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Field Trials of the Site Characterization and Analysis Penetrometer System at the Savannah River Site (SRS)

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WES

Prepared for U.S. Department of Energy

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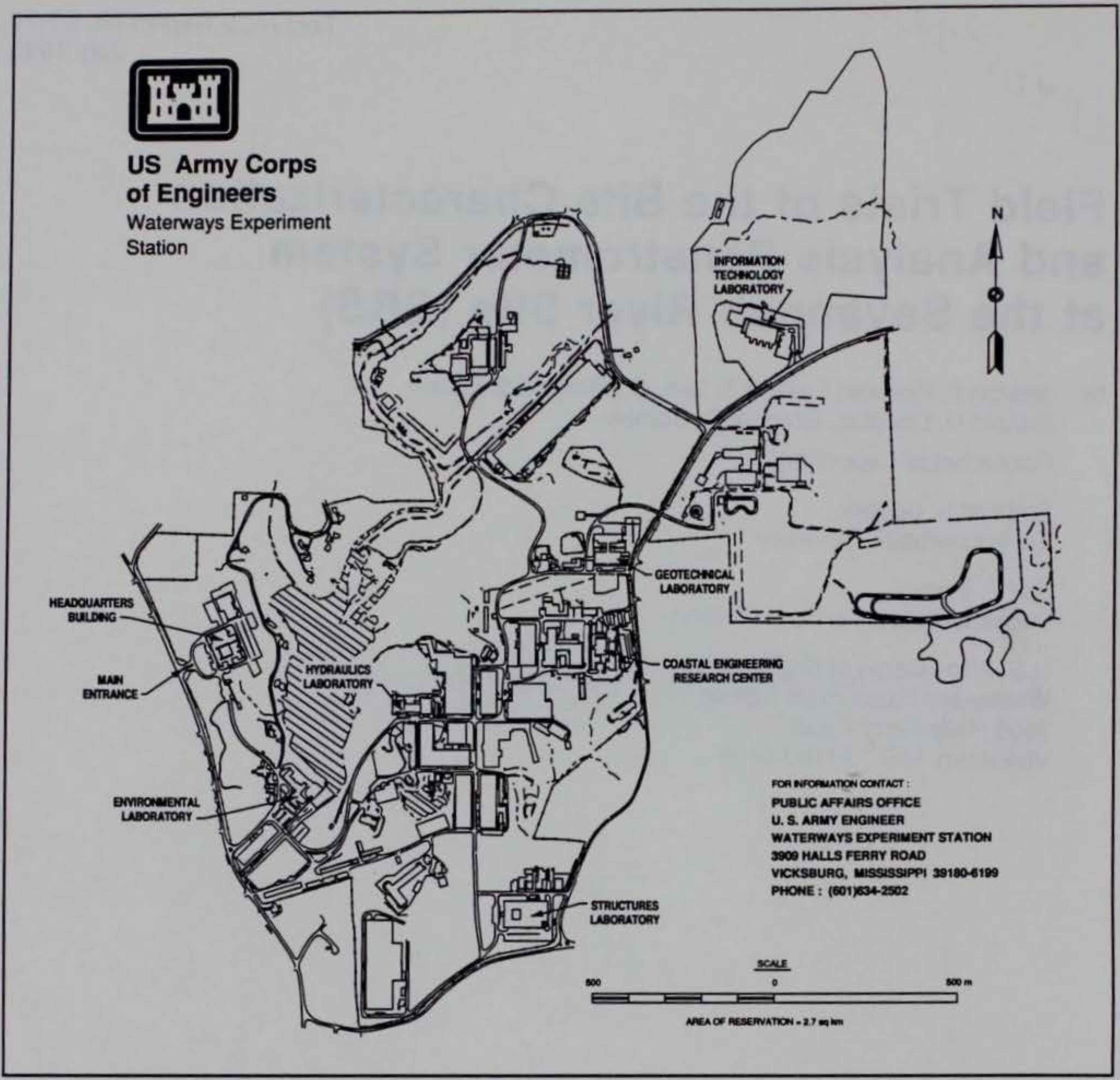

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Contents

Preface vi

1—Introduction 1

Background 1
Purpose 2
Site Descriptions 2
Savannah River Site - general 3
Integrated Demonstration (TCE) Site 4
Central Shops (POL) Site 4
D-area Oil Seepage Basin 5

2—Experimental Equipment and Methods 6

Site Characterization and Analysis Penetrometer System 6
Site Mapping Techniques 7
Geophysical Survey Equipment 8
Soil Characterization Methods 8
Determination of soil strength and soil type 8
Penetrometer soil resistivity measurement 10
Penetrometer resistivity module 10
Resistivity calibration 13
Soil fluorescence measurement 14
General concepts 14
Fluorometer calibration 17
Sampling Procedures and Chemical Analysis 20
Grouting to Seal Penetrometer Test Holes 20
Data Reduction Methods 21
Data acquisition 21
Computer site characterization and visualization 21

3—Synopsis of Field Activities 23

Penetrometer Operations 23
Integrated Demonstration (TCE) Site 23
Conventional CPT reconnaissance 23
SCAPS experiments 24
Central Shops (POL) Site 25
D-area Oil Seepage Basin 25
Implant Experiments 26
General 26

Lawrence Livermore National Laboratory (LLNL) "Optrode" 27
Illinois Institute of Technology Research Institute (IITRI) "Terratrog" 27
U.S. Army Engineer Waterways Experiment Station (WES) fiber optic sensor 30

4—Results and Discussion, FY 91 Experiments 32

Penetrometer Operations 32
Integrated Demonstration (TCE) Site 32
Resistivity response 32
Fluorometer response 33
Central Shops (POL) Site 34
Geophysical investigations 34
Resistivity response 34
Fluorometer response 34
D-area Oil Seepage Basin 34
Implant Experiments 39

5—FY 92 Experiments at SRS 40

General 40
Synopsis of Field Operations 40
LLNL Fiber Optic TCE Sensor 44
Summary and Discussion of FY 92 Experiments 44

6—Conclusions and Recommendations 45

Conclusions 45
Recommendations 46

References 47

Appendix A1: Soil Stratigraphy and Resistivity Response Data Integrated Demonstration (TCE) Site Fiscal Year 1991 . . . . A1

Appendix A2: Soil Stratigraphy and Resistivity Response Data Integrated Demonstration (TCE) Site Fiscal Year 1992 . . . . A8

Appendix A3: Soil Stratigraphy and Fluorometry Response Data Integrated Demonstration (TCE) Site A20

Appendix B1: Geophysical Investigation Data Central Shops (POL) Site B1

Appendix B2: Soil Stratigraphy and Resistivity Response Data Central Shops (POL) Site B8

Appendix B3: Soil Stratigraphy and Fluorometer Response Data Central Shops (POL) Site B11

Appendix C: Soil Stratigraphy and Fluorometer Response Data D-Area Oil Basin Site C1

SF 298

List of Figures

Figure 1. WES site characterization and analysis penetrometer system (SCAPS) truck 1

Figure 2. Savannah River Site (SRS) site map 3

Figure 3. Integrated Demonstration Test Site monitoring well layout 5

Figure 4. Cone penetrometer cross section 9

Figure 5. Load cell calibration 11

Figure 6. Relationship of cone behavior and soil classification 12

Figure 7. Resistivity penetrometer cross section 13

Figure 8. Diagram of Wenner electrode in soil 14

Figure 9. Resistivity module calibration 15

Figure 10. Fluorometer system 16

Figure 11. Spectral fluorescence data examples for three hydrocarbon fuels 18

Figure 12. Fluorometry calibration for diesel fuel, marine, in Ottawa sand 19

Figure 13. Integrated Demonstration (TCE) Site penetrometer operations, FY 90-91 24

Figure 14. Central Shops (POL) Site map 26

Figure 15. D - Area Oil Seepage Basin Site map 27

Figure 16. Lawrence Livermore National Laboratory Optrode diagram 28

Figure 17. Illinois Institute of Technology Terratrog diagram 29

Figure 18. U.S. Army Engineer Waterways Experiment Station POL implant diagram 31

Figure 19. Comparison of resistivities measured with depth by wireline survey and SCAPS penetrometer test CR-15A 33

Figure 20. 3-D Image of Central Shops POL plume, 500 ppm 35

Figure 21. 3-D Image of Central Shops POL plume, 4000 ppm 37

Figure 22. Integrated Demonstration (TCE) Site map, FY 92 experiments 41

Preface

The Earthquake Engineering and Geosciences Division (EEGD), Geotechnical Laboratory (GL), Waterways Experiment Station (WES), was sponsored to conduct this study through the following instruments: Military Interdepartmental Purchase Request (MIPR) No. N90-42, issued 2 March 1990 by the Air Force Civil Engineering Support Agency (AFCESA), Tyndall Air Force Base, Florida; and Inter-Agency Agreements (IAA) Nos. DE-AI01-90EM50010 and DE-AI01-92EW50602, issued 25 August 1990 and 4 November 1991, respectively, by the Department of Energy (DOE). This report describes a demonstration/evaluation of the Site Characterization and Analysis Penetrometer System (SCAPS) at an Integrated Demonstration Site where solvents were present and at other hydrocarbon-contaminated sites at the Department of Energy's (DOE's) Savannah River Site (SRS) near Aiken, South Carolina. The SRS is managed and operated by the Westinghouse Savannah River Company (WSRC) under a DOE contract.

The operation was conducted as part of a joint Department of Defense (DOD)/DOE research project on the application of cone penetrometer-based technology for the detection and delineation of contaminated soils. Control, coordination, and direction of the various phases of this study were provided by Messrs. Tom Anderson and Jerry Hyde, Office of Technology Development, DOE, and Dr. Dawn S. Kaback, Environmental Sciences Section, WSRC.

The SCAPS field penetrometer operations were conducted by the following personnel: Dr. Joseph P. Koester and Messrs. Richard S. Olsen, Donald H. Douglas and Karl F. Konecny of EEGD; Messrs. Eugene A. Graves, Jeff F. Powell, and Bobby E. Reed of the Instrumentation Services Division (ISD), Mr. Donald S. Harris of the Engineering and Construction Services Division (E&CSD), and Mr. Stafford S. Cooper, Special Projects Group, Environmental Engineering Division (EED), Environmental Laboratory, WES. Geophysical surveys were conducted in support of the field efforts by Messrs. Michael K. Sharp and José Llopis of EEGD.

Dr. Fred Milanovich, of the Lawrence Livermore National Laboratory (LLNL), performed field experiments on a prototype "Optrode" fiber-optic implant in a joint exercise with the SCAPS field crew during the period 20-22 April 1991. Dr. Dan Lucero and Mr. Mark Glover, of the Illinois Institute of Technology Research Institute (IITRI), tested a "Terratrog" soil gas sampling implant during the period 23-27 April 1991. Messrs. Cooper, Reed, Powell, Harris, and Konecny performed experiments with a prototype fiber optic implant designed and built by WES during the period 27-30 April 1991.

A subsequent series of SCAPS and LLNL implant experiments were conducted at SRS during the period 18 May to 1 June 1992, during which time the SCAPS crew consisted of Messrs. Konecny, Harris, Powell, and Landris T. Lee, Jr., (the latter of EEGD), with the assistance of Mr. Paul C. Dew, under contract to ISD. Mr. John H. Ballard of the Environmental Systems Division, Environmental Laboratory, WES also participated. LLNL representatives for this operation were Dr. Milanovich, Mr. Steven B. Brown, and Mr. Bill W. Colston. Activities and accomplishments associated with this later exercise are also described herein.

This report was prepared by Dr. Koester and Messrs. Lee, Olsen, Douglas, and Gregory D. Comes, all of EEGD, Mr. Cooper, EED, and Mr. Powell, ISD. Data processing and computer drafting assistance was provided by Ms. Amy M. Chrestman and Messrs. Gary Hennington and Rodney Leist of EEGD.

Mr. Stafford S. Cooper, EED, was Project Manager for this effort. The project was conducted under the direct supervision of Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch, Dr. A. G. Franklin, Chief, EEGD, and Dr. W. F. Marcuson III, Director, GL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

1 Introduction

Background

The Earthquake Engineering and Geosciences Division (EEGD) was requested by the Office of Technology Development, U.S. Department of Energy (DOE) to demonstrate the Site Characterization and Analysis Penetrometer System (SCAPS; penetrometer truck shown in Figure 1) at three sites at the Savannah River Site (SRS) where the subsurface soil was known or suspected to be contaminated with either process solvents or fuels. The SCAPS was initially deployed to the SRS Integrated Demonstration Site, where a full-scale demonstration of a novel air stripping technique to remove volatile organic compounds (VOC's) was in progress. The SCAPS was later

Figure 1. WES site characterization and analysis penetrometer system (SCAPS) truck

relocated to detect and delineate the extent of a suspected plume of diesel fuel and its by-products of decomposition in the subsurface at a fuel distribution facility. A limited study was also made of a third site that was anticipated to be contaminated with heavier oils and greases.

In addition to site characterization experiments using its own specialized cone penetrometer test (CPT) equipment, the SCAPS was evaluated as a delivery and support mechanism for two prototype monitoring implants: an "Optrode" fiber-optic chemical sensor, developed by the Lawrence Livermore National Laboratory (LLNL); and the "Terratrog" osmotic soil gas sampler, developed by the Illinois Institute of Technology Research Institute (IITRI). The capability of the SCAPS to rapidly obtain soil samples from depth for laboratory contaminant analysis was also demonstrated at the Integrated Demonstration Site and the fuel distribution facility. A small number of soil samples were collected in a special pushed-tube device and analyzed by Westinghouse Savannah River Company (WSRC) scientists for soil type and contamination to evaluate SCAPS direct measurements.

Purpose

The purpose of these field investigations was to demonstrate and evaluate the effectiveness and versatility of the SCAPS for geotechnical and environmental site characterization activities. Specific objectives of this study were to: demonstrate SCAPS capabilities to penetrate to depths of at least 150 ft (45.7 m) at the SRS Integrated Demonstration Site, demonstrate and evaluate the SCAPS capabilities to classify and delineate the soil layers encountered, and evaluate the performance of SCAPS resistivity and fiber optic sensors to detect known solvent and hydrocarbon contamination in soils.

The entire complement of SCAPS equipment and technology was exercised: control and topographic surveying procedures; surface geophysical investigation methods; the penetrometer probes themselves (including instrumentation for measuring soil strength, electrical resistivity and fluorometry); soil sampling devices; soil grouting equipment; and data reduction, including advanced data visualization techniques.

Site Descriptions

Savannah River Site - general

The Savannah River Site, operated by Westinghouse, is located near Aiken, South Carolina (Figure 2) on a 300 square mile (7.77×10^8 m^2) wooded area along the Savannah River (Westinghouse Savannah River Company 1991). The primary mission of the facility is production of nuclear materials. An in-house Environmental Restoration Program is responsible for

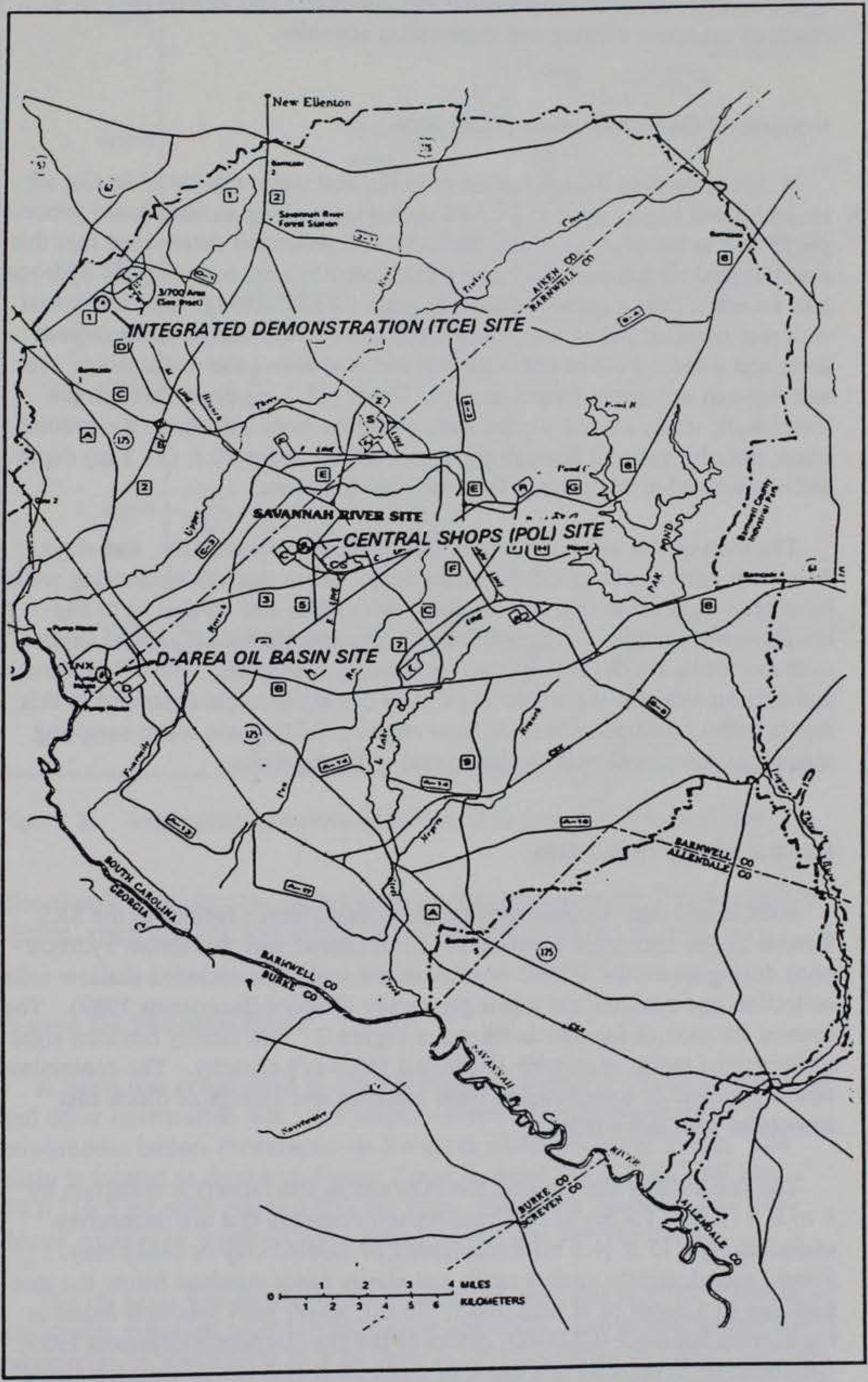


Figure 2. Savannah River Site (SRS) site map

identification and remediation of all on-site inactive waste sites. Hundreds of permanent groundwater monitoring wells have been installed throughout the entire facility; much is known about soil conditions and stratigraphy as a result of extensive drilling and exploration activities.

Integrated Demonstration (TCE) Site

A full-scale field demonstration of horizontal wells applied to in situ air stripping was begun prior to SCAPS deployment along an abandoned process sewer line in the M Area of the SRS. WSRC personnel determined that this sewer leaked trichloroethylene and tetrachloroethylene, both organic hydrocarbon solvents, over a period of several years (WSRC 1991). One horizontal well was installed below the groundwater table in the known contaminated area, and a second horizontal well was installed above the water table. Air was injected into groundwater at about 150 ft (45.7 m) depth through the lower well, while air and vapors were extracted from soil above the groundwater table by vacuum through the upper well at about 70 ft (21.3 m) depth and were piped to the surface for additional treatment.

The soils at this site consist of stiff, interbedded sands, silts, and clays. The water table is about 135 ft (41 m) deep. More than 50 monitoring wells have been installed at this site (marked with circles and labeled as in Figure 3); water samples were obtained by contractor personnel several times each day while the WES field study was being conducted. The SCAPS truck and support vehicles were able to perform the experiments described in this report without interference to or from ongoing drilling and water sampling operations associated with the horizontal well operations.

Central Shops (POL) Site

Soils in and near an underground diesel fuel storage facility in the SRS Central Shops area were found to be contaminated with petroleum hydrocarbons during an earlier WSRC environmental study that included shallow soils collection and analysis and a soil gas survey (Dupont Biosystems 1989). The general location of this site is shown in Figure 2. The facility contains eight underground tanks, each with 12,000 gal (45.4 m^3) capacity. The contamination is believed to have resulted from handling and storage of diesel fuel associated with these tanks.

The fuel facility site (termed the POL site in this report) is underlain by 4 to 6 ft (1.2 to 1.8 m) of disturbed topsoil materials that are themselves underlain by a 15 ft (4.6 m) thick deposit of mottled clay or sandy clay. Poorly sorted, tightly packed sands and clayey sands continue below the mottled clay to a depth of at least 164 ft (50 m), where marl was first found in the deepest borehole (CSD-4D) drilled at the site (Dupont Biosystems 1989). Groundwater is perched at a depth of about 25 ft (7.6 m) at some locations; the continuous groundwater table at the site ranges in depth from 50 to 74 ft (15.2 to 22.6 m) across the POL site; with an east-west gradient (SRS

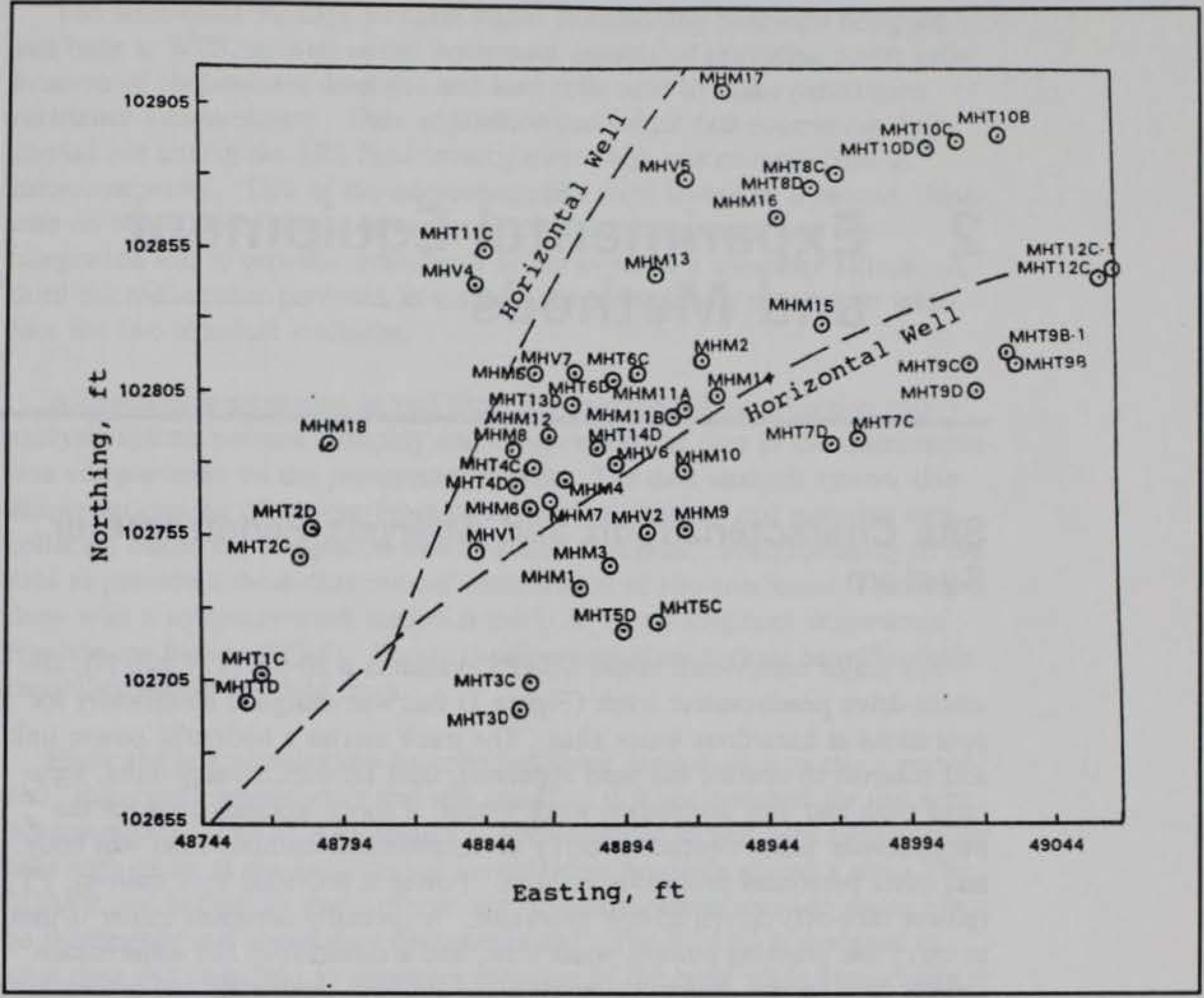


Figure 3. Integrated Demonstration Test Site monitoring well layout

directions). The site was judged to be an excellent candidate site for SCAPS testing, since no rock was anticipated as shallow as 75 ft (22.9 m).

D-area Oil Seepage Basin

A basin was constructed in 1952 to collect waste oil products from D-area and other onsite areas that were judged unacceptable for incineration in powerhouse boilers (Westinghouse Savannah River Company 1990). The basin is located as shown in Figure 2, and is about 383 ft (116.7 m) long, 54 ft (16.5 m) wide and 6.6 ft (2 m) deep. Numerous 55-gallon (0.21 m^3) drums containing waste oil were placed, over time, into the basin.

The oil basin was deactivated and backfilled with soil in 1975; standing oil and drums remained after the backfilling operation. The groundwater table is reported to be about 18 ft (5.5 m) deep in soils consisting of sands, silts, and clays with little gravel present. The SCAPS crew onsite to evaluate prototype implant devices in April 1991 was requested to perform a limited investigation of the D-Area site using the penetrometer-based fluorometer system.

2 Experimental Equipment and Methods

Site Characterization and Analysis Penetrometer System

The major component of the SCAPS system is a 20-ton (177,920 N), all-wheel-drive penetrometer truck (Figure 1) that was designed specifically for operations at hazardous waste sites. The truck carries a hydraulic power unit and controls to operate the push apparatus, dual air conditioning units, separated push and data acquisition work spaces, a shock-isolated floor for the penetrometer instrumentation, easily decontaminated stainless steel van body, and other personnel protection features. Power is provided by a built-in, PTO (power take-off) driven 25-kW generator. A specially designed trailer is used to carry the grouting pumps, water tank, and a closed-loop hot water/steam cleaner to clean the penetrometer rods and probes. Push rods and probes are forced through a chamber, suspended beneath the truck floor, that is sealed at top and bottom with rubber plates that form a septum configuration. On withdrawal from the soil, the rods and probes may be sprayed with hot water or steam, and the effluent from this chamber may be collected for offsite disposal if required by the host site. Permission was granted by SRS authorities to drain the cleaning chamber to the ground surface during the tests described in this report.

The Site Characterization and Analysis Penetrometer System (SCAPS), includes a suite of surface geophysical equipment, survey and mapping equipment, special penetrometers with screening sensors for contaminant detection, and soil and pore fluid penetrometer samplers. The SCAPS "screening" penetrometers are equipped with sensors that can determine physical and chemical characteristics of soil layers through which the penetrometer tip is forced. Depth is determined by a built in string potentiometer that is attached to the hydraulic ram used to push the penetrometers into the ground. The truck is, by standard operating procedure, leveled prior to pushing any probe; the travel of the penetrometer is assumed to be vertical throughout each test. The SCAPS penetrometers include sensors that can determine the strength, electrical resistivity, and spectral properties (in this case, the fluorescence) of soils.

The electronics package includes signal conditioning hardware designed and built at WES, as well as test equipment capable of providing onsite calibrations of contaminant detectors and load cells used to make penetration resistance measurements. Data acquisition and initial data processing were carried out during the SRS field investigations with one of three built-in microcomputers. Two of the microcomputers were identical; a second, duplicate on-board microcomputer was used for data management and file integration and to provide redundancy in the event of a computer failure. A third microcomputer performs as a server for a token ring network to interface the two identical machines.

All sensors are sampled in real time; the automatic data collection and analysis system permits a display and interpretation of data in the instrumentation compartment on the penetrometer truck. The data analysis system also allows processing of various types of surface geophysical and mapping data collected onsite for integration into a unified data base. Postprocessing of the data to provide a three-dimensional visualization of site conditions is presently done with a computer work station at the U.S. Army Engineer Waterways Experiment Station (WES). Future development plans include providing this capability within the field truck.

Fluid and soil samples can be collected using devices such as the commercial "stab type" groundwater and soil samplers that are designed for use with penetrometers. The SCAPS system is also equipped to seal each penetrometer hole with grout as the geotechnical investigation proceeds across a site. The SCAPS unit is built so that surfaces and compartments exposed to waste can be thoroughly and completely decontaminated. The SCAPS is designed to save time and costs and to minimize exposure of the crew while sensor data or samples are collected.

Site Mapping Techniques

The location of penetrometer push points and the layout of the geophysical survey stations is accomplished using a total station electronic distance measuring system (EDM) that is designed to be accurate to within 0.05 ft per mile (10 cm per km). The site mapping work at the SRS was done with an EDM unit equipped with an electronic notebook to permit data transfer to the microcomputers in the SCAPS truck. Monitoring wells at both the Integrated Demonstration (TCE) and the Central Shops area (POL) sites served as topographic survey control points; known positions and elevations were provided by WSRC to the SCAPS field crew on site. Survey coordinates given in this report are referenced to the local SRS coordinate system. Topographic surface features and all of the penetrometer push points at the POL and TCE sites were surveyed using the EDM, recorded electronically and transferred to a computer in the SCAPS truck to permit generation of preliminary field maps. Final POL and TCE site maps used in this report were generated at the WES using a computer assisted drafting program on a computer work station. The D-Area oil seepage basin site was surveyed by tape measure only.

Geophysical Survey Equipment

Limited geophysical site surveys were performed at the TCE and POL sites to determine if buried metal or other hard objects might pose a hazard to penetrometer experiments. This procedure has been adopted as standard for the SCAPS; geophysical examination of a potential penetrometer test site is not yet routinely done in commercial practice. Two non-destructive geophysical instruments were used during SCAPS operations at SRS: soil conductivity and magnetic susceptibility surveys were performed using a Geonics EM-31™ Terrain Conductivity System (Geonics Inc., Mississauga, Ontario, Canada); and total magnetic field intensity and vertical magnetic gradient were measured using an EDA OMNI IV™ Magnetometer System (EDA Inc., Toronto, Ontario, Canada).

Conductivity surveys were performed by traversing the TCE and POL sites with the EM-31™ instrument configured to measure the quadrature-phase component of an induced electromagnetic field; a magnetic susceptibility survey was also conducted of the POL site by operating the EM-31™ in the in-phase mode. Discrete measurements were recorded at the POL site for conductivity, magnetic susceptibility, total magnetic field strength and vertical magnetic gradient surveys at 25 ft (7.6 m) centers within a predefined reference grid that encompassed the area intended for SCAPS push point selection. Conductivity and magnetic field intensity data are depicted in plan contours and three-dimensional space in Appendix B1. Magnetometer data for total field and magnetic gradient are also presented in three-dimensional space in Appendix B1. Sites for subsequent penetrometer operations were selected based on these survey results; areas with high local magnetic and conductivity anomalies were assumed to be caused by buried debris.

Soil Characterization Methods

Determination of soil strength and soil type

A sectional view of a cone penetrometer equipped to measure soil strength is shown in Figure 4. The exterior dimensions of the penetrometer tip correspond to an internationally adopted design for cone penetrometers. The point load cell is loaded in compression as the cone tip is advanced, at a standard rate of 2 cm/sec, through soil. The friction sleeve load cell used during these experiments was in the form of a hollow cylinder which was split along its cylindrical axis and had strain gauges attached to the inside surface of each resulting half shell. The friction sleeve cell halves surrounded the tip load cell and were also loaded in compression when soil friction acted on the friction sleeve which jackets the front of the probe. The design employed in this soil strength unit allows the tip penetration resistance and sleeve friction to be measured independently and continuously.

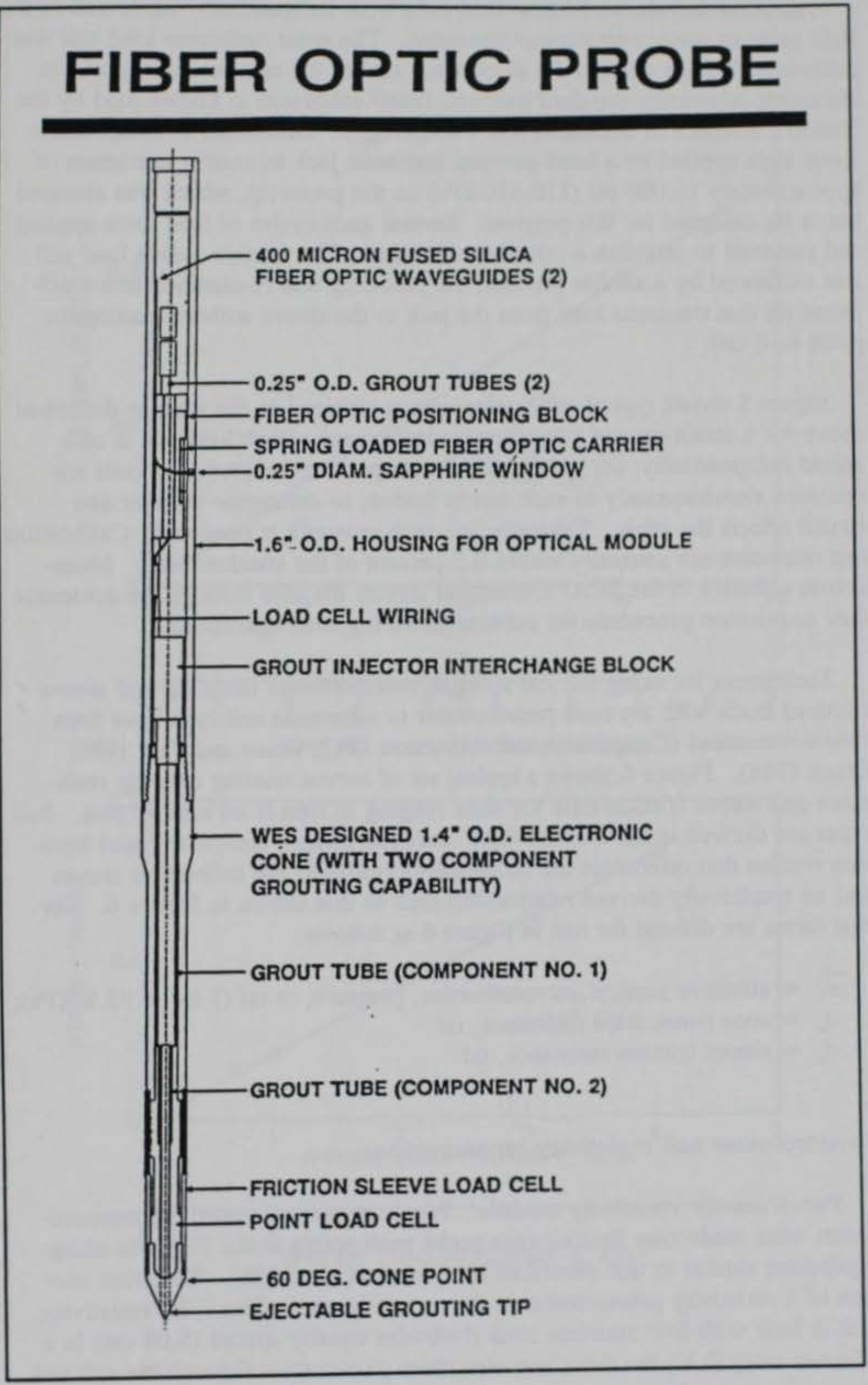


Figure 4. Cone penetrometer cross section

The point and sleeve friction load cells were independently calibrated in the field prior to cone penetrometer operation. The point resistance load cell was calibrated through the SCAPS electronics against the response of a portable electronic laboratory standard load cell (itself calibrated to known load by the National Institute of Standards and Technology). Increments of compressive force were applied by a hand-pumped hydraulic jack to exert a maximum of approximately 16,000 psi (110,316 kPa) on the probe tip, which was clamped into a jig designed for this purpose. Several such cycles of load were applied and removed to establish a reliable calibration. The friction sleeve load cell was calibrated by a similar process; the probe tip was re-clamped into a different jig that transmits load from the jack to the sleeve without loading the point load cell.

Figure 5 shows typical calibration curves obtained in the manner described above for a strain-gauged penetrometer instrument. Each load cell is calibrated independently, but the output of both point and sleeve load cells are recorded simultaneously as each one is loaded, to determine whether one circuit affects the other. Typically, no such crosstalk is observed. Calibration test responses are generally within 0.5 percent of the standard load. Menu-driven software in the SCAPS computer directs the user through the automatic data acquisition procedure for calibration during field operations.

Techniques for using the soil strength measurements (cone tip and sleeve friction) made with the cone penetrometer to determine soil type have been well-documented (Campanella and Robertson 1982; Olsen and Farr 1986; Olsen 1988). Figure 6 shows a typical set of curves relating cone tip resistance and sleeve friction ratio for soils ranging in type from sand to peat. Soil types are derived in the SCAPS field operation using a computer-based iteration routine that references the strain gauge readings, the calibration curves and an empirically derived relationship such as that shown in Figure 6. Several terms are defined for use in Figure 6 as follows:

$\overline{\sigma}_v$ = effective vertical, or overburden, pressure, in tsf (1 tsf = 95.8 KPa);
q_c = cone penetration resistance, tsf
f_s = sleeve friction resistance, tsf

Penetrometer soil resistivity measurement

Penetrometer resistivity module. Penetrometer soil resistivity measurements were made near fluorescence probe push points at the TCE site using equipment similar to that described by Cooper et al. (1988). The cross section of a resistivity penetrometer is shown in Figure 7. The WES resistivity unit is built with four stainless steel electrodes equally spaced (5.08 cm) in a Wenner array (i.e., the outer two electrodes pass current through the soil and inner two electrodes measure potential drop across a fixed distance) on an externally electrically insulated section of penetrometer rod (diagrammed in Figure 8). The outer surface of each electrode is flush with the surface of the insulation material, which consists of machined Teflon™ cylindrical sleeves. The resistivity module is, overall, slightly larger in diameter than the standard

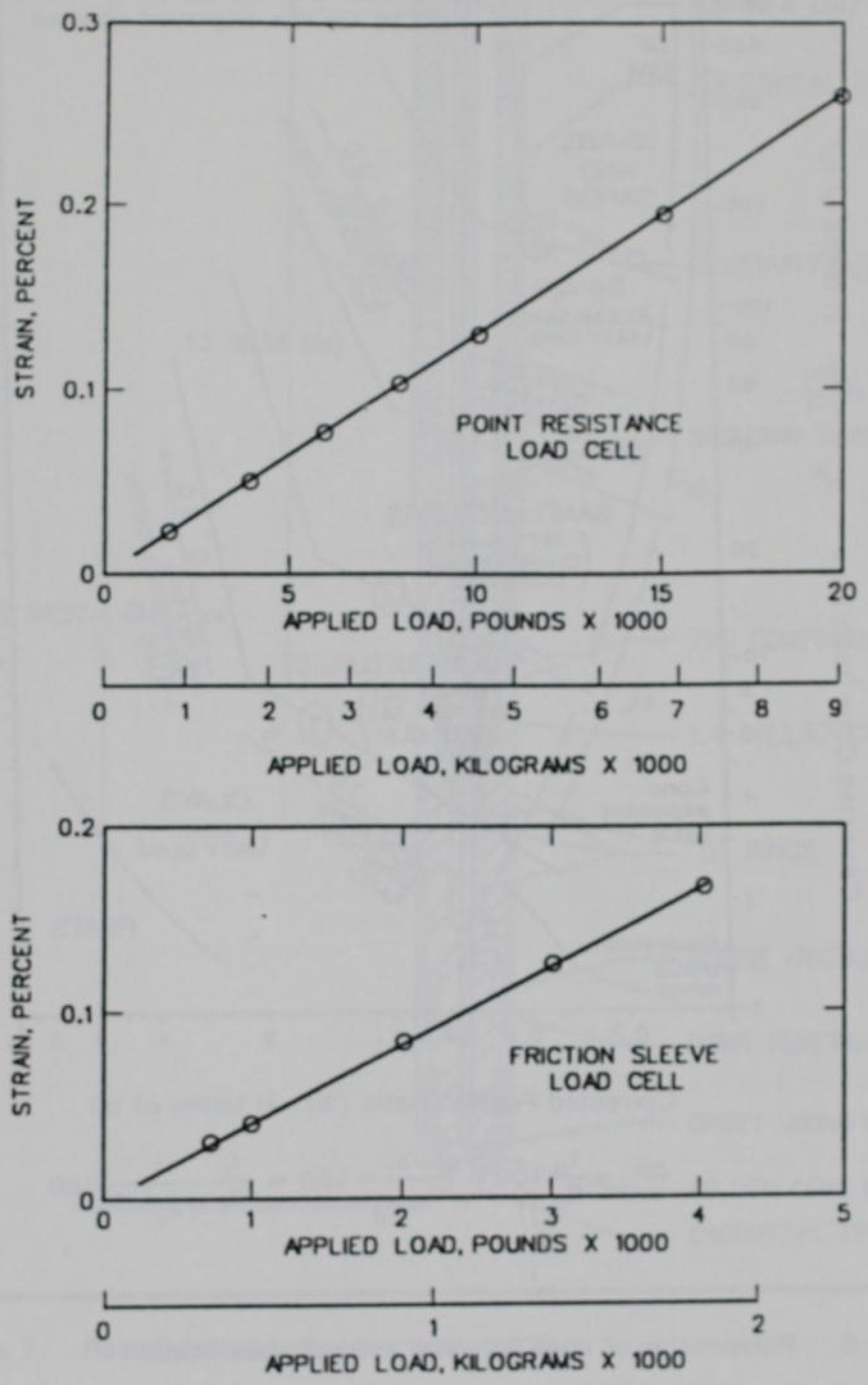
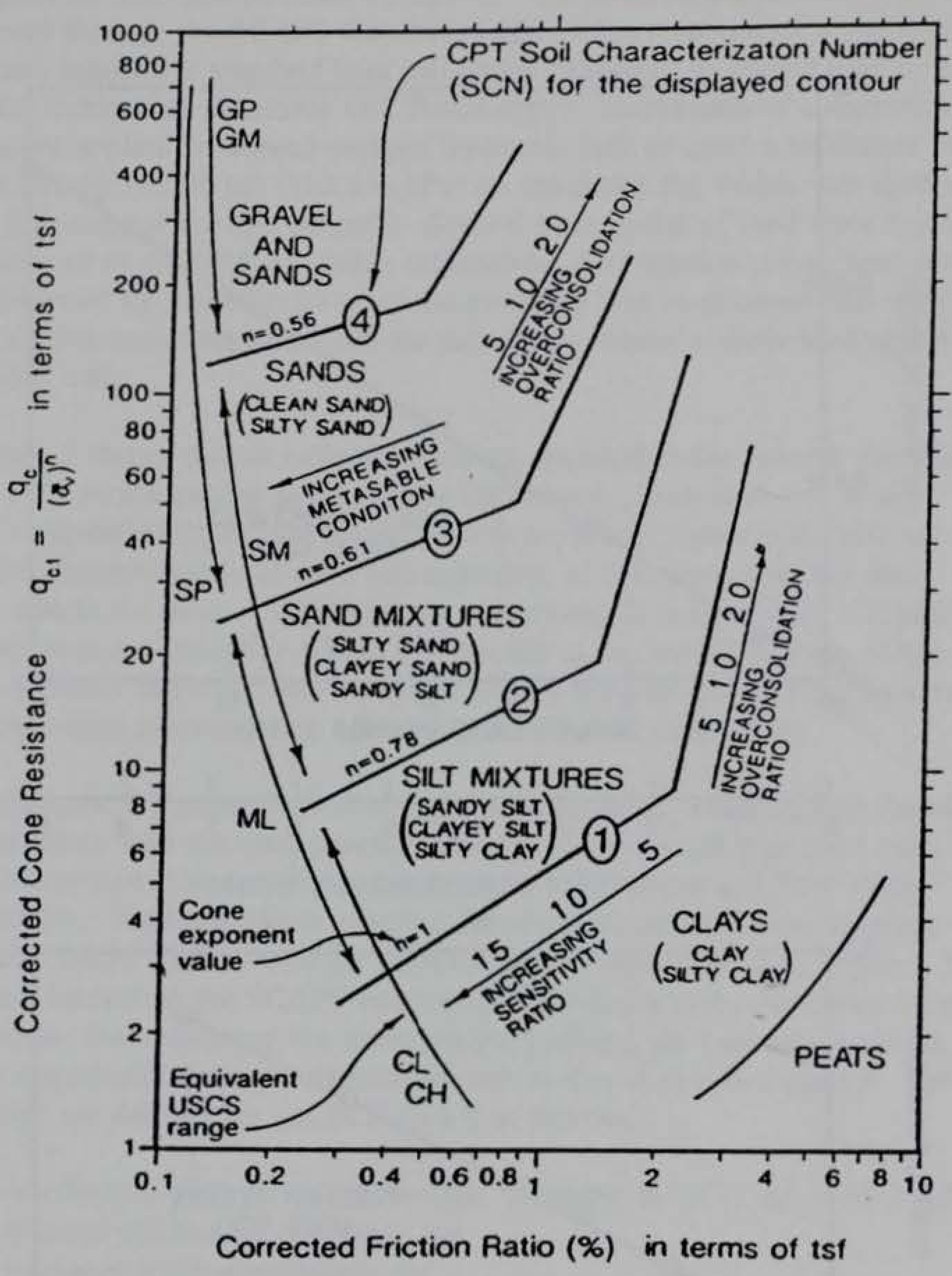


Figure 5. Load cell calibration



$$FR_1 = \frac{f_{s1}}{q_{c1}} 100 = \frac{f_s/\bar{\sigma}_v}{q_c/(\bar{\sigma}_v)^n} 100 = \frac{f_s}{q_c} \frac{1}{(\bar{\sigma}_v)^{(1-n)}} 100$$

Figure 6. Relationship of cone behavior and soil classification

penetrometer rod (4.06 cm compared to 3.56 cm) to assure that the electrodes make uniform contact with the surrounding soil.

Resistivity measurements are made by passing a DC current between the two outer electrodes and measuring the voltage drop across the two inner electrodes. The power supply for the resistivity unit is designed to maintain a small constant current (20 mA) through the excitation circuit. The nominal

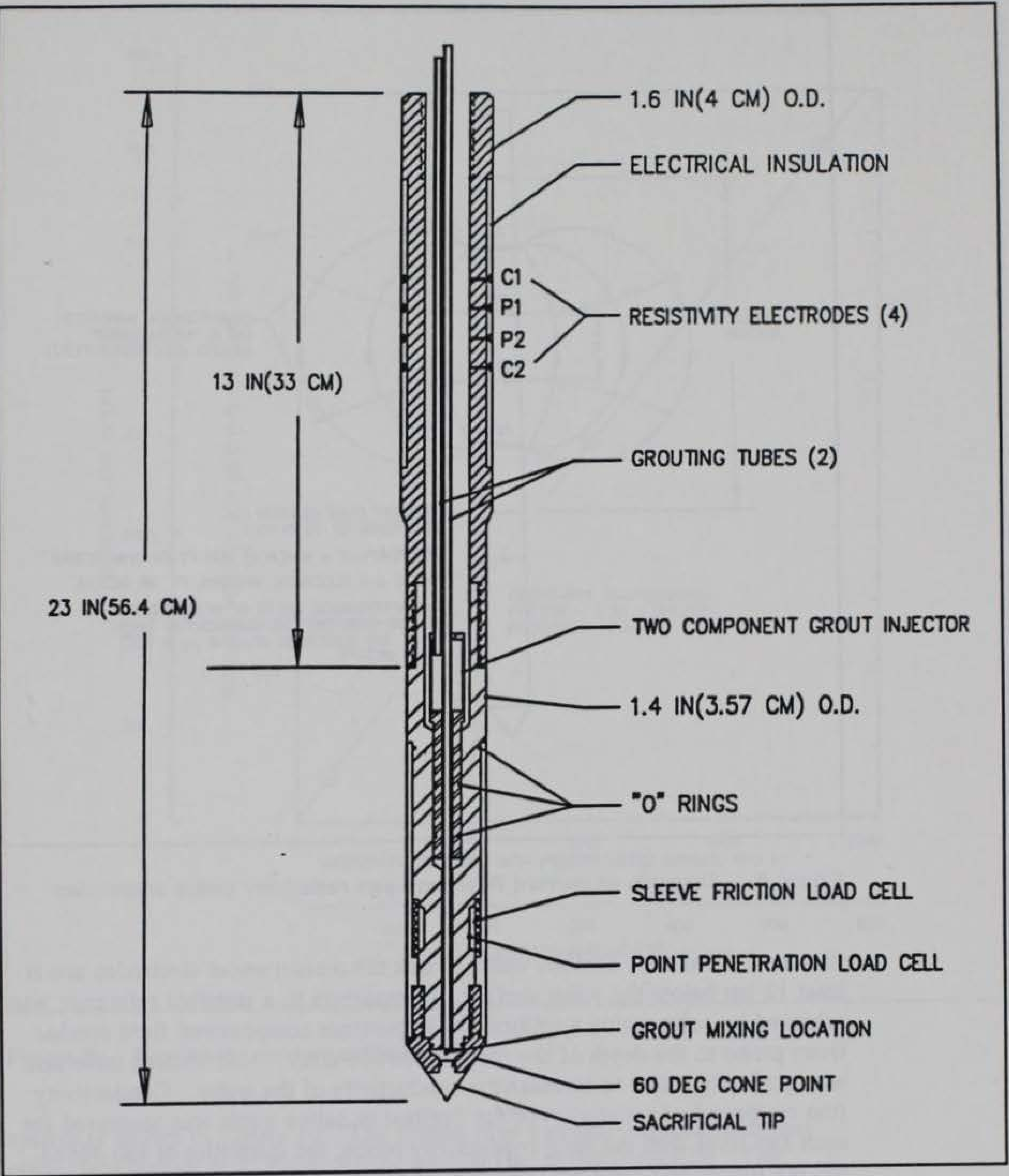


Figure 7. Resistivity penetrometer cross section

resistivity is calculated using the excitation current, the voltage drop across the inner electrodes, and predetermined geometric factors derived from potential field theory.

