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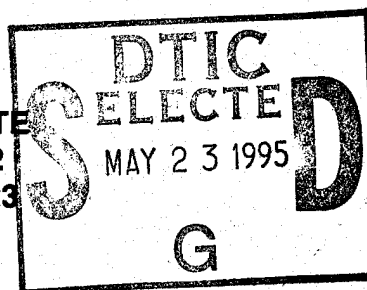


**AIR FORCE SITE CHARACTERIZATION AND ANALYSIS PENETROMETER SYSTEM (AFSCAPS): LASER-INDUCED FLUORESCENCE CONE PENETROMETER - TESTING AT CARSWELL AFB TX (VOL III OF V)**

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This technical report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS) where it will be available to the general public, including foreign nationals.

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## PREFACE

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This work was sponsored by the Oklahoma City Air Logistics Command, Directorate of Environmental Management (OC-ALC/EM) and the U.S. Air Force Civil Engineering Support Agency (AFCESA). Ms. Beverly Allen of OC-ALC/EM and Mr. Bruce Nielsen of AFCESA/RAVW were the Government technical program managers.

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## EXECUTIVE SUMMARY

### A. OBJECTIVE

The Air Force Site Characterization and Analysis Penetrometer System (AFSCAPS) project was initiated to further develop the combined technology of the U.S. Army Corps of Engineers Waterways Experiment Station's (WES) SCAPS program and the Air Force Laser Spectroscopy Program. The purpose of the program was to enable the Air Force to address characterization, remediation and post-remedial monitoring of fuel-contaminated sites in a more efficient and effective manner. The primary objectives of this program were to develop, demonstrate, and evaluate the Laser-Induced Fluorescence-Cone Penetrometer Technique (LIF-CPT) system for the characterization of petroleum fuel-contaminated sites.

### B. BACKGROUND

The Department of Defense is conducting nationwide remediation efforts to clean up contaminated military and weapons facilities. It has been estimated that remediation of these DoD facilities will require expenditure of \$24 billion dollars by the DoD over the next 30 years. Identifying, characterizing and developing remediation plans for these contaminated sites is a high priority for the DoD.

Potential cost savings realized through cone penetrometer-based environmental site investigations have fostered federal research and development efforts by the U.S. Army, Navy and Air Force. Together they have supported the Tri-service Site Characterization and Analysis Penetrometer System (SCAPS) program. To better characterize hazardous waste sites, improved investigative tools and methods are being developed for use with cone penetrometers. One such tool is the laser fluorimeter. Initially developed at WES, specifically for use in detecting diesel fuel marine (DFM) for the U.S. Navy, the Air Force has sponsored additional research to modify the laser fluorimeter/cone penetrometer system for use in detecting jet fuel, heating oil and gasoline-contaminated soils.

### C. SCOPE

To accomplish the objectives of this project the following tasks were completed:

- ◆ evaluation of the current LIF state-of-art,
- ◆ development of specifications for the new LIF system,
- ◆ fabrication and laboratory testing/evaluation of the LIF-CPT system,
- ◆ field demonstrations and evaluations at Tinker and Carswell AFBs of the AF LIF-CPT system.

This technical report is organized in five separate volumes:

- ◆ Volume I discusses the development of the LIF-CPT system including a review of the current state-of-art of the WES SCAPS program and NDSU's research work.
- ◆ Volume II is a review of the sites investigated at Tinker AFB.
- ◆ Volume III presents results from Carswell AFB.

- ◆ Volume IV consists of comprehensive appendix of all LIF-CPT logs, boring logs, WTM plots, and demonstration, test and evaluation (DT&E) plans for both Tinker and Carswell AFB's.
- ◆ Finally, Volume V contains the laboratory analytical data for samples obtained at Tinker AFB.

## **D. METHODOLOGY**

The WES system employed a nitrogen laser system that is limited to the emission of a single excitation wavelength of 337 nanometers (nm). This is useful for the detection of large multi-ring fuels such as DFM but it has been shown that light fuels such as jet fuels and gasoline have only weak spectral signatures when excited with a 337 nm light pulse. Excitations at shorter wavelengths, such as 280 to 290 nm for jet fuels and 260 nm for gasoline, provide much stronger and distinctive fluorescence spectra. One of the primary goals of this project was to develop and test a tunable laser that allows the investigator to select the most appropriate wavelength depending on the contaminant of interest and site conditions.

Under this program, North Dakota state University (NDSU) developed and tested a laser fluorimeter to analyze aromatic hydrocarbons in situ. The NDSU system features a full-wavelength tunable dye system with a pulsed laser (Nd:YAG), fiber optic probe and detection system. Applied Research Associates, Inc. (ARA) incorporated the laser system with a cone penetrometer truck producing a robust site assessment tool capable of quickly locating and quantifying fugitive petroleum, oil and lubricant (POL) contamination.

## **E. TEST DESCRIPTION**

The test program consisted of two phases, (1) evaluation of the LIF-CPT probe under laboratory conditions, and (2) evaluation of the LIF-CPT probe under field conditions.

The laboratory testing consisted of three major efforts (1) selecting and characterizing representative soils from Tinker AFB, (2) evaluation of the effect of bending the fiber-optic cable on the LIF response, and (3) determining the sensitivity of the LIF system to expected fuel contaminants.

During the field demonstration and evaluation program several objectives were addressed. Primarily, this phase demonstrated that a CPT deployed LIF system could be used to locate fuel-contaminated soils to at least the regulatory limits of 100 ppm. Other criteria such as system 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 were evaluated. In addition, the cost effectiveness of the LIF-CPT was evaluated as well as its ability to provide highly detailed real-time data for on-site graphical representation.

## **F. RESULTS**

The following summarizes the results from the laboratory and field evaluations:

- ◆ Attenuation due to bending in the fiber optic cable was not significant except at the probe end where the fibers are bent 90 degrees in a 1.25 inch radius. High

mechanical stresses caused the glass fibers to separate from the nylon jacket and move relative to the focal plane resulting in unacceptable baseline levels.

- ◆ The fluorescence spectra of JP-4 and JP-5 were indistinguishable using the LIF-CPT system. The WTM's of jet fuel and heating oil were noticeably different.
- ◆ Fluorescence of PAHs dominate the emission spectra of the subject fuels for excitation in the ultraviolet region shorter than 300 nm. The optimal excitation wavelength for continuous LIF-CPT soundings is 280-290 nm or shorter.
- ◆ The variation in the fluorescence spectral distribution is dependent on the matrix (i.e., neat, dissolved, on soil).
- ◆ Humic acids' contribution to LIF in soils play an important role in the long wavelength fluorescence spectral distribution.

## **G. CONCLUSIONS**

Evaluation of the AFSCAPS at Tinker AFB demonstrated that the combination of an LIF-CPT, onsite analytical laboratory, and onsite three-dimensional visualization software can provide more detailed and timely mapping of fuel contamination than can be accomplished by conventional drilling and sampling programs. The LIF-CPT can provide a continuous profile of the contaminant location and relative concentration with detection levels to at least the regulatory limits for TPH.

## **H. RECOMMENDATIONS**

A two-pronged approach is recommended for future development of the LIF-CPT. One aspect should be the continuation of the field studies to provide a broader database for further evaluation of the LIF-CPT probe in a wider range of geologic settings. The other aspect should include improvements in instrumentation, and laboratory and field methods in order to establish the bias, reproducibility, and error of the LIF-CPT system for regulatory acceptance.

## **I. APPLICATION**

The LIF-CPT system could be implemented by the Air Force as the primary technology to conduct environmental site assessments where petroleum, oils and lubricants are involved.

## **J. BENEFITS**

This technology could significantly reduce the time / cost of conducting site assessments and provide superior data to use as a basis for choosing 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

Applied Research Associates, Inc. and the North Dakota State University, under contract to the Air Force Civil Engineering and Services Center are developing a Laser-Induced Fluorescence-Cone Penetration Technique (LIF-CPT). As a part of this contract, a two-day demonstration of the system was conducted at Carswell AFB, Texas. Demonstration of the prototype LIF-CPT at Carswell AFB had been planned as a static demonstration, however, the week prior to the demonstration an estimated 800 gallons of gasoline was accidentally spilled into the ground as part of a tank leak test. This accidental leak provided an opportunity to assist base personnel in locating the lost gasoline and mapping the soil stratigraphy and water table. The demonstration program test plan was modified to assist Carswell AFB personnel in locating the lost gasoline using the LIF-CPT system. Over the two-day period, 15 LIF-CPT soundings were conducted, along with demonstrations of the system on each day. Results of this investigation are presented in this report, along with interpretations of the data.

### B. BACKGROUND

#### 1. Base Service Station Site Description

Carswell Air Force Base is located near Ft. Worth, Texas, with the Base Service Station (BSS) located at the corner of Rogner Drive and A-Street as shown in Figure 1. Locations of several monitoring wells and all of the CPT soundings are also plotted in Figure 1. Soils at the BSS vary from less than 5 feet thick at the BSS to nearly 50 feet thick in the vacant field between the BSS and West Fork of the Trinity River. The soils consist of unconsolidated Quaternary and recent alluvial deposits (sands, gravel, silts and clays). Underlying the soils are low-permeability limestones and shales of the Cretaceous Goodland and Walnut Formations which form a basal aquiclude (Reference 1). Groundwater at the site varies in depth from 2 to 13 feet below the ground surface and is unconfined. The general drainage direction is from the direction of the BSS, where

# Carswell AFB, TX Site Plan

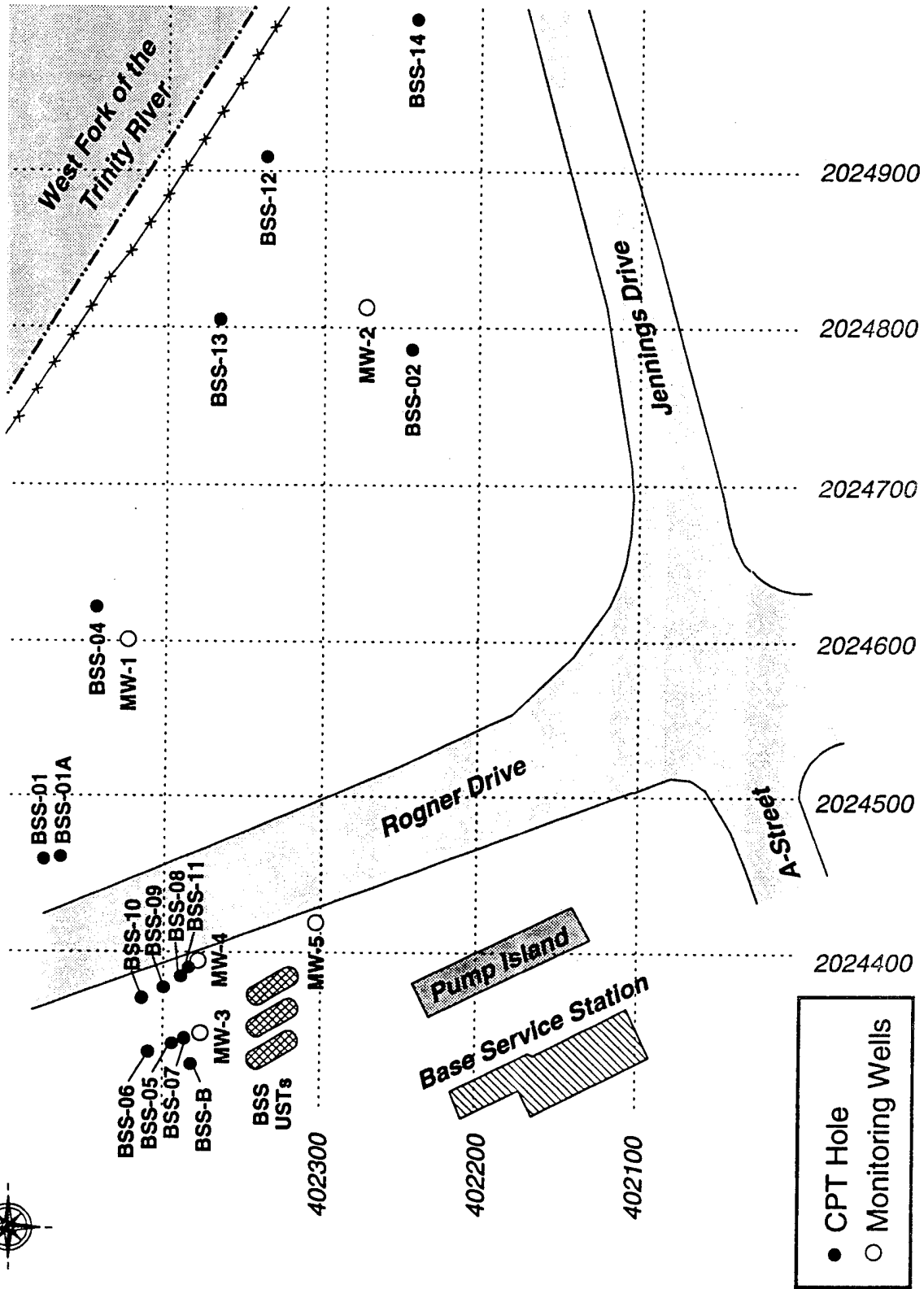
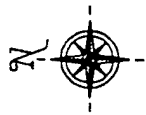


Figure 1  
Site map of the area surrounding the Base Service Station, Carswell AFB, showing Monitoring Well and LIF-CPT sampling locations.

the rock depth is less than 10 feet, northeast toward the West Fork of the Trinity River, where the rock depth is about 50 feet. The site is stratified with variable soil type and thickness in both the lateral and vertical direction, as will be further described in Section III.

## **2. Summary of Previous Investigations**

During April of 1992 discovery of a petroleum contaminant seeping into the West Fork of the Trinity River raised questions as to the integrity of the Base Service Station underground storage tanks. Subsequent investigations were conducted consisting of soil gas surveys, installation of two monitoring wells (Reference 2), and an Electromagnetic Offset Logging (EOL) conducted by MagnaScan, Inc. (Reference 3). Samples from the wells were tested for Total Petroleum (TPH) content, with the samples all indicating from less than 10 ppm to 20.6 ppm. Olfactory indication of the contamination was evident at several depths, with the most significant contamination at a depth of 16 to 18 feet in well MW-1 and 18 to 20 feet in well MW-2 (2). Close to the BSS underground tanks at well location BSS-B, elevated levels of Benzene (3200  $\mu\text{g/l}$ ), toluene (16,000  $\mu\text{g/L}$ ) and total xylenes (15,000  $\mu\text{g/L}$ ) were found in the samples obtained in May 1990 (1).

Upon completion of monitoring wells MW-1 and 2 on 10 August 1992, the EOL survey was conducted using these wells to raise and lower the EOL receiver. Interpretation of the EOL data indicated potential locations at which the plume may occur. However, the EOL survey, which measured resistivity contrast, required confirmation and validation with an independent field technique.

