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Vol II

DEMONSTRATION AND EVALUATION OF THE AIR FORCE SITE CHARACTERIZATION AND ANALYSIS PENETROMETER SYSTEM IN SUPPORT OF NATURAL ATTENUATION INITIATIVES

VOLUME II - DEMONSTRATION, TESTING, AND EVALUATION AT PLATTSBURG

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A second-generation tunable Laser-Induced Fluorescence-Cone Penetrometer Test (LIF-CPT) system has been developed and demonstrated at three different Air Force Bases as an alternative site characterization technology. This represents an innovative technology for delineating soil contamination resulting from fuel spills. Applied Research Associates, Inc. and Dakota Technologies, Inc. jointly conducted the system development and demonstration project. Demonstrations consisted of 2-week efforts at each of Air Force Bases: Plattsburgh Patrick/Cape Canaveral, and Dover. The data collected during these demonstration supported both evaluation of the LIF-CPT systems along with support for selecting a site for a natural attenuation experiment the Air Force is [planning. Data analysis indicates that the second generation system is operationally improved over the first-generation system and has improved detection capabilities. The improved detection capability is related to a new optical module used to focus laser light and filter the return signal to reduce the signal-to-noise ratio. Although the system is improved in many ways, some questions still exist concerning the influence soil type has had on some of the system responses. Further analysis is required to resolve these discrepancies.

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PREFACE

This report was prepared by Applied Research Associates, Inc. (ARA), 120-A Waterman Road, South Royalton, VT 05068 under U. S. Air Force Contract No. F08635-93-C-0020, SSG Subtask 8.01.1 for the Armstrong Laboratory Environics Directorate, AL/EQW-OL, 139 Barnes Dr. Suite 2, Building 1120, Tyndall AFB, FL 32403-5323.

This final report discusses the continued development of the combined technology of the cone penetrometer (CPT) and laser-induced fluorescence (LIF) as it pertains to the detection and quantification of petroleum oils and lubricants (POL's) within subsurface soils environments. Specifically the report covers a review of LIF-CPT technology; LIF-CPT system specifications; evaluation of the LIF-CPT probe under field conditions; and LIF data analysis/evaluation. The data and results of the field investigations were subsequently used to determine if bioventing or natural attenuation approaches are viable remedial alternatives at three U.S. Air Force Bases.

The work was performed between October 1993 and December 1994. The AL/EQW project officer was Mr. Bruce Nielsen.

EXECUTIVE SUMMARY

A. OBJECTIVE

Applied Research Inc. (ARA) and Dakota Technology, Inc. (DTI) were retained by the Armstrong Environics Directorate AL/EQ-QL to further develop laser-induced fluorescence-cone penetrometer technique (LIF-CPT) for use during environmental site investigations. The primary objective of the program was to develop and evaluate an improved LIF-CPT system for the characterization of fuel-contaminated sites. The evaluation was based on the results from demonstrations, testing and evaluation at three Air Force bases. A parallel goal of the demonstrations was to gather data for Engineering-Science, Inc. (E-S) to determine if bioventing or natural attenuation are viable alternatives for remediating numerous Air Force sites.

B. BACKGROUND

The Department of Defense (DoD) is seeking efficient and cost effective means to assess, remediate, and monitor petroleum-contaminated and hazardous waste sites at both active and decommissioned installations. The Air Force's Installation Restoration Program Information Management System (IRPIMS) database lists approximately 1,400 fuel-contaminated sites and 300 inactive firefighter training facilities; presently the IRPIMS database contains data from only one-half of the installations. Current environmental site investigations based on drilling technology are slow, expensive and potentially dangerous. Cone penetrometer (CPT) based investigations, on the other hand, allow real-time data collection and don't produce soil cuttings thus eliminating disposal costs and health and safety risks due to exposure.

Cone penetrometer testing gathers accurate in situ geotechnical information in a rapid and cost-effective manner. With adaptation of in situ geophysical and chemical sensors to the cone penetrometer probe, subsurface hydrogeology and the extent of contamination can be mapped simultaneously. The speed and continuous nature of the information generated by LIF-CPT reduces the need for costly and invasive subsurface sampling and installation of long term monitoring wells.

C. SCOPE

To fulfill the objectives of this project, the following tasks were completed; (1) Development, fabrication and integration of a field-deployable, wavelength-tunable LIF system, (2) Laboratory testing and evaluation of the LIF system, (3) Demonstration, testing and evaluation programs at Plattsburgh, Patrick/Cape Canaveral, and Dover Air Force Bases (AFB's), and (5) Delivery of a completed LIF system to the U. S. Army Corp. of Engineers.

Extensive evaluation and calibration of the LIF-CPT remained outside of the scope of this project. Such a study could not be completed during this project due to the dual objectives of developing the LIF-CPT, and employing the tool and other CPT capabilities on a production basis for the engineering-cost evaluation conducted by E-S.

D. METHODOLOGY

The United State Army Corp of Engineers Waterways Experimental Station (USAE WES) initially developed the LIF-CPT using a mercury lamp as an excitation source downhole within the cone. The resulting fluorescence was collected and directed to a detection system located in the cone penetrometer truck via a single optical fiber. WES soon eliminated the mercury lamp in favor of a pulsed laser source external to the cone; a nitrogen laser system, limited to the emission of a single excitation wavelength of 337 nanometer (nm) was employed. This was useful for the detection of large multi-ring fuels such as Diesel Fuel Marine (DFM) but proved ineffective for "lighter" fuels such as jet fuels and gasoline which require excitation at shorter wavelength. Further research sponsored by the Air Force concluded that a tunable wavelength, pulsed laser (Nd:YAG) with a fiber optic probe and detection system would satisfy the needs of the Air Force. During the scope of the current program Applied Research Associates, Inc., in cooperation with Dakota Technology, Inc. (DTI), refined the Nd:YAG pulsed LIF-CPT system and demonstrated its utility in the field.

E. TEST DESCRIPTION

The test program consisted of two phases; (1) redesign and build a new laser system based on the findings of a previous LIF-CPT development program, and (2) evaluation of the LIF-CPT system under field conditions at three Air Force Bases. The redesign of the LIF-CPT system consisted of two major efforts: (1) optimizing the overall laser system performance by upgrading individual components with state-of-art components and repackaging the system improving portability and durability, (2) redesign the LIF-CPT probe to maximize the performance and durability and minimize cost. During the field demonstration and evaluation program several objectives were addressed. The primary technical focus was to evaluate the LIF-CPT system in the field for reliability, stability and repeatability, correlation of LIF-CPT intensity to contaminate concentration and evaluation of the sources of data scatter in the chemical and LIF-CPT data.

F. RESULTS

During the three demonstrations the laser system performed quite well. Many of the system improvements greatly enhanced both field utility and system stability. Minor improvements are still needed to enhance power stability, although the recording of the current power levels is highly beneficial.

Evaluation of the LIF response shows that there are effects related to both the soil type and moisture content of the materials being tested. The effect of soil type is fairly significant, since at some locations no LIF response was recorded in visibly contaminated clay samples. The effect of moisture content is minimal. Further investigation into these responses would be highly beneficial. Finally, the limited data sets available permitted only speculation about possible correlations between LIF response and to be performed. The results form the statistical analysis are encouraging and additional testing performed.

G. CONCLUSIONS

In general the LIF and chemical analytical data agree well qualitatively. Evaluation of the limited chemical and LIF data indicates that their may be a correlation between total BTEX and Xylene concentrations and LIF response. The background limit of the LIF response was determined to be independent of the soil type but may have a weak dependency on moisture content. The background limit of the current LIF-CPT probe configuration is approximately 50 counts. There are still some unanswered questions regarding the response of the LIF system in different soils. Areas known to be highly contaminated showed little or no response in fine grained soils (e.g., silts and clays). Insufficient chemical data was available to fully validate the LIF system.

H. RECOMMENDATIONS

Additional data collection and evaluation is required to fully validate the LIF-CPT system. For future testing, it is strongly recommended that on-site analytical screening for Total Petroleum Hydrocarbons (TPH) by EPA method 418.1 be conducted on soil samples. This data can subsequently be used to correlate TPH concentration to LIF response. Combining objectives that include production-oriented data collection for other research is not recommended.

I. APPLICATION

The LIF-CPT system can be implemented by the Air Force as the primary technology to conduct environmental site assessments where petroleum, oils and lubricants are the contaminants of interest. It could be used both as an initial screening tool and/or as a tool to monitor the effectiveness of a particular remedial effort.

J. BENEFITS

Significant reductions in the time and cost of conducting environmental site assessments could be realized by implementing the LIF-CPT technology. This system provides superior data in real-time to use as a basis for selecting an appropriate remedial strategy.

K. TRANSFERABILITY OF TECHNOLOGY

Virtually all industrial contractors involved with subsurface environmental site assessments where petroleum oils and lubricants are concerned could profit from the use of LIF-CPT technology. The industry in general is constantly seeking ways to conduct business faster, cheaper, and better; CPT-LIF fulfills these criteria.

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SECTION I
INTRODUCTION

A. OBJECTIVE

The Armstrong Laboratory Environics Directorate (AL/EQ-OL) retained Applied Research Associates, Inc. (ARA) to demonstrate, test, and evaluate (DT&E) the application of the Air Force Site Characterization and Analysis Penetrometer System (AFSCAPS) to support bioventing and natural attenuation initiatives. The ultimate objective of these demonstrations is to provide rapid transition of commercially available or emerging cone penetrometer technology that has been developed by the Tri-Service SCAPS program to Air Force service agents. These demonstrated systems have primary application for standard geophysical, and petroleum, oil, and lubricants (POL) contamination characterization. Efforts of these DT&Es will determine if bioventing or natural attenuation approaches are viable remedial alternatives at numerous AFB fuel-contaminated sites.

This report documents the first DT&E conducted at Plattsburgh AFB, located in northeastern New York State. The purpose of this project was to define the oily phase petroleum hydrocarbon plume at a fire training facility. The cone penetrometer utilized optical fiber cables and a cone equipped with a sapphire window similar to that developed by the Tri-Service SCAPS program at Waterways Experiment Station (WES). The laser spectrometer system developed by the Air Force at North Dakota State University (NDSU) was the optical system used for launching laser light into the optical fiber and providing spectroscopic analysis of fluorescent light transmitted back to the surface.

B. BACKGROUND

1. Fire Training Area (FT-002) Site Description

Plattsburgh AFB is located in northeastern New York state and is bordered on the north by the City of Plattsburgh, on the south and west by the Town of Plattsburgh, and on the east by Lake Champlain. The area of concern for this investigation is Site FT-002 (see Figure 1). It is located approximately equidistant (500 feet) between the Plattsburgh AFB runway to the east and the base boundary to the west. The FT-002 site is bordered to the north by the Domestic Waste Landfill LF-022 and to the south by Domestic Waste/Spent Munitions Landfill LF-023.

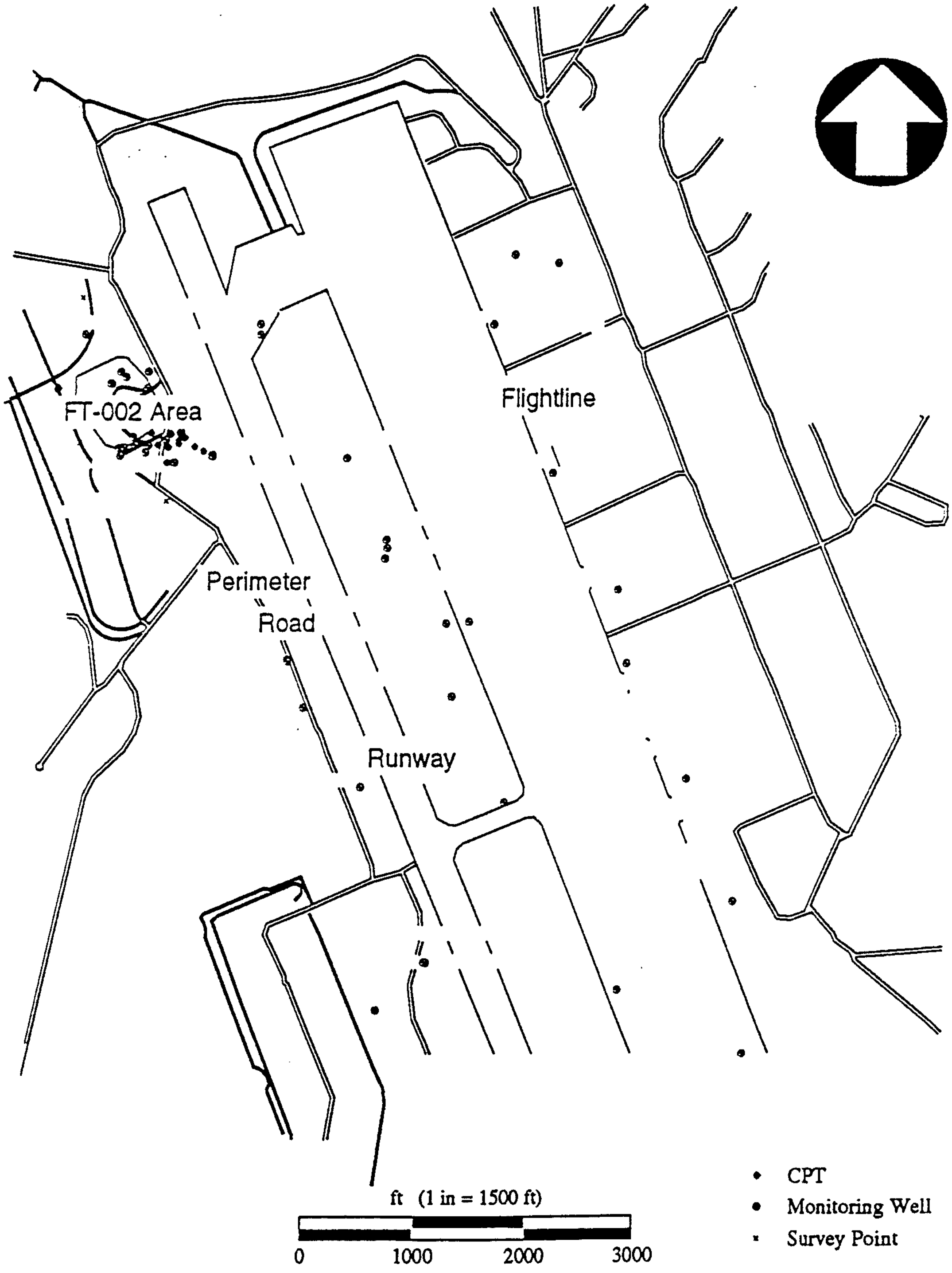


Figure 1. Plattsburgh AFB Base Map Showing Fire Training Area FT-002.

The FT-002 site was used to train base firefighting personnel from the mid-1950s until May 1989. During these exercises fires were ignited in four unlined fire training pits located in the FT-002 area. Fuel for the fires generally consisted of waste jet fuel (JP-4) mixed with waste oil, but on occasion was mixed with solvents and other chemicals. Others have suggested training activities may also have been conducted in an area north and west of the pits (ABB Environmental, Inc. and URS Consultants, Inc., 1993, Ref. 1). Locations of monitoriing points installed during these previous studies and installed during this study are plotted in Figure 2.

2. Summary of Previous Investigations

a. Site Geology and Hydrology

The results of previous investigations indicate that three distinct hydrogeologic units exist beneath the FT-002 area (ABB/URS, 1993), as shown in Figure 3. The uppermost aquifer is unconfined and is comprised of well-sorted, medium-to fine-grained sand. This stratigraphic section extends from the surface to approximately 90 feet below ground surface (BGS) on the west side of FT-002 and to approximately 20 feet BGS on the east side of the flightline.

The water table within this zone varies from surface water on the eastern side of the site to 35 feet BGS on the western side. The average horizontal hydraulic gradient proximate to the FT-002 site is approximately 0.010 foot/foot and oriented towards the southeast. Vertical hydraulic gradients have been identified in the study area. However, they vary spatially within the aquifer.

Immediately below the uppermost saturated zone lies a series of aquitards and aquicludes consisting of silts, clays and glacial tills. The thickness of this zone is estimated to be approximately 60 feet thick and effectively isolates the shallow saturated zone from the confined bedrock aquifer. The bedrock aquifer consists primarily of sandstone and crystalline rock to the west of Plattsburgh AFB and carbonate rock beneath the AFB (Giese and Hobba, 1970, Ref. 2).

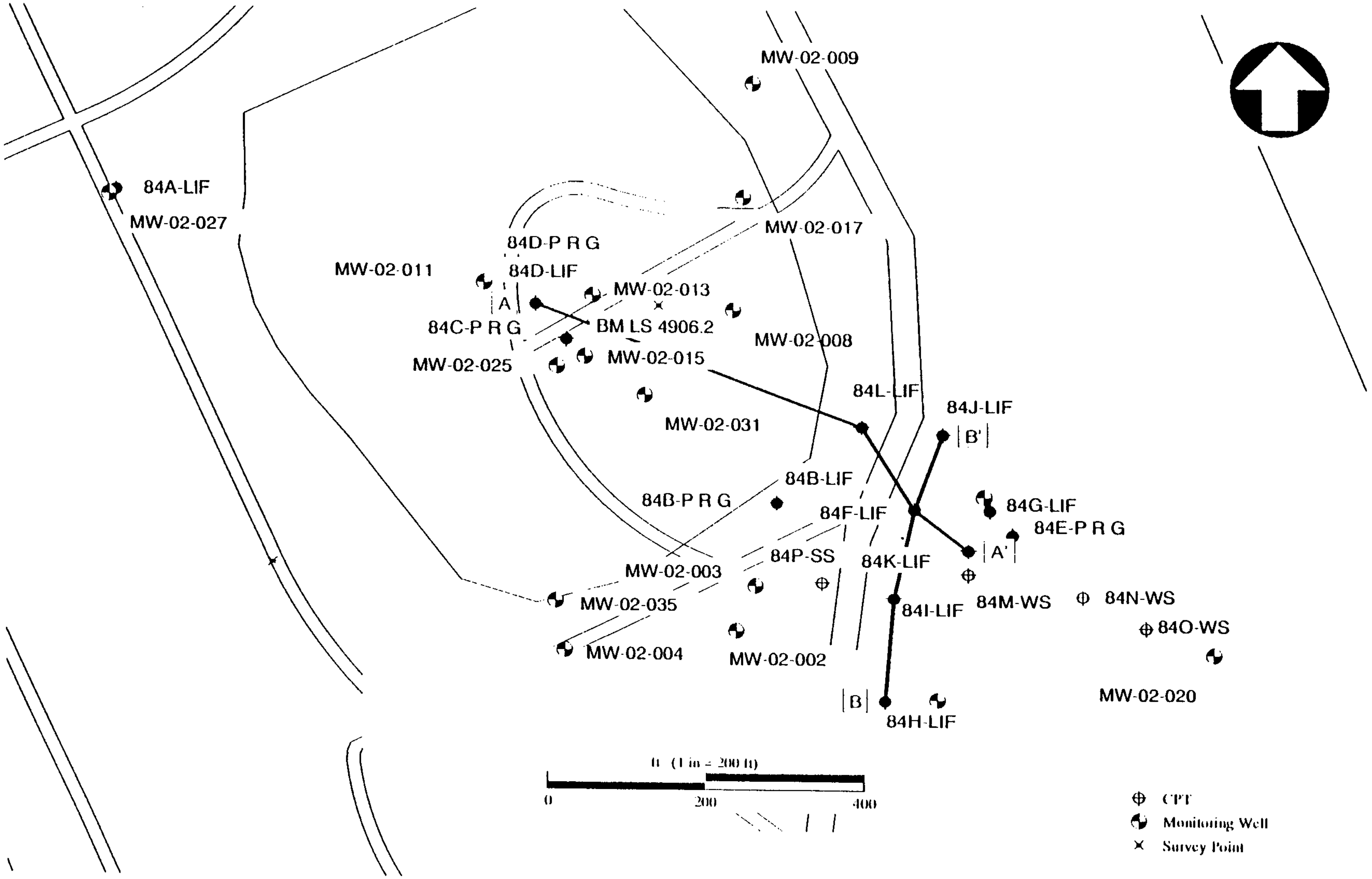
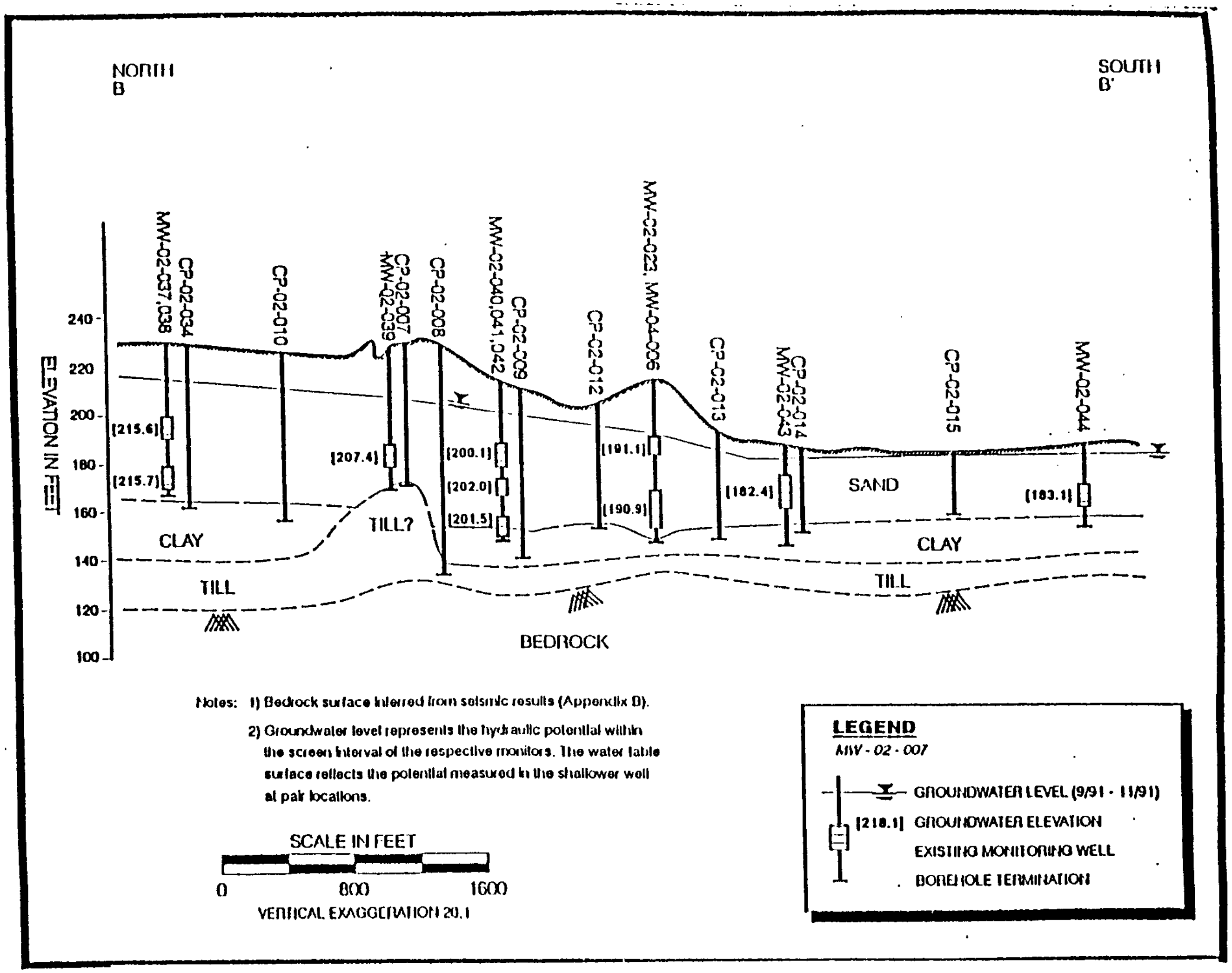


Figure 2. Site map of FT-002 fire training area.



Notes: 1) Bedrock surface inferred from seismic results (Appendix B).

2) Groundwater level represents the hydraulic potential within the screen interval of the respective monitors. The water table surface reflects the potential measured in the shallower well at pair locations.

Figure 3. North-South Geologic Profile, Plattsburgh AFB, New York (Source: ABB/URS, 1993).

b. Soil and Groundwater Quality

Previous investigations have determined the nature and extent of soil and groundwater contamination near to the FT-002 site. Chemical constituents, including volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) have been identified in both subsurface soils and groundwater.

Solvents TCE and DCE and fuel-related compounds benzene, ethylbenzene, toluene, and xylenes (BTEX) are the primary VOCs of concern within the soils. SVOCs include naphthalene, 2-methylnaphthalene, and four phenolics (i.e., phenol, 2-methylphenol, 4-methylphenol, and 2,4-dimethylphenol). Oily phase fuel hydrocarbons (i.e., JP-4 jet fuel) and chlorinated solvents (i.e., TCE and 1,2,-DCE) have been identified downgradient of Pit 1, Pit 4, and the oil/water separator within the capillary fringe and floating on the groundwater surface.

Analysis of groundwater analytical data indicates the presence of a dissolved-phase plume consisting of fuel-related compounds and chlorinated solvents proximate to FT-002. The plume originates at FT-002 and extends downgradient of the runway and taxiway to the east. The areal and vertical extent of the chlorinated solvent and BTEX plumes are illustrated in Figures 4, 5, 6 and 7, respectively.

C. SCOPE/APPROACH

To meet the primary objectives of defining the oily phase petroleum hydrocarbon plume and providing necessary data to support the Bioplume II ® modeling effort, the following scope was completed.

- Soil gas/resistivity profiling (5 soundings)
- Soil characterization using the Piezo/CPT (14 soundings)
- LIF measurements using the CPT (9 soundings)
- Grouting all CPT soundings

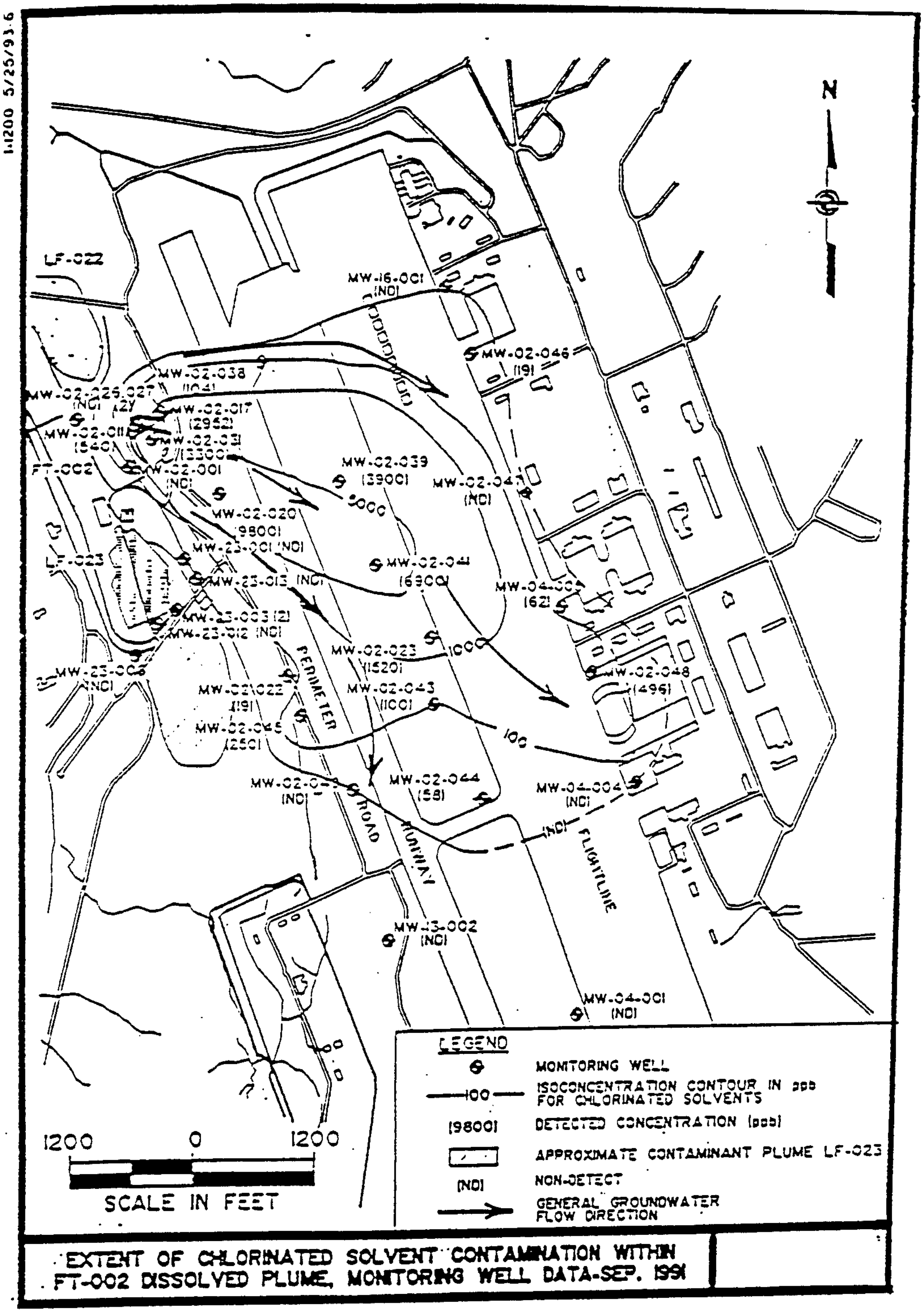
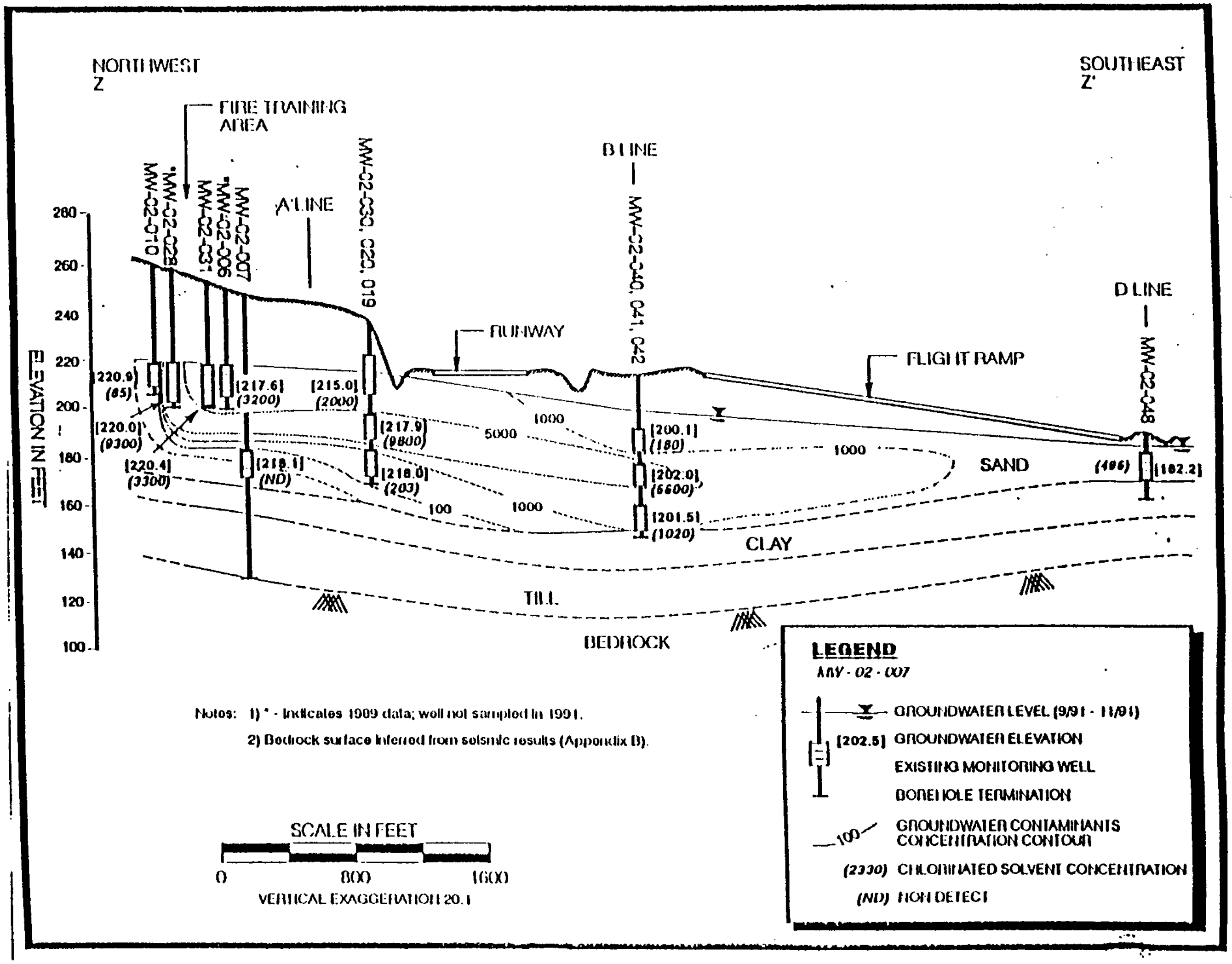


Figure 4. Areal Extent of Chlorinated Solvent Contamination, Plattsburgh AFB, New York (Source: ABB/URS, 1993).



Notes: 1) * - Indicates 1989 data; well not sampled in 1991.
2) Bedrock surface inferred from seismic results (Appendix B).

Figure 5. Vertical Extent of Chlorinated Solvent Contamination, Plattsburgh AFB, New York (Source: ABB/URS, 1993).

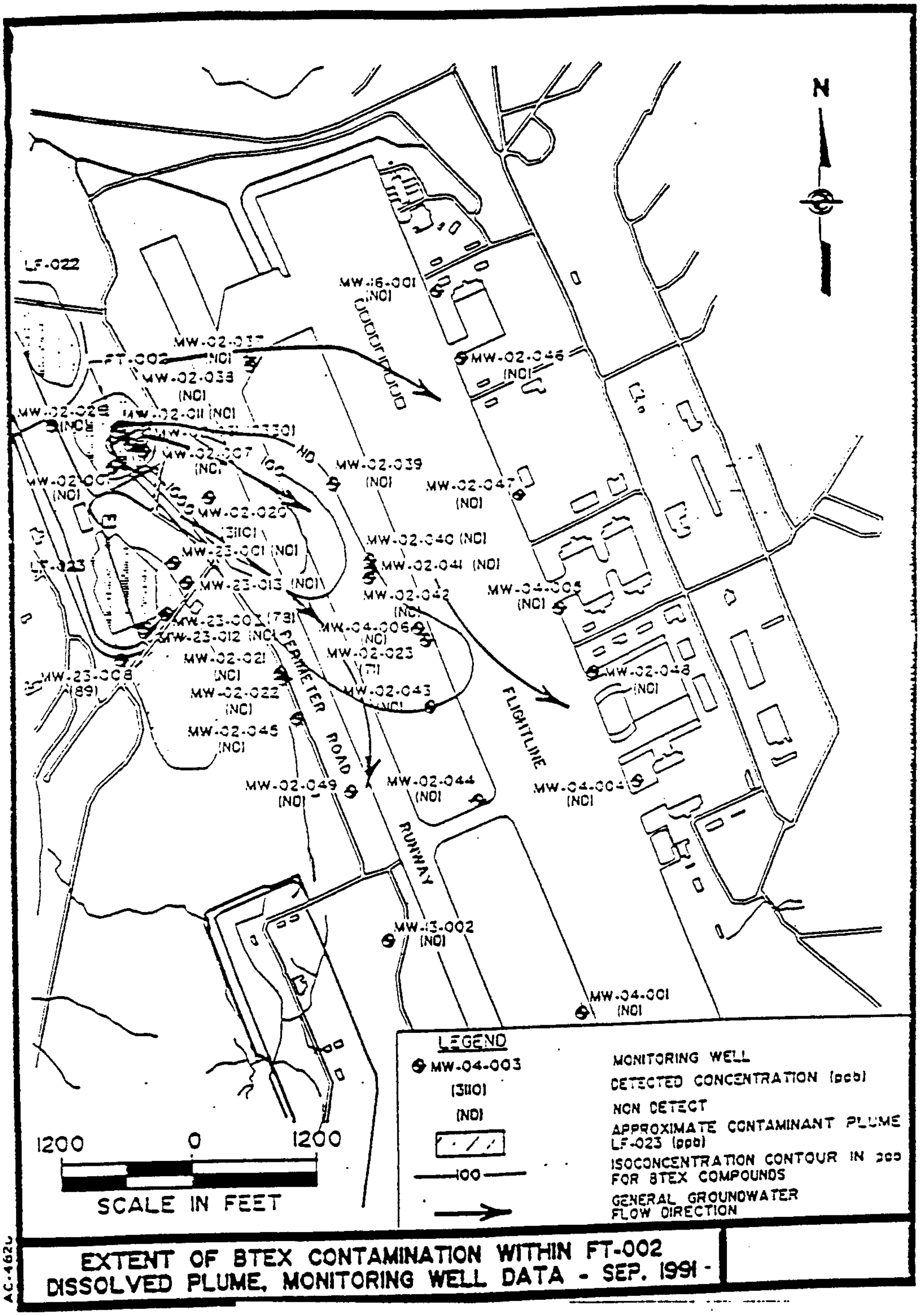
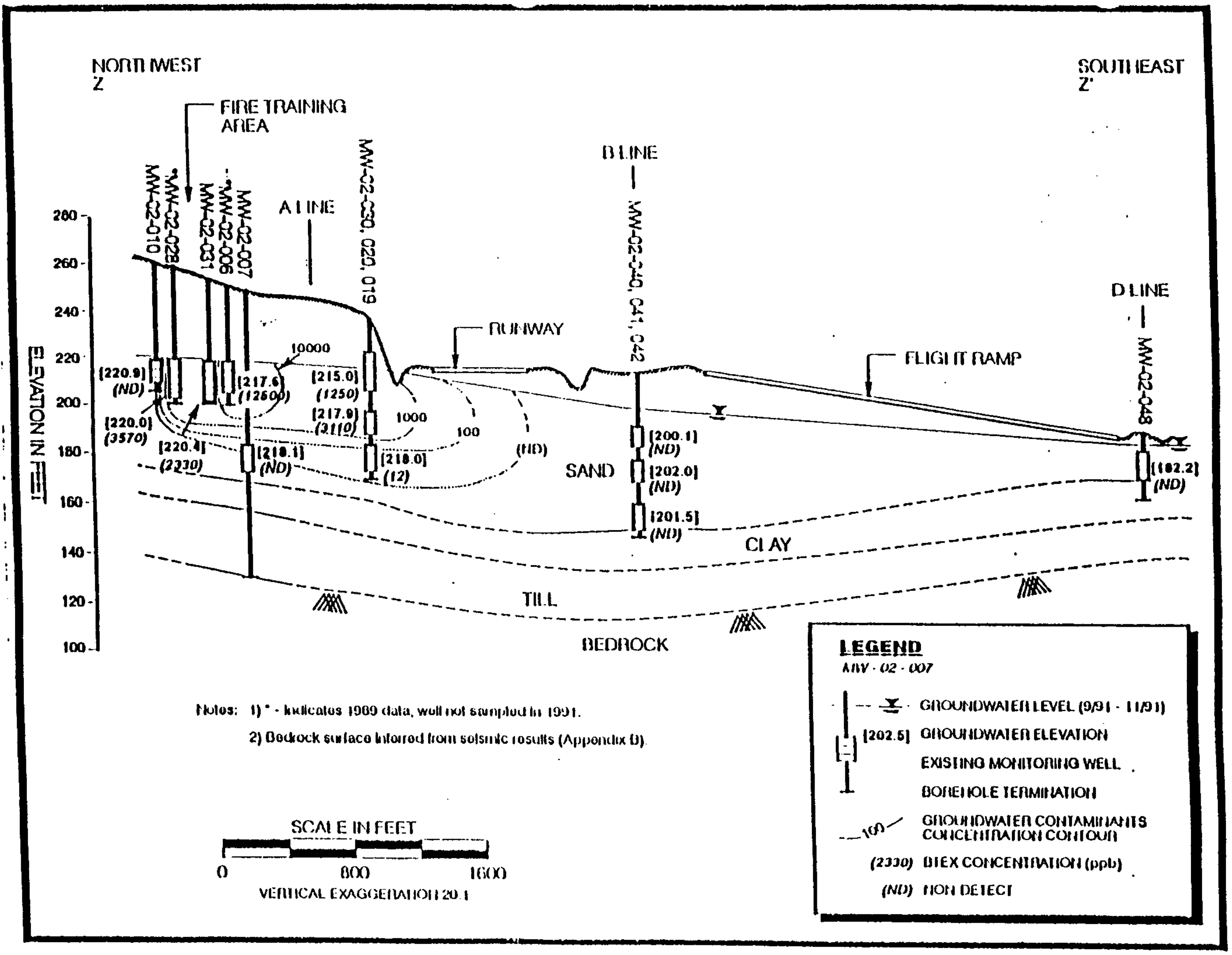


Figure 6. Areal Extent of BTEX Contamination, Plattsburgh, AFB, New York (Source: ABB/URS, 1993).