Resistivity calibration. Penetrometer resistivity modules are calibrated using the SCAPS truck data acquisition system and software in the same manner as for field data acquisition. The calibration of the resistivity module is done by immersing the electrode array in a vertical plastic cylinder (25 cm in

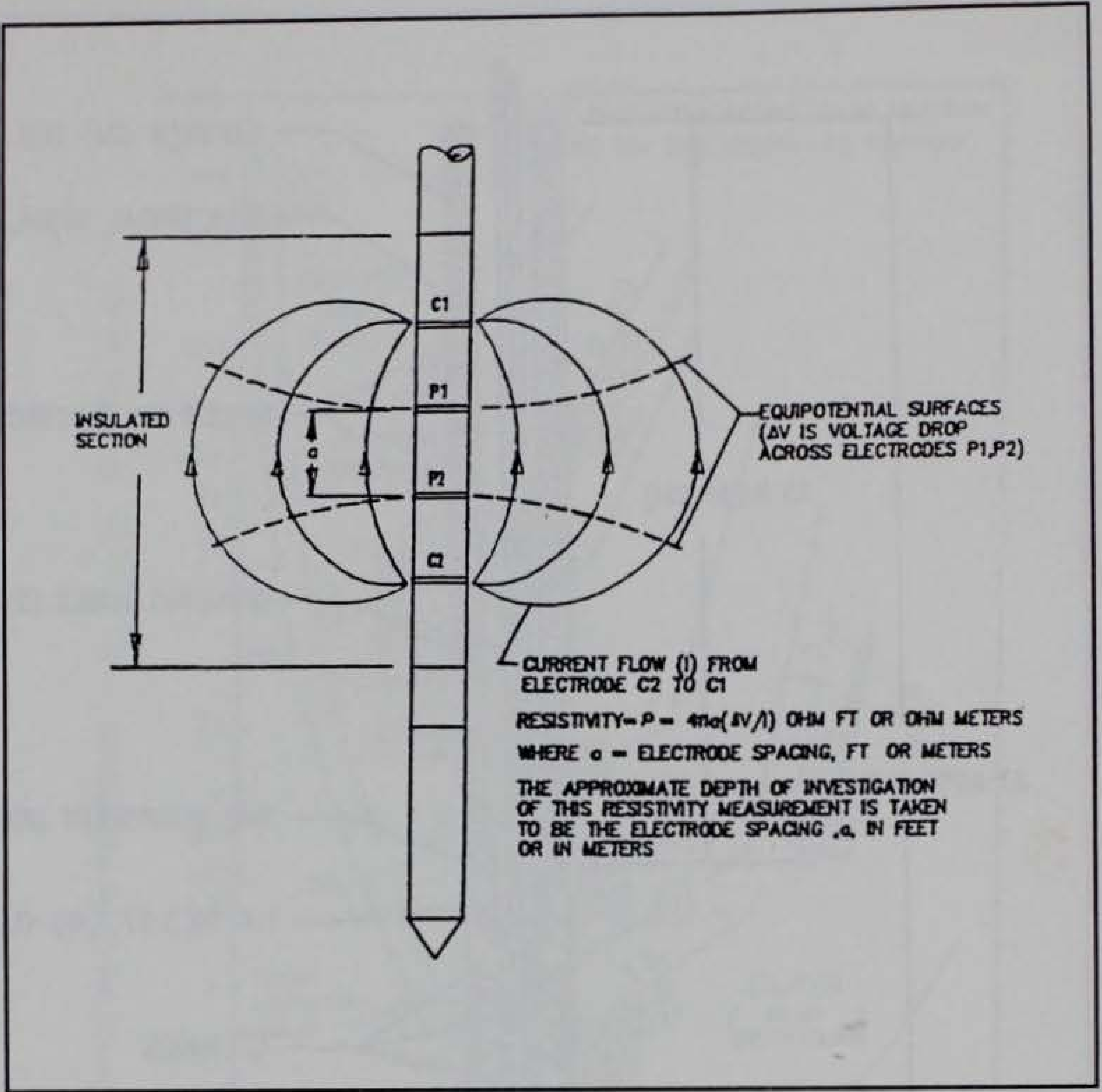


Figure 8. Diagram of current flow between resistivity probe electrodes

diameter) filled with distilled water so that the measurement electrodes are at least 12 cm below the water surface. Comparison to a standard reference was achieved by submerging a calibrated, temperature compensated fluid conductivity probe to the depth of the probe electrode array. Non-iodized table salt was gradually added to increase the conductivity of the water. Conductivity (the reciprocal of resistivity) of the distilled or saline water was measured for each salt level with the fluid conductivity probe; the quantities of salt added did not matter and were not recorded. A typical calibration curve generated by this procedure for a DC resistivity module is shown in Figure 9.

Soil fluorescence measurement

General concepts. A special soil fluorometer probe designed, built, and patented by WES for the SCAPS was used in these investigations. The fluorescence energy collection and interpretation electronics used were similar to a design developed by Lieberman, Inman and Theriault (1989) for use in measuring fluorescence in seawater. A schematic of the penetrometer fluorometer

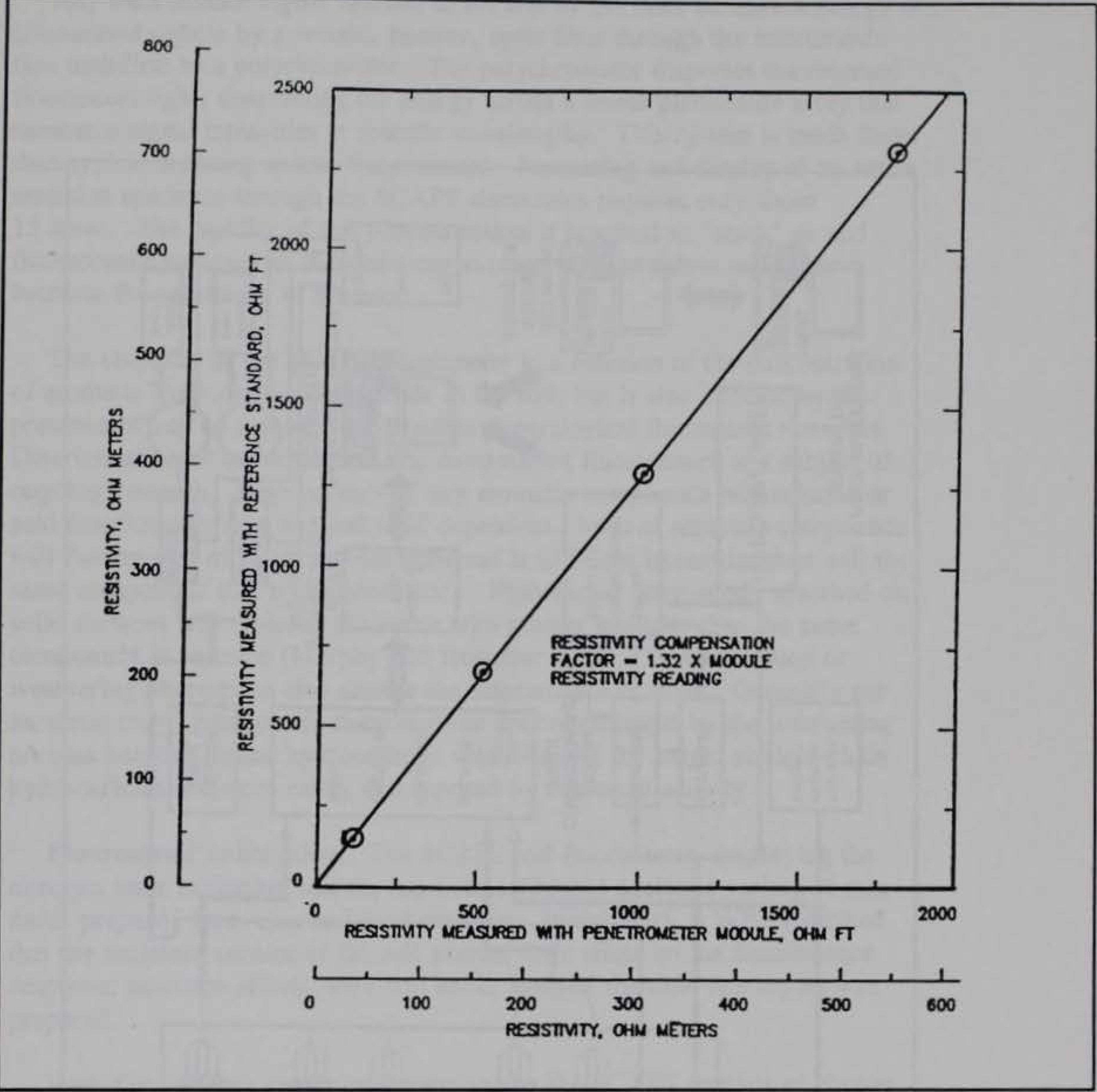


Figure 9. Resistivity module calibration

system is shown in Figure 10. The system fires a pulsed nitrogen laser that emits light energy at 337 nanometers wavelength, in the ultraviolet. The invisible laser light is directed into two optical silicon fibers: a timing circuit fiber and the downhole sample irradiation fiber. The portion of each laser energy pulse diverted to the timing circuit fiber may be used to trigger fluorescence detection circuitry and accommodate a precalibrated delay. Collimated laser energy not diverted to the timing fiber is directed into an optical fiber that passes down the center of the penetrometer rod as part of the instrumentation umbilical. The downhole fiber terminates at a 6.35-mm diam sapphire window through which the light passes onto the soil surface adjacent to the window.

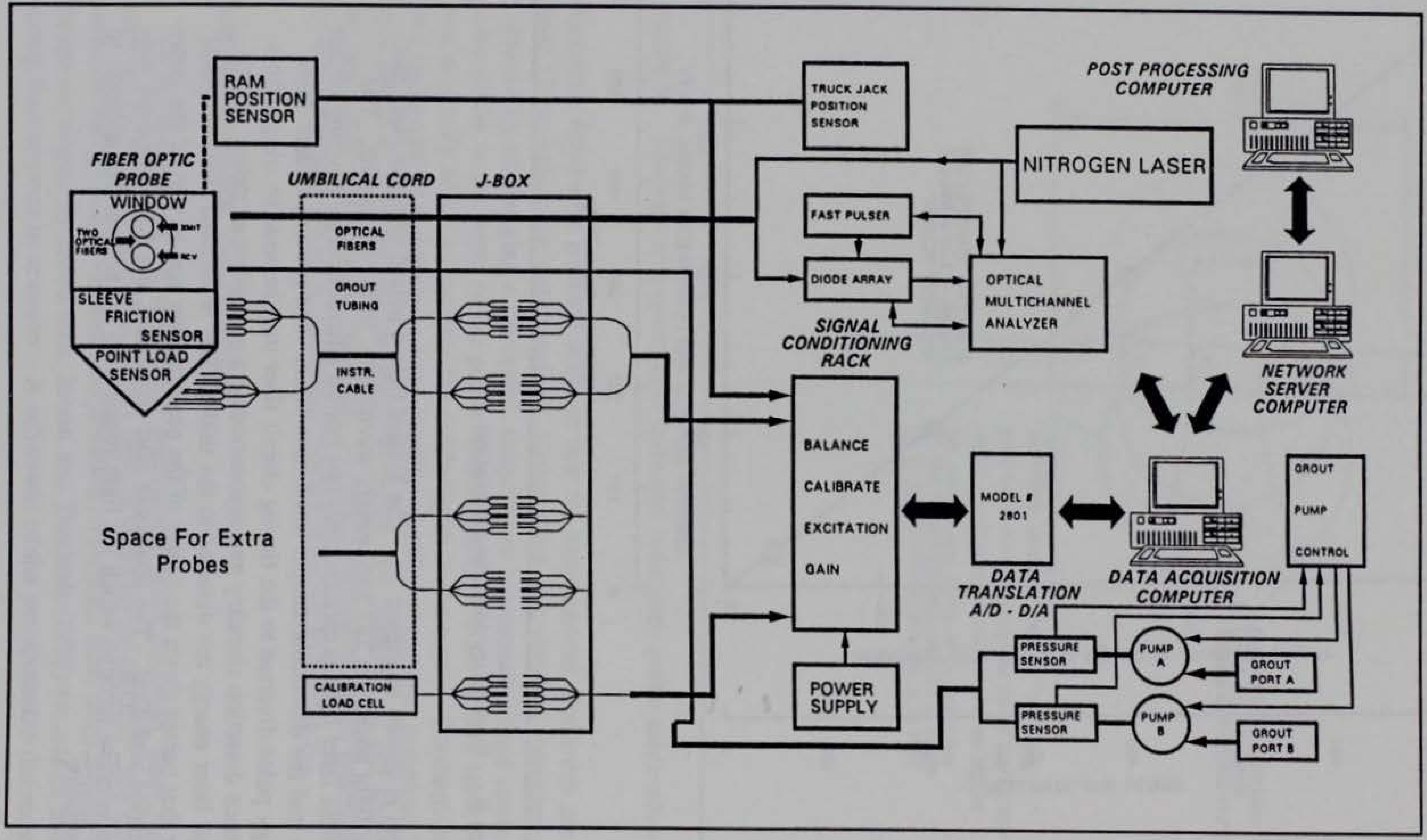


Figure 10. Fluorometer system

Any fluorescence signal induced in the soil by the laser excitation energy is transmitted uphole by a second, passive, optic fiber through the instrumentation umbilical to a polychromator. The polychromator disperses the returned fluorescent light, distributing the energy across a linear photodiode array that measures signal intensities at specific wavelengths. This system is much faster than typical scanning spectrofluorometers. Processing and display of an entire emission spectrum through the SCAPS electronics requires only about 15 msec. The rapidity of this process makes it practical to "stack" or add fluorescence returned as induced from successive laser pulses and thus increase the sensitivity of the unit.

The response of the SCAPS fluorometer is a function of the concentration of aromatic hydrocarbon compounds in the soil, but is also affected by the presence of any of a number of possible mineralogical fluorescent materials. Discrimination of mineralogical and contaminant fluorescence is a subject of ongoing research. Fluorescence of any aromatic compounds within basic or acid functional groups is usually pH dependent. Ionized aromatic compounds will fluoresce at different wavelengths and at different intensities than will the same compounds in a non-ionized state. Fluorescing compounds adsorbed on solid surfaces will typically fluoresce with greater intensity than the same compounds in solution (Murphy and Hostetler 1989). Decomposition or weathering phenomena also change the fluorescence of fuels. Generally the aromatic (ring) compounds that fluoresce are concentrated by the weathering process because lighter hydrocarbons volatilize and the longer straight-chain hydrocarbons are more easily decomposed by microbial activity.

Fluorometer calibration. The SCAPS soil fluorometer, employing the nitrogen laser excitation source, has been calibrated against a variety of standards prepared from clay and sand matrices. Initial work at WES indicated that the moisture content of the soil exerted little effect on the fluorescence response; moisture effects were still under study at the time this report was prepared.

Each fluorescence spectrum determined by the SCAPS consists of photon counts measured in the soil at a rate of 1024 points (over a wavelength range of 300 to 800 nm) for every 2-cm (0.8-in.) depth interval. The data processing system employed at SRS recorded all spectral intensity measurements and corrected the data for instrument drift with time. The drift-corrected data were screened to determine photon counts for the peak of interest in excess of the background level observed in a given data set. Example data are shown for three hydrocarbon fuels in Figure 11. Figure 12 is the calibration curve developed using laboratory-analyzed samples of Ottawa sand contaminated with fresh diesel fuel, marine (DFM) that was coded into the SCAPS data acquisition and processing software at the time of the SRS investigations. The calibration relationship was developed for a site where DFM was the target contaminant. The data points plotted in Figure 12 are extracted from a SCAPS field investigation at the Jacksonville Naval Air Station, Florida (report in production at the time of the current study) and are shown here to illustrate general agreement with laboratory correlations; no error ranges are available for the data, and the data are not archived. The SCAPS field

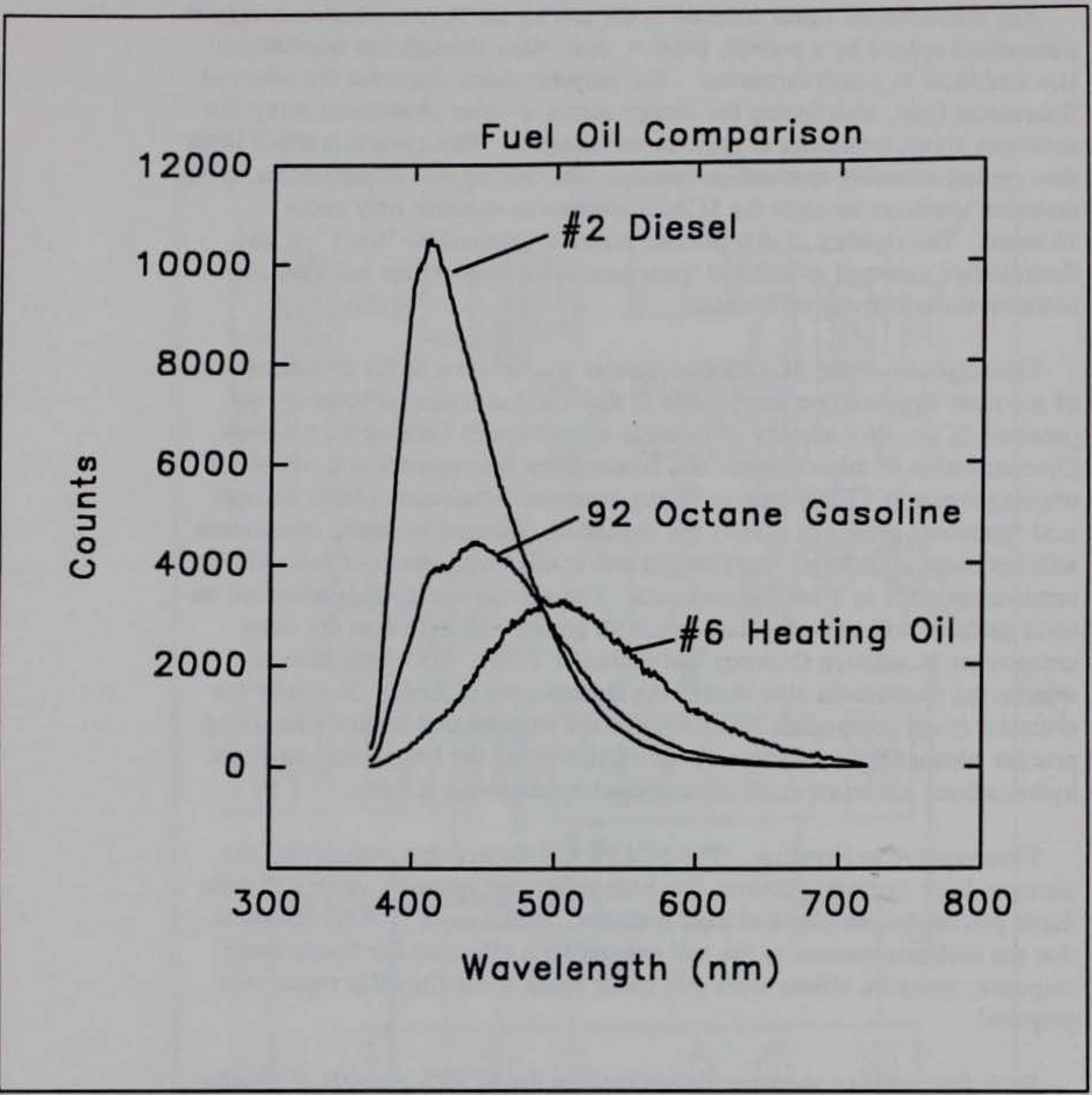


Figure 11. Spectral fluorescence data examples for three hydrocarbon fuels

fluorescence data were presented in this report as the concentration of diesel fuel, marine (DFM) that would produce an equivalent fluorescence according to the curve and associated equations in Figure 12. No site-specific calibration was developed using SRS soils or contaminants; the fluorescence data reported herein should not, therefore, be interpreted quantitatively.

Data files containing the estimated contaminant concentration, the map coordinates, and the depth below a surveyed datum elevation were prepared from the spectral data. The final data files were eventually transformed into a three-dimensional gridded file of equivalent fuel concentrations and plotted using a visualization program, as described in more detail in a later section.

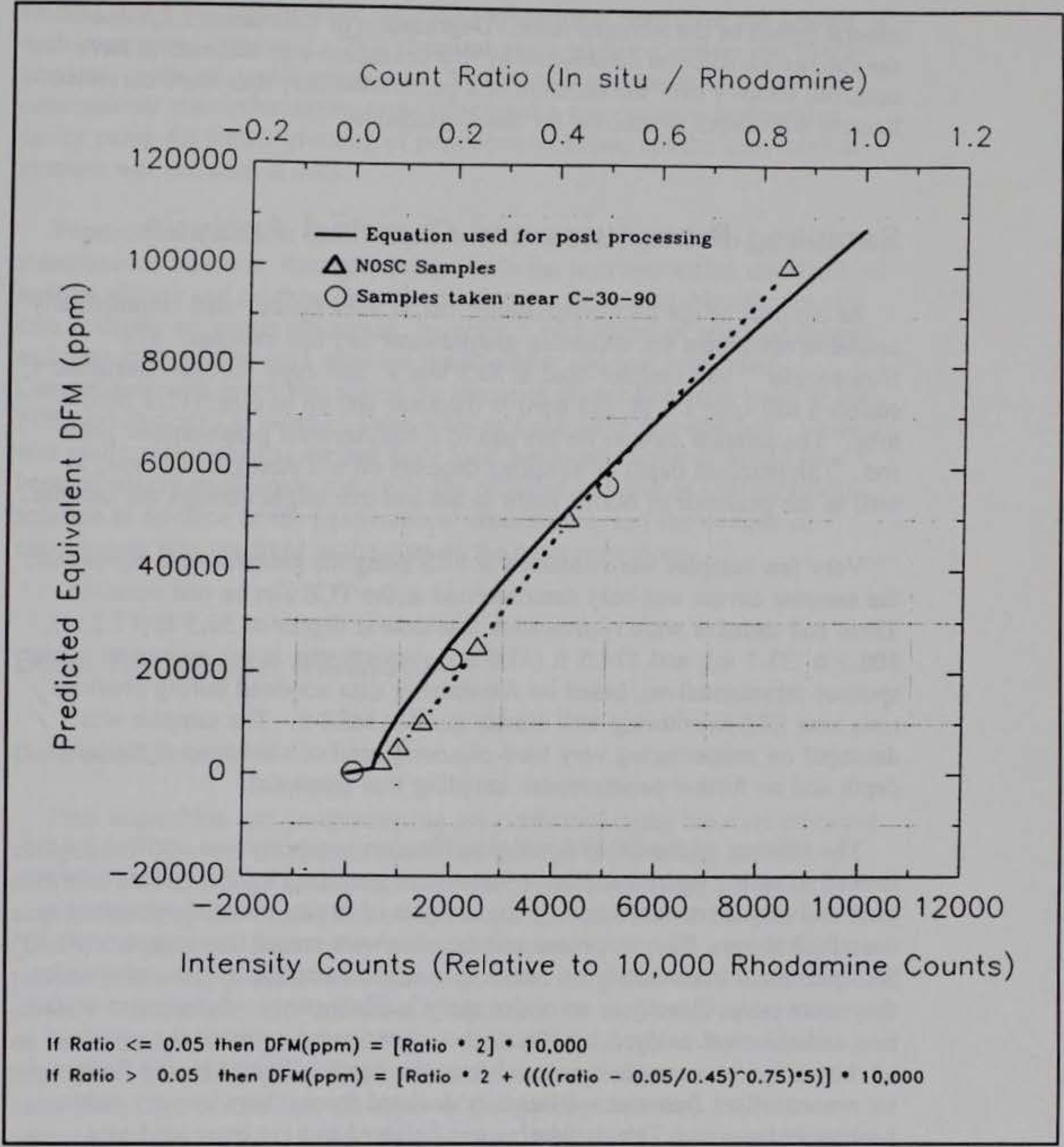


Figure 12. Fluorometry calibration for diesel fuel, marine, in Ottawa sand

The SCAPS fluorometer probe was, in effect, site-normalized to signal transmission performance prior to and following each penetrometer test to account for any degradation of the fiber optic system. Signal degradation may be caused by a variety of phenomena, including pitting of the planar surface of the terminal end of the silicon fiber caused by repetitive laser energy bombardment, abrasion of the sapphire window on the side of the probe, or bending damage to the fiber resulting from rod handling operations during a test. The field calibration was performed with a glass vial containing rhodamine solution (10 micro-molar concentration in ethanol and water), affixed to fit flush against the sapphire window on the fluorometer probe, exposed to several pulses of the nitrogen laser. Degradation in fluorescent response of the rhodamine solution determined by this procedure was assumed to have occurred steadily over the duration of a penetration test; data were corrected linearly with depth to account for this degradation.

Sampling Procedures and Chemical Analysis

At the time of the SRS experiments, the SCAPS system used commercially available equipment for collecting groundwater and soil samples. The Hogentogler™ soil sampler used at SRS was a "stab-type" sampler designed to collect a soil core 1.4 in. (35 mm) in diameter and up to 6 in. (15.2 mm) long. The sampler mounts on the end of a conventional penetrometer push rod. The practical depth of sampling depends on soil strength and type, as well as the presence of buried items in the soil that might damage the sampler.

Very few samples were obtained at SRS using the penetrometer equipment; the sampler device was only demonstrated at the TCE site on one occasion. Three soil samples were recovered at that time at depths of 56.5 ft (17.2 m), 108.5 ft (33.1 m), and 124.5 ft (37.9 m), respectively, at the request of onsite sponsor representatives, based on fluorometer data acquired during previous tests near SRS monitoring well cluster number MSB-9. The sampler was damaged on encountering very hard cemented sand or sandstone at the latter depth and no further penetrometer sampling was attempted.

The efficacy of the SCAPS soil classification capability was verified by the limited sampling operations; layer boundaries predicted by the system between sand and clay were confirmed by the samples of in situ material recovered as described above. The recovered soil samples were sealed into septum vials by SRS personnel immediately on removal from the sampling device, whereupon they were taken directly to an onsite analytical laboratory. Subsequent extraction and chemical analysis by Westinghouse personnel revealed the presence of rhodamine in a sample recovered from the depth indicated by the fluorometer record where fluorescence intensity deviated from otherwise very stable background values. The rhodamine was believed to have been used as a tracer dye in earlier drilling operations on the site. No TCE was detected by extraction and chemical analysis of the soil samples obtained using the SCAPS equipment.

Grouting to Seal Penetrometer Test Holes

The SCAPS unit was equipped at the time of these experiments to seal the penetrometer holes it produced using either a liquid (chemical) grout or conventional Portland cement-based grout. The chemical grout system was designed to inject a two-component grout through tubes running down the center of the penetrometer rod and seal the penetrometer hole as the rod was withdrawn. The system used two high-pressure, positive-displacement pumps feeding into a pressure/volume regulating system that controlled the amount of each component dispensed. This chemical grout injection system can handle acrylate, urethane, or silicate grouts. The SCAPS equipment also includes a conventional cement/bentonite grout mixer and a low-pressure progressive cavity pump for tremie grouting of penetrometer holes, but the conventional systems was not used at SRS.

Penetrometer holes at the TCE site were sealed by one of two methods: simultaneous injection, through tubing within the instrumentation umbilical, of sodium silicate and calcium chloride solutions to form insoluble calcium silicate at depth; or tremie placement, by gravity, of a slurry of portland cement and bentonite drilling mud after the penetrometer rod was withdrawn. Cement/bentonite grout was placed by tremie in all penetrometer holes at the POL and D-Area Oil Seepage Basin sites as a choice of convenience. Cement was easily replenished as needed from local hardware stores; it would have been necessary to estimate and order the required quantity of sodium silicate solution in advance of the penetrometer experiments, and the number of experiments was not fixed at the start of the latter operations.

Data Reduction Methods

Data acquisition

Data acquisition and postprocessing are performed using separate on-board computers. The two computers are linked through a token ring network to facilitate data exchange during and after the penetration testing. The data acquisition computer controls an onboard optical multichannel analyzer (OMA, the principal fluorometry analysis component) through a general purpose interface bus (GPIB). The data acquisition computer is also interfaced directly with the amplifier and filter components for the measurement of strain on the cone tip and sleeve, amplifiers for the electrical resistivity measurements, and a variable potentiometer that senses the position of the hydraulic rams (data used to calculate the depth of the penetrometer tip). All data are recorded on the network server computer hard disk during the penetration test, and transferred to the postprocessing computer while the probe is being withdrawn. Data summaries prepared on the SCAPS truck are shown in the Appendixes.

Computer site characterization and visualization

SCAPS penetrometer data were interpreted on return of the field data to WES using a Silicon Graphics™ work-station and three-dimensional visualization software, specifically the Interactive Volume Modeler™ (IVM), developed by Dynamic Graphics, Inc.™. The IVM accepts spatially-scattered data (referenced to a common coordinate system) in ASCII format and creates a uniform three-dimensional grid. Smooth extrapolation and interpretation for points are used to create grid values within and near the existing data. A lateral clipping plane is created to clip extrapolated data outside the bounds of the original data. The basic data control the location of each known value but the aspect of the final three-dimensional shapes produced from a data set can be altered by varying the weighting on the three-dimensional grid derived from the original data. Weighting values for the derived grid are typically selected by examining volume plots and judging which spacing combination produces a plot that most closely agrees with the original data points (i.e., that which minimizes residuals between modeled and measured data).

A completed three-dimensional visualization model is presented as a series of surfaces that represent specific values of the variable under study. The plot of the surfaces can be presented as a series of drawings of the site or as a computer-generated video image that shows the soil volume with the data boundaries presented in varying colors. The IVM software can rotate the volume so that the limits of the parameter can be observed from all three sides. Subprograms are available that allow the volume model to be sliced at various points so that the variation of the parameter can be observed inside the projected volume. Three-dimensional digital imaging techniques have previously been applied to model the contamination pattern at SRS in three dimensions as measured from groundwater samples (Nichols, Looney and Huddleston 1992).

3 Synopsis of Field Activities

Penetrometer Operations

Integrated Demonstration (TCE) Site

Conventional CPT reconnaissance. A reconnaissance CPT investigation was made of the TCE site by personnel and CPT equipment from the U.S. Army Engineer District, Vicksburg (CELMK) during the period 13-15 June 1990. The primary purpose of this initial study was to determine penetration conditions at the site, specifically to ascertain the maximum attainable depth using a standard CPT truck. The CELMK penetrometer was equipped with a hole expanding device, or "breaker," consisting of a short segment of drill rod from which protruded four diametrically opposed lugs. The lugs were about 0.5-in. (0.013 m) square and extended the diameter of the hole about 1 in. (0.025 m). The breaker was located immediately behind the active electronic cone, and served to reduce soil friction along the push rod string above this point. It was still necessary to cycle the hydraulic ram force on the penetrometer push rods to reduce friction along the rods and assure that most of the pushing force was transmitted to the cone tip. Digital CPT data records were not correlatable to depth as a consequence of this cycling procedure, since the automatic depth measurement instrumentation did not track net penetration. Profiles of soil type and strength parameters were thus not processed.

Three CPT penetrations were completed to various depths by the CELMK crew near monitoring well MSB-15AA (see Figure 13); the greatest depth reached was 154 ft (46.9 m). It became clear from these tests that penetrometer operations deeper than about 150 ft (45.7 m) were not feasible. Instrumentation cable assemblies, or umbilicals, designed and built at WES to support subsequent SCAPS penetrometer tests at the TCE site were assembled to reach 150 ft (45.7 m); each of four umbilicals (two each for fiber optic fluorometers and resistivity probes) were fabricated to have a length of about 300 ft (91.4 m) to provide for adequate slack and conduit routing within the SCAPS truck. On-board rod racks hold sequential stacks of push rods; slack must be provided between each rod on the rack to accommodate the safe bending radius of the silicon optical fibers within the umbilical (about 1.5 ft, or 0.5 m, of slack was sufficient) and to facilitate manipulation of each segment during successive attachment to the string of rods being pushed.

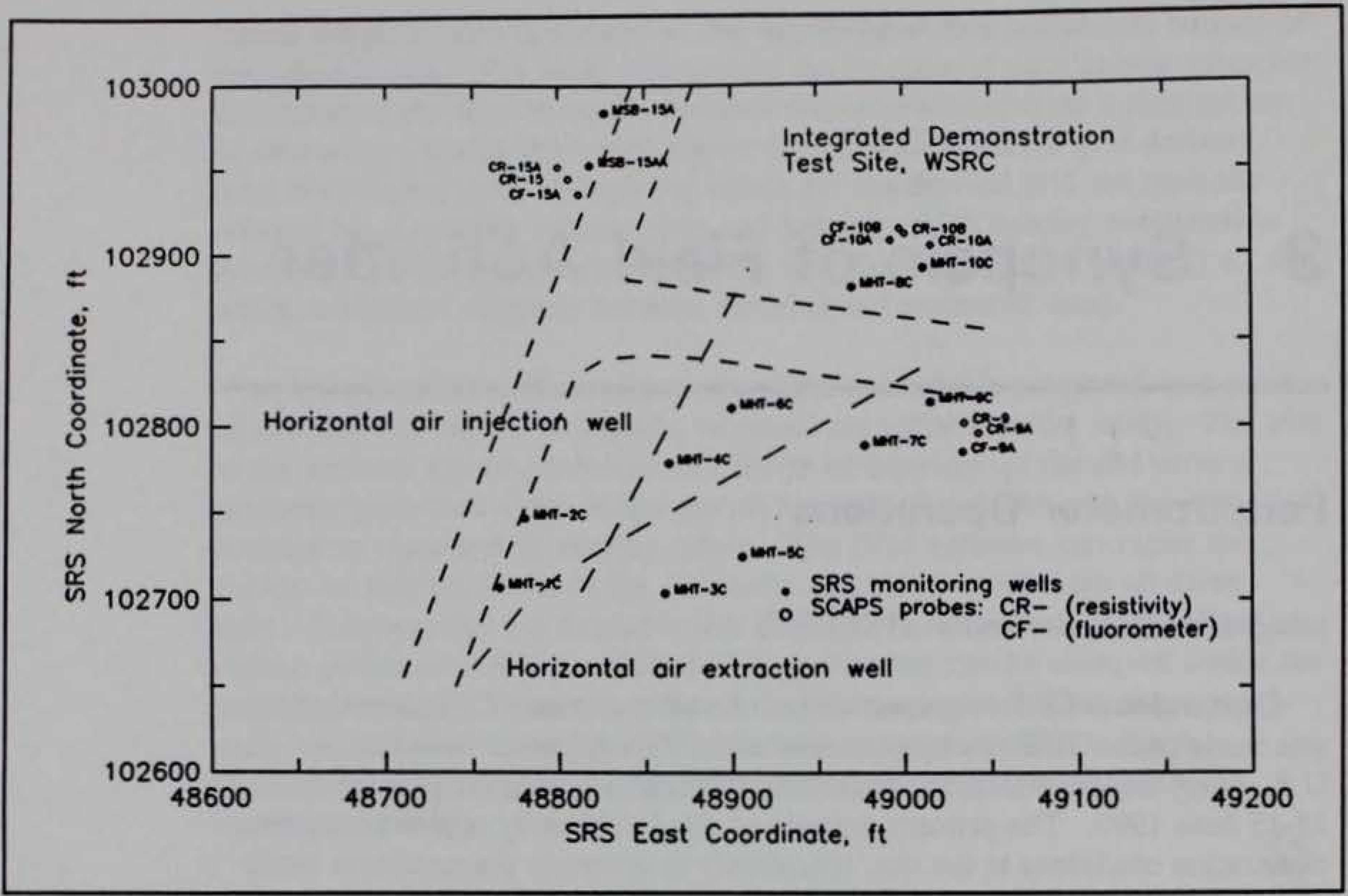


Figure 13. Integrated Demonstration (TCE) Site penetrometer operations, FY 90-91

SCAPS experiments. The SCAPS penetrometer truck was first deployed to the TCE site during the period 8-17 December 1990, during which time six resistivity probes and four fiber optic fluorometer probes were completed to an average depth of about 150 ft (45.7 m). Figure 13 shows the plan of SCAPS penetrometer tests conducted in this study at the TCE site. All tests were performed near existing monitoring wells or well clusters, in response to requests by onsite sponsor representatives. Specific test results are presented in Part IV.

The first SCAPS test was conducted using a resistivity probe and was located about 15 ft (4.6 m) southwest (SRS directions) of a monitoring well designated MSB-15AA, in the vicinity of a conventional CPT performed by CELMK as described in the previous section. This probe was built with a hole expander ring, made of heat-treated steel, at the leading edge of its electrode array to reduce rod friction and permit maximum penetration depth. Resistivity data were erratic, for which it was thought that poor electrical contact between the electrodes and surrounding soil was responsible. The hole expander ring was subsequently ground flush to the probe onsite and a second test performed about 3.5 ft (1.1 m) north of the first; resistivity data were greatly improved for this and all subsequent tests.

Additional resistivity probes were conducted near monitoring well clusters numbered MHT-9 and MHT-10, as depicted in plan view in Figure 13. The typical maximum depth achieved by continuous pushing (no rods were pulled during a test and re-pushed to reduce friction in the hole) was about 154 ft (46.9 m).

The resistivity probe and its umbilical were removed from the SCAPS truck and the push rod segments following completion of resistivity studies at the TCE site. A fiber optic probe umbilical was threaded, in the field, through an adequate number of 1-meter hollow push rods and installed into the data acquisition system of the SCAPS truck to configure the system for fluorometer studies.

The installed fiber optic fluorometer was calibrated prior to its first push at the TCE site in the manner described in Part II for strain gauge load and fluorescence intensity data acquisition. Five tests were then performed to depths of about 154 ft (46.9 m) in the vicinities of the monitoring well clusters listed earlier (Figure 13).

Central Shops (POL) Site

A total of 34 fiber optic fluorometer tests and two resistivity penetrometer tests were performed at the locations shown in Figure 14 to detect and delineate the extent of underground hydrocarbon contamination that might have emanated from a diesel fuel tank farm in the Central Shops Area. Penetration depths generally ranged from 50 ft (15.2 m) to 75 ft (22.9 m). Penetrometer locations were typically selected on 100 ft (30.5 m) centers and corresponded with a grid established for the geophysical surveys described earlier; several points were tested outside the geophysical survey boundaries at the request of Dr. Terry Hazen, WSRC, to refine initial data interpretation.

Sufficient fluorometric data were obtained and processed to produce three dimensional visualizations of subsurface contaminant concentrations at the POL site. Specific results of fluorometer and resistivity probe data are discussed in Chapter 4.

D-area Oil Seepage Basin

A series of SCAPS fluorometer penetration tests were conducted within the boundaries of the D-Area Oil Seepage Basin, as sketched in Figure 15. The second test, designated CF-02-DO, reached a depth of about 30 ft (9.1 m); all others were about 50 ft (15.2 m) deep. No resistivity tests were performed at this site. Results are discussed in Chapter 4.

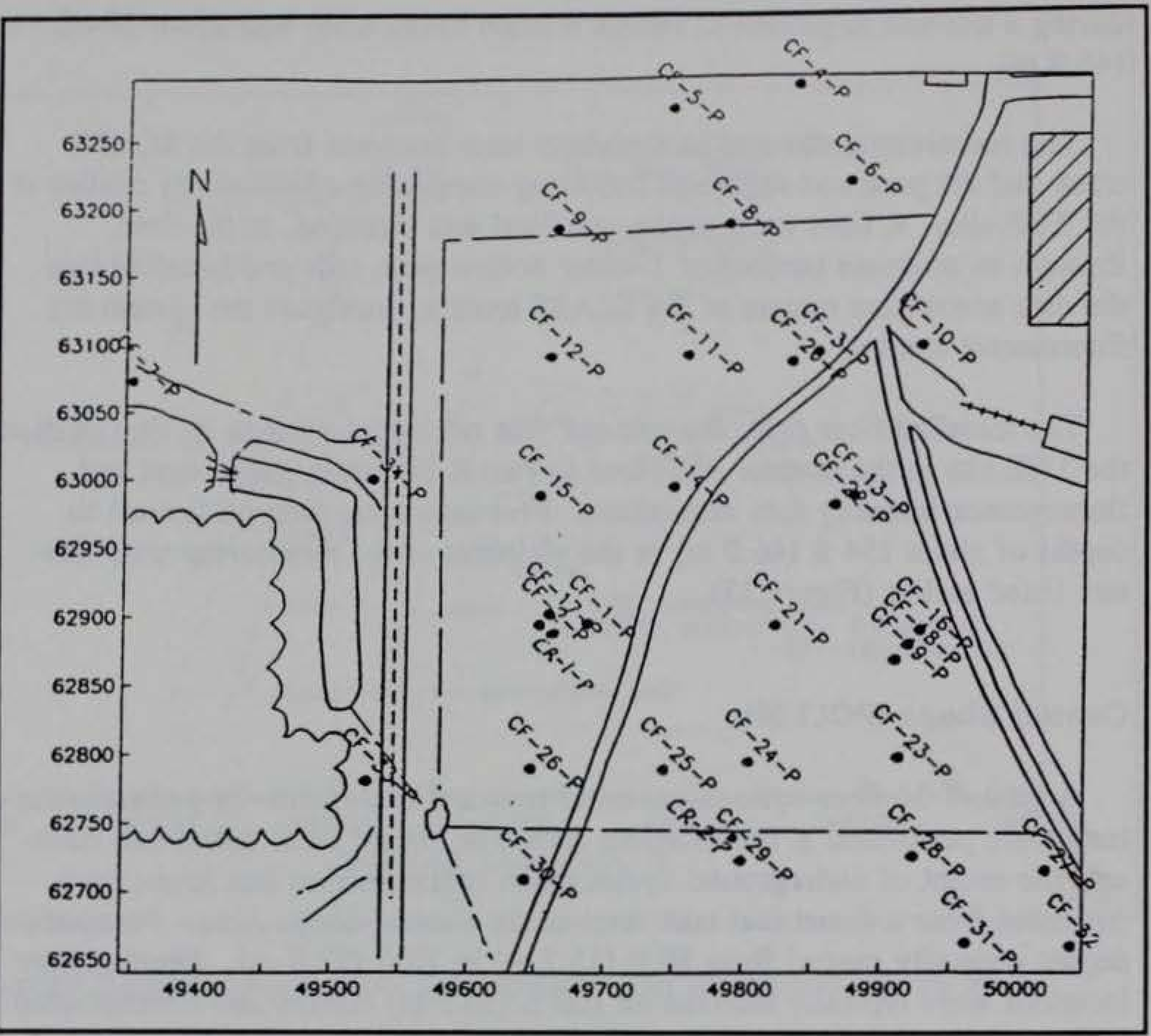


Figure 14. Central Shops (POL) Site map

Implant Experiments

General

The primary SCAPS mission for exercises conducted during the period 20-27 April 1991 was to evaluate its reliability as a delivery mechanism to implant devices such as the two discussed below, as well as to assess the structural adequacy of the implant systems themselves for field conditions. Preliminary implant sensor data acquired during these initial tests were retained for additional processing by the Lawrence Livermore National Laboratory (LLNL) and the Illinois Institute of Technology Research Institute (IITRI); no sensor data from the implant experiments were processed by WES for presentation in this report. Chpater 5 describes, in more detail, a subsequent investigation of a TCE-specific LLNL device during a field exercise conducted during the period 18 May - 1 June 1992.

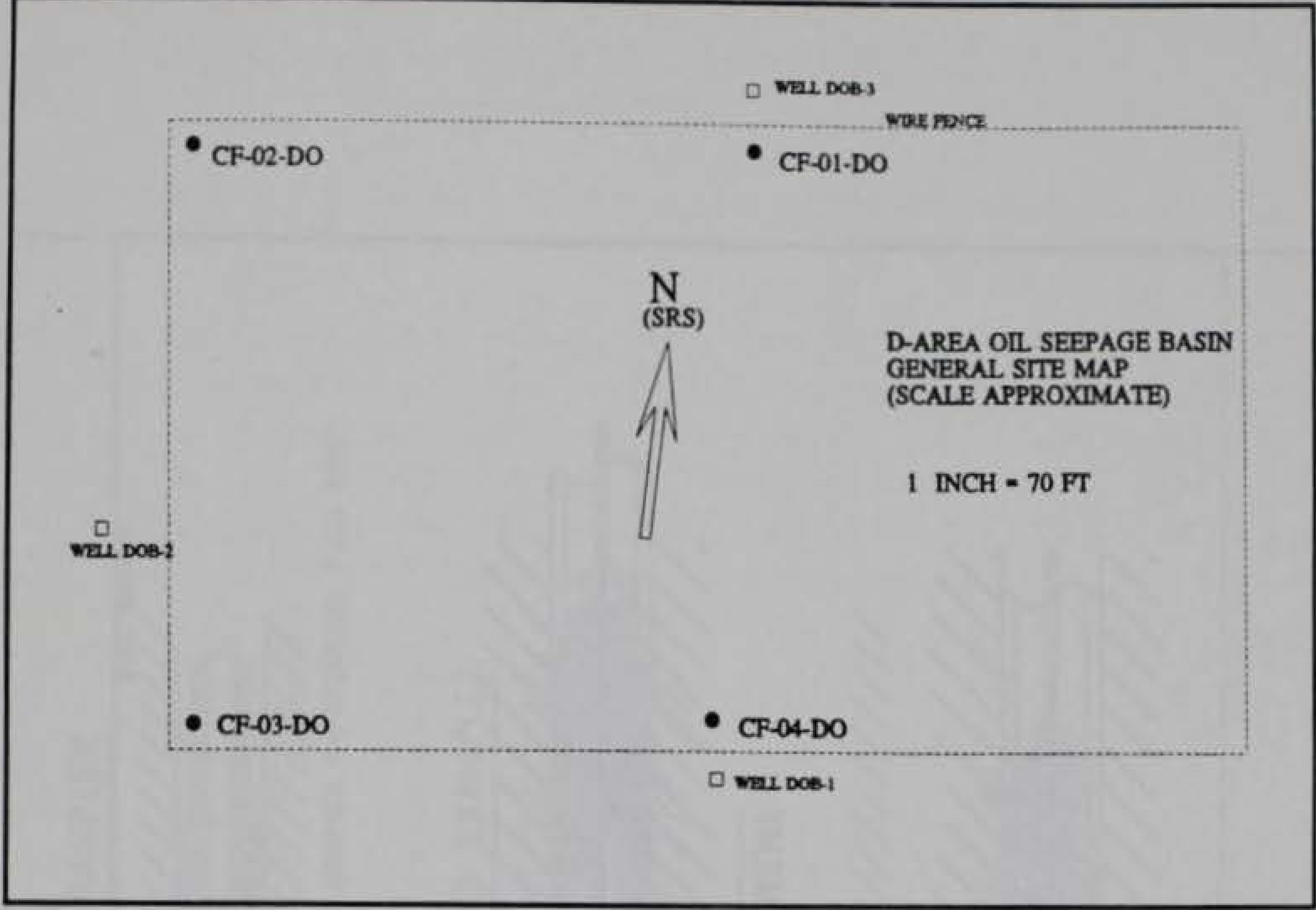


Figure 15. D-area Oil Seepage Basin Site map

Lawrence Livermore National Laboratory (LLNL) "Optrode"

Field experiments were performed on a prototype fiber optic sensor designated the "Optrode", during the period 20-22 April 1991. Figure 16 is a diagram of the LLNL sensor. The Central Shops (POL) Site was selected for tests due to the presence of underground hydrocarbon contamination. The sensor was integrated with the SCAPS push rod system, pushed to a shallow depth, and retracted approximately 2 in. (5.08 cm). The expendable probe tip was thus disengaged, and the sensor element (a length of silicon fiber doped with a photosensitive, hydrocarbon-reactive coating) was exposed to the soil. Several interval readings were taken with time of exposure, and the apparatus was retracted to the surface.

Illinois Institute of Technology Research Institute (IITRI) "Terratrog"

The Illinois Institute of Technology Research Institute (IITRI) sensor for in situ soil vapor detection ("Terratrog") was field tested during the period 23-27 April 1991. Figure 17 is a diagram of the Terratrog sensor. The field prototype sensor was evaluated at the Integrated Demonstration (TCE) Site, due to the reported presence of soil gas phases of the contaminants TCE and tetrachloroethylene in the vadose zone at this location (Westinghouse Savannah River Company 1991). The sensor was integrated with the SCAPS push rod system and pushed to a depth of approximately 14 ft (4.2 m) below surface near SRS monitoring well MHT-2C. The sensor was left in place at that

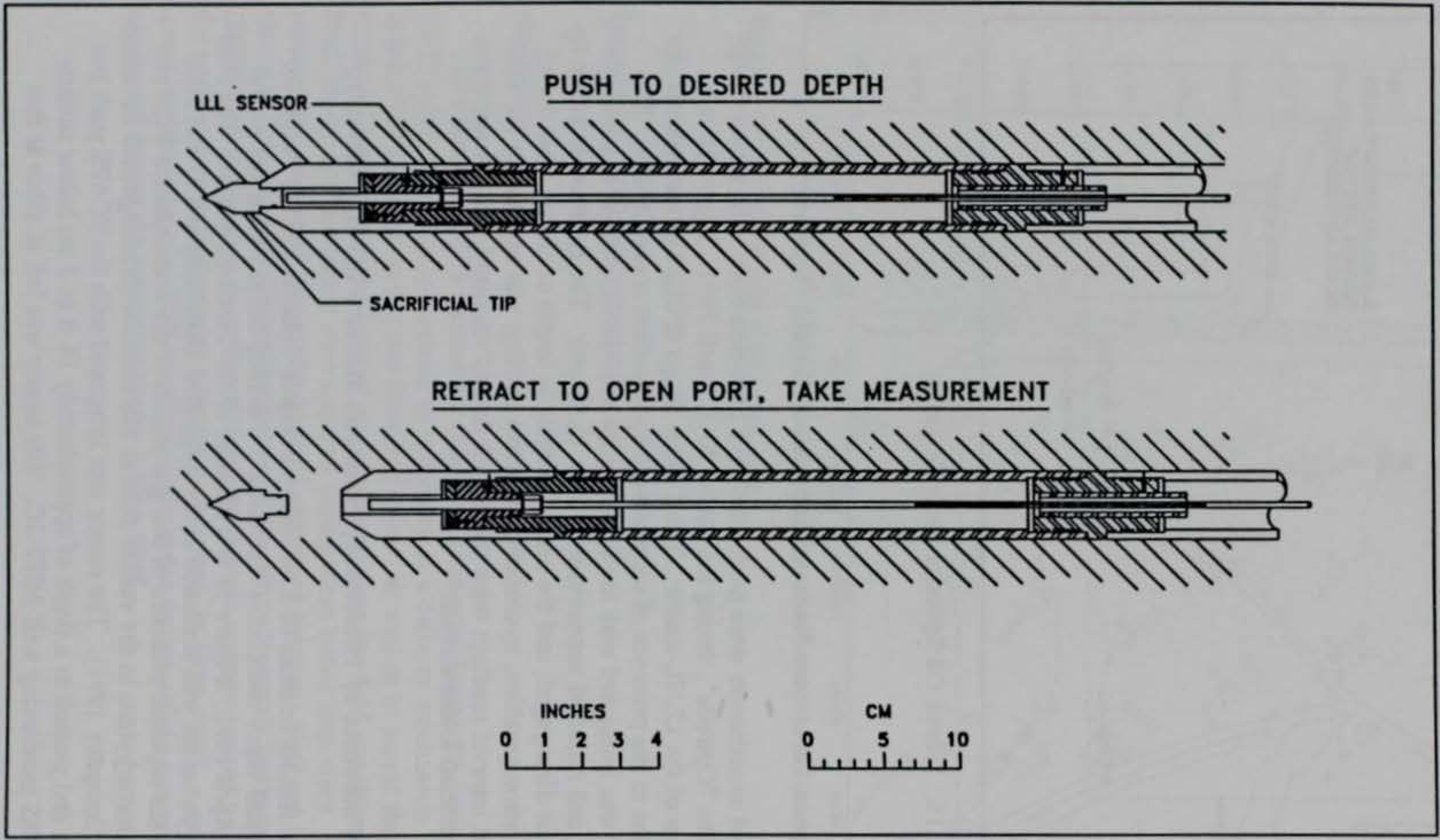


Figure 16. Lawrence Livermore National Laboratory optrode diagram

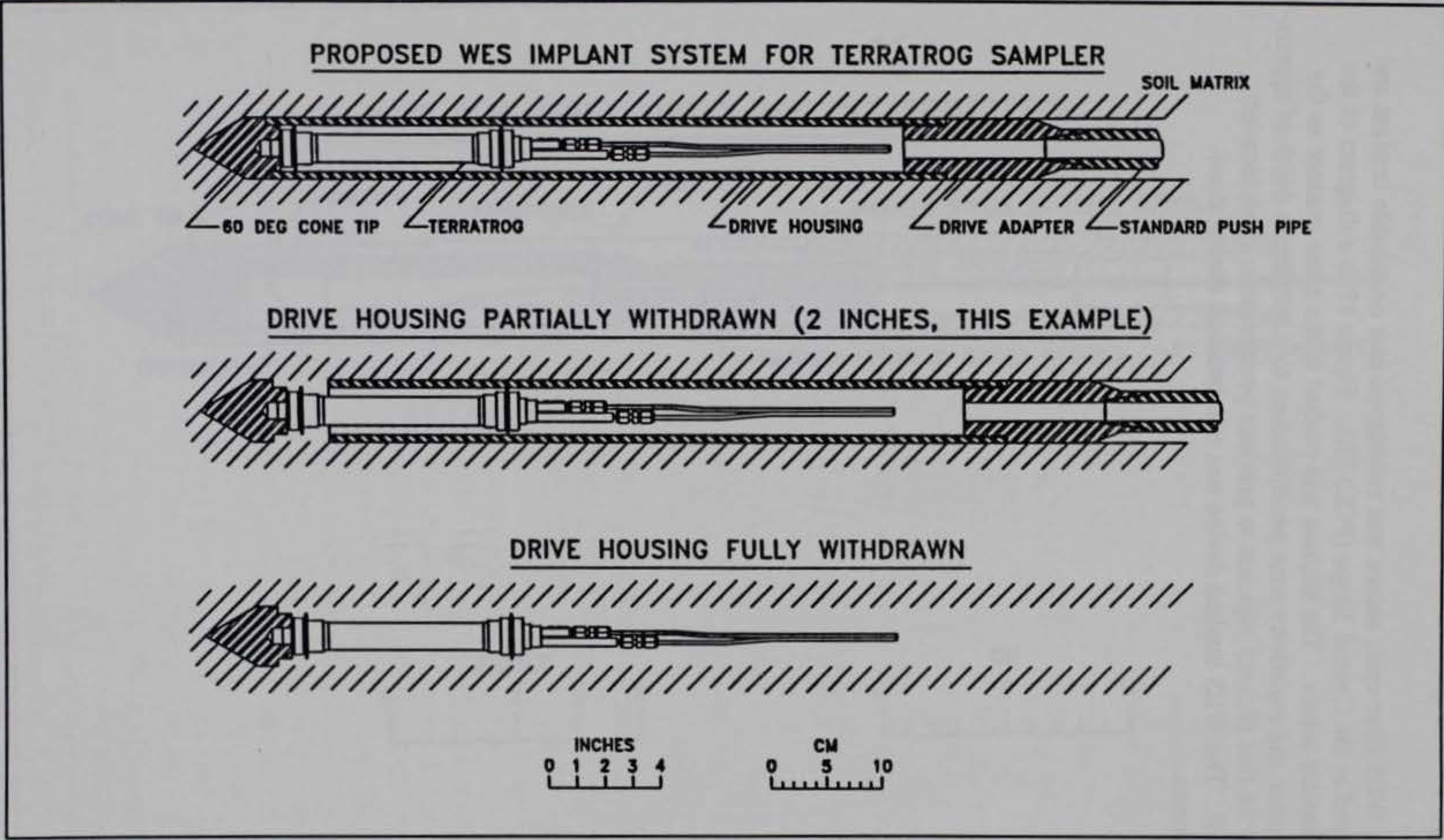


Figure 17. Illinois Institute of Technology Terratrog diagram

depth and the push rod was retracted, providing the capability for soil gas to be sampled over an indefinite period and drawn through internal tubing to the surface for analysis using a portable gas chromatograph.