### **C. SCOPE/APPROACH**

Due to the gasoline spill that occurred during the week of 28 September 1992, a principal objective of this demonstration was gathering data to assist in defining the site geology, locating the gasoline plume and evaluating the EOL survey. Objectives accomplished under this effort include: (1) field testing consisting of LIF-CPT and field data analysis; (2) analysis of the CPT data to develop cross sections of the site geology, a map of the piezo-metric surface and identification of the groundwater flow direction. It had been planned to develop three-dimensional maps of the

plume location and site geology, but insufficient data were collected to develop these maps. Specific objectives achieved and presented in this report are:

- Soil characterization using the piezo-CPT
- LIF measurements using the CPT
- Grouting of the CPT soundings
- Development of groundwater table map
- Development of site Cross Sections
- Analytical Laboratory Testing of Grab Samples

#### **D. REPORT ORGANIZATION**

Section II of this report contains a description of the LIF-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 day demonstration, along with a discussion of the data are presented in Section III. Also presented in Section III is an evaluation of the CPT-based soil classification system, cross sections of soil stratigraphy, 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 pore pressure dissipation data that was used to determine the groundwater table contours. Appendix C contains the results of analytical laboratory testing on grab samples obtained from monitoring wells and the Trinity River.

## SECTION II

### DATA ACQUISITION AND ANALYSIS METHODS

#### A. INTRODUCTION

This section begins with a discussion of the methods used to perform the LIF-CPT test and the data obtained. These 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 Data

The electronic cone penetrometer test (CPT) was originally developed for use in consolidated clay soils. Over the years, 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 2. A pressure transducer in the cone is used to measure the pore water pressure as the probe is pushed into the ground (Piezo-CPT). The probe may also include three seismic transducers, which are used to perform downhole seismic surveys. In addition, a resistivity module may be attached to the cone assembly to measure variances in soil conductance, which assists in locating contamination plumes.

##### 2. Piezo-Electric Cone Penetration Testing

The cone penetrometer tests are conducted using the ARA penetrometer truck. The penetrometer equipment is mounted inside an 18-foot van body attached to a ten-wheel truck chassis

# AFSCAPS for Fuel-Contaminated Sites

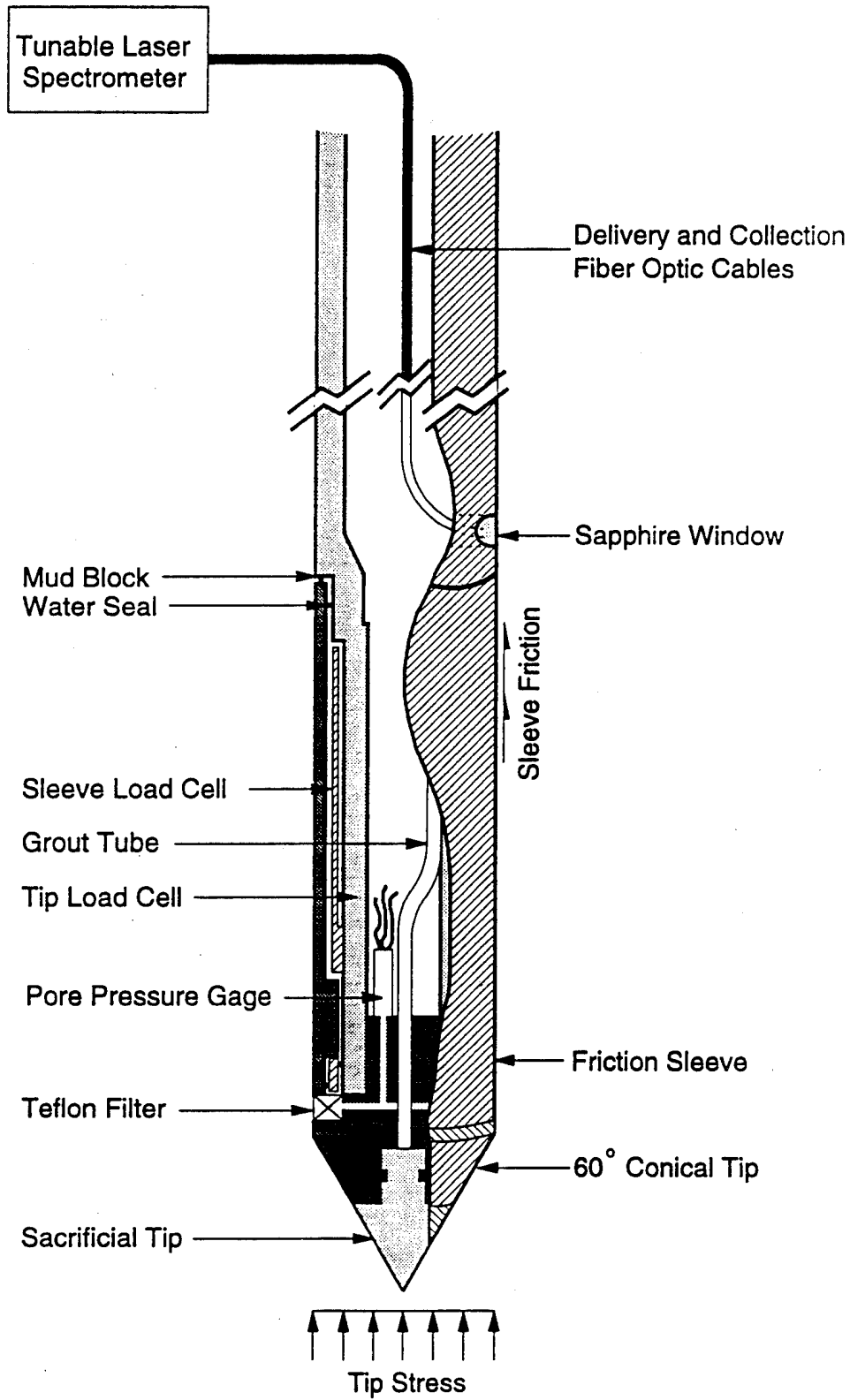


Figure 2. Schematic of Laser Induced Fluorescence-Cone Penetrometer Probe.

with a turbo-charged 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 45,000 pounds. This push capacity is limited in strong soils by the structural bending capacity of the 1.405-inch OD push rods, and not the weight of the truck. There is the possibility of the push rods buckling, which is the reason for the current 45,000-pound limitation. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck frame.

The penetrometer probe is of standard dimensions having a 1.405-inches diameter, 60 degree conical tip, and a 1.405-inch diameter by 5.27-inch long friction sleeve. The shoulder between the base of the tip and the porous filter is 0.08-inch 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 (Reference 4).

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 is transmitted from the probe assembly via a cable running through the push tubes. The analog data is 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-inch of cone advance. The depth of penetration is measured using a string potentiometer mounted on the push frame.

As shown in Figure 2, 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 (Reference 5). The magnitude of the penetration pore pressure is a function of the soil compressibility and, most importantly, 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, resulting 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.

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 is amplified and filtered at 1 Hz. Seismic signals are amplified as required and filtered at 1000 Hz. Once amplified, the analog signals are transmitted to a 16 bit high speed analog-to-digital converter board, where the signals are digitized; usually at the rate of one sample per second for the penetration data and 5,000 samples per second for the seismic data. 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, dissipation, and resistivity data are plotted. Plots can typically be available within 30 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.

### **3. Grouting of the Penetration Holes**

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 ¼-inch bentonite pellets at the end of each day. Sealing the CPT holes in this manner was deemed adequate, since the LIF showed no contamination and the risk of cross-contamination was minimal.

#### **4. Saturation of the Piezo-Cone**

As shown in Figure 2, 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  $\mu$ m porous polyethylene filter which is 0.25 in high and 0.202 in thick. The pressure transducer is connected to the porous filter through a pressure port as shown in Figure 2. 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 deair the silicone oil before use and also to saturate the porous filters with oil. The probe is assembled with the pressure transducer up and the cavity above the pressure transducer filled with deaired 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.

#### **5. 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 string potentiometer, 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.

## **6. Penetration Data Format**

A penetration profile, from the BSS site, is shown in Figure 3. Plotted as a function of elevation are the measured tip resistance, sleeve friction, friction ratio, and pore pressure. When the surface elevation of the test location is unknown, the penetration data are plotted against depth.

Tip resistance,  $q_c$  (lb/in<sup>2</sup>), is obtained by dividing the vertical force on the conical tip by the effective tip area (1.550 in<sup>2</sup>). The tip resistance is then corrected for pore pressures acting behind the conical tip as discussed in the next section. The corrected tip resistance,  $q_r$  (lb/in<sup>2</sup>), is plotted in the penetration profile. Sleeve friction,  $f_s$  (lb/in<sup>2</sup>), is obtained by dividing the total frictional force on the sleeve by the sleeve's surface area (23.26 in<sup>2</sup>). 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

North 402245

East 2024500

Elevation 560.352

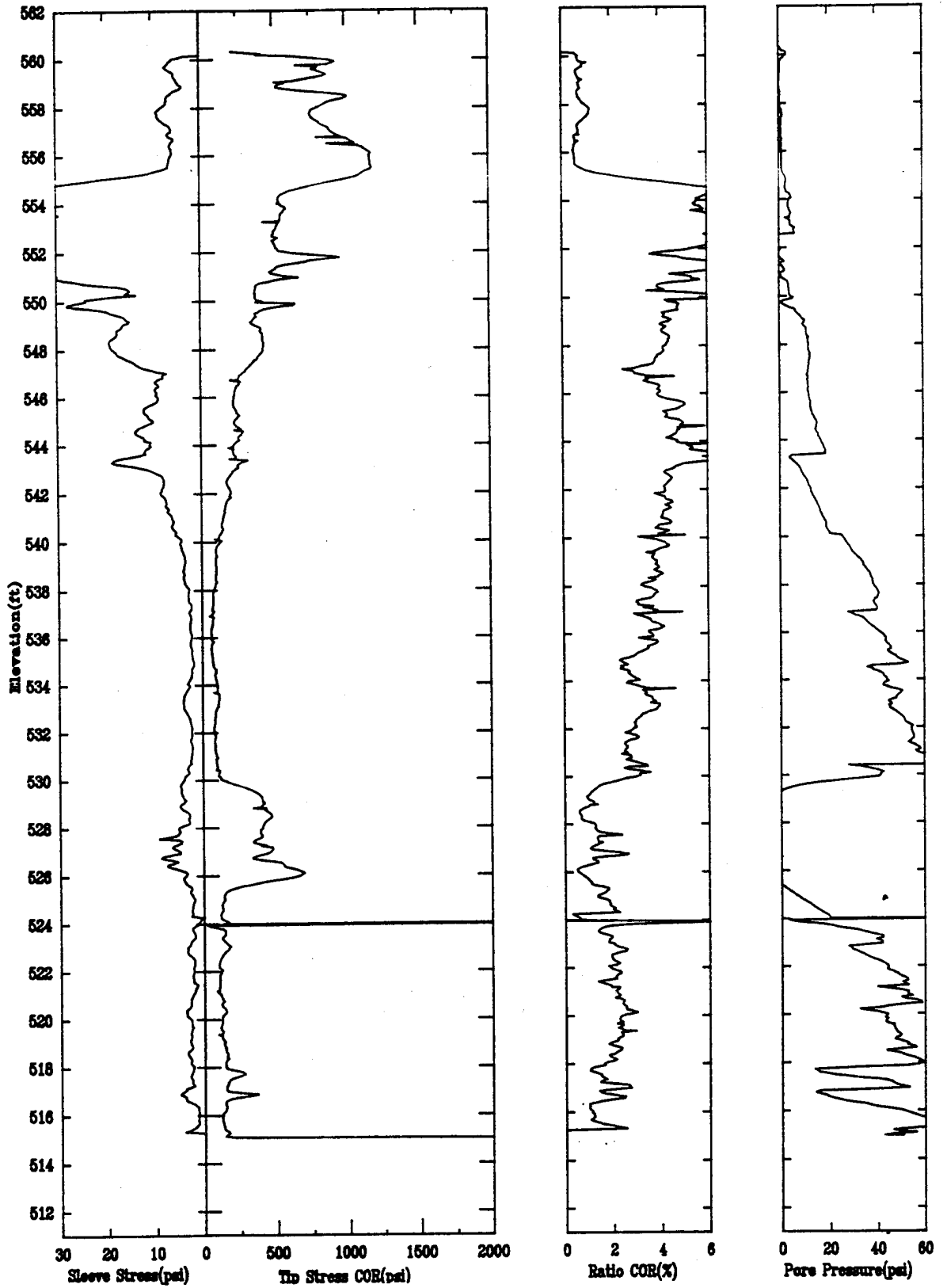


Figure 3. Typical LIF-CPT Data from the Base Service Station Area.

North 402245

East 2024500

Elevation 560.352

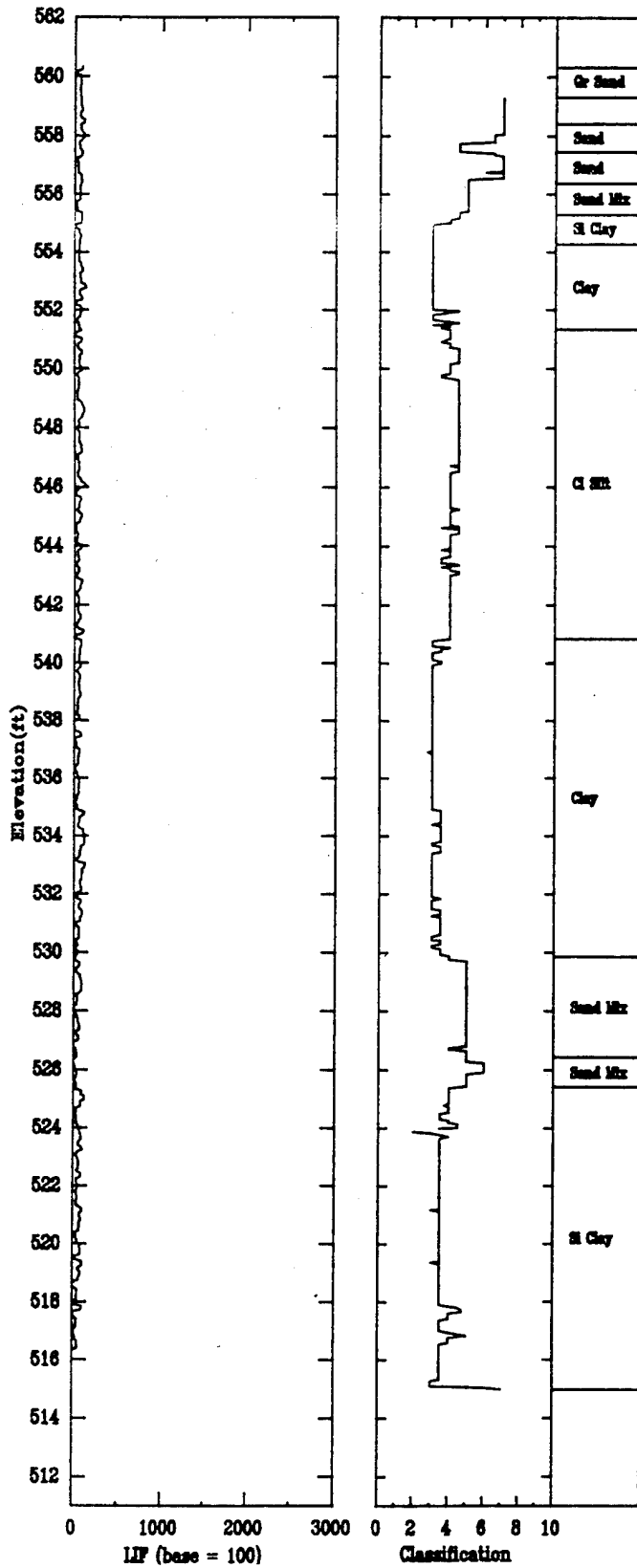


Figure 3. Typical LIF-CPT Data from the Base Service Station Area (Continued).