Notes: 1) * - Indicates 1989 data, well not sampled in 1991.
2) Bedrock surface inferred from seismic results (Appendix B).

Figure 7. Vertical Extent of BTEX Contamination, Plattsburgh, New York (Source: ABB/URS, 1993).

- Development of a groundwater potentiometric map based on the Piezo-CPT data

- Discrete water sampling at six locations and several depths, respectively

- Discrete soil sampling at six locations and several depths, respectively.

D. REPORT ORGANIZATION

Section II of this report contains a description of the CPT testing method and documents the field techniques, calibration methods, data acquisition system, grouting methods, and analysis methods used to derive properties and stratigraphy from the CPT data. Discussion of the field efforts during the two-week demonstration, along with a discussion of the data are presented in Section III. Also presented in Section III is an evaluation of the CPT results, oily phase petroleum hydrocarbon plume location, and a contour plot showing the direction of the groundwater flow. The summaries and conclusions obtained during the project are presented in Section IV. Appendix A contains profiles of LIF-CPT data and soil classifications. Appendix B contains Resistivity-CPT data and soil classifications. Appendix C contains the soil gas monitoring data. Locations of all groundwater and soil sampling activities performed for the EPA are presented in Table 1. Results from the analytical testing of these samples are summarized in Table 2 and fully reported in Appendix D.

TEST ID	SITE	LOCATION	DATE	TYPE	DEPTHS OF PENETRATION OR SAMPLE DEPTHS (FT)
84A-LIF	84	A	11/30/93	PCPT-LIF	52.6
84C-1 P/R/G	84	C	12/2/93	PCPT-R&G	17.2
84C-2 P/R/G	84	C	12/2/93	PCPT-R&G	48.3
84D P/R/G	84	D	12/2/93	PCPT-R&G	47.0
84E P/R/G	84	E	12/2/93	PCPT-R&G	35.6
84B P/R/G	84	B	12/2/93	PCPT-R&G	35.6
84B-LIF-2	84	B	12/3/93	PCPT-LIF	61.7
84F-LIF	84	F	12/3/93	PCPT-LIF	52.2
84G-LIF	84	G	12/3/93	PCPT-LIF	46
84B WS-1	84	B	12/3/93	WS	34.8, 56
84I-LIF	84	I	12/4/93	PCPT-LIF	39
84J-LIF	84	J	12/4/93	PCPT-LIF	42.8
84K-LIF	84	K	12/4/93	PCPT-LIF	38.8
84L-LIF	84	L	12/4/93	PCPT-LIF	39.3
84H-LIF	84	H	12/4/93	PCPT-LIF	38
84B-SOIL	84	B	12/4/93	SS	33, 32.5
84F WS-1	84	F	12/5/93	WS	38, 48, 53, 68
84E-WS-2	84	E	12/6/93	WS	52, 68
84M-WS-1	84	M	12/6/93	WS	41, 61
84E-WS-1	84	E	12/6/93	WS	32, 52
84F-SS-3	84	F	12/7/93	SS	32.6
84L-SS-1	84	L	12/7/93	SS	32.5
84O-WS-1	84	O	12/7/93	WS	22
84N-WS-1	84	N	12/7/93	WS	37, 57
84F-SS-1	84	F	12/7/93	SS	35.7, 36.8
84D-SS-3	84	D	12/7/93	SS	7.5, 9, 10.5, 12, 13.5, 15, 16.5, 18, 19.5, 21, 22.5, 24
84O-WS-1	84	O	12/8/93	WS	32, 47
84D-SS-1	84	D	12/8/93	SS	4.5, 6, 41, 42.5, 44.5, 46.4, 47
84P-SS-1	84	P	12/9/93	SS	27.5, 29, 30.5
84D-SS-15	84	D	12/9/93	SS	36.5, 38, 39.5, 39.5
84P-WELL	84	P	12/10/93	MW	33
84F-SS-1	84	F	12/10/93	SS	30, 31.5, 33, 27, 28.5 32, 35
TOTAL LF OF PENETRATION					2,546.5

LEGEND

LIF - LASER INDUCED	CPT - CONE PENETROMTER	G - SOIL GAS	WS - WATER SAMPLER
P - Piezo	SS - SOIL SAMPLE	R - RESISTIVITY	MW - MONITORING WELL

Table 1. CPT Soundings (Plattsburg AFB, New York)

Table 2. Results of Soil and Groundwater Chemical Analysis for TPH

Sample Code (pfeffer)	Date	Sample Location (ft) Below Ground Surface	TPH mg/kg Dry Basis	OVM
3	12/7/93	84F 28.5-29	"	"
4	12/7/93	84F 28-28.5	"	"
5	12/7/93	84F 27.5-28	<10	nr
6	12/7/93	84F 31-31.5	"	"
7	12/7/93	84F 30.5-31	"	"
8	12/7/93	84F 30-30.5	"	"
9	12/7/93	84L 31.5-32.5	<10	nr
10	12/8/93	84B 31-32.5	189	nr
11	12/8/93	84B 31.5-33	nr	"
12	12/8/93	84D 3-3.5	<10	nr
13	12/8/93	84D 3.5-4	"	"
14	12/8/93	84D 4-4.5	"	"
15	12/8/93	84D 4.5-5	"	"
16	12/8/93	84D 5-5.5	"	"
17	12/8/93	84D 5.5-6	"	"
18	12/8/93	84D 6-6.5	18	"
19	12/8/93	84D 7-7.5	<10	"
20	12/8/93	84D 7.5-8	"	0
21	12/8/93	84D 8-8.5	"	3
22	12/8/93	84D 8.5-9	"	2
23	12/8/93	84D 16-16.5	208	655
24	12/8/93	84D 15.5-16	412	297
25	12/8/93	84D 15-15.5	"	45
26	12/8/93	84D 14.5-15	"	1
27	12/8/93	84D 16.5-17 A	518	584
28	12/8/93	84D 16.5-17 B	38	nr
29	12/8/93	84D 17-17.5	540	663
30	12/8/93	84D 17.5-18	448	591
31	12/8/93	84D 18-18.5	423	709
32	12/8/93	84D 18.5-19	345	616
33	12/8/93	84D 19-19.5	303	610
34	12/8/93	84D 19.5-20	288	673
35	12/8/93	84D 20-20.5	236	481
36	12/8/93	84D 20.5-21	115	631
37	12/8/93	84D 14-14.5	"	0
38	12/8/93	84D 13.5-14	"	1
39	12/8/93	84D 13-13.5	"	1
40	12/8/93	84D 12.5-13	"	2
41	12/8/93	84D 12-12.5	"	3
42	12/8/93	84D 11.5-12	"	1
43	12/8/93	84D 11-11.5	<10	3
44	12/8/93	84D 10.5-11	"	2

Table 2. Results of Soil and Groundwater Chemical Analysis for TPH (Concluded)

Sample Code (pfeffer)	Date	Sample Location (ft) Below Ground Surface	TPH mg/kg Dry Basis	OVM
45	12/8/93	84D 10-10.5	"	"
46	12/8/93	84D 9.5-10	"	nr
47	12/8/93	84D 9-9.5	"	1
48	12/8/93	84D 21-21.5	179	558
49	12/8/93	84D 21.5-22	234	488
50	12/8/93	84D 22-22.5	222	584
51	12/8/93	84D 22.5-23	324	562
52	12/8/93	84D 23-23.5	371	713
53	12/8/93	84D 23.5-24	19	501
54	12/9/93	84D 35-35.5	11	42
55	12/9/95	84D 35.5-36	<10	38
56	12/9/95	84D 36-36.5	338	219
57	12/9/95	84D 36.5-37	478	471
58	12/9/95	84D 37-37.5	757	408
59	12/9/95	84D 37.5-38	1,010	490
60	12/9/95	84D 38-38.5	1,880	521
61	12/9/95	84D 38.5-39	3,940	414
62	12/9/95	84D 39-39.5	7,530	454
63	12/9/95	84D 39.5-40	12,500	340
64	12/9/95	84D 40-40.5	12,000	490
65	12/9/95	84D 40.5-41	7,870	348
66	12/9/95	84D 41-41.5	1,940	521
67	12/9/95	84D 44-44.3	<10	5
68	12/9/95	84P 26-26.5	<10	1
69	12/9/95	84P 26.5-27	"	1
70	12/9/95	84P 27-27.5	"	1
71	12/9/95	84P 27.5-28	"	1
72	12/9/95	84P 28-28.5	"	33
73	12/9/95	84P 28.5-29	"	14
74	12/9/95	84P 29-29.5	"	11
75	12/10/93	84F 28.5-29	"	1
76	12/10/93	84F 29-29.5	"	6
77	12/10/93	84F 29.5-30	11	44
78	12/10/93	84F 25.5-26	"	2
79	12/10/93	84F 26-26.5	"	1
80	12/10/93	84F 26.5-27	"	3
81	12/10/93	84F 27-27.5	"	1
82	12/10/93	84F 27.5-28	"	1
83	12/10/93	84F 28-28.5	"	1
84	12/10/93	84F 30-30.5	76	208
85	12/10/93	84F 30.5-31	81	408

SECTION II
DATA ACQUISITION AND ANALYSIS METHODS

A. INTRODUCTION

This section begins with a discussion of the various CPT sensors used to obtain data. Calibration methods for the CPT sensors are discussed next. All data are recorded on the CPT truck computer and stored for later processing. The methods and algorithms used to process the data into useful presentations are also presented in this section.

B. TECHNICAL APPROACH

1. Cone Penetration Testing

The electronic cone penetrometer test (CPT) was originally developed for use in consolidated clay soils. Cone and push system designs have evolved to the point where they can now be used in strong cemented soils and even soft rock. ARA's penetrometer consists of an instrumented probe which is forced into the ground using a hydraulic load frame mounted on a heavy truck with the weight of the truck providing the necessary reaction mass. The probe has a conical tip and a friction sleeve which independently measures vertical resistance beneath the tip as well as frictional resistance on the side of the probe as functions of depth. A schematic view of ARA's LIF-CPT penetrometer probe is shown in Figure 8. A pressure transducer in the cone is used to measure the pore water pressure as the probe is pushed into the ground (Piezo-CPT). In addition, a Resistivity-CPT module, shown in Figure 9, was used on this demonstration to measure variances in soil conductance, which assists in locating contamination plumes. The standard Resistivity-CPT setup was modified to include soil gas monitoring through a sintered steel filter. The soil gas was pulled into the cone system using a vacuum and travelled up to the truck through a high density polypropylene tube for analysis in the CPT rig.

Cone Penetration Testing by nature of the test leaves an open hole which represents a potential contaminant pathway. To close these pathways, the CPT holes were filled with 1/4-inch bentonite pellets or granular bentonite at the end of each day. Sealing the CPT holes in this manner was deemed adequate by Plattsburgh Air Force Base representatives.

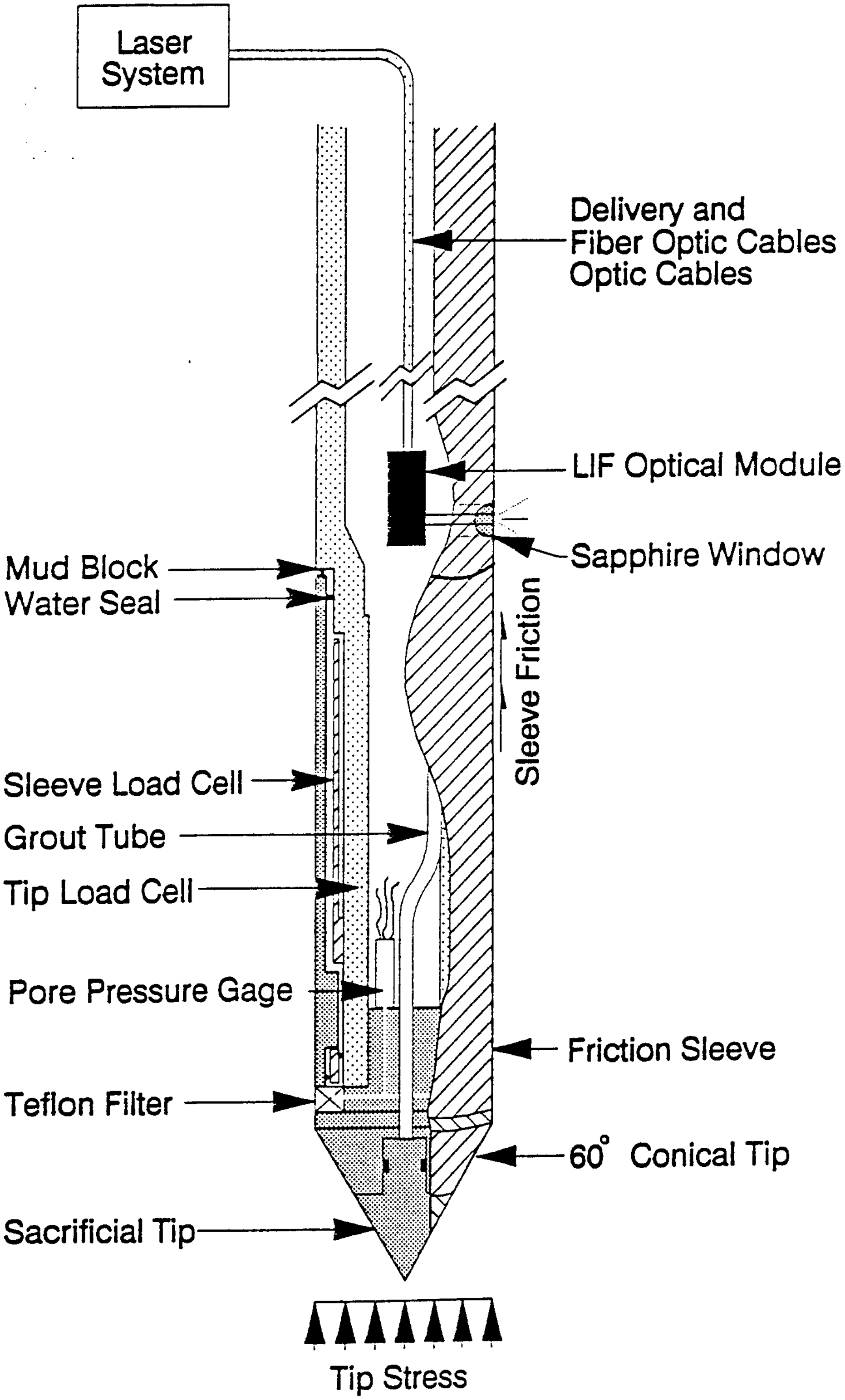


Figure 8. Schematic of Laser Induced Fluorescence-Cone Pentetrometer probe.

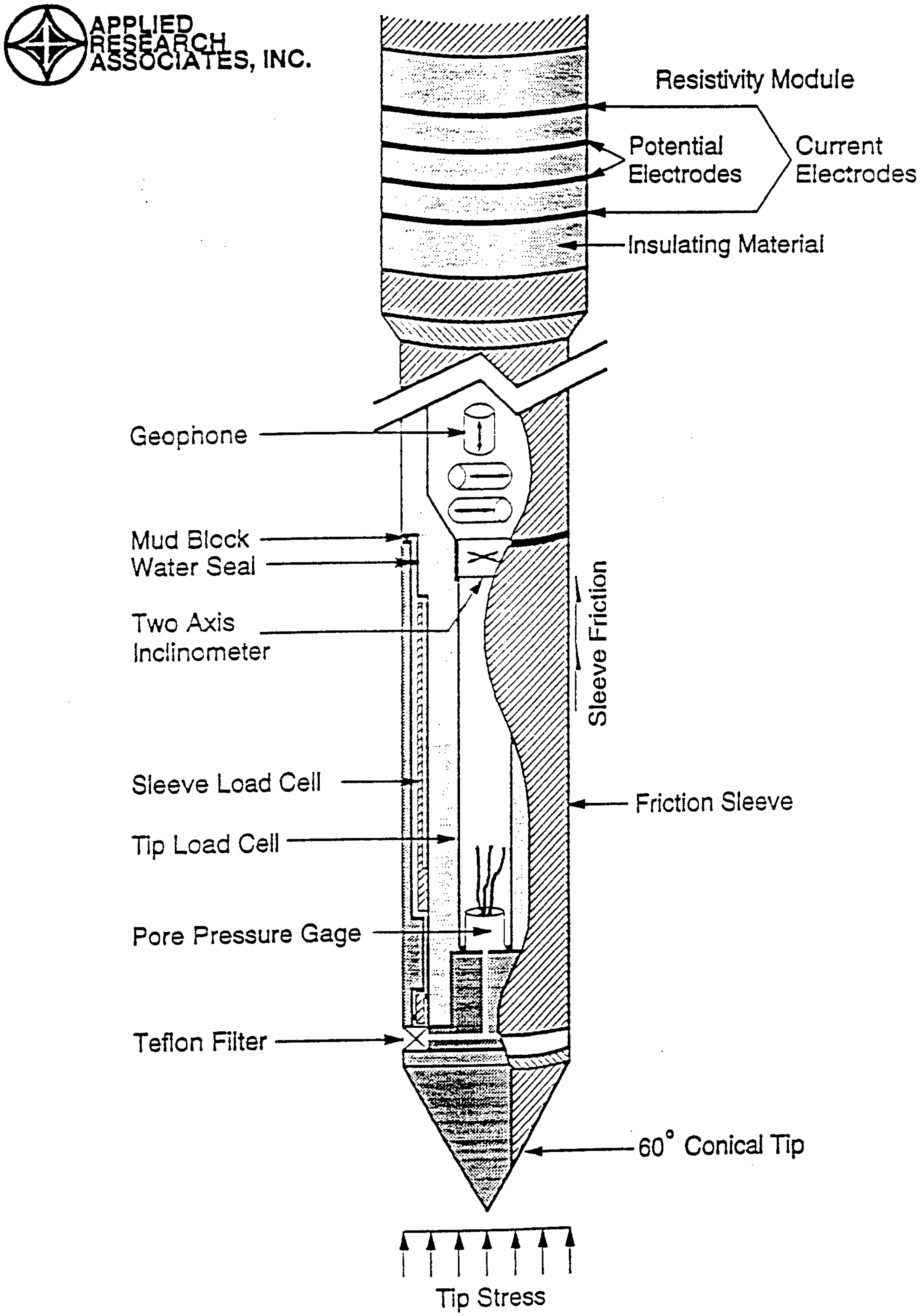


Figure 9. Schematic of ARA's Cone Penetrometer Probe Including Resistivity Module.

2. Piezo Cone Penetration

The cone penetrometer tests are conducted using the ARA penetrometer truck. The penetrometer equipment is mounted inside a 18 feet van body attached to a 10 wheel truck chassis with a turbocharged diesel engine. Ballast in the form of metal weights and a steel water tank, which can hold 5,000 pounds of water, are added to the truck to achieve an overall push capability of 60,000 pounds. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck frame.

A 15 cm^2 penetrometer probe was used, and has a 1.75-inch diameter, 60° conical tip, and a 1.75-inch diameter by 6.50-inch long friction sleeve. The shoulder between the base of the tip and the porous filter is 0.08 inches long. The penetrometer is normally advanced vertically into the soil at a constant rate of 48 in/min, although this rate must sometimes be reduced as hard layers are encountered and also when the LIF probe is being used. The electronic cone penetrometer test is conducted in accordance with ASTM D3441, 1986 (Ref. 3).

Inside the probe, two load cells independently measure the vertical resistance against the conical tip and the side friction along the sleeve. Each load cell is a cylinder of uniform cross section inside the probe which is instrumented with four strain gages in a full-bridge circuit. Forces are sensed by the load cells and the data are transmitted from the probe assembly via a cable running through the push tubes. The analog data are digitized, recorded, and plotted by computer in the penetrometer truck. A set of data is normally recorded each second, for a minimum resolution of about one data point every 0.8 inches of cone advance. The depth of penetration is measured using a extensiometer mounted inside one of the push cylinders.

As shown in Figure 8, the piezo-cone probe senses the pore pressure immediately behind the tip. Currently, there is no accepted standard for the location of the sensing element. ARA chose to locate the sensing element behind the tip as the filter is protected from the direct thrust of the penetrometer and the measured pore pressure can be used to correct the tip resistance data (discussed below) as recommended by Robertson and Campanella, 1988 (Ref. 4). The magnitude of the penetration pore pressure is a function of the soil compressibility and, most important, permeability. In freely draining soil layers, the measured pore pressures will be very close to the hydrostatic pressure computed from the elevation of the water table. When low-permeability soil layers are encountered, excess pore pressures generated by the penetration process can not dissipate rapidly and this results in measured pore pressures which are significantly higher than the hydrostatic pressures. Whenever the penetrometer is stopped to add another section of push tube, or when a pore pressure dissipation test is run, the excess pore pressure may begin to dissipate. When the penetration is resumed, the pore pressure quickly rises to the level measured before the penetrometer was stopped. This process causes some of the spikes that may appear in the penetration pore pressure data.

3. Saturation of the Piezo-Cone

As shown in Figure 8, penetration pore pressures are measured with a pressure transducer located behind the tip in the lower end of the probe. Water pressures in the soil are sensed through a 250-micrometer porous polyethylene filter 0.25-inch high and 0.202-inch thick. The pressure transducer is connected to the porous filter through a pressure port as shown in Figure 8. The pressure port and the filter are filled with a high-viscosity silicone oil.

If the pressure transducer is to respond rapidly and correctly to changing pore pressures upon penetration, the filter and pressure port must be saturated with oil upon assembly of the probe. A vacuum pump is used to de-air the silicone oil before use and saturate the porous filters with oil. The probe is assembled with the pressure transducer up and the cavity above the pressure transducer filled with de-aired oil. A previously saturated filter is then placed on a tip and oil is poured over the threads. When the cone tip is then screwed into place, excess oil is ejected through the pressure port and filter, thereby forcing out any trapped air.

Saturation of the piezo cone is verified with field calibrations performed before the probe is inserted into the ground. The high viscosity of the silicone oil coupled with the small pore space in the filter prevents the loss of saturation as the cone is pushed through dry soils. Saturation of the cone can be verified with a calibration check at the completion of the penetration. Extensive field experience has proven the reliability of this technique with no known case where saturation of the piezo-cone was lost.

4. LIF Cone Penetrometer Test

The LIF-CPT probe is used to make fluorescence measurements of the soils as the cone is inserted into the ground. The laser light is generated inside the penetrometer truck using a full-wavelength tunable-dye laser system developed by NDSU. The laser system consists of a pulsed-laser pump (Nd:YAG), a single tunable dye laser, and the necessary optics to launch the light into the fiber-optic bundle. The fiber-optic bundle consists of one transmission line surrounded by 6 collection lines. This bundle is used to guide the light to and from the LIF module attached to the CPT probe. The LIF system measures the fluoresced light coming into the probe at a wavelength of 340 nm. The time decay of this light is recorded by the laser computer and averaged over 20 shots of the laser. The area under the average time decay curve is then integrated to determine an intensity value. These intensity values are then averaged every two seconds as the CPT is being advanced, and the average transferred to the CPT computer and stored. These intensity values are recorded versus depth for each of the LIF-CPT pushes.

5. Resistivity Cone Penetrometer Test

Resistivity, one of the oldest geophysical exploration techniques, was originally developed to locate mineral and oil deposits and groundwater supplies. The measurement principal exploited by resistivity surveying is that an electrical contrast exists between different geological materials and that this electrical contrast can be used to identify and locate geologic materials. Resistivity surveys are being increasingly used in contaminated site investigation programs to delineate the extent and degree of contamination at a site. These surveys rely on the electric contrasts that typically exist between contaminated soils and uncontaminated soils. For example, leachate from a landfill will contain a higher concentration of dissolved solids, which will decrease the resistivity of the groundwater (Shinn, 1990, Ref. 5). Soils contaminated with hydrocarbons (fuel oils, cleaning solvents, etc.) will typically have higher resistivity than uncontaminated soils as the hydrocarbon can act as an insulator.

The Resistivity-CPT (R-CPT) is an adaptation of conventional borehole tools. The R-CPT probe is in direct contact with the soil and pore fluid which eliminates two problems associated with borehole resistivity surveys: (1) intrusion of drilling fluids into borehole walls which changes the resistivity of the media, and (2) the requirement that any casing material be non-conducting.

Figure 9 is a schematic of ARA's R-CPT probe. The probe consists of four electrodes separated by high strength (Kevlar®-nylon) plastic reinforced insulators. The outer two electrodes induce an electric current into the soil and the inner two electrodes measure the potential drop, which is proportional to the resistivity of the soil. To avoid polarization effects the four electrode array is operated at a frequency of 40 HZ. Electronics in the CPT vehicle are used to modulate and demodulate the current and potential measurement signals to and from the probe. The probe is calibrated in a large water solution in which the conductivity is varied. The data from the calibration tests are used to determine the probe calibration factor, which is dependent on the probe geometry.

6. Data Acquisition

Electronic data acquisition equipment for the cone penetrometer consists of an IBM compatible 486 computer with a graphics monitor and a rack of eight customized signal conditioners. Analog signals are transmitted from the probe to the signal conditioners where the CPT data are amplified and filtered at 1 Hz. The digital data are then read into memory, plotted on a graphics monitor, and written to the internal hard disk for future processing. Data displayed on screen can be used to determine site layering as it is encountered. This allows important decisions to be made in real-time directly in the field. Upon completion of the test, the penetration, LIF, dissipation, and resistivity data are plotted. Plots can typically be available within ten minutes of completing the test. Floppy disks containing the data are brought to ARA's New England Division in South Royalton, Vermont, for preparation of final report plots and analysis.

7. Field Calibrations

Many factors can effectively change the calibration factors used to convert the raw instrument readouts, measured in volts, to units of force or pressure. As a quality control measure, as well as a check for instrument damage, the load cells, the pressure transducer, and the resistivity sensor are routinely calibrated in the field. Calibrations are completed with the probe ready to insert into the ground so that any factor affecting any component of the instrumentation system will be included and detected during the calibration.

The tip and sleeve load cells are calibrated with the conical tip and friction sleeve in place on the probe. For each calibration, the probe is placed in the push frame and loaded onto a precision reference load cell. The reference load cell is periodically calibrated in ARA's laboratory against NIST traceable standards. To calibrate the pore pressure transducer, the saturated probe is inserted into a pressure chamber with air pressure supplied by the compressor on the truck. The reference transducer in the pressure chamber is also periodically calibrated against an NIST traceable instrument in ARA's laboratory. Additionally, the extensiometer, used to measure the depth of penetration, is periodically checked against a tape measure.

Each instrument is calibrated using a specially written computer code that displays the output from the reference device and the probe instrument in graphical form. During the calibration procedure, the operator checks for linearity and repeatability in the instrument output. At the completion of each calibration, this code computes the needed calibration factors using a linear regression algorithm. In general, each probe instrument is calibrated at the beginning of each day of field testing. Furthermore, the pressure transducer is recalibrated each time the porous filter is changed and the cone is resaturated. Calibrations are also performed to verify the operation of any instrument if damage is suspected.

The LIF is calibrated after the CPT probe has been calibrated. This is accomplished by placing a cuvette containing 1 percent JP-4 on sand next to the sapphire window. The fluorescence response is set to 2,048 on the laser computer. This causes a "count" of LIF response to represent 1/2,048 (1 bit) of the area under the time delay curve of the calibration mixture.

8. Penetration Data Correction

A typical penetration profile, from the FT-002 site, is shown in Figure 10a. Plotted as a function of elevation are the measured tip resistance, sleeve friction, friction ratio, pore pressure, soil layering, classification, and LIF data. When the surface elevation of the test location is unknown, the penetration data are plotted against depth.

Tip resistance, q_c (pounds/inches^2), is obtained by dividing the vertical force on the conical tip by the effective tip area (1.550 inches^2). The tip resistance is then corrected for pore pressures acting behind the conical tip as discussed in the next section. The corrected tip resistance, q_T (pounds/inches^2), is plotted in the penetration profile. Sleeve friction, f_s (pounds/inches^2), is obtained by dividing the total frictional force on the sleeve by the sleeve's surface area (23.26 inches^2). The offset between the depth at the tip and the depth at the friction sleeve is corrected by shifting the sleeve friction profile downward so that it corresponds to the depth at the centroid of the tip. In addition to the tip resistance and sleeve friction, a friction ratio profile is plotted for each location. This ratio is simply the sleeve friction expressed as a percentage of the tip resistance at a given depth. In uncemented soils, the friction ratio can be correlated to soil type. The final profile shown in Figure 10a is the pore pressure that is measured as the probe is advanced. This measurement is useful for identifying clay layers as the pore pressure rises significantly above the hydrostatic level.

9. Pore Pressure Correction of Tip Stress

Cone penetrometers, by necessity, mnust have a joint between the tip sleeve. Pore pressure acting behind the tip decreases the total tip resistance that would be measured I fthe penetromter was without joints. The influence of pore pressure in these joints is

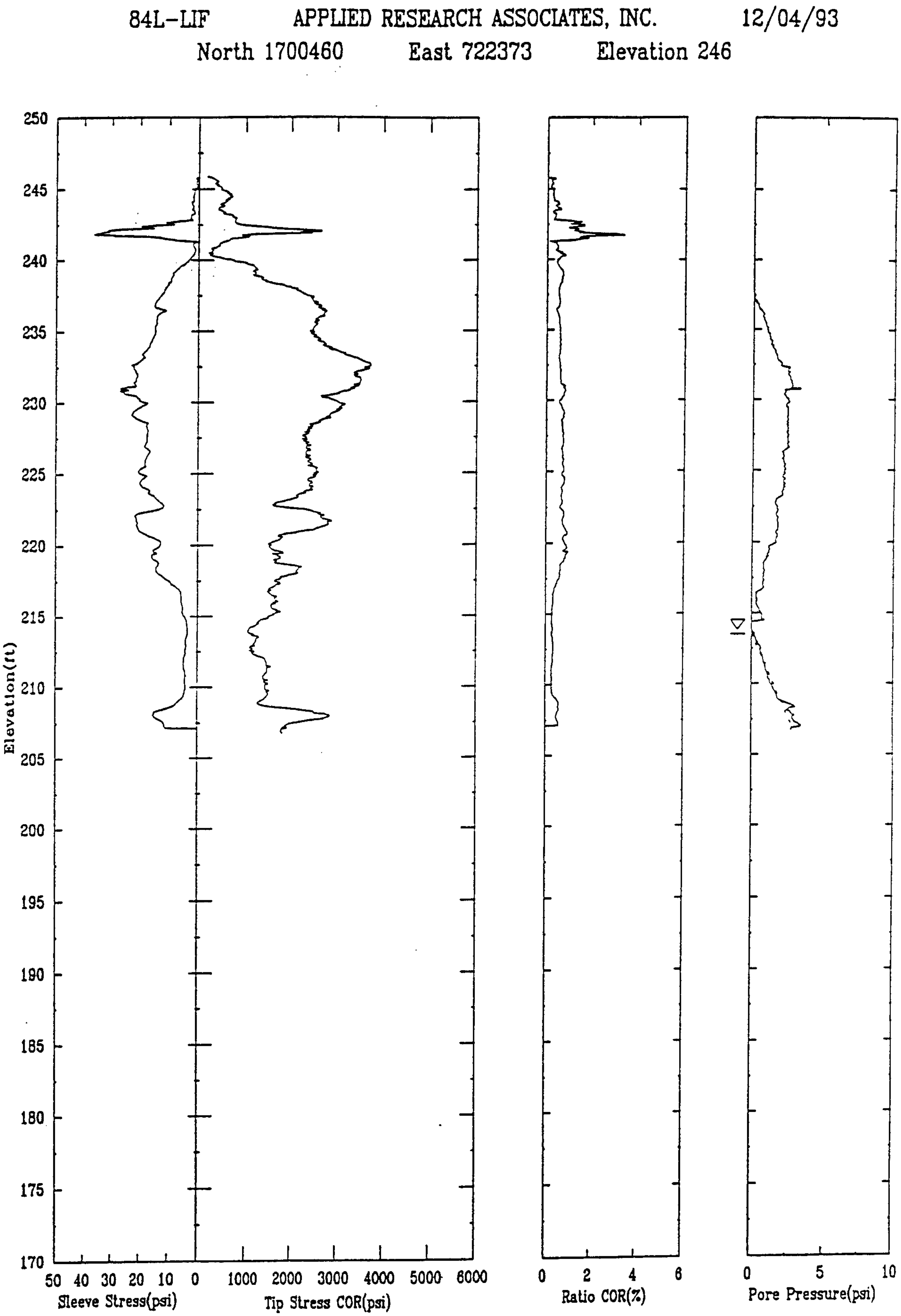
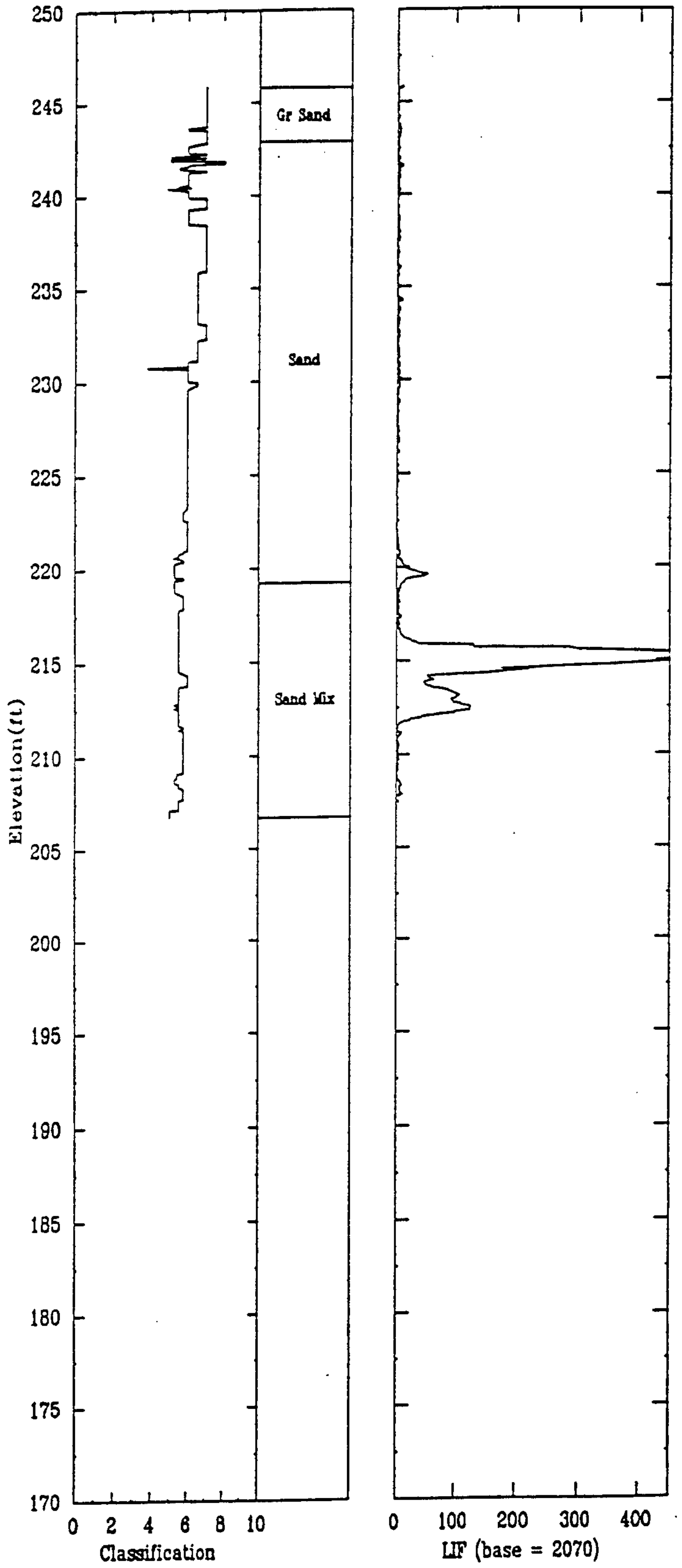


Figure 10. Typical Penetration Profile from FT-002 Site.



84L-LIF APPLIED RESEARCH ASSOCIATES, INC. 12/04/93

North 1700460 East 722373 Elevation 246

Figure 10 Typical Penetration Profile from FT-002 Site (Continued).

compensated for by using the net area concept (Ref. 4). The corrected tip resistance is given by:

$$q_t = q_c + u\left(1 - \frac{A_n}{A_T}\right) \qquad (1)$$

where q_t = corrected tip resistance
q_c = measured tip resistance
u = penetration pore pressure measured behind the tip
A_n = net area behind the tip not subjected to the pore pressure (1.257 inches^2)
A_t = projected area of the tip (1.550 inches^2).

Hence, for the ARA cone design, the tip resistance is corrected as:

$$q_T = q_c + u(.1890) \qquad (2)$$

Laboratory calibrations have verified Equation (2) for ARA's piezo-cone design.

A joint also exists behind the top of the sleeve (see Figure 8). However, since the sleeve is designed to have the same cross sectional area on both ends, the pore pressures acting on the sleeve cancel out. Laboratory tests have verified that the sleeve is not subjected to unequal end area effects. Thus, no correction for pore pressure is needed for the sleeve friction data.

The net effect of applying the pore pressure correction is to increase the tip resistance and to decrease the friction ratio. Generally, this correction is only significant when the pore pressures are high while measured tip resistance is very low.

10. Depth Correction of the Penetration Data

If the cone penetrometer is stopped or pulled back during a test, misleading data can result. For instance, when the probe is stopped to add the next push rod section, or when a pore pressure dissipation test is run, the excess pore pressures will dissipate towards the hydrostatic pore pressure. When the penetration is resumed, the pore pressure generally rises very quickly to the pressures experienced prior to the pause in the test. In addition, the probe is sometimes pulled back and cycled up and down at intervals in deep holes to reduce soil friction on the push tubes. This results in erroneous tip stress data when the cone is advanced in the previously penetrated hole.

To eliminate this misleading data from the penetration profile, the data are numerically edited before they are plotted or used in further analysis. Each time the penetrometer stops or backs up, as apparent from the depth data, the penetration data are not plotted. Plotting of successive data is resumed only after the tip is fully reengaged in the soil by one tip length (1.52 inches) of new penetration. This algorithm also eliminates any data acquired at the ground surface before the tip has been completely inserted into the ground. The sleeve data are similarly treated and this results in the first data point not occurring at the ground surface, as can be seen in some tip and sleeve profiles. These procedures ensure that all of the penetration data plotted and used for analysis were acquired with the probe advancing fully into undisturbed soil.

11. LIF Data Analysis

To eliminate the hole-to-hole variance of the laser intensity, the median of a minimum of 41 points are used to determine a baseline value. The baseline value is then subtracted from all the readings in the profile. This produces profiles which can be compared and overlaid, since any equipment variances between tests have been minimized. The baseline corrected LIF values are the values presented in the LIF profile shown in Figure 10b. The baseline value is shown at the base of the plot. LIF profiles are presented in Appendix A for all locations.

12. Resistivity Analysis

Geophysical resistivity surveys measure the electric resistivity contrast of earth materials and has been used for many years to locate mineral and oil deposits. The resistivity of natural deposits is a function of the soil type, degree of consolidation, water content, pore fluid, and conductivity. Of these parameters, soil type and pore fluid conductivity have the largest influence. Location of separate phase NAPLs exploits the resistivity contrast that will exist between a NAPL saturated soil and a water saturated soil. NAPLs and other hydrocarbons act as insulators, whereas soil moisture acts as a conductor. Studies by Shinn, 1990 (Ref. 5), Seusy, 1992 (Ref. 6), and Annan, 1991 (Ref. 7), indicated that both surface and downhole resistivity surveys can be used to locate NAPLS.

Electrical properties of natural deposits of soils can span six orders of magnitude, with the dominant variables being the soil porosity, conductivity of the pore fluid and clay content. Table 3 and Figure 11 present typical resistivities of various soils and rock types. These values are useful in preliminary modeling calculations to determine where significant contrasts can be achieved.