U.S. Army Engineer Waterways Experiment Station (WES) fiber optic sensor

The WES fiber optic sensor was redesigned as a detachable implant and was tested at the Central Shops (POL) Site. Figure 18 is a diagram of the WES implant sensor. The implant was pushed in the same manner as the fluorometer and resistivity cone penetrometers to a maximum depth of approximately 28 feet (8.5 m) adjacent to previous penetrometer push location CF-19-P. The WES implant device was not detached during these experiments.

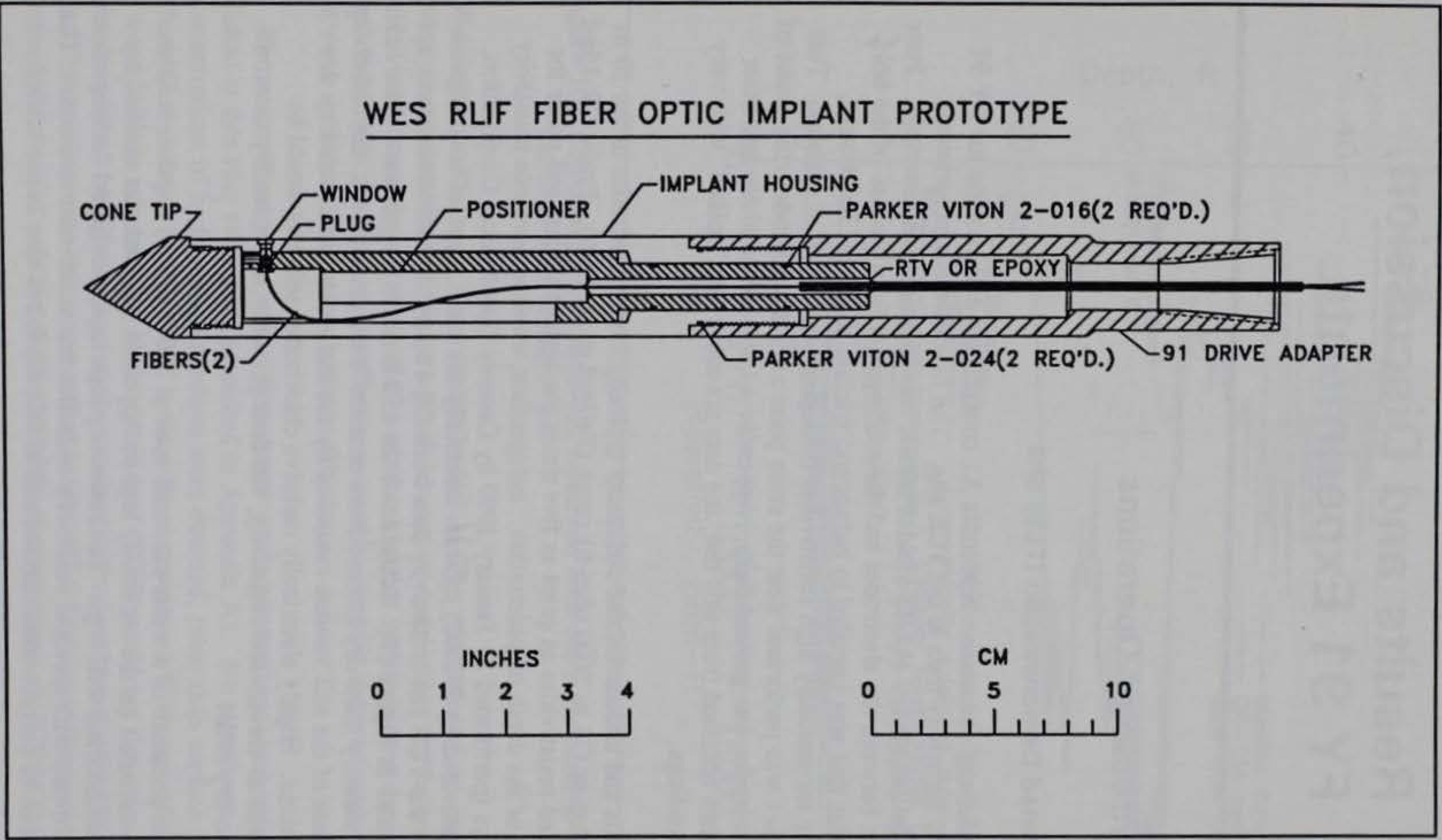


Figure 18. U.S. Army Engineer Waterways Experiment Station POL implant diagram

4 Results and Discussion, FY 91 Experiments

Penetrometer Operations

Integrated Demonstration (TCE) Site

Resistivity response. Appendix A1 contains six data records for FY 91 SCAPS resistivity tests at the TCE site. The first of these experiments (CR-15-t) attempted at SRS yielded erratic resistivity data as described. Poor contact between the electrodes and the soil resulted from the use of the hole expander that was intended to reduce rod friction above the instrument, causing anomalously high resistivities throughout the depth of pushing. Test CR-15a-t was performed near the same point after the expander ring ahead of the electrodes was ground flush. Appendix A1 shows resistivity and other CPT data obtained from this test; the data are much less "spiked" with very high readings.

Soils and unconsolidated sediments typically have resistivities in the 10 to 800 ohm-m (33 to 2600 ohm-ft) range (Telford et al. 1976). Probe CR-15a-t revealed resistivities as great as five times the highest typical soil value for much of the depth of penetration. Independent wireline borehole resistivity surveys (performed 31 January 1990 by Century Geophysical Corporation, data provided by WSRC) indicate essentially the same range of soil resistivities at the TCE site (resistivity data from CR-15a and the wireline survey are compared in Figure 19). Soils above the 130 ft (39 m) depth were observed to be visually quite dry (no moisture contents were determined); the resistivity response of the soil volume measured by the test would be elevated by dry conditions. Highly electrically resistive chlorinated solvents would be expected to elevate soil resistivity, but their presence is not readily determinable in dry soils.

The presence of a water-saturated zone at 130 ft (39 m) depth is consistently revealed on the resistivity logs in Appendix A1, and was verified by SRS monitoring well logs. The resistivity logs in Appendix A1 indicate that a zone of soil with elevated resistivity underlies this water-saturated zone. The presence of solvent-contaminated soil at this depth has also been verified

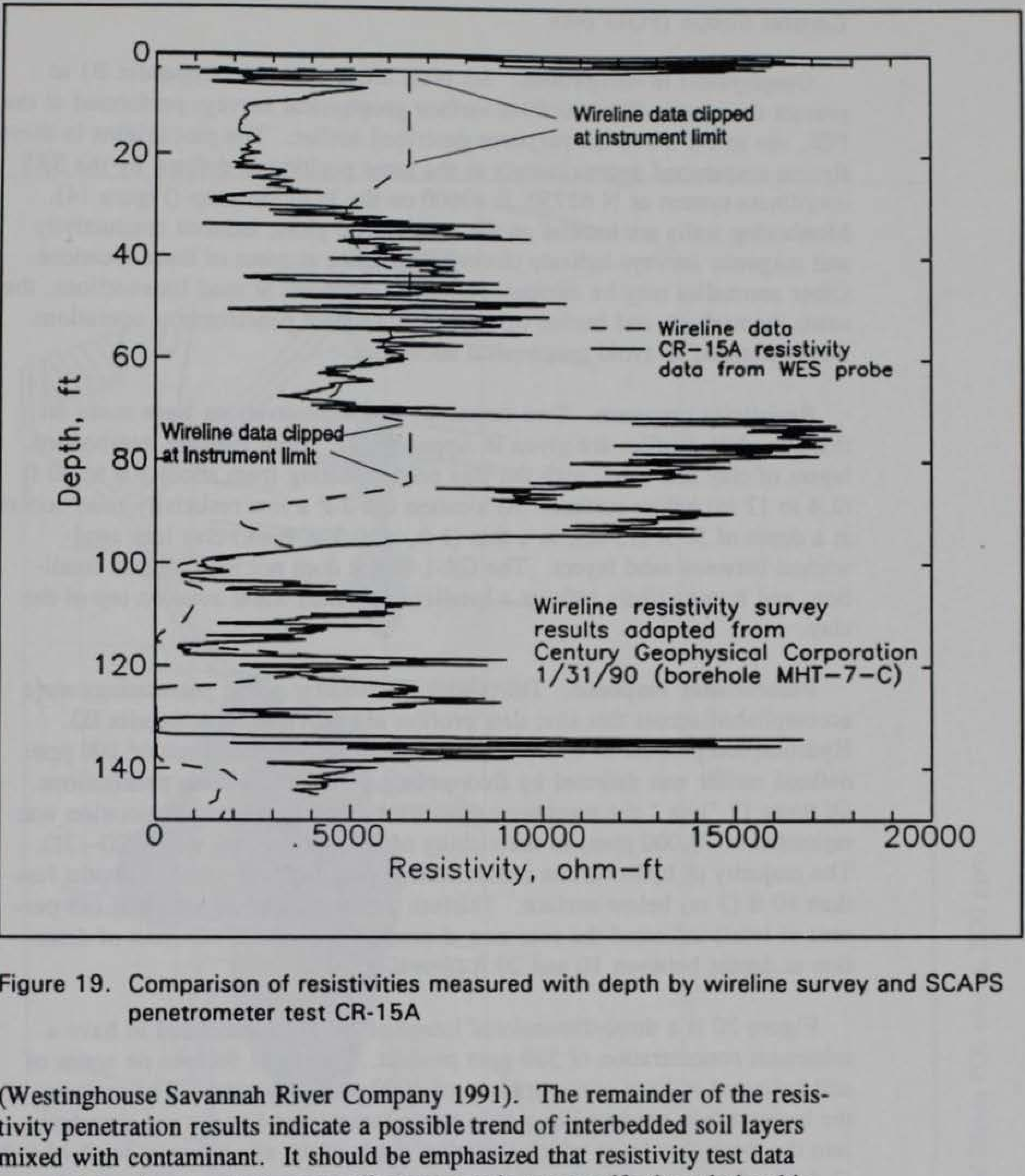


Figure 19. Comparison of resistivities measured with depth by wireline survey and SCAPS penetrometer test CR-15A

(Westinghouse Savannah River Company 1991). The remainder of the resistivity penetration results indicate a possible trend of interbedded soil layers mixed with contaminant. It should be emphasized that resistivity test data reported herein are relative; no effort was made to quantify the relationship between resistivity and contaminants at this site.

Fluorometer response. Five fluorometer probe penetrations were accomplished at this site; results are presented in Appendix A3. No significant concentrations of hydrocarbon products were detected, other than surface effects likely caused by diesel fuel spillage from previous drill rig operations. It was known in advance that trichloroethylene (TCE) would not fluoresce when irradiated by light energy at the wavelength produced by the SCAPS laser, hence there was little expectation that the WES fiber optic fluorometer system would prove capable of detecting low concentrations of TCE in soil.

Central Shops (POL) Site

Geophysical investigations. Six plots are provided in Appendix B1 to present the results obtained from surface geophysical surveys performed at the POL site in FY 91 to the purposes described earlier. The plot origins in these figures correspond approximately to the same position as defined by the SRS coordinate system as N 62750, E 49600 on the POL site map (Figure 14). Monitoring wells are located on the geophysical plots; induced conductivity and magnetic surveys indicate obvious anomalies at some of these locations. Other anomalies may be attributed to metal signposts at road intersections, the roads themselves, and buried culverts. Subsequent penetrometer operations were patterned to avoid geophysical anomalies.

Resistivity response. Two resistivity probe penetrations were made on this site; data profiles are given in Appendix B2. Both indicate interbedded layers of clay and sand, with the clay predominating from about 8 ft to 40 ft (2.4 to 12 m) below surface. At location CR-2-P a low resistivity zone occurs at a depth of 50 ft (15 m), in a thin (1 ft, or 0.3 m thick) clay lens sandwiched between sand layers. The CR-1-P plot does not indicate this condition, and it most likely reflects a localized, perched water zone on top of the clay.

Fluorometer response. Thirty-four fluorometer probe penetrations were accomplished across this site; data profiles are provided in Appendix B3. Hydrocarbon product in concentrations above the detection limit of 200 ppm defined earlier was detected by fluorometry during 17 of these penetrations. Of these 17 "hits," the maximum equivalent diesel product concentration was estimated at 70,000 ppm, in the vicinity of SRS monitoring well CSD-13D. The majority of hydrocarbon contamination detected was found at depths less than 10 ft (3 m) below surface. Thirteen penetrometer test locations (48 percent of total) indicated the presence of product near the lower limit of detection at depths between 10 and 20 ft (3 to 6 m).

Figure 20 is a three-dimensional image of the areas estimated to have a minimum concentration of 500 ppm product. Figure 21 focuses on zones of soil indicated to have concentrations of 4000 ppm or greater. The majority of the hydrocarbon product lies within sandy lenses, and has not yet absorbed into the thick clay layer which underlies much of the site below a depth of 8 ft (2.4 m). Low-concentration contaminated zones that appear within the clay layer probably emanated from isolated leaks or spills; it is not known whether site soils as deep as these latter zones have been disturbed by excavation, or whether pipelines once existed and are now removed.

D-area Oil Seepage Basin

Four fluorometer probe penetrations were accomplished at this site (mapped in Figure 15, data presented in Appendix C and hydrocarbon product was detected at all four locations along the fence perimeter. The majority of the hydrocarbon concentration lies at depths between 10 to 20 ft (3 to 6 m).

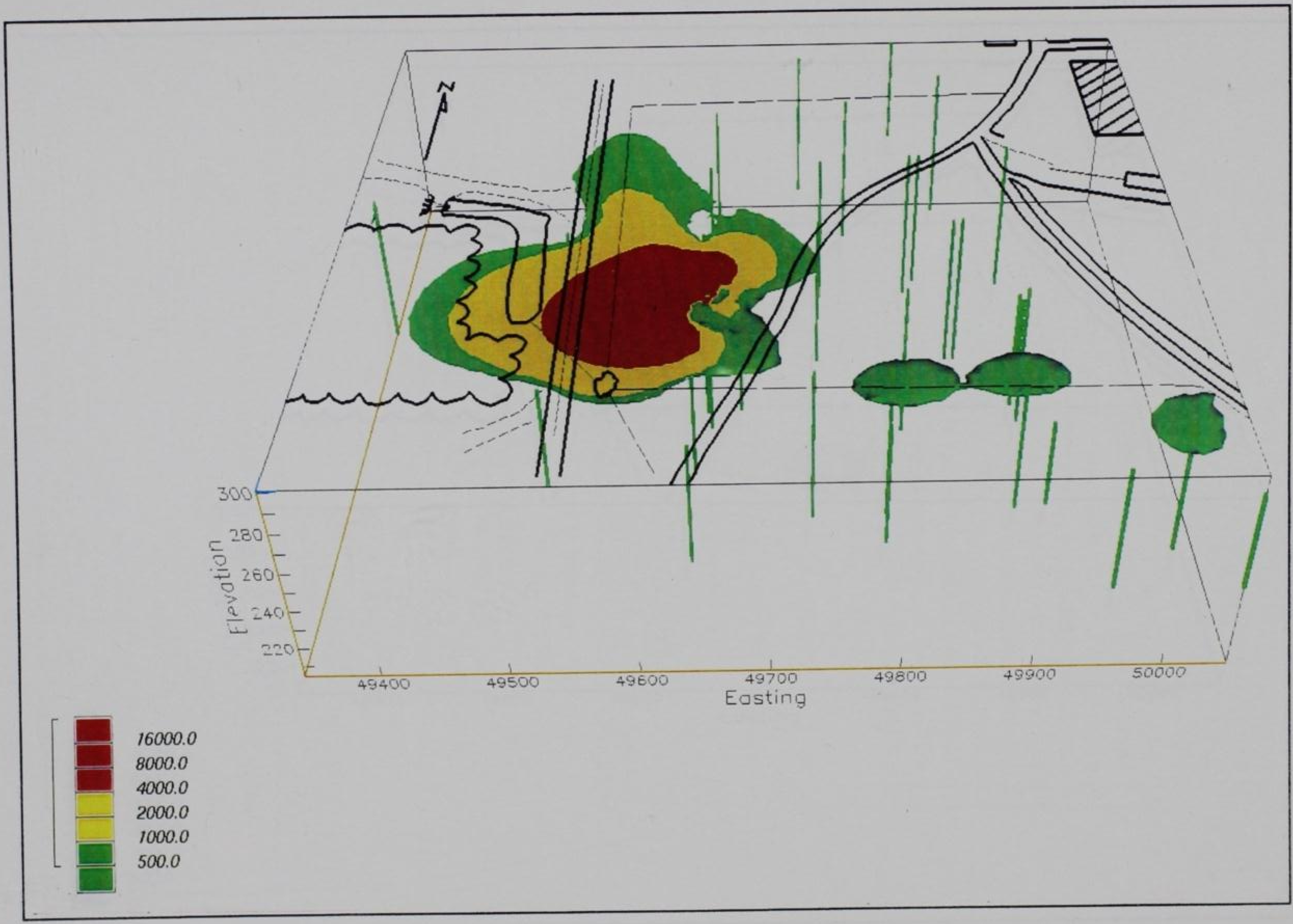


Figure 20. 3-D Image of Central Shops POL plume, 500 ppm

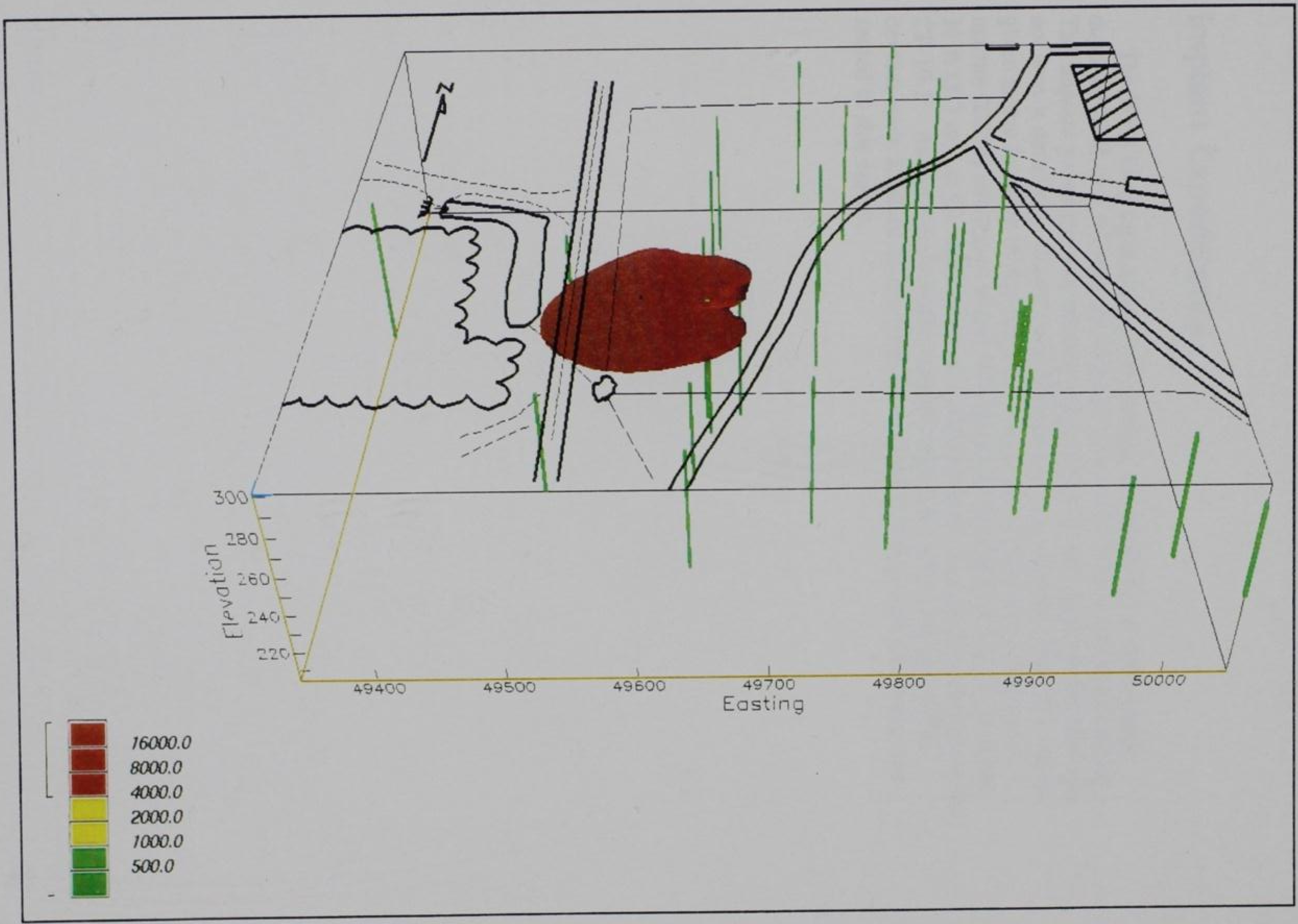


Figure 21. 3-D Image of Central Shops POL plume, 4000 ppm

The maximum equivalent diesel concentration averages about 1000 ppm and is found in both sandy and clayey layers. This site is know to have been excavated and refilled (Westinghouse Savannah River Company 1990); no uniform clay underlies the area as at the Central Shops POL site. There is a higher likelihood for the hydrocarbon contamination in the soils at the D-Area Basin to seep downward due to the absence of such a confining clayey layer.

Implant Experiments

The WES fiber optic sensor was pushed, continuously, to a maximum depth of 28 ft (8.5 m) near the location of test CF-19-P as discussed earlier. The implant prototype was not stopped to reside at any depth during this test, nor was it detached. A profile of fluorometry data obtained from this test is given in the last plot in Appendix B3. A predicted equivalent diesel fuel, marine (DFM) content of about 1000 ppm was indicated at a depth of about 12 ft (3.7 m), at the same depth as a slightly lower concentration found in test CF-19-P. As previously stated, implant data from the LLNL and IITRI devices were retained by the respective agencies and are not separately presented in this report.

5 FY 92 Experiments at SRS

General

The SCAPS was deployed to the Savannah River Site during the period 18 May - 1 June 1992 to perform a series of penetrometer resistivity experiments and to support a field study on a Lawrence Livermore National Laboratory (LLNL) fiber optic sensor for detection of chlorinated solvents. All activities during this period were conducted at the Integrated Demonstration Site described earlier.

Synopsis of Field Operations

The following tasks were planned through discussions with WSRC personnel to precede arrival of a team and equipment from LLNL:

a. The SCAPS was assigned to perform resistivity measurements adjacent to existing monitoring wells instrumented with downhole resistivity sensors. These monitoring wells and the resistivity data collected are used for research purposes by another LLNL component, primarily to ascertain effects of changing soil resistivity as the chlorinated solvent concentrations decrease (due to the ongoing air-stripping site remediation previously discussed). The SCAPS resistivity data were intended to complement the downhole data and assist in generation of tomography visualization for subsurface resistivity patterns.

b. The SCAPS was also assigned to assist in locating a suspected perched water table. The perched water table had been logged during the drilling of some of the monitoring wells. It was anticipated that the SCAPS resistivity probe could verify this feature.

c. One of the monitoring wells adjacent to the horizontal well air stripping plant consistently exhibited positive air pressure when sampled. It was postulated that a highly permeable sand layer was providing a "short circuit" for a portion of the injected air to circumvent the extraction well process. The SCAPS was tasked to attempt to identify the location of the unknown layer.

The first penetration test location was selected halfway between SRS monitoring wells MHM14 and MHM15 (see site map, Figure 22). These wells were placed by LLNL and instrumented with resistivity sensors for the purpose described earlier. Previous site investigations did not indicate the presence of buried obstacles, and after consultation with onsite WSRC personnel it was decided not to conduct a geophysical site clearance investigation.

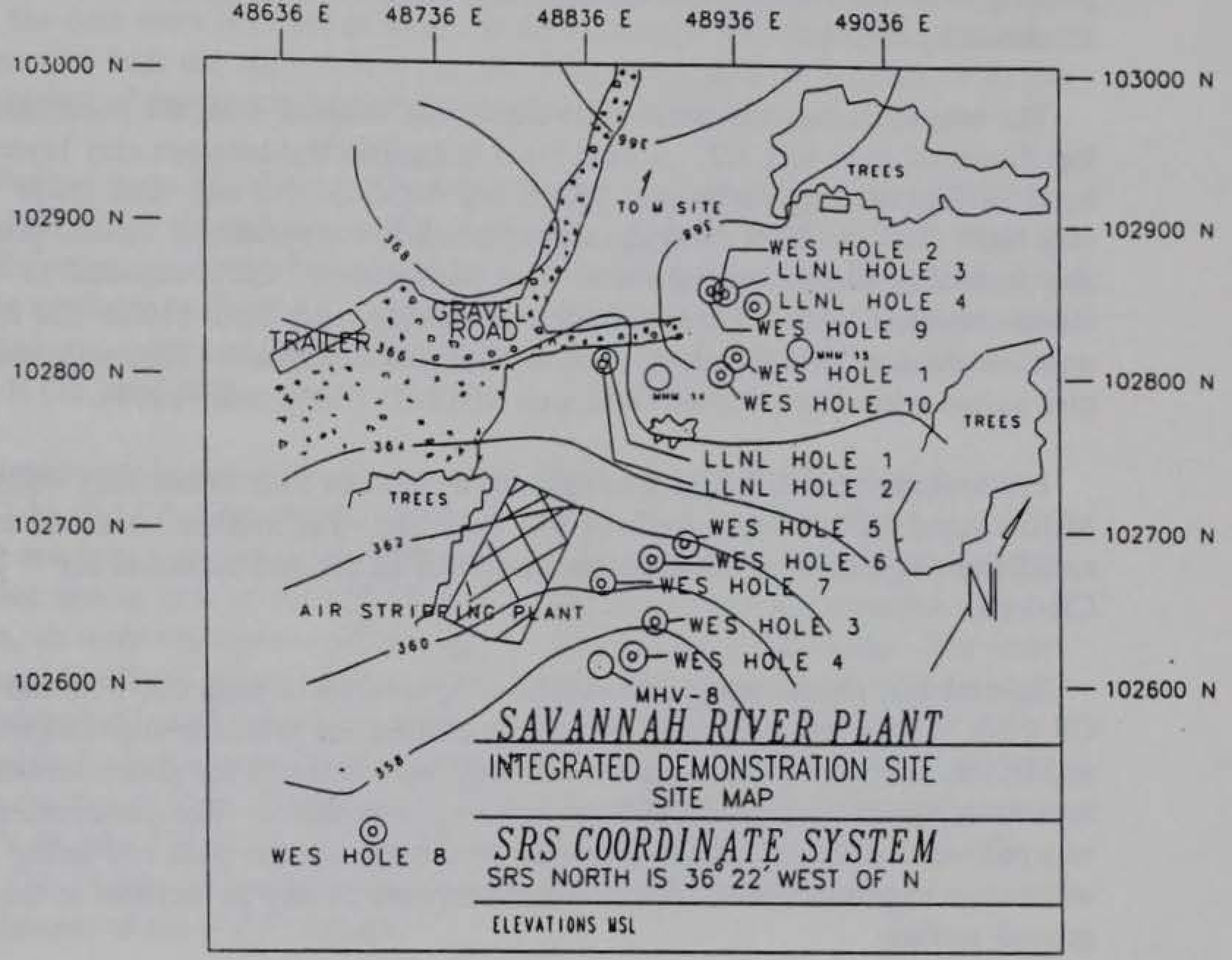


Figure 22. Integrated Demonstration (TCE) Site map, FY 92 experiments

The first penetrometer test (CR-1-M, shown in Appendix A2) was conducted using the resistivity probe described earlier to a depth of 130 ft (39.4 m) through interbedded layers of sand and clay. The hydraulic ram force required for penetration generally increased with depth, due to accumulated friction along the push rod string. The ram force temporarily reached 18 tons (16,200 kg) at a depth of 110 ft (33 m), but decreased slightly below this depth to lower values until the test was terminated. The water table at the time of these tests was estimated to be found at elevation 230 ft MSL (or about 130 ft depth) above a green clay aquitard that overlies a confined aquifer. Eddy et al. (1991) provide a detailed description of the hydrogeology of this site.

Sleeve friction data acquired during penetration test CR-1-M appeared to be excessively low (raw data are plotted in Appendix A2), possibly as a result of calibration error. The SCAPS crew added an artificial offset stress of 1.3 tsf to prevent subsequent plotting of negative friction data. The sleeve friction values adjusted in this manner for Test CR-1-M are represented in Appendix A2. Friction sleeve data were similarly adjusted (i.e., increased) by 0.6 tsf prior to being plotted for tests CR-2-M, CR-3-M and CR-4-M. Friction sleeve data from subsequent penetrometer tests were not adjusted prior to plotting, with the exception of the data for Test CR-13-M, which were increased by 0.07 tsf.

The suspected perched water table depth was inferred from the penetration log shown in Appendix A2. A sand layer is sandwiched between clay layers between depths of approximately 100 to 105 ft (30 to 31.8 m). The lower clay layer (110 to 120 ft depth) produced much lower resistivity values, probably indicating higher soil moisture. The contaminant TCE is expected to elevate resistivity, thus it is not likely that the clay layer from 110 to 120 ft contains much of this chemical. The elevation of this zone of high soil moisture agrees with data obtained from well MHT9D (Eddy et al. 1991).

Penetrometer test CR-2-M was conducted between SRS monitoring wells MHM13 and MHM16 to a depth of 130 ft (39 m). Penetration resistance and resistivity response were observed to be similar to the data recorded for CR-1-M.

Subtask (c), above, was pursued following conduct of tests CR-1-M and CR-2-M. The monitoring well exhibiting effluent air pressure was designated as MHV8; several locations around this well were selected for penetrometer tests to delineate the permeable layer believed responsible. The penetrometer was pushed to different depths at several locations, and the push rod string withdrawn to produce a small hole for observation of any air outflow at the ground surface.

Using a hand-held OVA meter, the concentration of methane outflow was also measured at each hole. Methane outflow would confirm communication of injected air, because the air stripping plant injection well inputs a 1 percent methane mixture for microbial contaminant degradation (Rossabi 1992). Penetrometer holes remained open in the stiff, dry ground at the TCE site until grouted closed by the SCAPS crew; the unsaturated soils did not slough back on withdrawal of the probe and its push rods. Penetrometer test CR-3-M was continued until the capacity of the hydraulic ram was reached at 118 ft (36 m) depth (elevation 240 ft MSL). After penetrometer retraction, a 1 percent methane gas outflow was observed.

Penetrometer test CR-4-M was pushed to a depth of 112 ft (34 m), elevation 244 ft (74.4 m) MSL, and 1 percent methane gas outflow was again observed. Test CR-05-M was pushed to a depth of 118 ft (36 m), elevation 243 ft (74 m) MSL, and no gas outflow was observed. Test CR-06-M was pushed to a depth of 75 ft (23 m), elevation 185 ft MSL, and no gas outflow was observed.

Test CR-9-M was pushed to a depth of 91 ft (27.5 m), elevation 269 ft MSL, and a 1 percent methane gas outflow was observed. Having confirmed that the gas outflow was traveling from the injection well through a sand lens or lenses between elevation 244 and 269 ft (74 and 82 m) MSL, no further attempts to isolate the permeable stratum or strata were pursued.

No data plots are provided for tests CR-07-M, CR-08-M and CR-10-M. These experiments were performed on artificially-prepared specimens of water and soil at the ground surface to verify performance of the resistivity electronics; the data were not used to interpret penetrometer tests of in situ material. These two tests did not produce profiles with depth, thus their inclusion in the discussion of results would be inconsistent with the chosen format.

Penetrometer test CR-11-M was performed between SRS wells MHT19-C and MHT15-C to complement the downhole resistivity measurements taken at depth in these wells on behalf of LLNL. No downhole resistivity data were made available to WES for evaluation or comparisons. The penetrometer was pushed to capacity of the hydraulic ram at a depth of 109 ft (33 m), elevation 247 ft (75.3 m) MSL.

Penetrometer tests CR-12-M and CR-13-M were pushed adjacent to CR-2-M and CR-1-M, respectively. These final tests were performed to compare data acquired using different cone tip and sleeve configurations. The friction sleeve used in test CR-12-M was not heat-treated for abrasion resistance, as were the sleeve sections used in all previous FY 92 tests. The cone tip used in CR-12-M was heat-treated, and was machined with a 5/16-in. cylindrical sidewall behind the 60°-apex cone section. The diameter of this cylindrical sidewall was identical to that of the friction sleeve section; this cone tip was used in all previous FY 92 tests, but differs from the design used in FY 91 (the FY 91 tip was machined with a 1/8-in. cylindrical sidewall). Test CR-13-M was pushed with the untreated, softer metal sleeve and a cone tip element of the FY 91 design.

No appreciable differences were observed in the soil classification profiles determined for adjacent test locations by these tests. It should be noted, however, that new load cell calibrations were performed prior to tests CR-12-M and CR-13-M that resulted in calibration factor changes in the data acquisition and post-processing software. In addition, as discussed previously, a significant increase was applied to the friction sleeve data (following the test) of test CR-1-M that was not applied to the data of test CR-13-M; a lesser adjustment was applied to the friction sleeve data of test CR-2-M that was not applied to the data of test CR-12-M. Future comparability tests on sleeve and tip configurations should include calibrations prior to all tests involved in the comparison, and similar, if any, adjustments to the data prior to determination of soil classification and plotting.

LLNL Fiber Optic TCE Sensor

The LLNL team arrived onsite with a fiber optic implant sensor packaged for the cone penetrometer the latter week of the SCAPS site visit. The LLNL sensor was developed for the purpose of detecting chlorinated solvents (Daley et al. 1992), and through coordination between LLNL and WES was packaged for incorporation into the SCAPS penetrometer. The sensor is a variation of the coated-fiber "Optrode" implant described earlier and demonstrated at the POL site.

No measurements other than hydraulic ram force and depth were taken by the SCAPS crew as the LLNL sensor was advanced below ground. After pushing the sensor to depth, its data collection system was initiated by retracting the probe about 6 in. (15 cm) to expose the TCE-sensitive coated fiber to any solvent contaminant vapor that might be present in the gas phase of the soil.

Summary and Discussion of FY 92 Experiments

Ten resistivity penetrations and four LLNL sensor penetrations were completed at this Integrated Demonstration Site during the FY 92 series of experiments described above. The maximum depth of penetration achieved was 130 ft (39 m). Each penetrometer test hole was plugged with grout after completion of the test throughout its full depth. Each hole was tremie-grouted with a mixture having one-half bag of Portland cement and three cups of bentonite for 5 gal of water per batch as required. The hole volumes were calculated from the dimensions of the penetrometer device and the push rod string used. Grout volumes matched calculated hole volumes in all cases except one, which required a small additional amount to fill.

During each probe extraction, the push rods and penetrometer device were automatically steam-cleaned with fresh water. This decontamination procedure was approved prior to the field deployment by the South Carolina Department of Natural Resources (SCDNR).

Coupled soil classification and resistivity analyses located a suspected zone of perched water at about 100 ft (30.5 m). The resistivity measurements obtained will supplement ongoing research studies at this site, in addition to providing verification of highly concentrated contaminant zones (although the concentrations are constantly changing as a result of the ongoing site remediation effort). The penetrometer was also successfully employed to open conduits for vertical air flow through the interbedded layers in the unsaturated zone. The cone penetrometer system was also adapted as a support and delivery platform for demonstration of a new TCE-specific fiber optic implant sensor developed by LLNL.

6 Conclusions and Recommendations

Conclusions

Field operations conducted during FY 91 and FY 92 at the Savannah River Site provided a large array of information regarding application of the SCAPS system. The system was successfully demonstrated to: provide site characterization of subsurface soil stratigraphy, resistivity and fluorometric response (the latter within the design constraints of the fluorometry excitation source and reception system); as a platform for delivery of and support to in situ sensor implants; and as a platform for implementation of innovative technology such as the LLNL fiber optic sensor system. Major conclusions developed from field exercises at SRS include:

a. The role of the SCAPS as a viable site assessment and screening tool was reinforced. Useful data were collected at each of three different sites within a very short operational time, demonstrating the relative economy of the system when compared with conventional monitoring well installation, logging, and sampling procedures.

b. Cone penetrometer-based soil stratigraphy, electrical resistivity, and fiber optic fluorometer sensors were employed successfully. Data acquisition and processing were accomplished onsite, within the duration of each penetration test. The capability to effectively exploit three-dimensional volume imaging for (for the SCAPS configuration deployed, hydrocarbon) contaminant visualization was demonstrated on data processed at WES after the field tests were completed.

c. The SCAPS detection limits for hydrocarbon contamination are not equivalent to standard analytical laboratory limits, but the capability to detect and delineate hydrocarbons in soil was demonstrated to affirm the role of the SCAPS as a site screening technology.

d. The use of the SCAPS as a research platform was demonstrated by the successful integration and support of innovative technologies developed by other research organizations outside the WES.

Recommendations

The following recommendations are made based on experience gained through deployment and operation of the SCAPS at SRS:

a. The fiber optic sensor should be adopted as the standard screening method for hydrocarbon compound-contaminated sites using the SCAPS. Site-specific calibrations for fluorescence peak intensity versus concentration are recommended to provide for more accurate quantification of specific hydrocarbon product contamination.

b. Procedures should be developed to facilitate site-specific resistivity calibration for specific electrolytic contaminants. Soil electrical resistivity measurements obtained using the SCAPS probe sensor serve to validate soil stratigraphy and locate concentrations of conductive (and non-conductive) contaminants below the water table.

c. Hardened (vacuum heat-treated) sleeve and tip elements have proved their value in enhancing abrasion resistance and survivability; specific developmental research is urgently recommended to properly account for frictional property changes induced in the sleeve by hardening and the concomitant effect on soil classification.

d. Standard CPT measurements (cone tip resistance and sleeve friction), used in conjunction with the soil classification algorithm software, allow highly detailed mapping of soil stratigraphy and should always be employed during CPT-based environmental site characterization programs.

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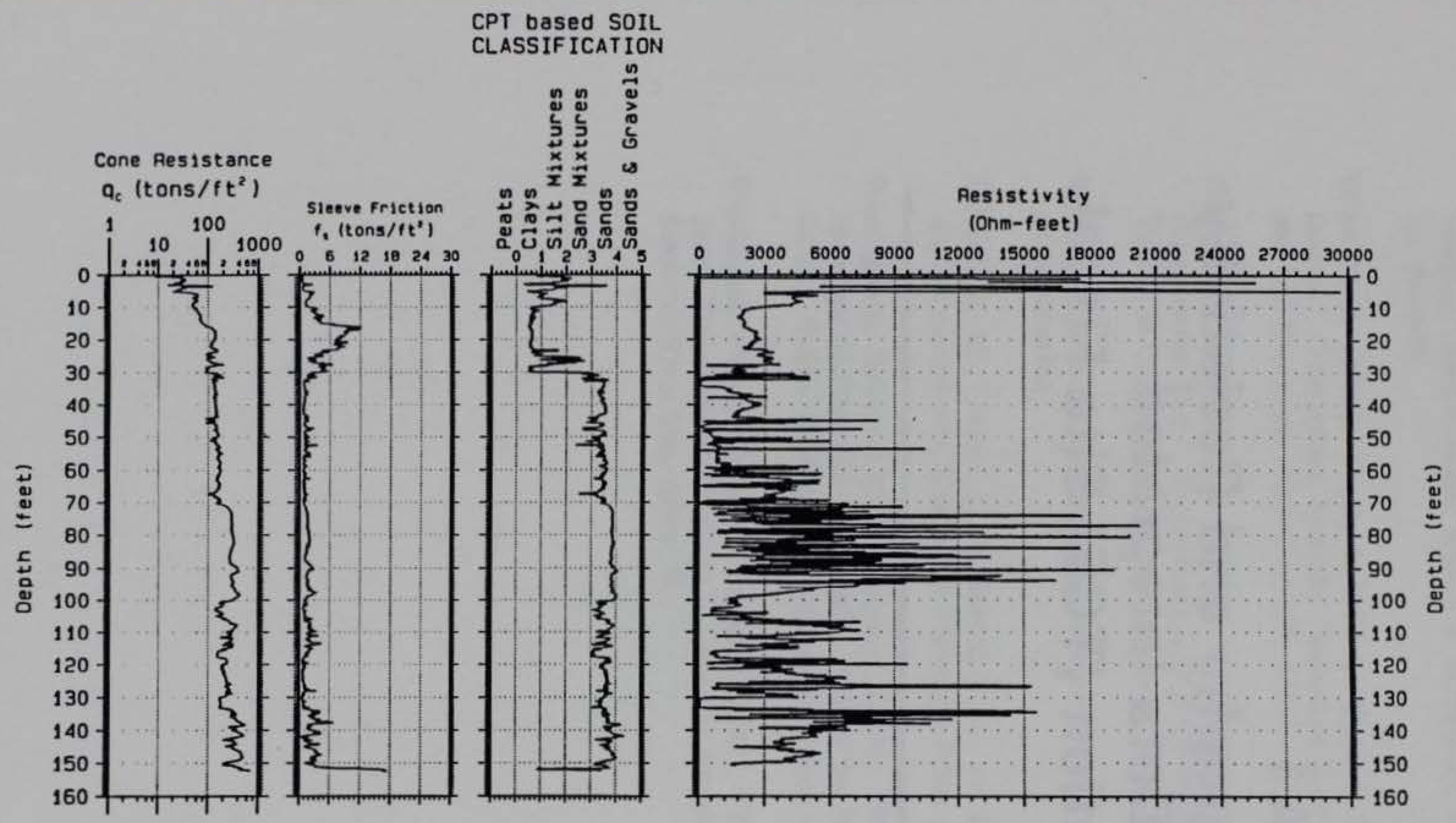
Appendix A1
Soil Stratigraphy and Resistivity Response Data Integrated Demonstration (TCE) Site Fiscal Year 1991



CPT: CR-15-T

Project: Savannah River Site, TCE Area

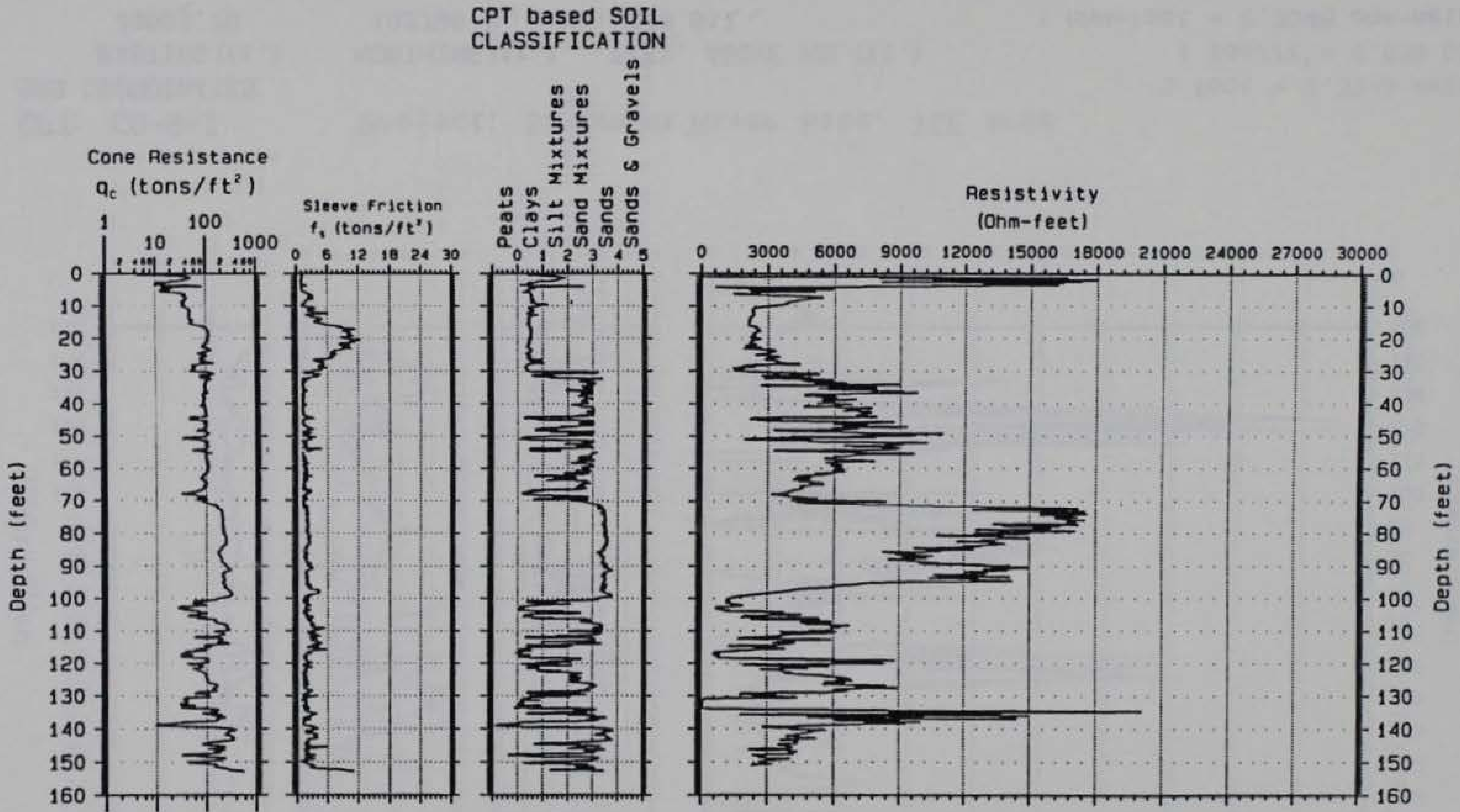
SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48801.59	102948.4	367.006