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 3 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.

## 7. Pore Pressure Correction of Tip Stress

Cone penetrometers, by necessity, must have a joint between the tip and sleeve. Pore pressure acting behind the tip decreases the total tip resistance that would be measured if the penetrometer was without joints. The influence of pore pressure in these joints is compensated for by using the net area concept (5). The corrected tip resistance is given by:

$$q_T = q_c + u \left[ 1 - \frac{A_n}{A_T} \right] \quad (1)$$

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 in<sup>2</sup>)
- $A_T$  = projected area of the tip (1.550 in<sup>2</sup>).

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

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

Laboratory calibrations have verified Equation 2.2 for ARA's piezo-cone design.

A joint also exists behind the top of the sleeve (see Figure 2). 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.

## **8. Numerical Editing of the Penetration Data**

Any time that 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 tube 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 is numerically edited before it is plotted or used in further analysis. Each time the penetrometer stops or backs up, as apparent from the depth data, the penetration data is not plotted. Plotting of successive data is resumed only after the tip is fully reengaged in the soil by one tip length (1.22 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 that are plotted and used for analysis were acquired with the probe advancing fully into undisturbed soil.

## **9. LIF Intensity Data**

The LIF module 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 six 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 forty 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 average every four 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.

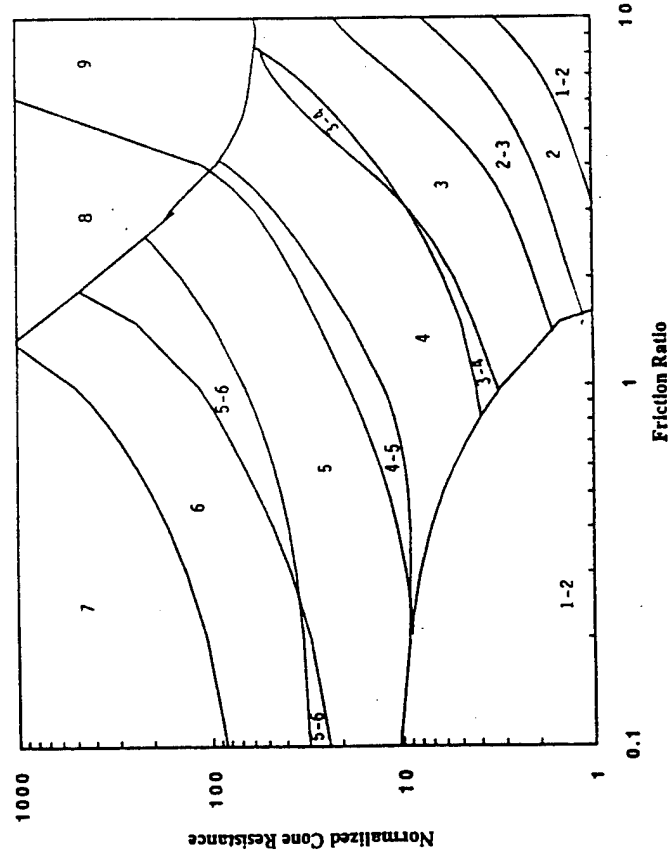
To eliminate the hole to hole variance of the laser intensity, the median of the minimum 41 points is used to determine a baseline value. The baseline value is then subtracted from all the readings in the profile. This produces profiles which can be compared and overlaid, since any equipment variances between tests have been eliminated. The baseline corrected LIF values are the values presented in the LIF profile shown in Figure 3. The baseline value is shown at the base of the plot. LIF profiles are presented in Appendix A for all locations.

## **10. 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 described in Reference 6, and are summarized in the two charts shown in Figure 4. 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 4, 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:

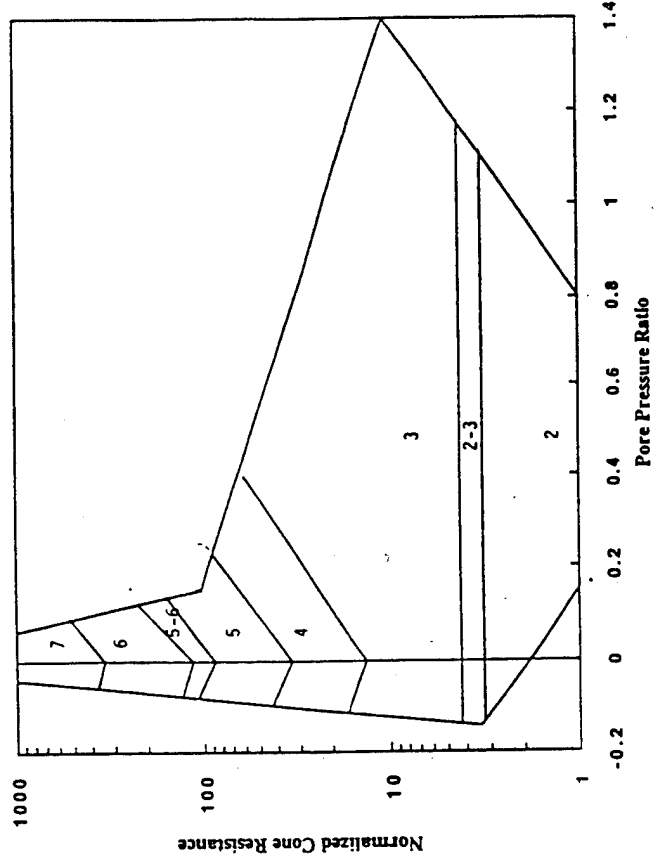
Fresh Kills Friction Ratio Classification Chart



$$\text{FRICTION RATIO} = \frac{f_c}{q_t - v_{vm}} \times 100\%$$

- 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

Fresh Kills Pore Pressure Classification Chart



$$\text{PORE PRESSURE RATIO} = B_f = \frac{u - u_o}{q_t - \sigma_{vm}}$$

- 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  
 ARA's soil classification system based on CPT data.

$$q_n = \frac{q_T - \sigma_{vo}}{\sigma_{vo}'} \quad (3)$$

where:

- $q_n$  = normalized tip stress
- $q_T$  = corrected tip resistance from Equation 2.2
- $\sigma_{vo}$  = total overburden stress
- $\sigma_{vo}'$  = effective overburden stress

The pore pressure ratio,  $B_q$ , is defined as:

$$B_q = \frac{u_{meas} - u_o}{q_T - \sigma_{vo}} \quad (4)$$

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:

$$f_{SN} = \frac{f_s}{q_T - \sigma_{vo}} \times 100\% \quad (5)$$

The plot of any point of the  $q_n$  versus  $B_q$  or  $f_{SN}$  value normally falls in a classification zone of Figure 4. The classification zone number corresponds to a soil type as shown in the figure. The classification zone number is then used in determination of a unified soil classification profile (described below) which is then plotted versus elevation for each penetration test as shown in Figure 3. At some depths, the CPT data will fall outside of the range of the classification chart. When this occurs, no data is 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 4 into a single unified estimate, as shown in the classification profile indicated in Figure 3. 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:

<u>Classification Range</u>	<u>Soil Type</u>
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 layering provides a summary of the engineering classification of soil stratigraphy.

## SECTION III

### DATA DISCUSSION AND ANALYSIS

#### A. FIELD EFFORTS

The LIF-CPT truck and field crew were mobilized to Carswell AFB on 4 October and conducted the two day demonstration on October 5 and 6, 1992. During the demonstration, 274 lineal feet of penetration testing was completed at 15 locations. The deepest sounding was to 47 feet; however, soundings closest to the BSS encountered refusal at depths as shallow as two feet in a layer that was initially identified as caliche. Drilling near the BSS penetrated this caliche layer, with bedrock encountered just below the caliche. Three CPT tests just east of Rogner Drive encountered refusal at a depth of about 5 feet. The bedrock contour maps indicate shallow bedrock at these locations (1). The contour maps, as well as the CPT tests indicate that the bedrock depth is increasing toward the river. Figure 1 shows the CPT locations, and Table 1 lists the tests, locations, depths of penetration, and water table depth.

#### B. DESCRIPTION OF TYPICAL PIEZO/LIF-CPT DATA

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, followed by comparison of adjacent profiles to show the consistency of the CPT data.

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. In general, tip resistance increases as the coarse grained soil content increases, tip resistance, and decreases as the fine grained content increases. This trend can be affected by the degree of consolidation of the soils, with the degree of consolidation increasing both the tip and

Table 1. SUMMARY OF PIEZO/LIF-CPT AT THE CARSWELL AFB SERVICE STATION.

TEST ID	NORTHING	EASTING	ELEVATION	DEPTH (ft)	WATER TABLE DEPTH (FT)
MW-1	402,425	2,024,600	560.957	48.5	13.0
MW-2	402,275	2,024,810	558.322	49	16.0
BSS-01	402,475	2,024,460	561.307	5.22	6.307
BSS-01A	402,465	2,024,465	561.057	5.35	6.057
BSS-02	402,245	2,024,785	556.682	36.38	7.782
BSS-03	402,545	2,024,500	560.352	45.99	12.052
BSS-04	402,450	2,024,620	560.437	46.84	12.937
BSS-05	402,405	2,024,355	565.762	7.97	N/A
BSS-06	402,420	2,024,350	565.647	7.47	1.647
BSS-07	402,395	2,024,360	565.697	8.22	N/A
BSS-08	402,380	2,024,395	561.177	2.32	N/A
BSS-09	402,400	2,024,385	561.232	4.50	N/A
BSS-10	402,415	2,024,380	561.247	3.93	N/A
BSS-11	402,380	2,024,395	561.177	4.68	N/A
BSS-12	402,340	2,024,910	558.602	30.00	23.502
BSS-13	402,370	2,024,805	559.082	35.10	20.182
BSS-14	402,245	2,024,975	553.342	29.68	14.342

sleeve stresses. 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, as is observed at this site. 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-ECPT data, an analyst can interpret the stratigraphy and soil types visually as described below.

The CPT data from penetration BSS-004 is plotted in Figure 5, showing the friction sleeve, tip, friction ratio and pore pressure data as functions of elevation. Sounding BSS-004 is located near well MW-1. The tip resistance is generally less than 500 psi through most of the profile, indicating a low strength normally consolidated soil. The tip resistance increases from the surface to elevation 558 in a material with a friction ratio approaching 2, which is interpreted to be a clayey sand. Below elevation 558 feet the tip resistance, sleeve stress and friction ratio all decrease. The low tip resistance, and decreasing friction ratio indicate a weak clayey soil. At elevation 555 feet, sleeve stress and friction ratio both increase, indicating an increase in fine grained soil content. An increase in the fine grained soil content is also indicated by an increase in pore pressure at this elevation. The observed pore pressures are occurring in a very wet but not fully saturated clayey soil, as the water table depth (as determined from dissipation test data) is at elevation 547.5. Positive pore pressures above the water table can be created by the CPT probe compressing the soil around the probe during the penetration. In nearly saturated clays the CPT probe creates sufficiently large volume strains to crush out the air void space and saturate the soil adjacent to the probe. In clays this can result in high positive pore pressures. At elevation 546 feet, the tip resistance, sleeve stress and friction ratio all decrease, indicating a very weak soil. Referring to the soil classification chart in Section II, this type of response would be typical of very weak clays or sensitive soils.

The tip resistance, sleeve stress and friction ratio continue to decrease, with the pore pressure increasing to elevation 528.5 feet. The soils in this zone are interpreted to be clays due to the combination of low tip and sleeve stresses and pore pressures in excess of the hydrostatic pressure.