Electrical models of the response of saturated and partially saturated soils and rocks have been developed, with the most widely used model being Archie's law or variants of Archie's Law. Archie's Law (Saksa, 1987, Ref. 9) is an empirically derived model which relates the total conductivity (the reciprocal of resistivity) of a soil, pore water and contaminant mixture as:

$$\sigma_T = \frac{\sigma_w s^b n_t^m}{a} \tag{3}$$

where σ_T = total observed electrical conductivity, smho/m
σ_W = conductivity of fluid constituent, smho/m
n_t = total porosity
s = degree of saturation
a, b, m = empirical factors: $a \cong 1$, $b \cong 2$, $m = 1.3$ to 2 for unconsolidated sediments.

Equation (3) assumes that the soil matrix does not constitute a flow path for the electrical current. This is valid when the soil grain conductivity is much less than that of the pore fluid. A more general solution is to replace σ_W with the bulk conductivity of the soil defined as:

$$\sigma_b = \sigma_w + \sigma_m + \sigma_s \tag{4}$$

where σ_b = bulk conductivity, smho/m
σ_W = conductivity of fluid constituent, smho/m
σ_m = conductivity of the soil grains, smho/m
σ_S = the conductivity of the grain surface double layer.

The grain surface conductivity can increase the bulk conductivity by 15% to 30% (Pfannkuch 1969, Ref. 10). In very saline solutions, the influence of σ_S is probably not large. Saksa, et al. (1987) suggest that bulk resistivity can be modeled using:

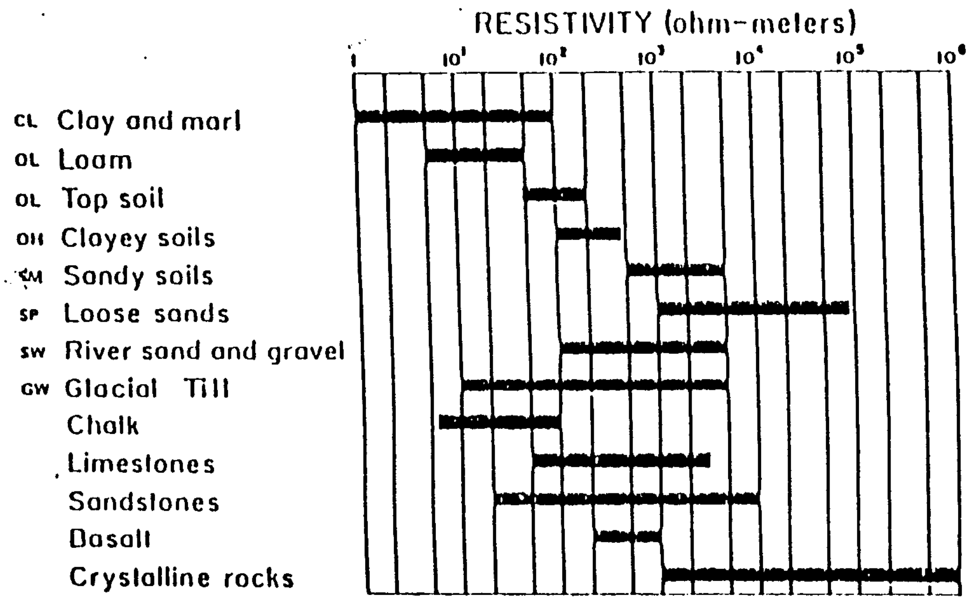


Figure 11. Resistivity Ranges for Various Terrain Materials

Table 3 RESISTIVITIES OF SEDIMENTS (REF. 8)

Rock Type	**Resistivity Range (Ωm)**
Consolidated shales	20 to 2×10^3
Argillites	8 to 10×10^2
Conglomerates	2×10^3 to 10^4
Sandstones	1 to 6.4×10^8
Limestones	50 to 10^7
Dolomite	3.5×10^2 to 5×10^3
Unconsolidated wet clay	20
Marls	3 to 70
Clays	1 to 100
Alluvium and sands	10 to 800
Oil sands	4 to 800

$$\begin{aligned}\sigma_m &= 0.0001\\ \sigma_s &= 0.1\mathrm{abs}(\log\sigma_w)\sigma_w\end{aligned} \qquad (5)$$

which yields $\sigma_S = 0\%$ of σ_W when $\sigma_W = 1.0$ smho/m

$\sigma_S = 30\%$ of σ_W when $\sigma_W = 0.0001$ smho/m

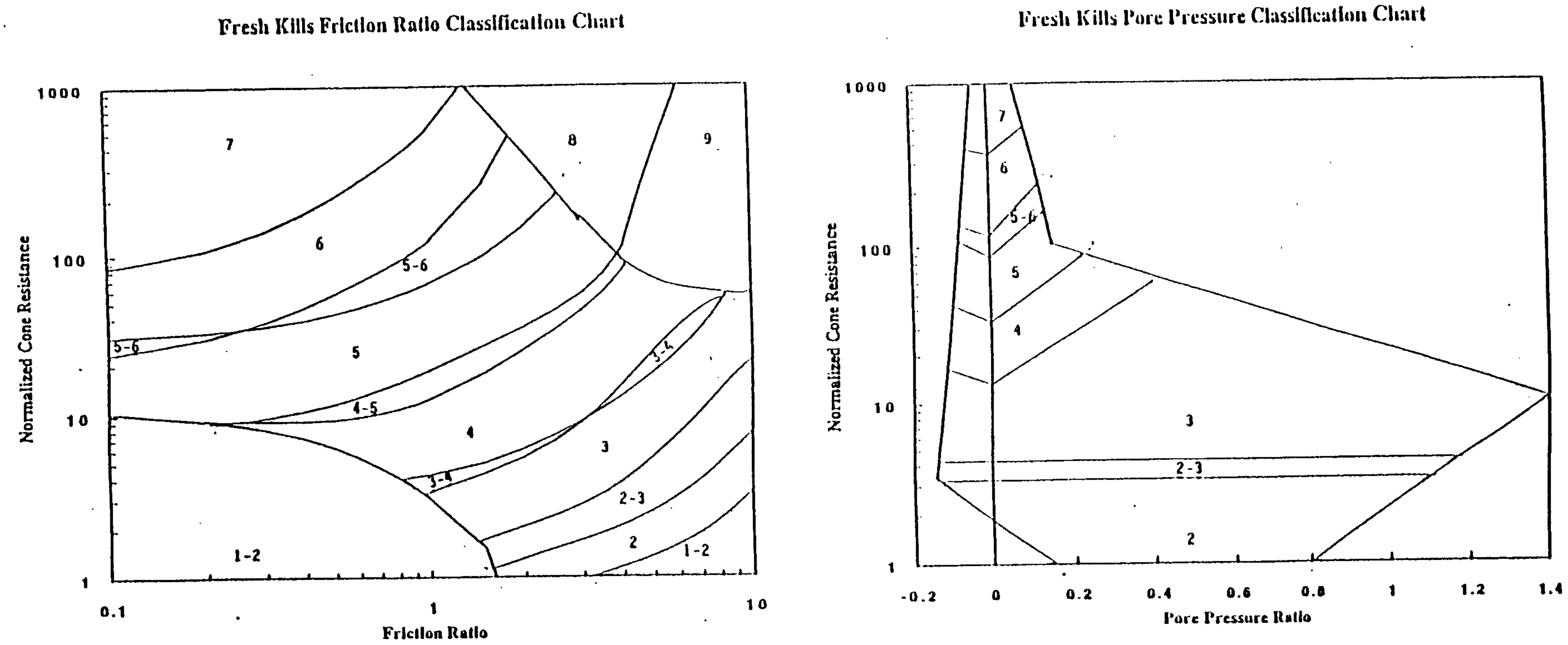
Major uncertainties associated with these predictions are the water resistivity as a function of degree of contamination (which is determined from laboratory testing), clay content (which greatly affects the soil grain conductivity), and degree of saturation and soil porosity. Of these, the clay content, degree of saturation and soil porosity have the greatest influence on the accuracy of the resistivity calculations.

13. Soil Classification From the CPT

The tip resistance, friction ratio, and pore pressure values from CPT profiles can be used to determine soil classification versus depth. The methodology used in this report to classify the soils is based on specific empirical correlations that were developed by Timian et al., 1992 (Ref. 11) and are summarized in the two charts shown in Figure 12. In general, clean, coarse grained soils have high strengths with relatively low sleeve friction, while finer grained soils have low strengths and high side friction (cohesion). Similarly, as shown in the second chart of Figure 12, a correlation exists between soil type and the ratio of tip stress to pore pressure response. Clean, coarse grained soils tend to have high strengths, but are permeable and develop little or no excess pore pressure during penetration. Fine grained soils are weak and impermeable and tend to develop high excess pore pressures during penetration.

Soil classification can be determined from the charts by comparing the normalized tip resistance to the pore pressure ratio or to the normalized friction ratio. The tip resistance is normalized according to:

$$q_n = \frac{q_T - \sigma_{vo}}{\sigma_{vo}'} \qquad (6)$$


Fresh Kills Friction Ratio Classification Chart

Fresh Kills Pore Pressure Classification Chart

FRICTION RATIO $\frac{f_s}{q_t - \sigma_{vo}} \times 100\%$

1. Sensitive, Fine Grained
2. Organic Soils-Peat
3. Clays - Clay to Silty Clay
4. Silty Mixtures - Clayey Silt to Sandy Silt
5. Sand Mixtures - Silty Sand to Sandy Silt

PORE PRESSURE RATIO $B_q = \frac{u - u_o}{q_t - \sigma_{vo}}$

6. Sands - Clean Sand to Silty Sand
7. Gravelly Sand to Sand
8. Very Stiff Sand to Clayey* Sand
9. Very Stiff, Fine Grained*

(*) Heavily Overconsolidated or Cemented

Figure 12. ARA's Soil Classification System Based on CPT Data.

where: q_n = normalized tip stress
q_T = corrected tip resistance from Equation 2
σ_{vo} = total overburden stress
σ_{vo} = effective overburden stress

The pore pressure ratio, B_q, is defined as:

$$B_q = \frac{u_{meas} - u_o}{q_T - \sigma_{vo}} \tag{7}$$

where: u_{meas} = measured penetration pore pressure
u_o = static pore pressure, determined from the water table elevation

and the normalized friction ratio, f_{SN} is defined as:

$$f_{SN} = \frac{f_s}{q_T - \sigma_{vo}} \times 100\% \tag{8}$$

The plot of any point of the q_n versus B_q or f_{SN} value normally falls in a classification zone of Figure 12. The classification zone number corresponds to a soil type as shown in the figure. The classification zone number is then used to determine the Unified Soil Classification System (USCS) profile (described below) which is then plotted versus elevation for each penetration test as shown in Figure 10b. At some depths, the CPT data will fall outside of the range of the classification chart. When this occurs, no data are plotted and a break is seen in the classification profile.

The next step in developing the soil classification profile is reconciliation of the similarities and differences between the two soil classification methods shown in Figure 12 into a single unified estimate, as shown in the classification profile indicated in Figure 10b. This profile represents a point by point weighted average of the two methods, with weighting factors based on confidence levels established for each measurement used in the classifications. These confidence levels are based on measurement amplitudes, consistency, and engineering experience with CPT data.

The classification profiles are very detailed, frequently indicating significant variability in soil types over small changes in elevation. In order to provide a simplified soil stratigraphy for comparison to standard boring logs, a layering and generalized classification system was implemented (i.e., soil unit descriptions located to the right of the classification profile). A minimum layer thickness of 1.0 feet was selected. Layer thicknesses are determined based on the variability of the soil classification profile. The layer sequence is begun at the ground surface and layer thicknesses are determined based on deviation from the running mean of the soil classification number. Whenever an additional 6-inch increment deviates from the running mean by more than 0.50, a new layer is started, otherwise, this material is added to the layer above and the next 6 inch section is evaluated.

The soil type for the layer is determined by the mean value for the complete layer. The ten types are classified as:

Classification Range	Soil Type
1.00 - 2.25	Sensitive Clay
2.25 - 2.75	Soft Clay
2.75 - 3.25	Clay
3.25 - 3.75	Silty Clay
3.75 - 4.25	Clayey Silt
4.25 - 4.75	Sandy Fine Grained
4.75 - 5.75	Sand Mixture
5.75 - 6.75	Sand
6.75 - 7.50	Gravelly Sand
7.50 - 9.00	Over Consolidated (OC)

Again, a more detailed classification can be determined from the classification profile plotted just to the left of the soil type (unit) layers. The profile summarizes the engineering classification of soil stratigraphy.

SECTION III
DATA DISCUSSION AND ANALYSIS

A. FIELD EFFORTS

1. Piezo/Resistivity/Soil Gas-CPT Testing

ARA completed five piezo/resistivity/soil gas (P/R/G) soundings on 2 December 1993 at locations 84B-PRG, 84C-1-PRG, 84C-2-PRG, 84D-PRG and 84E-PRG. Cone refusal was encountered at a depth of 17.2 feet below ground surface (bgs) at location 84C-1-PRG. The remaining four P/R/G soundings were advanced approximately five to ten feet into the water table with push depths ranging from 35.6 feet to 48.3 feet. Parameters measured during these pushes included pore water pressure, resistivity and several soil gas parameters (e.g., BTEX, TOC, water vapor, O_2/LEL and CO_2). ARA worked directly with Mr. Don Kampbell, Ph.D. from the U.S. EPA assisting in collecting soil gas data. A summary of all P/R/G soundings is included in Table 1. The results of these soundings will be discussed in Section II.B.1, 2 and 3. The P/R/G-CPT profiles are included as Appendix B.

2. LIF-CPT Soundings

Nine LIF-CPT soundings were completed during the course of this DT&E through a joint effort by ARA and Dakota Technologies, Inc. On 30 November, 1993 the first LIF-CPT sounding was completed at the upgradient (background) test location in the northwest corner of the FT-002 site. Due to a broken fiber-optic line, the remaining eight LIF-CPT pushes were postponed awaiting a new optical cable, which arrived at midday on 3 December, 1993. The remainder of the LIF-CPT pushes were completed on 3 and 4 December, 1993. Soundings were performed at locations 84A, 84B,84F, 84G, 84H, 84I, 84J, 84K, and 84L. The depths of these soundings ranged from 38 feet to 61.74 feet below ground surface. Pore water pressure was also measured during these pushes to allow determination of the water table. A summary of LIF-CPT soundings completed during this DT&E are presented in Table 1. The results will be discussed in Section III.B.4.

3. Water-CPT Sampling

ARA collected 17 discrete 1-liter groundwater samples from six locations near to the FT-002 fire training between 3 - 8 December, 1993. Samples were collected from locations 84B, 84E, 84F, 84M, 84N, and 84O at the depths indicated in Table 1. The sample depths were determined by Environmental-Science, Inc. and the U.S. EPA. The water samples were used to provide necessary data to support Bioplume II modeling efforts by Engineering-Science, Inc. The samples were subsequently analyzed by the U.S. EPA for various parameters including pH, dissolved oxygen, total organic carbon and volatile organic compounds.

Samples were collected using ARA's groundwater sampling probe that allows collection of water samples from discrete depth intervals. A 2-foot screened section was deemed adequate for the purpose of this investigation due to the relatively high permeability of the in situ soils. The sampling probe was thoroughly decontaminated using a high-pressure, hot water washer prior to use. A Teflon bailer was used to retrieve the samples after the wellpoint was set and purged. The results of the groundwater sampling were unavailable as of the date of this report and will be discussed in a subsequent report.

4. Soil-CPT Sampling

ARA collected 39 soil samples from five locations proximate to the FT-002 fire training area during the period from 4 to 10 December 1993. Samples were collected from locations 84B, 84D, 84F, 84L and 84P at the depths indicated in Table 1. The intent of the soil sampling was to provide data to substantiate the findings of both the resistivity and LIF data. The soil samples were obtained using both the 5-foot and the 2-foot Mostap® soil samplers. The samples were subsequently analyzed for total petroleum hydrocarbon (TPH) on a portable gas chromatograph by representatives of the U.S. EPA. The sampling apparatus was thoroughly decontaminated between samples using a high-pressure hot water washer. The results are discussed in Section III.B.5.

5. Small-diameter CPT Monitoring Well Installation

One small-diameter monitoring well was installed as part of the Plattsburgh AFB demonstration. The purpose of this installation was to demonstrate the utility of the CPT rig for well installation. The well point was designed as presented in Figure 13. As shown, the well

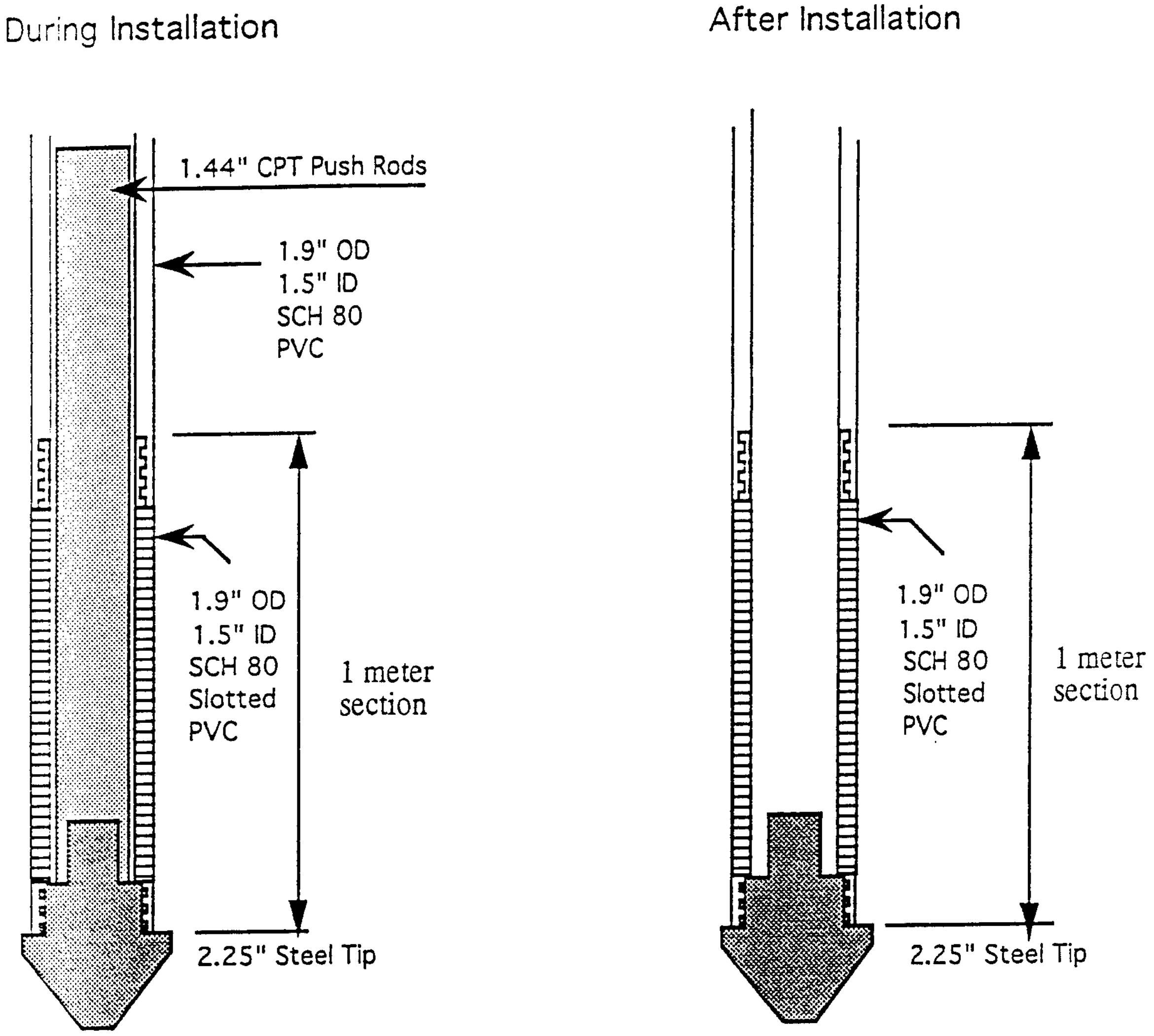


Figure 13. Schematic of Small Diameter Monitoring Well Installation.

point consists of a slightly oversized steel push point threaded onto one meter sections of flush threaded 1.5 inch PVC. The PVC used for this well consisted of schedule 80 PVC, either slotted to allow water into the well or solid to act as a riser. The outer diameter of the well was 1.9 inches while the inner diameter was 1.5 inches. The well point was pushed into the ground, using 1.44-inch CPT push rods. One meter sections of the PVC were added per push rod to incrementally advance the well. Once the well reached the final depth the CPT push rods are recovered, completing the installation. The current installation method allows a maximum soil drag force of 2650 pounds on the well materials. By using an oversized tip, the drag force on the PVC well sections are minimized for this geology. Other geologies may require a modification to control these drag forces. Once the well is set, the soils, which are under compression from the well installation process, expand to fill in the annulus created by the oversized tip. This seals the well against vertical migration. Installation of the well took place on December 10, 1993 at location 84P, which is located between FT-002 and the fence bordering the flightline. The well was completed to a depth of 33 feet in a period of one hour. At this location, the groundwater table is located at a depth of 28 feet, and the well was screened from 26.5 to 33 feet using two one meter screened sections. A key item to note is that no drilling waste was generated during this installation.

Based on this demonstration, these well points can be very economically installed. The materials costs are $5.10 per foot for screen sections and $2.92 per foot for the riser material. Installation time was approximately one hour at CPT rates ranging from $225.00 to $300.00 per hour. Therefore the cost for installation of this well was on the order of $350.00. No drilling wastes were generated so there were no disposal costs.

B. INTERPRETATION OF RESULTS

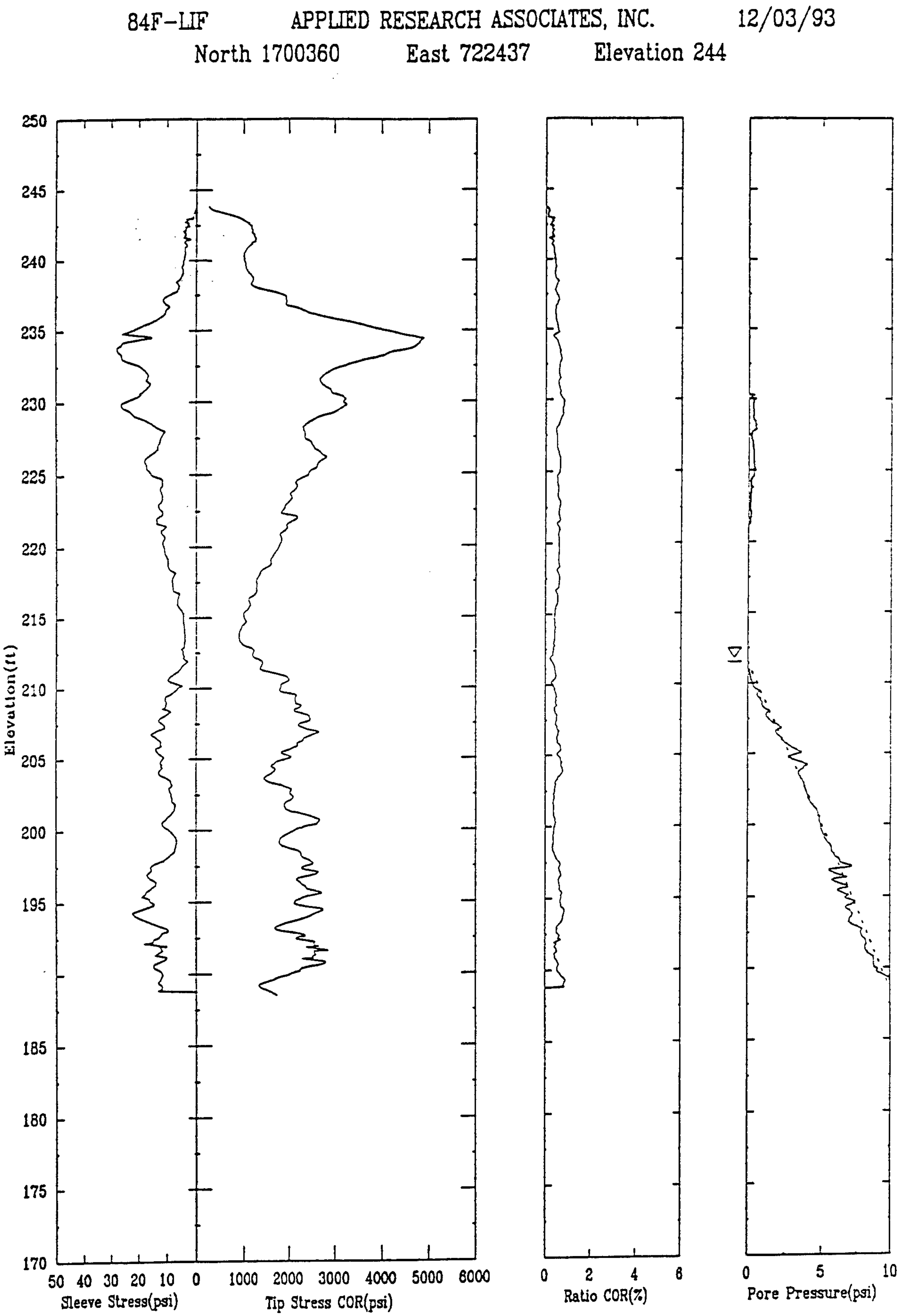
1. Typical P-CPT Profile

The CPT is considered one of the premier in situ techniques for determining soil stratigraphy and type. With the recent development of probes to detect soil and water contamination, the CPT is seeing increased use in environmental investigations. As the technique is relatively new to the United States geotechnical and environmental communities, a basic description of the process used to analyze CPT data is provided.

Comparison of tip stress, friction ratio and penetration pore pressure profiles are the most important parameters for estimating soil type and stratigraphy from CPT data. The magnitude of the tip resistance is a function of the strength of the soil, with stronger materials having higher tip resistances. Tip resistance also increases as the coarse grained soil content increases, and decreases as the fine grained content increases. The degree of consolidation of the soils can influence tip resistance with both the tip and sleeve stresses increasing as the degree of consolidation increases. Over consolidation can be caused by previous loading of the soil or desiccation. For a given soil, the tip stress increases with depth due to the increase in geostatic stresses.

The friction ratio is a good indicator of the cohesiveness of the soil, which in turn reflects the fine-grained soil content. Soils which are predominantly fine grained have friction ratios generally greater than 2, and sandy soils have ratios of 2 or less. Weak and sensitive clays will have friction ratios of less than 2. The penetration pore pressure response is a function of the soil's shear strength and stiffness, hydraulic conductivity and density. For normally consolidated soils, the penetration pore pressure will be greater than the static pore pressure for clays and silts and equal to the static pore pressure for clean sands. In overconsolidated, dense soils the pore pressure response can be less than the static pore pressure, especially in those soils which tend to dilate, such as silty sands. The combination of the friction ratio and pore pressure response provides a good identification of the soil stratigraphy. With this basic understanding of the P-CPT data, an analyst can interpret the stratigraphy and soil types visually as described below.

A typical penetration profile from the Plattsburgh AFB is presented in Figure 14a. This profile (84F-LIF) was completed to a depth of 55 feet and is representative of the geologic conditions at Plattsburgh AFB. These data as well as the other penetration data are presented in Appendices A and B. These plots include the sleeve stress, tip resistance, friction ratio, penetration pore pressure, and baseline LIF counts measured during the test, along with the soil classification and soil stratigraphy calculated from the data. For location 84F-LIF, the friction ratio profile is consistent and indicates that a sand material is present throughout the entire profile since the friction ratio is below one. Although the entire profile is all sand, the tip and sleeve measurements indicate that there are some minor variance in the sands, especially in regards to the strength and density of the sand. As the soil at this site is classified as a sand, changes in the sleeve and tip resistance with depth are largely related to the in situ density and gravity stresses. With this understanding, the increase in tip resistance at elevation 238 to 234 feet can be interpreted as an increase in the sand density. Below elevation 234 feet, the tip resistance decreases, reflecting a decrease in the sand density. The lowest tip resistance and, hence, the loosest sand zone in the entire profile exists between elevation 216 to 212 feet . From Elevation



84F-LIF APPLIED RESEARCH ASSOCIATES, INC. 12/03/93
North 1700360 East 722437 Elevation 244

Figure 14. Penetration Profile Representative of In Situ Geologic Conditions at Plattsburgh AFB.

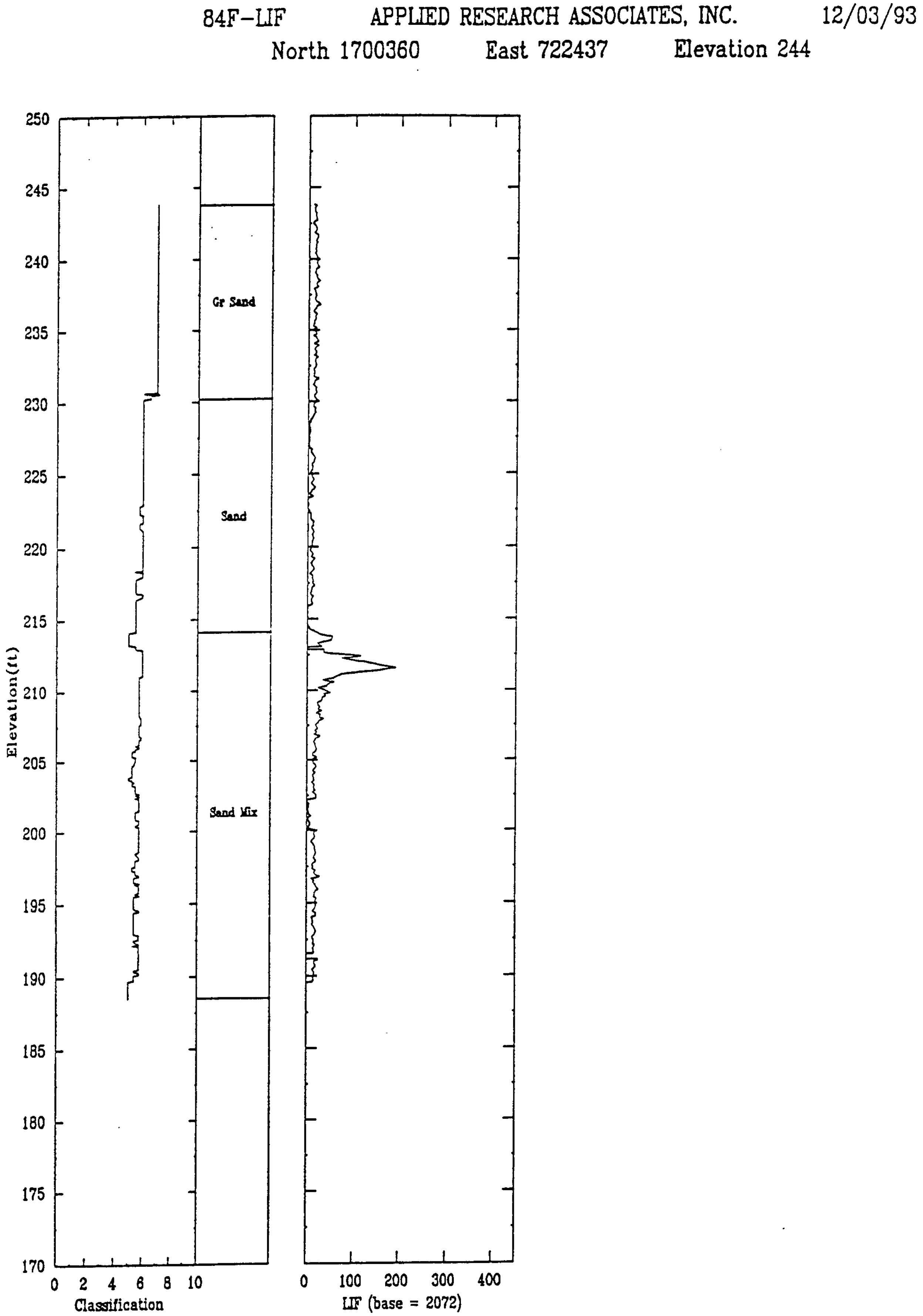


Figure 14. Penetration Profile Representative of In Situ Geologic Conditions at Plattsburgh AFB (Continued).

212 feet to the end of the profile at Elevation 189 feet the sand is fairly uniform, as exhibited by the tip stress profile.

The other information that can be gathered from the CPT data is the elevation of the water table. In sand materials the pore pressure will track along the hydrostatic line due to the permeable nature of sands. The hydrostatic can be extended to the intersection of zero pore pressure line. These two line will intersect at the elevation of the water table. For location 84F-LIF the water table elevation was determined to be 211.5 feet. This process was used to determine the water table for all CPT locations.

The LIF profile in Figure 14b, shows a sharp increase between elevation 215 to 210 feet. This zone, which lies principally above the water table, is interpreted to contain oily-phase fuel contamination, as will be further discussed in Section III.5.

2. Analysis of Resistivity Measurements

Soil resistivity profiles were measured using a CPT resistivity module at five locations during the demonstration. The objective of the resistivity measurement was to identify the extent of the oily phase petroleum product (oily phase) located above the water table. Since the fuels are nonconductive, high resistivity values were expected in zones of contamination. To make successful measurements the contaminant resistivity must be higher than the natural resistivity of the dry sands. For the Plattsburgh site this contrast was small based on the dry soil types (i.e. sands), although since the contamination is expected in the capillary fringe (i.e., floating on the water table) the contrast will increase as the soil water content increases, which decreases the resistivity. If the sand is moistened with fuel then the resistivity will increase over clean moist sand and most likely be higher than drier sands near the ground surface. Using these concepts the resistivity profiles were analyzed to determine the extent of the oily phase plume.

One of the five resistivity profiles (84C-1-P/R/G) reached refusal at a shallow depth in the dense sands located at an elevation of 17.2 feet below ground surface (bgs). This profile will not be discussed in this analysis. Of the other four profiles, the oily phase smear zone above the water table can be determined in two locations, whereas in the other two profiles it is difficult to tell if the oily phase is present. The locations where the oily phase can be seen are locations 84B-P/R/G and 84C-2-P/R/G (see Figures 15, and 16, respectively). The two locations

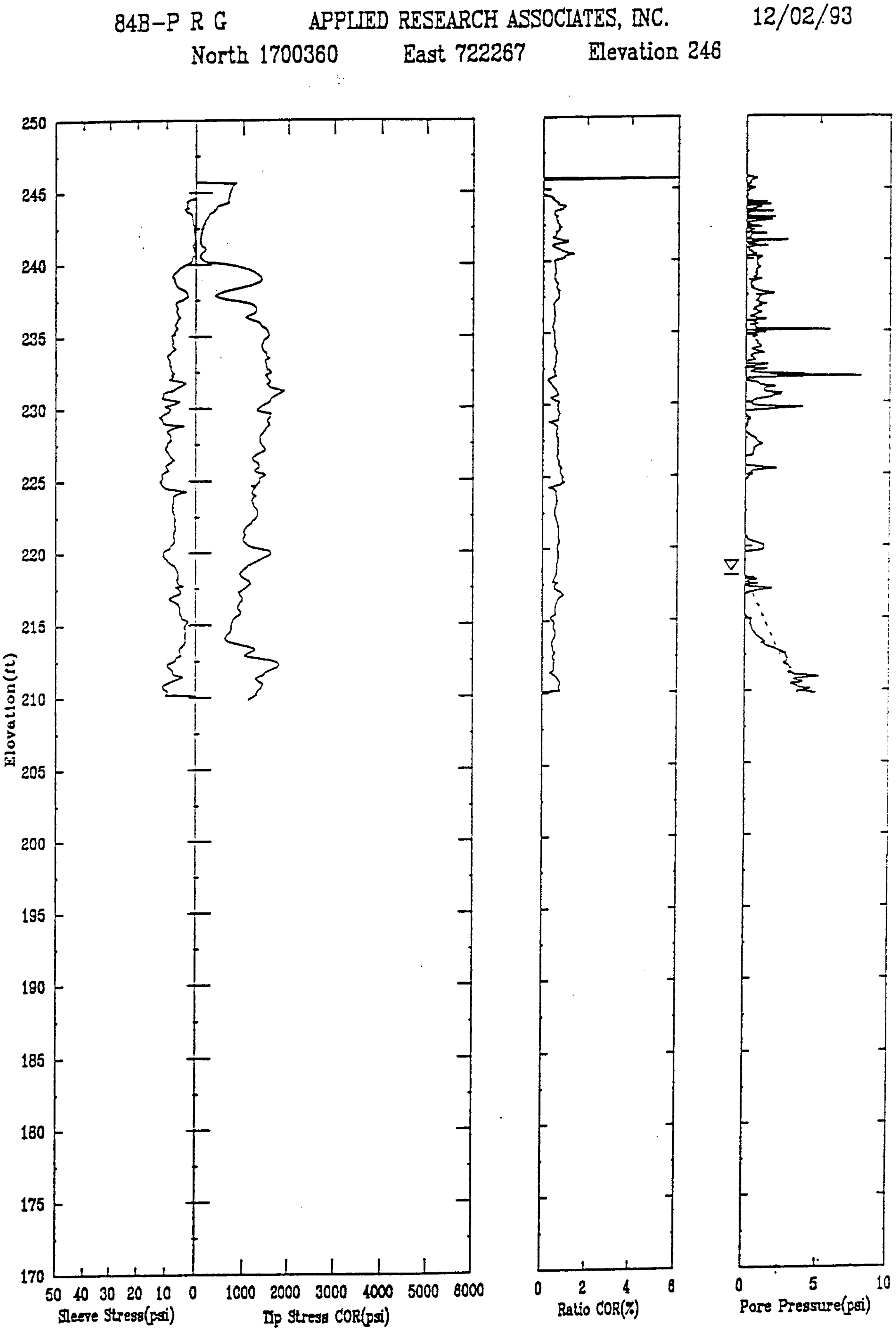


Figure 15. Resistivity Profile Indicating a Potentially Contaminated Zone from Elevations 220 feet to 225 feet MSL.

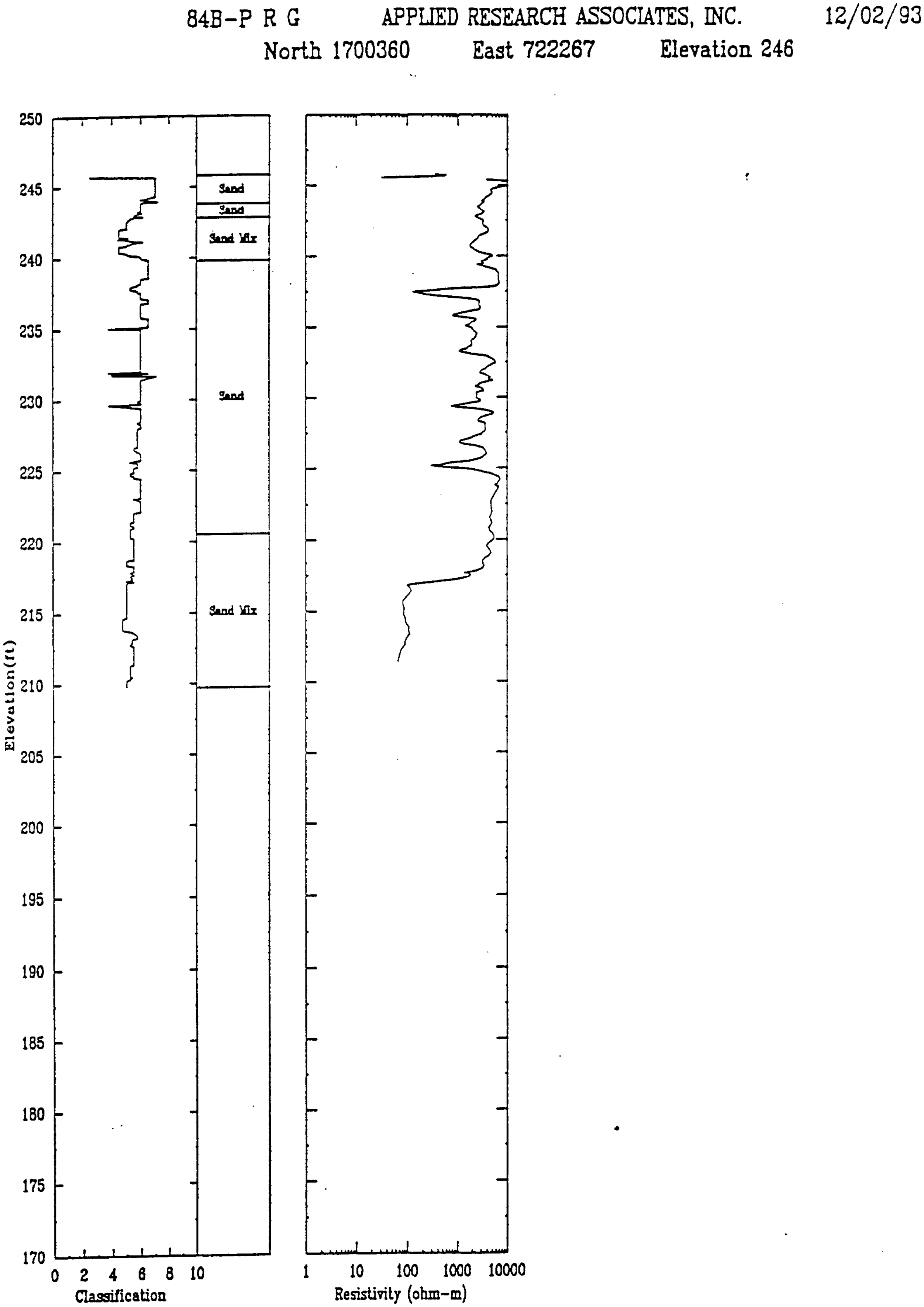


Figure 15. Resistivity Profile Indicating a Potentially Contaminated Zone from Elevations 220 feet to 225 feet MSL (Continued).