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars

1 ohm-foot = 0.3048 ohm-meters



CPT: CR-15A-T

Project: Savannah River Site, TCE Area

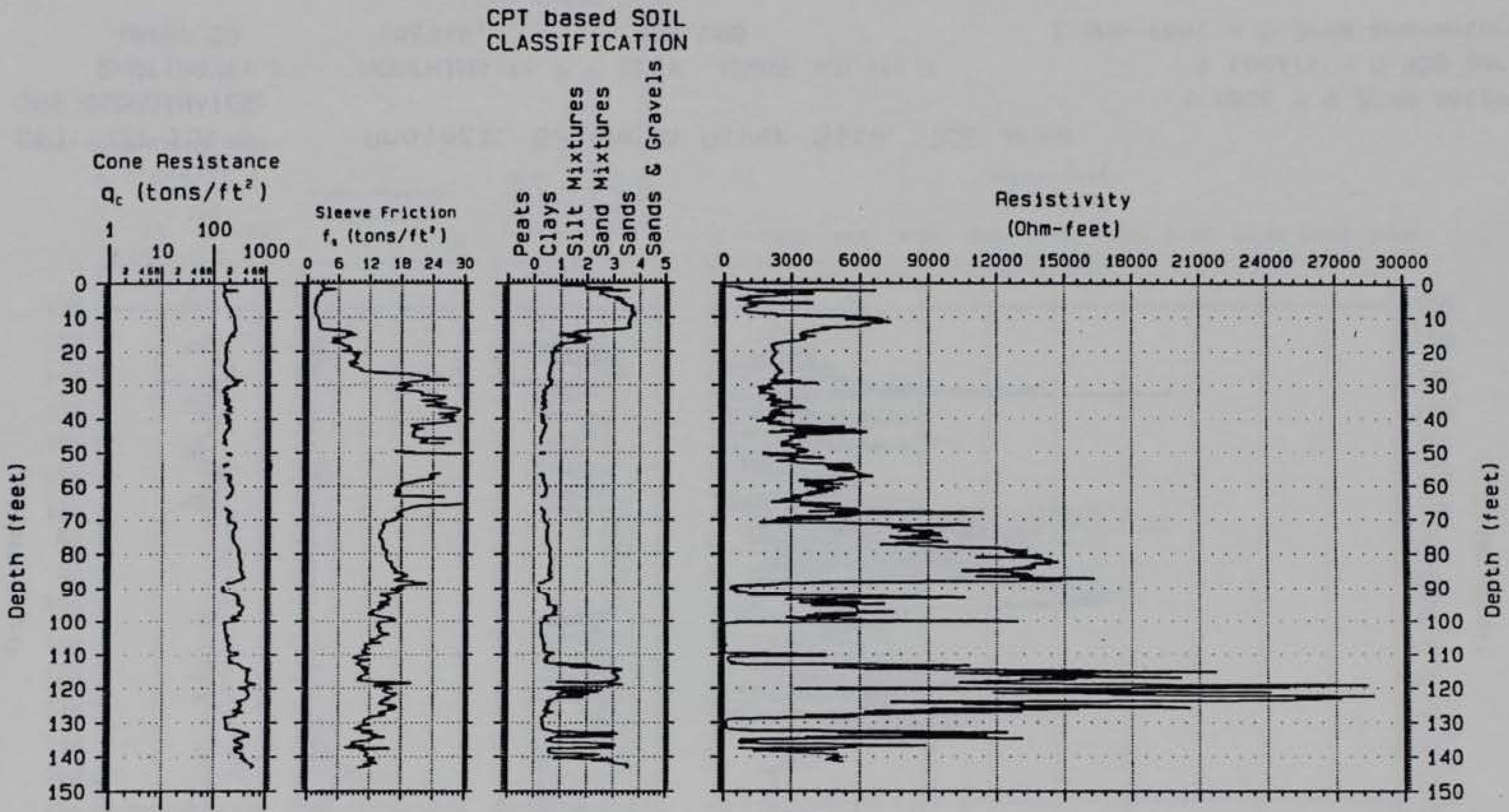
SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48797.59	102948.4	367.006

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars

1 ohm-foot = 0.3048 ohm-meters



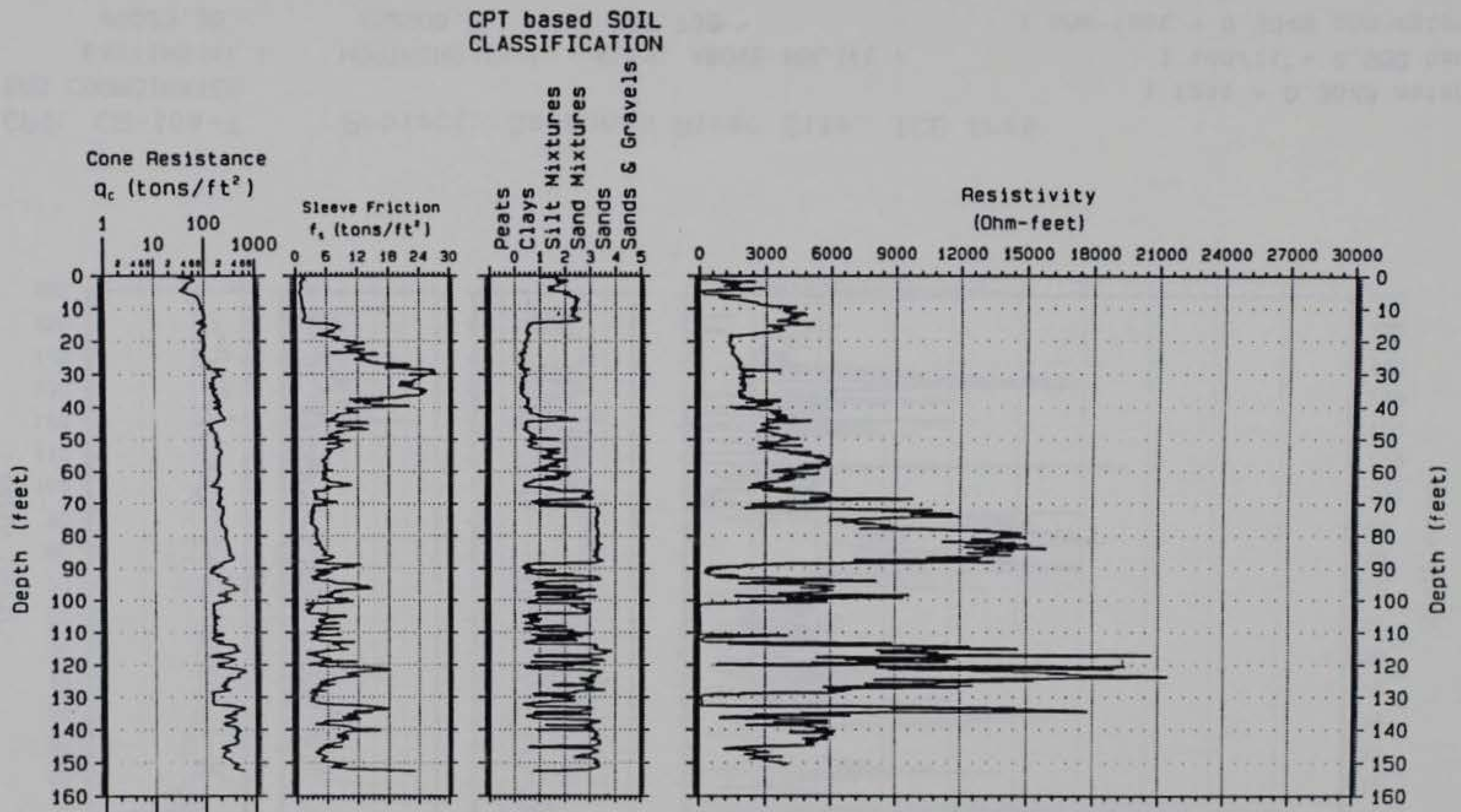
CPT: CR-9-T

Project: Savannah River Site, TCE Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
49023.78	102789.2	366.617

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters

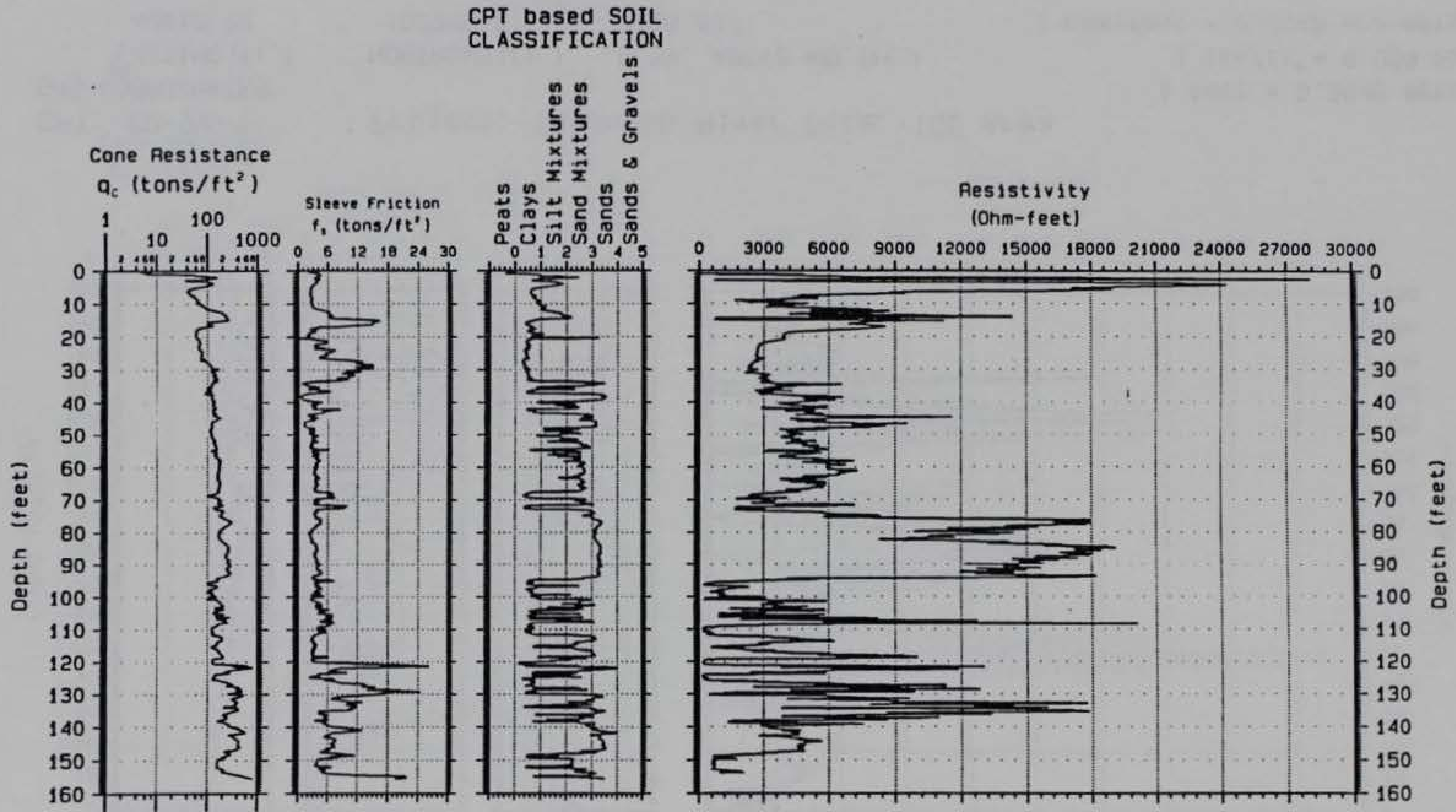


CPT: CR-9A-T   Project: Savannah River Site, TCE Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
49019.78	102789.2	366.617

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters



CPT: CR-10A-T

Project: Savannah River Site, TCE Area

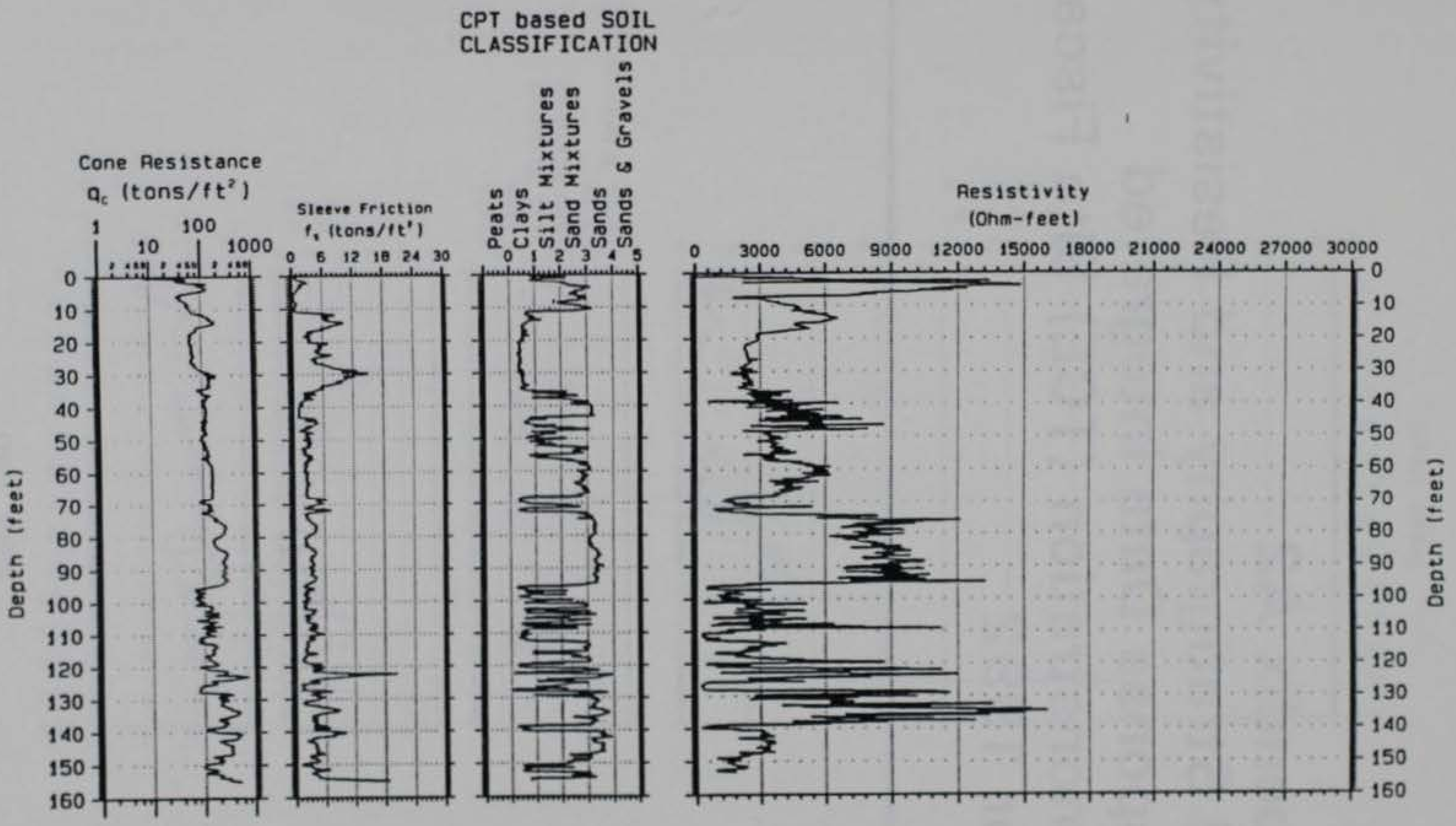
SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
49023.38	102908.6	368.739

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars

1 ohm-foot = 0.3048 ohm-meters



CPT: CR-10B-T

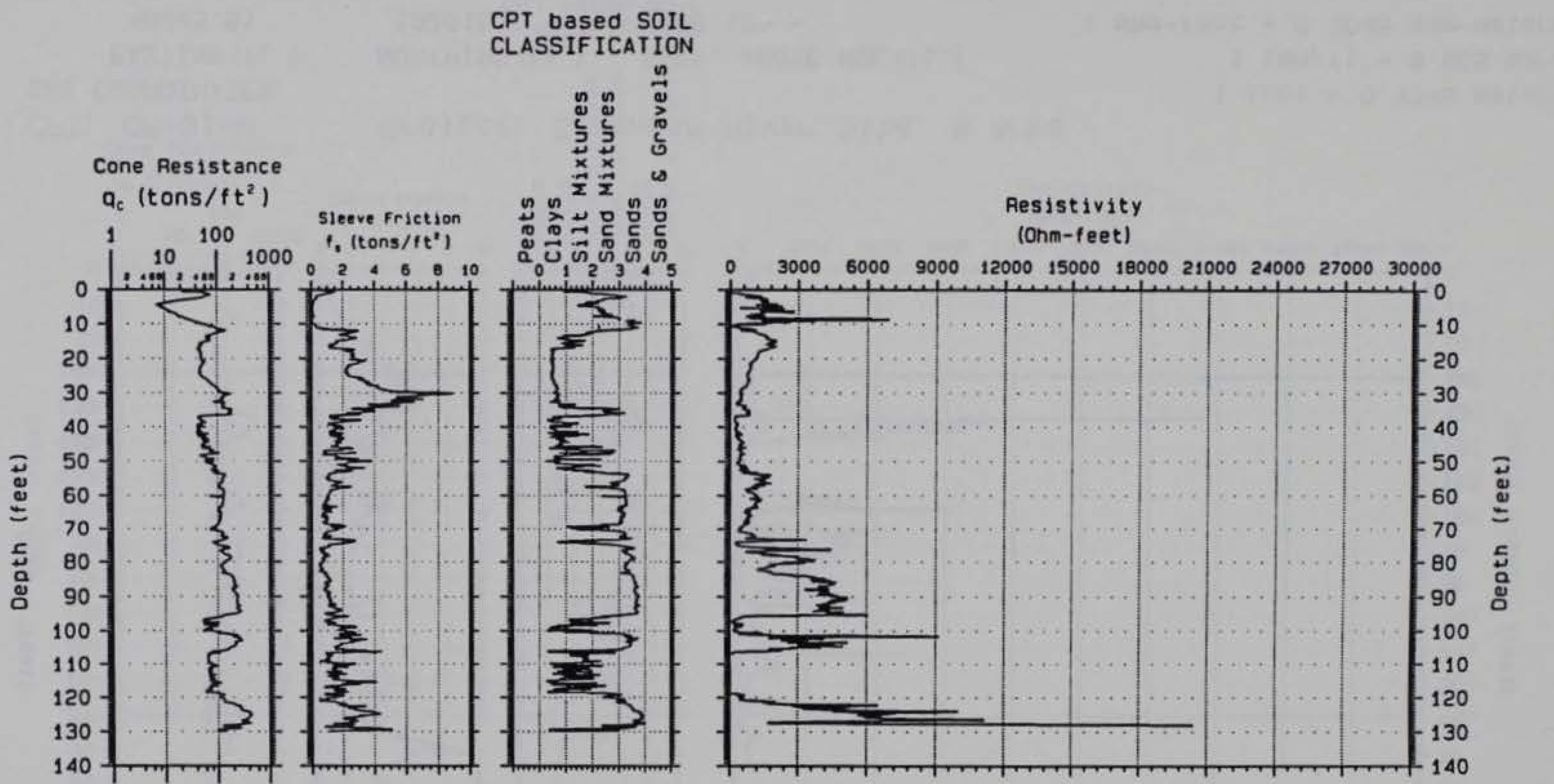
Project: Savannah River Site, TCE Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
49015.38	102915.5	368.766

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters

Appendix A2
Soil Stratigraphy and Resistivity Response Data Integrated Demonstration (TCE) Site Fiscal Year 1992



CPT: CR-01-M

Project: Savannah River Site, M Area

SRS COORDINATES:

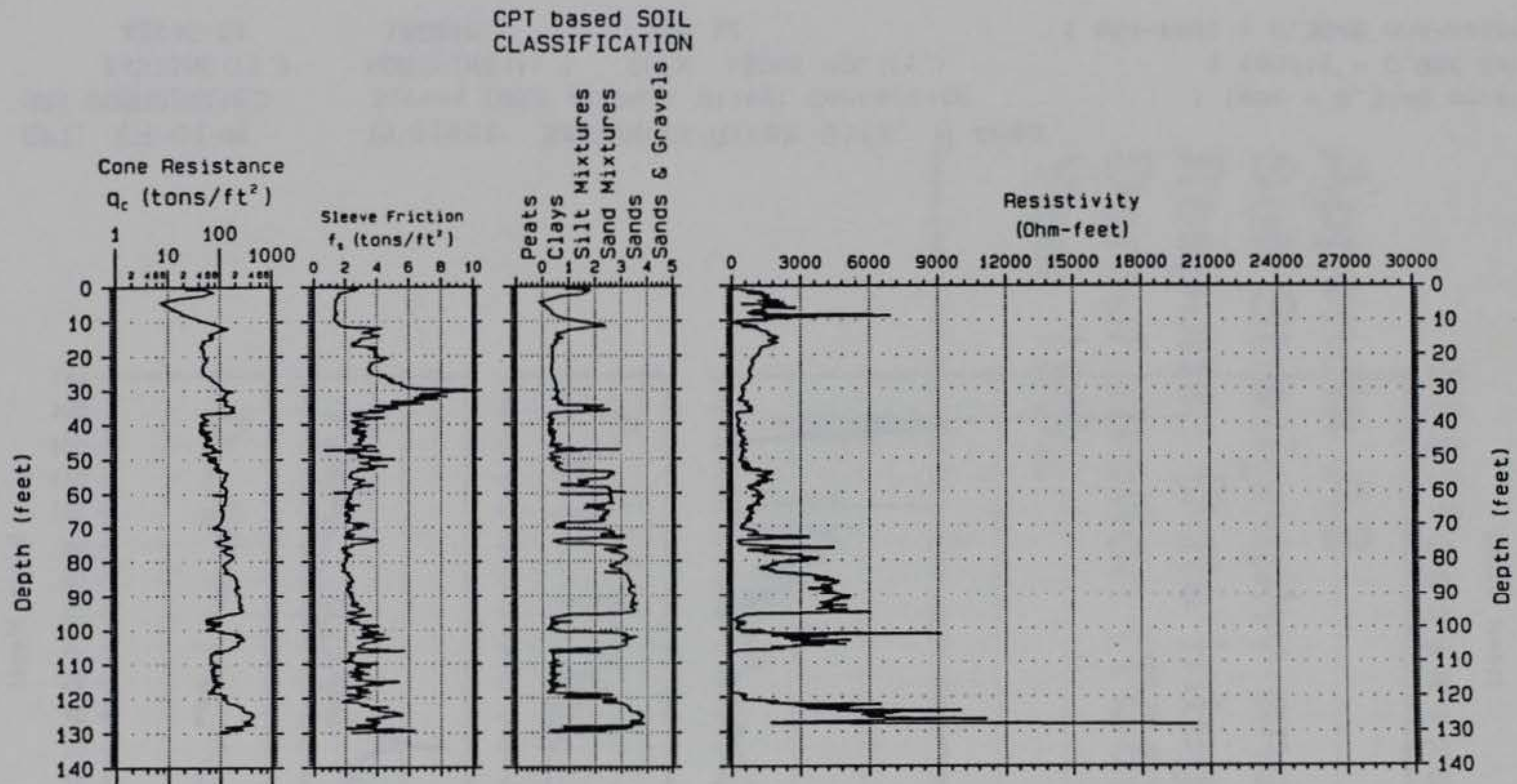
Sleeve Data Without Offset Correction

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48945.51	102816	368.12

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars

1 ohm-foot = 0.3048 ohm-meters



CPT: CR-01-M

Project: Savannah River Site, M Area

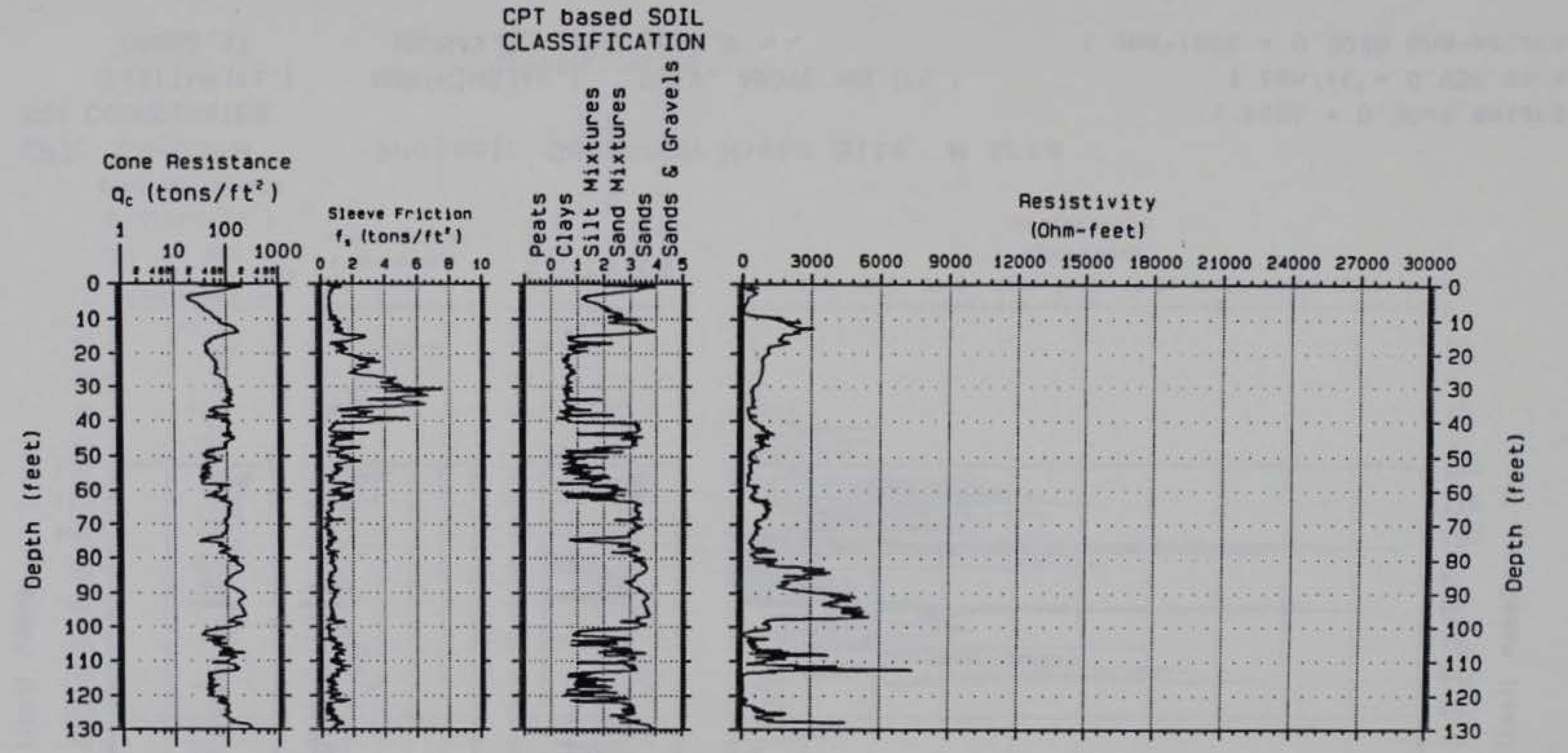
SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48945.51	102816	368.12

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars

1 ohm-foot = 0.3048 ohm-meters

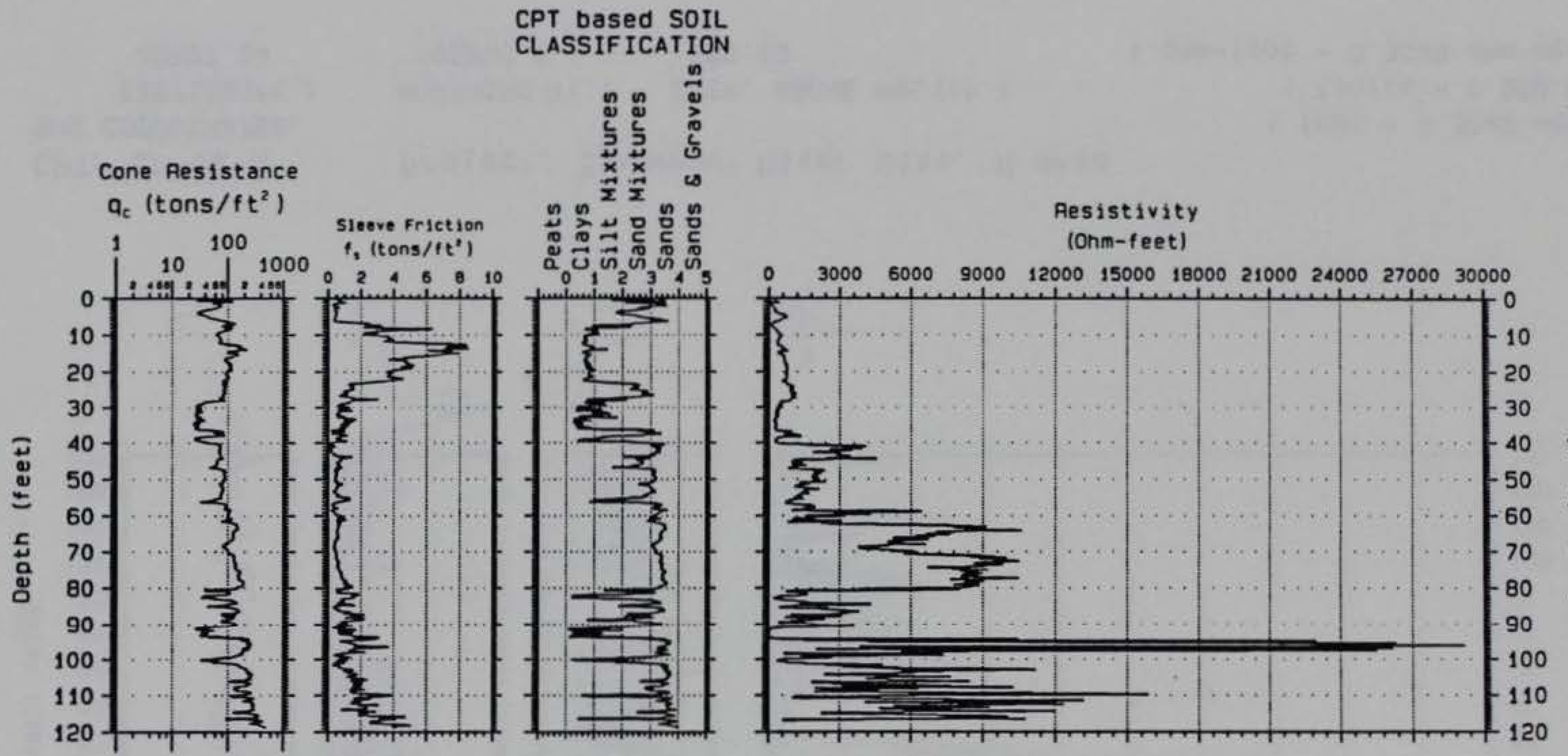


CPT: CR-02-M Project: Savannah River Site, M Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48927.84	102856.5	369.53

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters



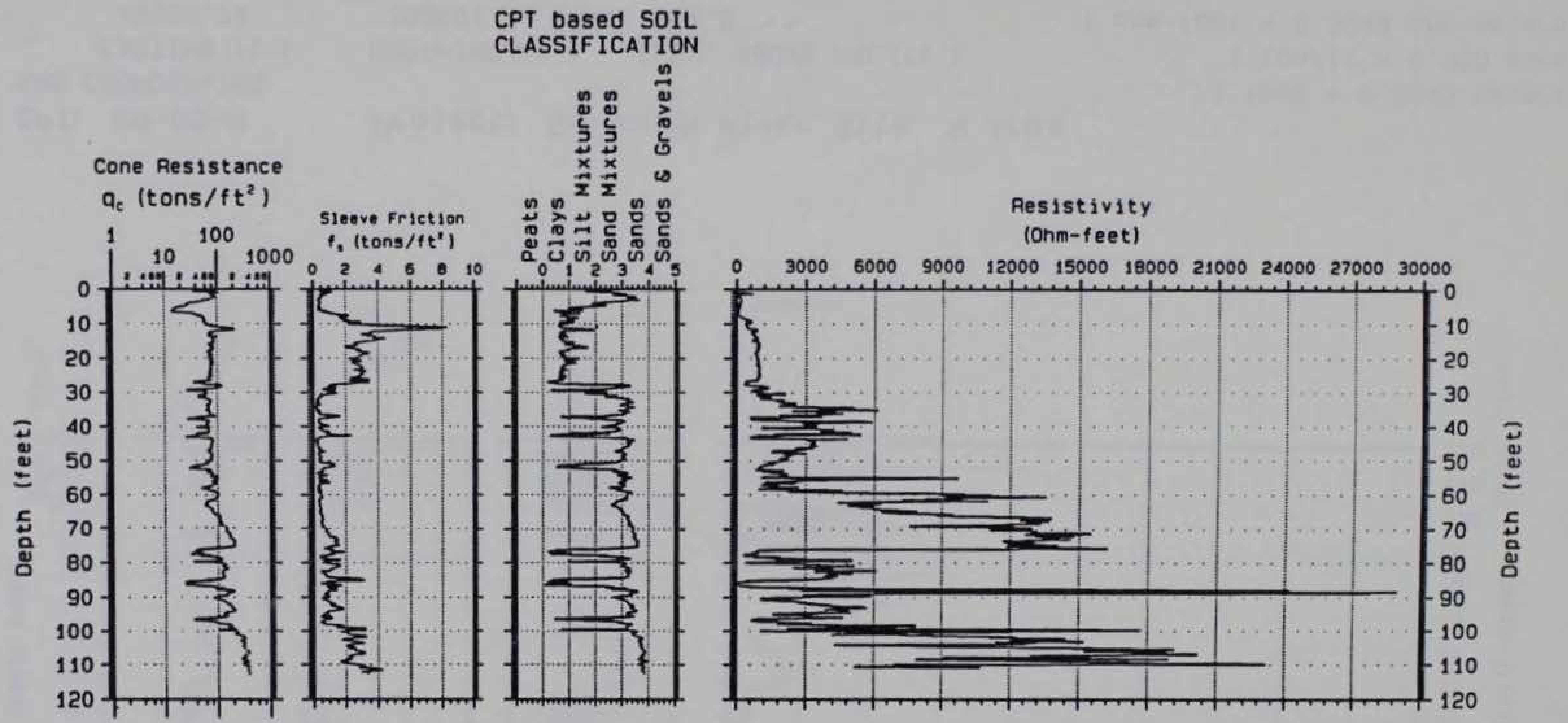
CPT: CR-03-M

Project: Savannah River Site, M Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48882.37	102643.9	358.5

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters



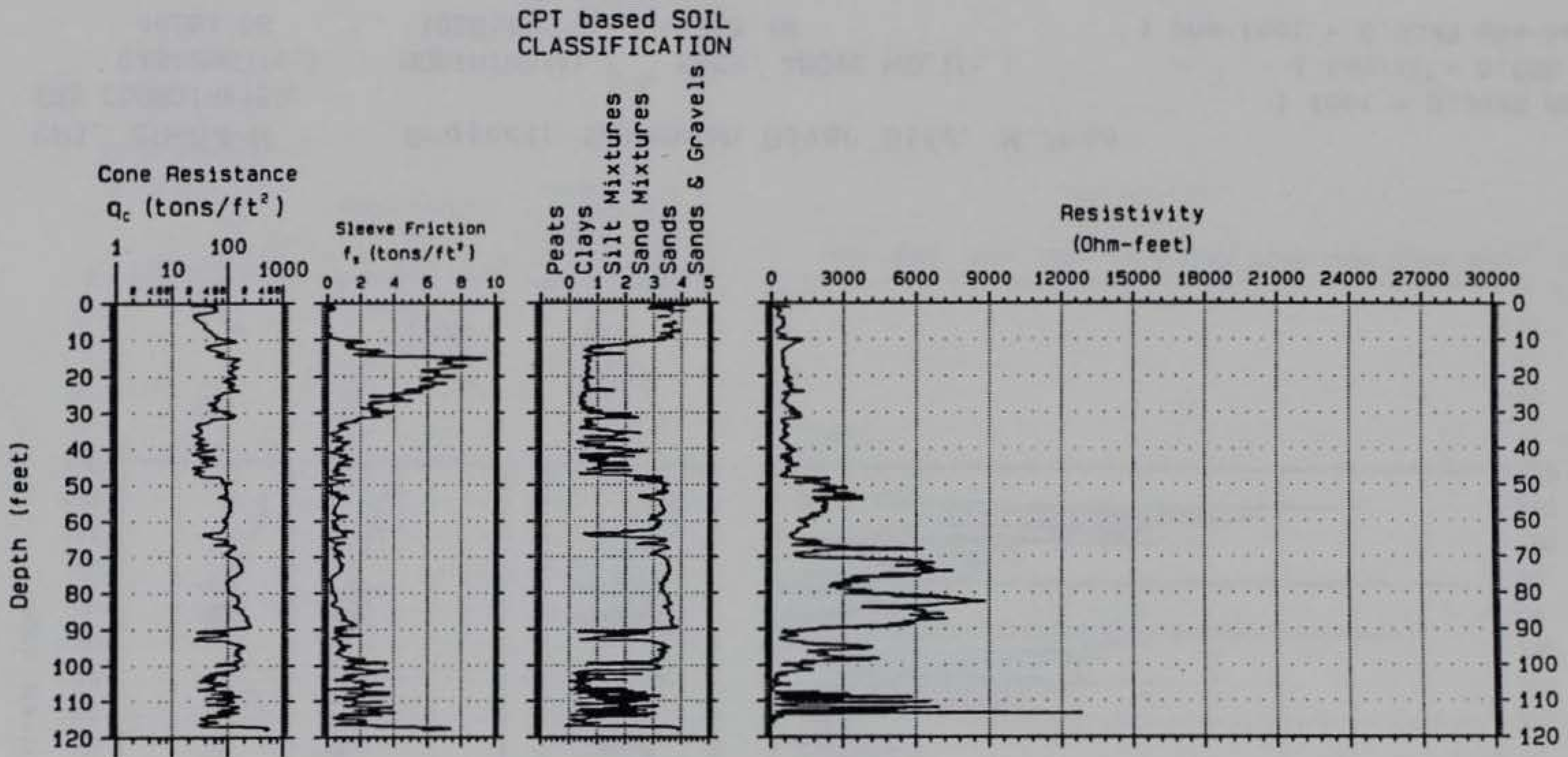
CPT: CR-04-M

Project: Savannah River Site, M Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48867.66	102618	356.46

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters



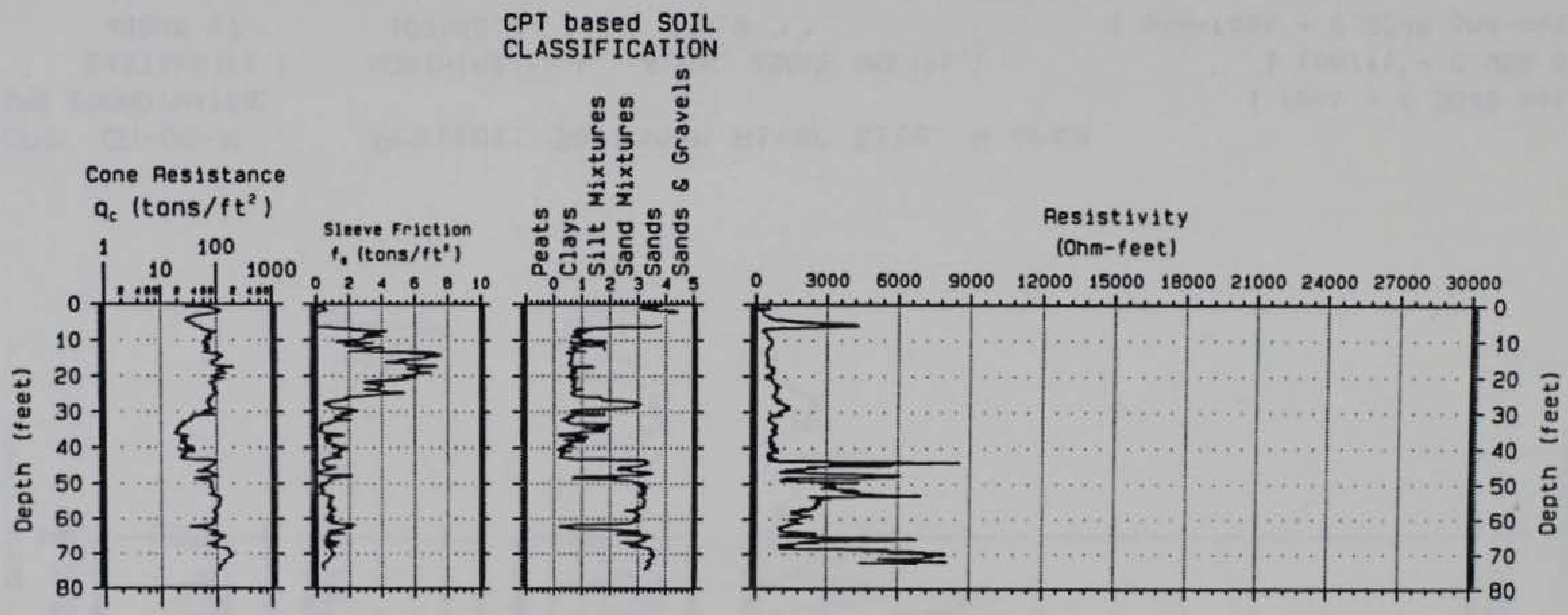
CPT: CR-05-M

Project: Savannah River Site, M Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48903.74	102691.4	361.8

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars
1 ohm-fpot = 0.3048 ohm-meters



CPT: CR-06-M

Project: Savannah River Site, M Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
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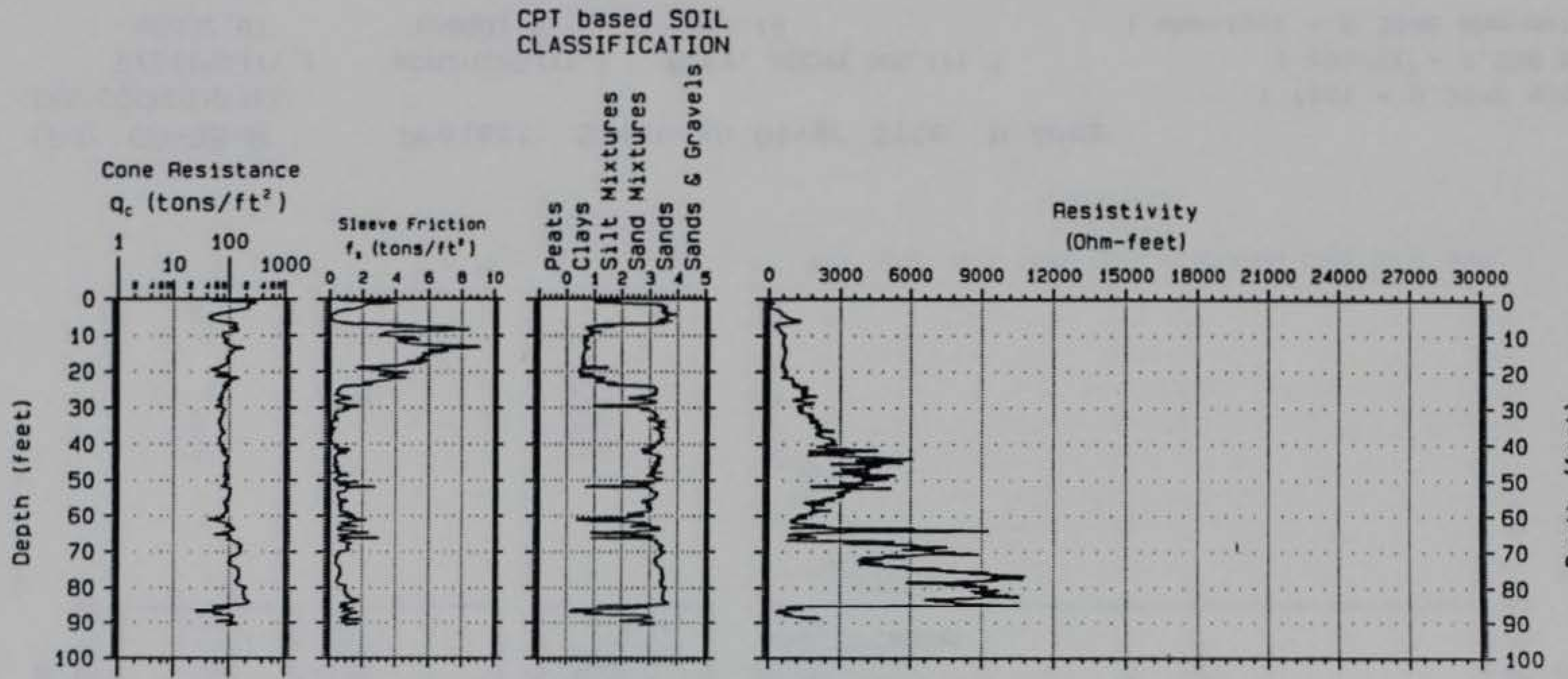
1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters



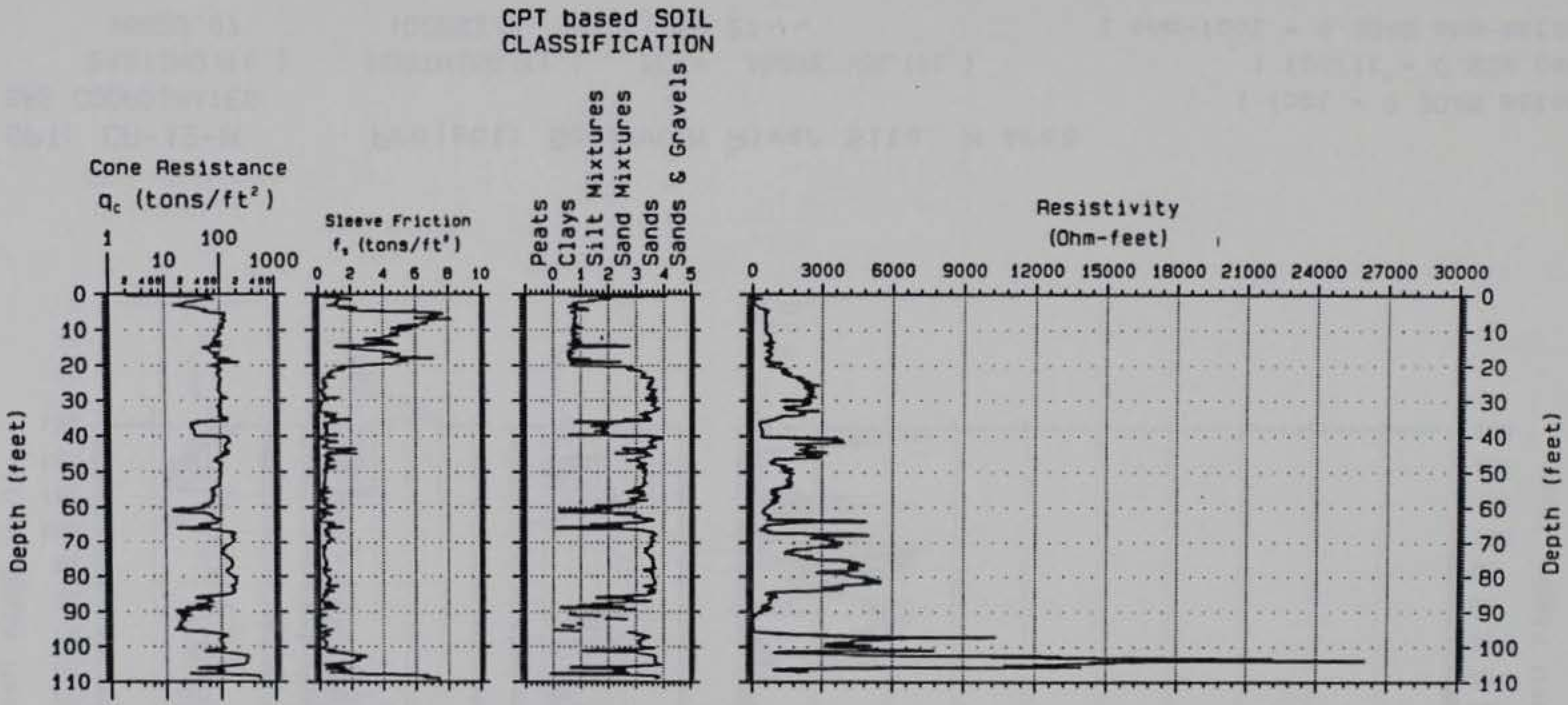
CPT: CR-09-M

Project: Savannah River Site, M Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48846.97	102668.2	360.6

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters

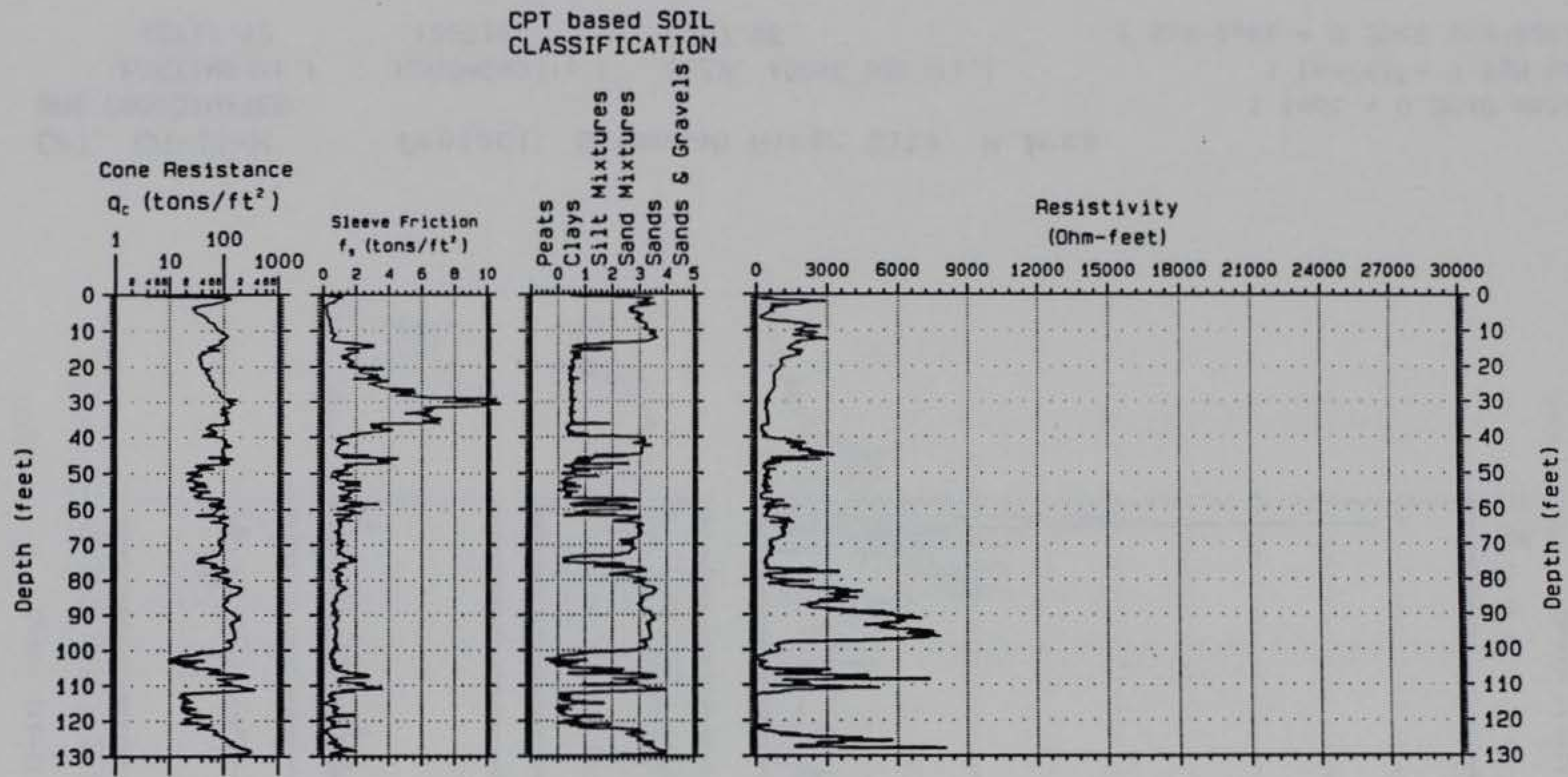


CPT: CR-11-M Project: Savannah River Site, M Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48717.62	102513	357.06