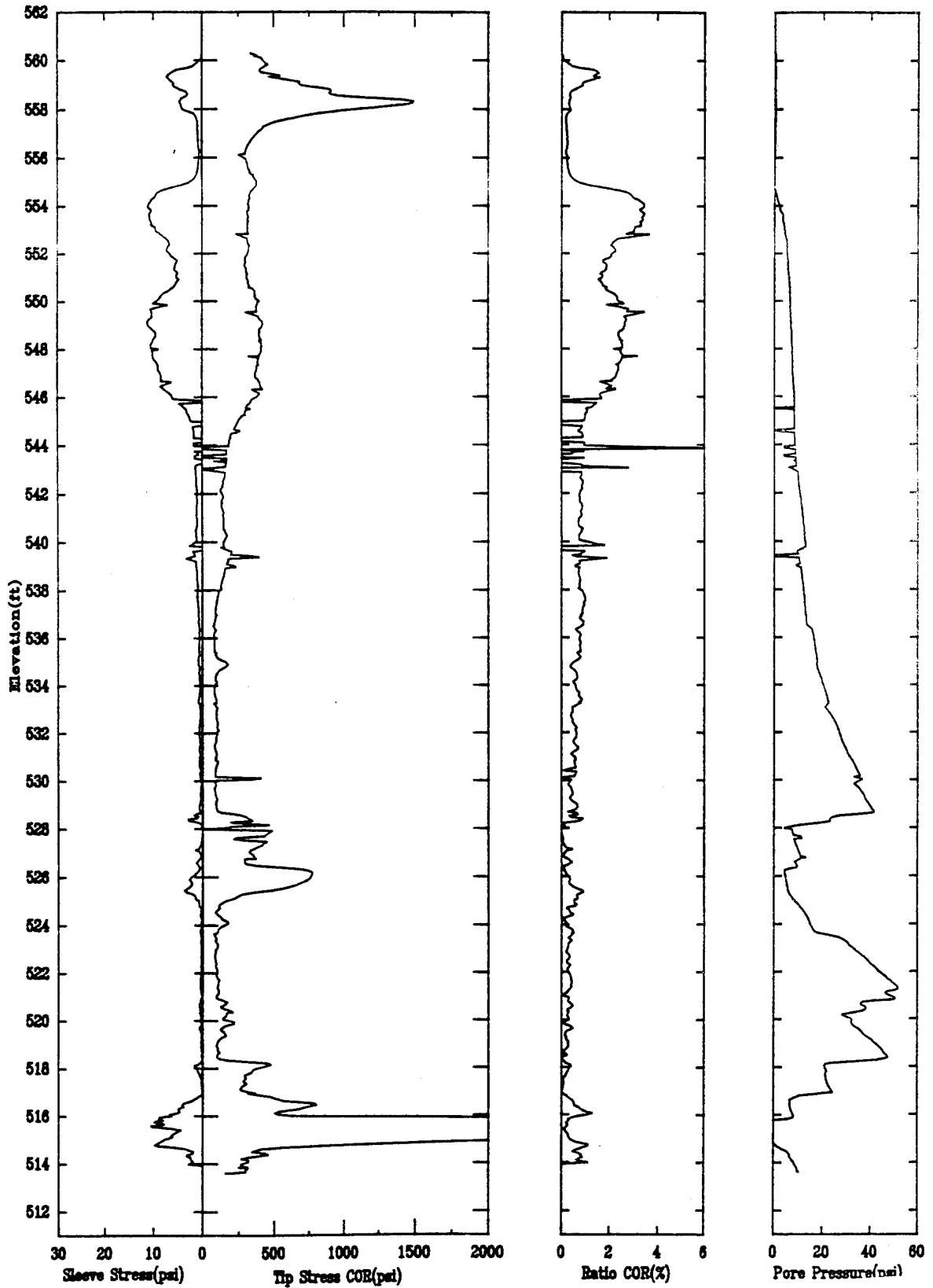


Figure 5 Typical LIF-CPT data from BSS-04 along with LIF profile and soil stratigraphy.

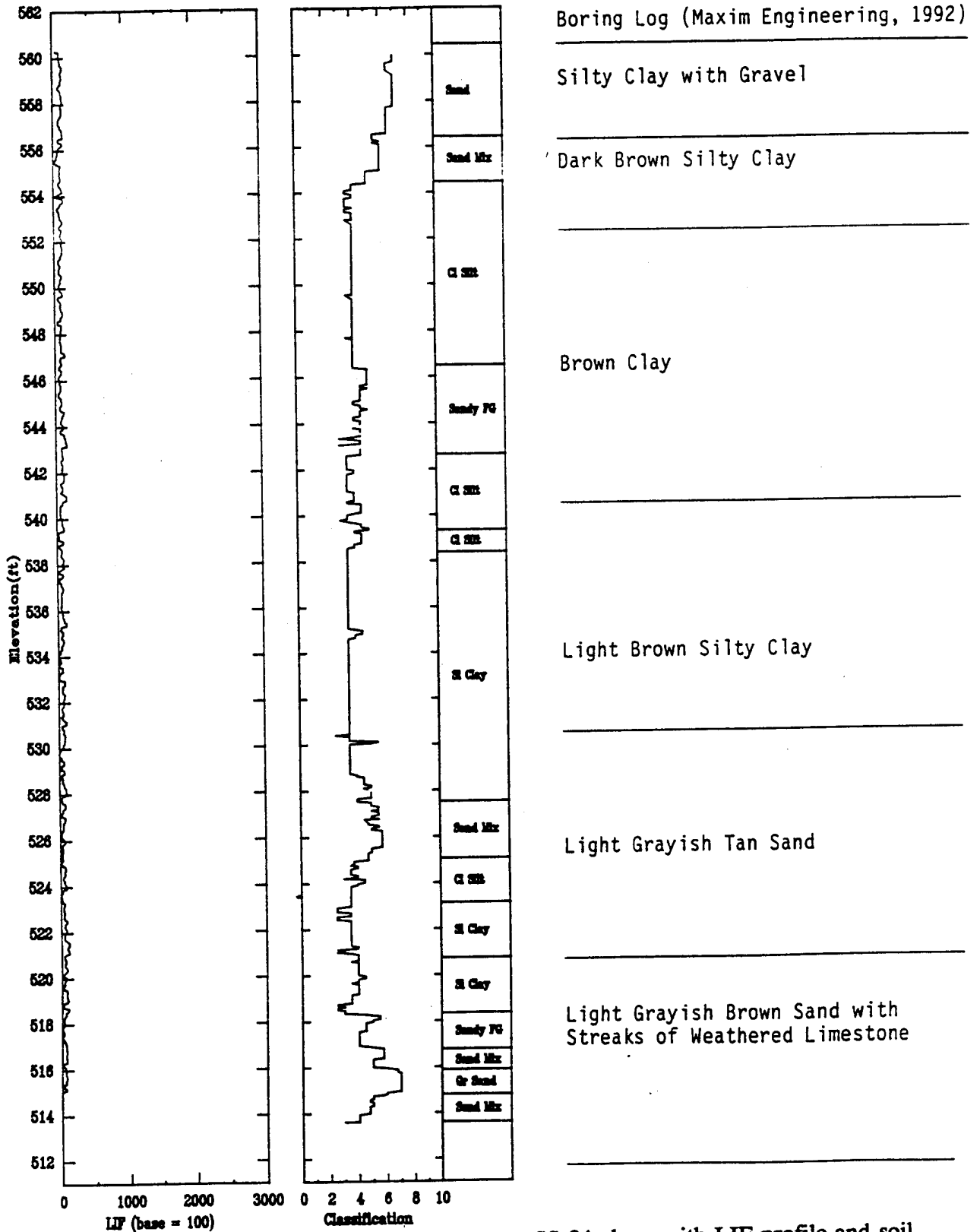


Figure 5 Typical LIF-CPT data from BSS-04 along with LIF profile and soil stratigraphy (continued).

From elevation 528.5 feet to elevation 525 feet the tip resistance and sleeve stress increase significantly and the pore pressure decreases to about the hydrostatic pressure, indicating a sand zone. Below elevation 525 feet the clay is encountered again, as seen by the decrease in tip and sleeve stresses, and the increase in pore pressure. At elevation 518.5 feet the tip resistances begin to increase with the pore pressure decreasing indicating a sandy zone. This zone is located just above the weathered bedrock which is encountered at elevation 516 feet, as observed by the very rapid increase in tip resistance to a maximum of 10,000 psi at elevation 516 feet. Refusal occurred at elevation 513.8 feet when the expanded section could not be pushed through the weathered bedrock material.

The LIF profile and soil classification are also plotted in Figure 5. The LIF profile will be discussed later, but generally varies between 0 and 50 counts, indicating either that no gasoline contamination is present, or the contamination is below the detection limits of the LIF probe. For jet fuels, the detection limit is about 100 ppm of Total Petroleum Hydrocarbons (TPH), which corresponds to an LIF value of 100 counts, baseline corrected.

Soil classifications and stratigraphic units plotted in Figure 5 are based on the soil classification charts and algorithms discussed in Section II. Also shown is the geologic log for well MW-1. The classification chart is in general agreement with the borehole data available from well MW-1. The CPT-derived soil classification system shows that the site consists principally of clays with occasional sandy zones overlying bedrock. Sands are encountered near the bedrock.

### **1. Cross Section of CPT Tip Resistance and Soil Classification**

A cross section of CPT tip resistances and soil classification profiles running roughly parallel to the West Fork of Trinity River are plotted in Figures 6 and 7. The overall character of the penetrations are quite similar in that the upper drier clays have higher tip resistances (and strength) than the clays below the water table at about the 546 feet elevation. Below the water table the tip resistance decreases in all of the profiles, indicating a decrease in strength of the clay. Two sandy zones are evident above the bedrock, especially at the north end of the cross section (BSS-3 and BSS-4). Sounding BSS-3 shows the top of the first layer is at a depth of 28 feet (elevation 532

feet), and the top of the second sandy layer at a depth of about 34 feet (elevation 525.5 feet). At the southern end of the section (BSS-12, BSS-13, BSS-14), the soundings were conducted only to the top of the first sandy zone to establish the water table depth and to evaluate the occurrence (or in this case the lack) of gasoline contamination. The top of the first sandy zones is observed, but the tests were not conducted to a sufficient depth to fully characterize the soil stratigraphy to bedrock. Tests for occurrence of gasoline contamination can be concluded at the water table level as gasoline is lighter than water, and therefore floats on top of the water table.

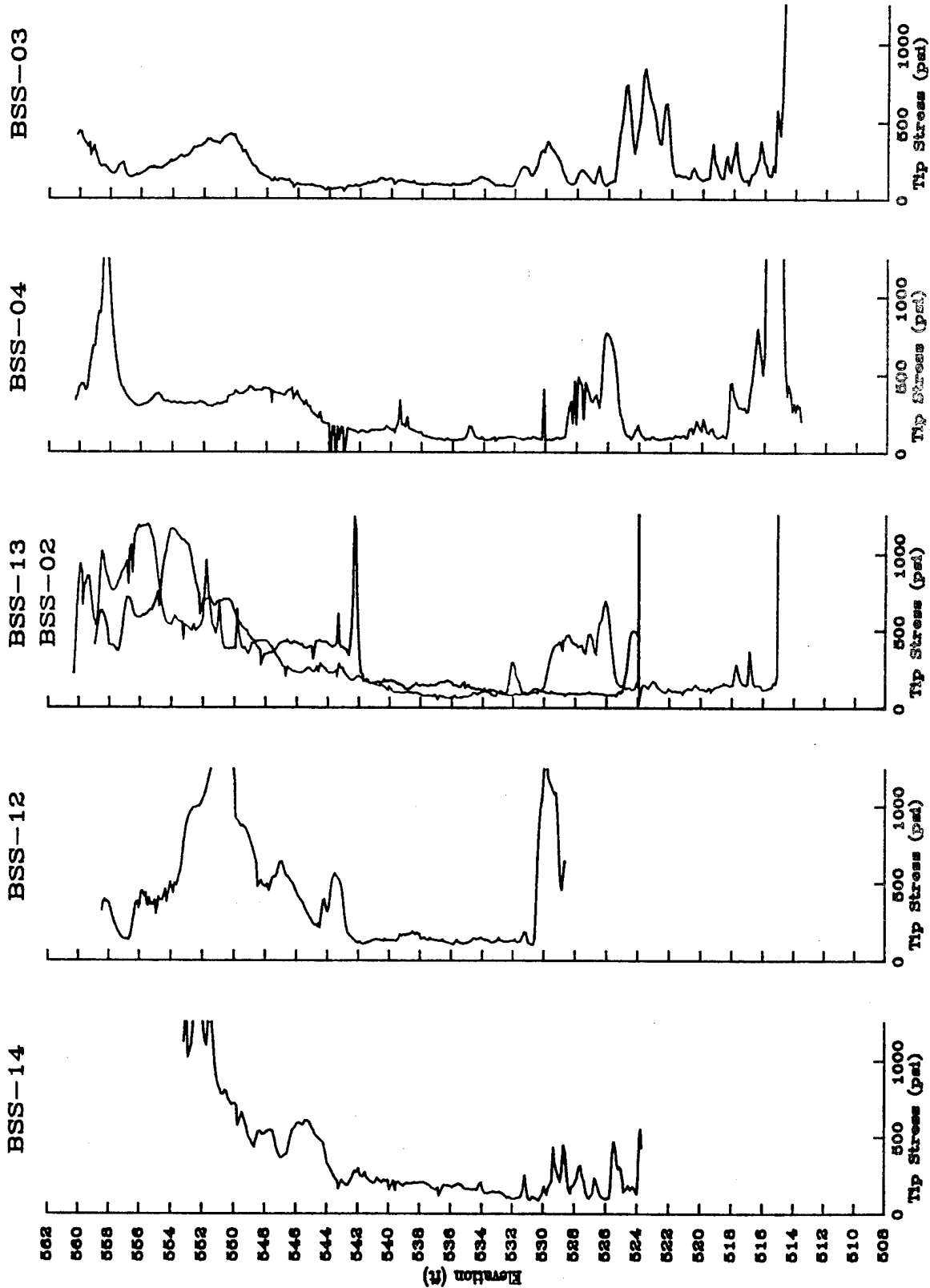
## **2. Water Table Contour Map**

A contour plot of the water table based solely on the Piezo-CPT data derived from pore pressure dissipation tests is plotted in Figure 8. The map shows that the direction of water flow is toward the West Fork of the Trinity River. The contour map developed from the CPT piezo data is in good agreement with that developed from monitoring well data and presented in the Installation Restoration Program (IRP) Stage 2 investigation (1). 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 needs to be obtained to reduce the uncertainty in these plots. This data can be obtained either from additional CPT soundings or boring logs.

## **3. Evaluation of LIF to Locate Gasoline Spills**

The LIF system was designed so that the excitation wavelength could be varied between 260 nm (which provides higher excitation of Benzene, Toluene and Xylene) and 290 nm (which provides the optimum wavelengths to excite jet fuels). As the heavier jet fuels and heating fuels are of primary interest to the Air Force, the AFSCAPS project has concentrated on locating these fuels using the 290 nm light source, leaving evaluation of the 260 nm source, which is optimal for gasoline, to future projects. As shown in Figure 9, the LIF system can detect JP-4 to a level of about 100 ppm.

