Former manufactured gas plant
GC	Gas chromatography
GC/FID	Gas chromatography/flame ionization detector
GC/MS	Gas chromatography/Mass Spectrometry
GC/PID	Gas chromatography/photoionization detector
GIS	Geographical Information System
GPR	Ground penetrating radar
GRM	Generalized Reciprocal Method
GSSI	Geophysical Survey Systems, Inc.
HPLC	High pressure liquid chromatography
Hz	Hertz
IDNR	Iowa Department of Natural Resources
IES	Iowa Electric Service
IMA	Immunoassay
IT	Innovative technologies
LCU	Lower cohesive unit
LIF	Laser induced fluorescence
MDL	Method detection limit
MHz	Megahertz
ML	Map locations
MLH	McLaren/Hart
MS	Mass spectrometry
ms	Milliseconds
MW	Molecular Weight

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NAPL	Non-aqueous phase liquid
ND	Non-detect
NERI	Northeast Research Institute
ns	Nanoseconds
OTD	Office of Technology Development
PAHs	Polynuclear aromatic hydrocarbons
POL	Petroleum, oil, and lubricant
PPM	Parts per million
QA/QC	Quality assurance and quality control
RI	Remedial Investigation
SCAPS	Site Characterization and Analysis Penetrometer System
SFE	Supercritical fluid extraction
SOPT	State-of-the-practice technologies
SVOCs	Semivolatile organic compounds
TD-GC/MS	Thermal Desorption-Gas Chromatography/Mass Spectrometry
TD-MS	Thermal Desorption/Mass Spectrometry
TRPH	Total recoverable petroleum hydrocarbon
UCU	Upper cohesive unit
U.S.-EPA	United States Environmental Protection Agency
UST	Underground storage tank
WES	Waterways Experiment Station
VOA	Volatile organic analysis
VOCs	Volatile organic compounds

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