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters



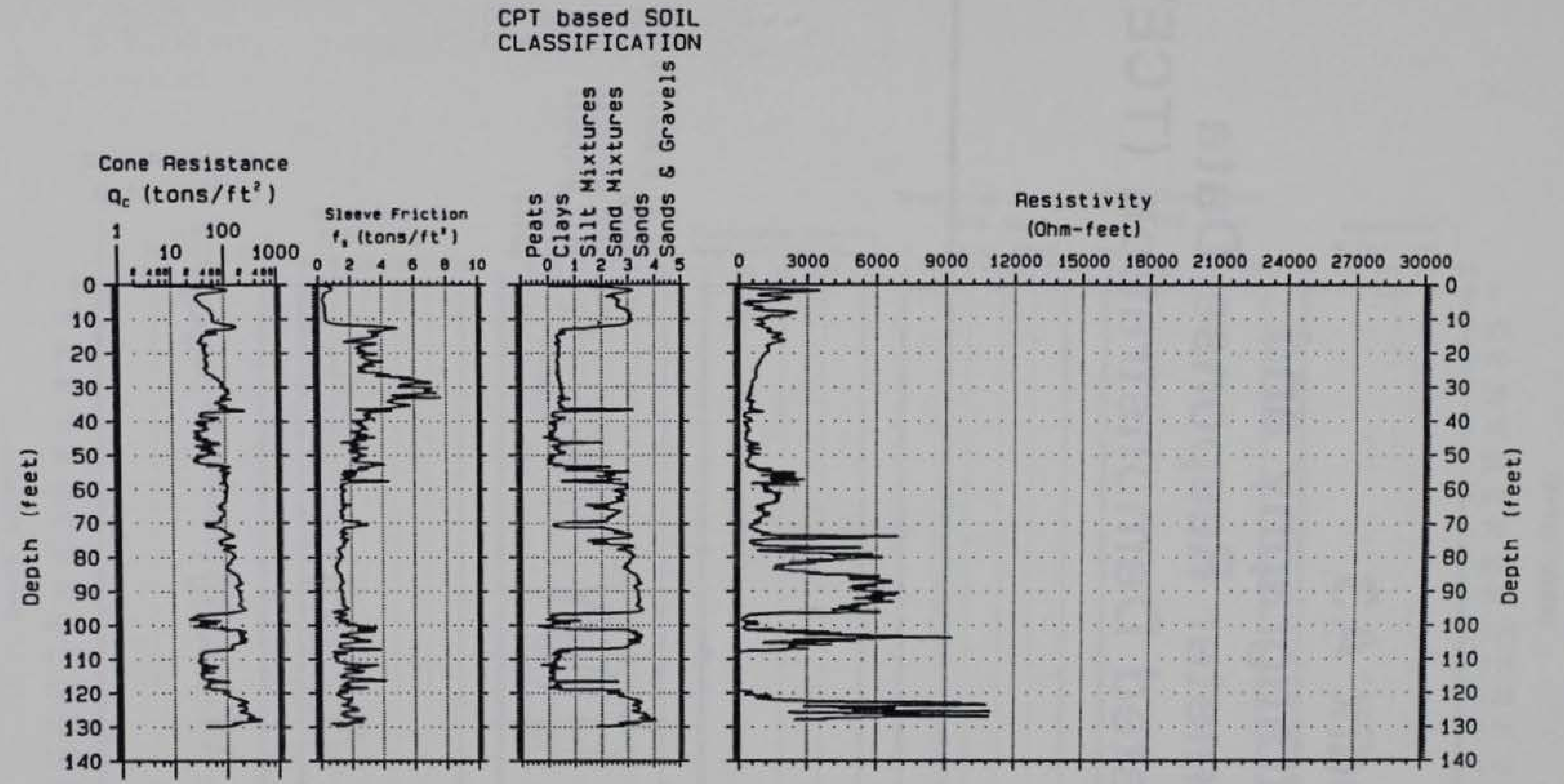
CPT: CR-12-M

Project: Savannah River Site, M Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48920.07	102853.3	369.27

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters



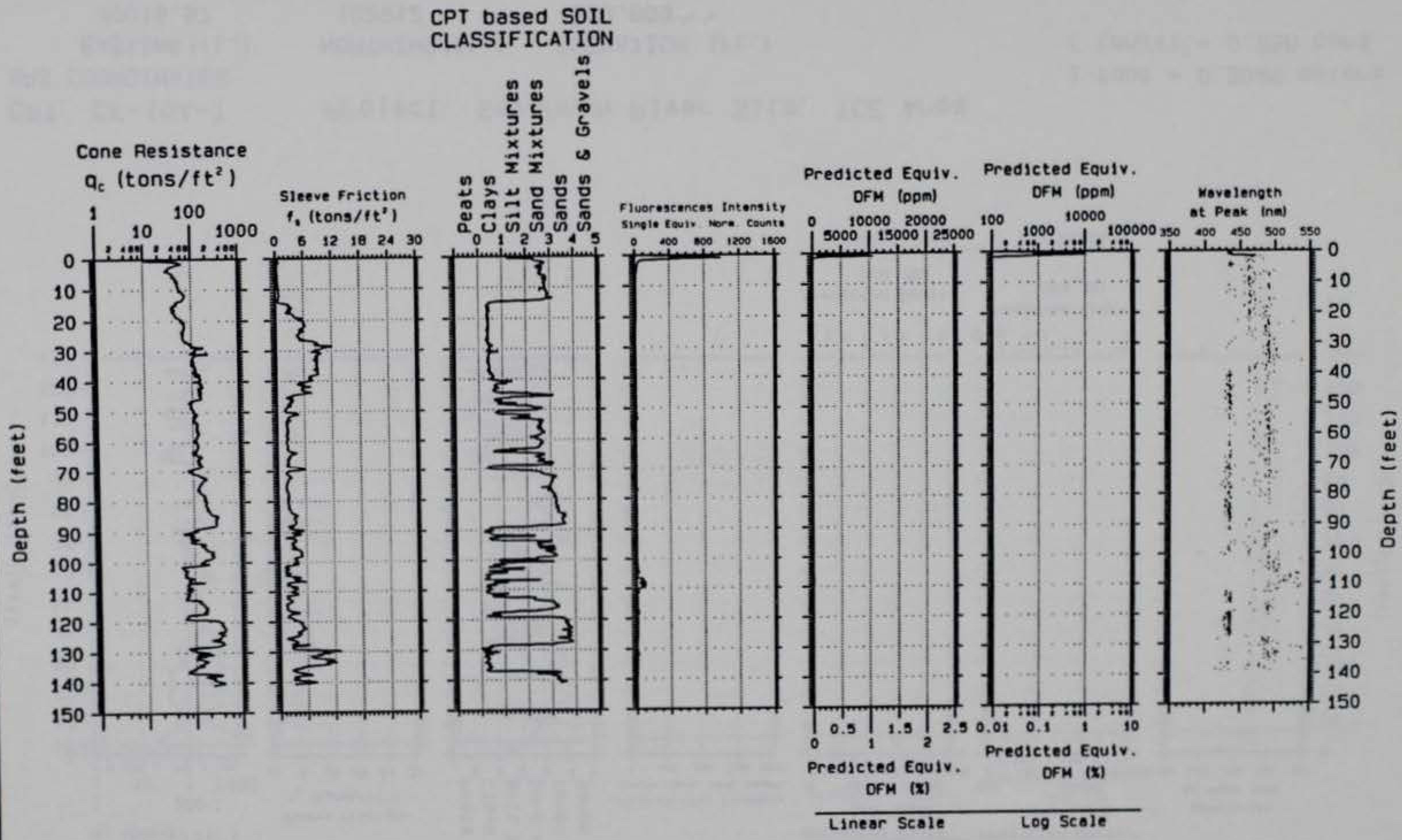
CPT: CR-13-M Project: Savannah River Site, M Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
48941.78	102813.7	368.02

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters

Appendix A3
Soil Stratigraphy and Fluorometer Response Data Integrated Demonstration (TCE) Site



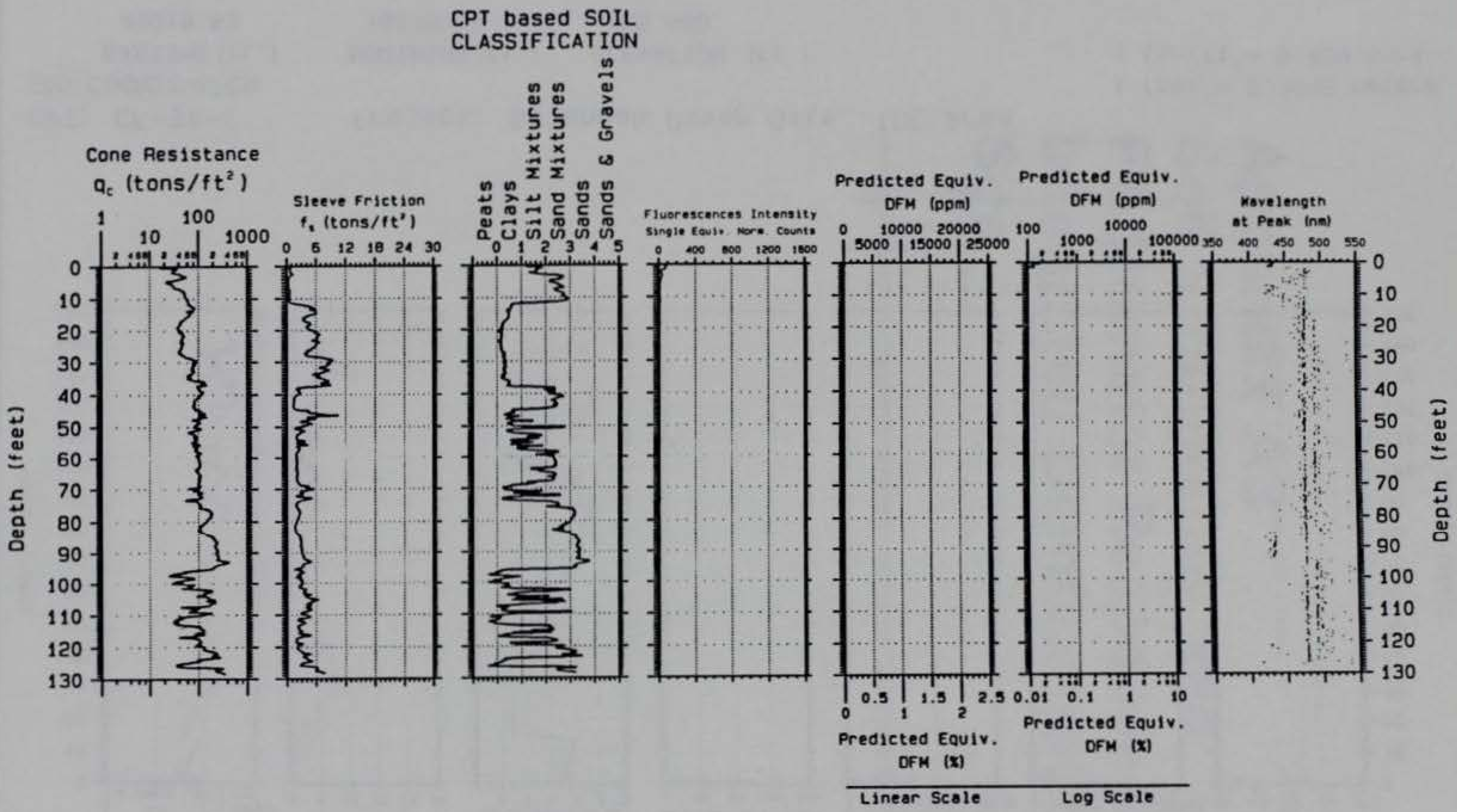
CPT: CF-9A-T

Project: Savannah River Site, TCE Area

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49018.63	102783.9	366.589



CPT: CF-10A-T

Project: Savannah River Site, TCE Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
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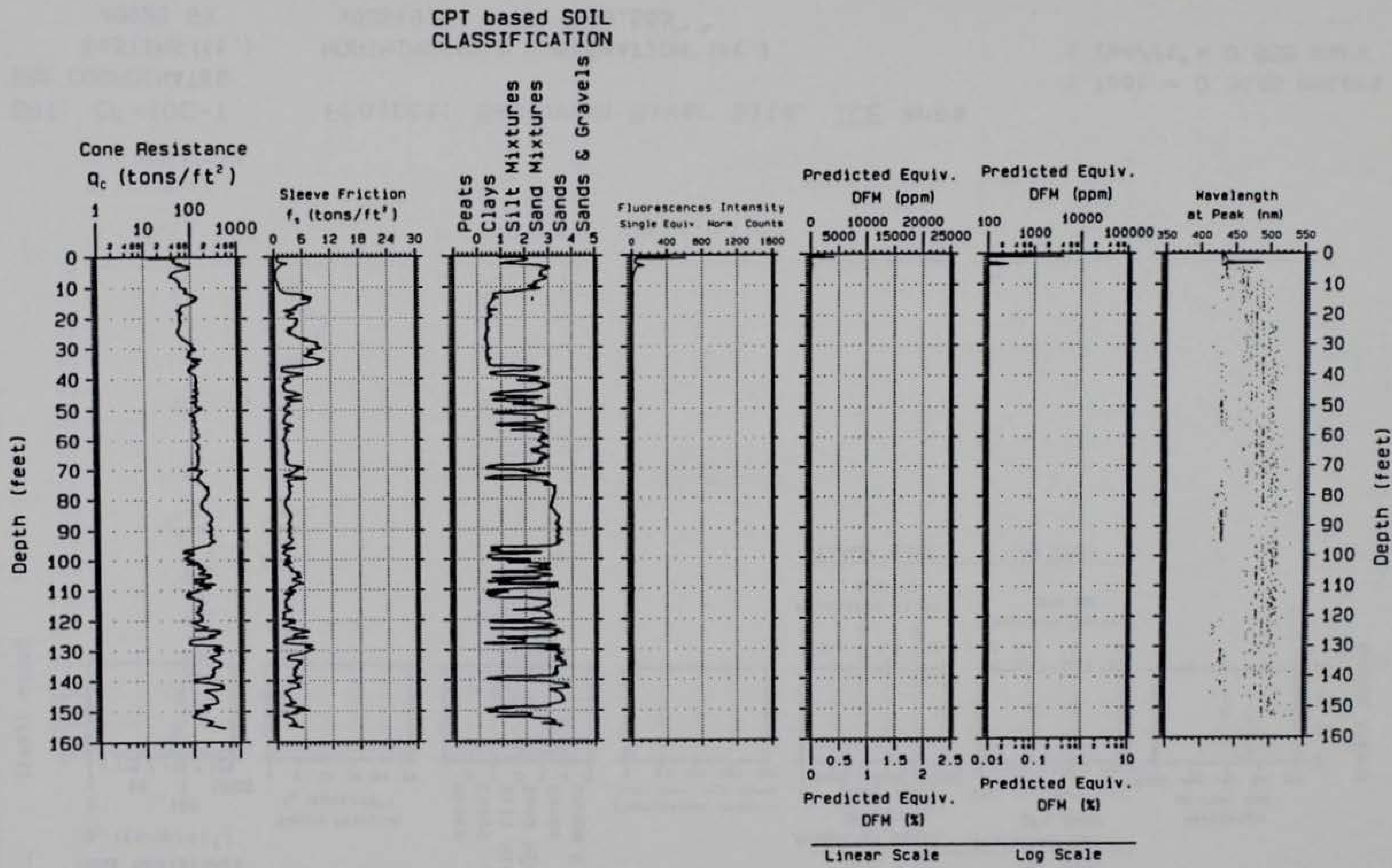
1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-10B-T

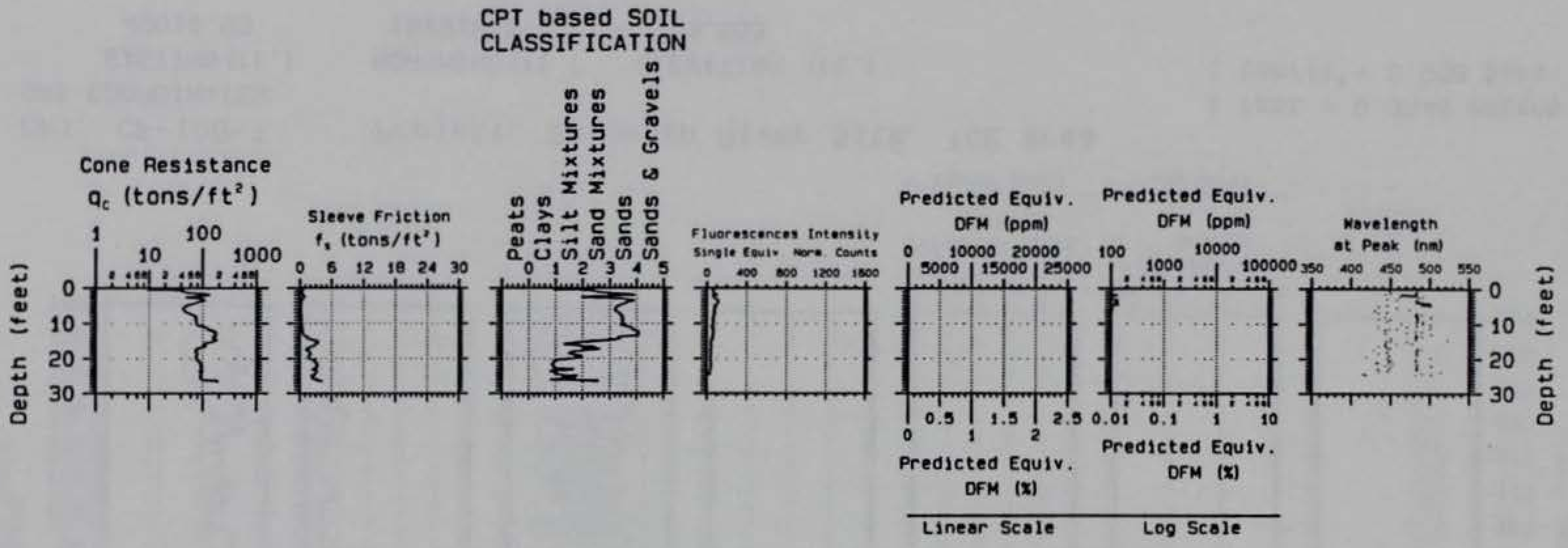
Project: Savannah River Site, TCE Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49010.93	102919.5	368.553

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-10C-T

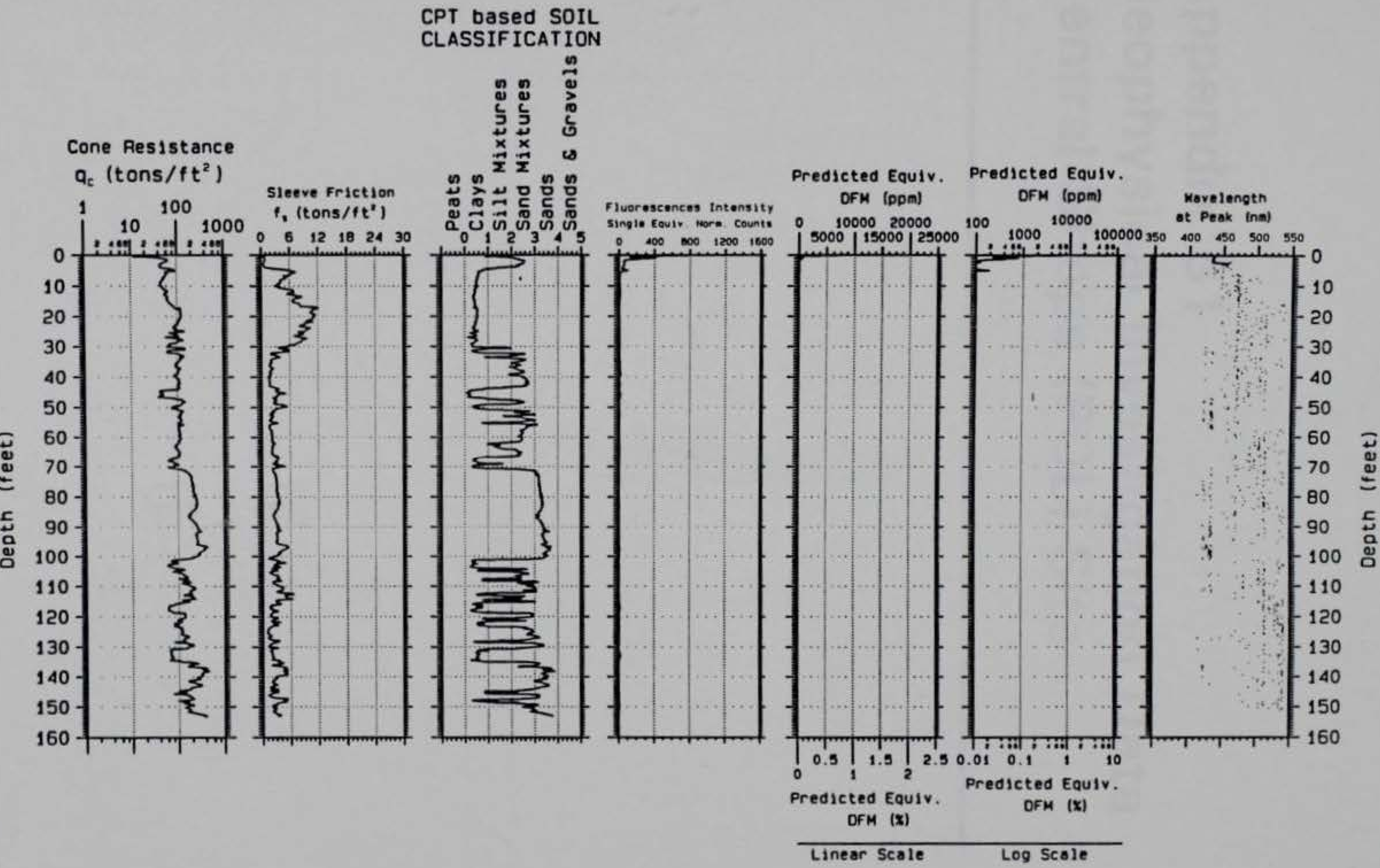
Project: Savannah River Site, TCE Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49025.93	102919.5	368.553

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-15A-T Project: Savannah River Site, TCE Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
48805.29	102929.6	367.436

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars

Appendix B1
Geophysical Investigation Data
Central Shops (POL) Site

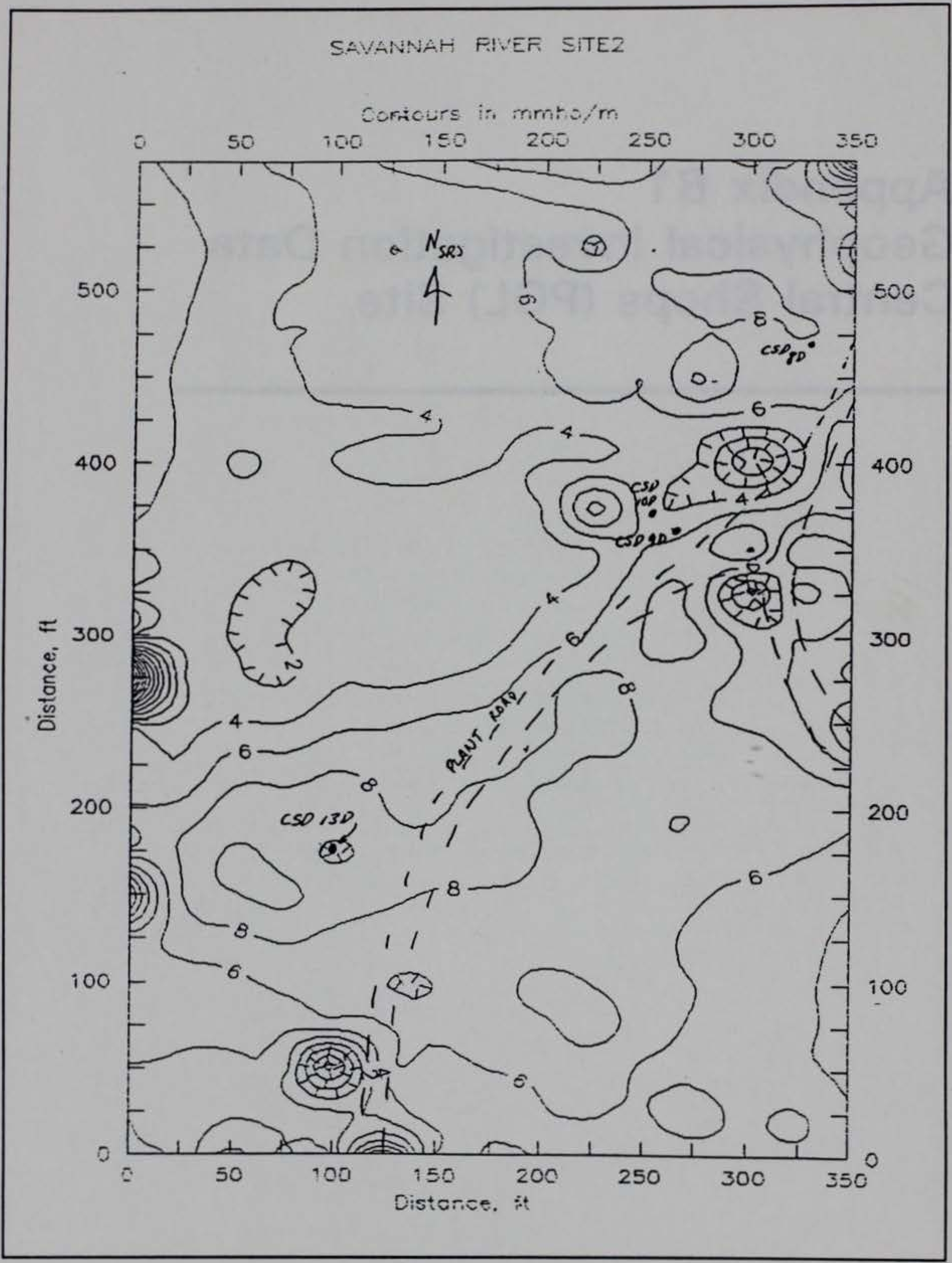


Figure 1. EM-31 terrain conductivity contours produced using the field system at the SRS Central Shops POL Site (not additionally processed)

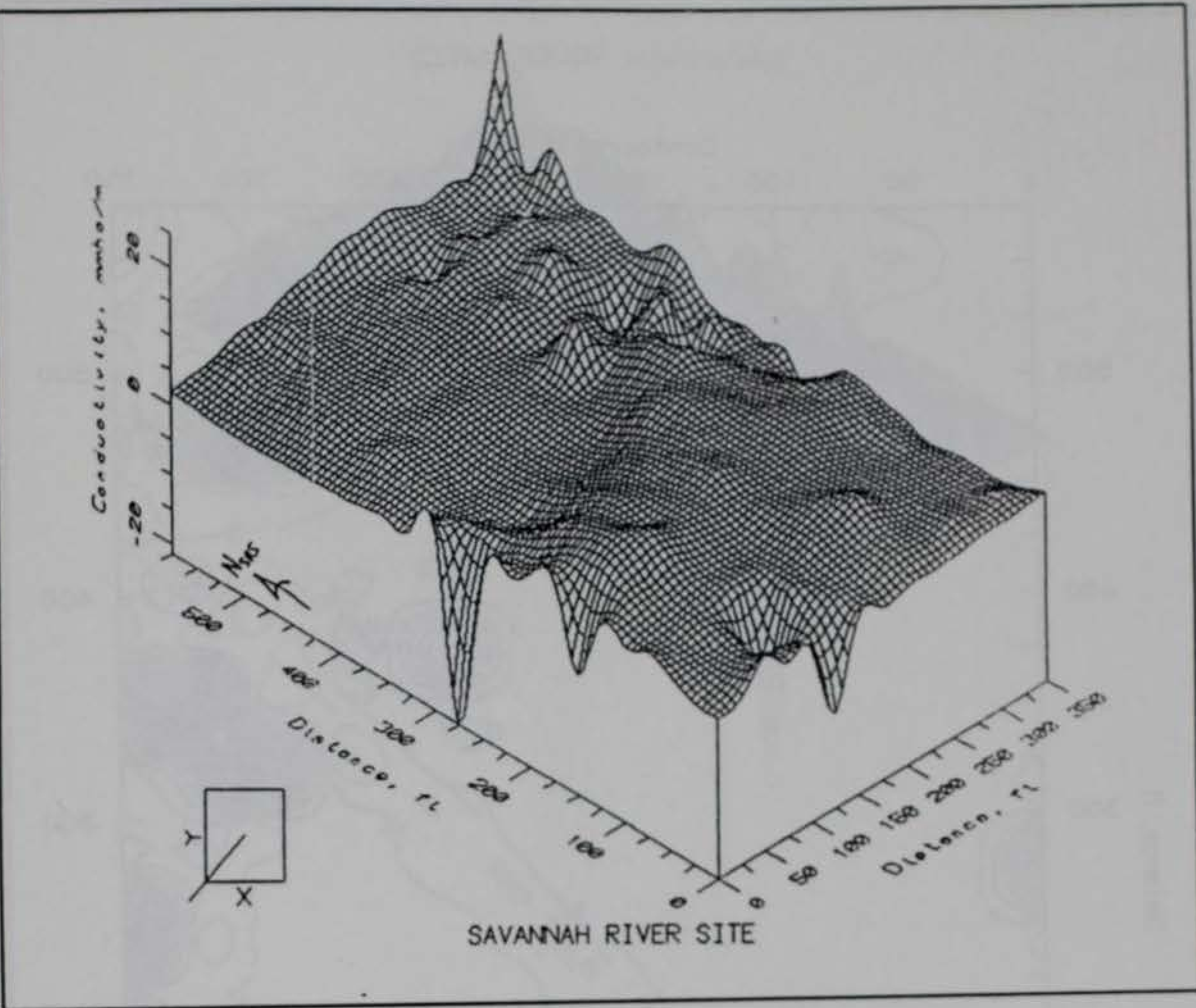


Figure 2. EM-31 terrain conductivity 3-D surface plot produced using the field system at the SRS Central Shops POL Site (not additionally processed)

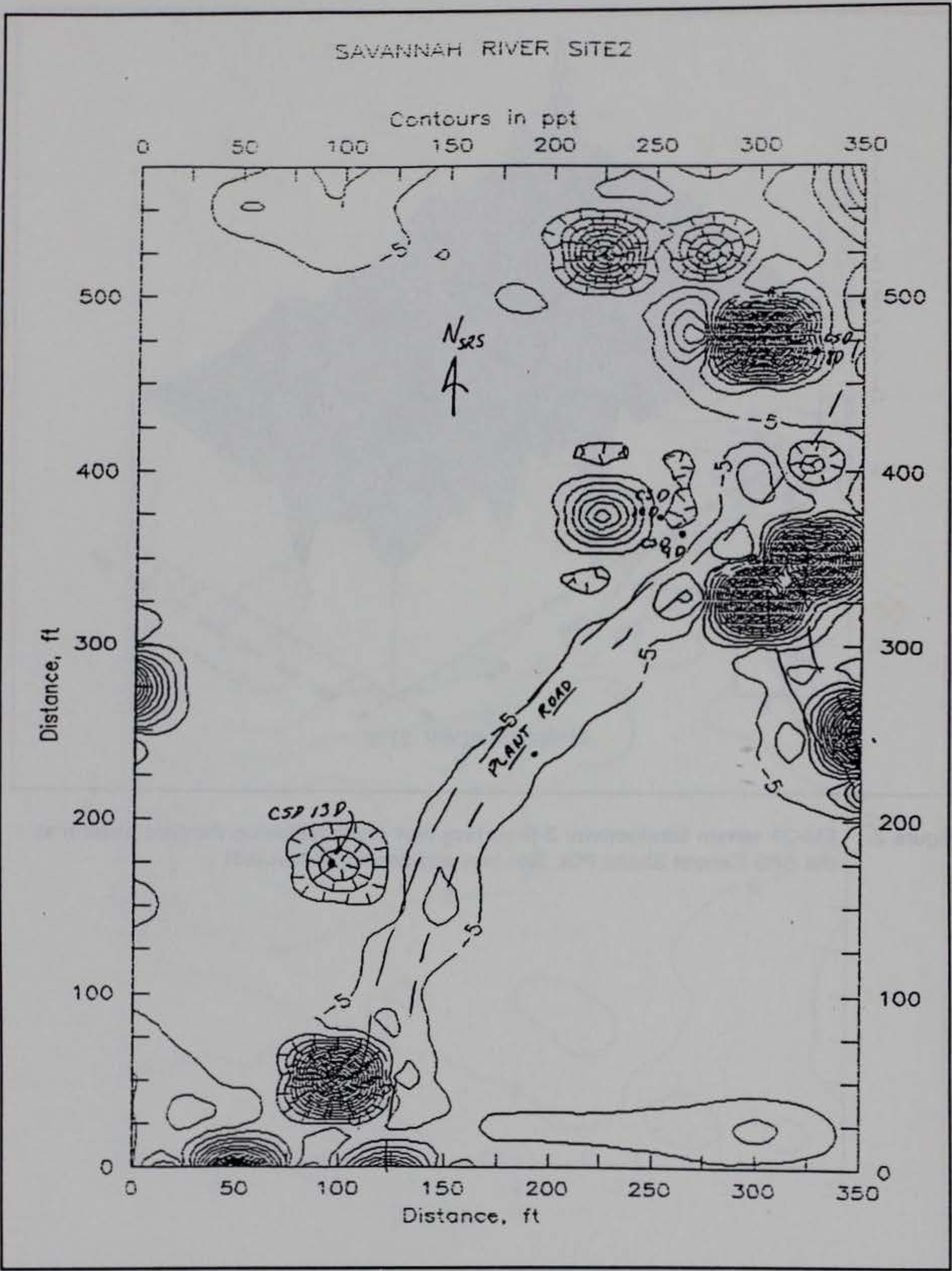


Figure 3. EM-31 terrain magnetic susceptibility contours produced using the field system at the SRS Central Shops POL Site (not additionally processed)

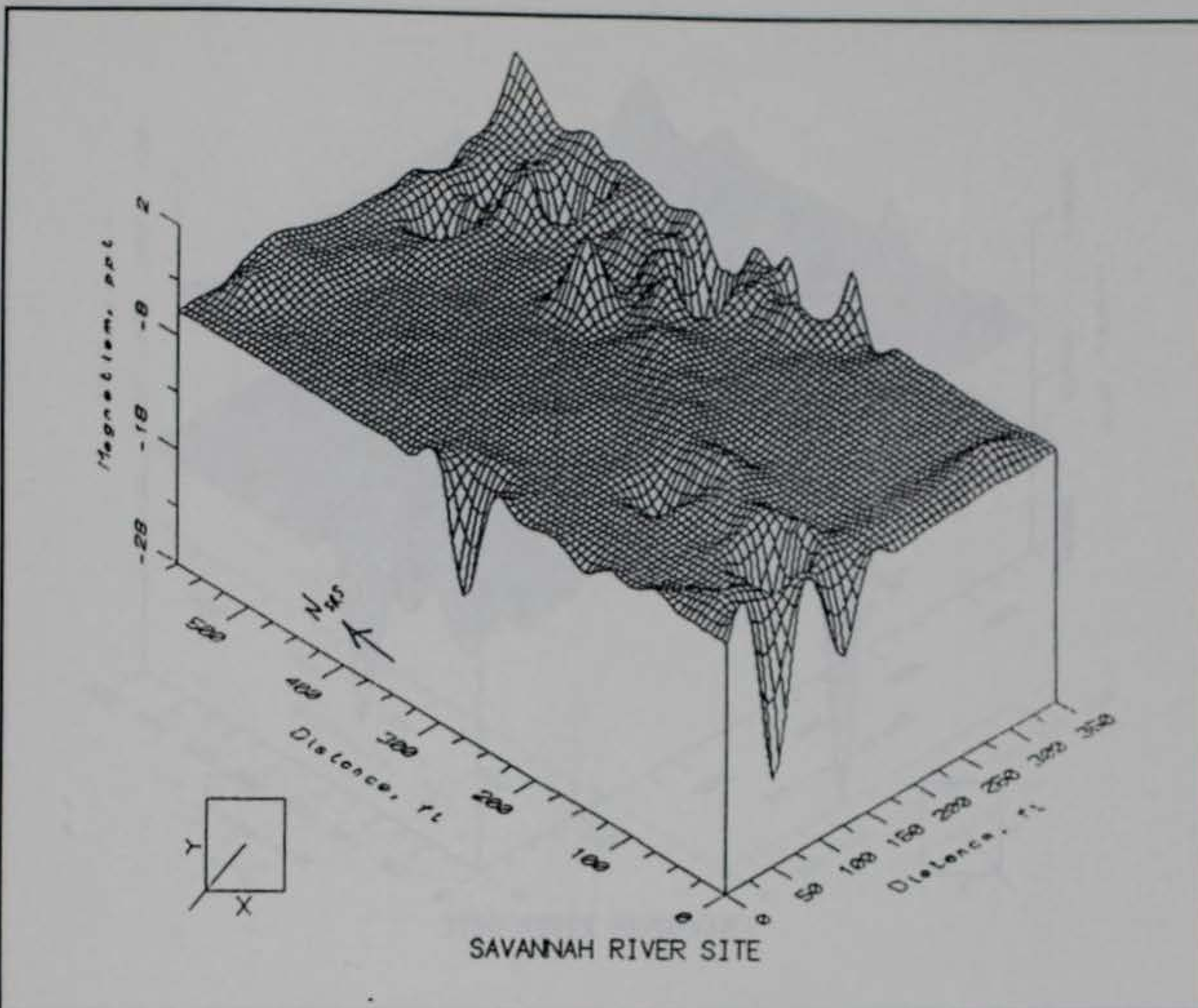


Figure 4. EM-31 terrain magnetic susceptibility 3-D surface plot produced using the field system at the SRS Central Shops POL Site (not additionally processed)

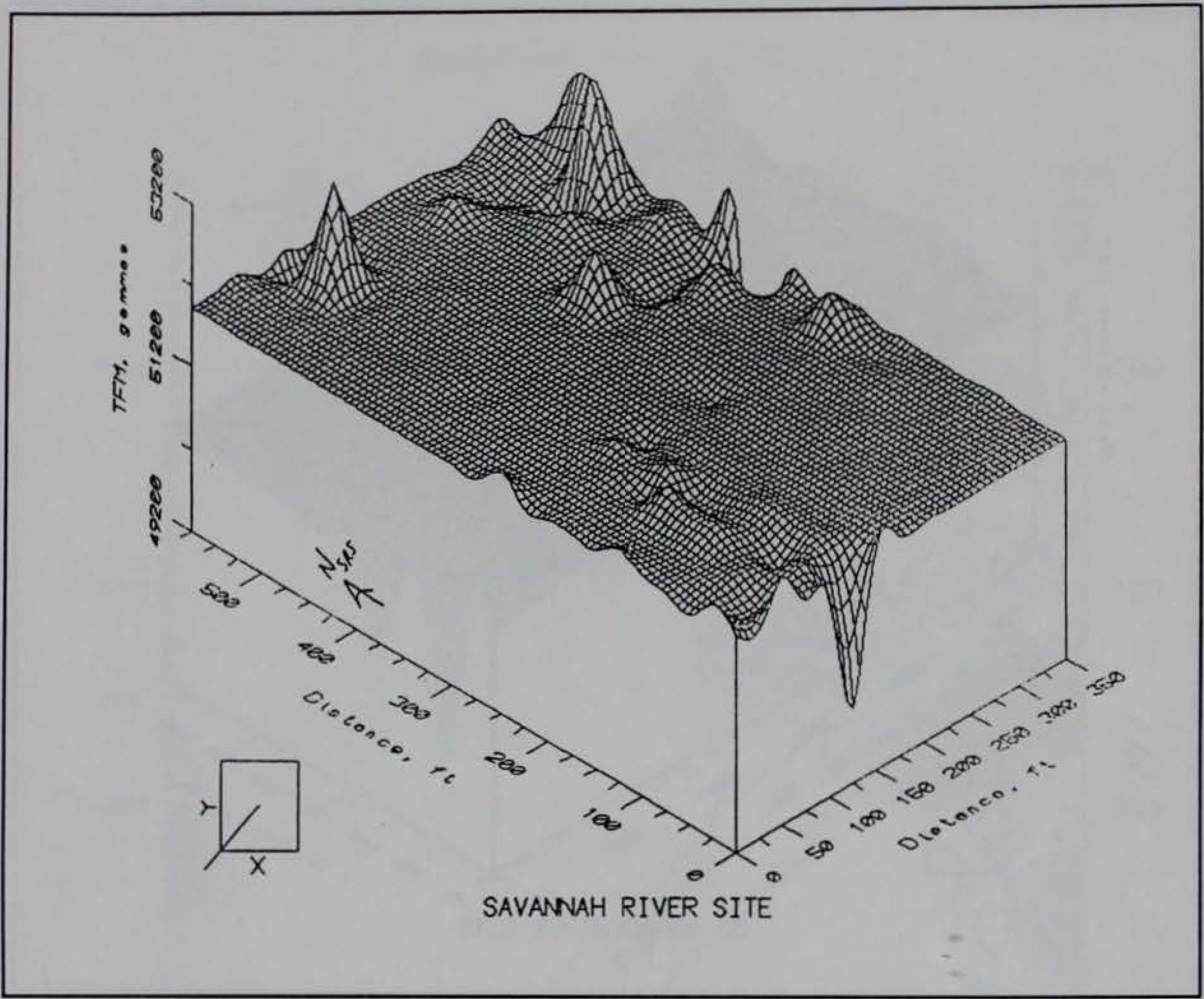


Figure 5. EDA OMNI-IV total magnetic field intensity 3-D surface plot produced using the field system at the SRS Central Shops POL Site (not additionally processed)

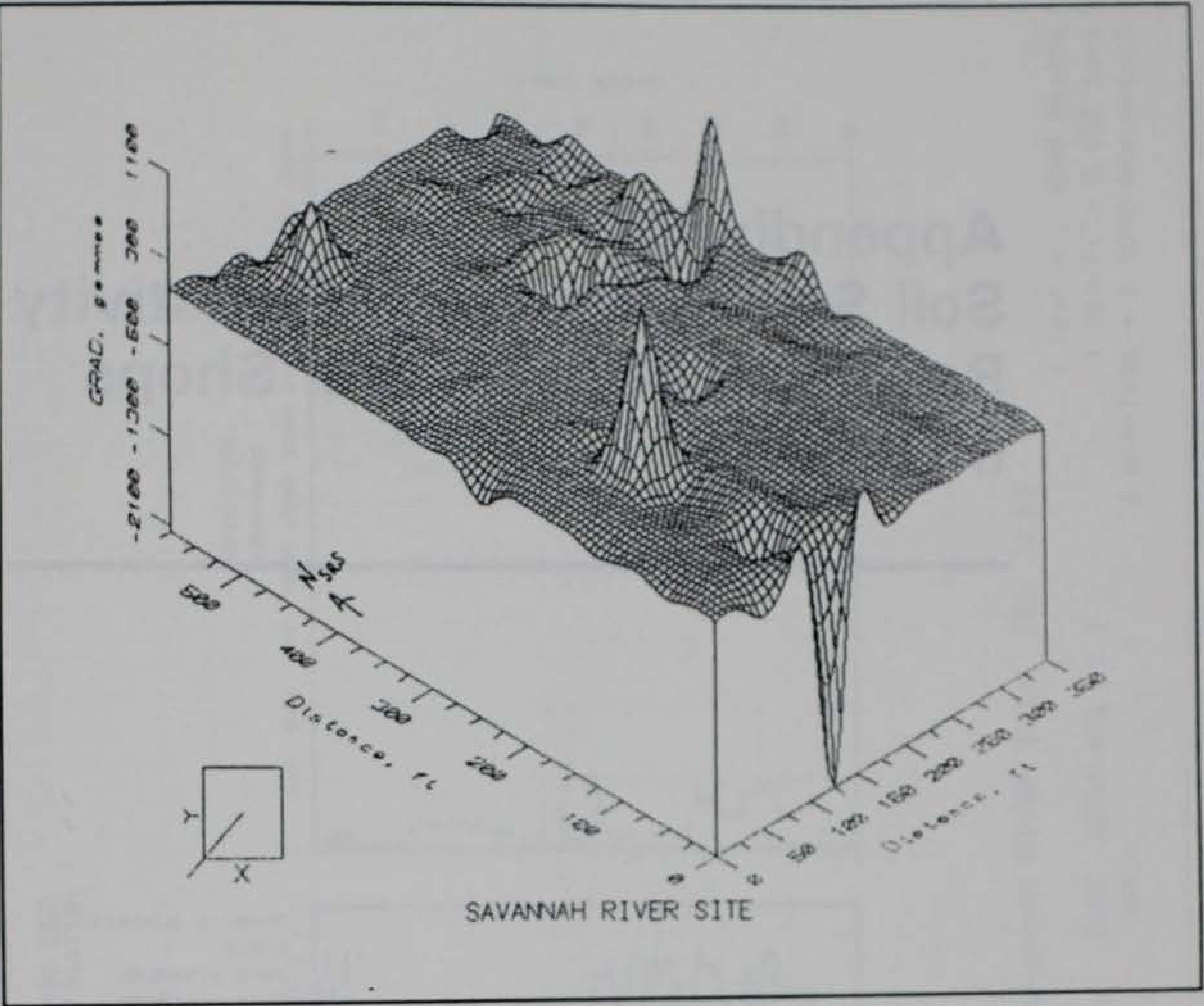
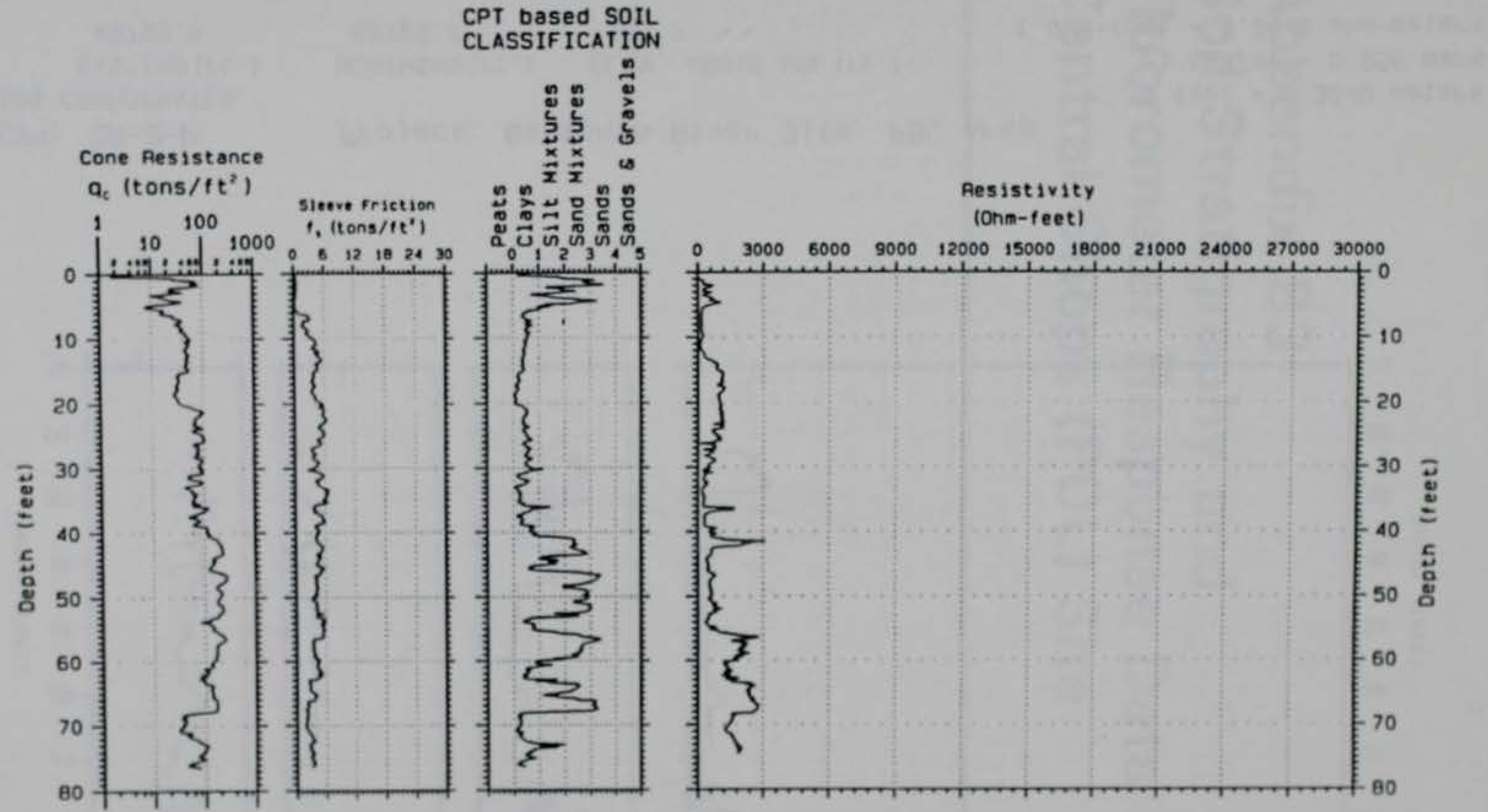


Figure 6. EDA OMNI-IV magnetic field intensity gradient 3-D surface plot produced using the field system at the SRS Central Shops POL Site (not additionally processed)

Appendix B2
Soil Stratigraphy and Resistivity Response Data Central Shops (POL) Site