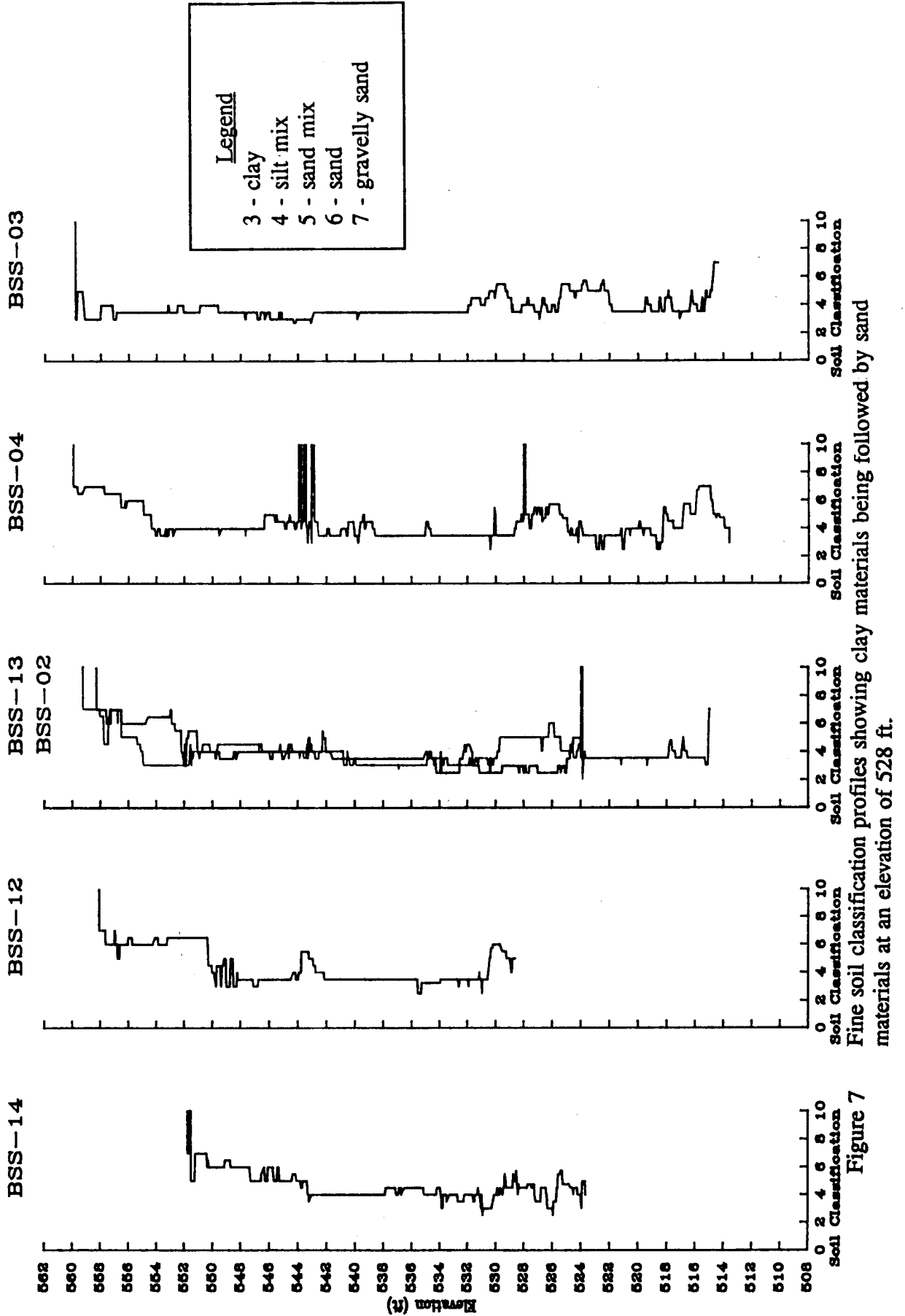
Carswell AFB, TX



Tip stress profile from fine location parallel to the West Fork of the Trinity River showing a consistent sand layer at elevation 528 ft.

Figure 6

Carswell AFB, TX



Fine soil classification profiles showing clay materials being followed by sand materials at an elevation of 528 ft.

Figure 7

# Carswell AFB, TX Site Plan

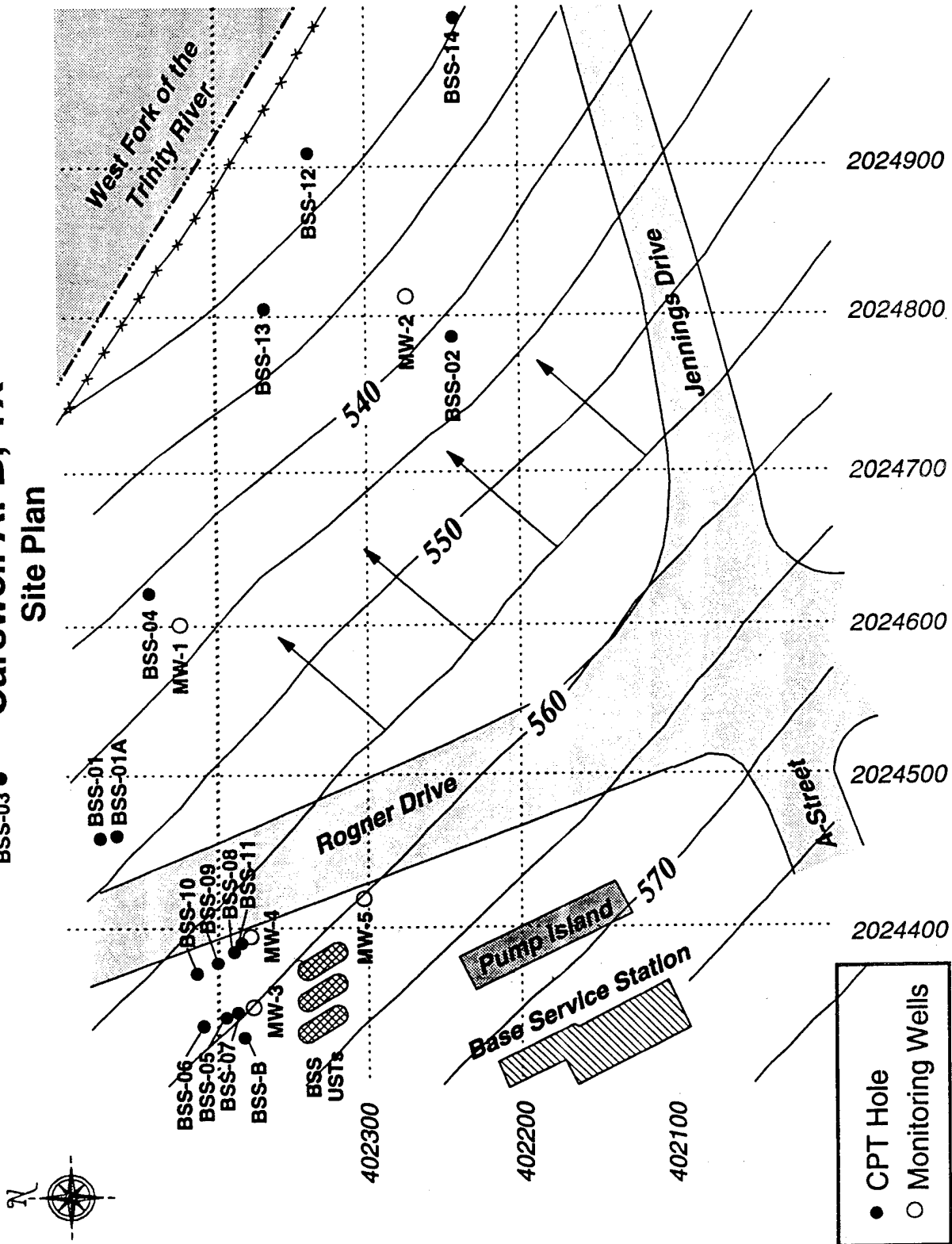
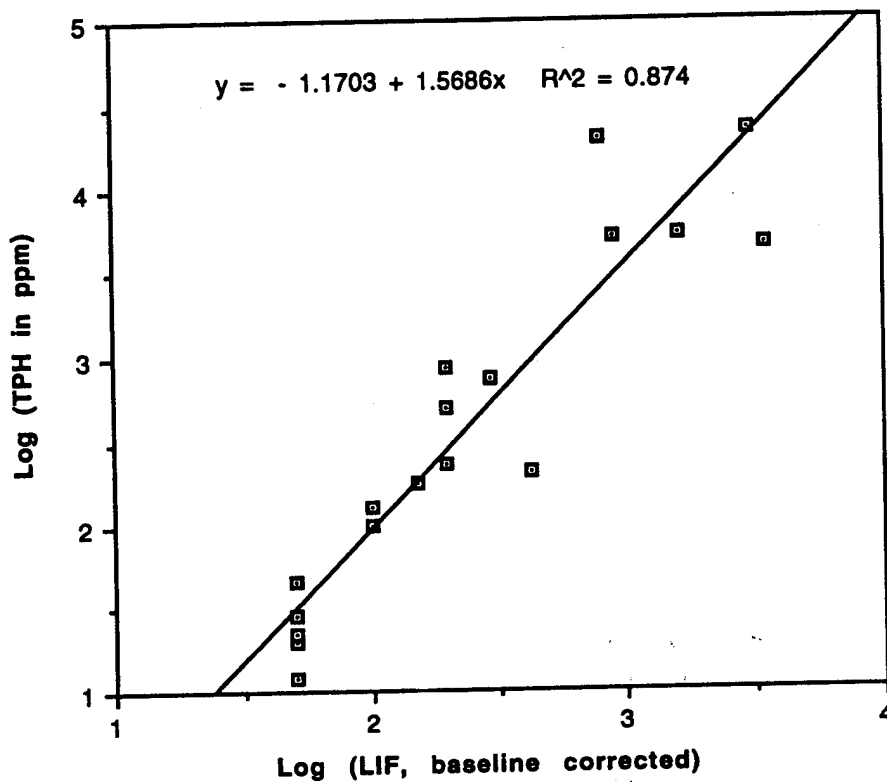


Figure 8 Site map of BSS area showing contours of the groundwater elevation and flow direction lines.

**Correlation Between LIF and TPH Based on Data Obtained  
at Fuel Purge Turnaround Area, Tinker AFB, OK.**



**Figure 9** Correlation plot and line of Best Fit between LIF Intensity and TPH concentration of JP-4.

For the gasoline spill at Carswell AFB, the 260 nm laser source would have been optimal, but no calibration of the system had been performed and the system response was unknown. Time did not permit these calibration procedures and methods to be developed, therefore, a field decision was made to use the 290 nm laser source which had been field tested at Tinker Air Force Base, and for which calibration methods had been developed.

A crude evaluation of the LIF-CPT probe sensitivity to gasoline was conducted that consisted of (1) spiking a soil sample with about 5 percent gasoline and measuring the LIF response, and (2) conducting soundings near the gasoline tanks where contamination was known to be present. On the basis of these tests, the LIF probe was shown to be sensitive to high gasoline concentrations, and the LIF-CPT soundings should be useful in locating the recent gasoline spill. However, as detailed calibration tests of the LIF-CPT probe have not been conducted, the gasoline detection limit of LIF-CPT probe has not been determined and no assessment regarding the presence or absence of gasoline above the Texas regulatory limits can be made.

The LIF data obtained from soundings BSS-05, 07 and 11 are plotted in Figure 10. These were located close to the gasoline tanks (see Figure 1) where the LIF showed evidence of gasoline contamination. The LIF data for sounding BSS-05 shows only background noise (140 counts) to a depth of 5.6 feet, at which depth a strong signal (as great as 1500 counts) is encountered. The strong signal at 5.6 feet is believed to be gasoline contamination. Once the probe was withdrawn a strong gasoline odor was detected at the top of the sounding. The thickness of the gasoline contamination could not be determined as refusal was encountered at a depth of about 7 feet. The LIF data does not extend to the entire depth of the penetration as the LIF sensor is located 1.75 feet behind the tip of the CPT probe. LIF data from sounding BSS-7, which was located 11 feet closer to the tanks, shows evidence of gasoline contamination with an LIF signal of 3000 counts. Sounding BSS-11, located in the ditch just below the gasoline tanks, also showed evidence of gasoline contamination at the bottom of the sounding. All of the soundings near the gasoline tanks encountered refusal at shallow depths and the thickness of the gasoline plume could not be determined.

Carswell AFB, TX

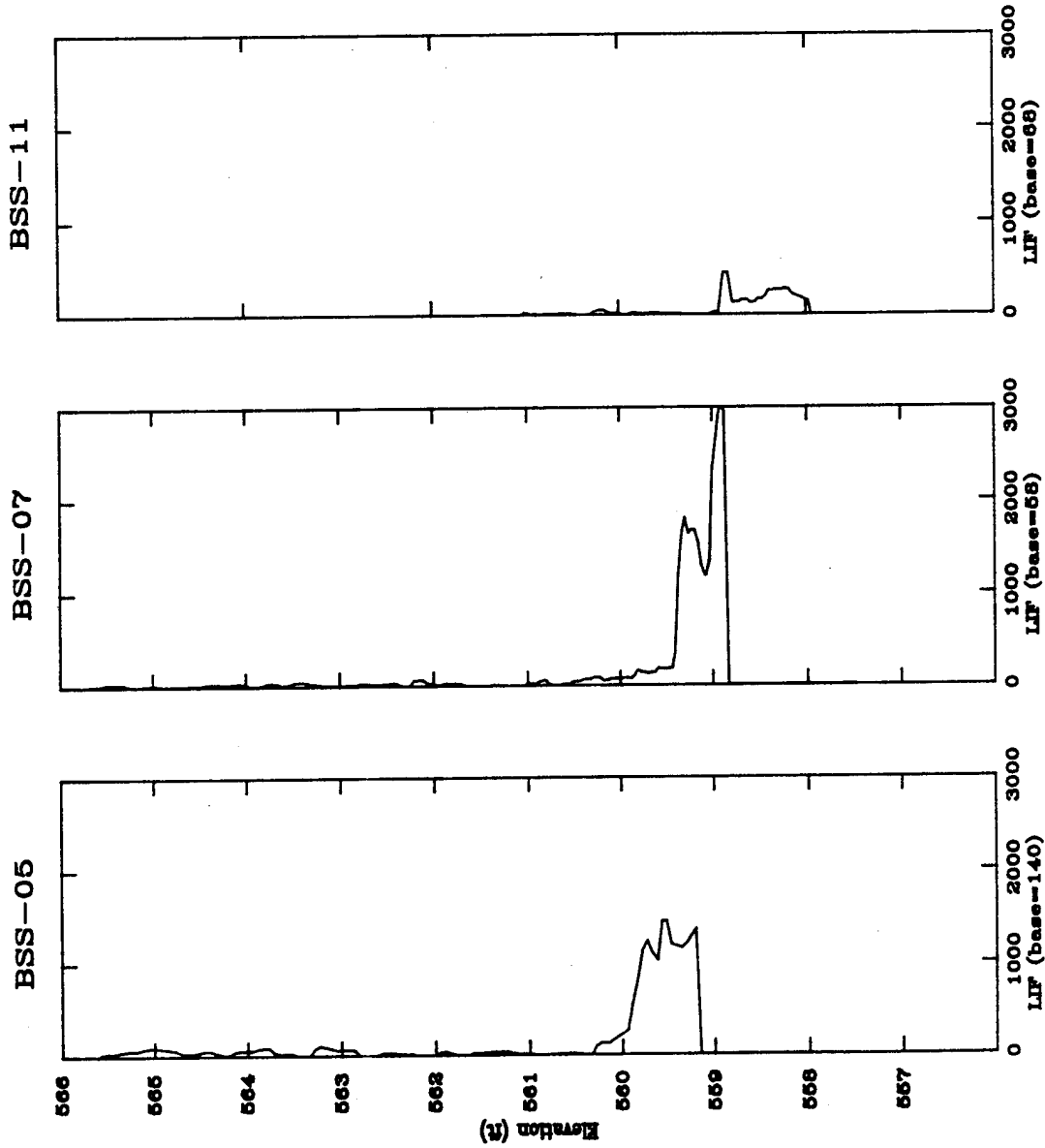


Figure 10 Three LIF profiles conducted near the BSS underground storage tanks showing LIF response to gasoline contamination.