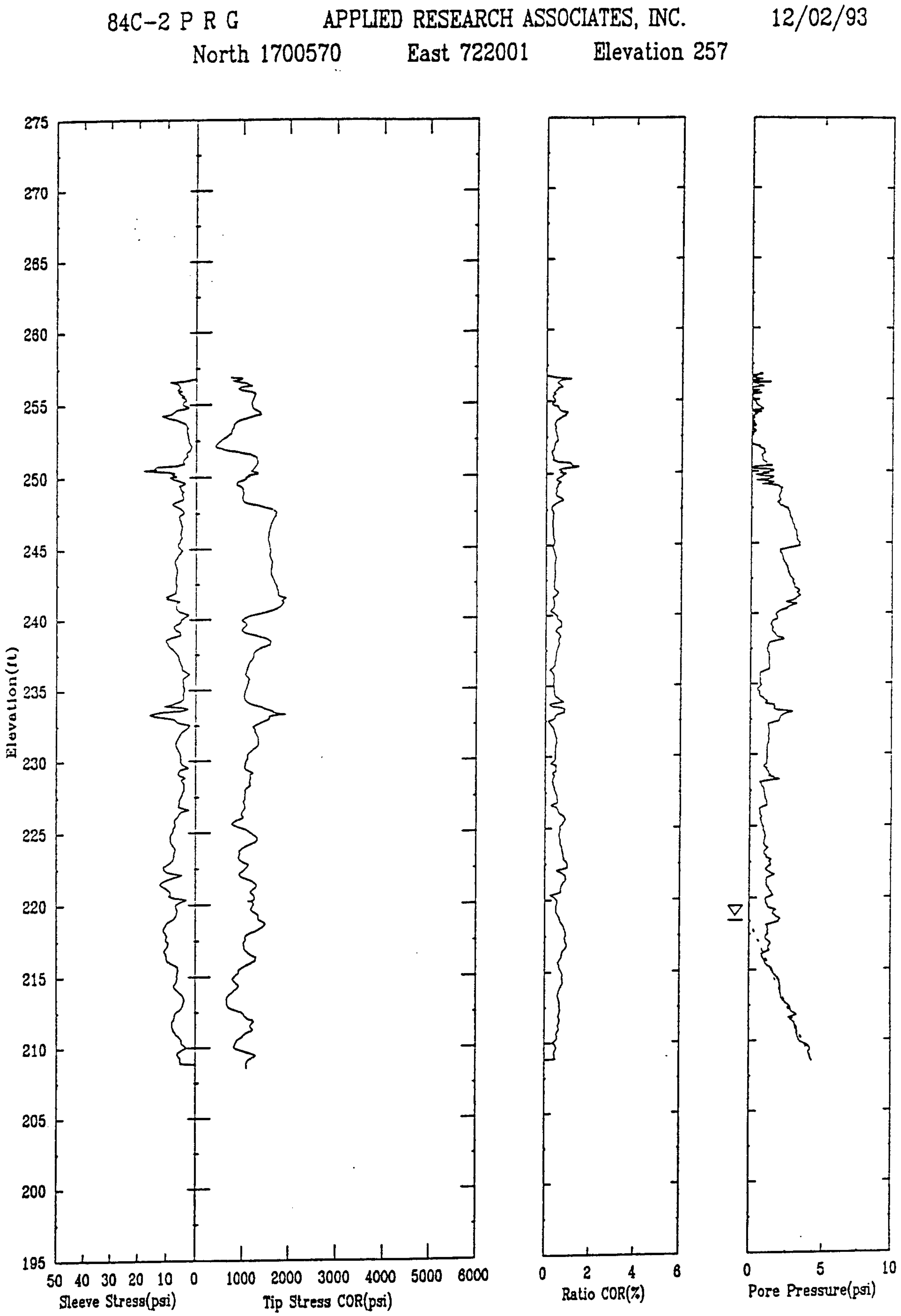


Figure 16. Resistivity Profile Indicating a Potentially Contaminated Zone from Elevations 218 feet to 224 feet MSL.

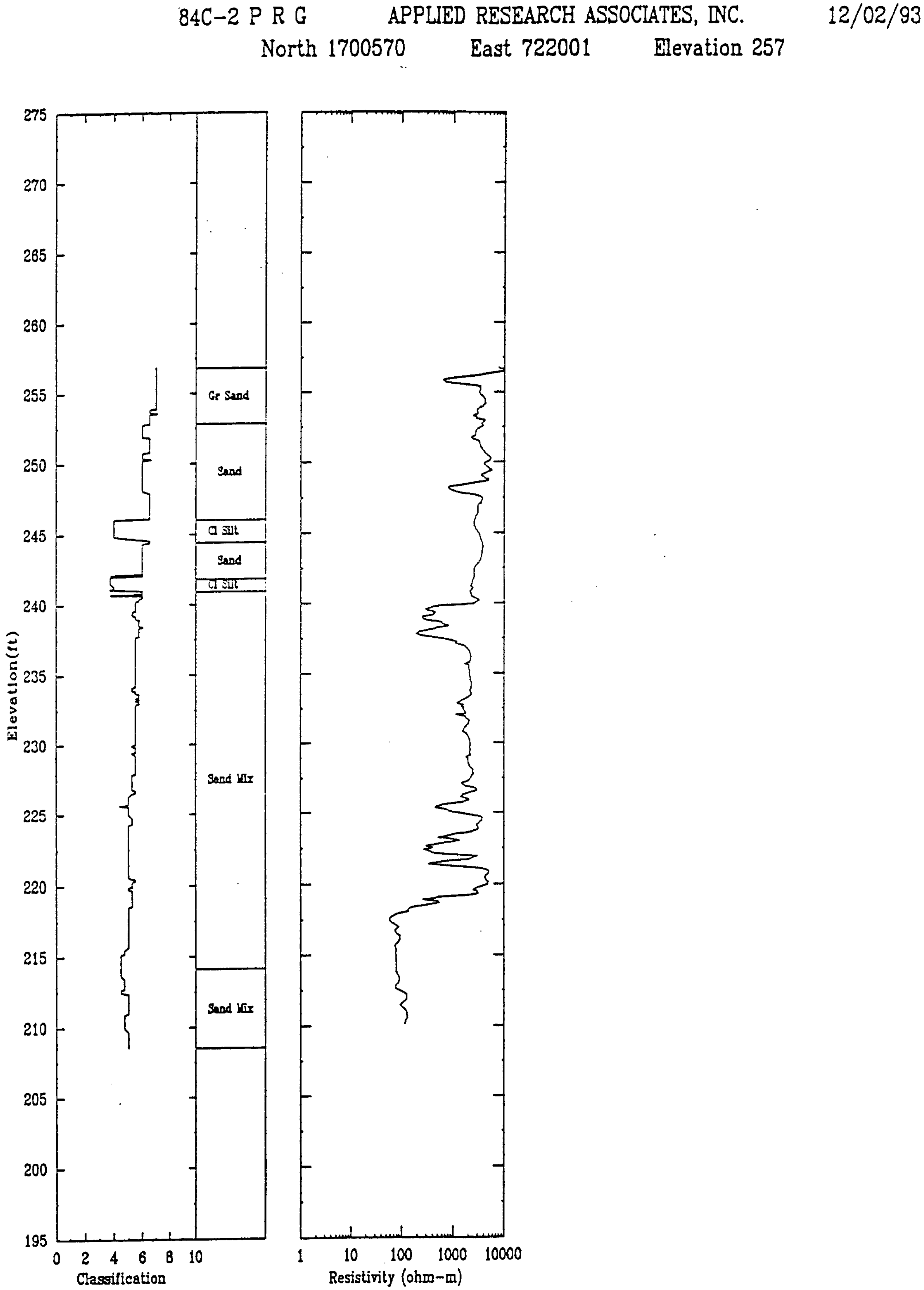


Figure 16. Resistivity Profile Indicating a Potentially Contaminated Zone from Elevations 218 feet to 224 feet MSL (Continued).

where the presence of a smear is more difficult to determine are locations 84D-P/R/G and 84E-P/R/G (see Figures 17 and 18, respectively).

At location 84B-P/R/G (Figures 15), the resistivity profile indicates a potentially contaminated zone from elevation 225 to 220 feet above mean sea level, with the water table being located at elevation 218.5 feet. The oily phase is identified by an increase in the peak resistivity to almost 4000 ohm-m whereas the same soil material from elevation 235 to 227 has a peak resistivity value of 2000 ohm-m. The same trends seen at location 84B-P/R/G (Figures 15) are also present at location 84C-2-P/R/G (Figure 16). At this location the oily phase is interpreted to be present from elevation 224 to 223 feet and again from 221.5 to 219, in a uniform material the extends from elevation 241to 214 feet. In the upper regions of this material the resistivity averages 2500 ohm-m whereas the lower region immediately above the water table averages 4500 ohm-m. Both of these locations are along the postulated flow line of the contaminant plume and therefore could be expected to exhibit a smeared oily-phase zone. Location 84B was also tested using LIF, and the LIF did indicate the potential for contamination, although not nearly to the levels found further down gradient. In addition, the detection limit of the LIF has not been determined, and there are significant differences in the soil region being measured between the two devices. The resistivity measures a soil sphere of approximately 4 inches in diameter located at the centroid of the resistivity module, whereas the LIF is measuring only a spot just outside the surface of the probe.

Determination of contamination at locations 84D-P/R/G and 84E-P/R/G were much more difficult and the analysis was not conclusive enough to say contamination was present. At location 84D-P/R/G (Figure 17) which is located in the old fuel pit, the resistivity of the sands are high in all regions including the capillary fringe. Although this might suggest contamination, there is a soil change from 225 to 220 feet and it is difficult to separate the soil resistivity from the potential contamination resistivity. In addition the average resistivity over this range is only 1500 ohm-m which is significantly lower than measured elsewhere. For these reasons, the oily phase could not be defined at this location. In comparison, the LIF response at this location was fairly low indicating a low level of contamination but over a large zone. The LIF contamination zone does span the zones of high resistivity measured at this location (241 to 220 feet) but the contamination can not be separated from the dry soil resistivity to successfully say this zone contains oily phase material.

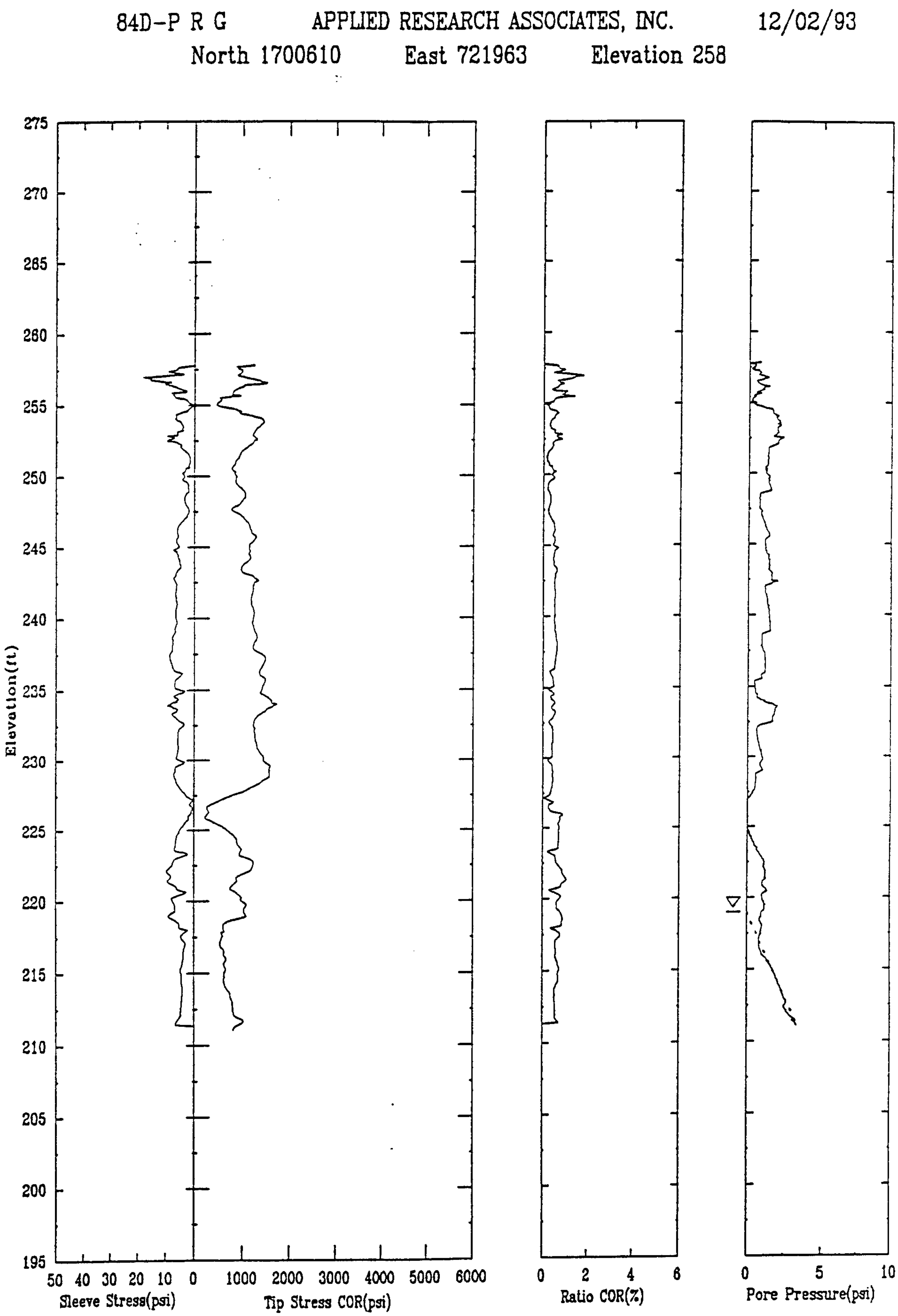


Figure 17. Resistivity Profile from Location 84D-P/R/G. Determination of Contamination from Resistivity Profile of this Area is Inconclusive.

84D-P R G APPLIED RESEARCH ASSOCIATES, INC. 12/02/93
North 1700610 East 721963 Elevation 258

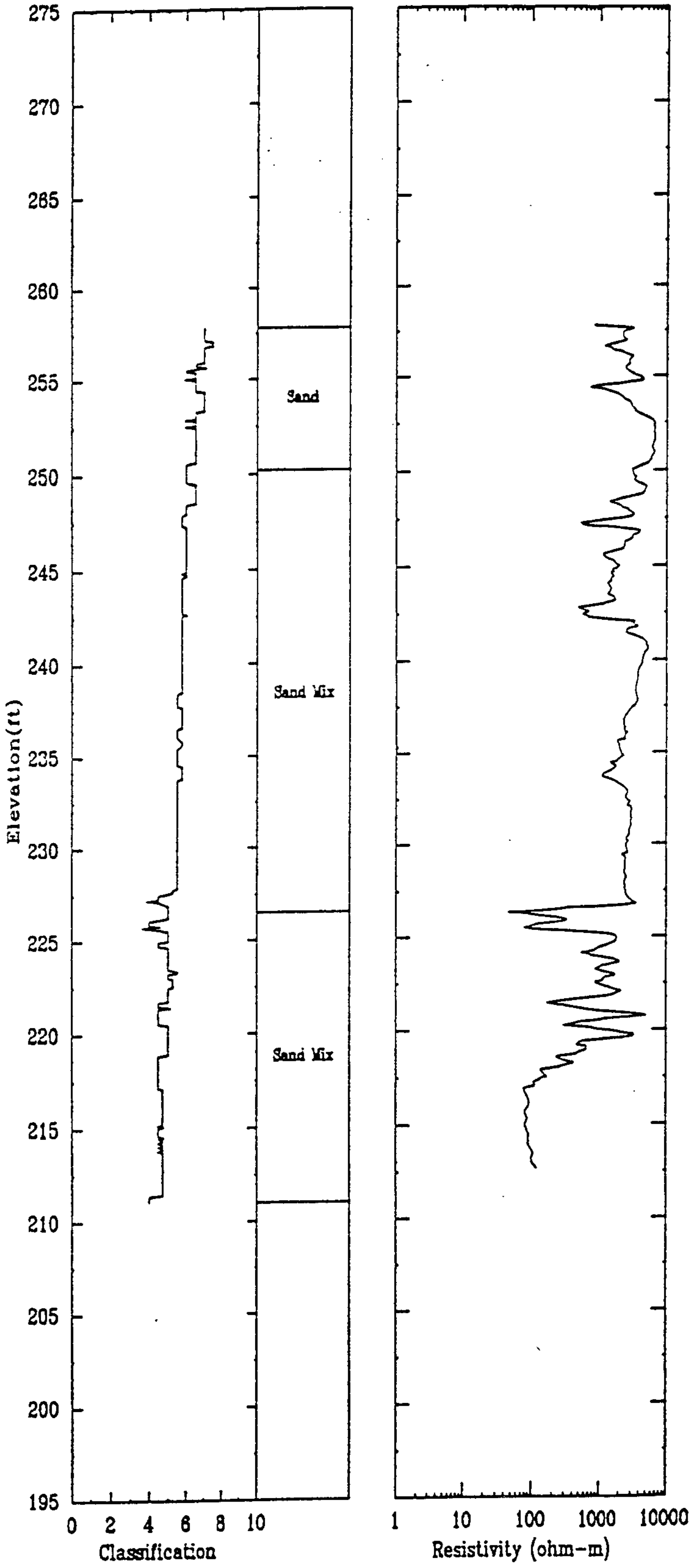


Figure 17. Resistivity Profile from Location 84D-P/R/G. Determination of Contamination from Resistivity Profile of this Area is Inconclusive (Continued).

The final location 84E-P/R/G (Figure 18) tested with the resistivity CPT was determined to be located in front of the toe of the contaminant plume. Once again the average resistivity located in the zone five feet above the water table is the same as the resistivity measured from 5 to 10 feet above the water table, making determination between the dry soil effect and the contamination effect difficult to separate. Although a LIF profile was not determined at this location, neighboring profiles indicate that this location is in front of the contamination plume.

In summary, the results of the resistivity profiles are in good agreement with the plume locations although interpretation of the results was based upon a small resistivity contrast. The general interpretations of the resistivity profiles made in the field were beneficial in directing the location of subsequent penetrations. At other sites where the resistivity contrast between clean and contaminated soil is more significant, the resistivity profiles will be more useful and conclusive than they were for this demonstration.

3. Soil Gas Sampling Measurements

ARA's piezo/resistivity probe was modified to allow simultaneous collection of soil gas samples. The probe was modified by adding a sintered steel filter to an existing piezo/resistivity probe. The filter material was designed to prevent migration of silt- and clay-sized particles into the polypropylene sampling line. A peristaltic vacuum pump was connected to the sampling line to draw the soil gas to the surface for analysis by a variety of portable gas analyzers. The soil gas was analyzed for benzene, toluene, ethylbenzene and xylene, total organic hydrocarbons and water vapor using a Bruel and Kjaer (B&K) model 1302 gas analyzer. Additional parameters were monitored by the U.S. EPA, including O_2/LEL and CO_2.

Two problems were encountered during soil-gas sampling at Plattsburgh AFB. The first is with regard to the vacuum pump used on the project. In ARA's previous work with this system, a high flow rate (2 liter/min) metal bellows pump system which incorporated a digital flow meter was used. By monitoring and controlling the flow rate, adequate flow to the soil-gas monitoring device was insured. When making measurements during a push, the depth at which the gas sample was obtained was backcalculated using the length of tubing to calculate the volume of gas concentration as a function of time.

With the peristaltic pump system, the flow rates were much lower (on the order of 300 cc/min) and were not monitored. Hence, determination of adequate flow through the

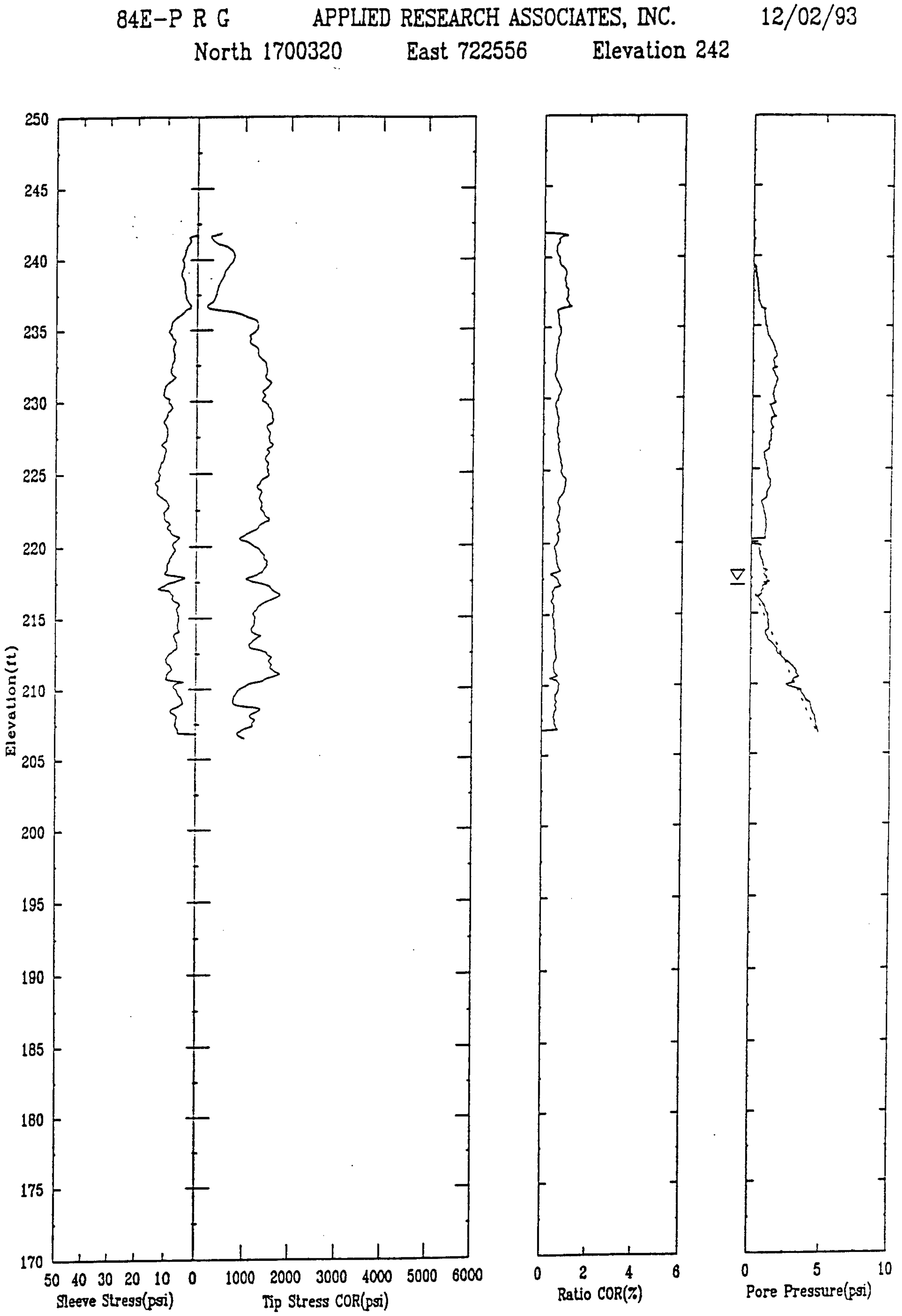


Figure 18a. Resistivity Profile from Location 84E-P/R/G. Determination of Contamination from Resistivity Profile of this Area is Inconclusive.

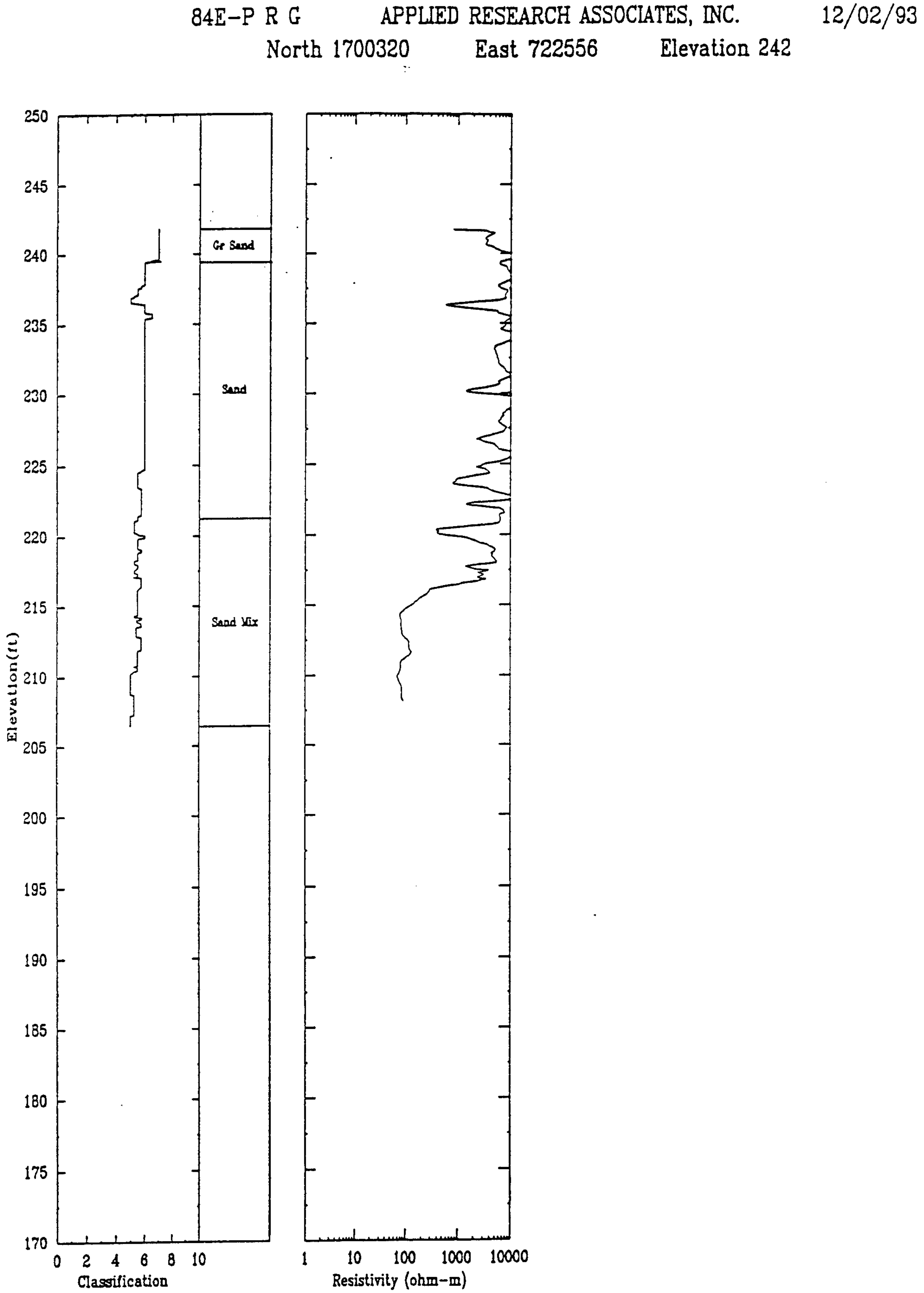


Figure 18b. Resistivity Profile from Location 84E-P/R/G. Determination of Contamination from Resistivity Profile of this Area is Inconclusive (Continued).

porous filter was not possible. On future demonstrations, the higher flow rate pump system should be used along with the digital flow meter. With this system, time required to clear the sample tubes can be decreased, the flow rates increased, and flow conditions monitored.

The second problem that occurred was that after the first push, the sintered metal appeared to have smeared and became clogged, constricting the gas flow. To alleviate this problem, it is recommended that (1) the filter be changed after every sounding, and (2) the metal filters be replaced with ceramic filters that are not as prone to smearing.

ARA presents the data collected by the B&K in Appendix C for review, however, the validity of the data is suspect. Soil gas data collected by the U.S. EPA were unavailable for reporting at this time.

4. Phreatic Surface Determination

A contour plot of the water table based solely on the Piezo-CPT data derived from the DT&E is plotted in Figure 19. The map shows that the direction of water flow is generally southeast with an average hydraulic gradient of 4%. The contour map developed from the Piezo-CPT data is in good agreement with that developed from monitoring well data presented in the ABB/URS, 1993 report. Contour maps are sensitive to the number and distribution of data points. As these maps are made from only the CPT data, the plots are being treated as preliminary, and are used to show only general trends. Additional data are required to reduce the uncertainty in these plots. ARA attempted to incorporate gauging data from existing monitoring wells that were collected by Engineering-Science, Inc. The monitoring well surface datum appeared to be in error for some of the well locations and, due to this uncertainty, these data could not be used to determine the phreatic surface.

5. Evaluation of the LIF-CPT Results

One of the primary goals for the demonstration was to locate the toe of the oily phase plume. This was accomplished using the LIF-CPT tool to rapidly screen a variety of locations. North-south and east-west cross-sections of the LIF count data are plotted in Figure 20 and 21, respectively, with the depth of suspected contamination highlighted in each figure. The first location tested was 84A-LIF (see Figure 20). This location was tested to establish the natural background fluorescence levels for the LIF-CPT on clean Plattsburgh soils. As expected the

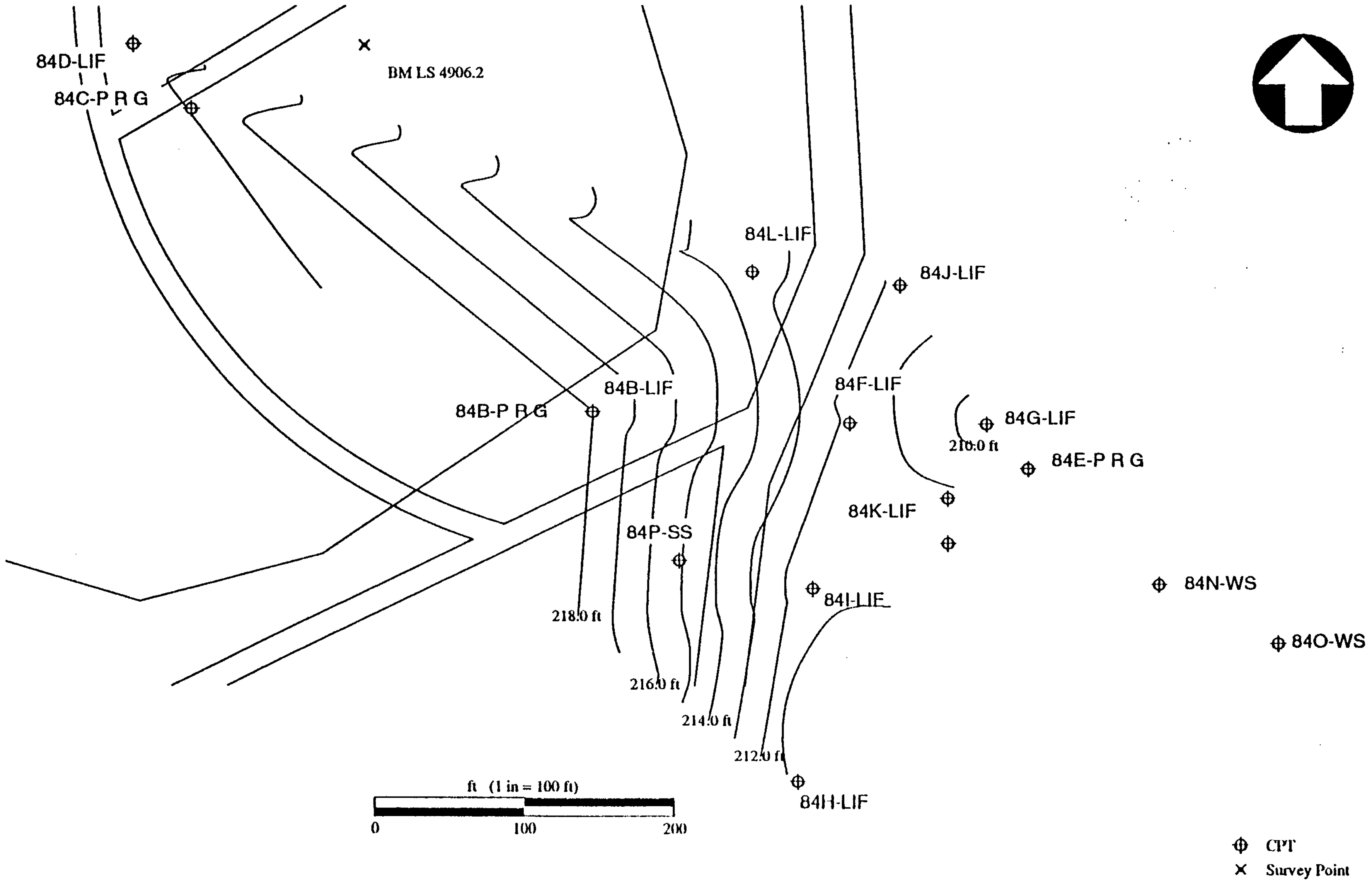


Figure 19. Plan View of Water Table Contours Based on CPT Data.

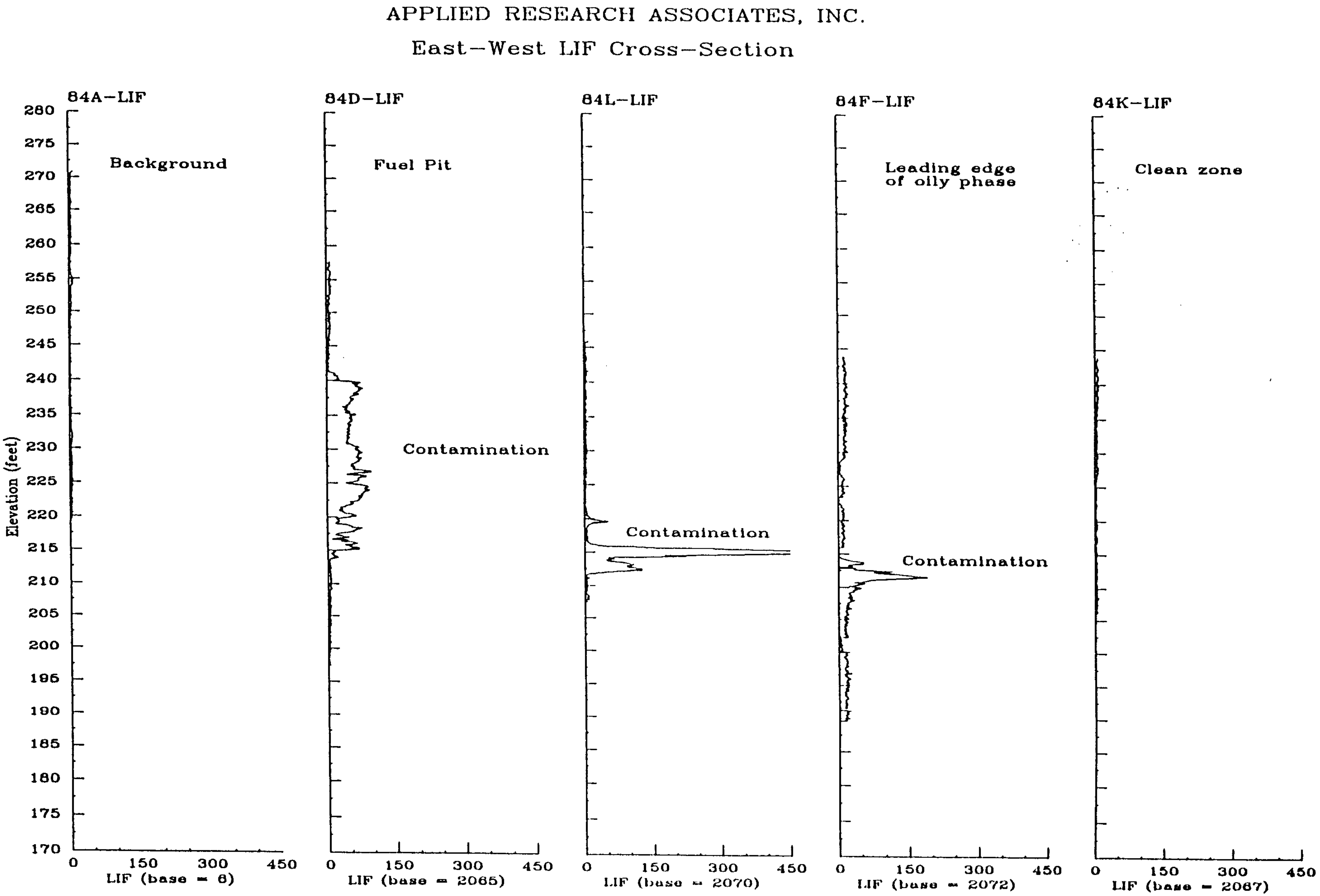


Figure 20. North-South Cross-Section of LIF Count Data.

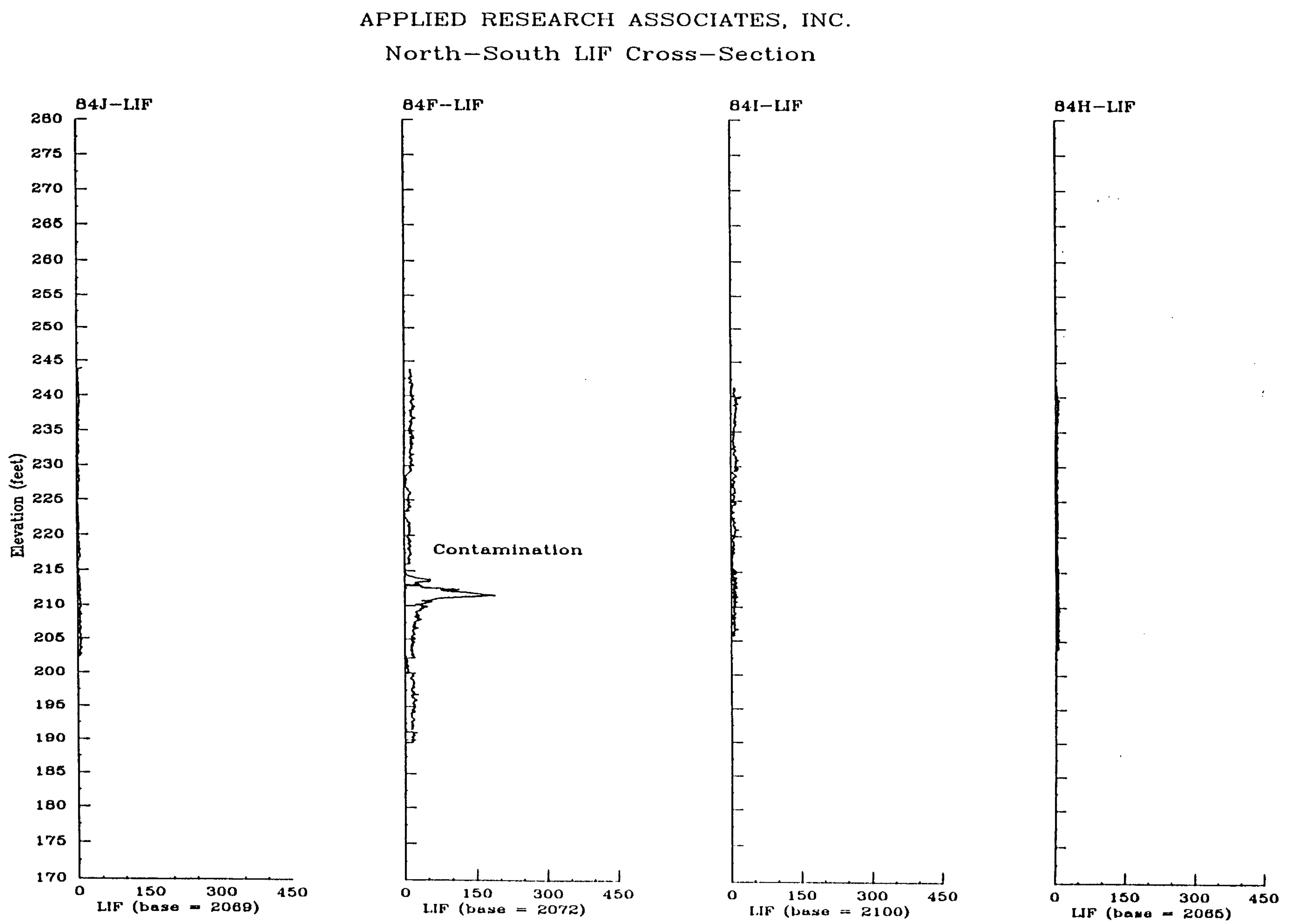


Figure 21. East-West Cross-Section of LIF Count Data.

average LIF response was very low averaging well below 10 counts for the entire profile. All the LIF results will be reported in counts since the laser system has not been calibrated to a more qualitative measuring system. Volume I of this report presents analysis of the soil sample and correlation to the LIF data.