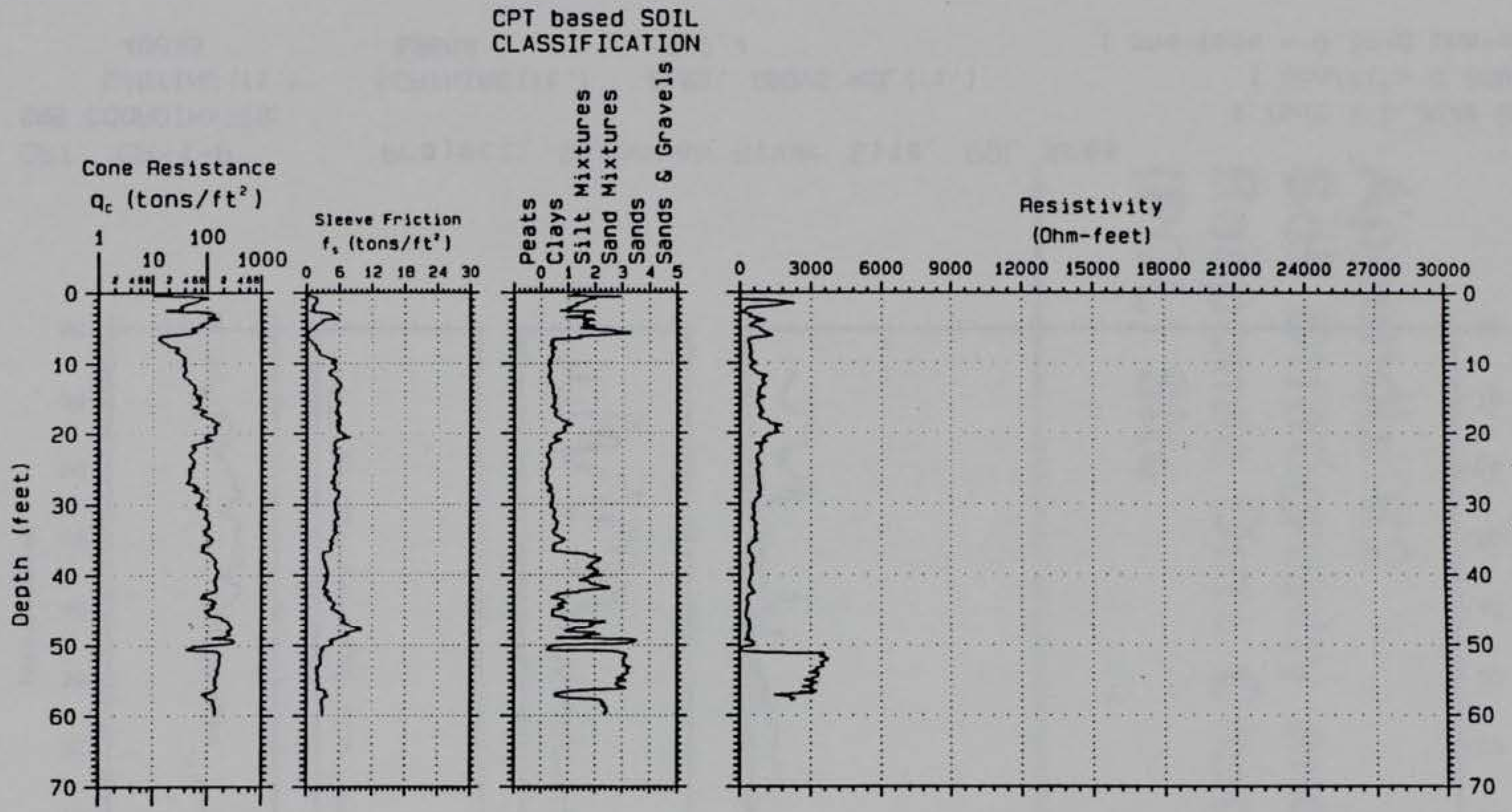
CPT: CR-1-P

Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
49645	62898	287.4

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars
1 ohm-foot = 0.3048 ohm-meters



CPT: CR-2-P

Project: Savannah River Site, POL Area

SRS COORDINATES:

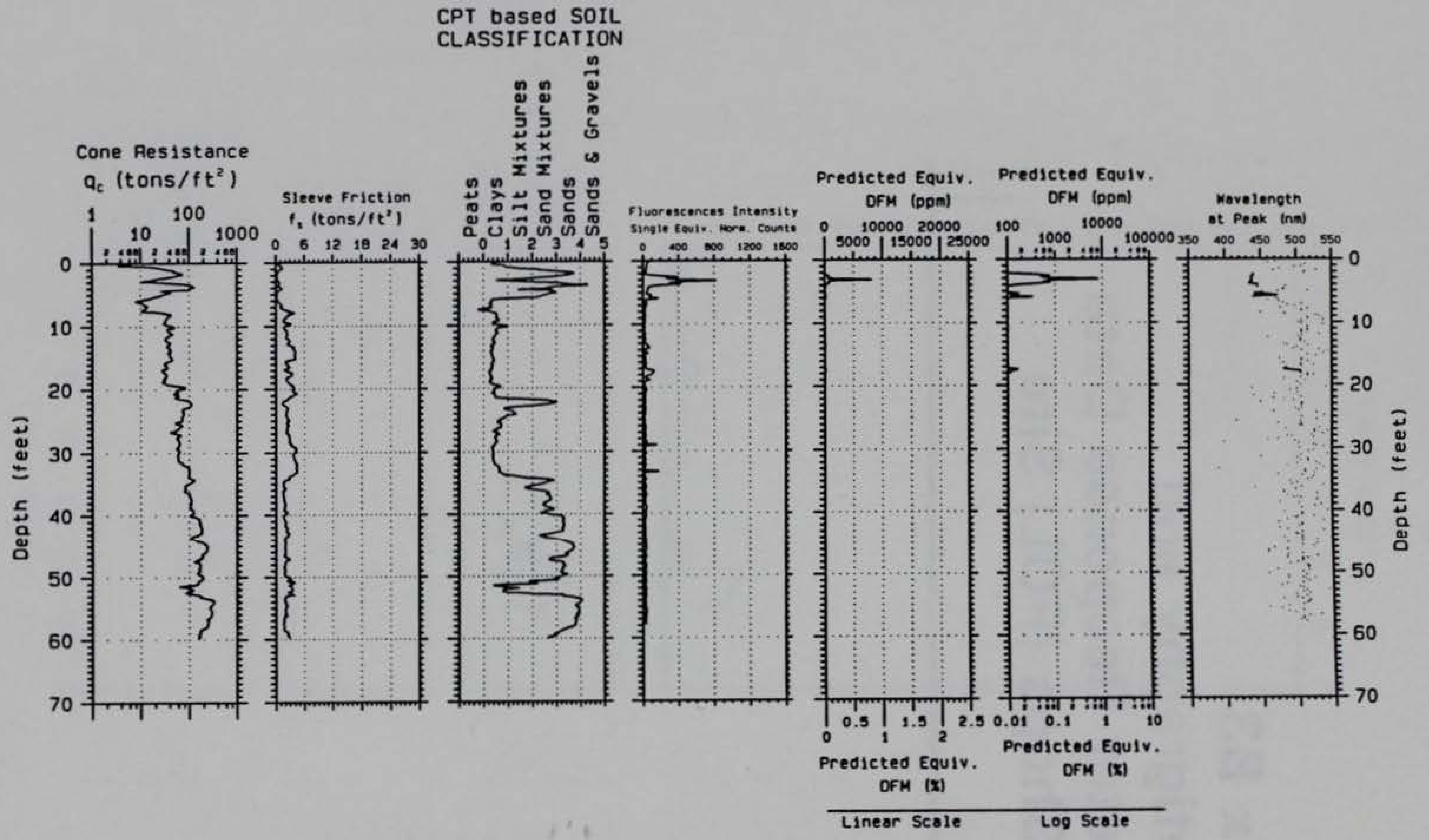
EASTING (ft.)	NORTHING (ft.)	ELEV. ABOVE MSL (ft.)
49793.5	62726.7	288.7

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars

1 ohm-foot = 0.3048 ohm-meters

Appendix B3
Soil Stratigraphy and Fluorometer Response Data Central Shops (POL) Site

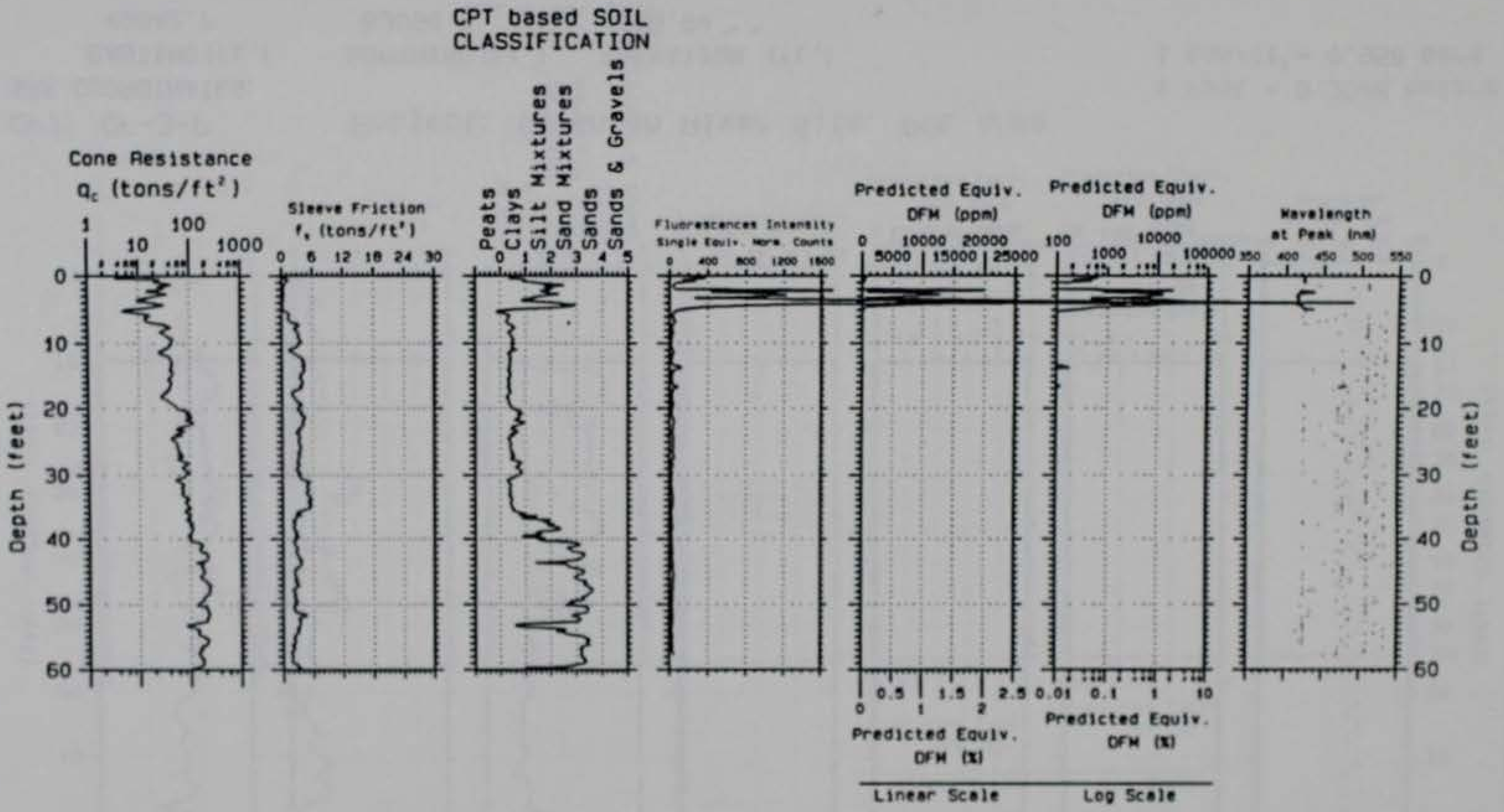


CPT: CF-1-P Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49679.2	62900.7	287.89

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars

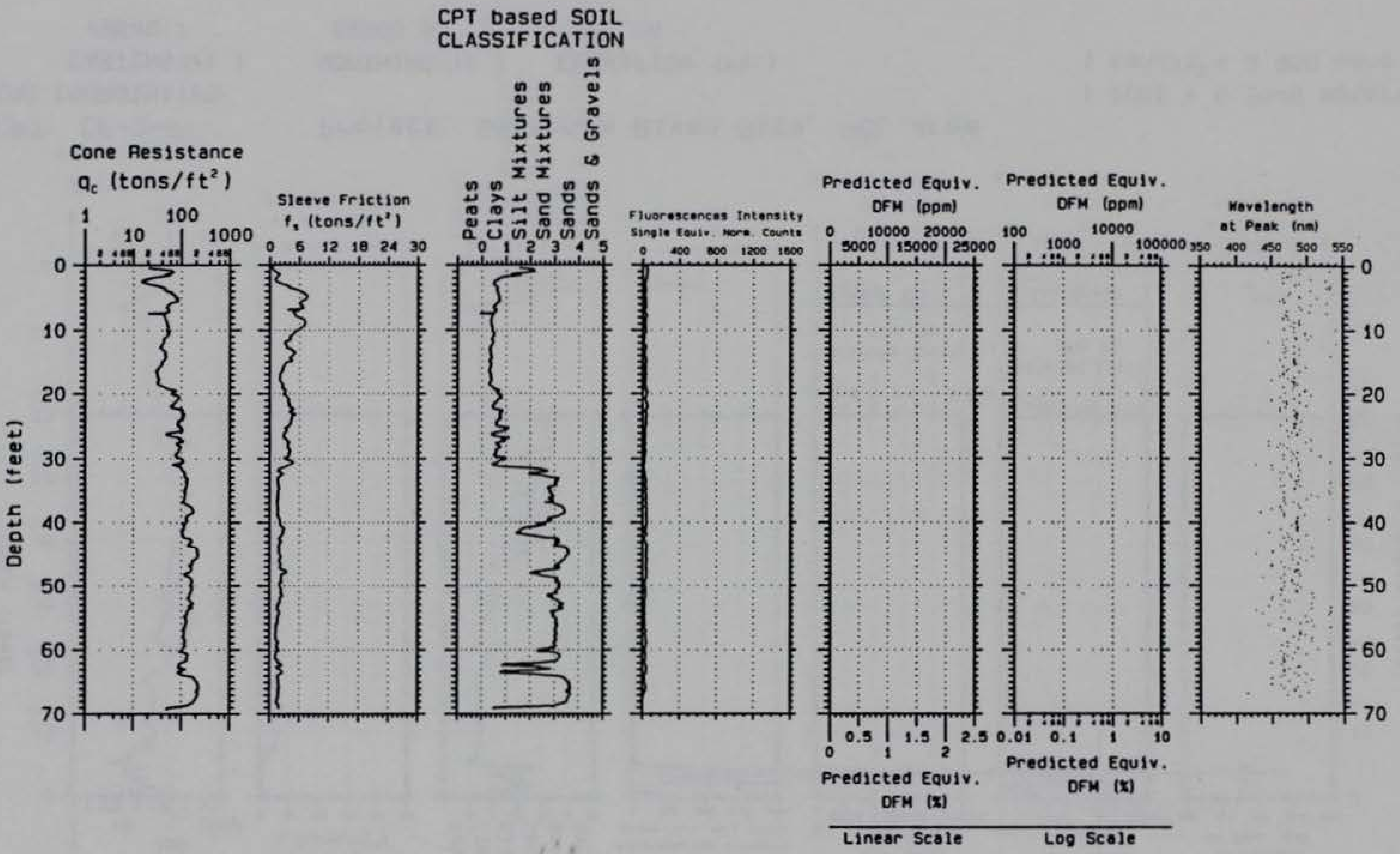


CPT: CF-2-P Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49649.7	62900.9	286.06

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars



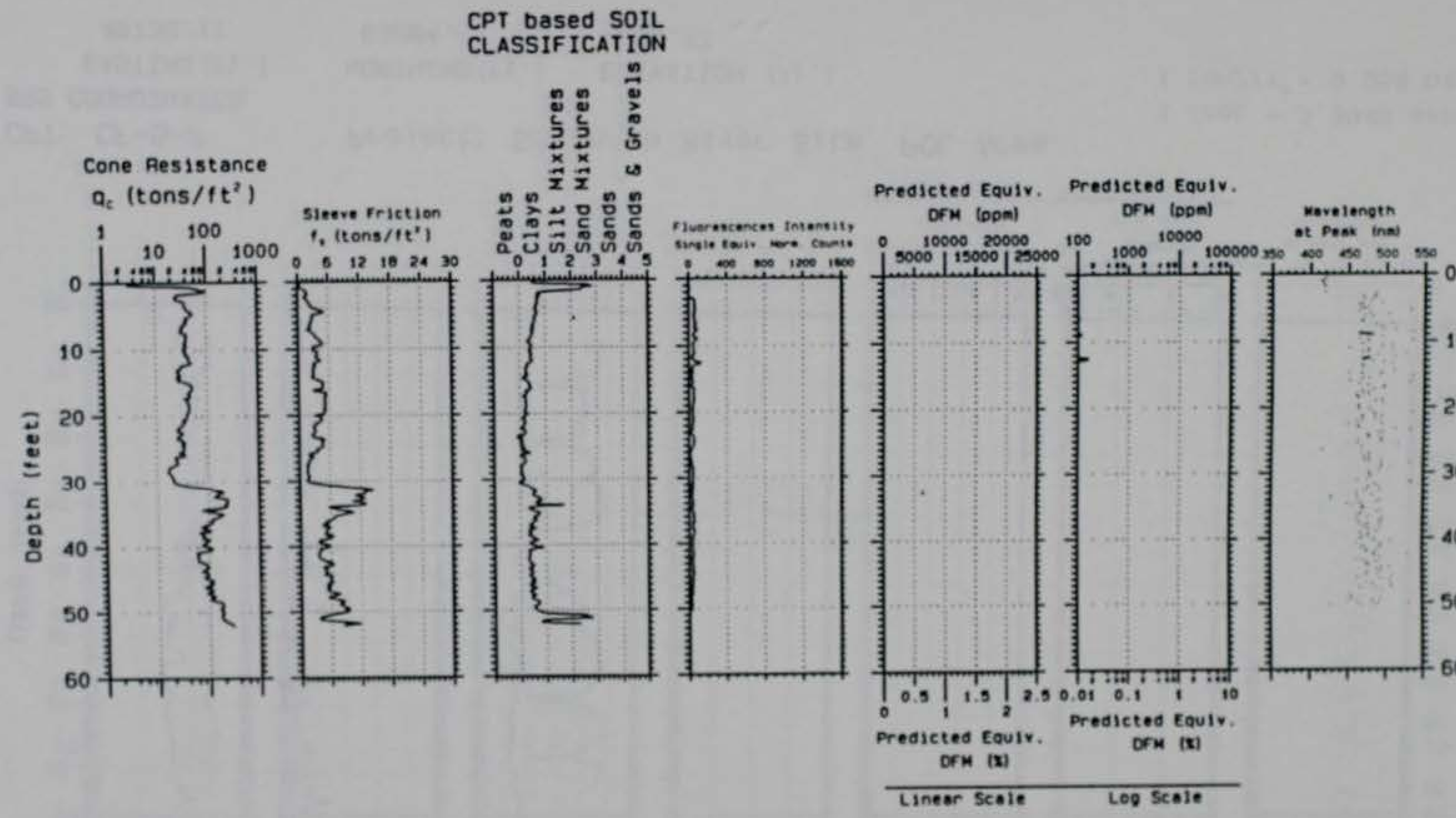
CPT: CF-3-P

Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49842.7	63096.5	295.94

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars



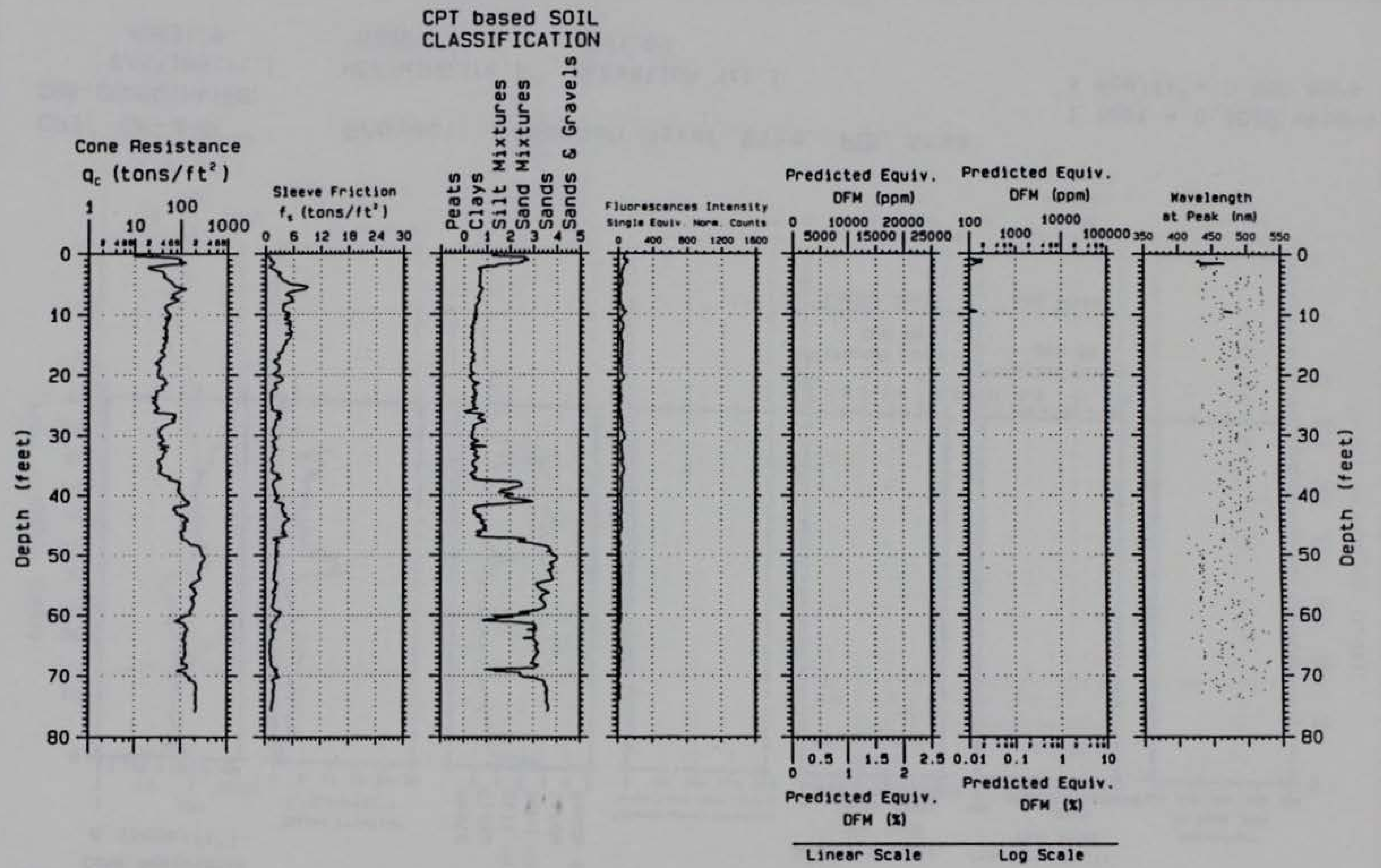
CPT: CF-4-P

Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49831.9	63298.7	301.09

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars



CPT: CF-5-P

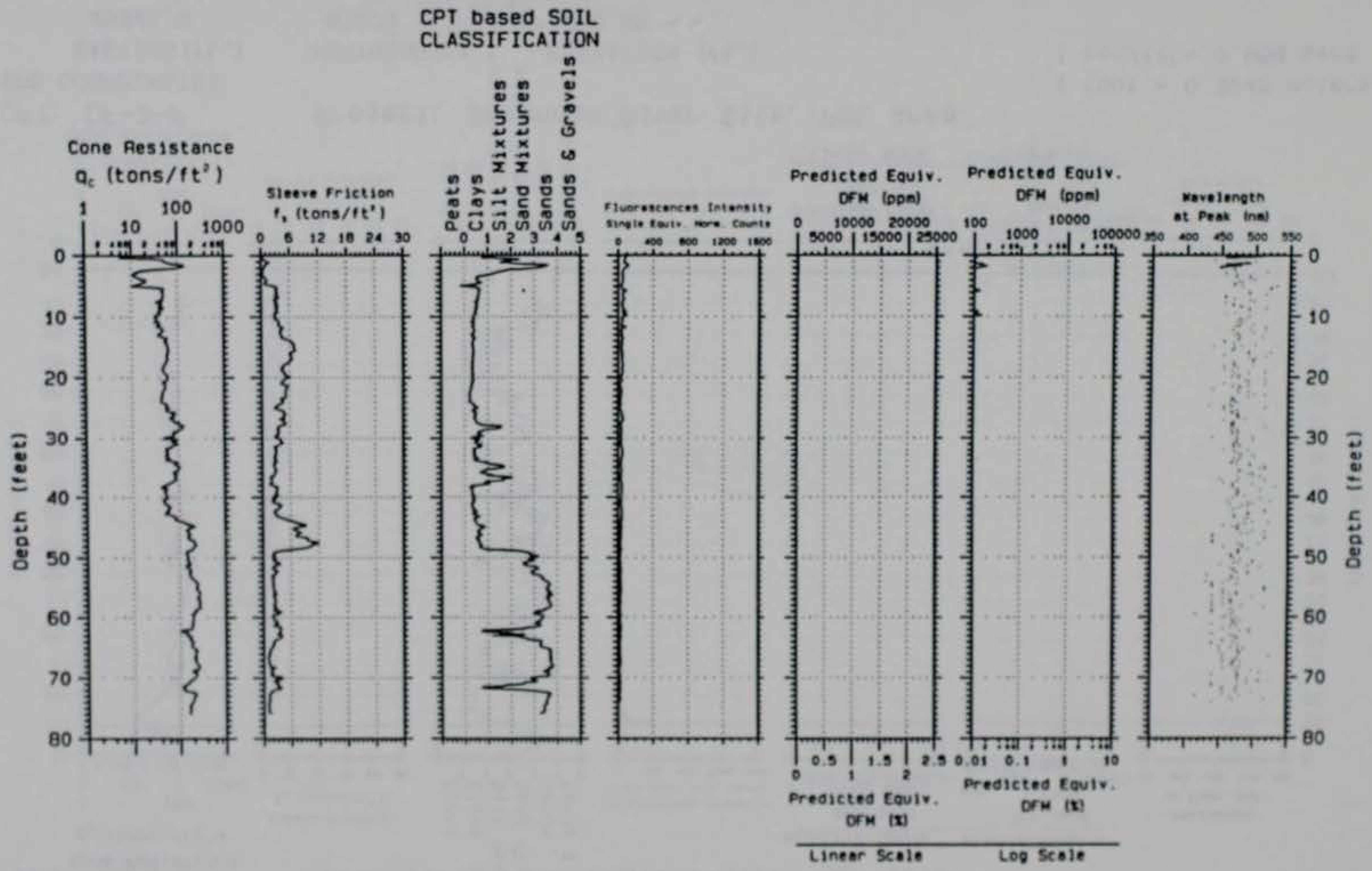
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49738.11	63284.66	296.77

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars



CPT: CF-6-P

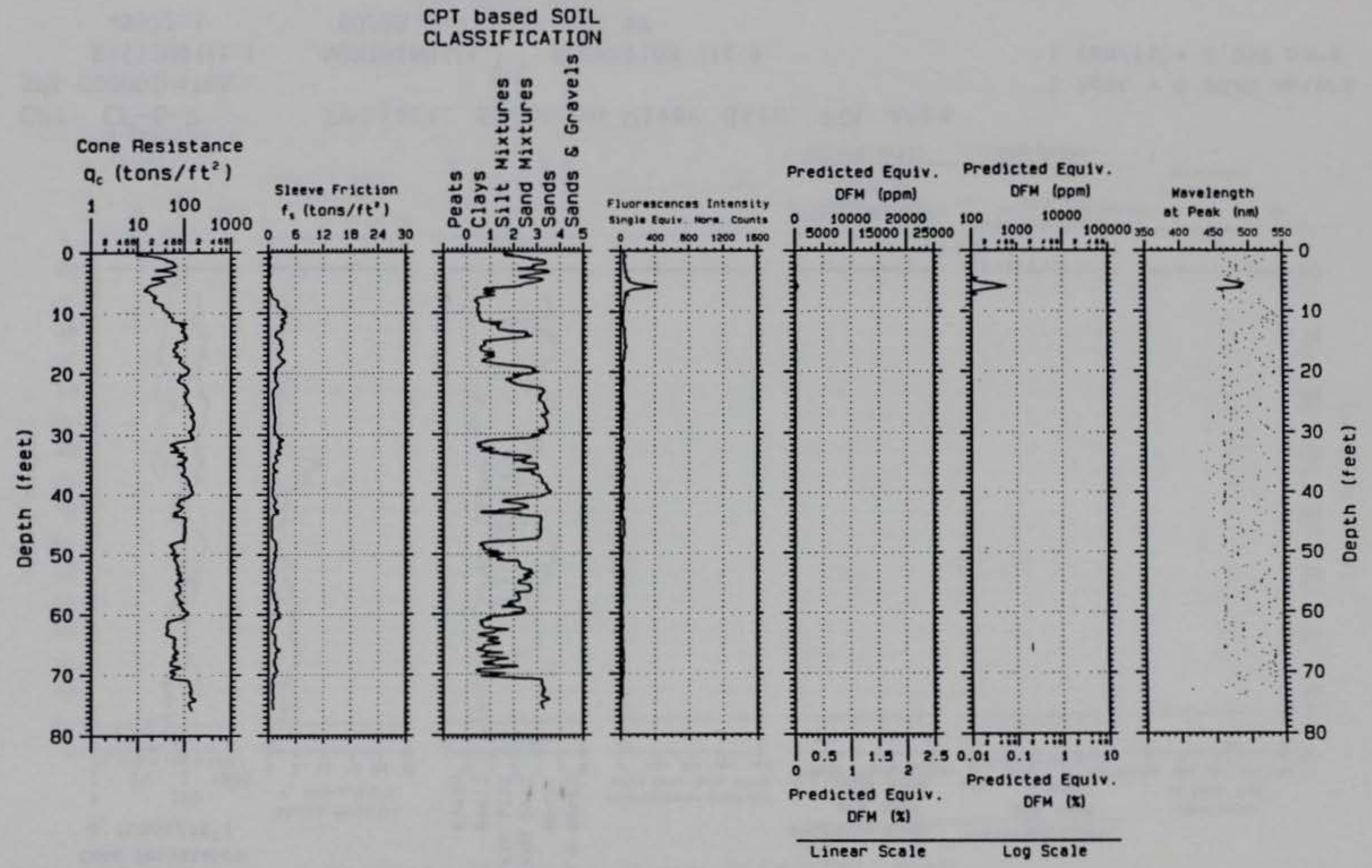
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49872.1	63225.6	301.67

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars

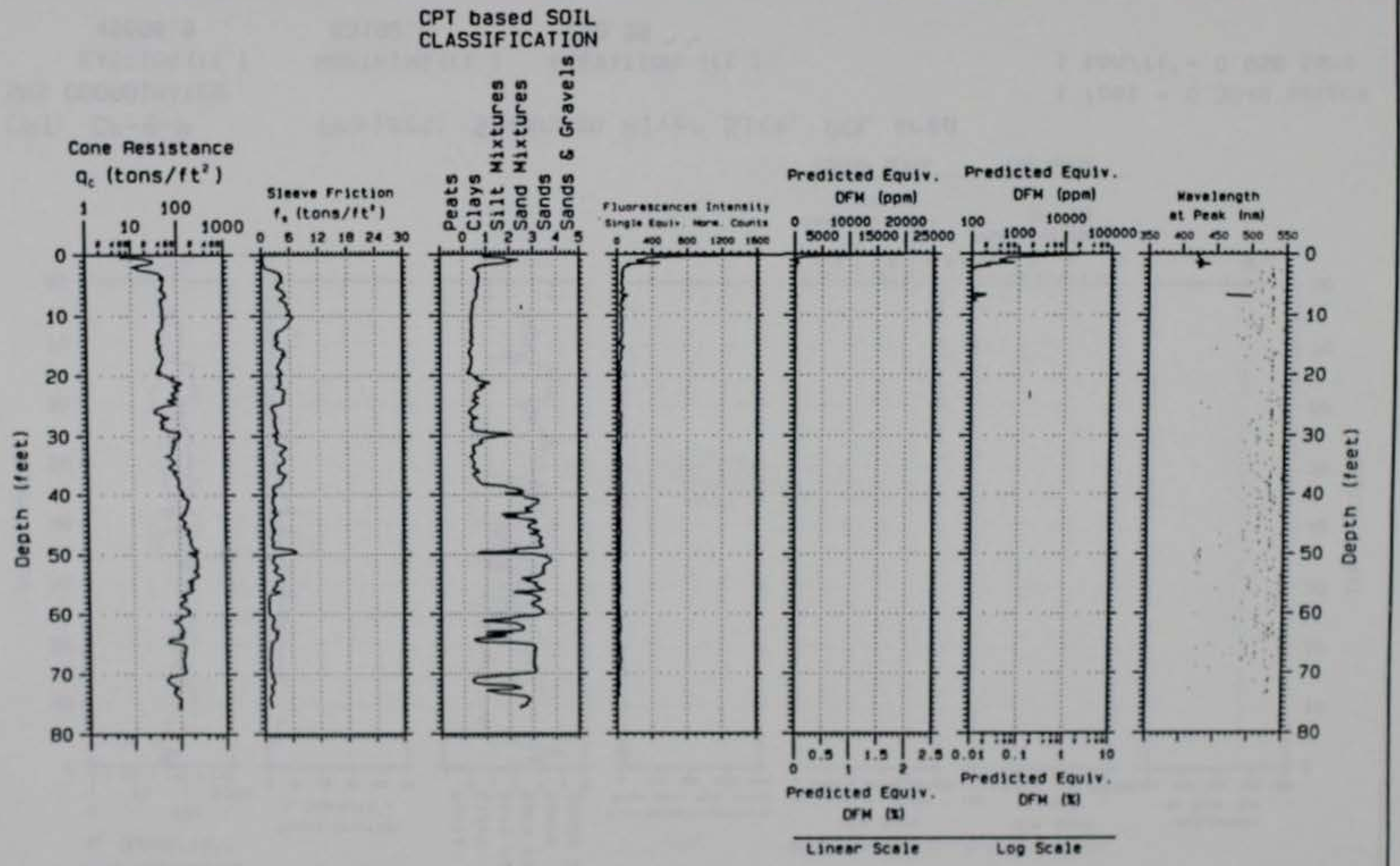


CPT: CF-7-P   Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49341.8	63079	280.69

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars



CPT: CF-8-P

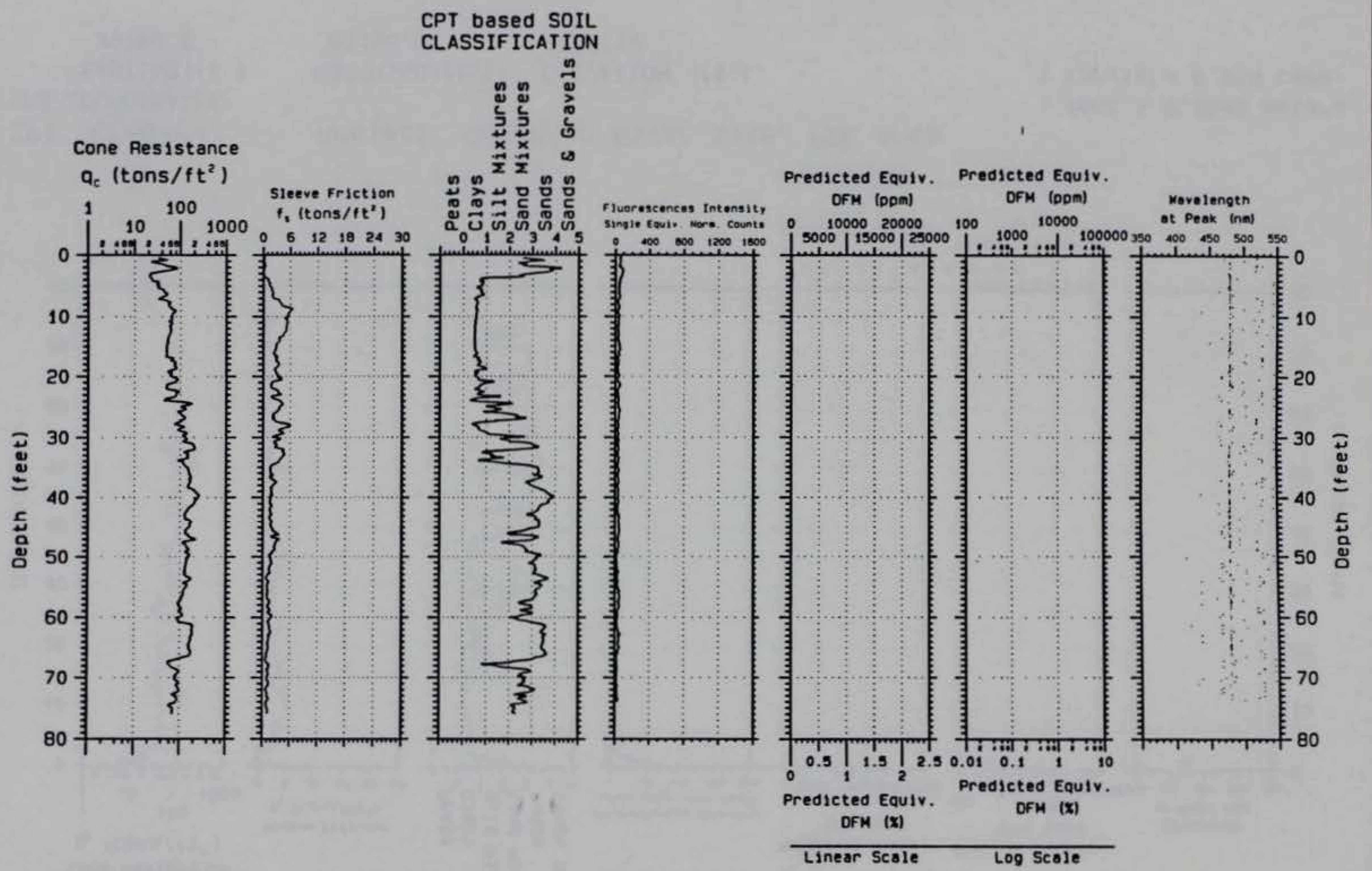
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49780.9	63196.9	296.12

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-9-P

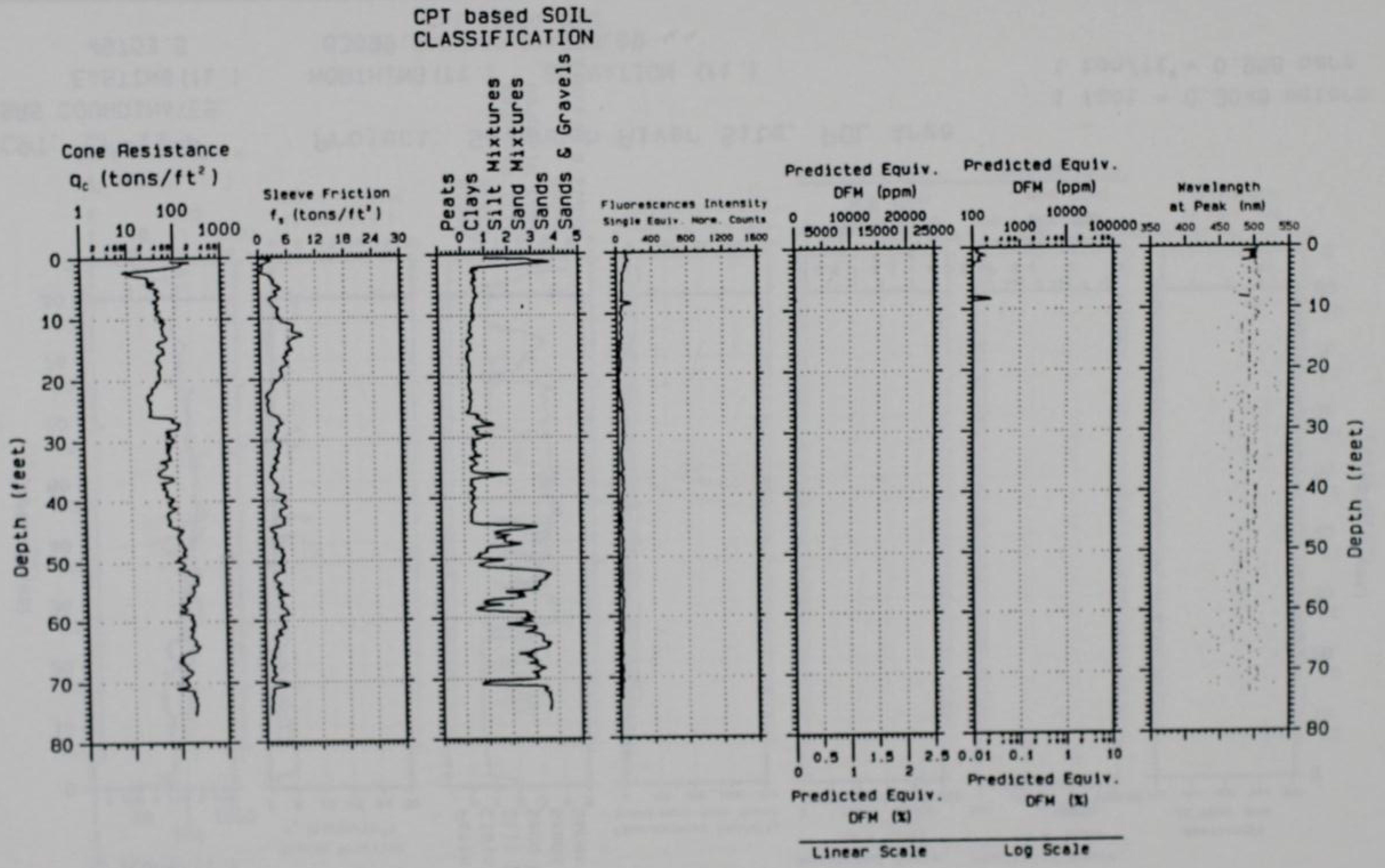
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49656.9	63192.8	292.35

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-10-P

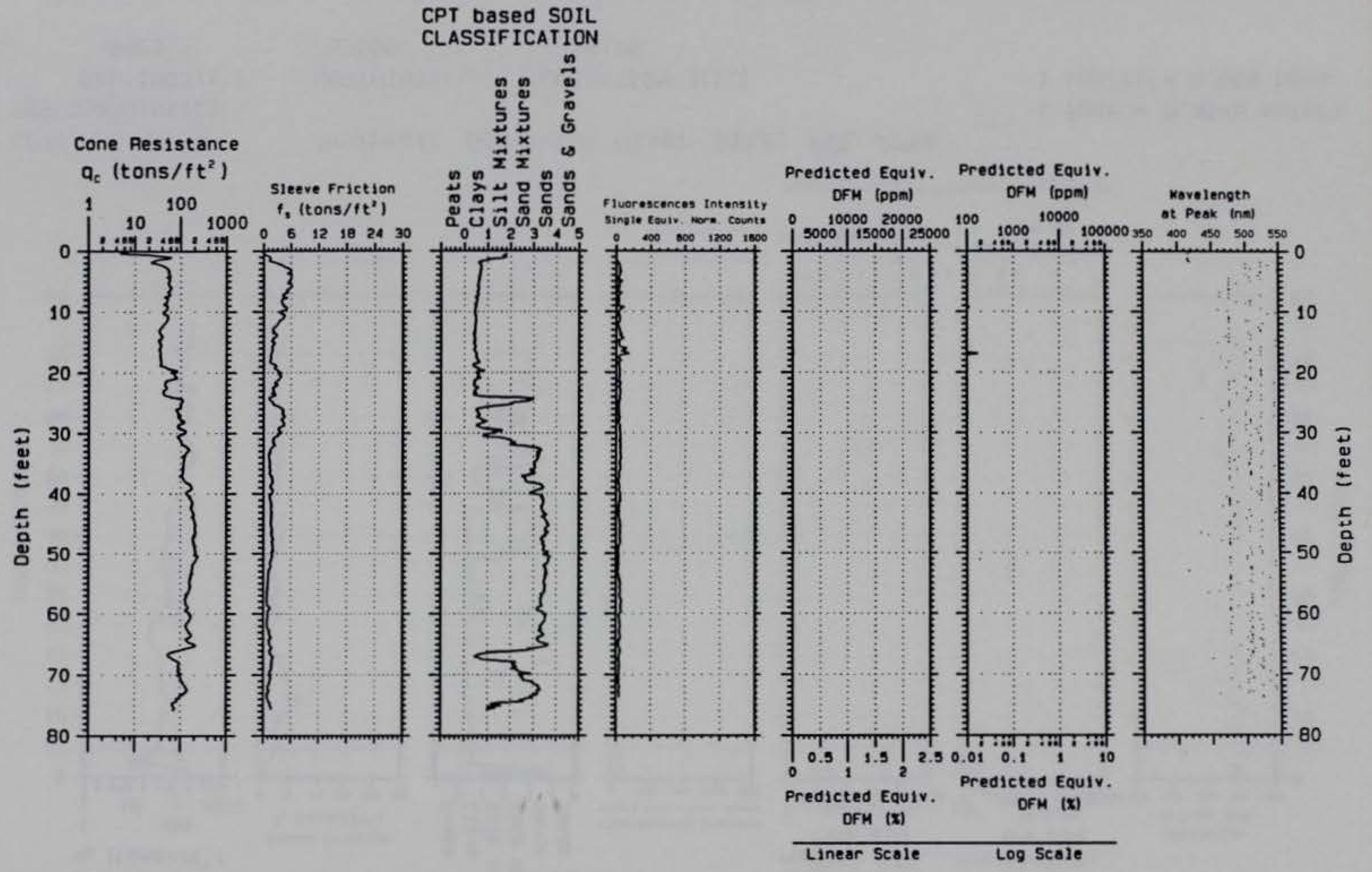
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49923	63096	299.56

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-11-P

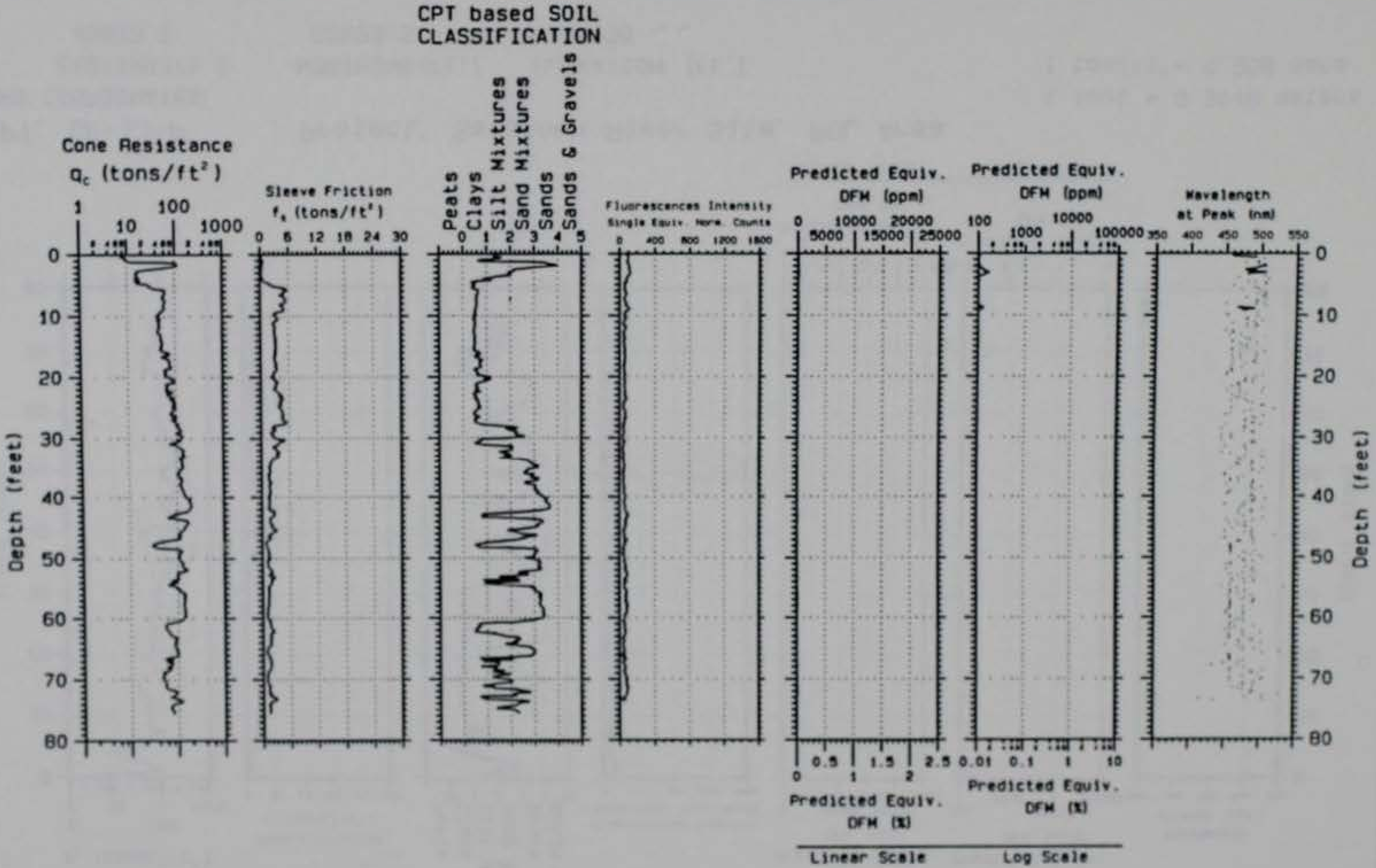
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49753.5	63099.2	292.09

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



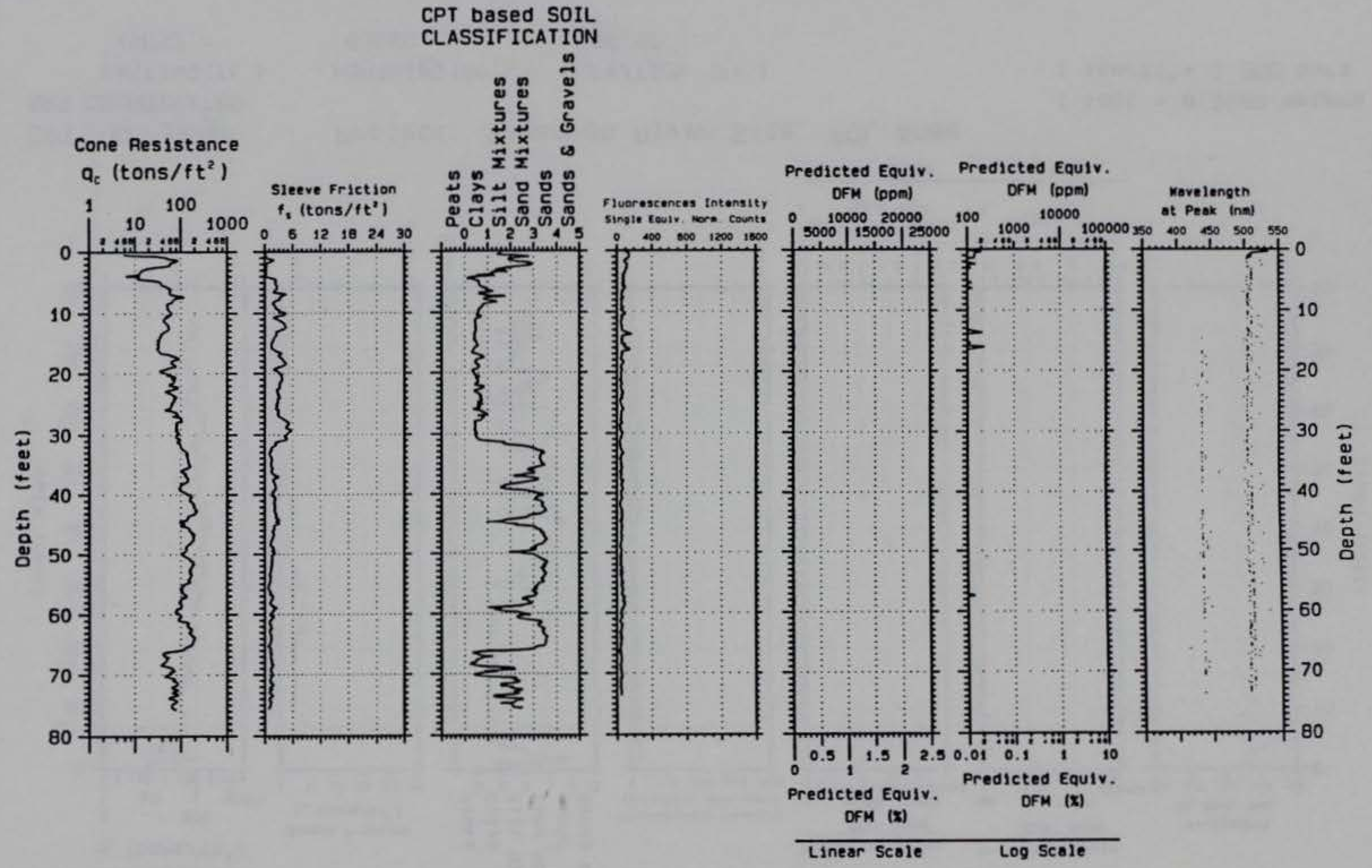
CPT: CF-12-P   Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49652.4	63099	289.57