Deep soundings were conducted in the field across from the gasoline station and the results from sounding BSS-04 (located adjacent to well MW-1) are typical. As refusal had been encountered at shallow depths near Rogner Drive, these soundings were conducted either 1) near previous boreholes where the bedrock was known to be deep and data was available for correlation to the LIF-CPT, or 2) near the base boundary to determine if the gasoline was migrating off base property. The LIF data for this sounding (plotted in Figure 5) shows no indication of any high level gasoline contamination, which would be expected if the recent gasoline spill had migrated to this location. The LIF data from this sounding as well as the other soundings in the field across from the BSS are interpreted to show no evidence of the lost gasoline. The soundings that were conducted during the two day demonstration period were conducted along likely travel paths for the gasoline spill. As of the date of these soundings, the data indicated that the gasoline had not yet reached these test locations or was too diluted to be detected. Time was not available to conduct a sufficiently dense grid of LIF soundings to locate the gasoline plume, and no firm conclusion can be drawn regarding the location of the gasoline plume. Location of the spill would require a more extensive grid of soundings than was possible during the demonstration.

#### **4. Evaluation of EOL Surveys**

Electromagnetic Offset Log surveys are routinely used in the oil industry to locate oil fields and are being increasingly used in the environmental field to identify areas of high degrees of contamination. The survey method relies on the electrical contrast that exist between either different soil types or between contaminated and clean soils. The survey is conducted by placing electrical coils on the surface and transmitting an AC signal that is coupled to the earth and picked up by receiver coils located in a borehole. The electrical energy transmitted to the receiver coil is a function of the electrical resistivity of the soil beneath the transmitter coil (3). Transmitter coils are moved about the site to characterize the entire site and the data analyzed to develop three-dimensional maps of apparent resistivity. By itself, the EOL provides no direct evidence of contamination, only that an electrical contrast exists. Independent methods are required to validate the EOL results. One of the objectives of the LIF-CPT testing was to determine if the resistivity contrast observed in the EOL data was related to gasoline contamination or to sand pockets, which have higher resistivity than clays. In addition, the sand pockets provide paths for the gasoline to readily move downgradient toward the Trinity River.

Apparent resistivities obtained by MagnaScan Corporation (3) are shown in Figures 11, 12 and 13 as color maps. The zones shown in red have been interpreted to be either gasoline contaminated areas or sandy zones located within the clays. Soundings were conducted with the LIF-CPT probe to determine if gasoline contamination or sands could be found at selected depths and locations. LIF-CPT sounding BSS-12 was conducted to penetrate the high electrical resistivity layer at a depth of 25 feet, as shown in Figure 12. The LIF data plotted in Figure 14 did not detect gasoline contamination throughout the entire profile. Based on work by Shinn and Bratton, (Reference 7), in order for the resistivity in clays or water-saturated sands to be influenced by gasoline, the degree of contamination must be 5 percent (50,000 ppm) or greater. This degree of contamination is easily detected by the LIF system, as discussed above. Therefore, it is concluded that the EOL response in this area is not due to gasoline contamination, but is most likely due to a change in the soil resistivity.

Examination of the CPT data profiles in Figure 14 shows that a sandy zone is encountered at a depth of 28.5 feet, which is deeper than the change in resistivity indicated by the EOL survey. This sandy zone is observed in all of the CPT data (at varying depths). It is expected that if the EOL survey is sensitive to the high resistivity sand layers several hot or red zones would be present on the plots for depths greater than 25 feet. While it has not been determined what is causing the resistivity contrast in the EOL 3-D maps, the CPT soundings can confirm that it is not responding to known sand pockets, and the LIF suggest that the contrast is not due to gasoline contamination. Although time did not permit CPT resistivity surveys to be conducted, these surveys would be very useful in validating the EOL and determining the source of the high resistance zones as observed in the EOL resistivity maps.

Carswell AFB, Ft. Worth, Texas  
 Apparent Resistivity at 25 feet.

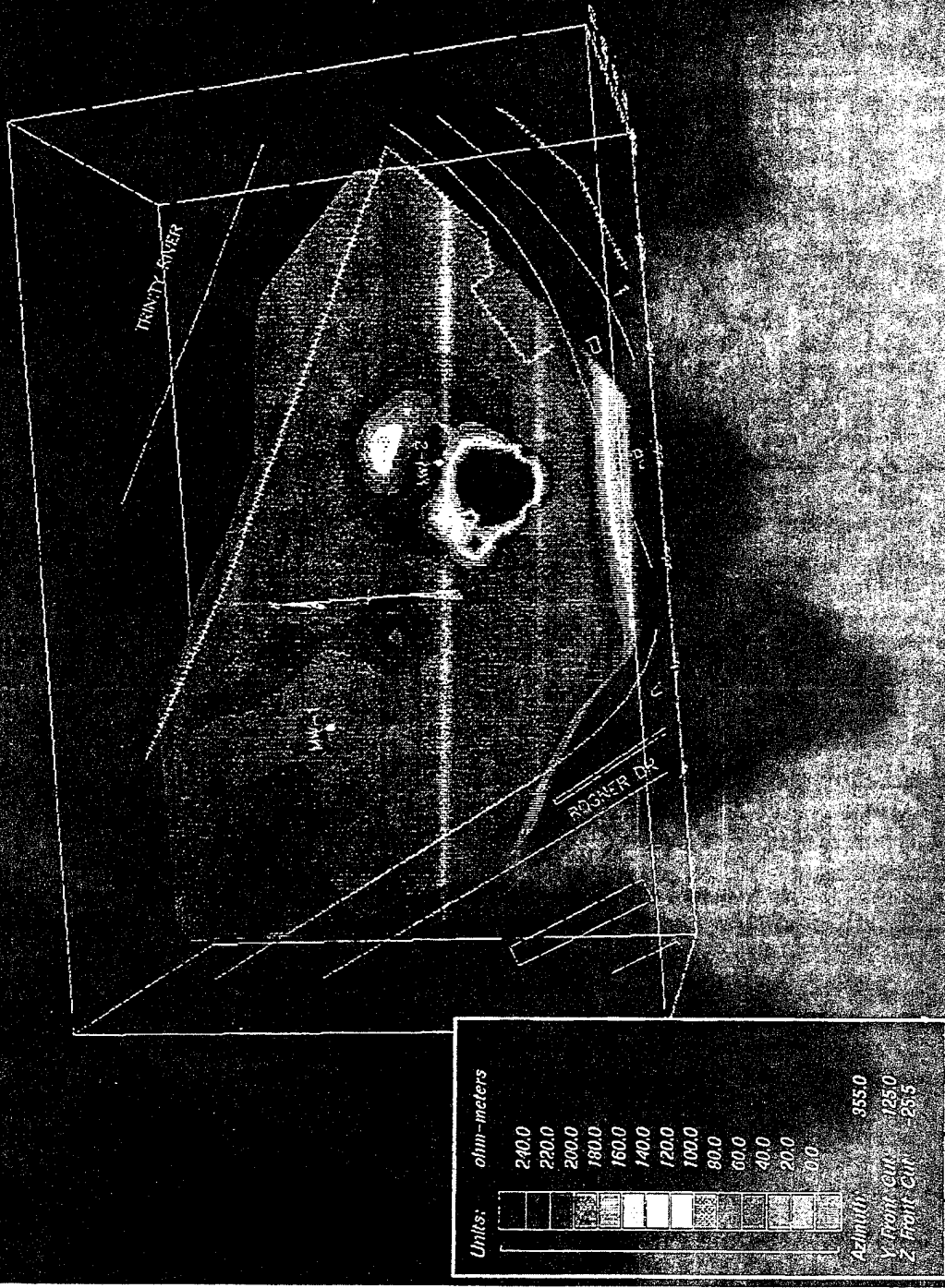


Figure 11 Apparent resistivity values near MW-1 and MW-2 at a depth of 25 ft determined by EOL techniques (MagnaScan, Inc., 1992).

Carswell AFB, Ft. Worth, Texas  
 Apparent Resistivity at 30 feet.

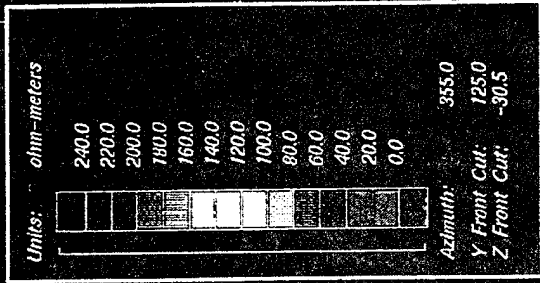
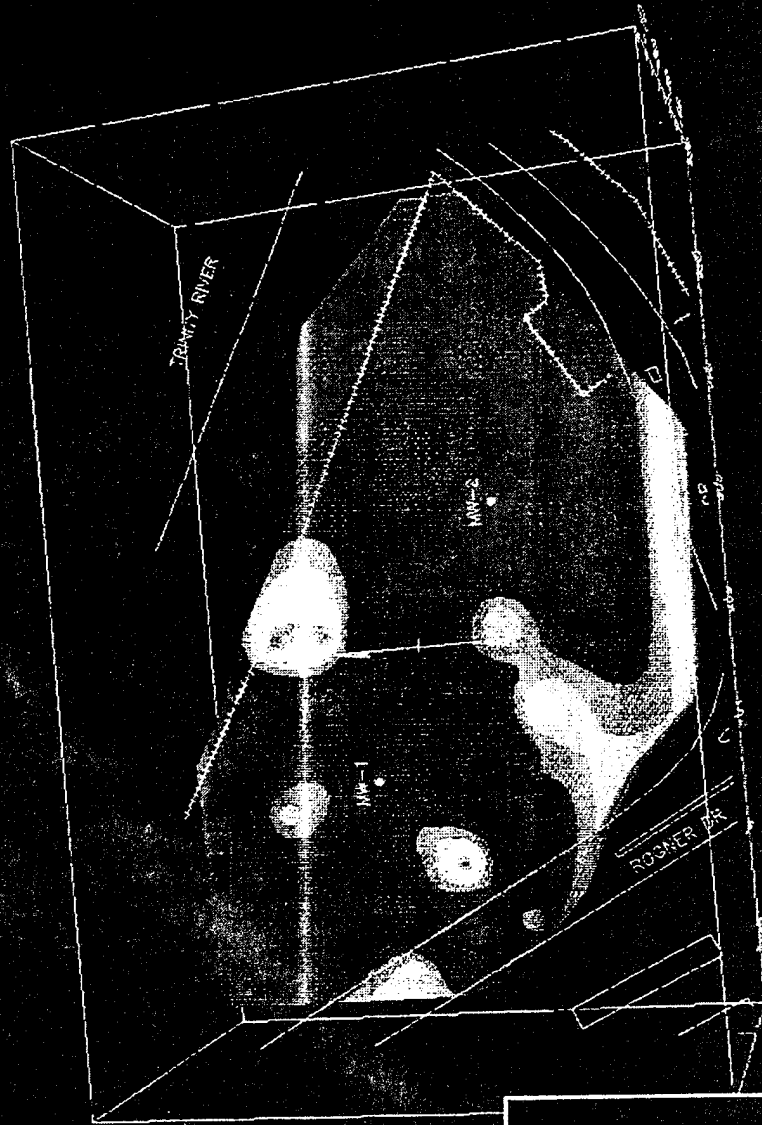


Figure 12 Apparent resistivity values near MW-1 and MW-2 at a depth of 30 ft determined by EOL techniques (MagnaScan, Inc., 1992).

Carswell AFB, Ft. Worth, Texas  
 Apparent Resistivity at 35 feet

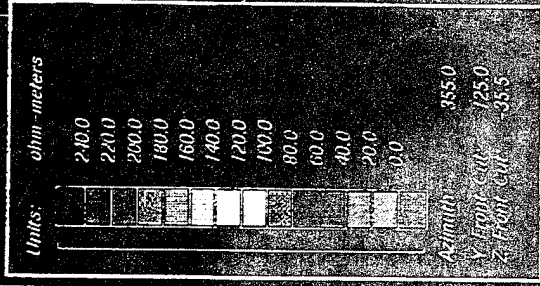
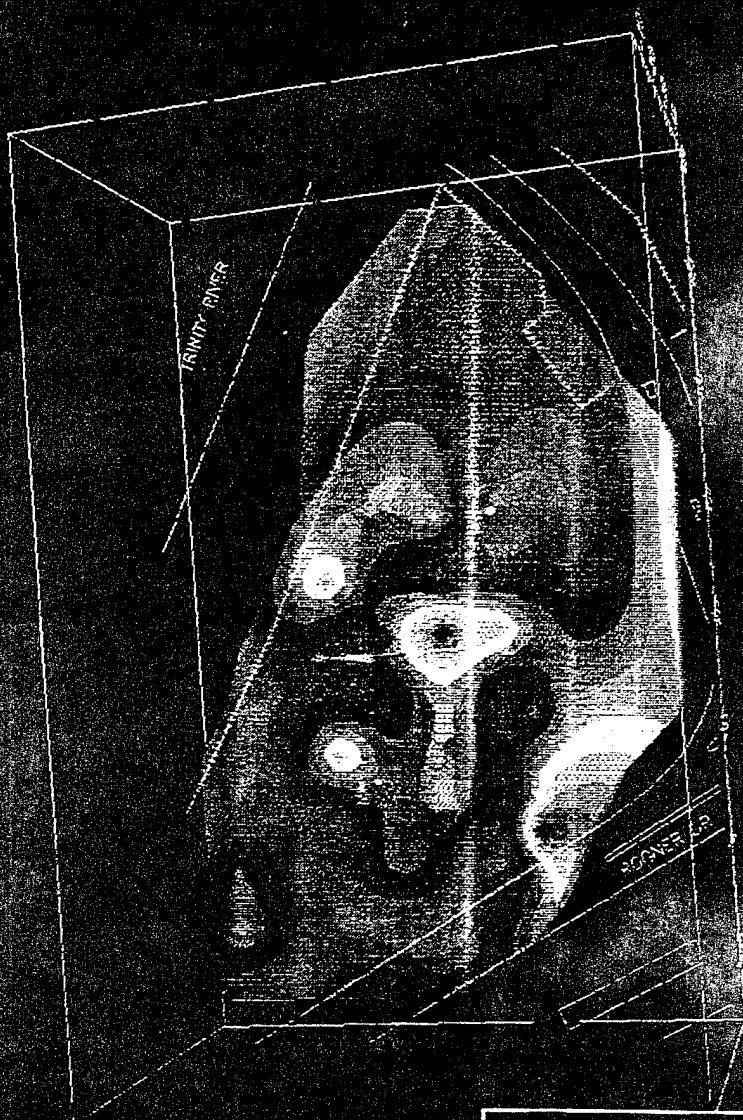


Figure 13 Apparent resistivity values near MW-1 and MW-2 at a depth of 35 ft as determined by EOL techniques (MagnaScan, Inc., 1992).