After testing in the background area, the second test was conducted at location 84B-LIF (see Figure 22). The test was conducted after the fiber-optic repair and represents the first test using the new fiber-optic cables. This entire profile shows an instrument drift as the temperature of the optics were warming up. Other than the instrument drift, a zone of fluorescence above the back ground level can bee seen from elevation 215 to 212 feet MSL. This is interpreted to be the oily phase plume fluorescence. Had the instrument not been drifting and corrections made for the power loss of the laser system during this drift, the magnitude would had been approximately 120 counts or about 4 times higher than the uncorrected 30 counts. Since a positive response occurred on this test, the next location was moved further southeast (i.e., down gradient) to find a location in front of the plume. At location 84F-LIF (Figure 20), the oily phase plume was again discovered at elevation 215 to 210 feet MSL. The peak LIF response at this location was quite high with a maximum of 190 counts. This indicates that at this location the oily phase plume is more concentrated than at location 84B-LIF. The final test conducted on December 3rd, was at location 84G-LIF. This profile is presented in Figure 23, and is typical of a profile interpreted to be out of the oily phase plume. The majority of the profile is below 20 counts, which is well below the other plume locations which had LIF counts of 100 or greater. Since this test was interpreted to be clean, the toe of the oily phase plume was determined to be located between locations 84F-LIF and 84G-LIF. These two locations are within 95 feet of each other, indicating that the edge of the plume is known within 85 feet.

Testing on December 4 was conducted to determine the width of the plume through location 84F-LIF. The first two tests (84H-LIF and 84I-LIF) were conducted south of location 84F-LIF as shown in Figure 2, with a cross-section of the data plotted in Figure 20. Both of these tests indicated no oily phase as evident by peak profiles values well below 20 counts. Location 84J-LIF, located 100 feet north of location 84F-LIF, was tested next and again this location had LIF counts well below 10, indicating no oily phase plume (see Figure 20). Based on this information the shape of the oily phase plume appears to be fairly thin, with the apex located around point 84F-LIF. To test this hypothesis, location 84K-LIF (see Figure 20) was tested southwest of 84F-LIF. Results were negative at this location, with all LIF measurements below 10 counts. The final LIF-CPT measurement made was at location 84L-LIF (see Figure 21). This

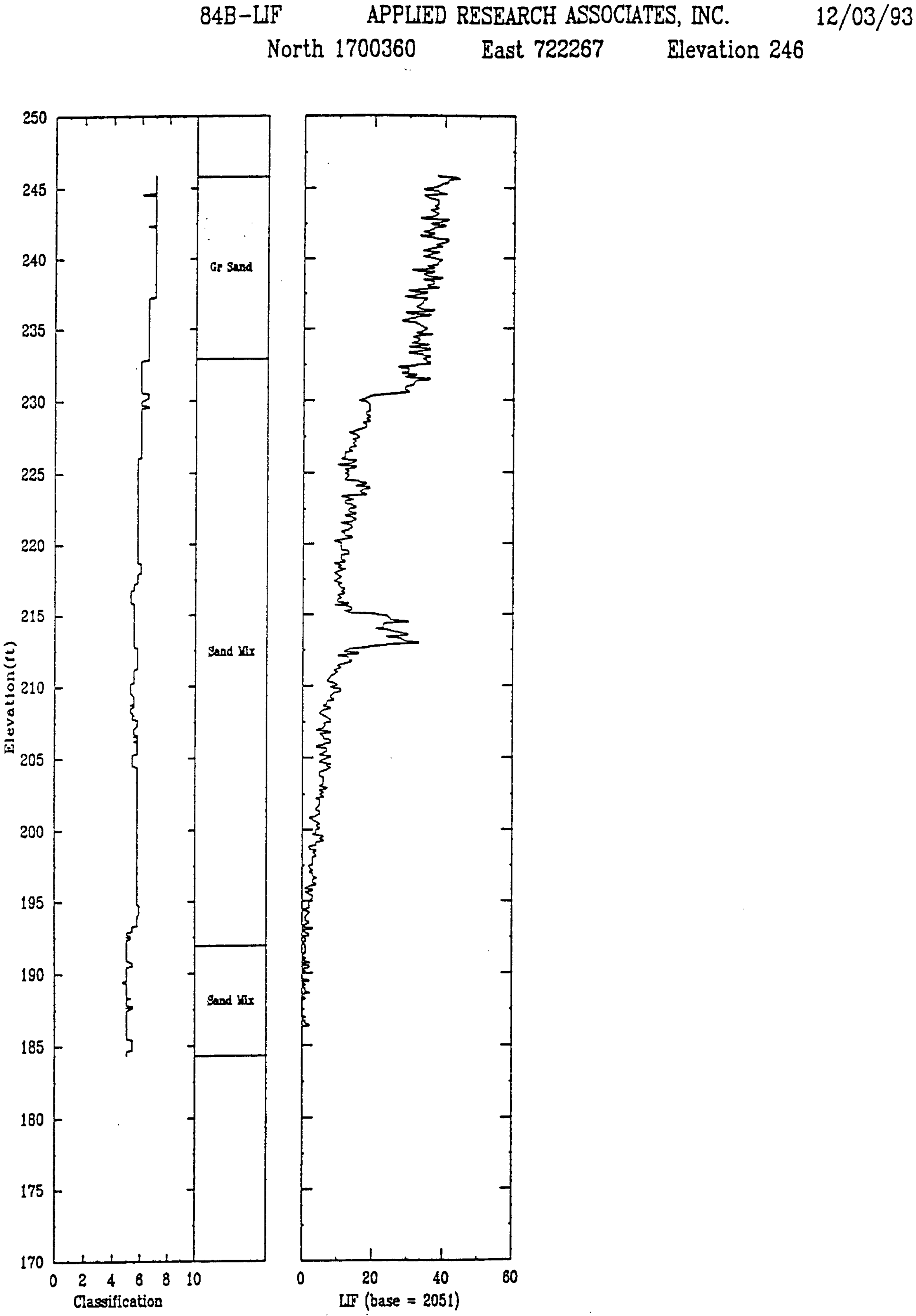


Figure 22. LIF-CPT Profile Illustrating Instrument Drift as the Temperature of the Optics Warmed Up.

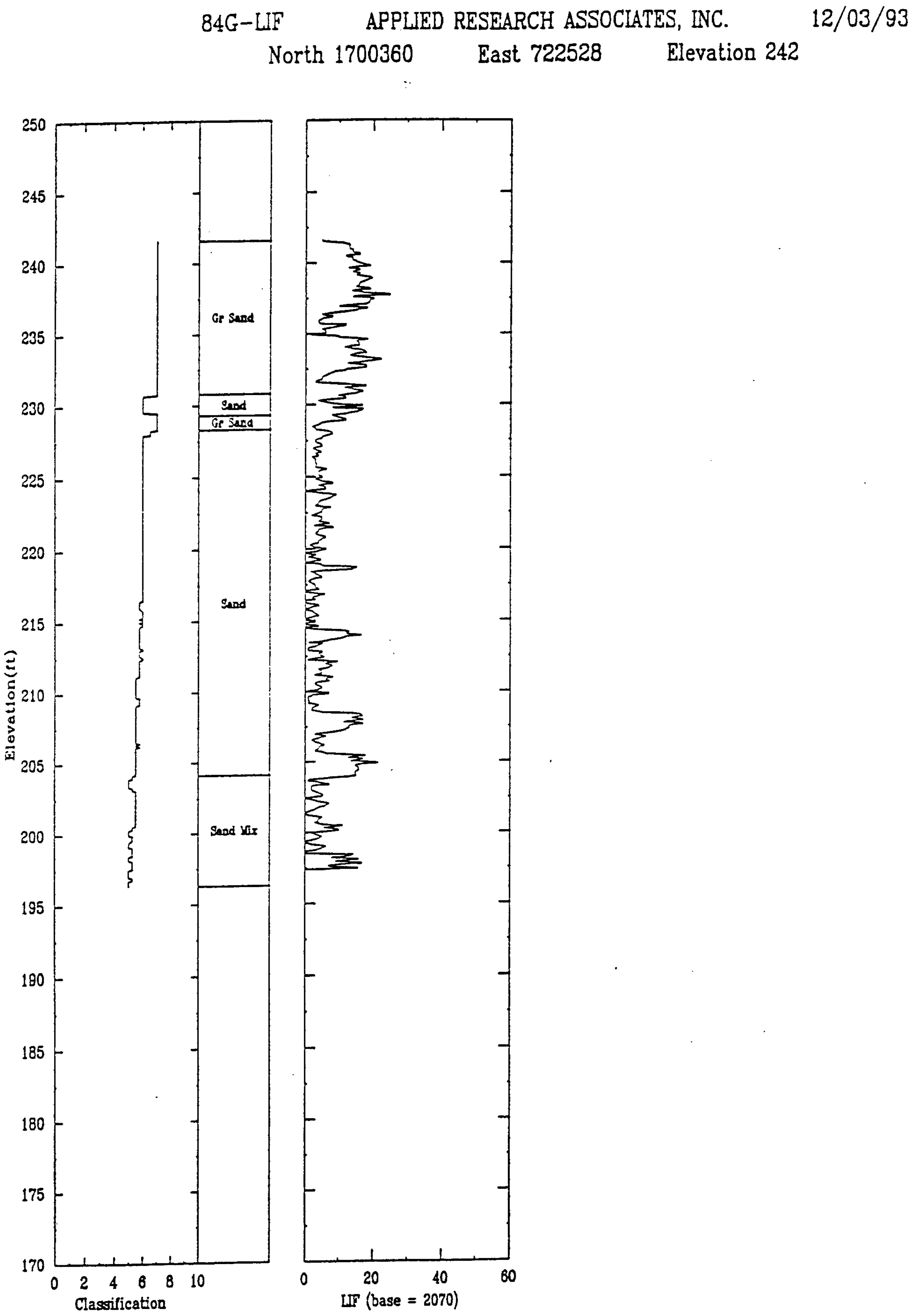
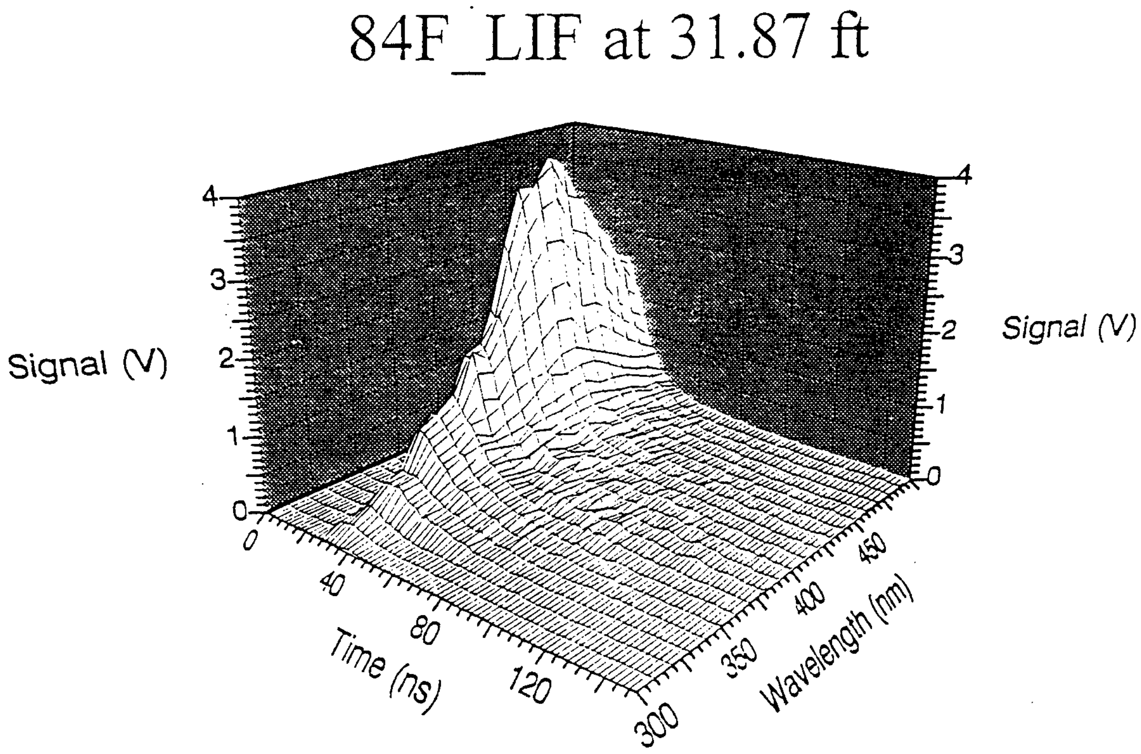


Figure 23. Typical LIF-CPT Profile of Soil Located Outside of the Oily Phase Plume

test was located 140 feet northeast of location 84B-LIF. At this location the highest LIF counts were recorded of over 450 counts. The oily phase plume is located at an elevation of 214 to 212 feet MSL at this location.

In summary, the LIF-CPT probe was successfully used to rapidly define the leading edge of the oily phase plume. Although the LIF count measurements provided no quantitative information during the investigation, it is expected that these results can be correlated to analytical results obtained by the EPA using soil samples collected from the same locations. To assist in this correlation, several Wavelength Time Matrices (WTMs) were conducted at various depths during the demonstration. To date, analysis of these data indicates that all the laser responses have been from the same contamination (i.e. all the WTMs have the same trends as a WTM of recovered oily phase product on Plattsburgh sand). The WTM from the recovered oily-phase product on sand is presented in Figure 24. The same trends present in this WTM are also present in the WTM taken from location 84F-LIF at an elevation of 212.1 feet, indicating the same contamination source.

In addition to rapidly identifying the plume boundary, the oily phase plume has been shown to extend approximately 620 feet southeast of the suspected source. The areal extent of the oily phase plume based on the LIF-CPT data collected during this DT&E is presented in Figure 25. It represents a color contour map of the maximum LIF values between elevation 218 and 208 feet MSL. This represents a region containing the groundwater table at all locations . The vertical extent of the oily phase plume is presented in the two cross sections in Figures 26 and 27. Several key aspects of the plume are clearly presented in these figures. First, that the oily phase plume is located on top of the groundwater table as expected since the plume is comprised of JP-4 and other LNAPL's which are lighter than water. The second aspect is that the plume appears to be moving southeasterly along the water table. Although the plume originated in the pits located near location 84D-LIF, the plume traveled downward at that location to the water table (i.e. this explains the significantly larger smear zone present at the pits than determined elsewhere) and then began moving southeasterly along the groundwater table surface. This plume extends transversely in the direction of groundwater movement and maintains an approximate width which correspond to the width of the zone used for the fire training exercises.



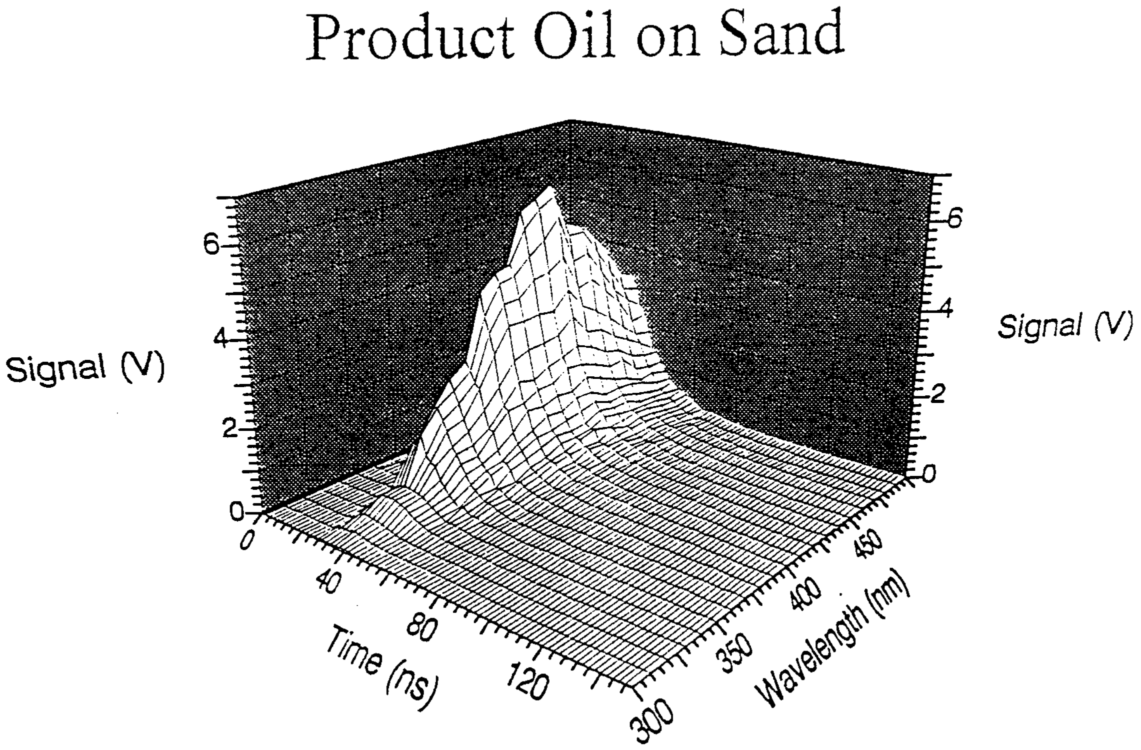


Figure 24. WTM from location 84F-LIF at 31.87 feet showing similar trends observed in the WTM of recovered Oily Phase Product on sand.

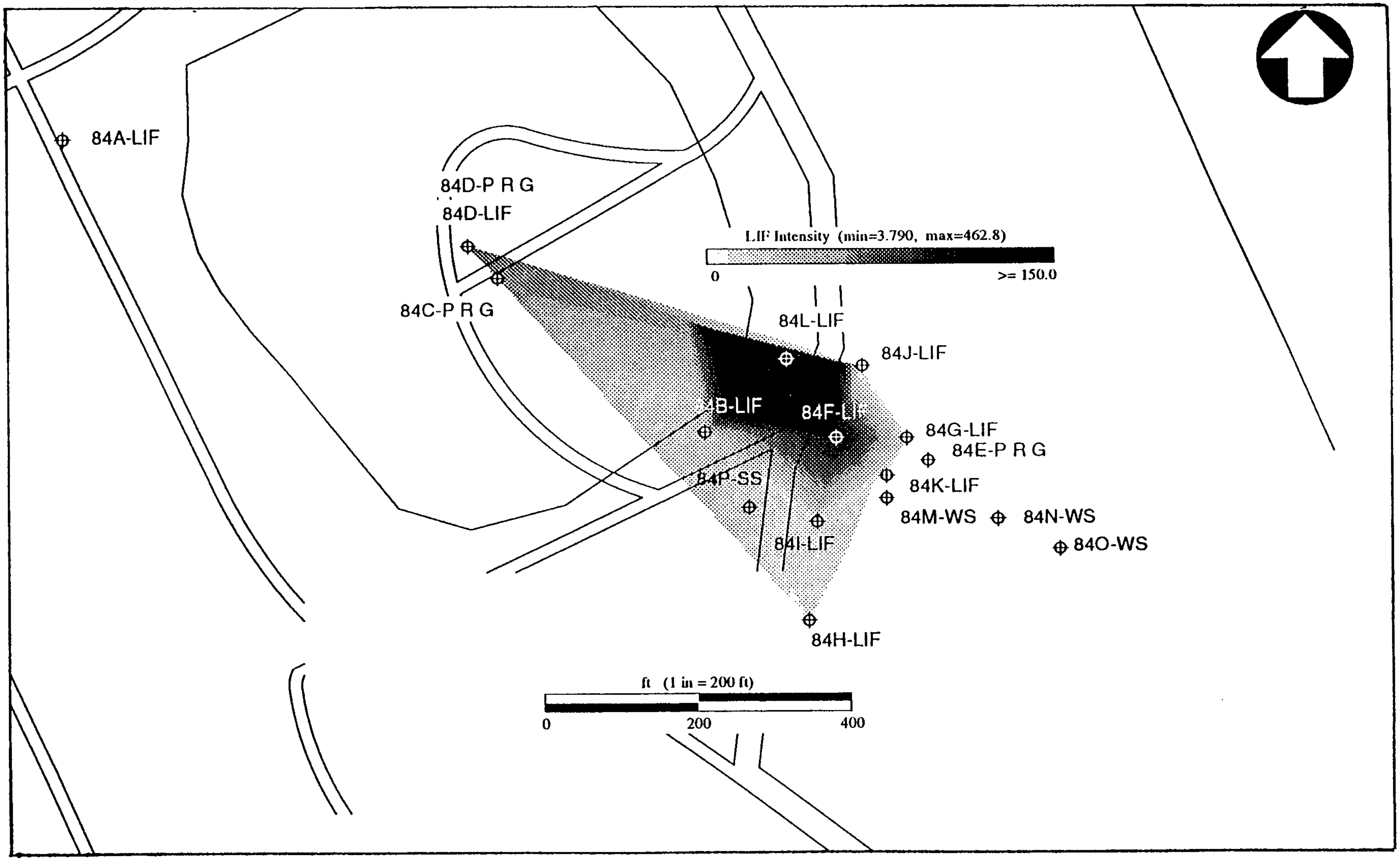


Figure 25. Plan View Showing Color Contour of Maximum LIF Values Between Elevations 208 ft and 218 ft MSL.

SECTION A-A'

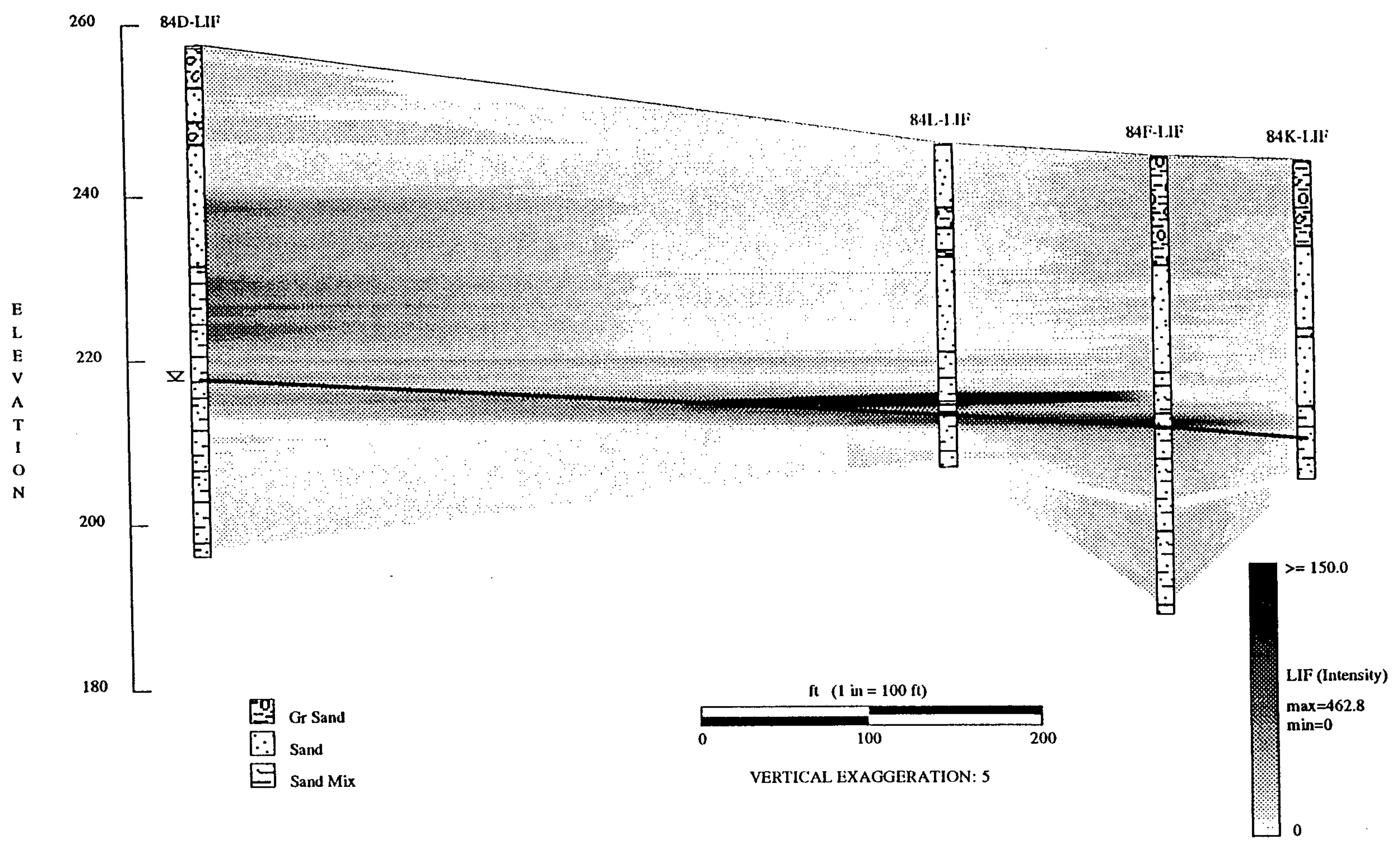


Figure 26. Profile of Section A-A' Showing Color Contour of LIF Intensity.

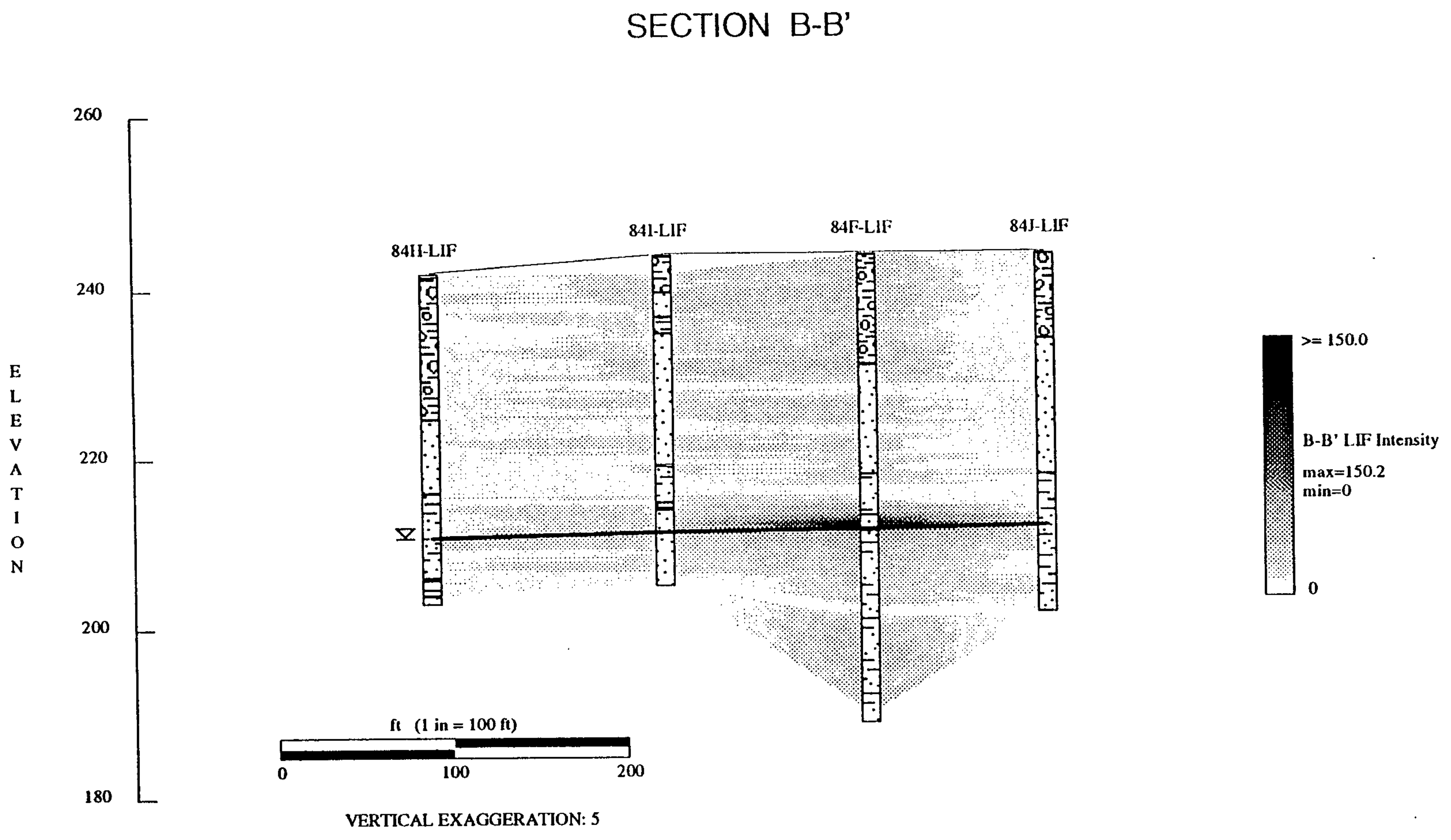


Figure 27. Profile of Section B-B'Showing Color Contour of LIF Intensity.

6. Evaluation of Soil Sampling Results

The soils observed during the course of this investigation consisted primarily of fine to medium poorly graded sands with little or no fines, with the exception of an occasional seam of silty fine sand. Granules were predominantly subangular to subrounded. These soils are classified as 'SP' according to the Unified Soils Classification System (USCS). The observed soils exhibit good correlation with the CPT classifications.

The soil chemical analytical results obtained by the U.S. EPA are discussed in Volume I of this report.

SECTION IV
SUMMARY AND CONCLUSIONS

During the 10-day demonstration performed at Plattsburgh AFB in support of site characterization activities for natural attenuation, several in situ CPT-based methods were used to identify and characterize the leading edge of the oily-phase plume. Cone penetration testing combined with either laser-induced fluorescence or resistivity and soil-gas monitoring was used to rapidly locate and define the leading edge of the oily-phase petroleum plume. Fifteen CPT locations were tested in a 3-day period to define the plume. Once the leading edge was identified, water and soil sampling using the CPT was performed to confirm the in situ testing and also provide samples for the EPA to analyze to determine the necessary parameters for Bioplume II® modeling efforts. The work involved obtaining seventeen 1-liter water samples from 6 locations at various depths and 39 soil samples at 5 locations at various depths. One small 1.5-inch diameter monitoring well was installed to a depth of 33 feet during the demonstration to demonstrate the ability of the CPT rig to perform a variety of on-site tasks.

The results from the CPT testing have been analyzed and the results clearly indicate the leading edge of the oily-phase plume has been defined. The full lateral extent and volume of the oily phase plume is not known. The contamination moved vertically beneath the training pit until the groundwater table was reached, after which it pooled on the groundwater table and then slowly began to slide along the water table in a southeast direction. Based on the LIF data, the highest concentration of oily phase contaminant appears to be centered approximately 440 feet down gradient of the pits.

This preliminary data report was prepared before all of the EPA analytic data were available, and therefore, does not include detailed comparisons of the LIF analytic data. In addition, analysis of the P/R-CPT data is incomplete. Preliminary analysis of this data indicates the potential for locating hydrocarbon plumes. However, the LIF-CPT probe appears to be more accurate and to require less detailed analysis to determine the water table depth. The best use of the P/R-CPT data appears to be with determining soil degree of saturation in the vadose zone. and porosity below the water.

In summary, the CPT was used to provide the necessary information for the characterization of the fire training area using natural attenuation. The CPT was demonstrated as a multi-use tool for performing real time investigation, soil and water sampling, and installation of monitoring wells. Some of the advantages of the AFSCAPS system that were demonstrated using the CPT were:

1. That the CPT is a rapid test and can greatly reduce costs.

2. That the CPT is minimally invasive and generates no drilling waste

3. That the CPT is a multiuse tool that can be used for all tasks of the site characterization process, including real time profiling, soil, water and gas sampling, and small-diameter well installation.

4. That real time determination of soil stratigraphy, water table depths and degree of contamination can be made with the LIF-CPT system. Using this data, selection of the next location was optimized for the purpose of identifying the leading edge of the oily phase plume. On full-scale investigations, this capability can greatly reduce the time required to characterize a site, and results in a more through investigation

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12. Culley, R.W., F.L. Jagodits, and R.S. Middleton, "E-Phase System Innovations in Subsurface Exploration," 54th Annual Meeting of Transportation Research Board, 1975.

APPENDIX A

LIF-CPT PROFILES

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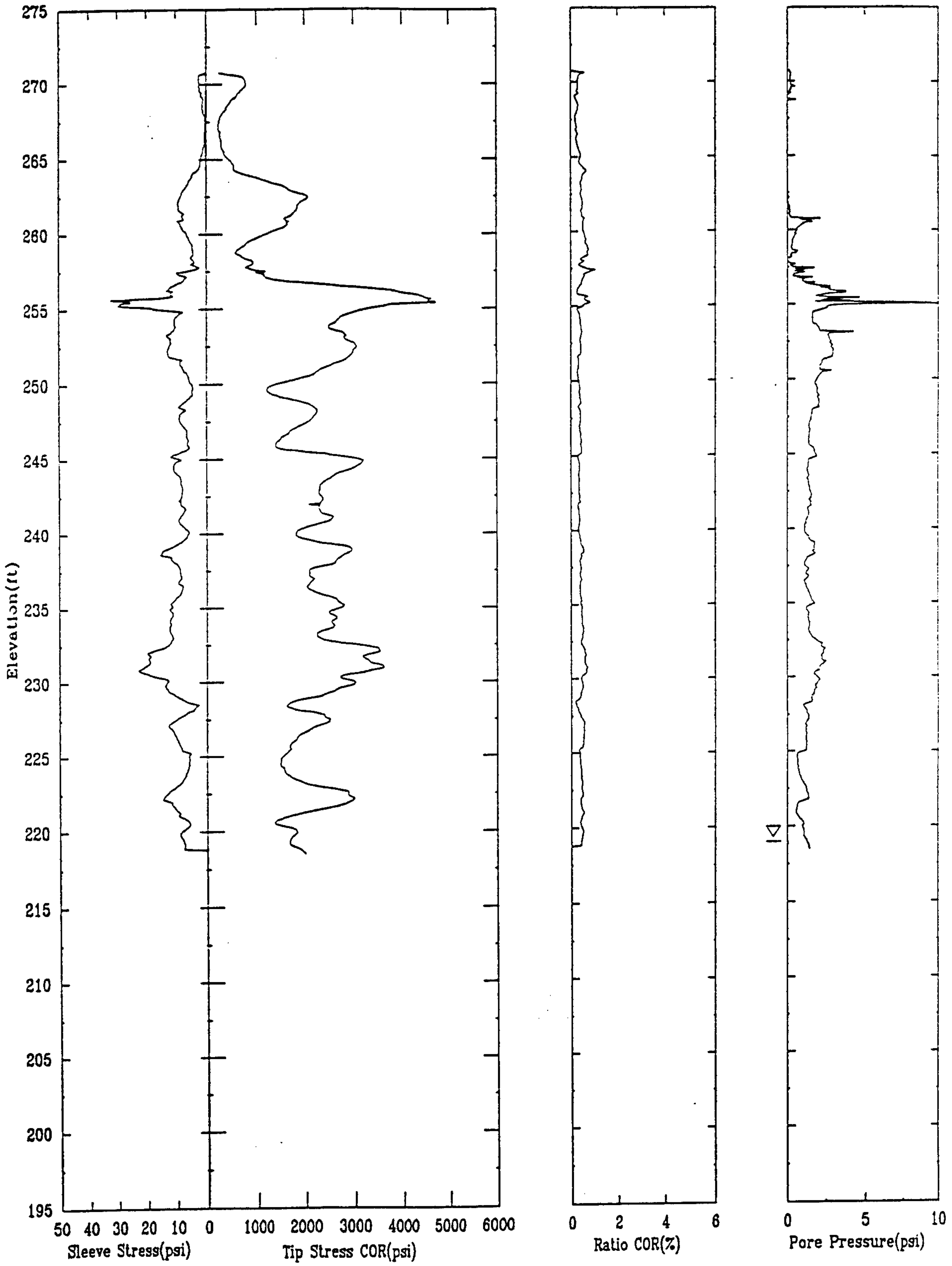
North 1700760 East 721440 Elevation 271



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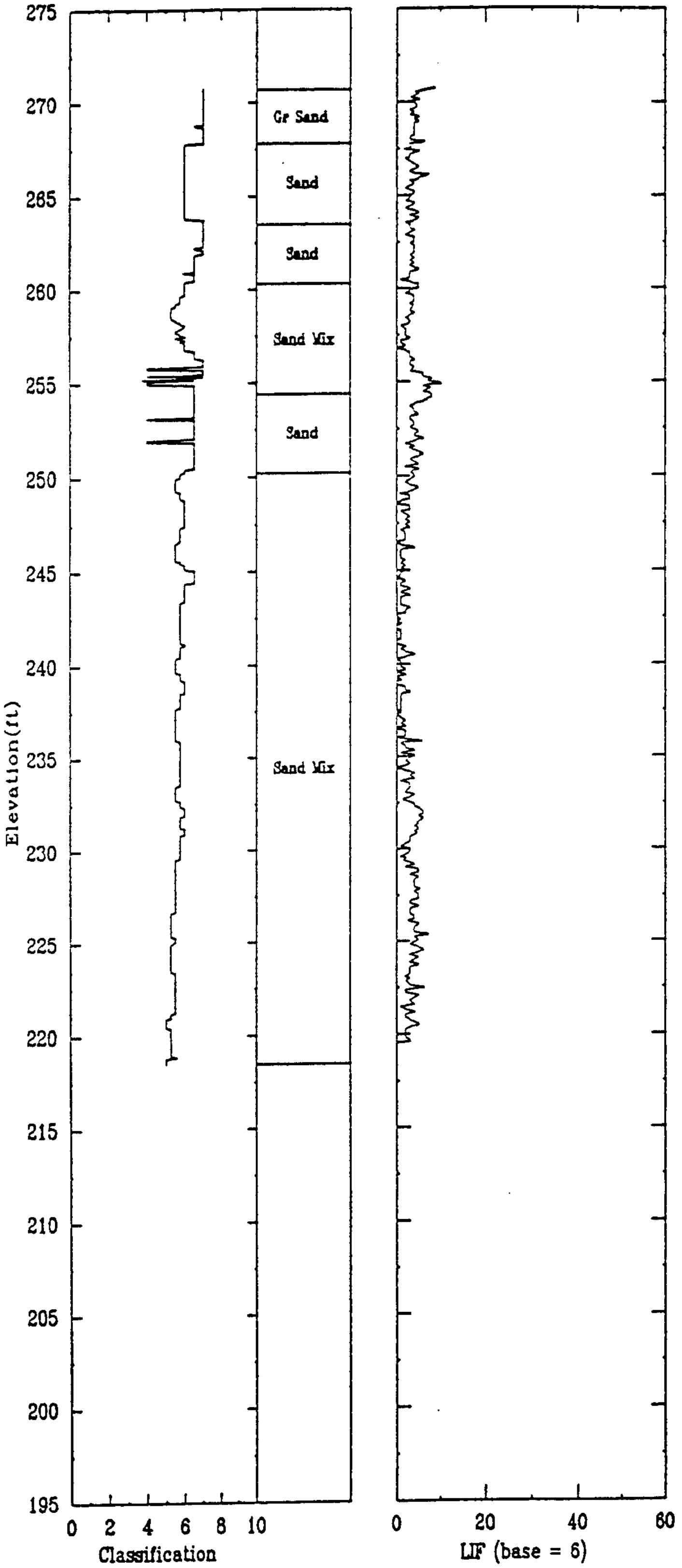