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars



CPT: CF-13-P

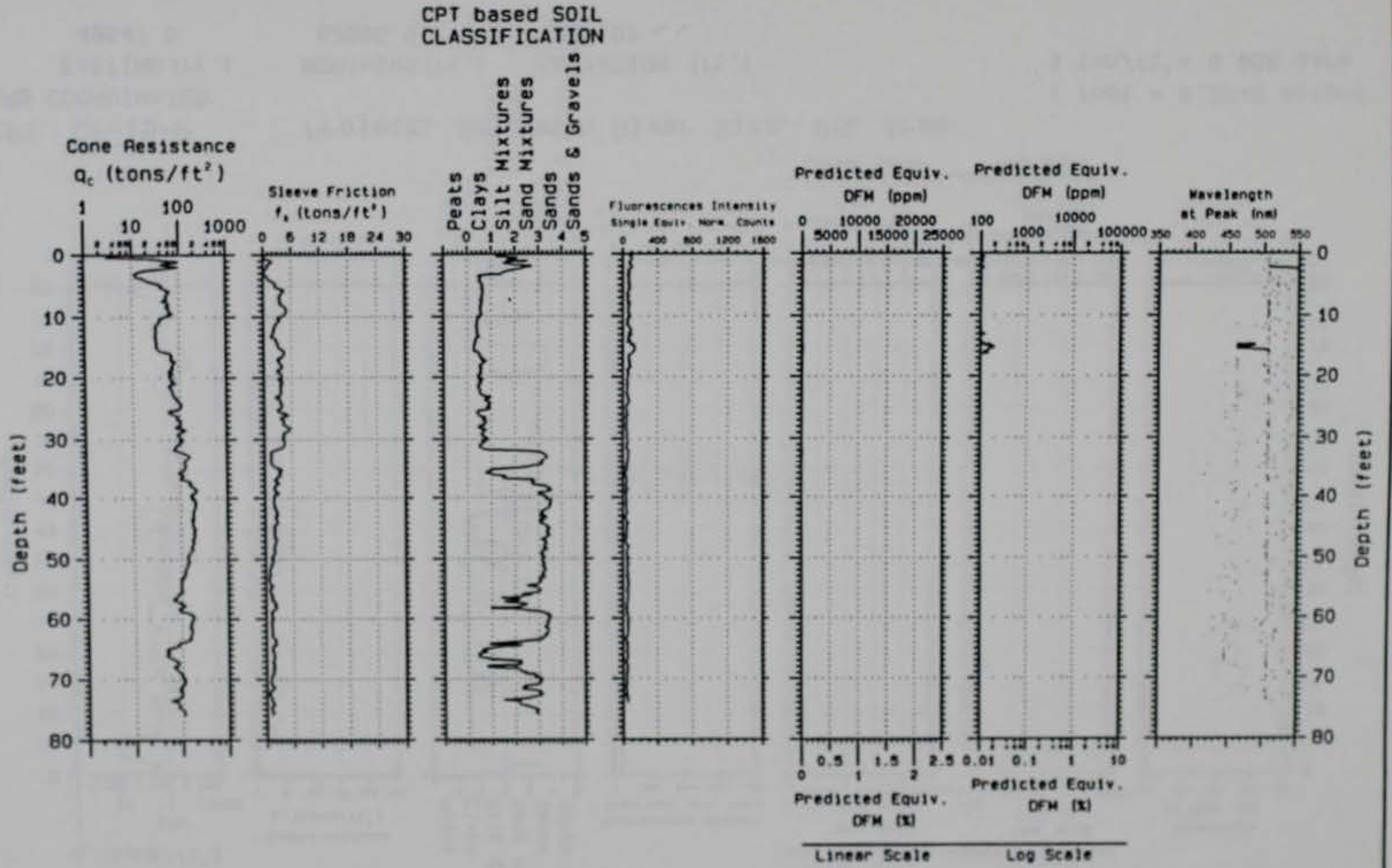
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49873.2	62993.5	294.36

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars



CPT: CF-14-P

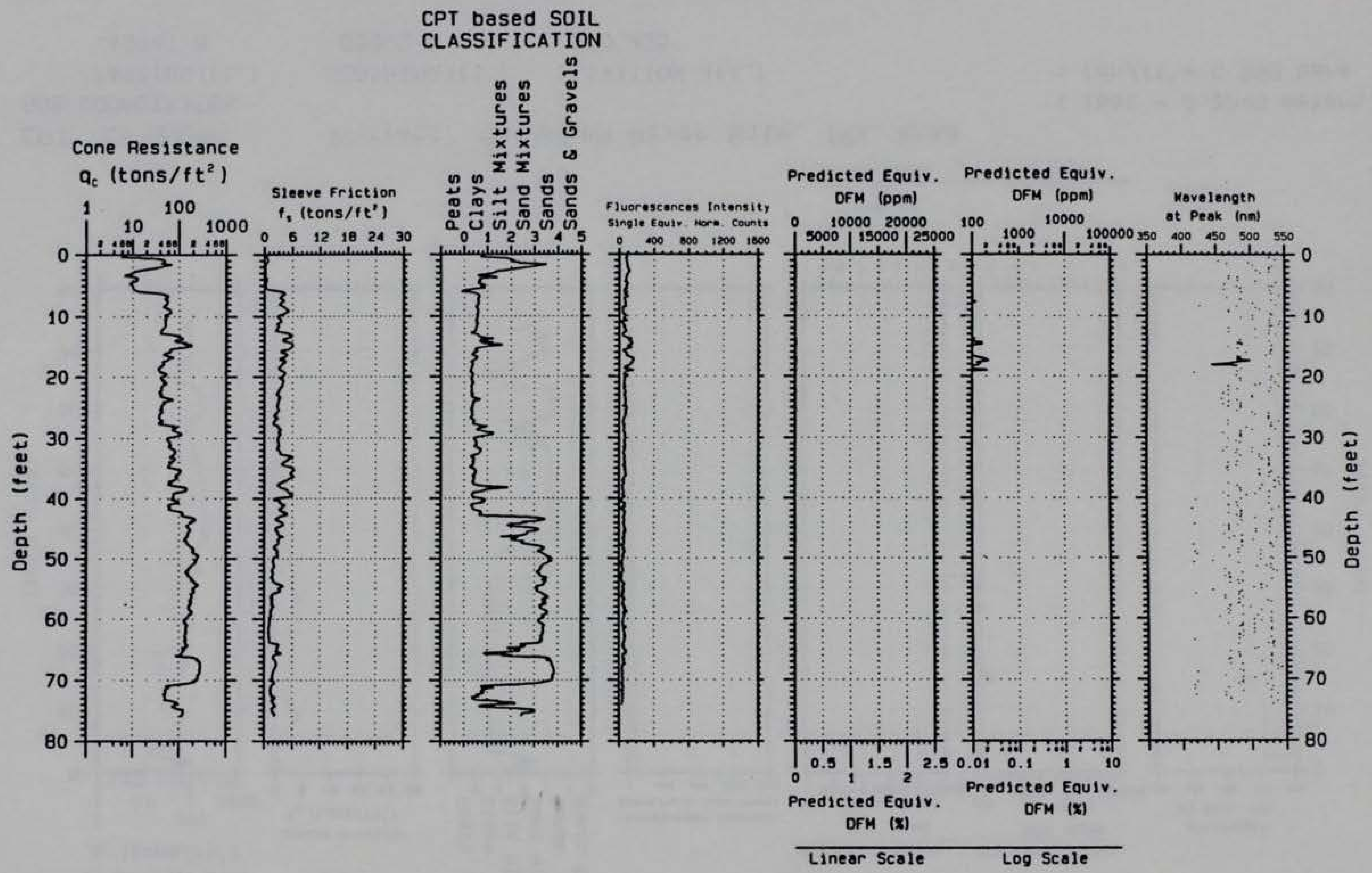
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49747.8	63002.9	290.495

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-15-P

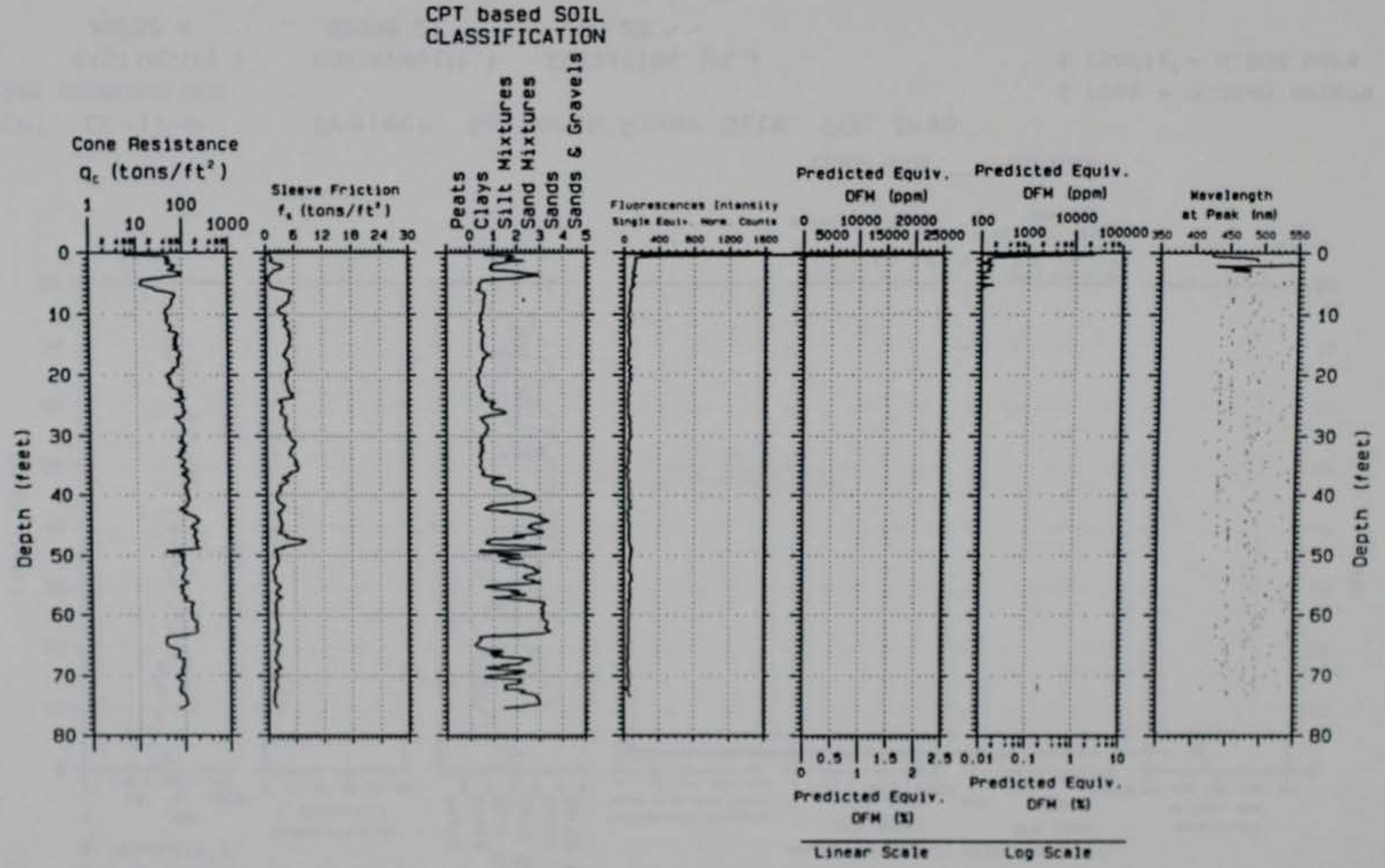
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49647.5	62996.9	287.07

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-16-P

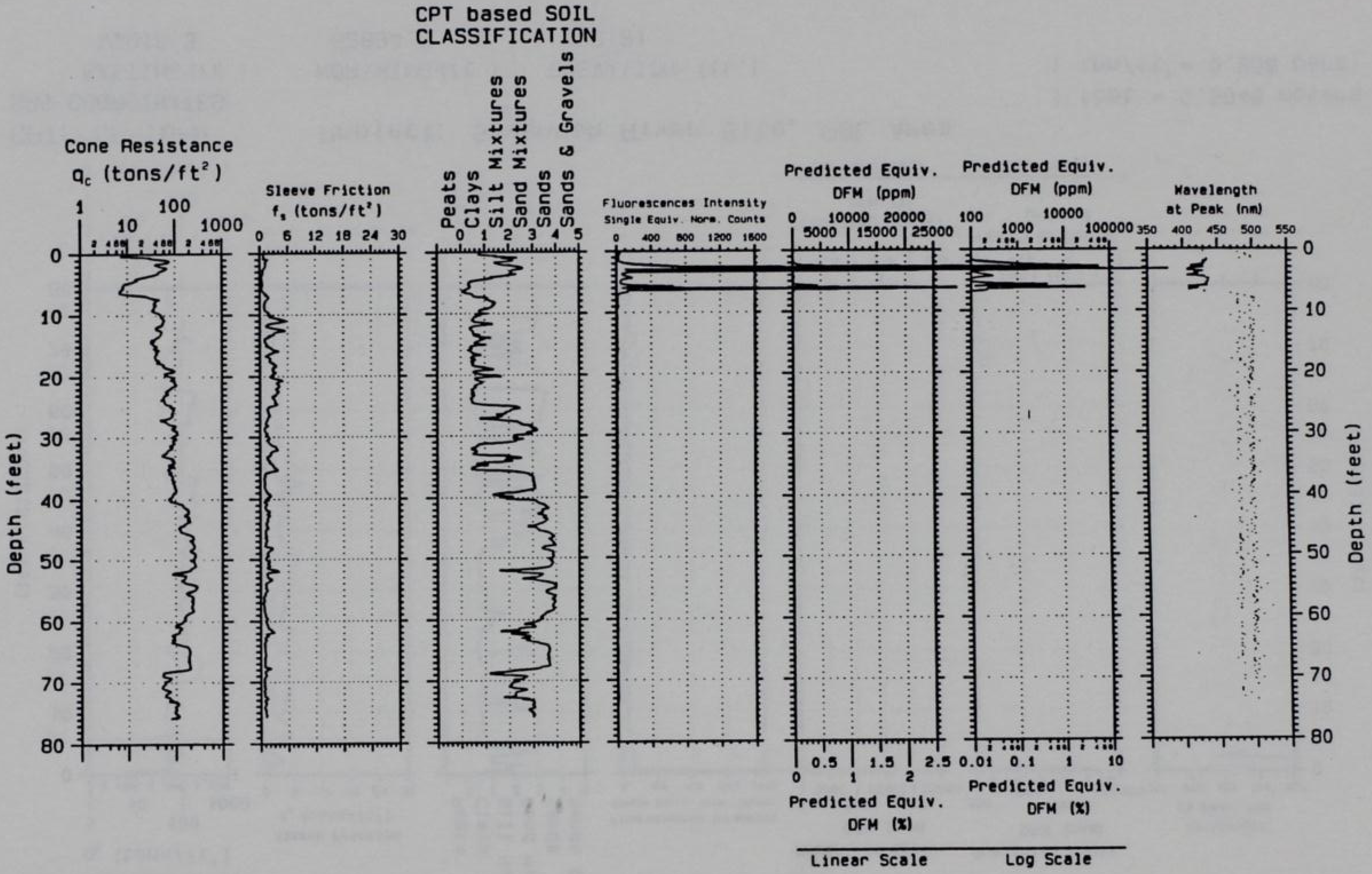
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49918.3	62894.5	292.21

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-17-P

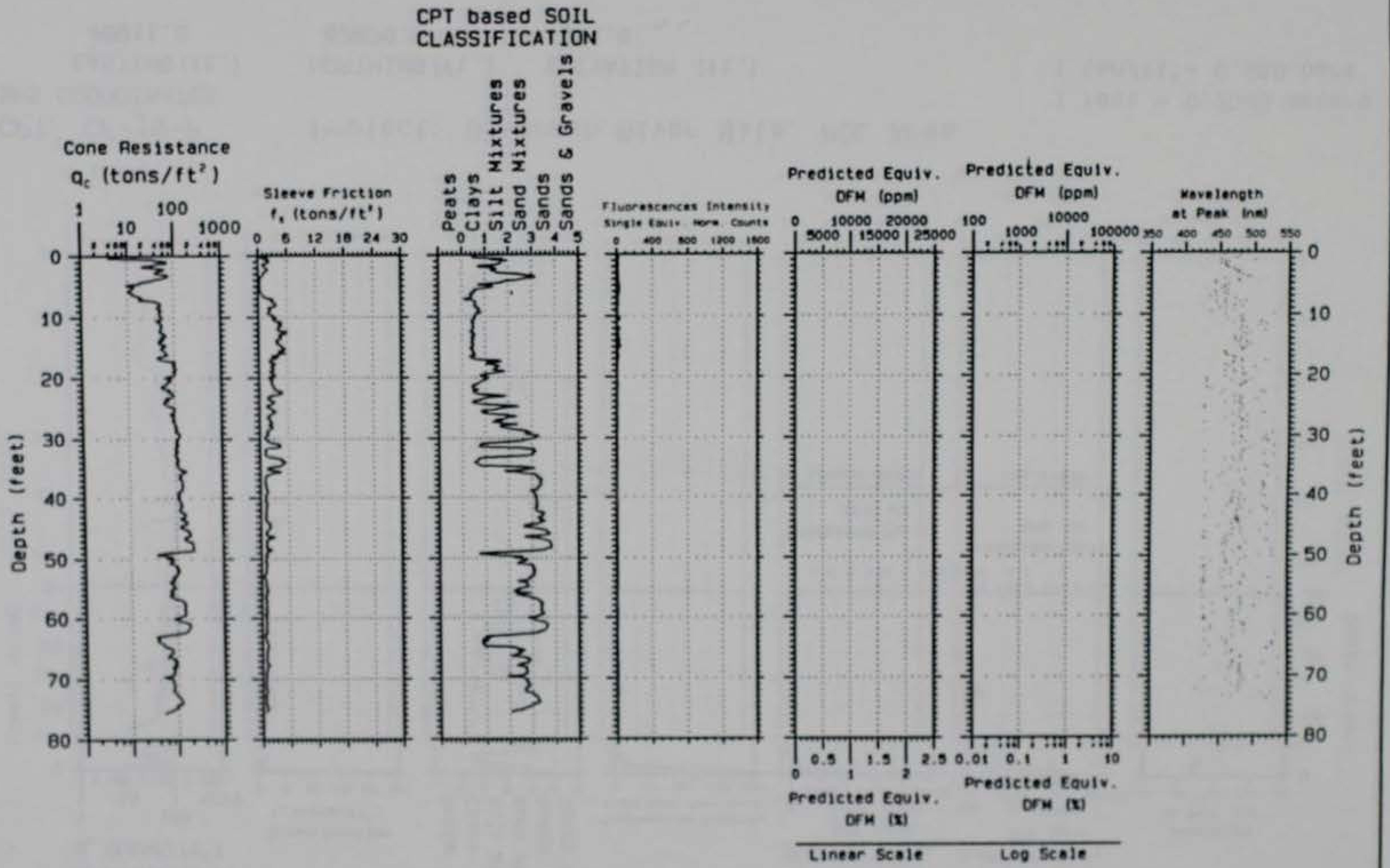
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49652.4	62908.2	286.22

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars

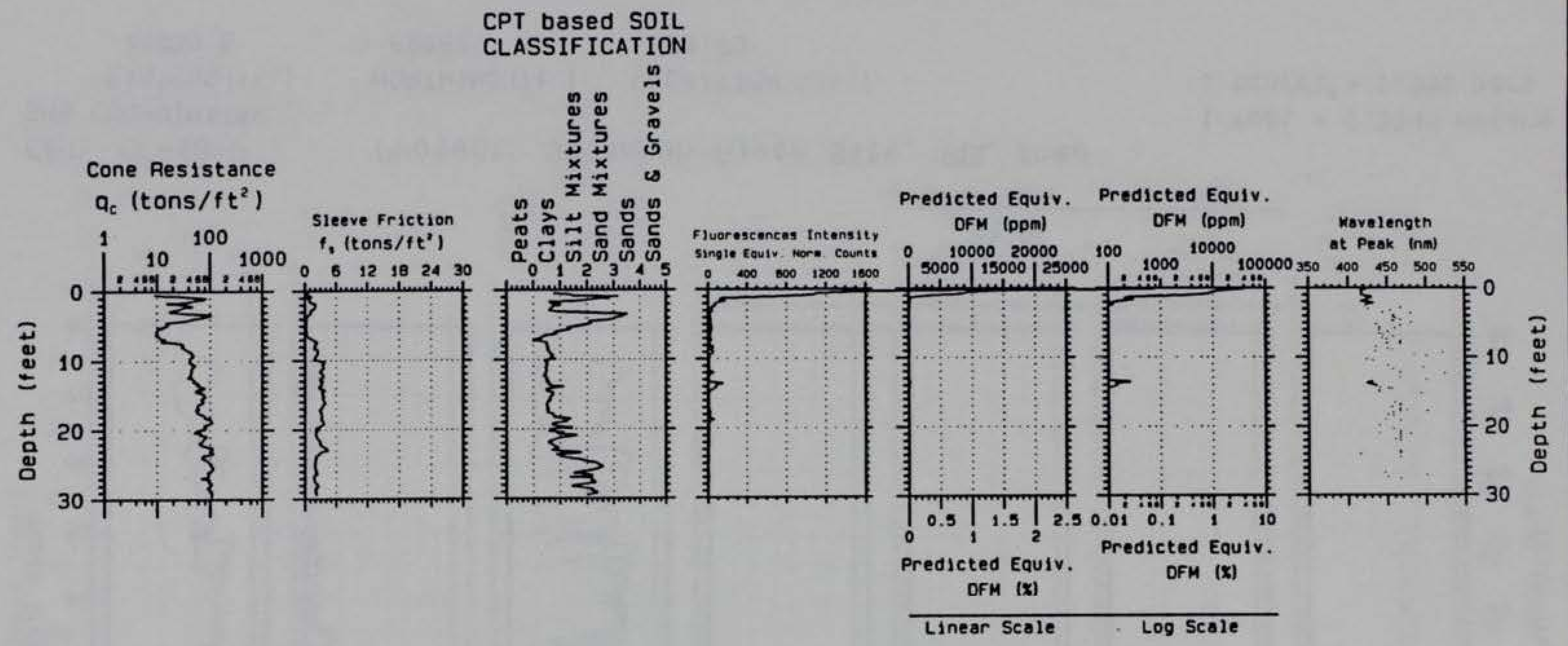


CPT: CF-18-P
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49909.6	62887	291.79

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars



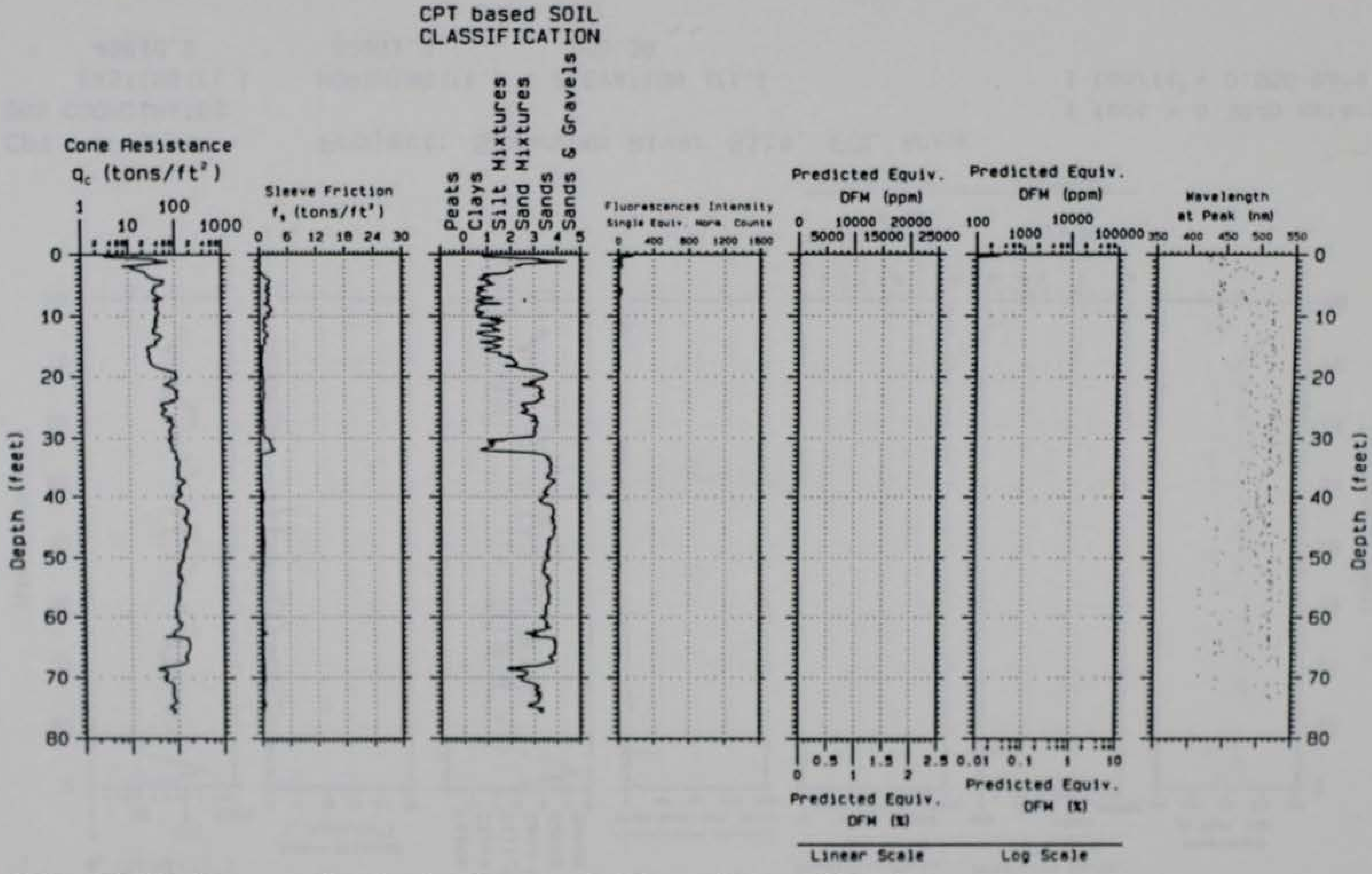
CPT: CF-19-P Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49911.3	62879.2	291.6

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars

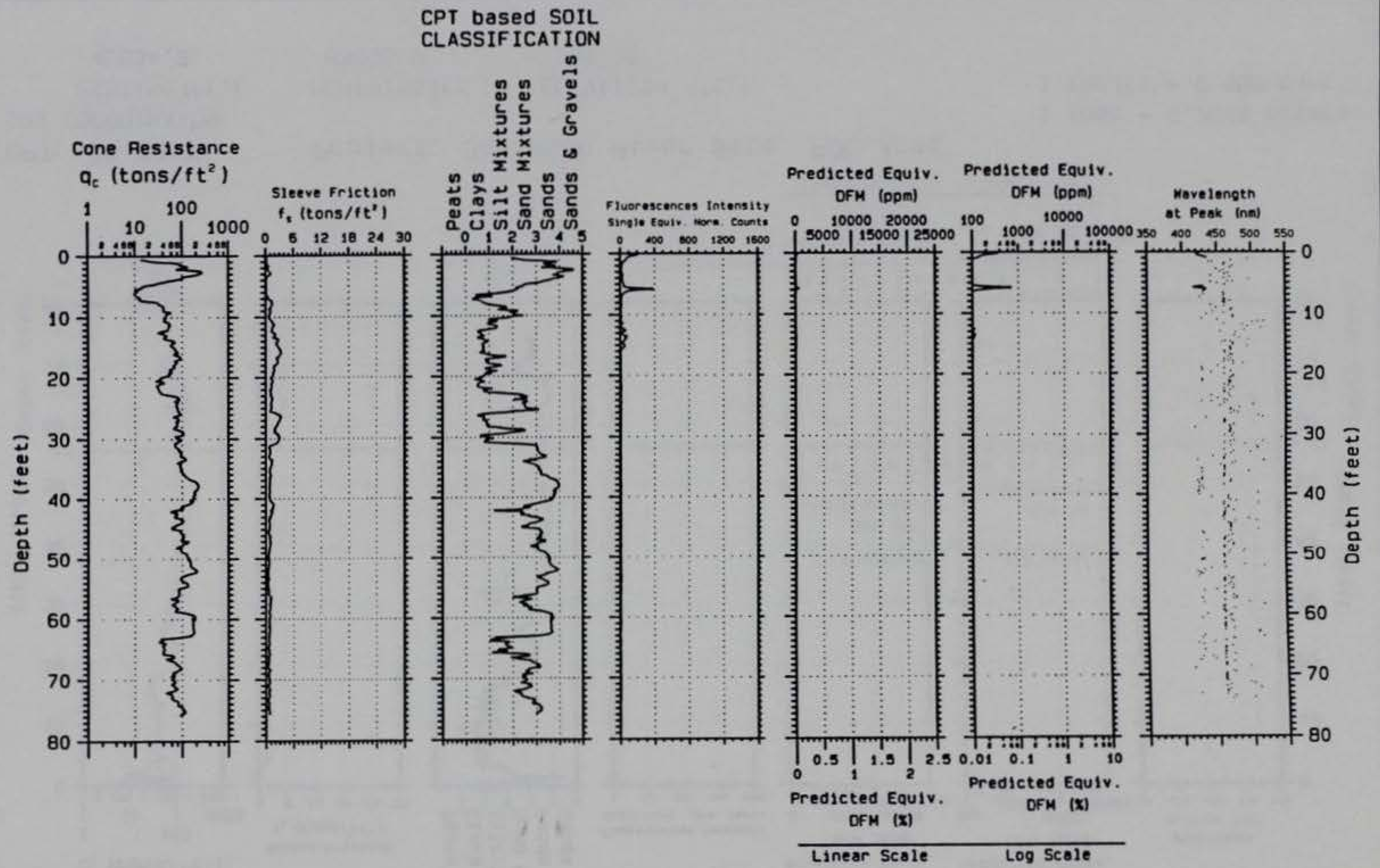


CPT: CF-20-P Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49834.2	63096.9	295.38

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars

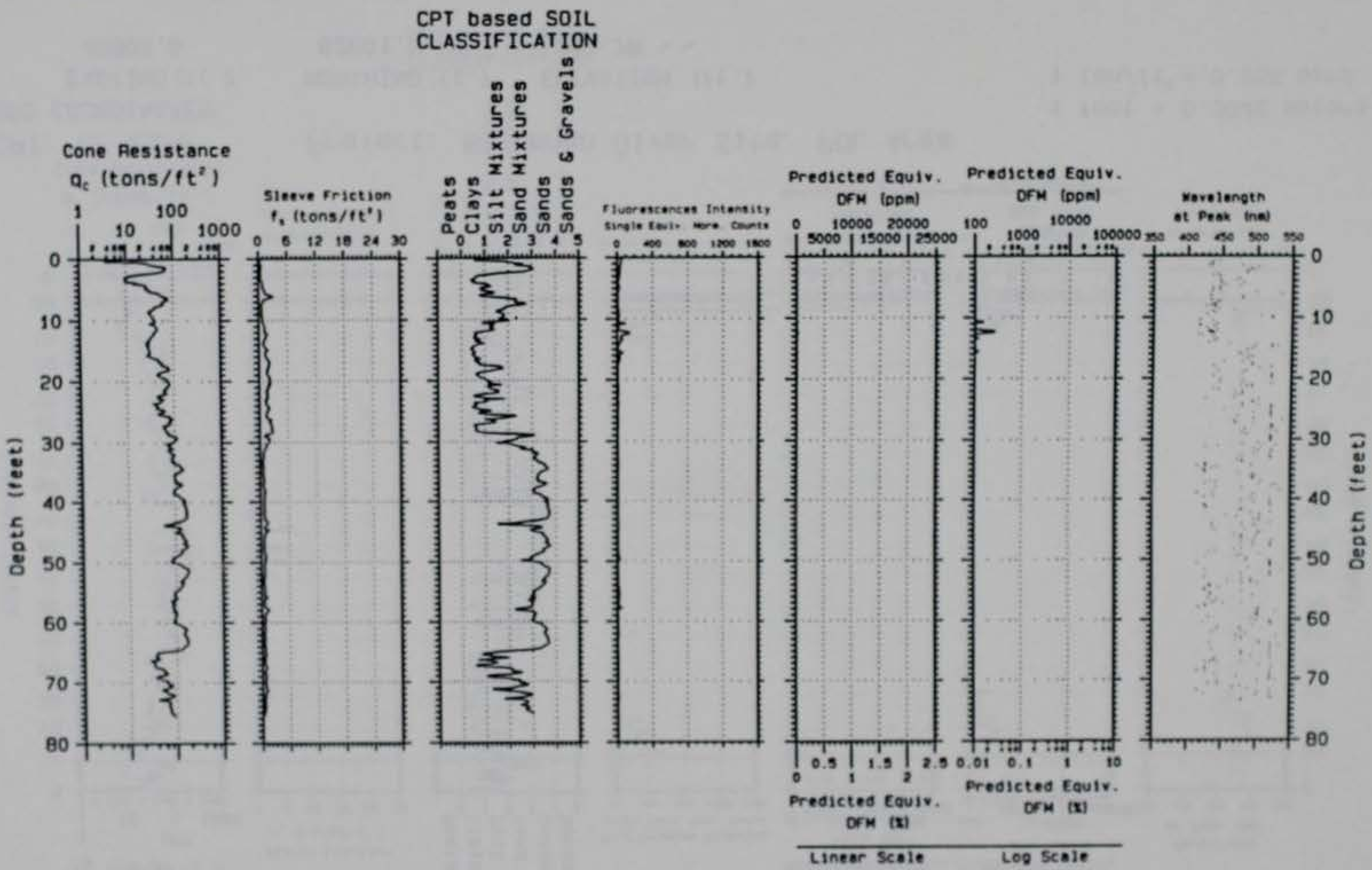


CPT: CF-21-P Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49818.9	62901.3	290.38

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars



CPT: CF-22-P

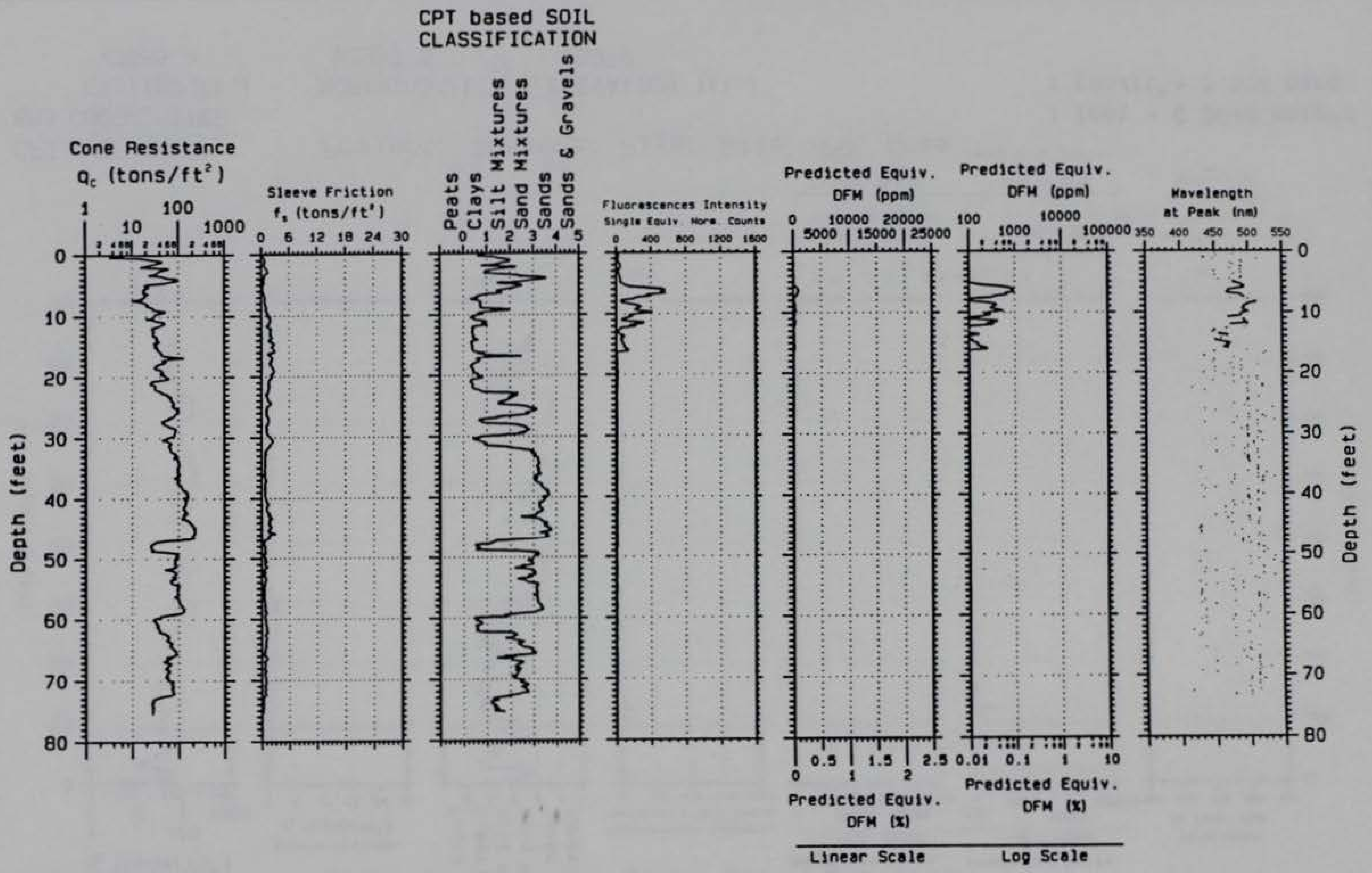
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49865.4	62993.5	293.9

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars



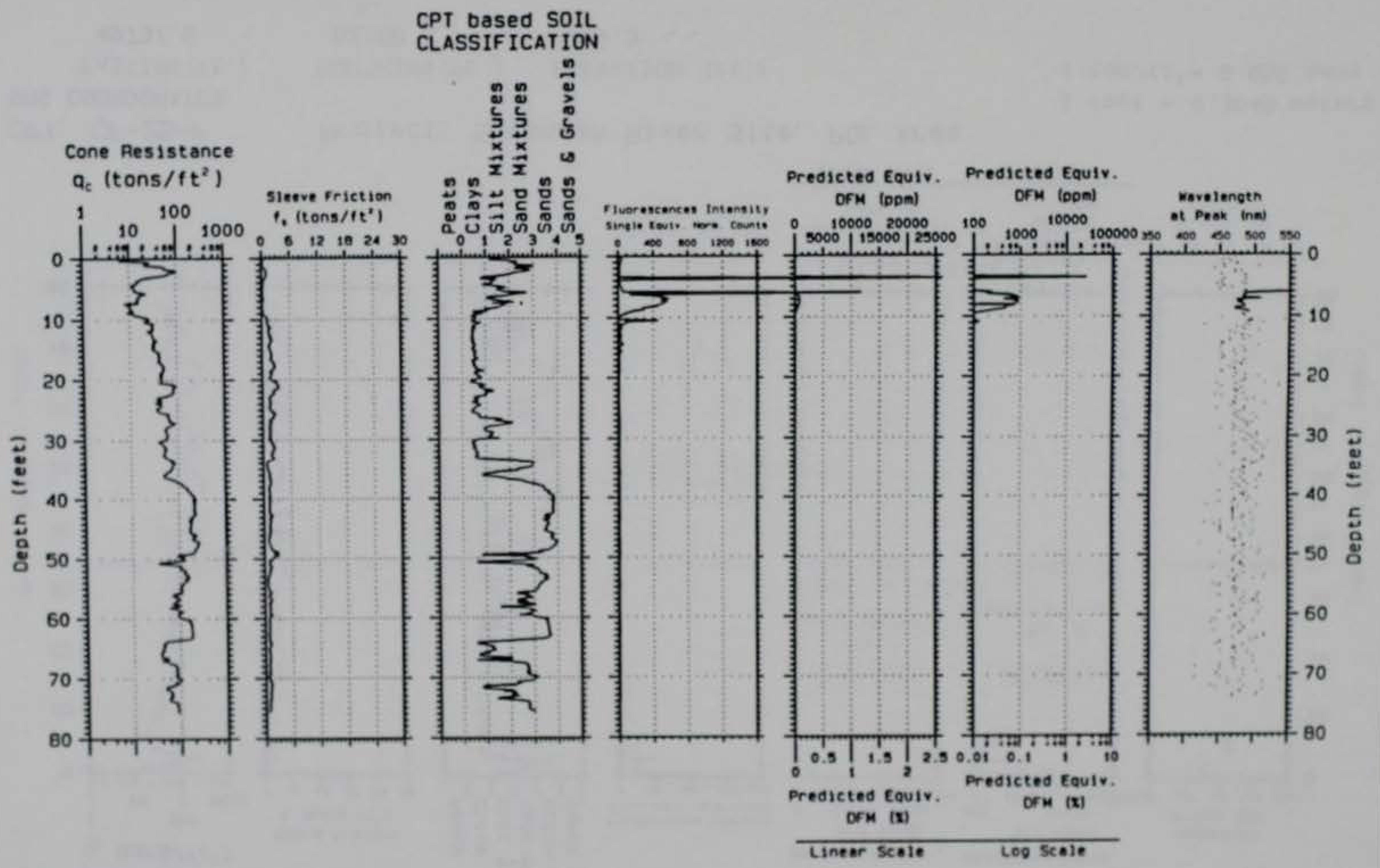
CPT: CF-23-P

Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49906.8	62801.8	288.78

1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars



CPT: CF-24-P

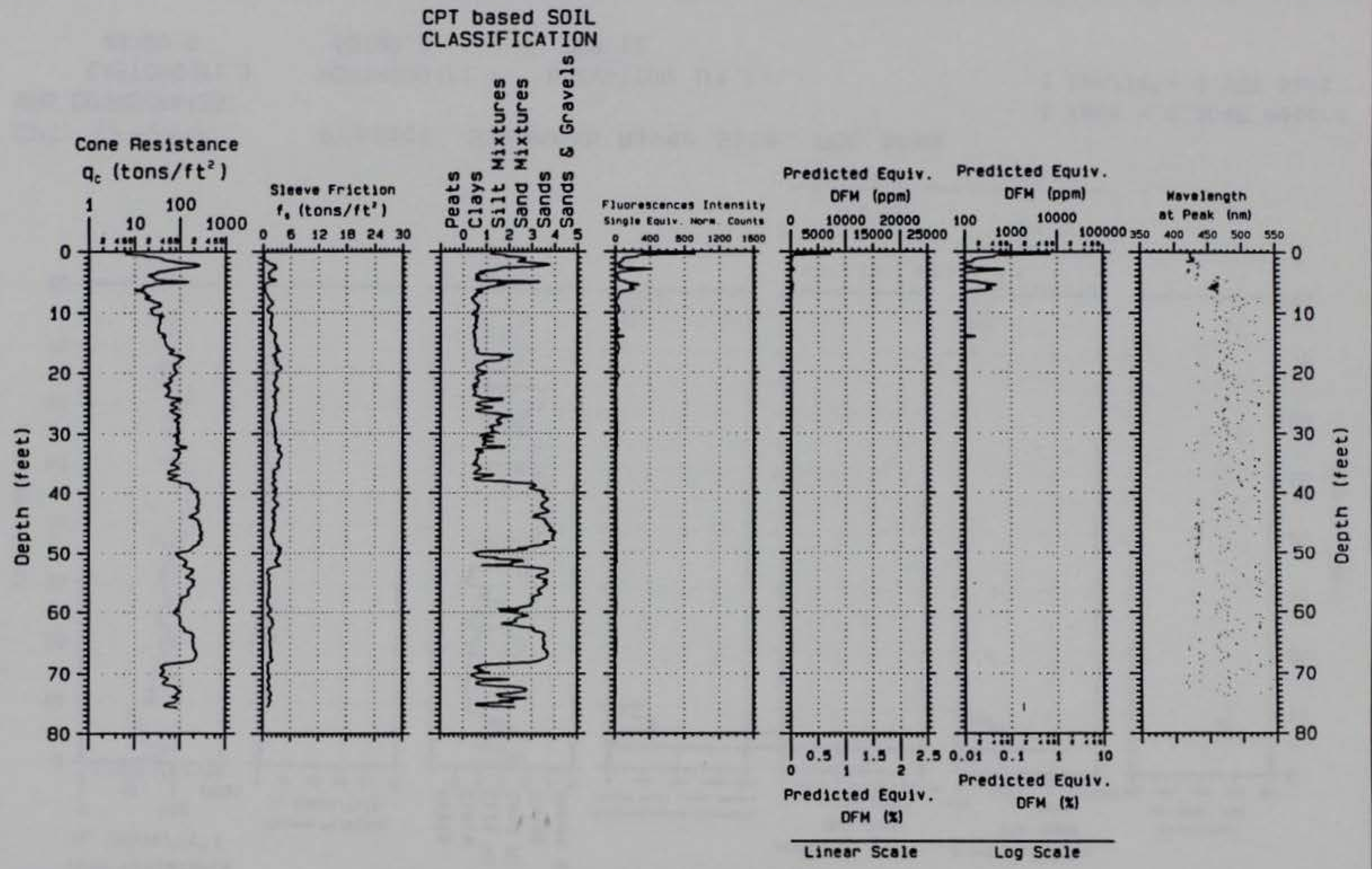
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49799.5	62799.3	288.12

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars



CPT: CF-25-P

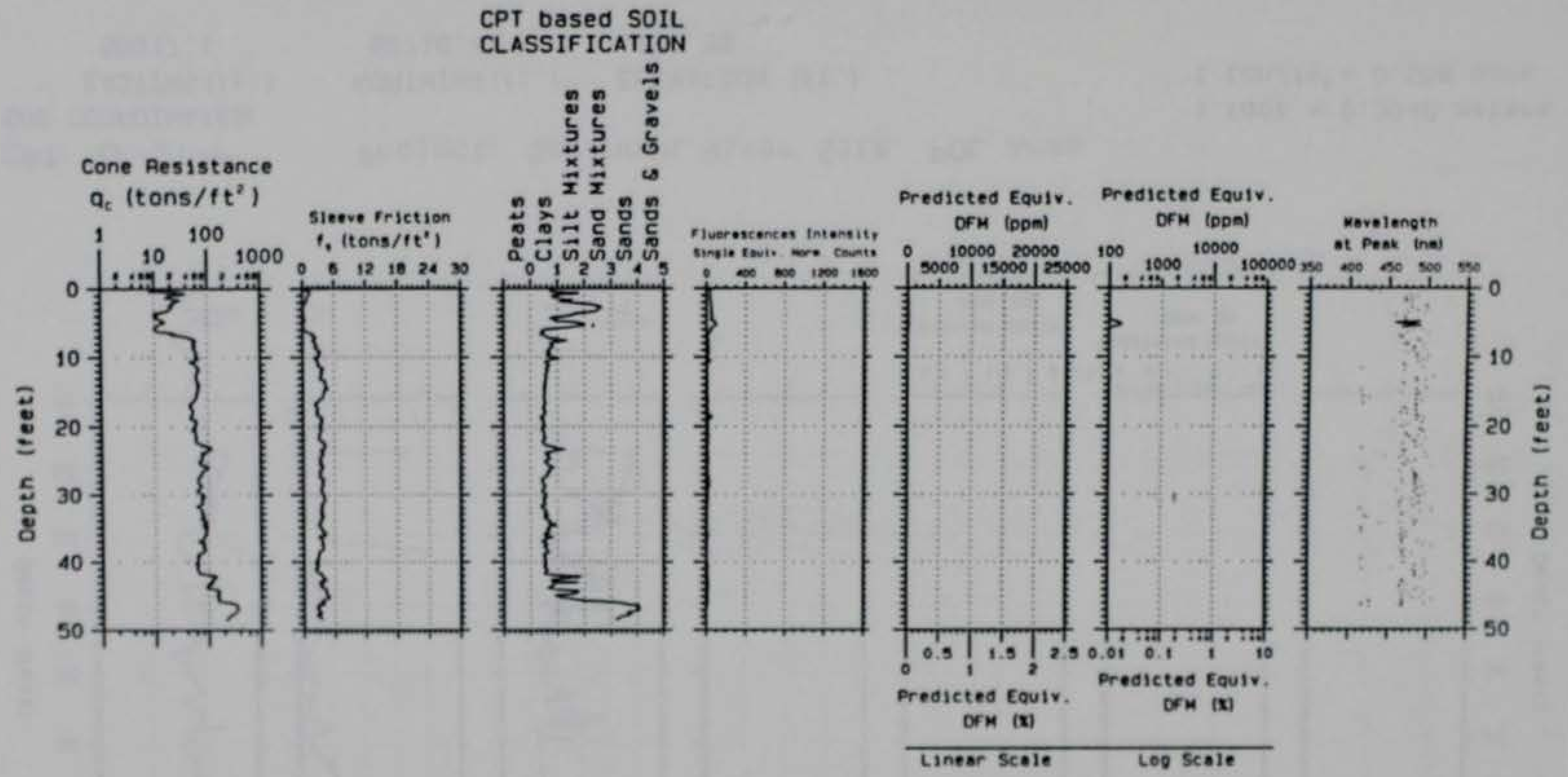
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49737.6	62799	287.3