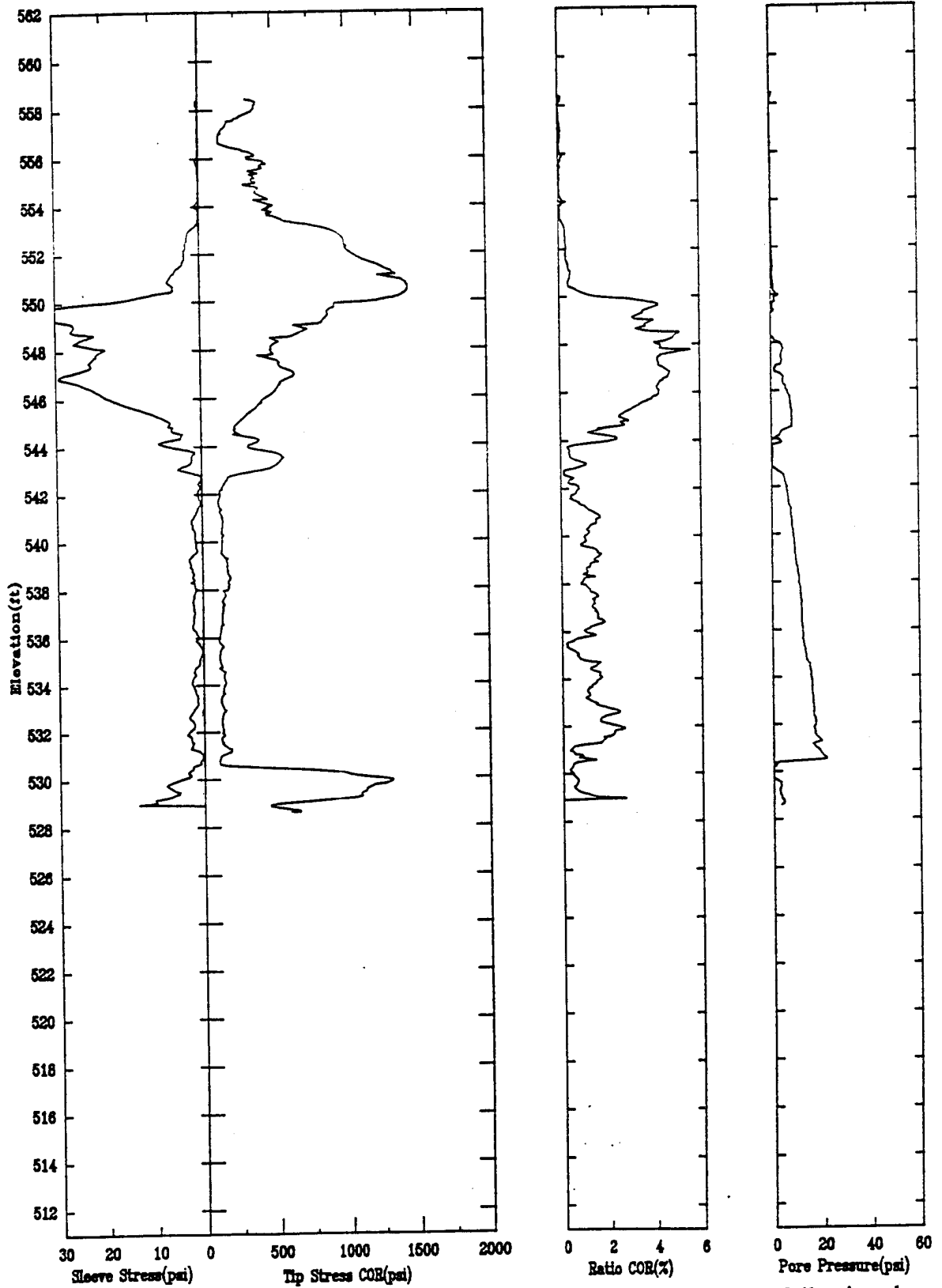


Figure 14 LIF-CPT data showing end of penetration in first sand layer following the soft clay material.

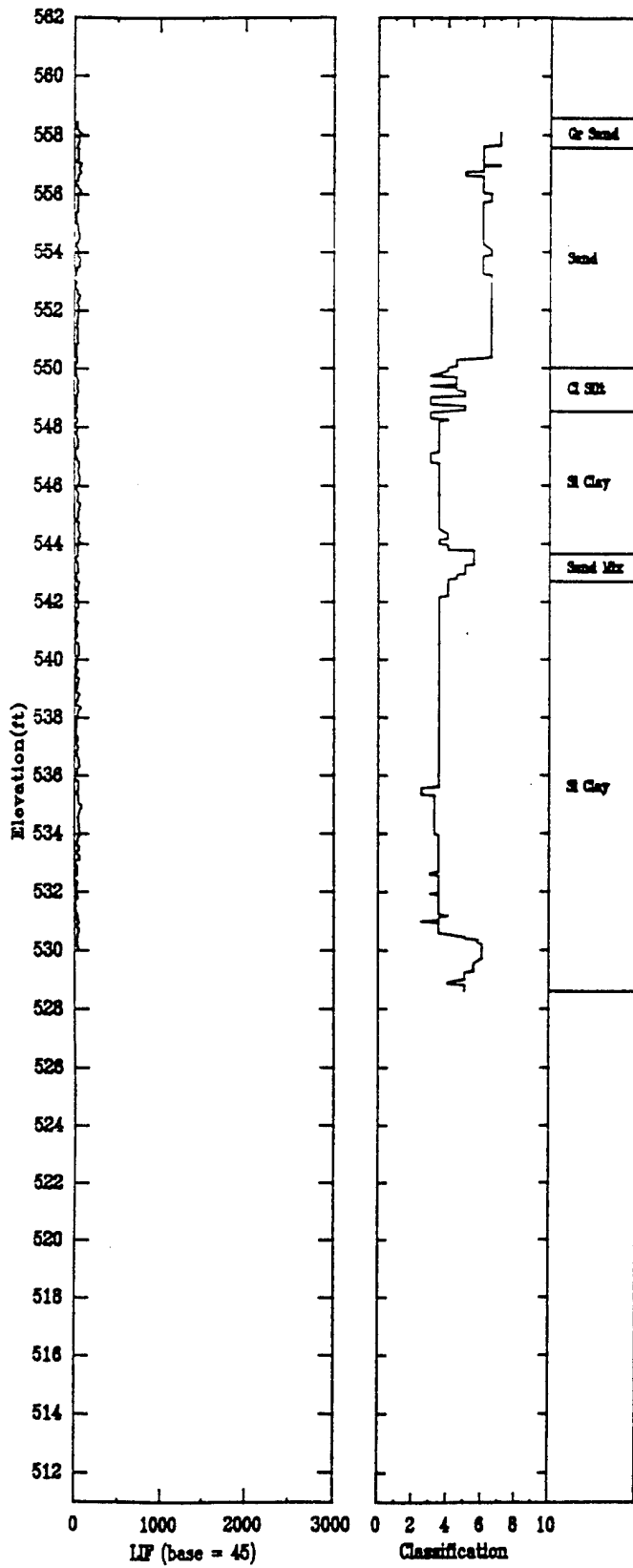


Figure 14 LIF-CPT data showing end of penetration in first sand layer following the soft clay material (continued).

## SECTION IV

### SUMMARY AND CONCLUSIONS

During the 2-day demonstration program performed at Carswell, AFB, a total of 15 Laser-Induced Fluorescence (LIF) Cone Penetrometer profiles were conducted in the area neighboring the Base Service Station (BSS). The profiles were conducted to determine soil stratigraphy, groundwater mapping, and the presence or absence of gasoline contamination. In particular, the LIF-CPT was being used to locate a recent 800 gallon gasoline spill during leak testing of the BSS underground storage tanks. Although the LIF-CPT probe has only been calibrated for JP-4 jet fuel at this stage, it was used to identify the presence of gasoline in the soils near the BSS underground storage tanks. The gasoline in this region was confirmed by olfactory methods. Subsequent testing across Rogner Drive from the BSS and near the West Fork of the Trinity river, did not indicate that the recent spill had migrated to the sounding locations in high concentrations. Since the LIF was not calibrated for gasoline, the sensitivity (i.e., detection limit) to gasoline is not known. The fact that the LIF results do not indicate any high level contamination from the recent spill, does not exclude the possibility that low levels of contamination are present.

The results from this demonstration were also compared to a previous EOL study. The results from that study suggested that in the area across the road from the BSS that either contamination or sandy soils are occasionally present at depths of 25 to 30 feet in selected locations. The results from the LIF-CPT study indicate that no gross contamination is present and that there are significant sandy soils in this area. The LIF-CPT indicate that the sandy soils at depths of 25 to 30 feet are much more consistent and abundant than the EOL study indicates. This increases the risk of contamination spread as the sandy soils represent contaminant pathways.

In summary, the 2-day LIF-CPT field testing program demonstrated the advantages of the AFSCAPS system including:

1. That the CPT is minimally invasive and generates no drilling waste.
2. That the CPT is a rapid test and greatly reduces cost.

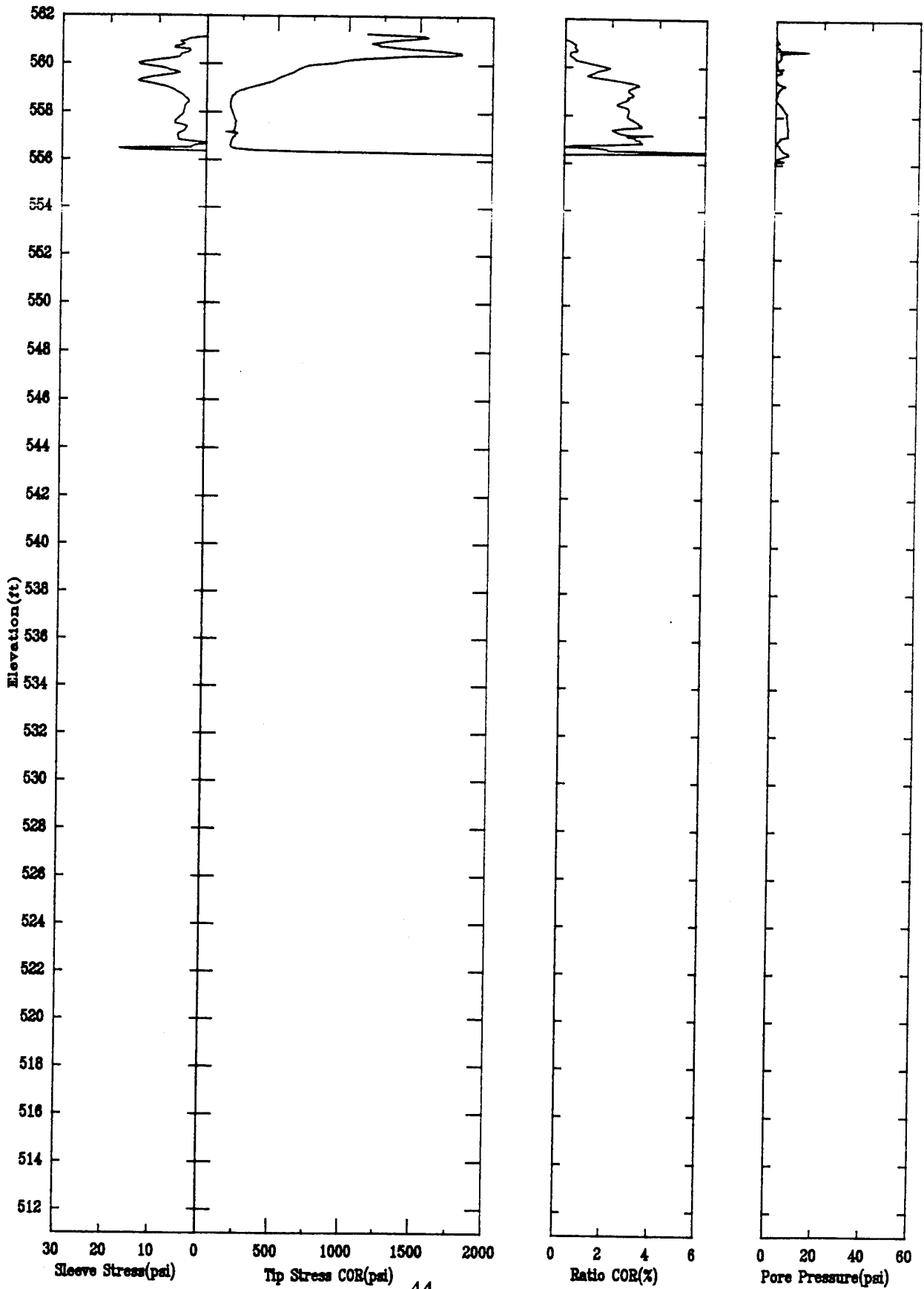
3. That continuous profiling of soil stratigraphy and contamination can be made in which even the thinnest soil layers can be detected. For many sites, thin sand seams carry the majority of the contaminants and are difficult to locate with conventional drilling techniques.
4. That real-time determination of soil stratigraphy, water table depth and degree of contamination can be made with the LIF-CPT. These data are used to optimize location of the next sounding. On full-scale investigations, this capability can greatly reduce the time required to characterize a site, and result in a more thorough the investigation.

## REFERENCES

1. RADIANT Corporation, Remedial Investigation for the East Area - Final Report for Carswell AFB, TX, USAF Contract F33615-87-D-4023, October, 1991.
2. Maxim Engineers, Inc., Limited Environmental Investigation and Assessment of Petroleum Hydrocarbon Impacts, Prepared for USAF, Carswell AFB, TX, Project No. 2492001270, September, 1992.
3. MagnaScan, Inc., Environmental Site Evaluation, Presented to Carswell AFB, TX, 1992.
4. American Society for Testing and Materials, Standard Method for Deep Quasi-Static, Cone and Friction Cone Penetration Tests of Soils, ASTM Designation: D3441, 1986.
5. Robertson, P.K., and R.G. Campanella, "Guidelines for Using the CPT, CPTU, and Marchetti DMT for Geotechnical Design: Vol. II - Using CPT and CPTU Data", Civil Engineering Dept., University of British Columbia, March 1988.
6. Timian, D.A., W.L. Bratton, B.E. Fisk, Piezo Electric Cone Penetration Tests in Support of Geotechnical Investigations at Sections 6/7 and 1/9 of Fresh Kills Landfill, Staten Island, New York - Development of Correlations for Soil Classification and In-Situ Properties, ARA, Inc. Contract No. 5693, May, 1992.
7. Shinn, J.D., and W.L. Bratton, Piezo-Resistivity Cone Penetration Technology Investigation of the M-Basin at the Savannah River Site, Aiken, SC, Report to Argonne National Laboratories, Contract No. 21042401, October, 1992.