84B-LIF APPLIED RESEARCH ASSOCIATES, INC. 12/03/93

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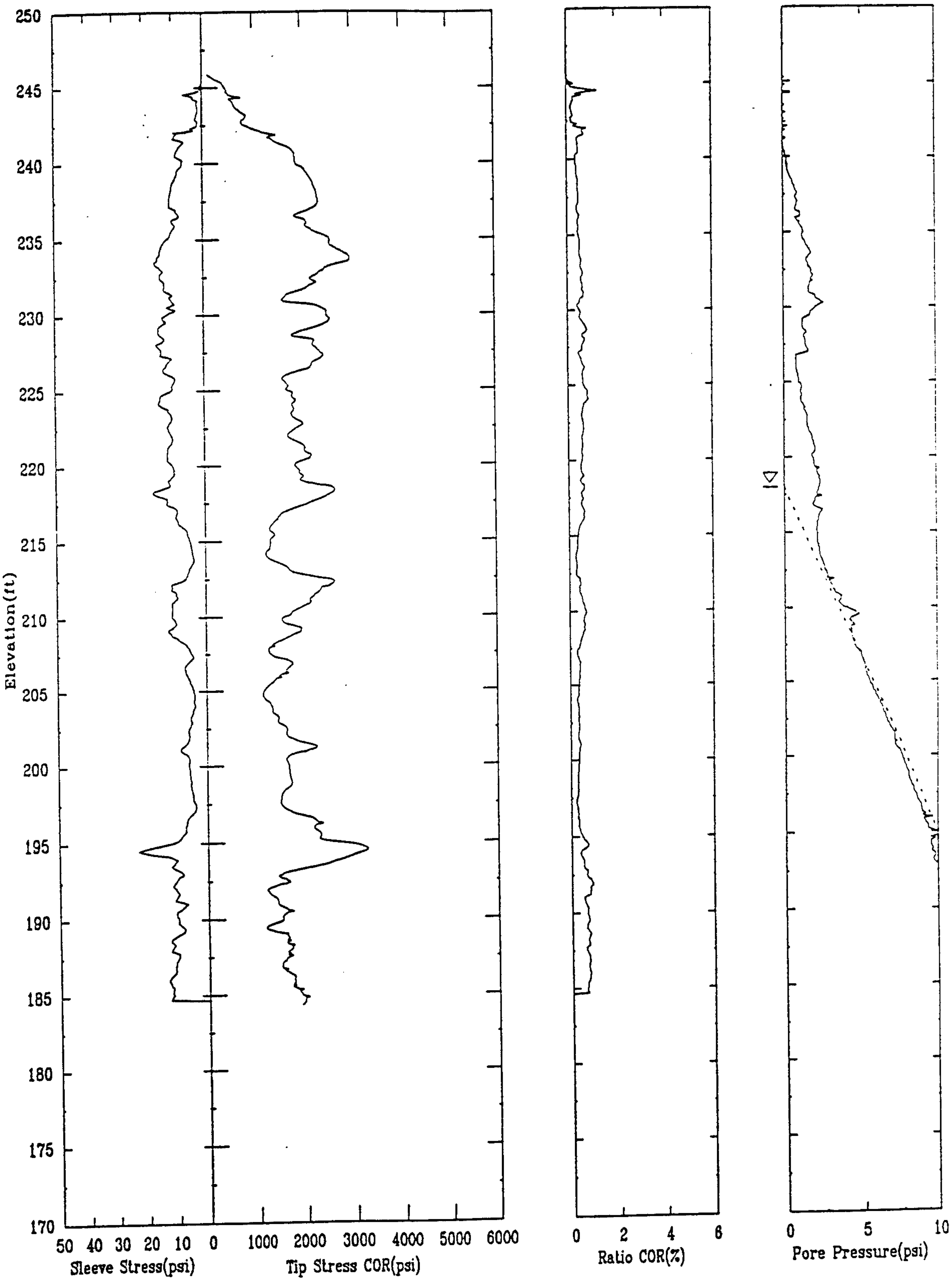

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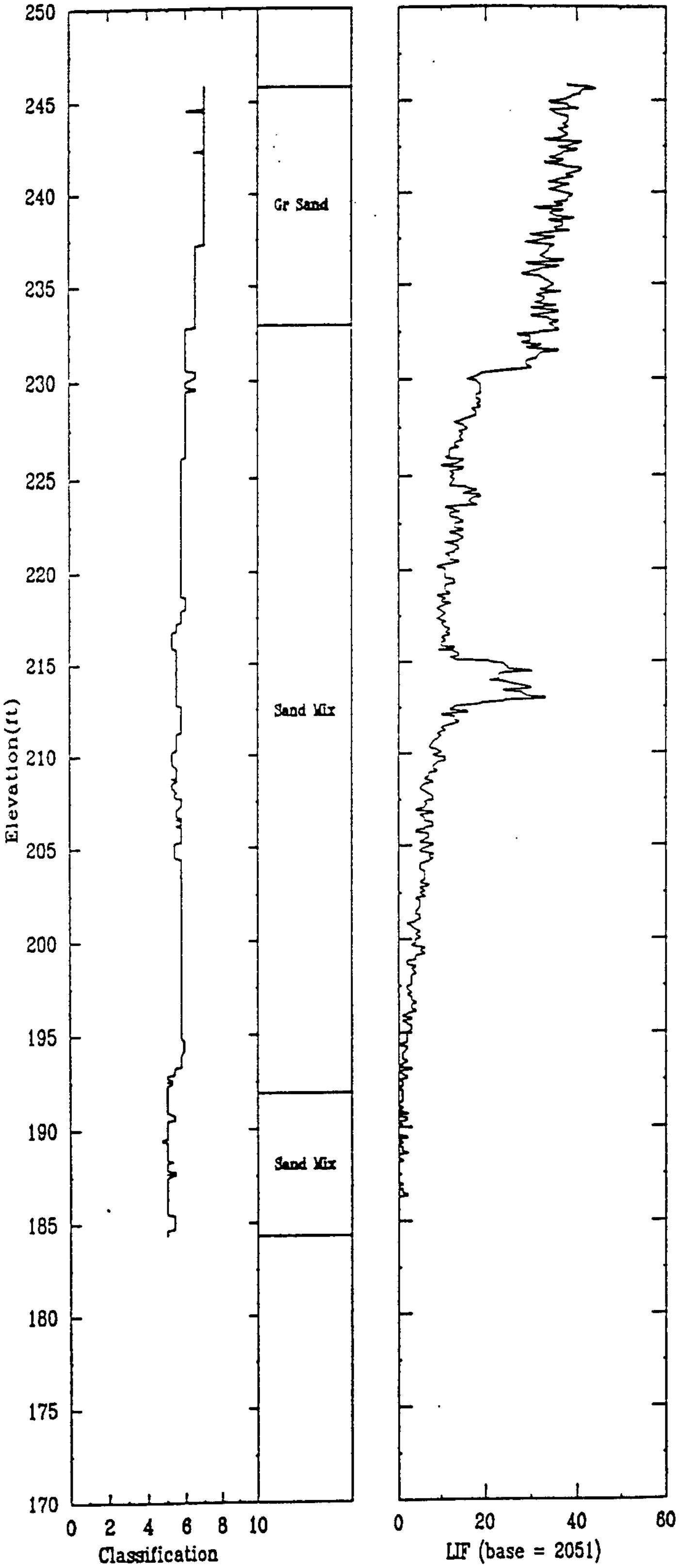

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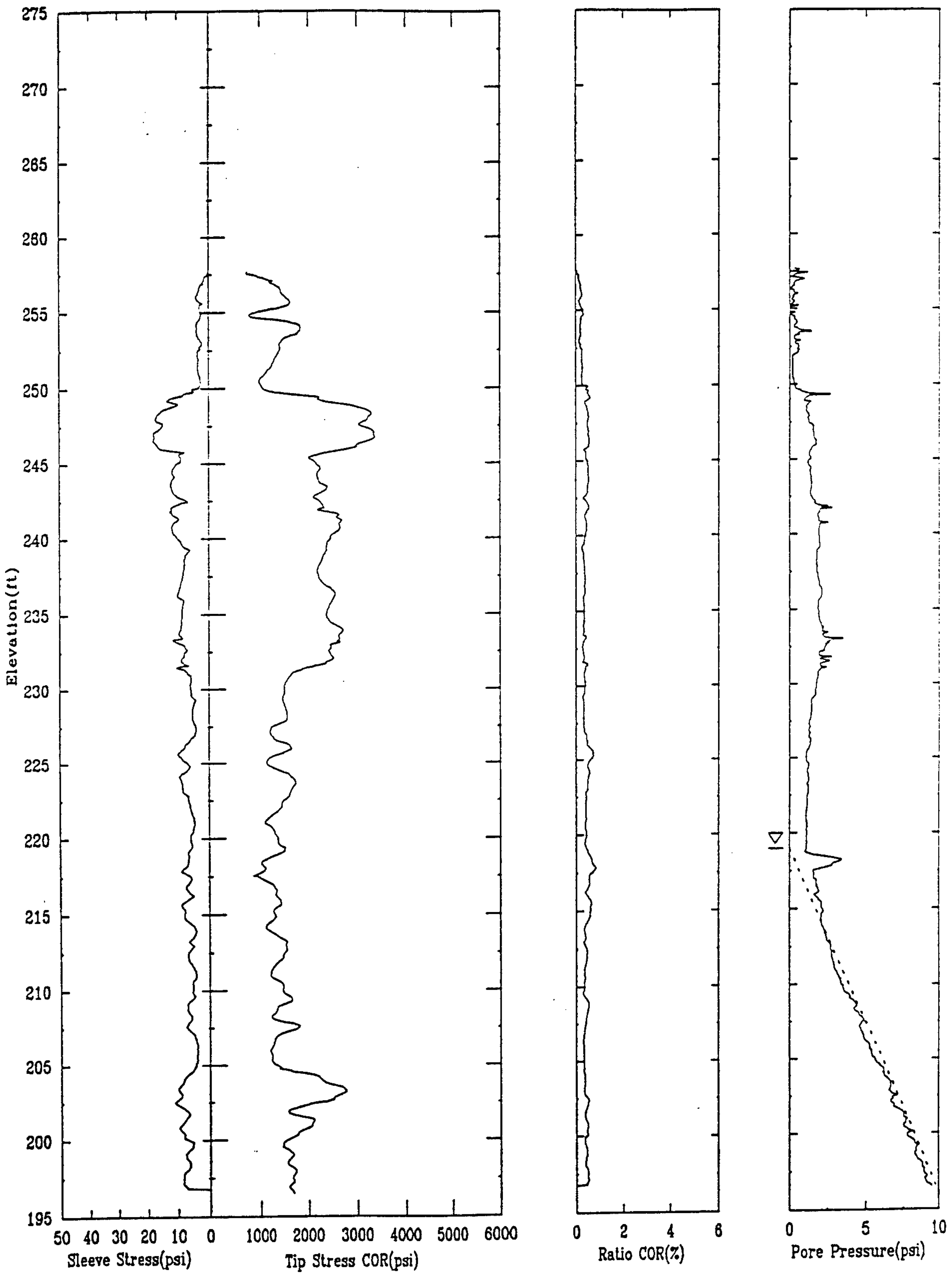

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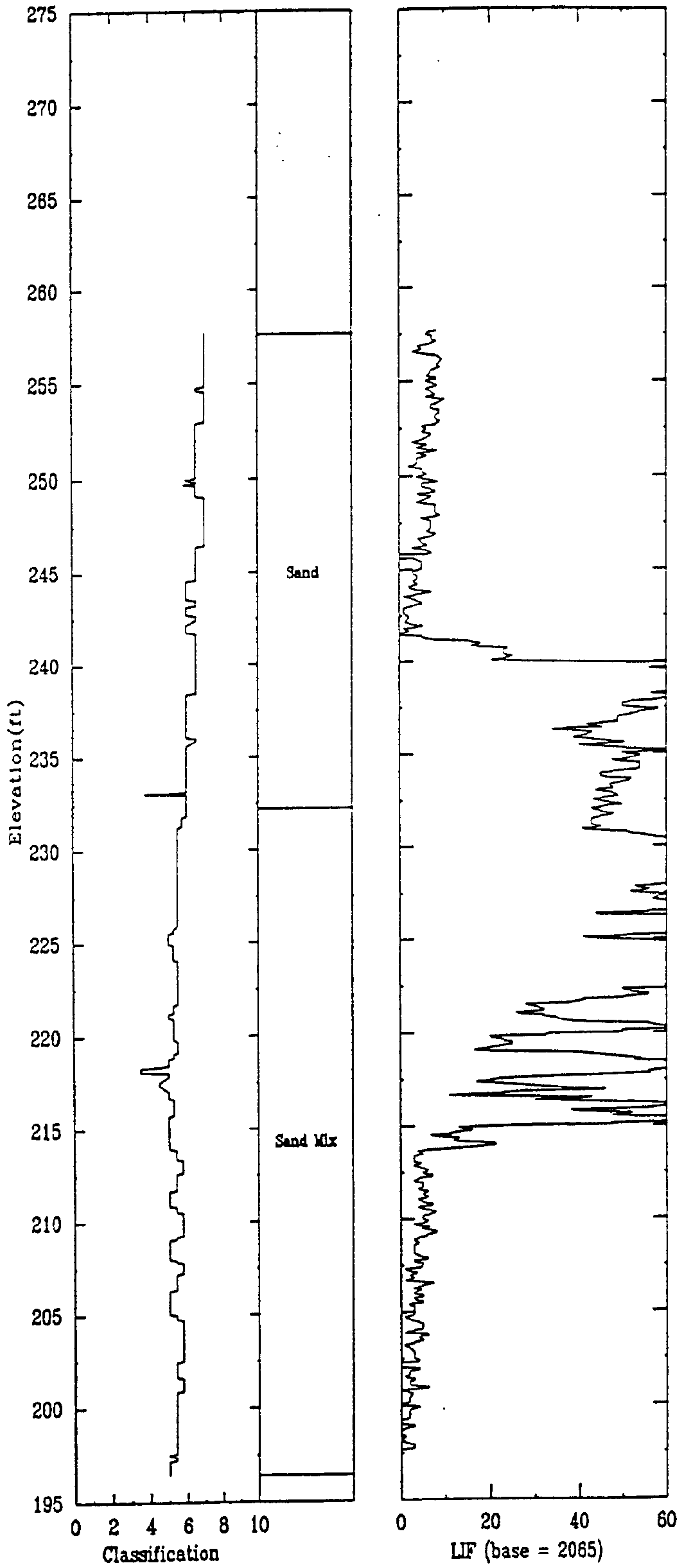

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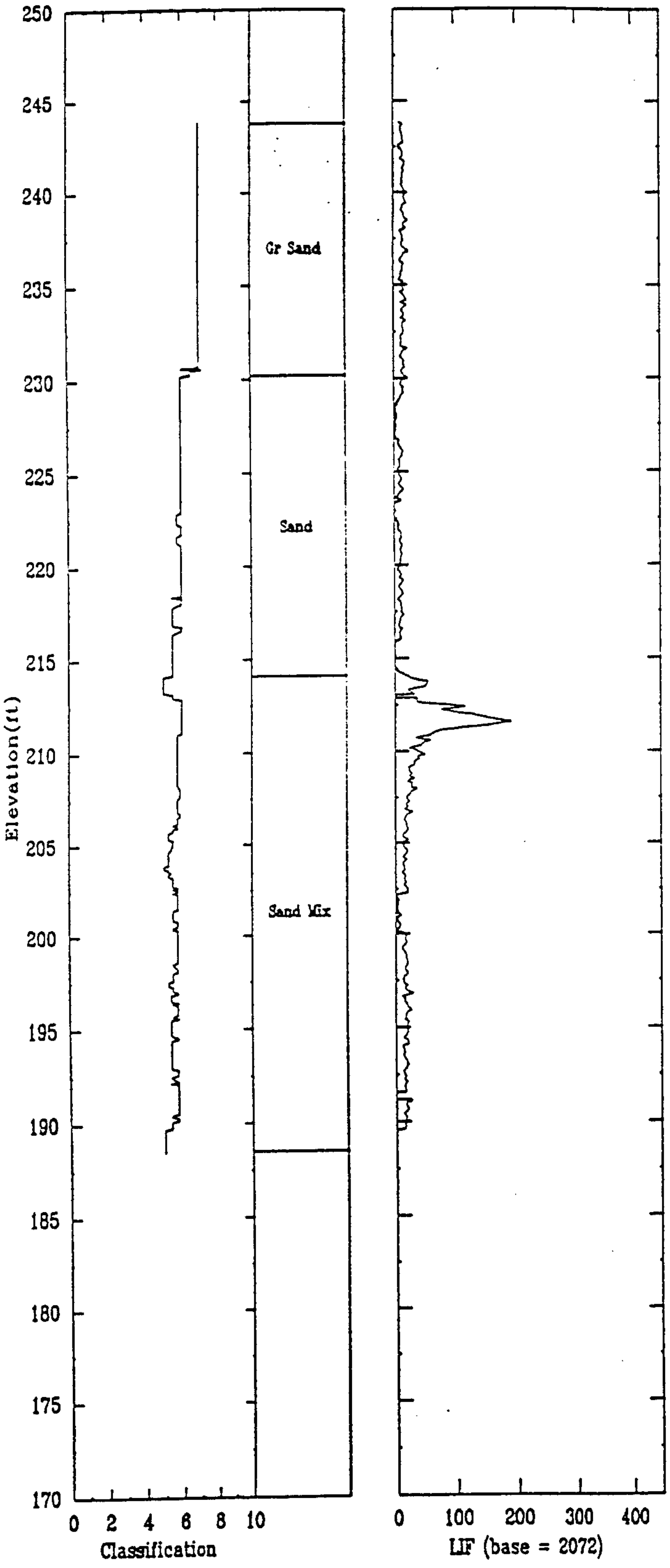

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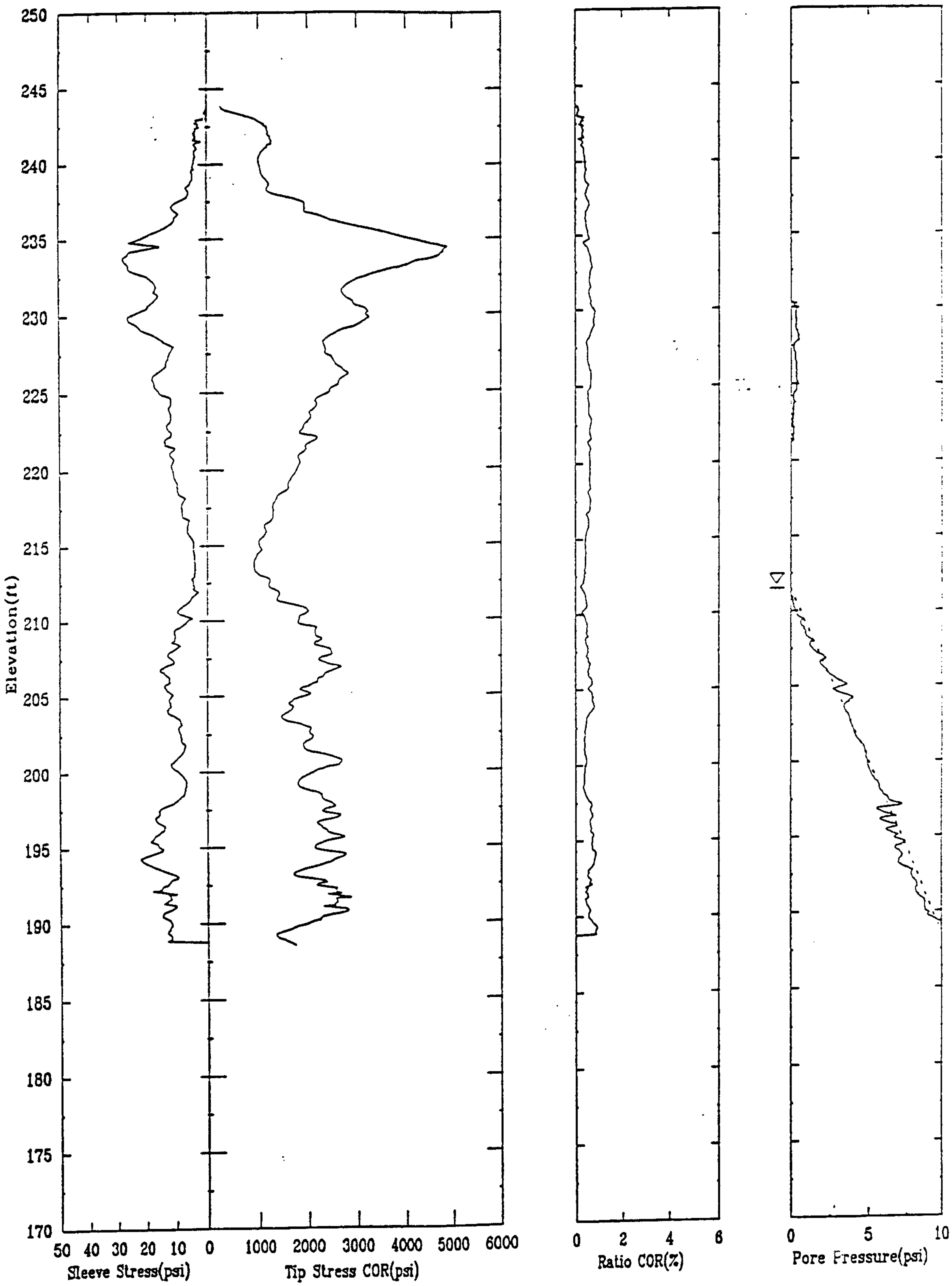

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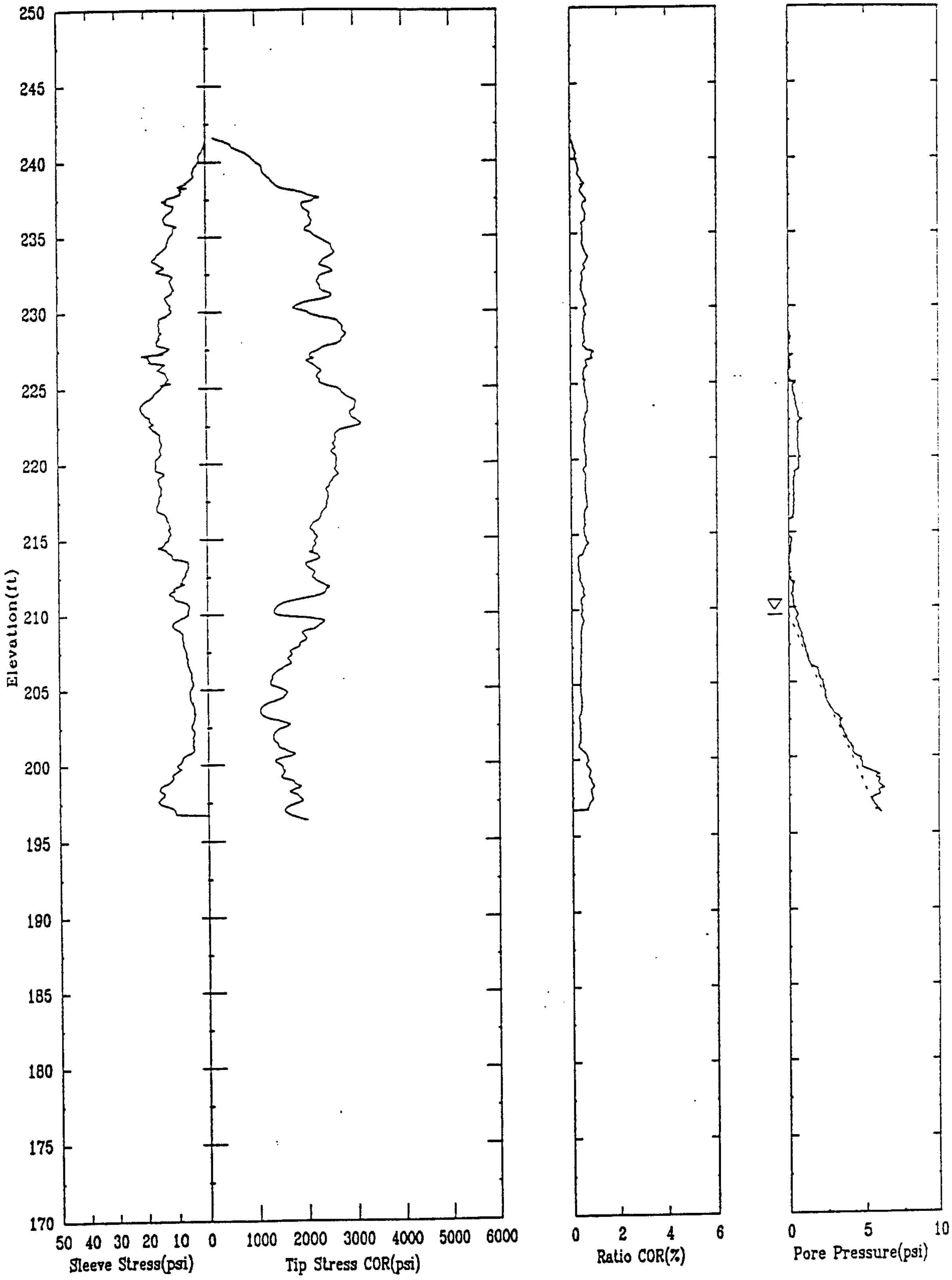

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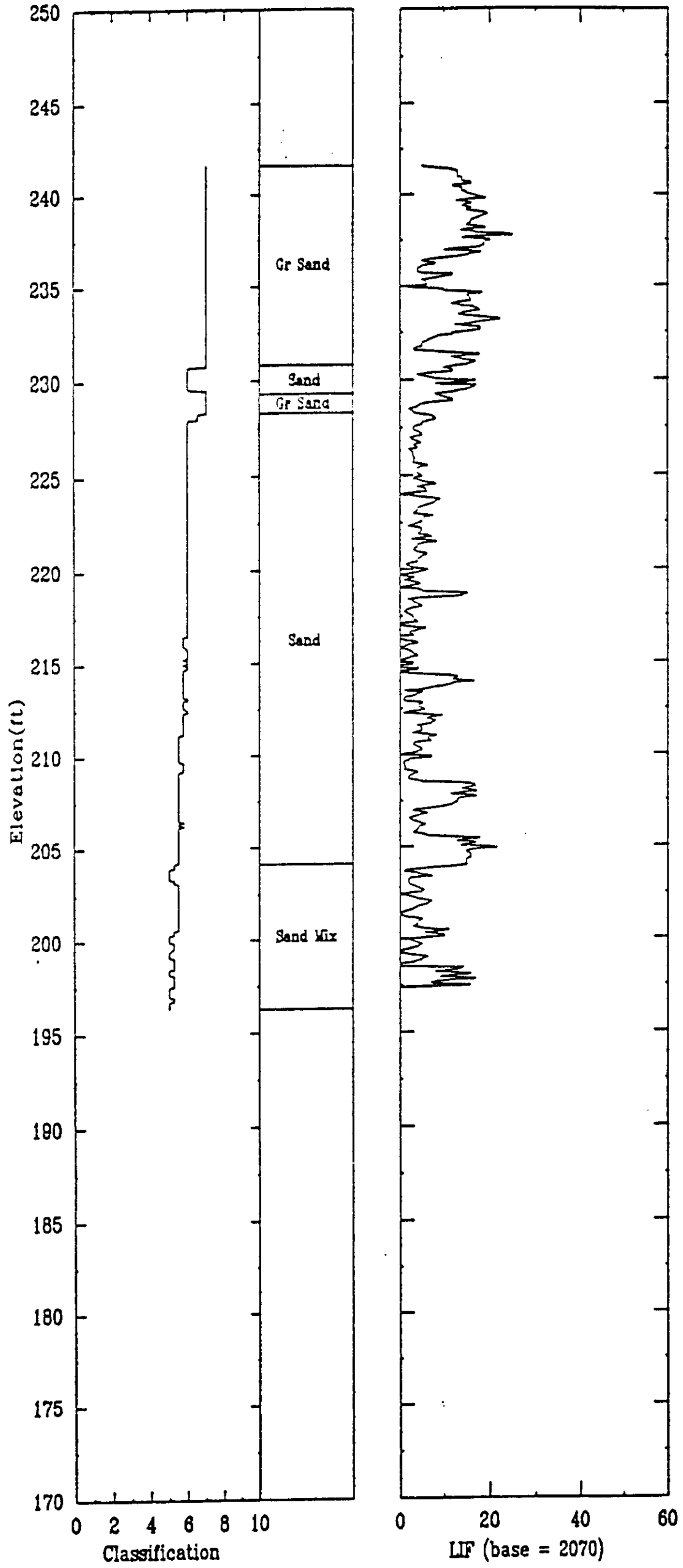

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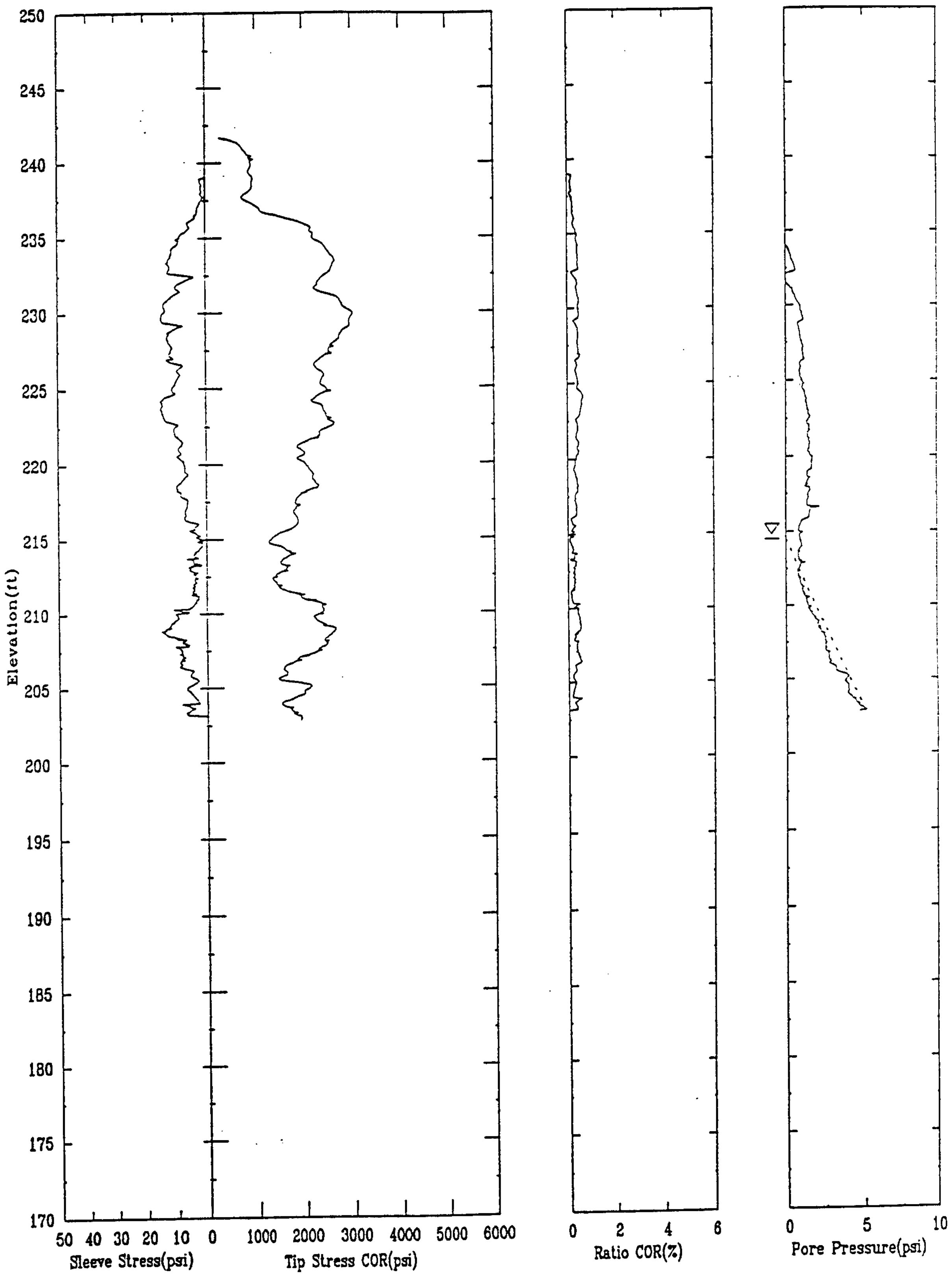

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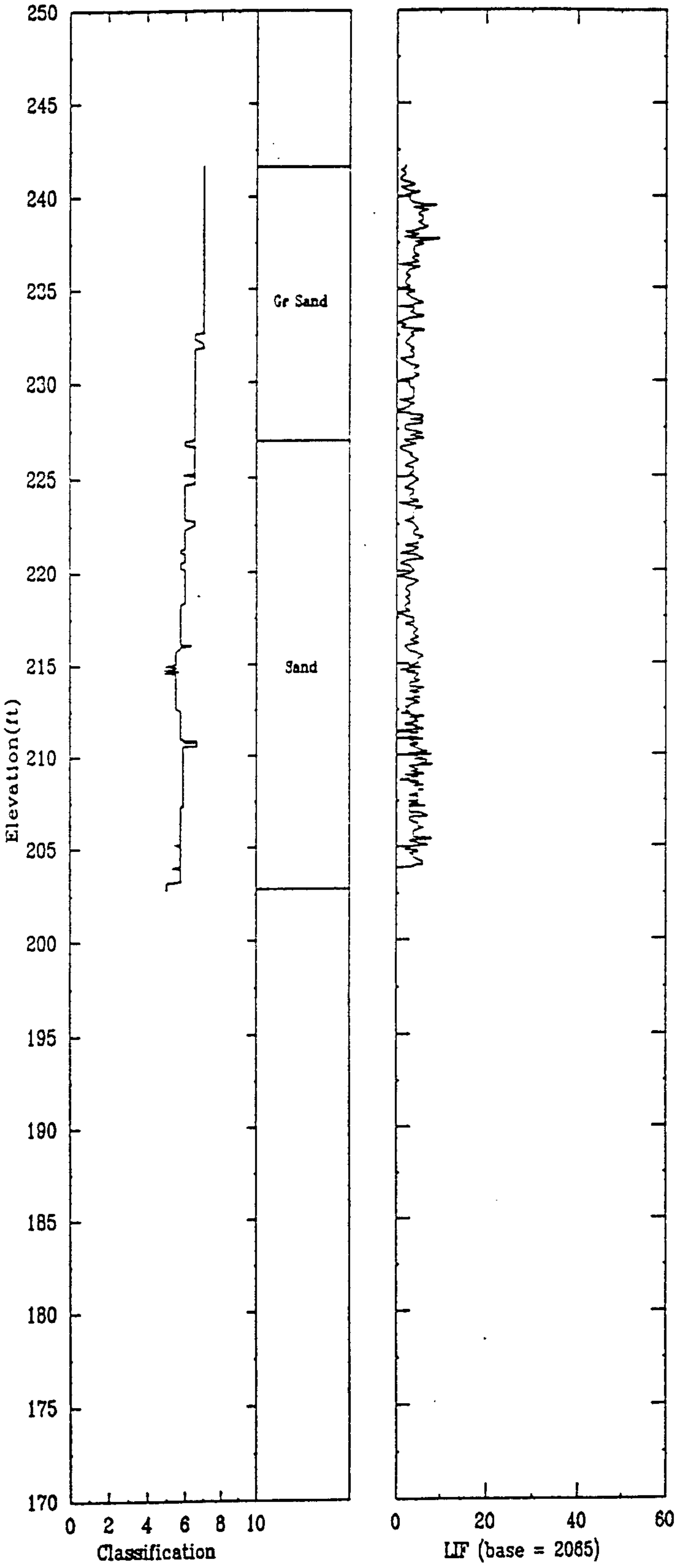

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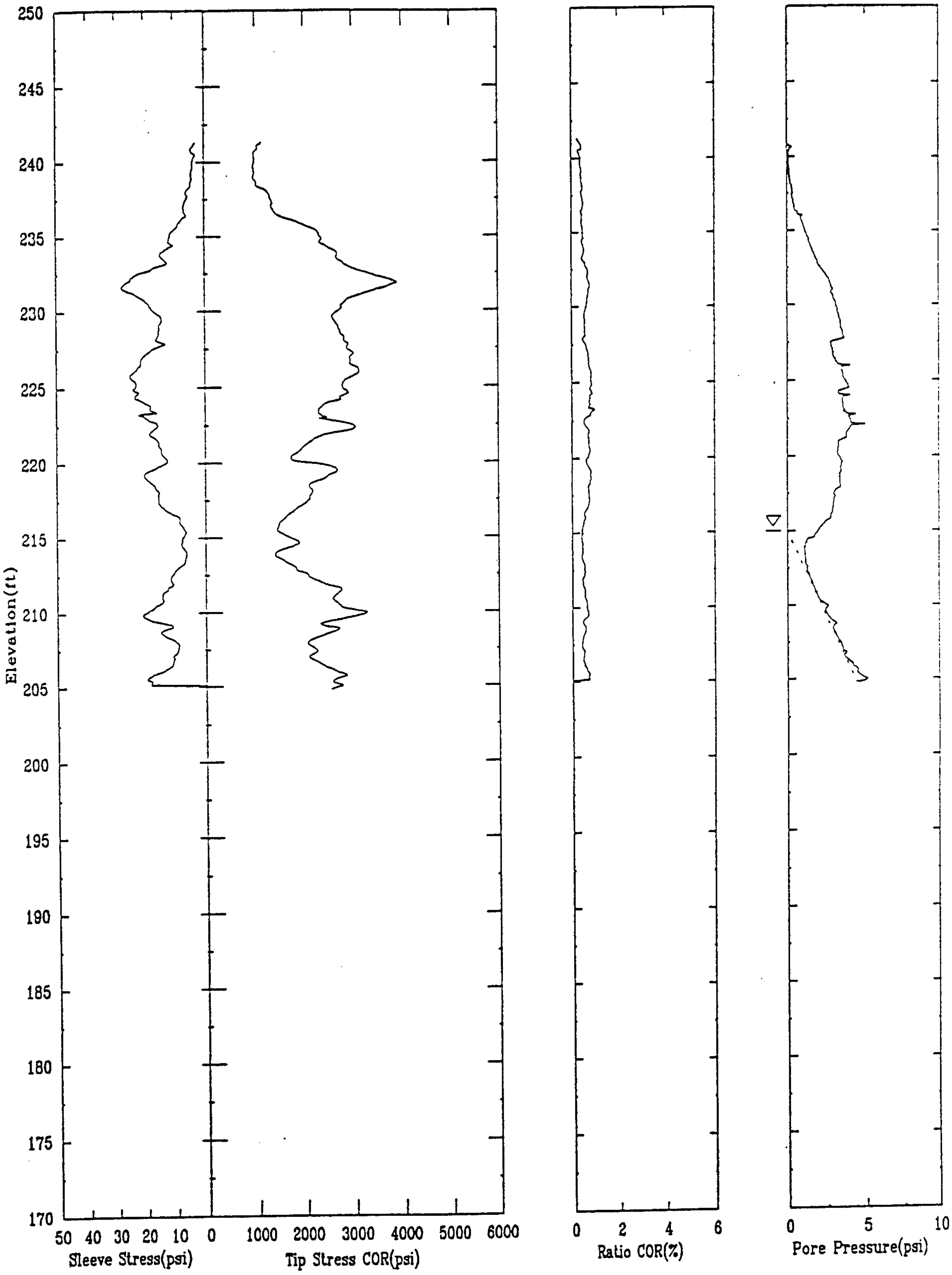