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-26-P

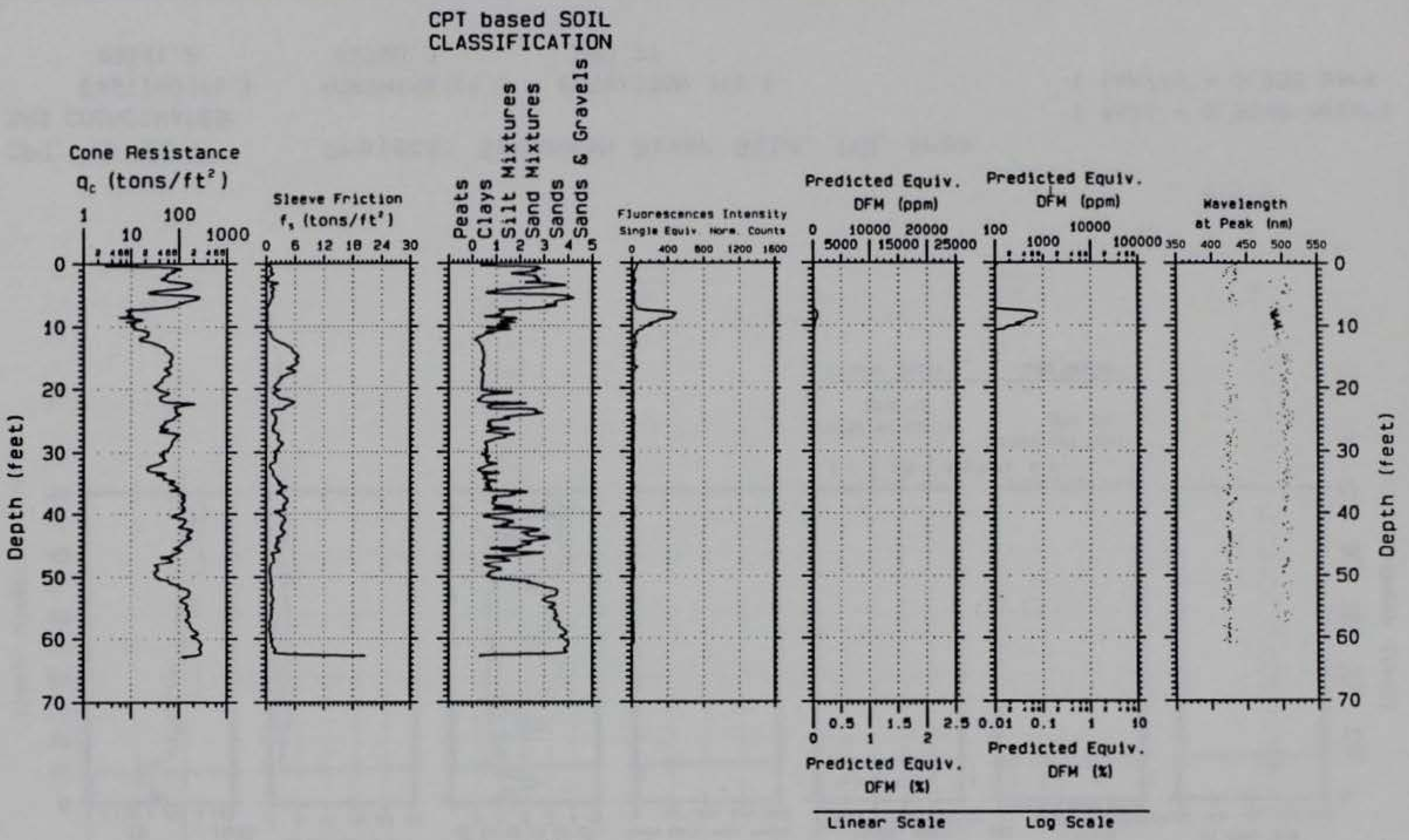
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49641.2	62798.3	285.27

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-27-P

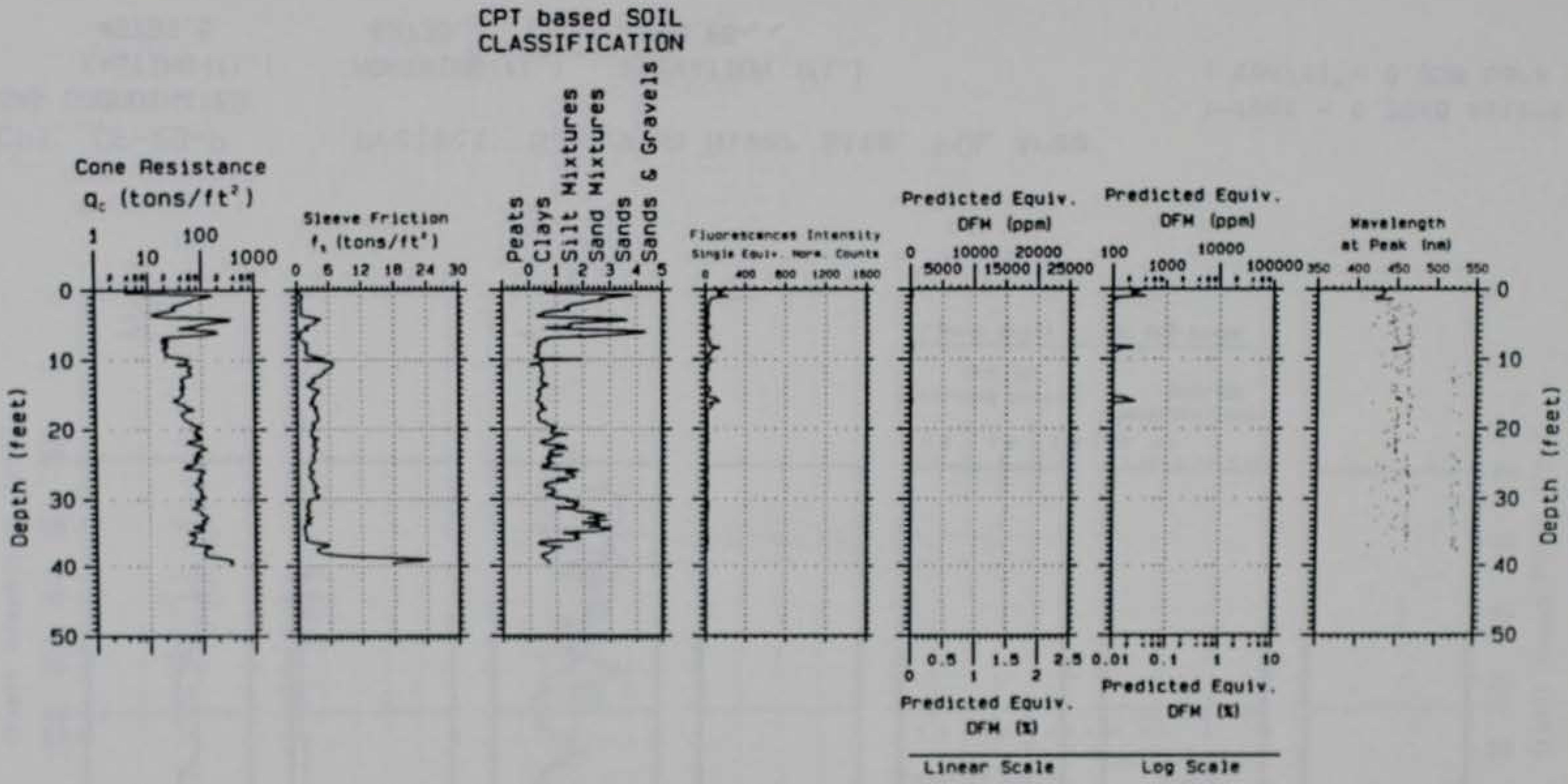
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
50017.1	62716.42	292.39

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-28-P

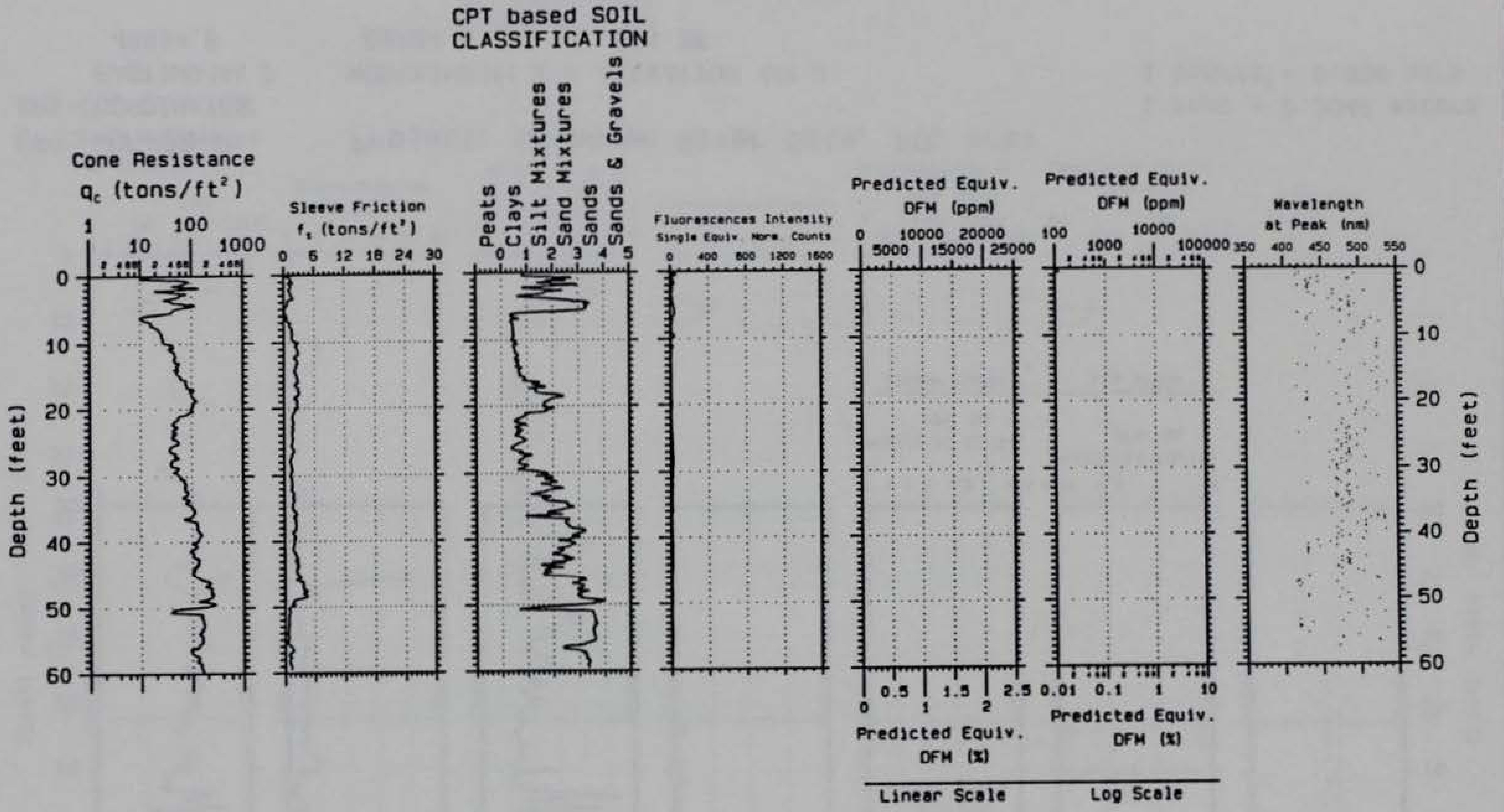
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49914.6	62724.4	291.38

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



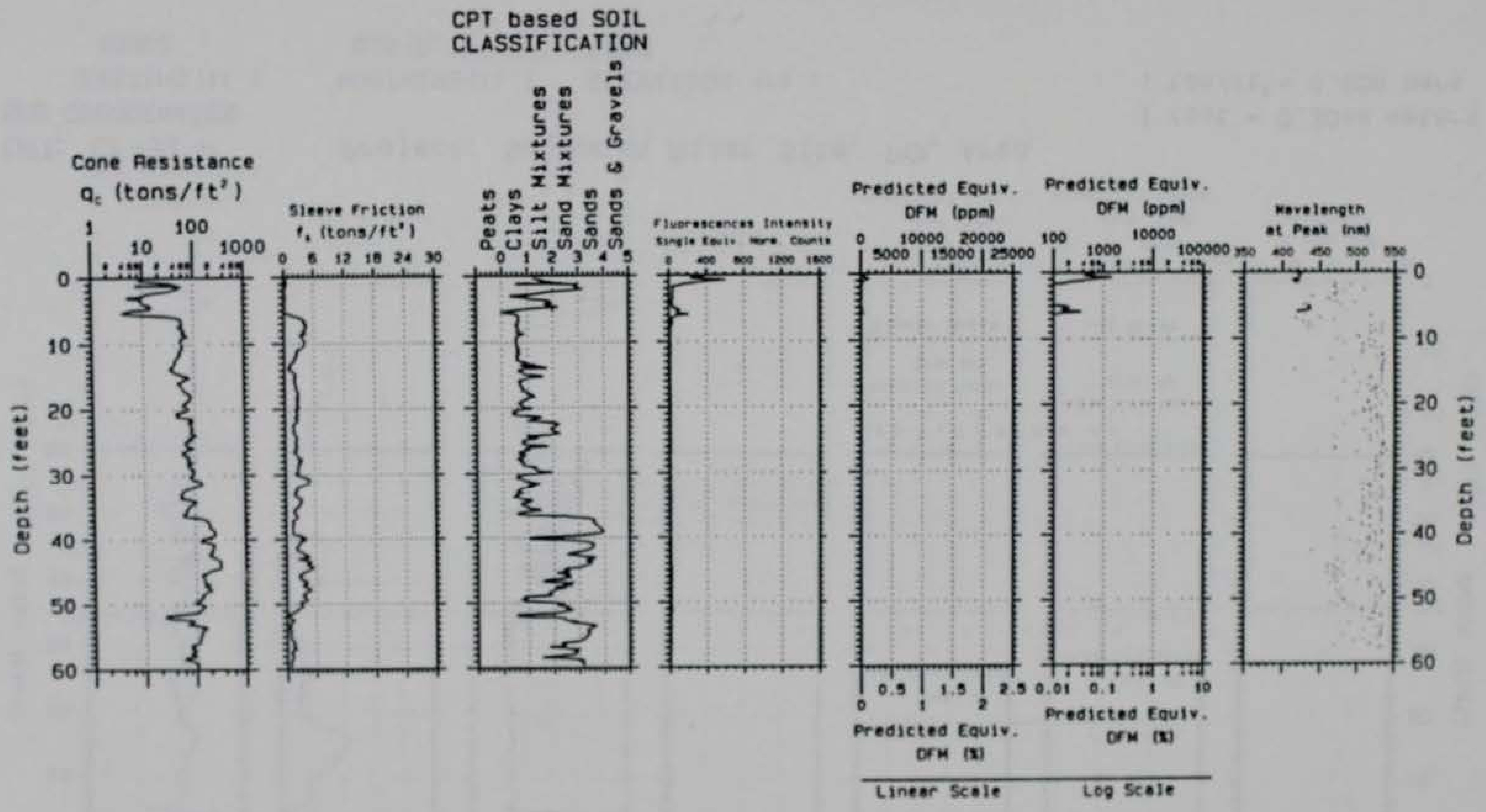
CPT: CF-29-P

Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49793.5	62730.7	288.66

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars



CPT: CF-30-P

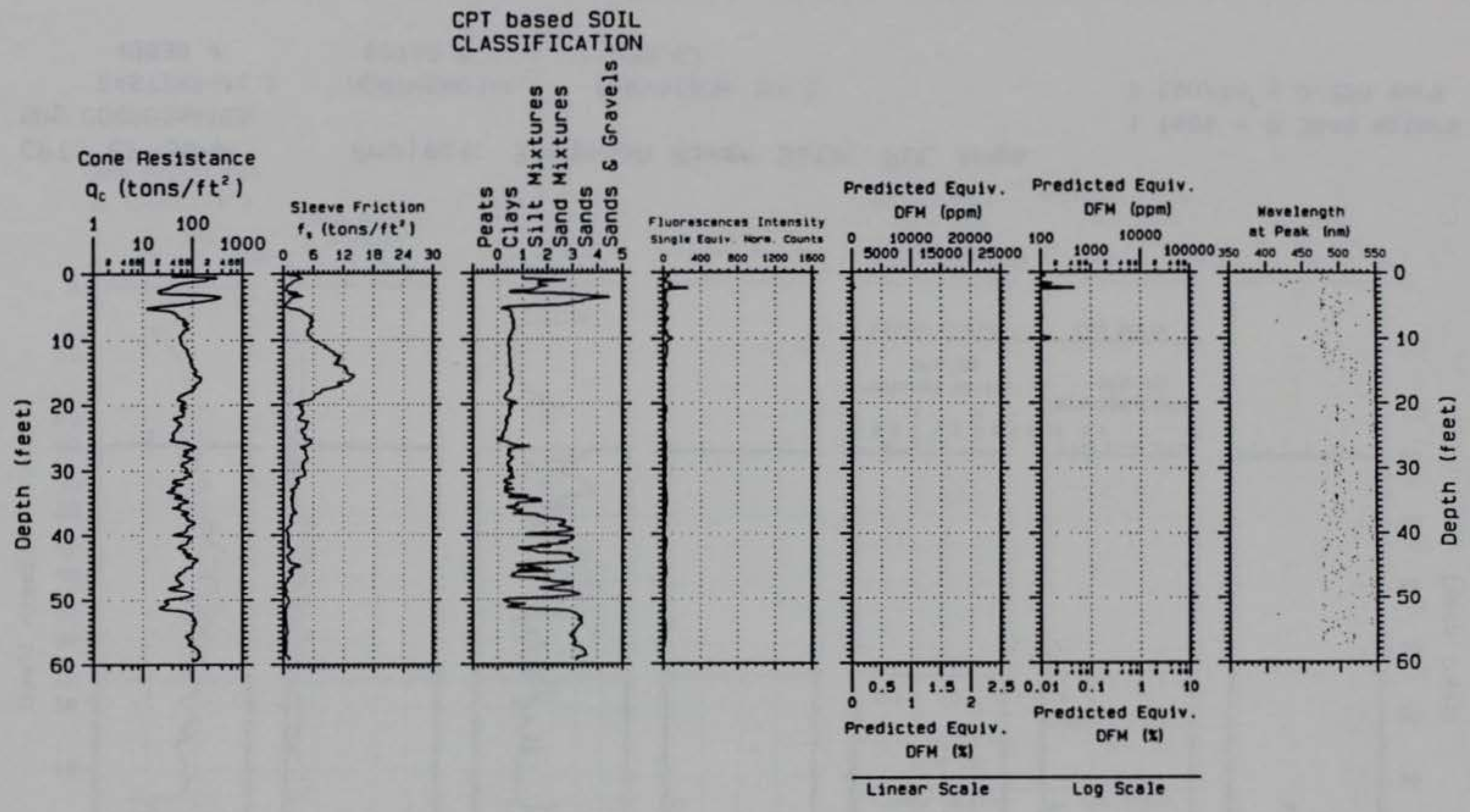
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49639.4	62718.4	285.53

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars

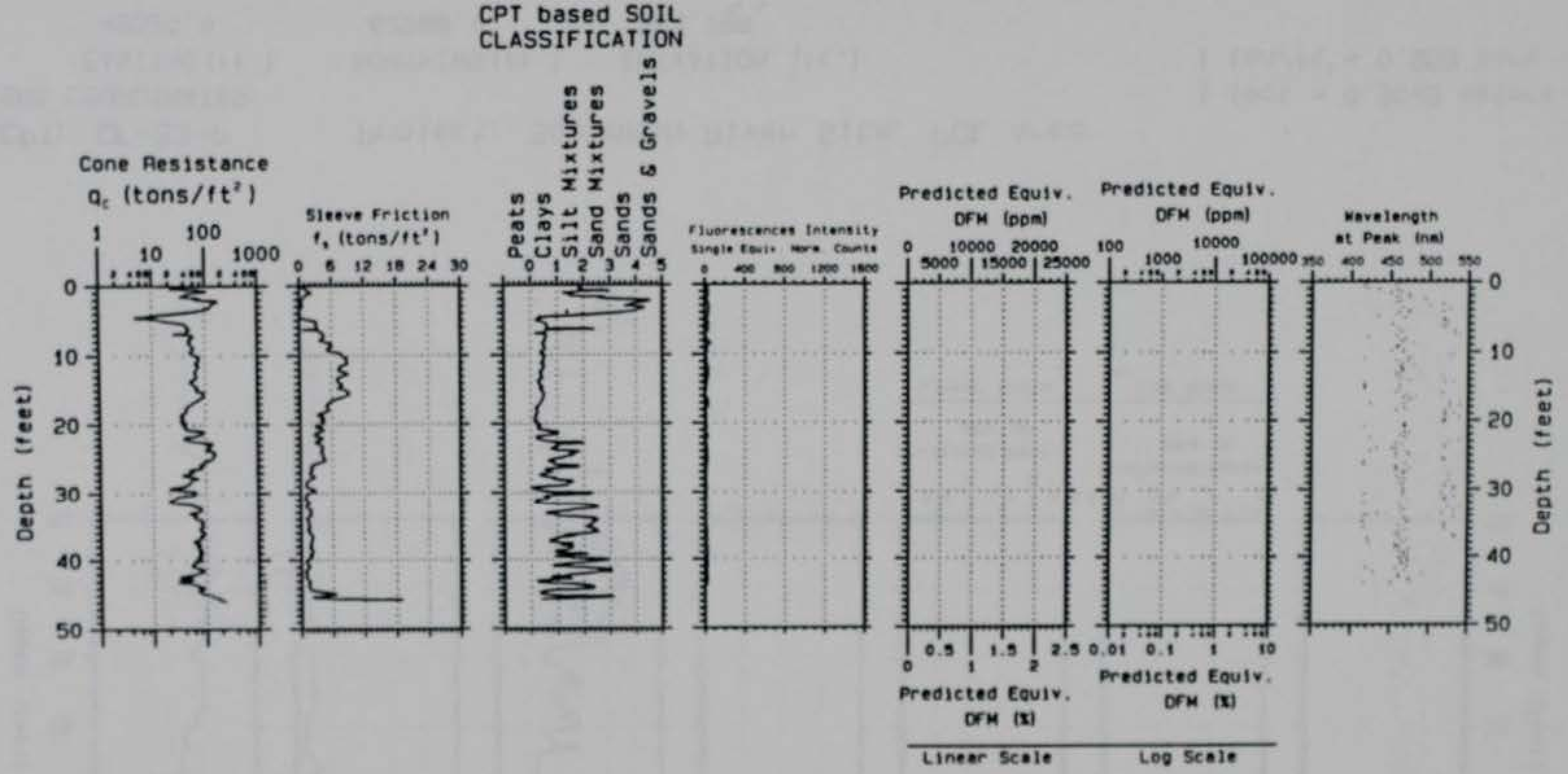


CPT: CF-31-P Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49962	62670.13	292

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars



CPT: CF-32-P

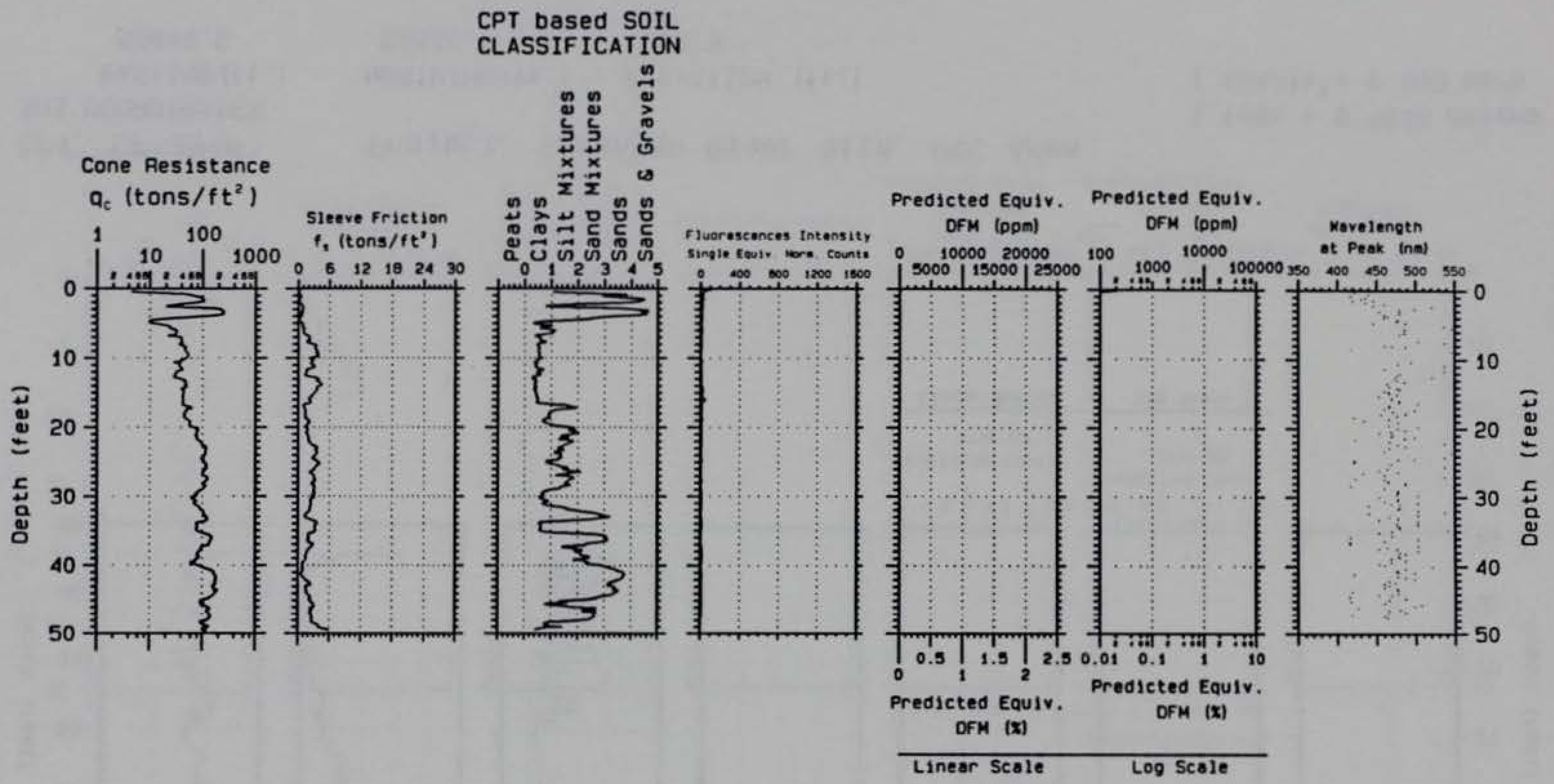
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
50049.9	62640.7	292.5

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars



CPT: CF-33-P

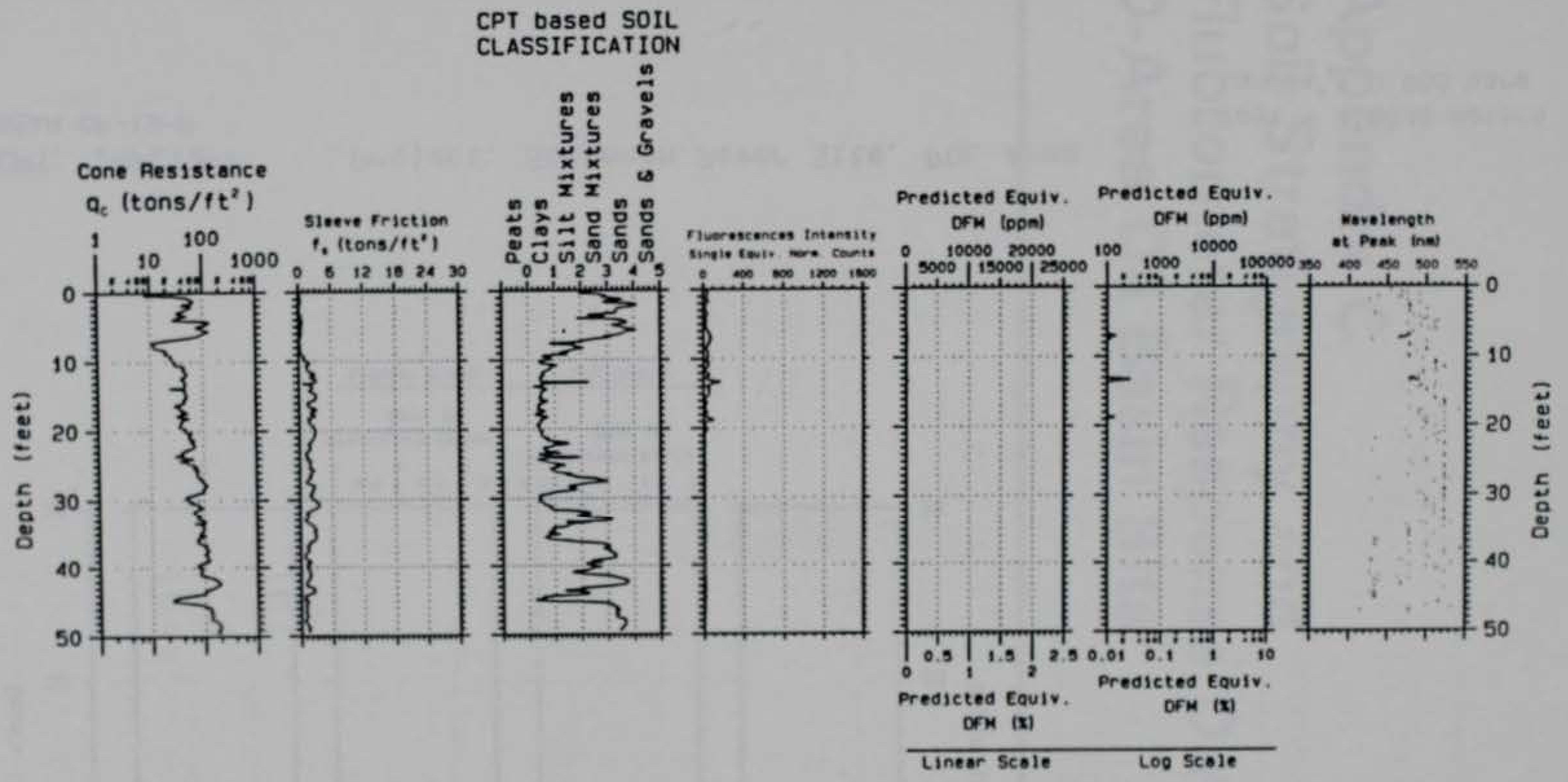
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49520.9	62788.4	284.798

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars



CPT: CF-34-P

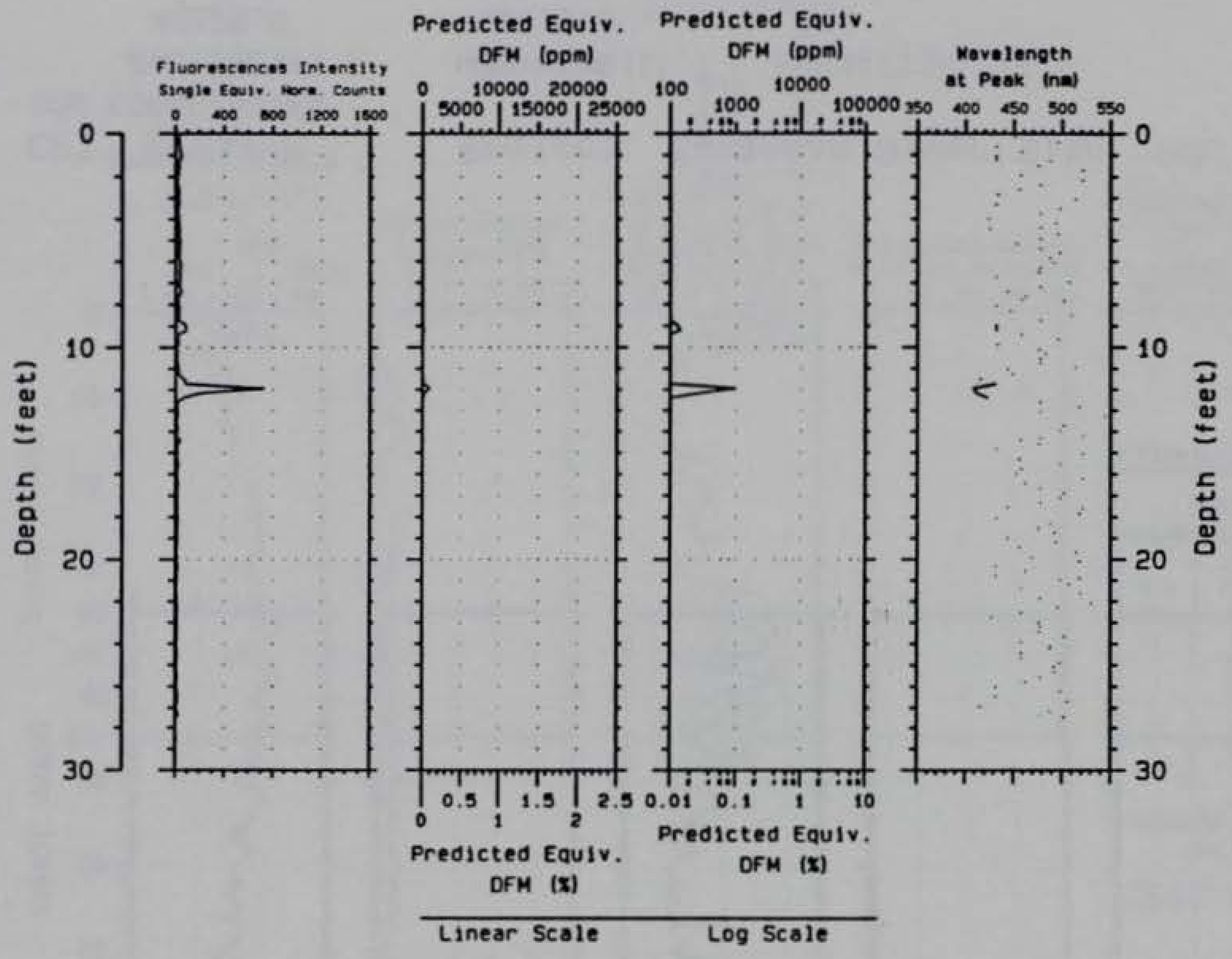
Project: Savannah River Site, POL Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
49525.9	63012.3	284

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars

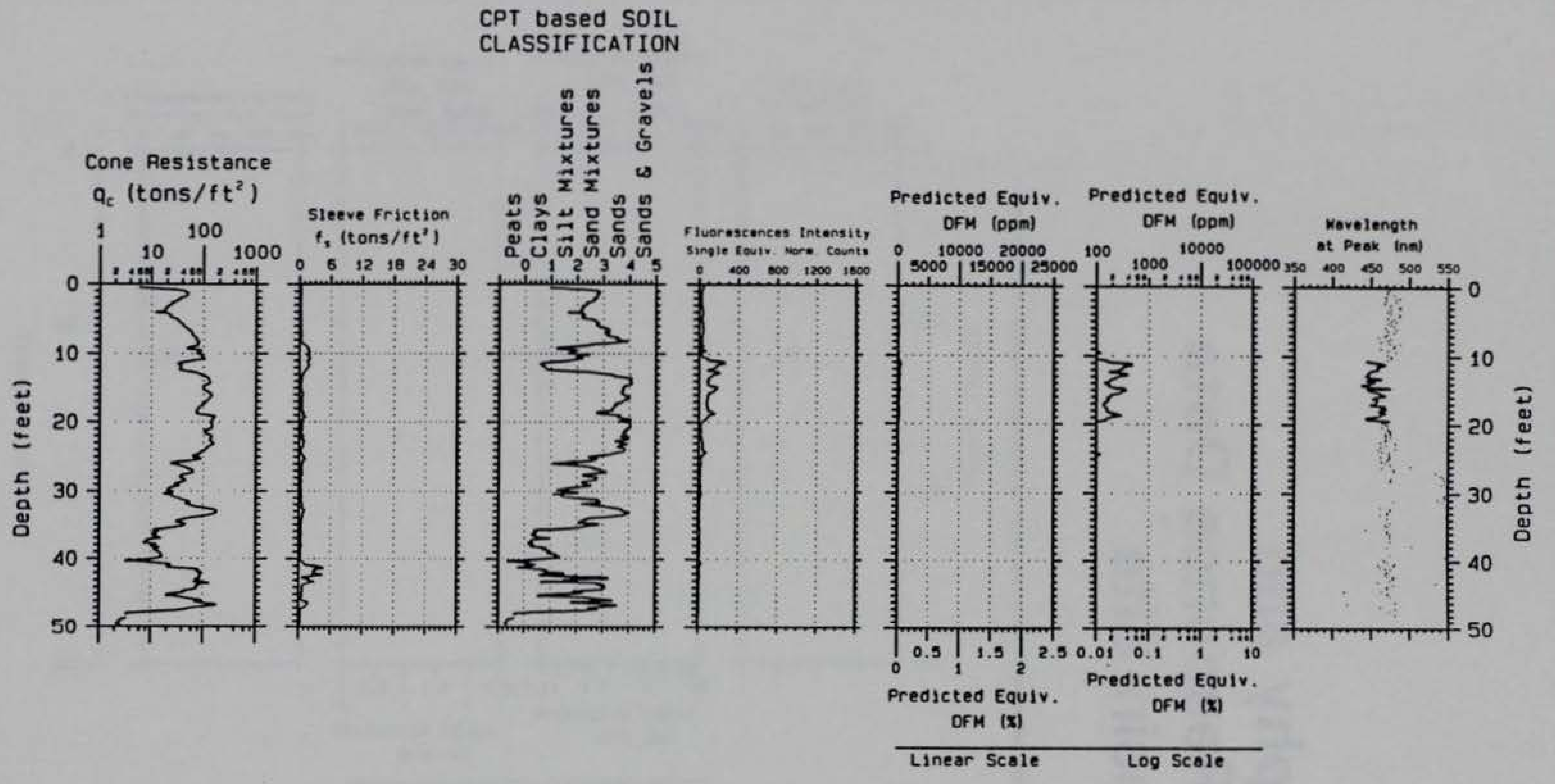


CPT: IMPLT2-P
NEAR CF-19-P

Project: Savannah River Site, POL Area

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars

Appendix C
Soil Stratigraphy and Fluorometer Response Data D-Area Oil Basin Site



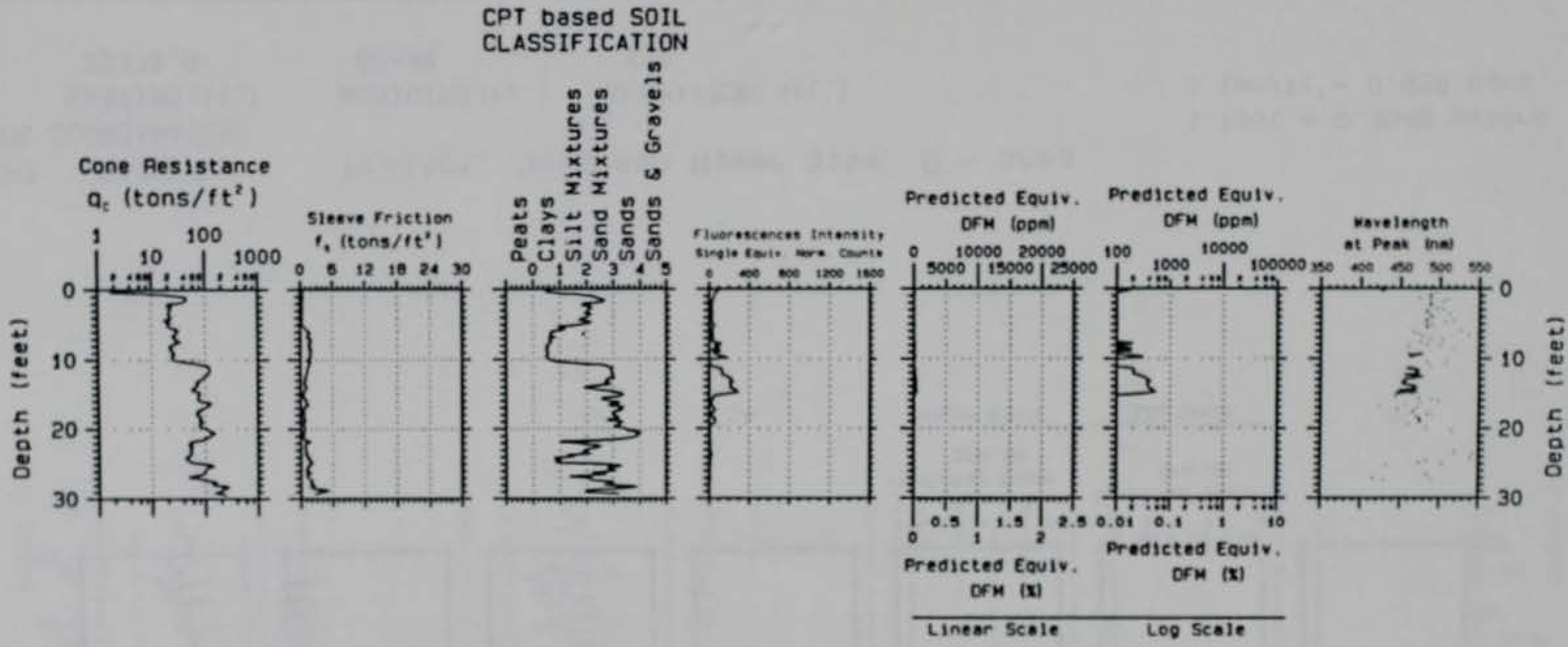
CPT: CF-01-DO

Project: Savannah River Site, D - Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
23636	68673	150

1 foot = 0.3048 meters
1 ton/ft^2 = 0.958 bars



CPT: CF-02-DO

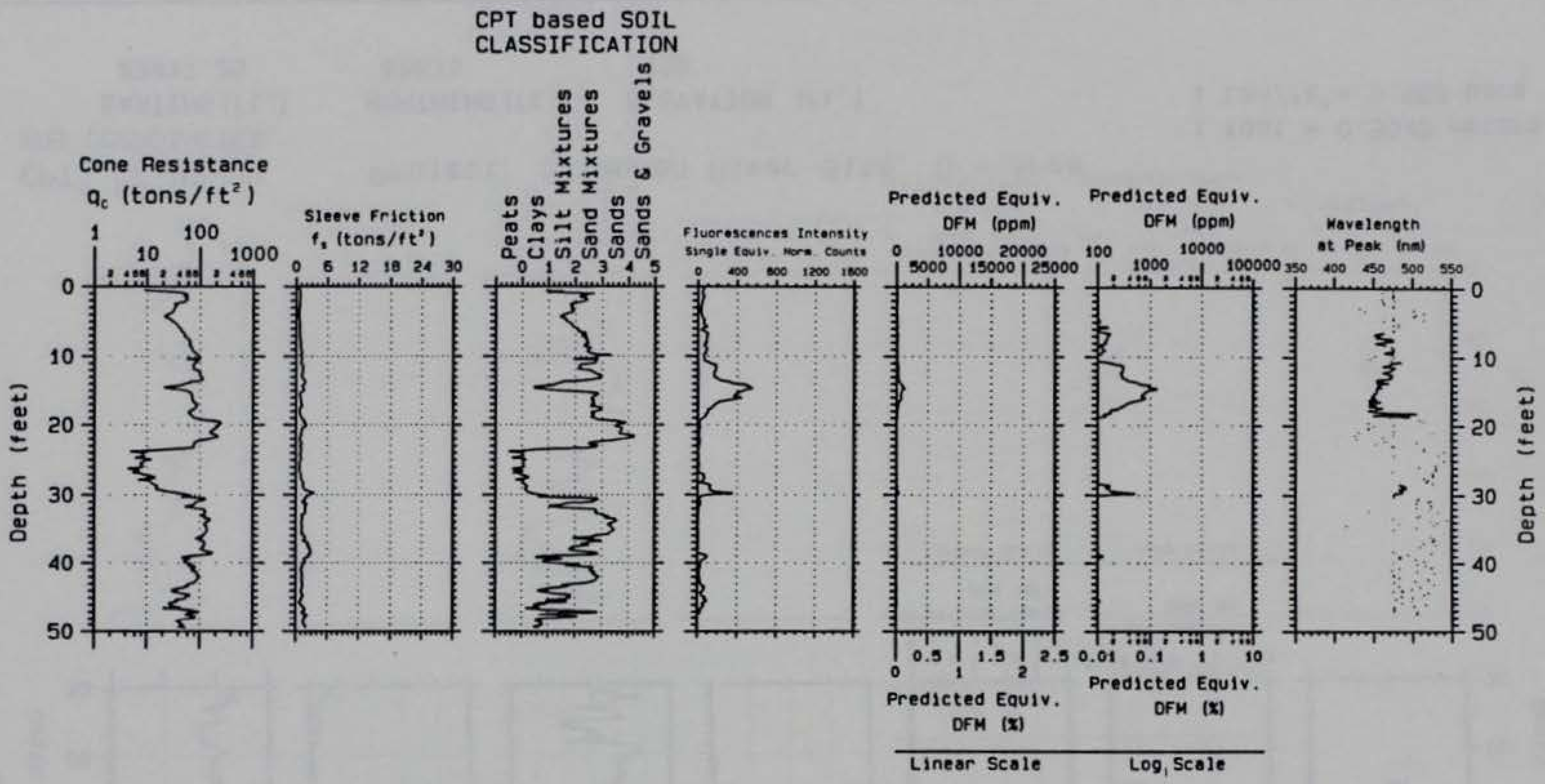
Project: Savannah River Site, D - Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
23417.25	68673	150

1 foot = 0.3048 meters

1 ton/ft² = 0.958 bars



CPT: CF-03-DO

Project: Savannah River Site, D - Area

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
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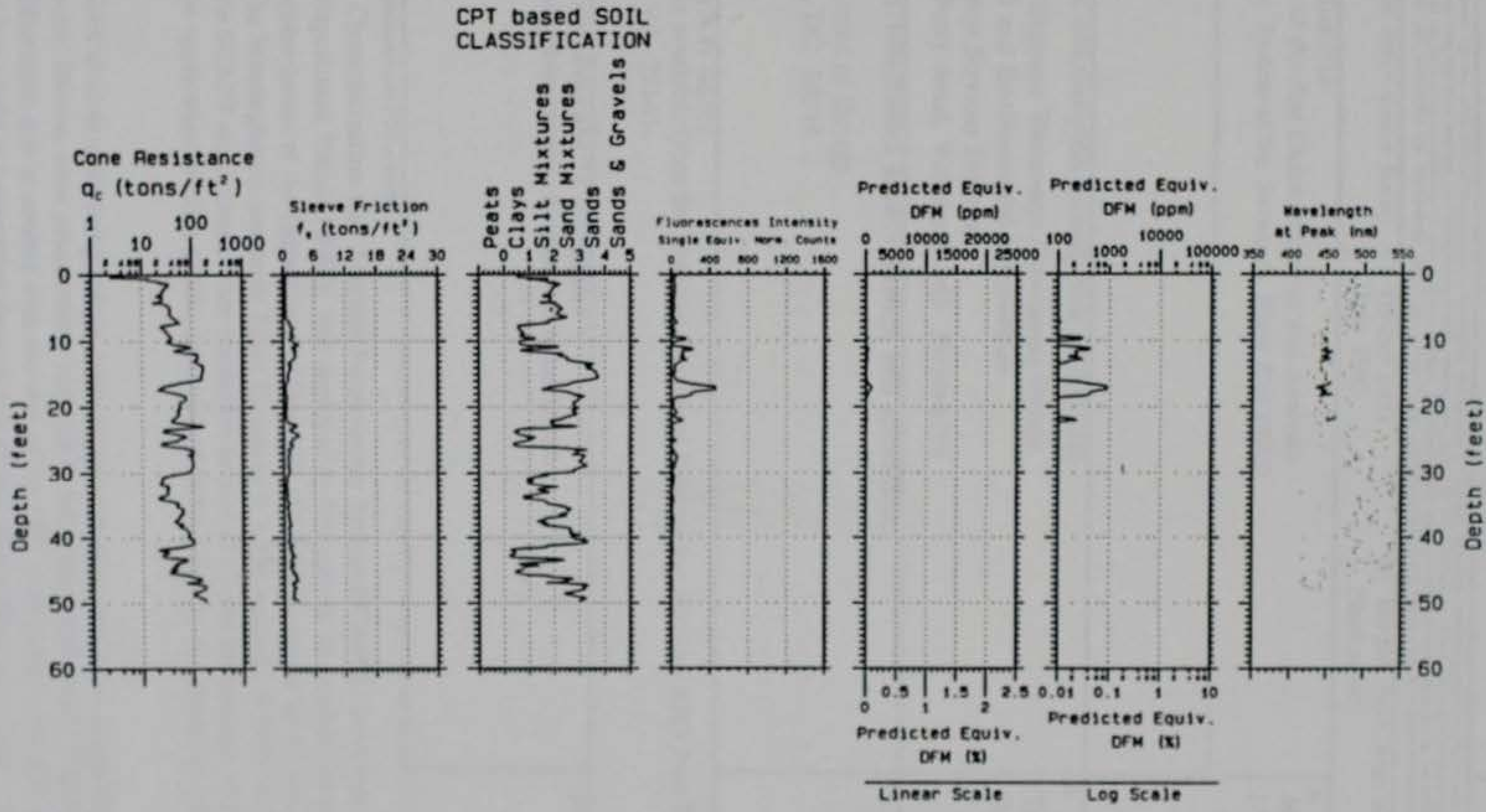
1 foot = 0.3048 meters
1 ton/ft² = 0.958 bars



CPT: CF-04-DO

Project: Savannah River Site, D - AREA

SRS COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
23563	68458	150

1 foot = 0.3048 meters

1 ton/ft^2 = 0.958 bars

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13. ABSTRACT *(Maximum 200 words)*

The Site Characterization and Analysis Penetrometer System (SCAPS), developed at the U.S. Army Engineer Waterways Experiment Station (WES), was deployed to demonstrate its capabilities to detect and delineate various subsurface contaminants at the Department of Energy's (DOE's) Savannah River Site (SRS) near Aiken, South Carolina. The Westinghouse Savannah River Company is under contract to DOE for management and operation of the SRS. The SCAPS experiments were conducted as part of a joint Department of Defense (DOD)/DOE research project on the application of cone penetrometer-based technology for the detection and delineation of contaminated soils.

Two SCAPS devices combining unique contaminant-screening processes (fluorometry and resistivity) with conventional electric friction cone penetrometer test (CPT) technology were used. The SCAPS fluorometer probe is designed to illuminate soil in contact with the side of the CPT with pulsed laser light as the CPT is pushed into the ground. The laser light is transmitted through one of two silicon fiber optic links downhole to pass through a small sapphire window in the side of the instrument. Fluorescent light energy induced by the laser in the soil is returned

(Continued)

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Fiber optics
Fluorescence
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through a second, passive fiber to spectrophotometry equipment at the surface. The SCAPS fluorometer probe detected and mapped hydrocarbon fuel contaminants in soil at two SRS facilities with concentrations as low as 200 ppm. Hydrocarbon contaminant concentrations measured at one site with the fluorometer probe were visualized in three dimensions using specialized computer graphics software.

The second CPT-based contaminant screening tool built into the SCAPS is a probe to measure soil electrical resistivity. Four equally-spaced electrode rings on the probe form a resistivity survey array that assesses electrical properties of a spherical volume of surrounding soil. The SCAPS resistivity probe detected high electrical resistivity in several experiments at depths where the presence of chlorinated solvents was known to have contaminated interbedded sands and clays.

The adaptability of the SCAPS to evolving contaminant detection technology was also demonstrated at SRS; several prototype contaminant detectors designed as permanent implants were pushed and tested using the SCAPS penetrometer equipment. These prototypes were removed once their functions were evaluated. The SCAPS provided complementary subsurface fluorometry and resistivity data and onsite ancillary support to outside investigators during the otherwise proprietary implant experiments.