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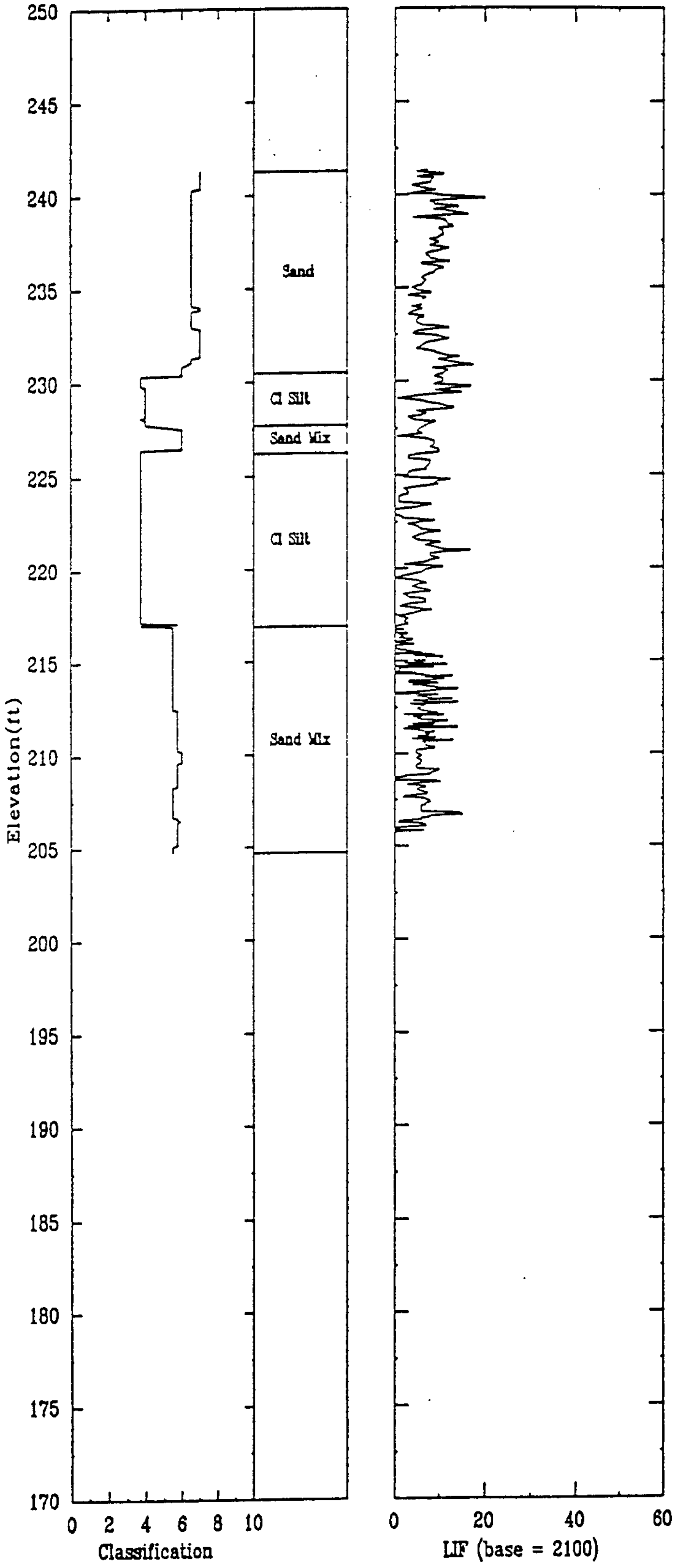

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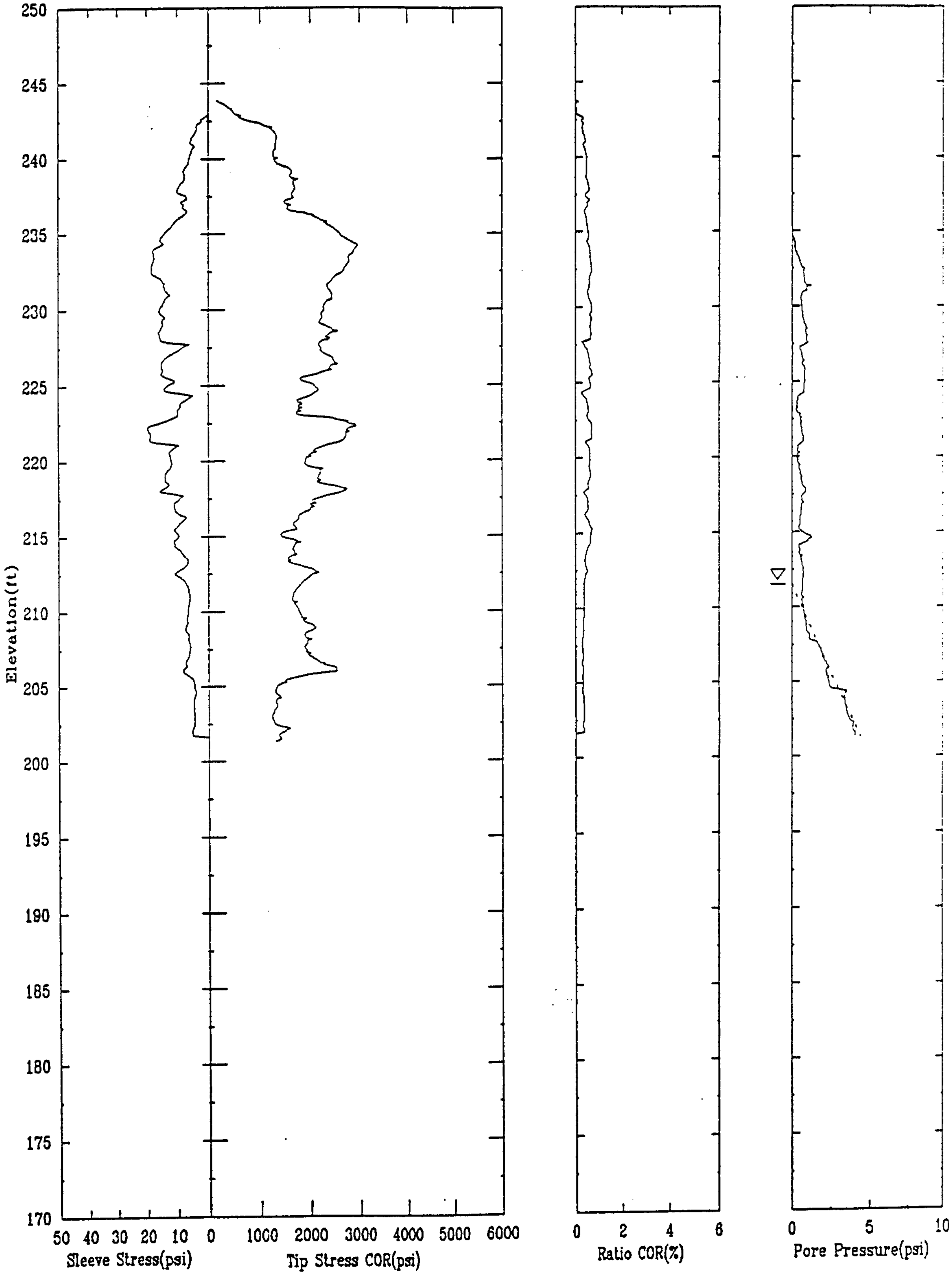

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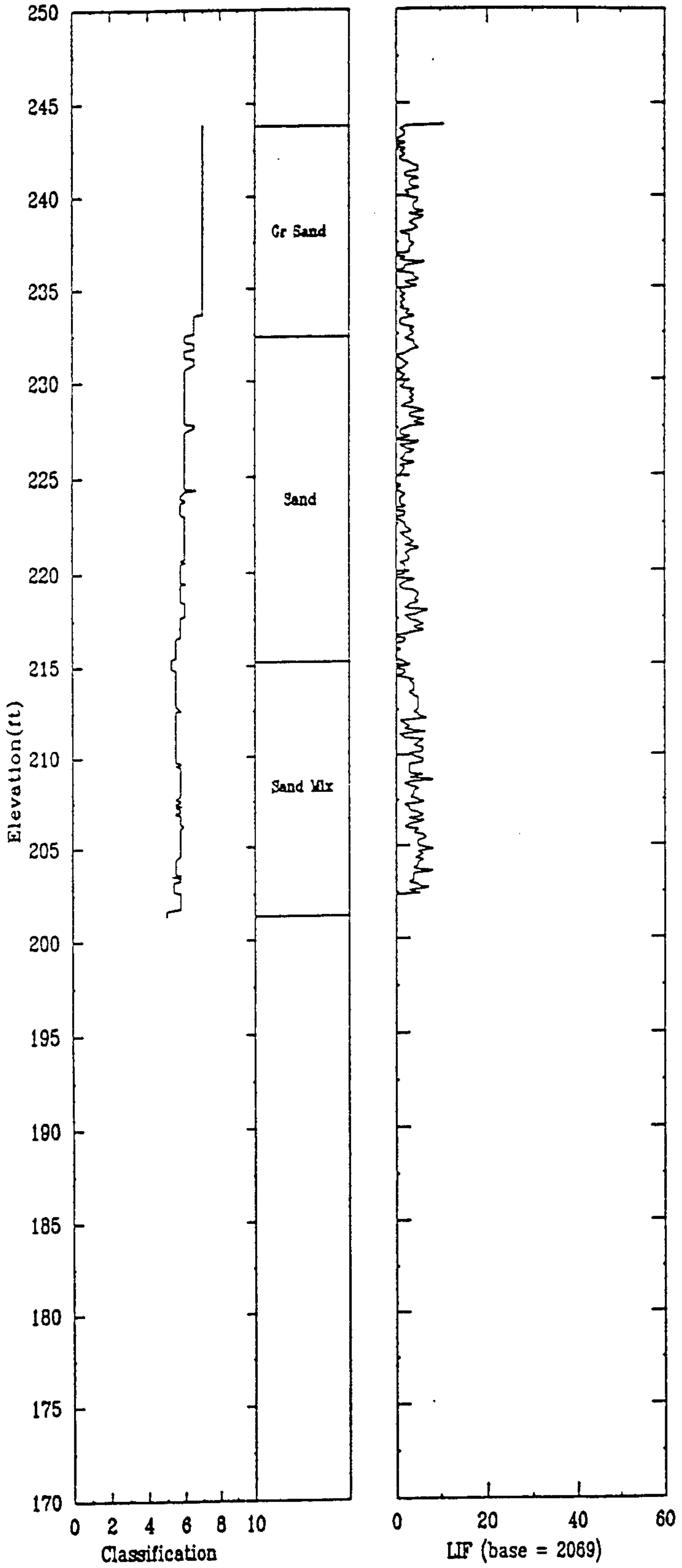

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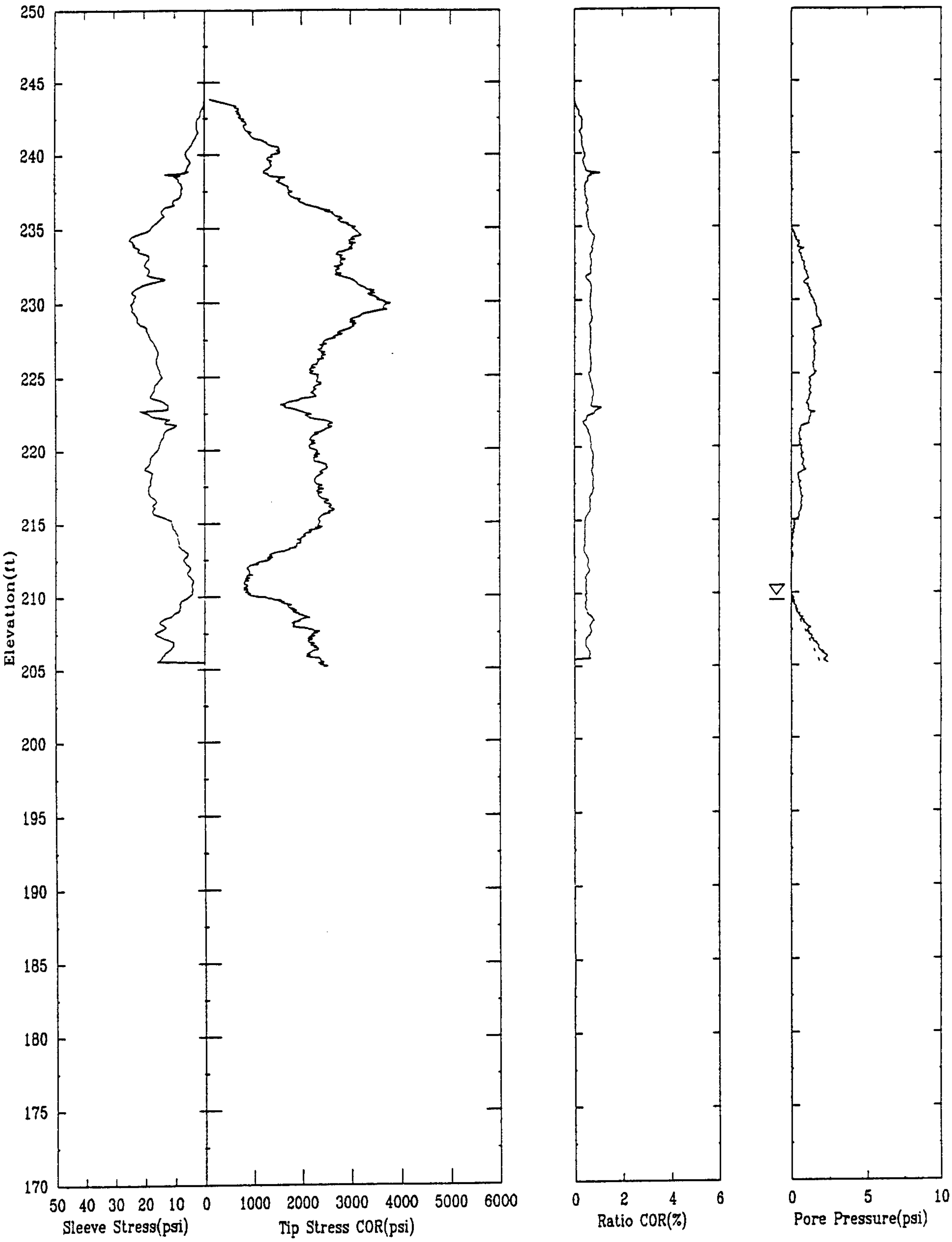

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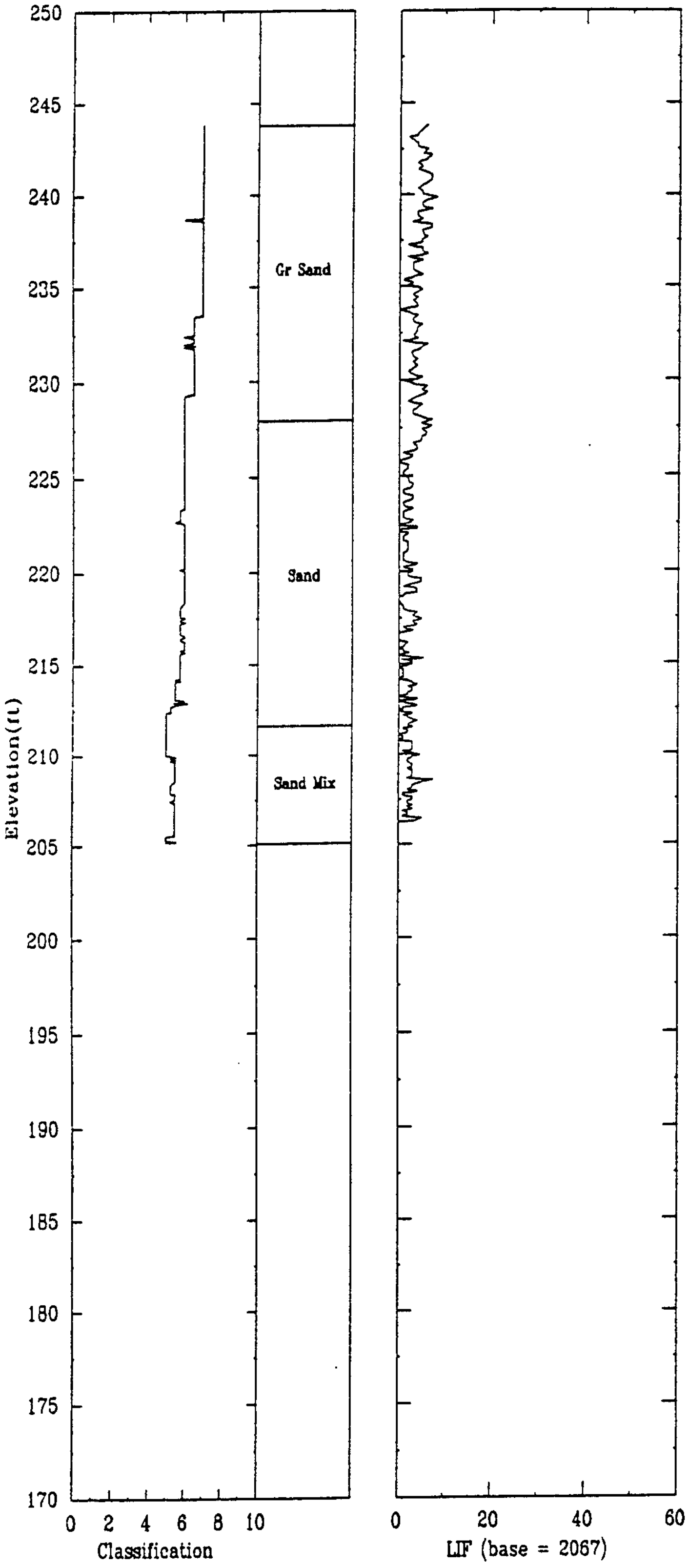

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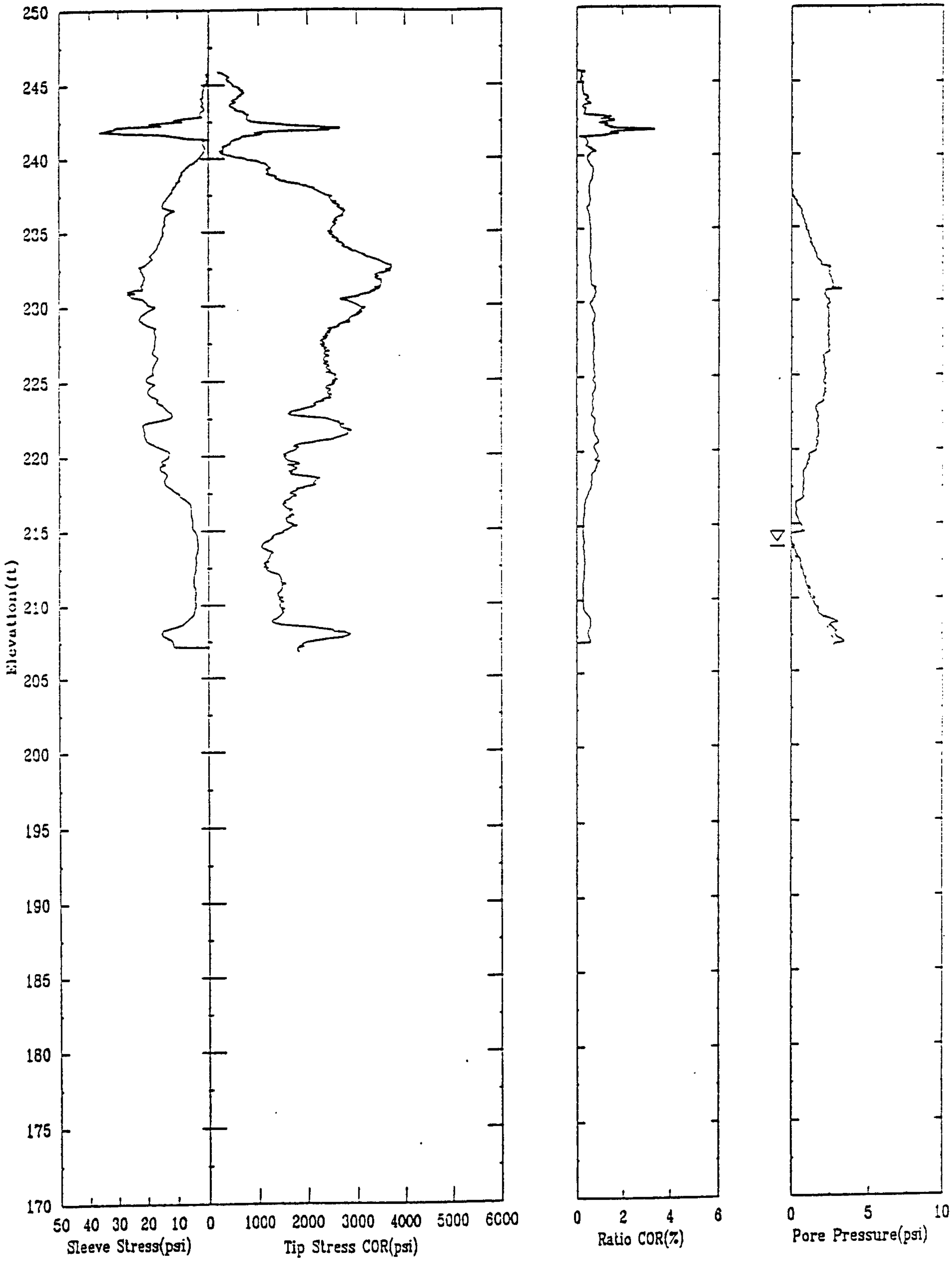

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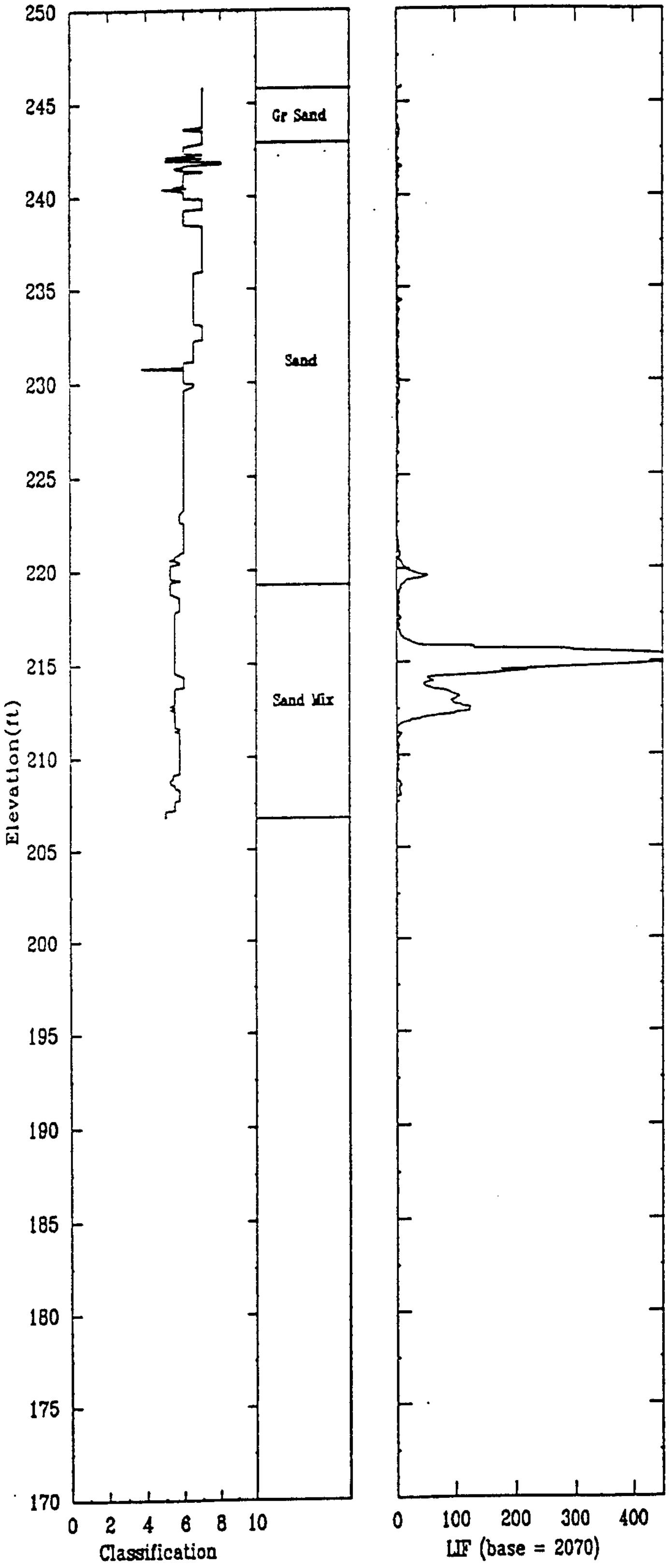

APPENDIX B

RESISTIVITY-CPT PROFILES

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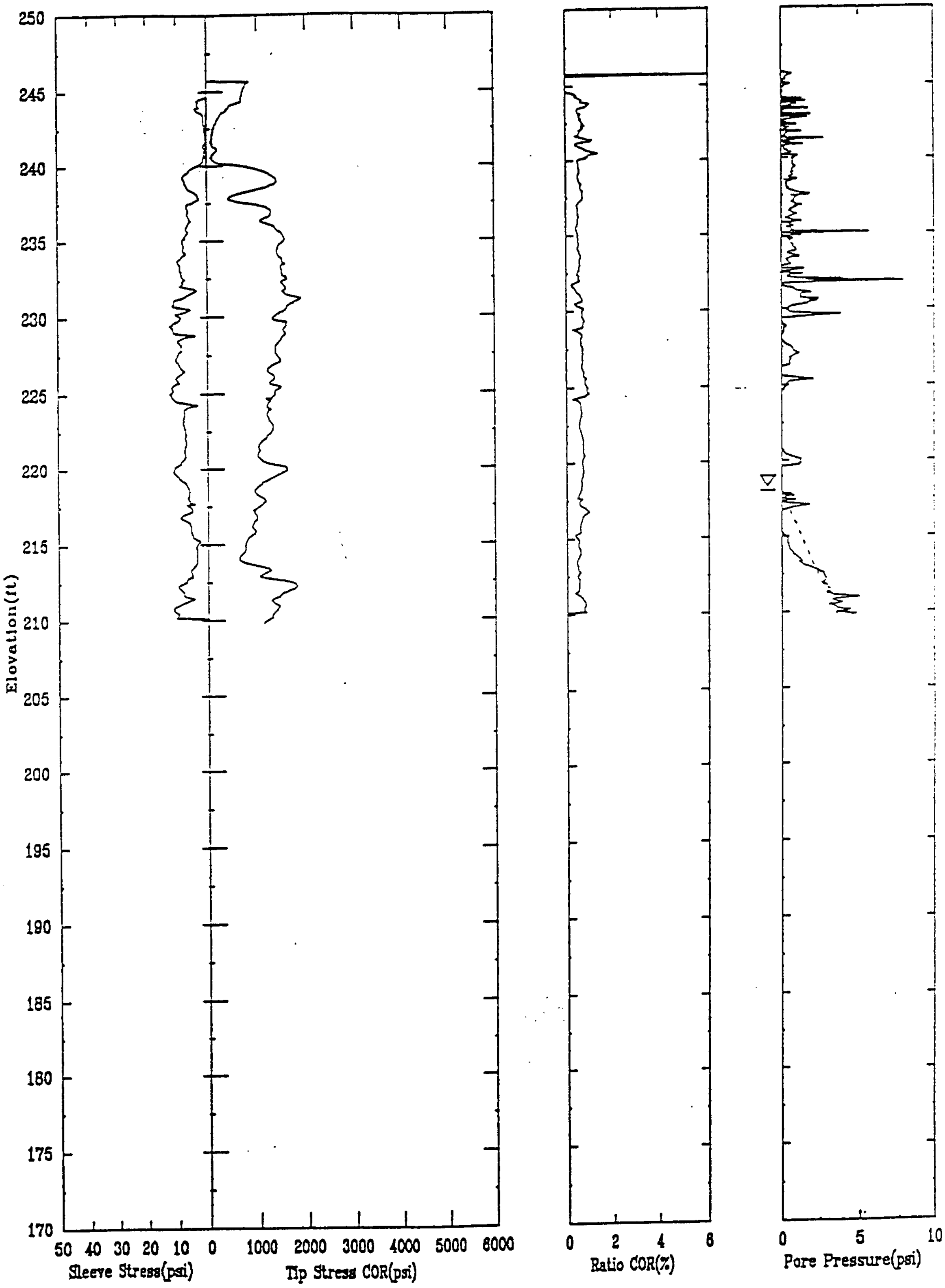

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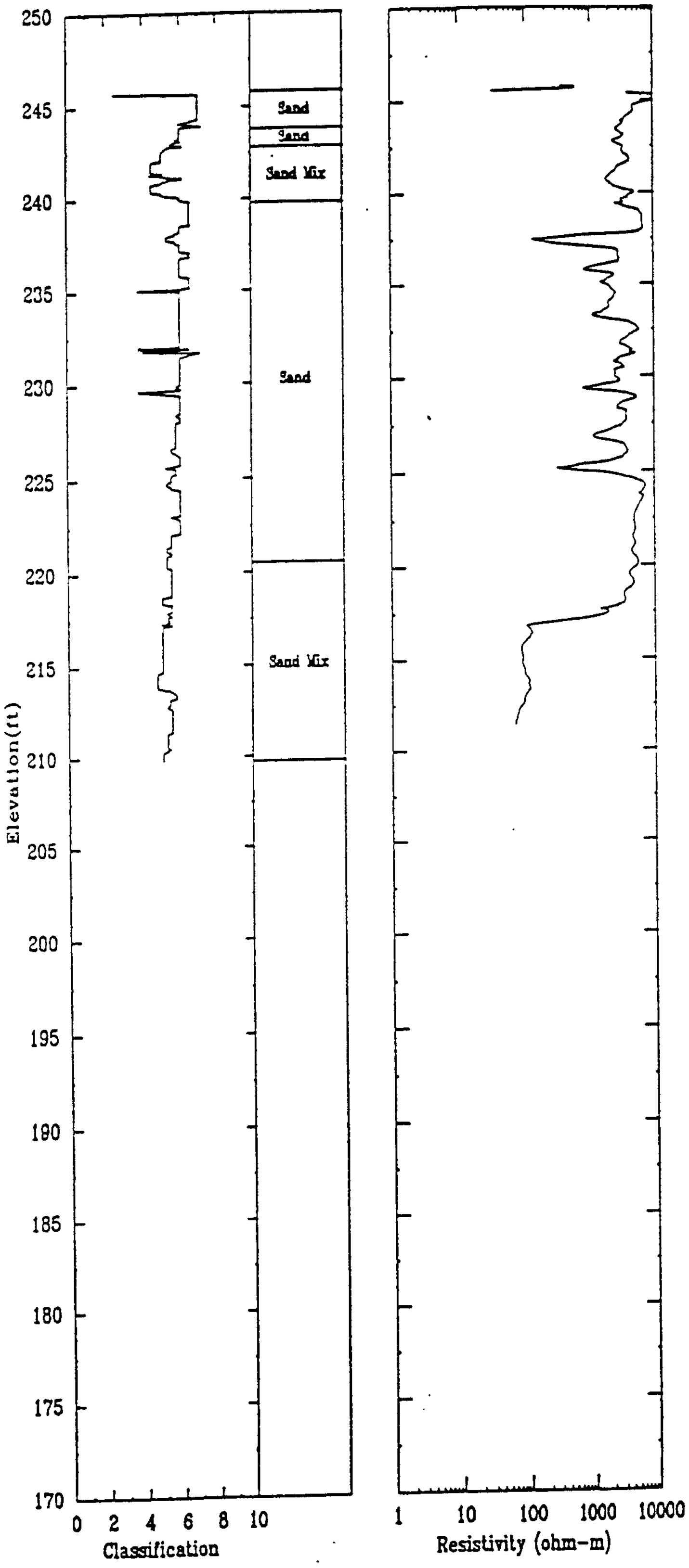

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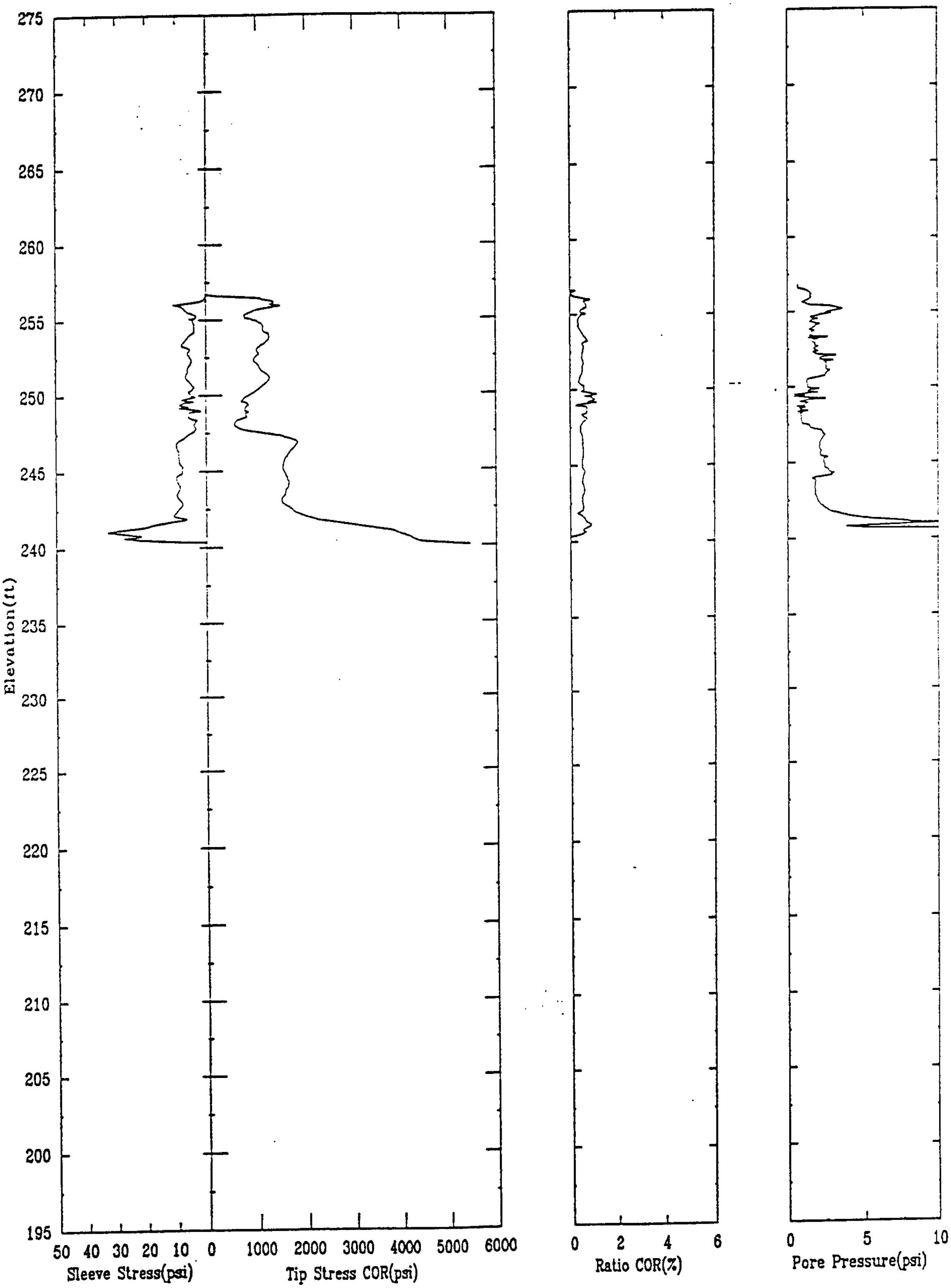

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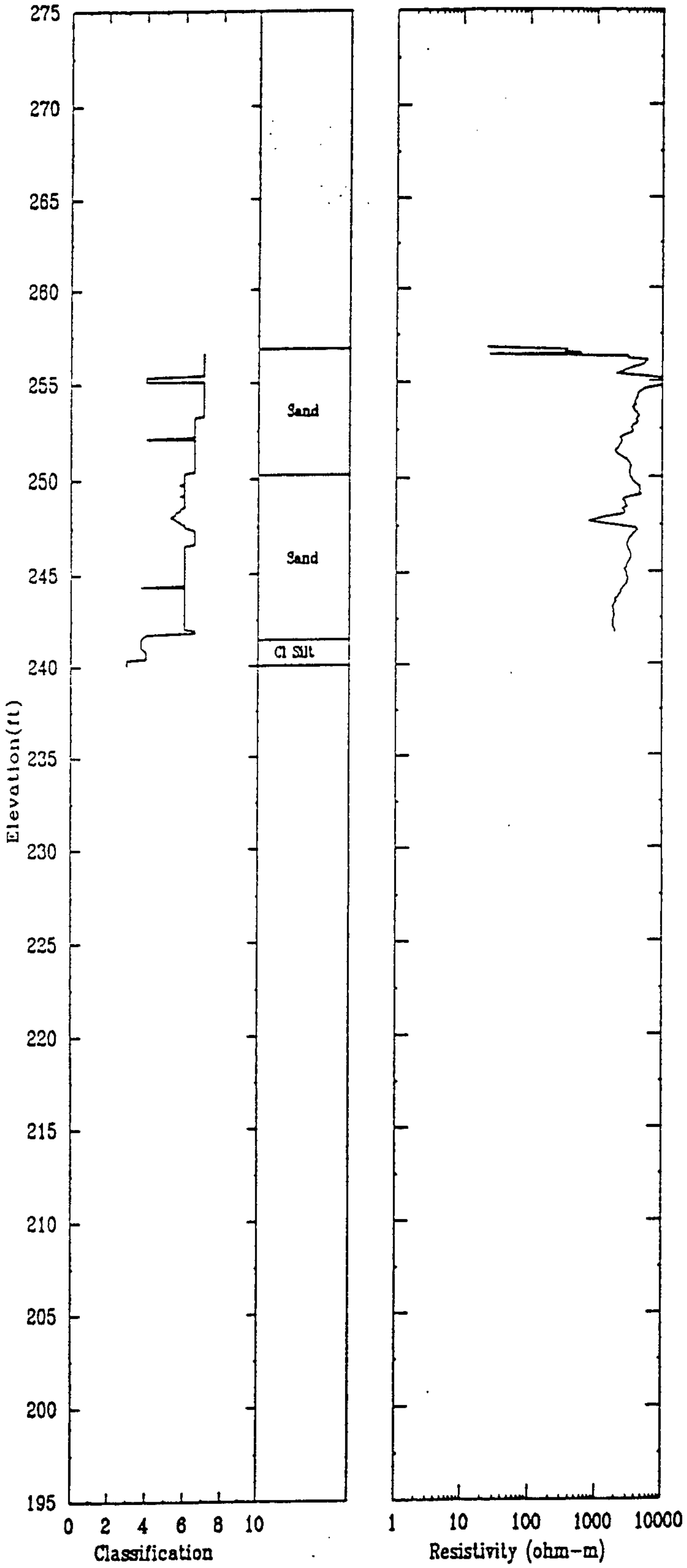

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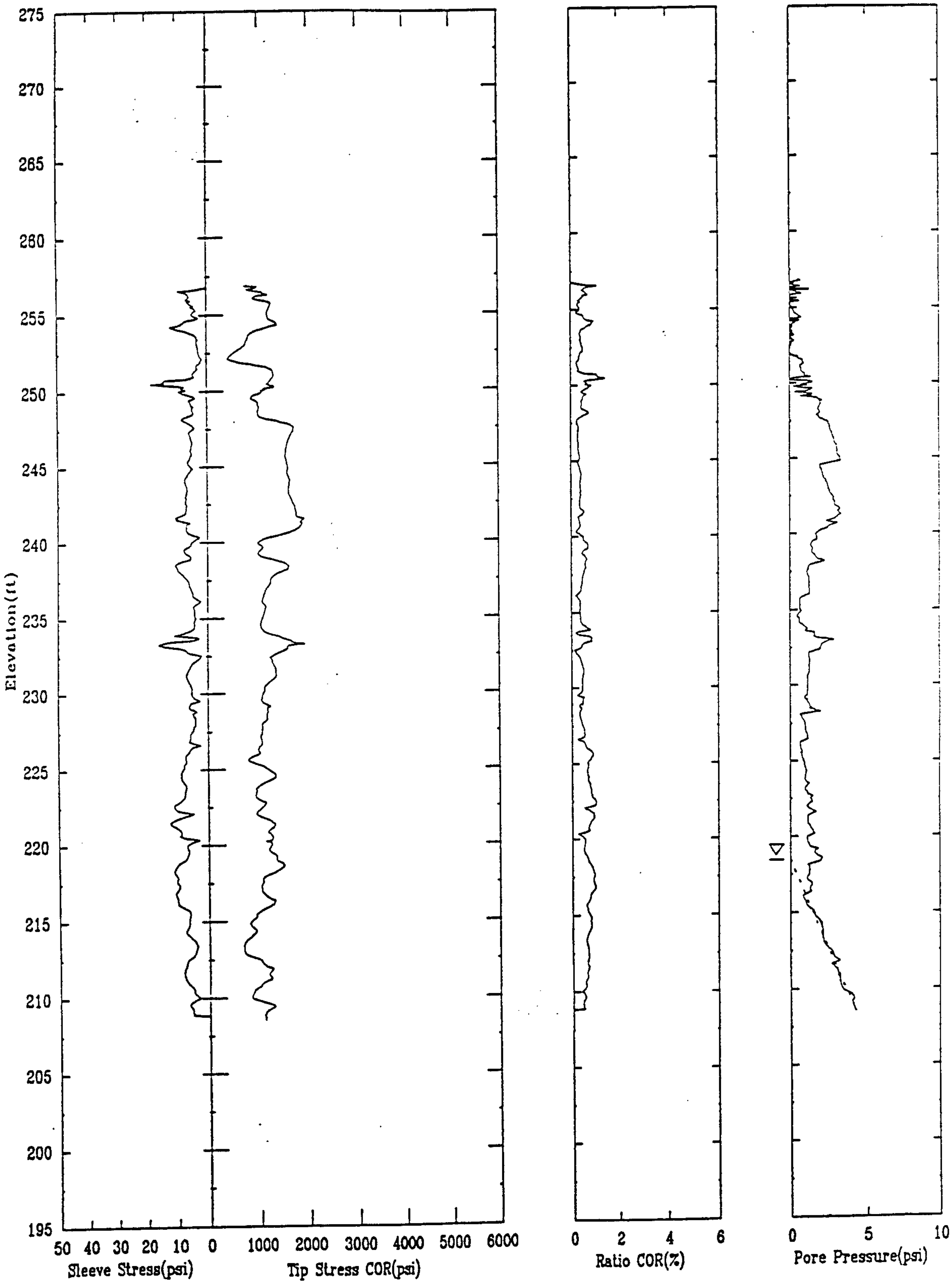

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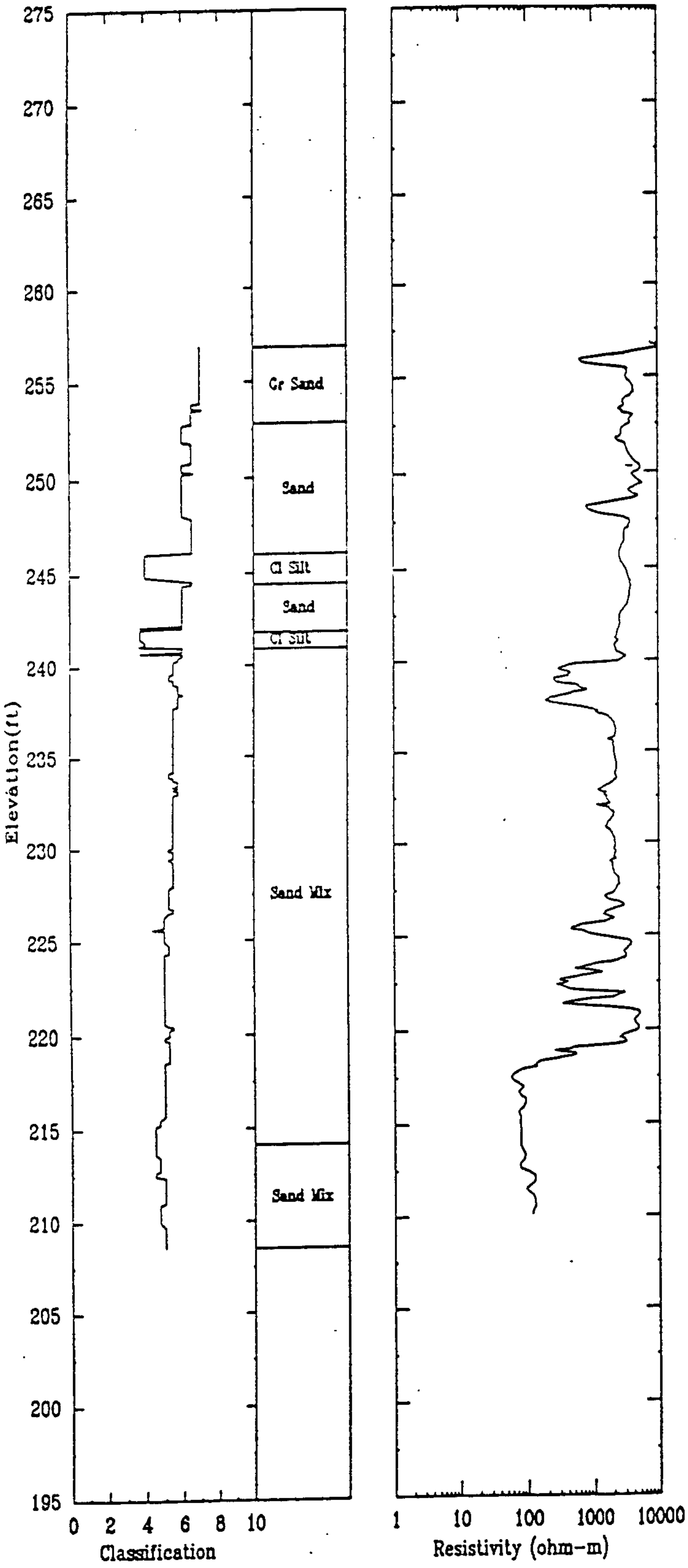

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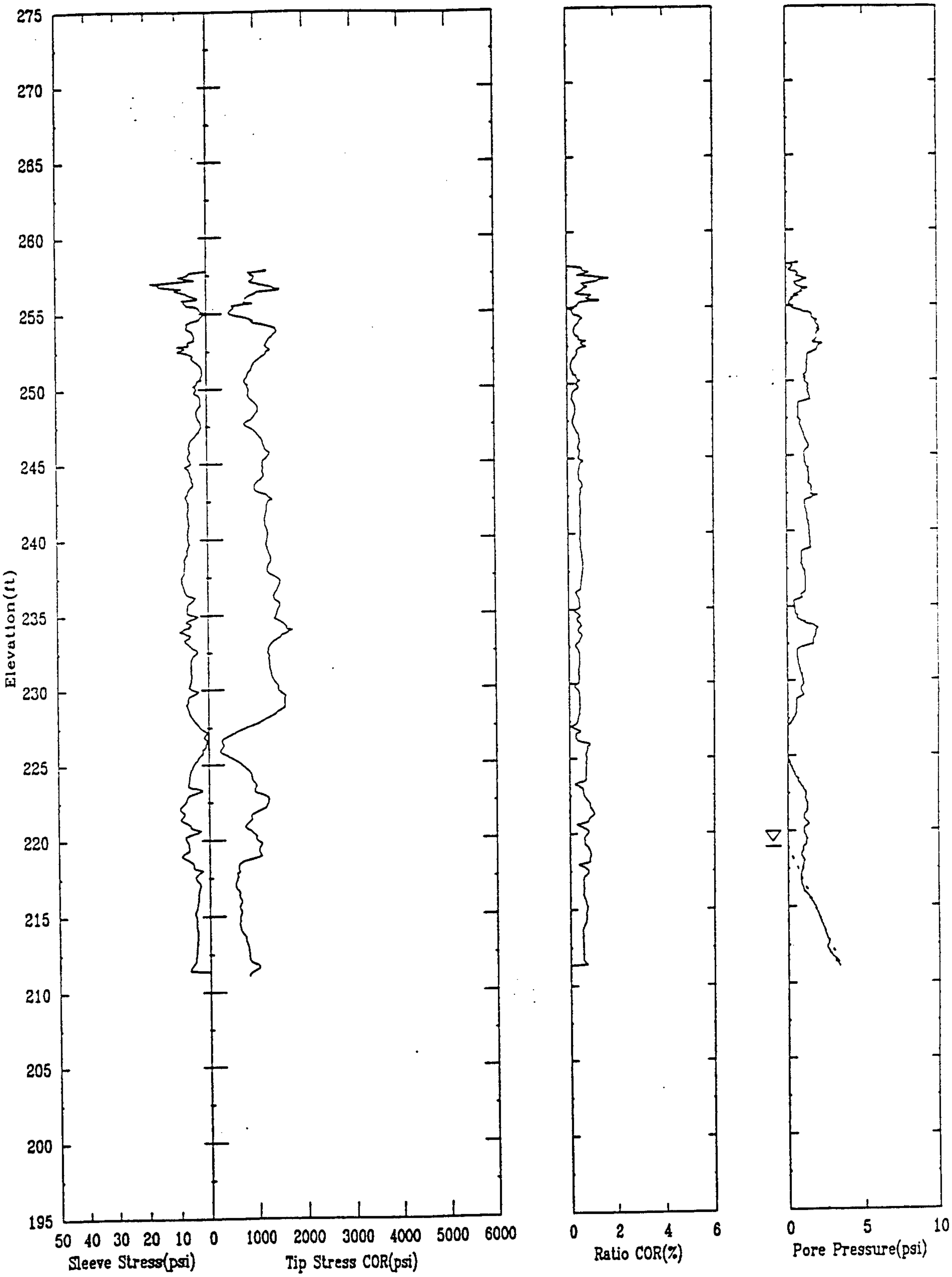

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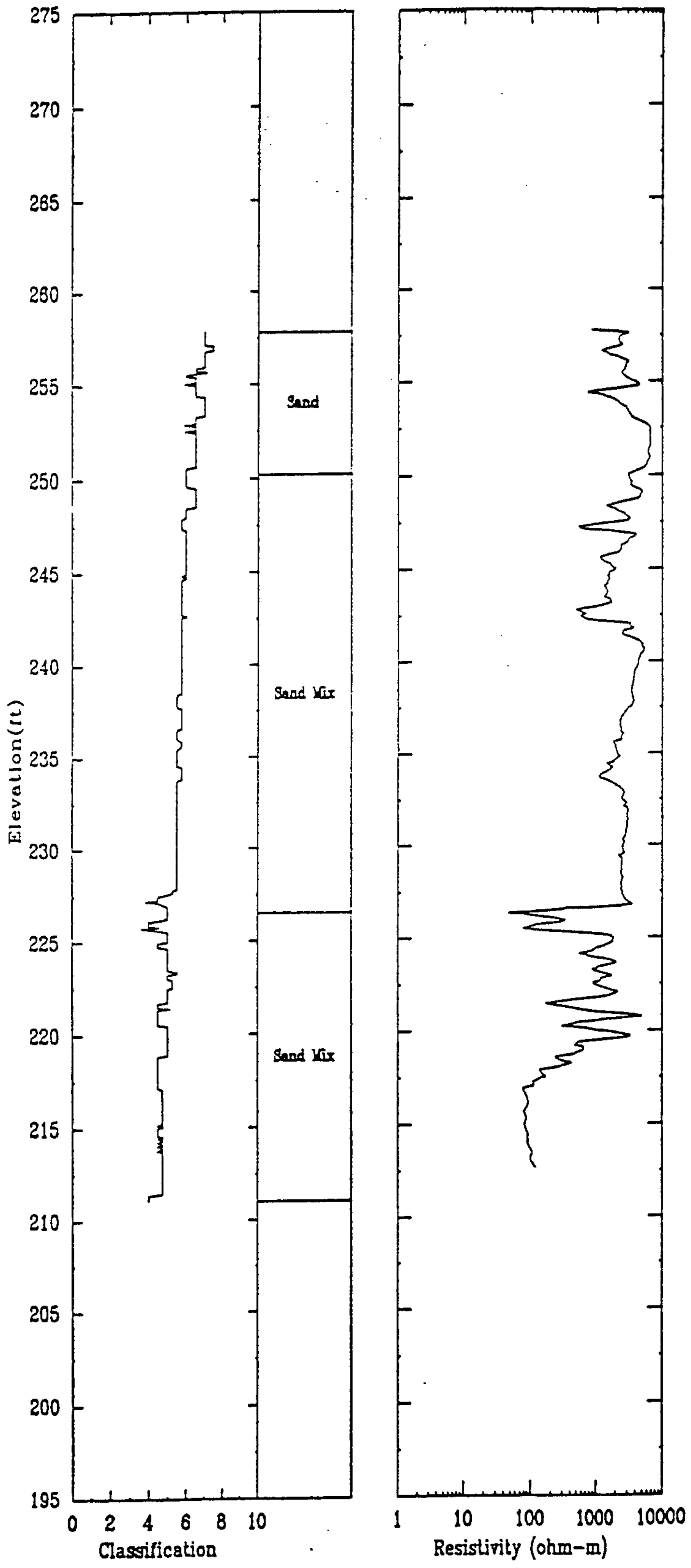

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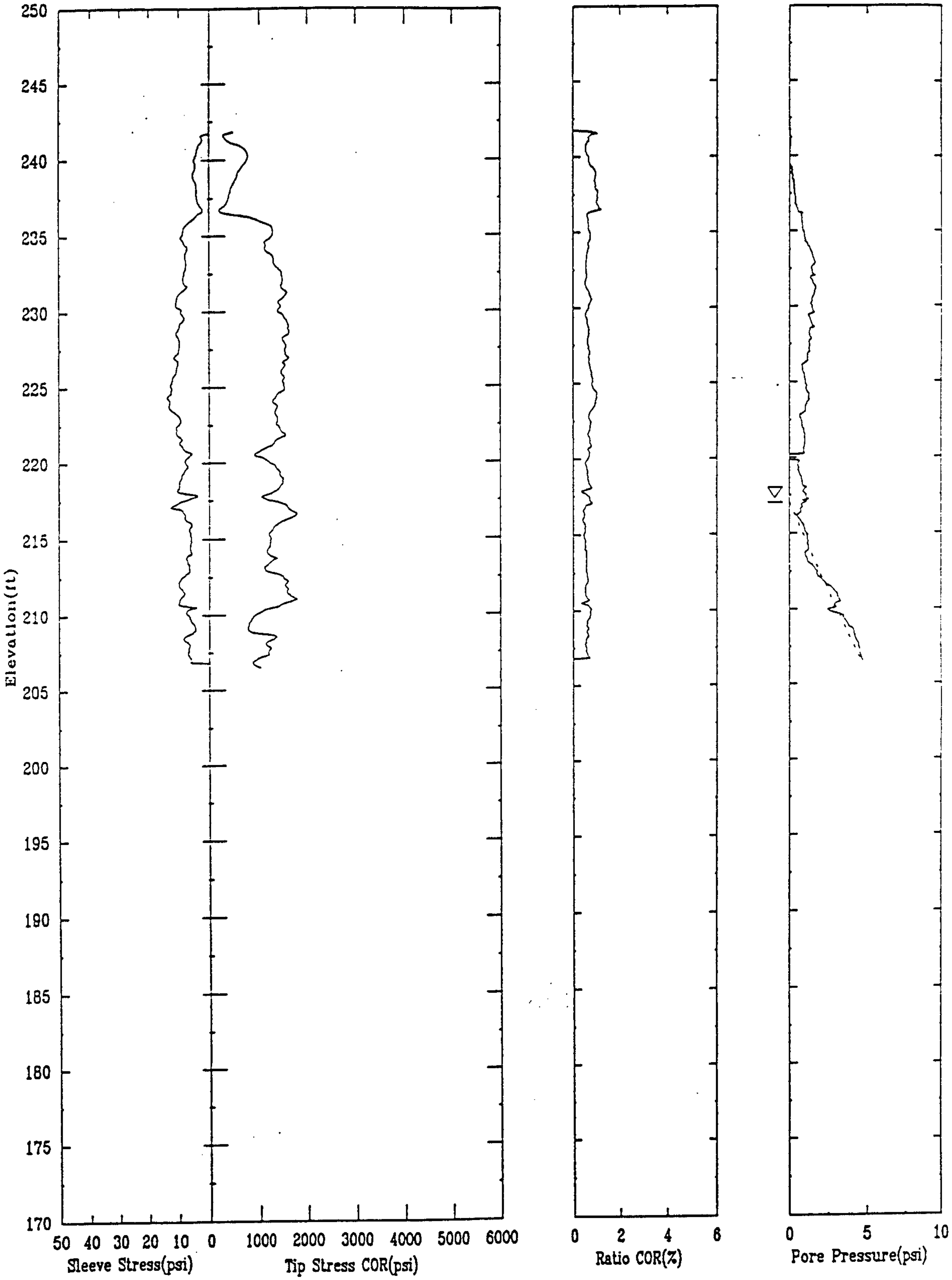

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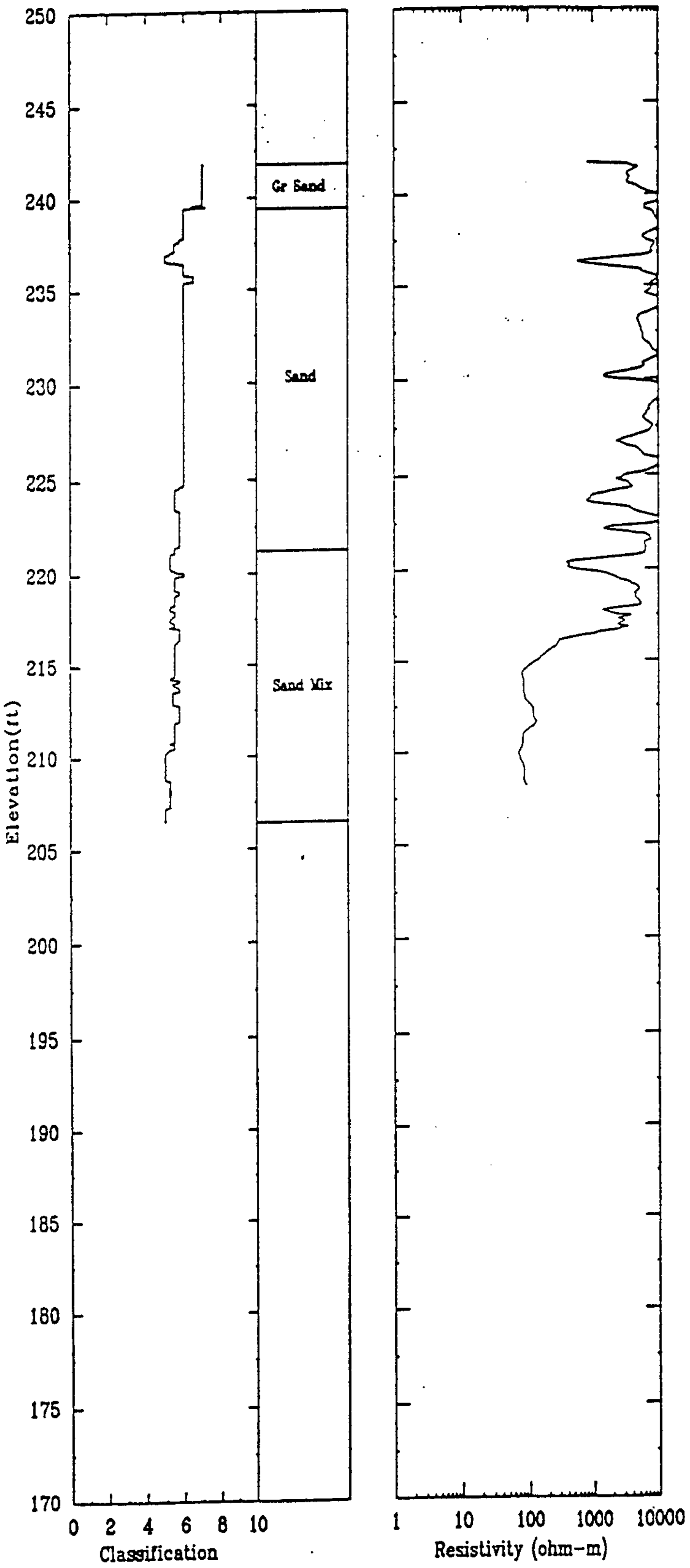

APPENDIX C

SOIL GAS MONITORING RESULTS

84 B- PRG

```
- 1302 Measurement Data ------- 1684173/2595 - 1993-12-14 00:37 - Page  1 -

1302 Settings:
--------------------------------------------------------------------------

Compensate for Water Vap. Interference    :            YES
Compensate for Cross Interference         :             NO
Sample Continuously                       :             NO
Sampling Interval                         :          00:02
Pre-set Monitoring Period                 :             NO

Measure
Gas A: Benzene                            :            YES
Gas B: Toluene                            :            YES
Gas C: Ethylbenzene                       :            YES
Gas D: Xylene                             :            YES
Gas E: TOC as Propane                     :            YES
Water Vapour                              :            YES

Sampling Tube Length                      :          110.0 ft
Air Pressure                              :          760.0 mmHg
Normalization Temperature                 :           20.0  C

General Information:
--------------------------------------------------------------------------
Start Time                                : 1993-12-02 09:21
Stop Time                                 : 1993-12-02 09:38
Results Not Averaged
Number of Event Marks                     :              0
Number of Recorded Samples                :              6

                 Alarm Limit        Max         Mean         Min      Std.Dev
--------------------------------------------------------------------------
Gas A:          ________      20.9E+00     12.0E+00    5.06E+00    6.49E+00
Gas B:          ________      55.9E+00     46.0E+00    37.7E+00    7.37E+00
Gas C:          ________      34.0E+00     22.9E+00    13.2E+00    8.78E+00
Gas D:          ________      7.55E+00     5.98E+00    5.05E+00     848E-03
Gas E:          ________      12.3E+00     6.06E+00     766E-03    5.14E+00
Water:                        10.1E+03     6.69E+03    5.08E+03    1.69E+03
```

84 B-PRG (Continued)

```
- 1302 Measurement Data ------- 1684173/2595 - 1993-12-14 00:37 - Page  2 -

Samples Measured From 1993-12-02 09:21
----------------------------------------------------------------------
Samp.   Time       Gas A      Gas B      Gas C      Gas D      Gas E     Water
 No.  hh:mm:ss       ppm        ppm        ppm        ppm        ppm     mg/m3
----------------------------------------------------------------------
   1  09:21:48  17.3E+00  55.9E+00  32.1E+00  5.32E+00  10.5E+00  5.55E+03
   2  09:25:08  20.9E+00  54.9E+00  34.0E+00  5.48E+00  12.3E+00  5.37E+03
   3  09:27:51  16.9E+00  47.9E+00  28.6E+00  5.05E+00  10.7E+00  5.08E+03
   4  09:30:41  6.55E+00  40.1E+00  15.7E+00  7.55E+00  1.21E+00  10.1E+03
   5  09:33:20  5.06E+00  39.5E+00  13.2E+00  5.97E+00   876E-03  7.09E+03
   6  09:35:58  5.43E+00  37.7E+00  14.1E+00  6.54E+00   766E-03  6.98E+03
```

84 C-1-PRG

```
- 1302 Measurement Data ------- 1684173/2595 - 1993-12-14 00:43 - Page  1 -

1302 Settings:
----------------------------------------------------------------------

Compensate for Water Vap. Interference   :              YES
Compensate for Cross Interference        :               NO
Sample Continuously                      :               NO
Sampling Interval                        :            00:02
Pre-set Monitoring Period                :               NO

Measure
Gas A: Benzene                           :              YES
Gas B: Toluene                           :              YES
Gas C: Ethylbenzene                      :              YES
Gas D: Xylene                            :              YES
Gas E: TOC as Propane                    :              YES
Water Vapour                             :              YES

Sampling Tube Length                     :            110.0 ft
Air Pressure                             :            760.0 mmHg
Normalization Temperature                :             20.0  C

General Information:
----------------------------------------------------------------------
Start Time                               : 1993-12-02 11:10
Stop Time                                : 1993-12-02 11:43
Results Not Averaged
Number of Event Marks                    :                0
Number of Recorded Samples               :               12

                  Alarm Limit        Max       Mean        Min    Std.Dev
----------------------------------------------------------------------
Gas A:            ________      79.6E+00   25.8E+00   2.30E+00   19.8E+00
Gas B:            ________       128E+00   48.2E+00   5.42E+00   30.5E+00
Gas C:            ________       124E+00   39.5E+00   2.74E+00   31.2E+00
Gas D:            ________      22.7E+00   7.20E+00   3.97E+00   5.40E+00
Gas E:            ________      25.6E+00   10.5E+00    411E-03   6.34E+00
Water:                          9.36E+03   6.94E+03   5.13E+03   1.20E+03
```

84 C-1-PRG (continued)

```
- 1302 Measurement Data ------- 1684173/2595 - 1993-12-14 00:43 - Page  2 -

Samples Measured From 1993-12-02 11:10
----------------------------------------------------------------------------
Samp.  Time       Gas A     Gas B     Gas C     Gas D     Gas E     Water
 No. hh:mm:ss       ppm       ppm       ppm       ppm       ppm     mg/m3
----------------------------------------------------------------------------
   1  11:10:51  2.30E+00  5.42E+00  2.74E+00  4.70E+00   411E-03  5.13E+03
   2  11:14:14  79.6E+00   128E+00   124E+00  3.97E+00  25.6E+00  8.72E+03
   3  11:16:54  39.8E+00  68.2E+00  61.3E+00  14.4E+00  18.1E+00  9.36E+03
   4  11:19:42  27.5E+00  50.8E+00  40.1E+00  22.7E+00  15.0E+00  8.11E+03
   5  11:22:21  22.2E+00  45.2E+00  34.7E+00  7.25E+00  12.7E+00  7.45E+03
   6  11:24:59  19.4E+00  40.4E+00  30.6E+00  4.91E+00  10.4E+00  7.03E+03
   7  11:27:38  17.1E+00  35.9E+00  25.1E+00  4.50E+00  8.70E+00  6.64E+03
   8  11:30:44  16.9E+00  36.1E+00  27.0E+00  4.68E+00  7.82E+00  6.56E+03
   9  11:33:20  14.7E+00  32.4E+00  22.0E+00  4.61E+00  6.72E+00  6.19E+03
  10  11:35:57  12.3E+00  27.5E+00  18.0E+00  4.69E+00  5.96E+00  6.03E+03
  11  11:38:31  12.4E+00  27.1E+00  17.5E+00  4.74E+00  5.49E+00  5.79E+03
  12  11:41:18  45.2E+00  80.5E+00  71.1E+00  5.54E+00  9.34E+00  6.24E+03
```

84 C-2-PRG

```
- 1302 Measurement Data ------- 1684173/2595 - 1993-12-14 00:44 - Page  1 -

1302 Settings:
-------------------------------------------------------------------------

Compensate for Water Vap. Interference   :              YES
Compensate for Cross Interference        :               NO
Sample Continuously                      :               NO
Sampling Interval                        :            00:02
Pre-set Monitoring Period                :               NO

Measure
Gas A: Benzene                           :              YES
Gas B: Toluene                           :              YES
Gas C: Ethylbenzene                      :              YES
Gas D: Xylene                            :              YES
Gas E: TOC as Propane                    :              YES
Water Vapour                             :              YES

Sampling Tube Length                     :            110.0 ft
Air Pressure                             :            760.0 mmHg
Normalization Temperature                :             20.0  C

General Information:
-------------------------------------------------------------------------
Start Time                               : 1993-12-02 12:28
Stop Time                                : 1993-12-02 13:01
Results Not Averaged
Number of Event Marks                    :                0
Number of Recorded Samples               :               12

               Alarm Limit         Max       Mean        Min    Std.Dev
-------------------------------------------------------------------------
Gas A:          ________      14.9E+00   9.98E+00   2.04E+00   3.71E+00
Gas B:          ________      33.8E+00   24.7E+00   5.45E+00   9.16E+00
Gas C:          ________      19.0E+00   14.3E+00   3.12E+00   5.52E+00
Gas D:          ________      8.23E+00   5.75E+00   2.16E+00   1.36E+00
Gas E:          ________      8.41E+00   5.49E+00    848E-03   2.80E+00
Water:                        9.46E+03   8.08E+03   4.57E+03   1.30E+03
```

84 C-2-PRG (continued)

```
- 1302 Measurement Data ------- 1684173/2595 - 1993-12-14 00:44 - Page  2 -

Samples Measured From 1993-12-02 12:29
--------------------------------------------------------------------------
Samp.   Time      Gas A     Gas B     Gas C     Gas D     Gas E     Water
 No.  hh:mm:ss      ppm       ppm       ppm       ppm       ppm     mg/m3
--------------------------------------------------------------------------
   1  12:29:00  2.04E+00  5.45E+00  3.12E+00  2.16E+00   700E-03  4.57E+03
   2  12:32:33  12.9E+00  27.3E+00  17.1E+00  4.97E+00  8.41E+00  8.66E+03
   3  12:35:17  12.5E+00  29.3E+00  17.2E+00  8.23E+00  7.31E+00  7.77E+03
   4  12:37:55  10.6E+00  28.8E+00  17.3E+00  6.93E+00  6.96E+00  8.33E+03
   5  12:40:32  11.3E+00  33.8E+00  16.0E+00  5.67E+00  6.83E+00  8.36E+03
   6  12:43:44  10.8E+00  30.0E+00  16.7E+00  5.23E+00  7.38E+00  8.70E+03
   7  12:46:22  14.9E+00  24.1E+00  17.6E+00  5.71E+00  7.16E+00  8.90E+03
   8  12:48:59  11.6E+00  32.5E+00  18.4E+00  5.62E+00  6.65E+00  8.99E+03
   9  12:51:50  12.1E+00  31.6E+00  19.0E+00  5.64E+00  6.61E+00  9.22E+03
  10  12:54:24  11.3E+00  30.4E+00  17.2E+00  6.55E+00  6.44E+00  9.46E+03
  11  12:56:56  5.05E+00  12.1E+00  5.88E+00  5.95E+00   810E-03  7.17E+03
  12  12:59:31  4.78E+00  11.2E+00  5.52E+00  6.35E+00   648E-03  6.85E+03
```

```
- 1302 Measurement Data ------- 1684173/2595 - 1993-12-14 00:49 - Page  1 -

1302 Settings:
----------------------------------------------------------------------

Compensate for Water Vap. Interference   :           YES
Compensate for Cross Interference        :            NO
Sample Continuously                      :            NO
Sampling Interval                        :         00:02
Pre-set Monitoring Period                :            NO

Measure
Gas A: Benzene                           :           YES
Gas B: Toluene                           :           YES
Gas C: Ethylbenzene                      :           YES
Gas D: Xylene                            :           YES
Gas E: TOC as Propane                    :           YES
Water Vapour                             :           YES

Sampling Tube Length                     :         110.0 ft
Air Pressure                             :         760.0 mmHg
Normalization Temperature                :          20.0  C

General Information:
----------------------------------------------------------------------
Start Time                               : 1993-12-02 15:33
Stop Time                                : 1993-12-02 16:11
Results Not Averaged
Number of Event Marks                    :             0
Number of Recorded Samples               :            14

               Alarm Limit       Max        Mean        Min     Std.Dev
-----------------------------------------------------------------------
Gas A:         ________     25.0E+00    15.1E+00   2.55E+00   8.88E+00
Gas B:         ________     46.4E+00    29.4E+00   3.80E+00   17.3E+00
Gas C:         ________     32.5E+00    19.8E+00   2.67E+00   12.1E+00
Gas D:         ________     25.8E+00    9.59E+00   3.05E+00   5.05E+00
Gas E:         ________     21.0E+00    12.0E+00    317E-03   8.56E+00
Water:                      13.1E+03    10.5E+03   4.87E+03   2.78E+03
```

84 D-PRG

```
- 1302 Measurement Data ------- 1684173/2595 - 1993-12-14 00:49 - Page  2 -

Samples Measured From 1993-12-02 15:33
----------------------------------------------------------------------------
Samp.  Time         Gas A      Gas B      Gas C      Gas D      Gas E     Water
 No.  hh:mm:ss        ppm        ppm        ppm        ppm        ppm     mg/m3
----------------------------------------------------------------------------
   1  15:33:49  2.55E+00  3.80E+00  2.67E+00  3.05E+00   317E-03  4.87E+03
   2  15:37:09  18.5E+00  32.1E+00  20.4E+00  12.1E+00  16.4E+00  12.0E+03
   3  15:39:49  20.6E+00  38.4E+00  26.0E+00  25.8E+00  17.2E+00  12.8E+03
   4  15:42:27  19.3E+00  41.6E+00  27.7E+00  11.8E+00  16.6E+00  13.1E+03
   5  15:45:16  22.0E+00  42.9E+00  31.9E+00  10.2E+00  18.2E+00  12.5E+03
   6  15:47:54  20.6E+00  41.9E+00  28.2E+00  8.92E+00  19.1E+00  13.0E+03
   7  15:50:34  23.2E+00  43.6E+00  28.9E+00  10.4E+00  19.4E+00  12.1E+03
   8  15:53:10  23.8E+00  45.8E+00  31.8E+00  8.95E+00  20.1E+00  11.9E+03
   9  15:56:36  25.0E+00  46.4E+00  32.5E+00  8.42E+00  21.0E+00  12.5E+03
  10  15:59:12  21.5E+00  44.9E+00  29.1E+00  8.11E+00  17.1E+00  12.7E+03
  11  16:01:47  4.27E+00  8.73E+00  5.14E+00  6.97E+00  1.06E+00  8.71E+03
  12  16:04:41  3.61E+00  6.38E+00  4.34E+00  6.24E+00   750E-03  7.17E+03
  13  16:07:18  3.95E+00  7.27E+00  3.83E+00  6.89E+00   667E-03  6.96E+03
  14  16:09:50  2.68E+00  7.16E+00  4.08E+00  6.48E+00   579E-03  7.01E+03
```

84 D-PRG (continued)

84 E-PRG

```
- 1302 Measurement Data ------- 1684173/2595 - 1993-12-14 00:54 - Page  1 -

1302 Settings:
-------------------------------------------------------------------------

Compensate for Water Vap. Interference    :           YES
Compensate for Cross Interference         :            NO
Sample Continuously                       :            NO
Sampling Interval                         :         00:02
Pre-set Monitoring Period                 :            NO

Measure
Gas A: Benzene                            :           YES
Gas B: Toluene                            :           YES
Gas C: Ethylbenzene                       :           YES
Gas D: Xylene                             :           YES
Gas E: TOC as Propane                     :           YES
Water Vapour                              :           YES

Sampling Tube Length                      :         110.0 ft
Air Pressure                              :         760.0 mmHg
Normalization Temperature                 :          20.0  C

General Information:
-------------------------------------------------------------------------
Start Time                                : 1993-12-02 17:37
Stop Time                                 : 1993-12-02 17:57
Results Not Averaged
Number of Event Marks                     :             0
Number of Recorded Samples                :             7

                Alarm Limit      Max        Mean        Min       Std.Dev
-------------------------------------------------------------------------
Gas A:          ________     18.4E+00   15.9E+00   12.5E+00   2.10E+00
Gas B:          ________     27.7E+00   24.7E+00   19.3E+00   3.42E+00
Gas C:          ________     20.7E+00   17.8E+00   12.1E+00   3.50E+00
Gas D:          ________     6.89E+00   5.78E+00   4.94E+00    609E-03
Gas E:          ________     12.7E+00   11.6E+00   10.1E+00    932E-03
Water:                       10.3E+03   9.10E+03   8.09E+03    822E+00
```

84 E-PRG (continued)

```
- 1302 Measurement Data ------- 1684173/2595 - 1993-12-14 00:54 - Page  2 -

Samples Measured From 1993-12-02 17:38
---------------------------------------------------------------------------
Samp.   Time       Gas A      Gas B      Gas C      Gas D      Gas E     Water
 No.  hh:mm:ss       ppm        ppm        ppm        ppm        ppm      mg/m3
---------------------------------------------------------------------------
   1  17:38:26  12.9E+00   19.5E+00   12.7E+00   6.89E+00   12.7E+00   8.12E+03
   2  17:41:45  12.5E+00   19.3E+00   12.1E+00   6.04E+00   10.1E+00   9.46E+03
   3  17:44:23  16.6E+00   25.3E+00   18.1E+00   5.62E+00   12.4E+00   9.26E+03
   4  17:46:59  18.4E+00   27.2E+00   19.6E+00   6.24E+00   12.0E+00   10.3E+03
   5  17:50:04  16.9E+00   27.2E+00   20.7E+00   4.94E+00   12.3E+00   9.99E+03
   6  17:52:39  17.2E+00   26.7E+00   20.6E+00   5.40E+00   11.4E+00   8.51E+03
   7  17:55:15  17.0E+00   27.7E+00   20.6E+00   5.32E+00   10.5E+00   8.09E+03
```

APPENDIX D

ANALYTICAL CHEMICAL TEST RESULTS

(The reverse of this page is blank.)

Sample Code (pfeffer)	Date	Sample Location (ft) Below Ground Surface	TPH mg/kg Dry Basis	OVM
45	12/8/93	84D 10-10.5	"	"
46	12/8/93	84D 9.5-10	"	nr
47	12/8/93	84D 9-9.5	"	!
48	12/8/93	84D 21-21.5	179	558
49	12/8/93	84D 21.5-22	234	488
50	12/8/93	84D 22-22.5	222	584
51	12/8/93	84D 22.5-23	324	562
52	12/8/93	84D 23-23.5	371	713
53	12/8/93	84D 23.5-24	19	501
54	12/9/93	84D 35-35.5	11	42
55	12/9/95	84D 35.5-36	<10	38
56	12/9/95	84D 36-36.5	338	219
57	12/9/95	84D 36.5-37	478	471
58	12/9/95	84D 37-37.5	757	408
59	12/9/95	84D 37.5-38	1,010	490
60	12/9/95	84D 38-38.5	1,880	521
61	12/9/95	84D 38.5-39	3,940	414
62	12/9/95	84D 39-39.5	7,530	454
63	12/9/95	84D 39.5-40	12,500	340
64	12/9/95	84D 40-40.5	12,000	490
65	12/9/95	84D 40.5-41	7,870	348
66	12/9/95	84D 41-41.5	1,940	521
67	12/9/95	84D 44-44.3	<10	5
68	12/9/95	84P 26-26.5	<10	1
69	12/9/95	84P 26.5-27	"	1
70	12/9/95	84P 27-27.5	"	1
71	12/9/95	84P 27.5-28	"	1
72	12/9/95	84P 28-28.5	"	33
73	12/9/95	84P 28.5-29	"	14
74	12/9/95	84P 29-29.5	"	11
75	12/10/93	84F 28.5-29	"	1
76	12/10/93	84F 29-29.5	"	6
77	12/10/93	84F 29.5-30	11	44
78	12/10/93	84F 25.5-26	"	2
79	12/10/93	84F 26-26.5	"	1
80	12/10/93	84F 26.5-27	"	3
81	12/10/93	84F 27-27.5	"	1
82	12/10/93	84F 27.5-28	"	1
83	12/10/93	84F 28-28.5	"	1
84	12/10/93	84F 30-30.5	76	208
85	12/10/93	84F 30.5-31	81	408

Sample Code (pfeffer)	Date	Sample Location (ft) Below Ground Surface	TPH mg/kg Dry Basis	OVM
3	12/7/93	84F 28.5-29	"	"
4	12/7/93	84F 28-28.5	"	"
5	12/7/93	84F 27.5-28	<10	nr
6	12/7/93	84F 31-31.5	"	"
7	12/7/93	84F 30.5-31	"	"
8	12/7/93	84F 30-30.5	"	"
9	12/7/93	84L 31.5-32.5	<10	nr
10	12/8/93	84B 31-32.5	189	nr
11	12/8/93	84B 31.5-33	nr	"
12	12/8/93	84D 3-3.5	<10	nr
13	12/8/93	84D 3.5-4	"	"
14	12/8/93	84D 4-4.5	"	"
15	12/8/93	84D 4.5-5	"	"
16	12/8/93	84D 5-5.5	"	"
17	12/8/93	84D 5.5-6	"	"
18	12/8/93	84D 6-6.5	18	"
19	12/8/93	84D 7-7.5	<10	"
20	12/8/93	84D 7.5-8	"	0
21	12/8/93	84D 8-8.5	"	3
22	12/8/93	84D 8.5-9	"	2
23	12/8/93	84D 16-16.5	208	655
24	12/8/93	84D 15.5-16	412	297
25	12/8/93	84D 15-15.5	"	45
26	12/8/93	84D 14.5-15	"	1
27	12/8/93	84D 16.5-17 A	518	584
28	12/8/93	84D 16.5-17 B	38	nr
29	12/8/93	84D 17-17.5	540	663
30	12/8/93	84D 17.5-18	448	591
31	12/8/93	84D 18-18.5	423	709
32	12/8/93	84D 18.5-19	345	616
33	12/8/93	84D 19-19.5	303	610
34	12/8/93	84D 19.5-20	288	673
35	12/8/93	84D 20-20.5	236	481
36	12/8/93	84D 20.5-21	115	631
37	12/8/93	84D 14-14.5	"	0
38	12/8/93	84D 13.5-14	"	1
39	12/8/93	84D 13-13.5	"	1
40	12/8/93	84D 12.5-13	"	2
41	12/8/93	84D 12-12.5	"	3
42	12/8/93	84D 11.5-12	"	1
43	12/8/93	84D 11-11.5	<10	3
44	12/8/93	84D 10.5-11	"	2