**APPENDIX A**

**LIF-CPT PROFILES**



BSS-01

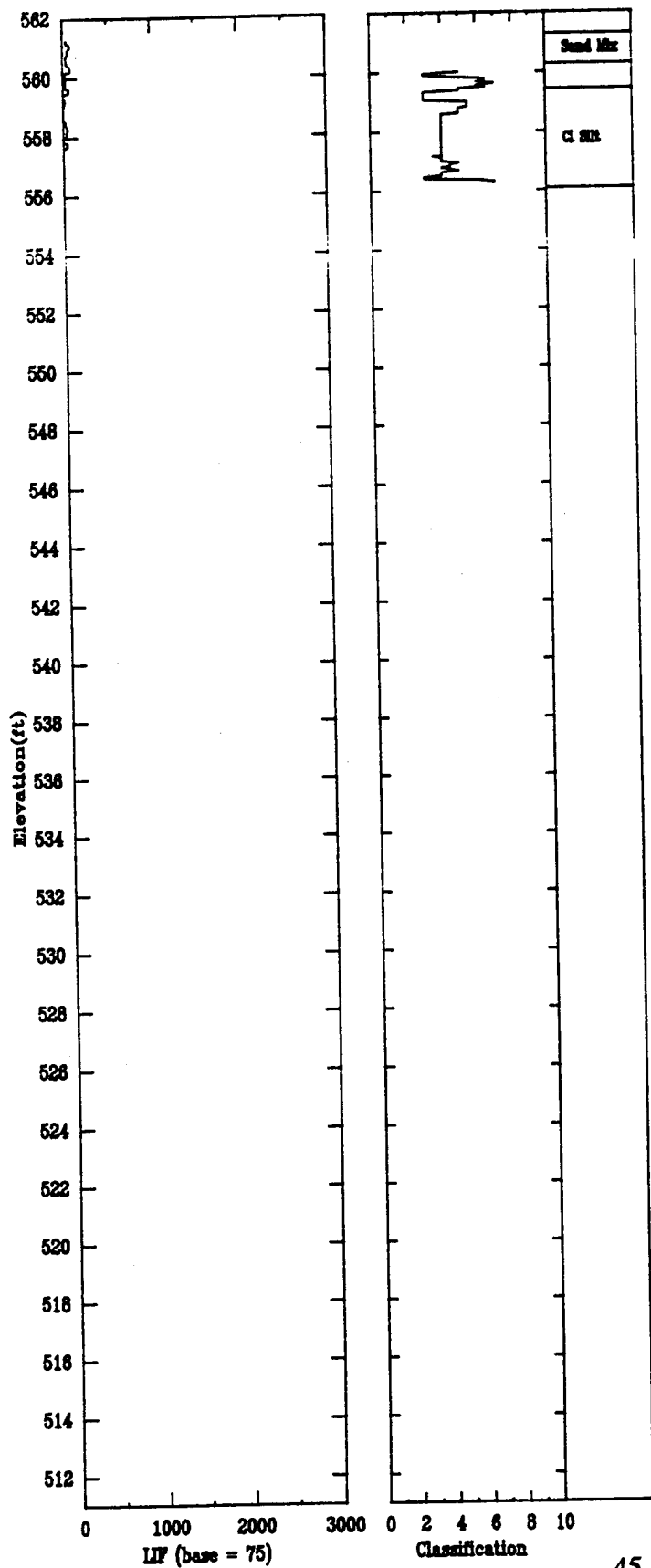
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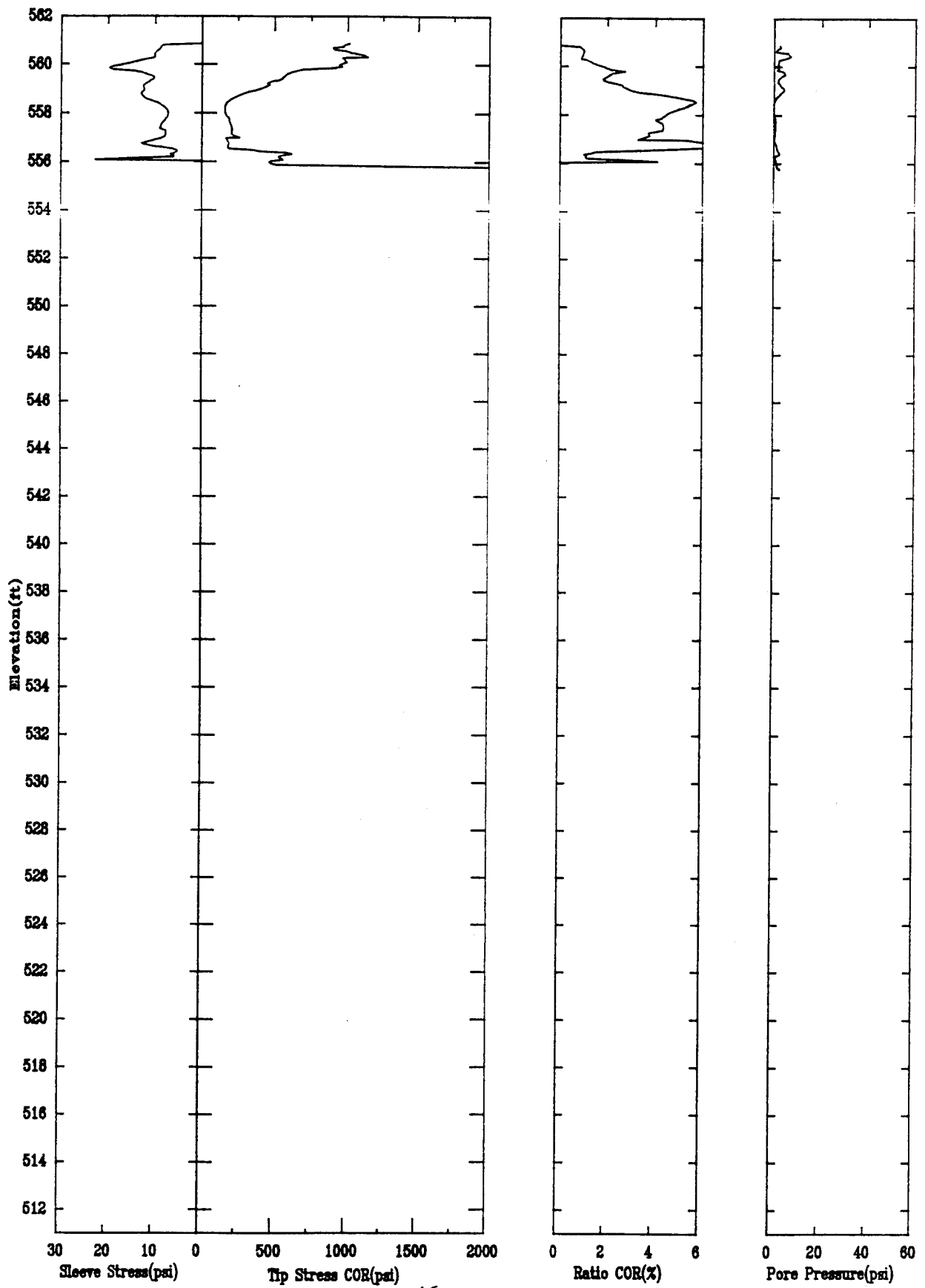
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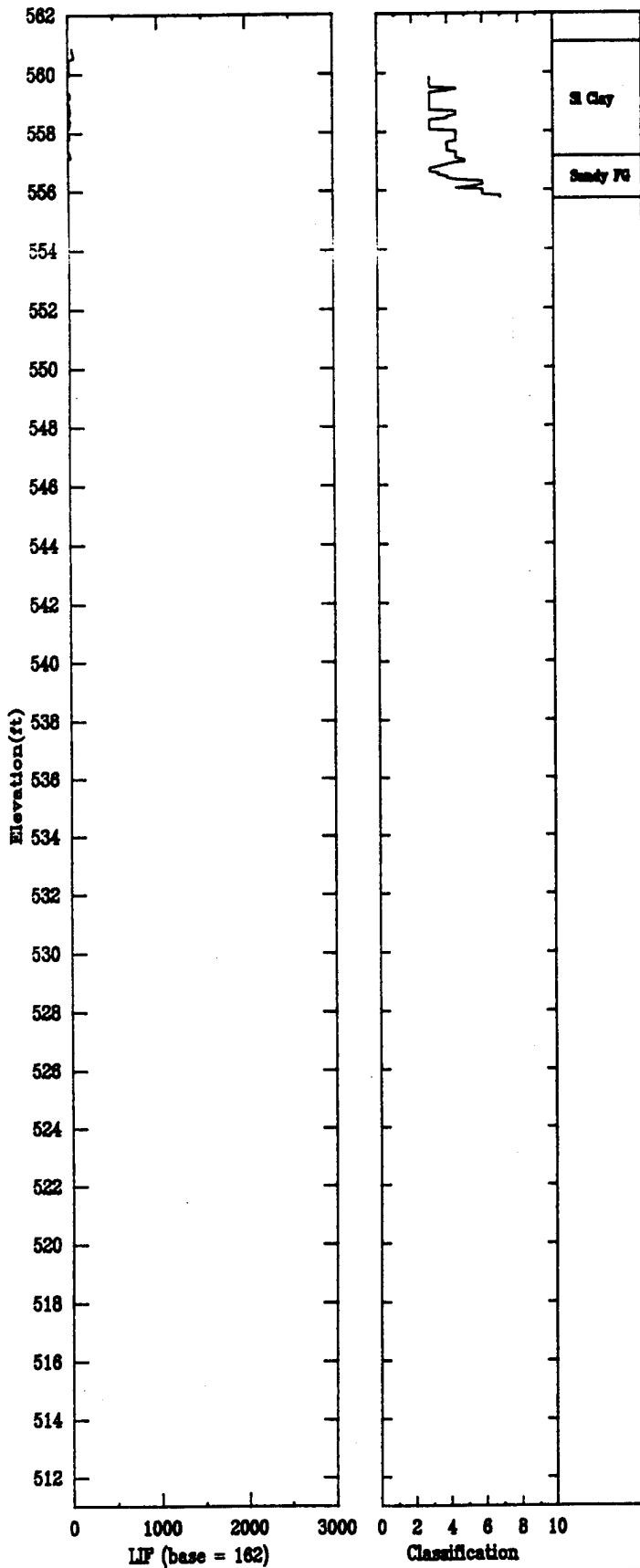
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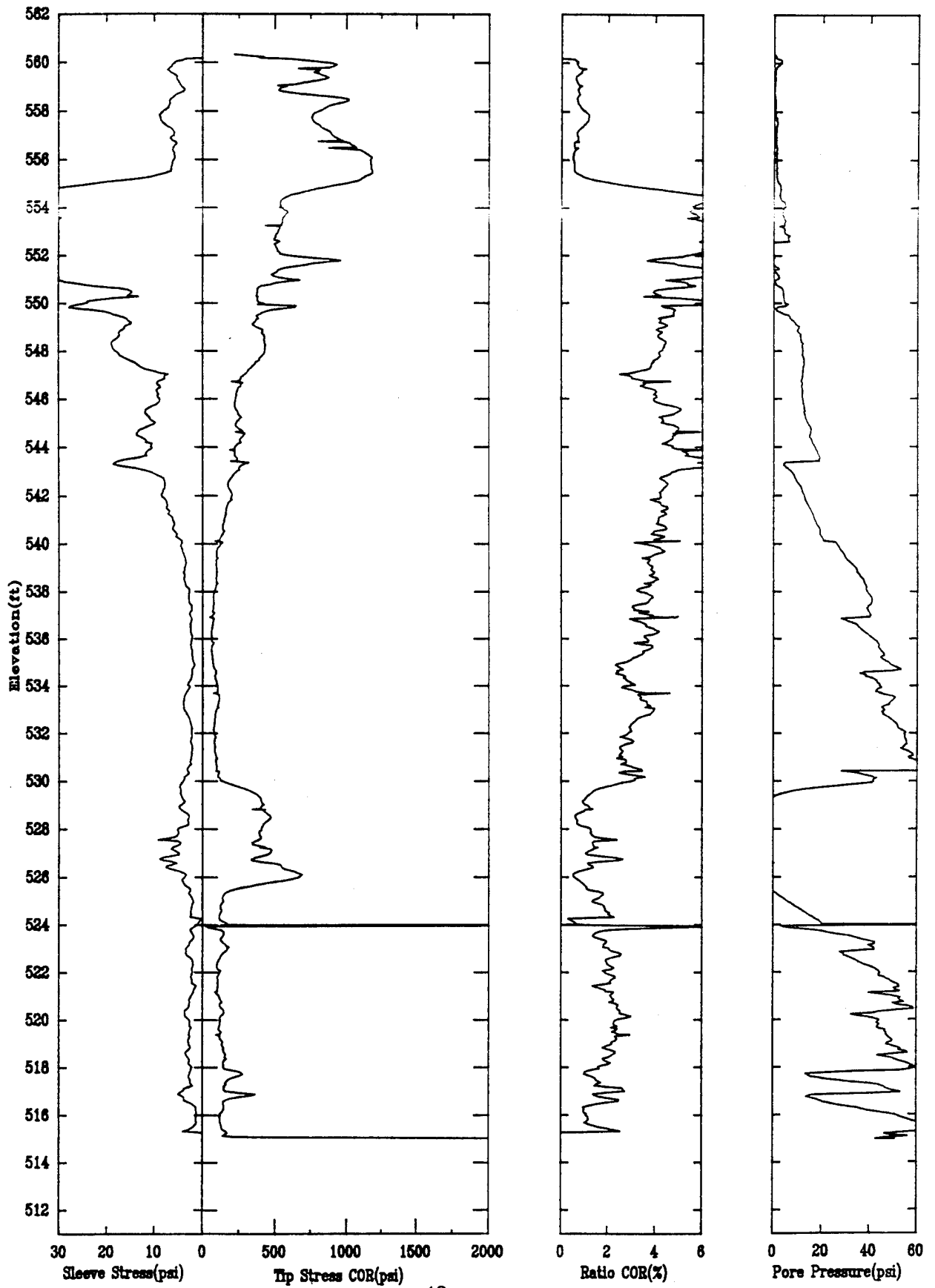
East 2024460

Elevation 561.307









BSS-02

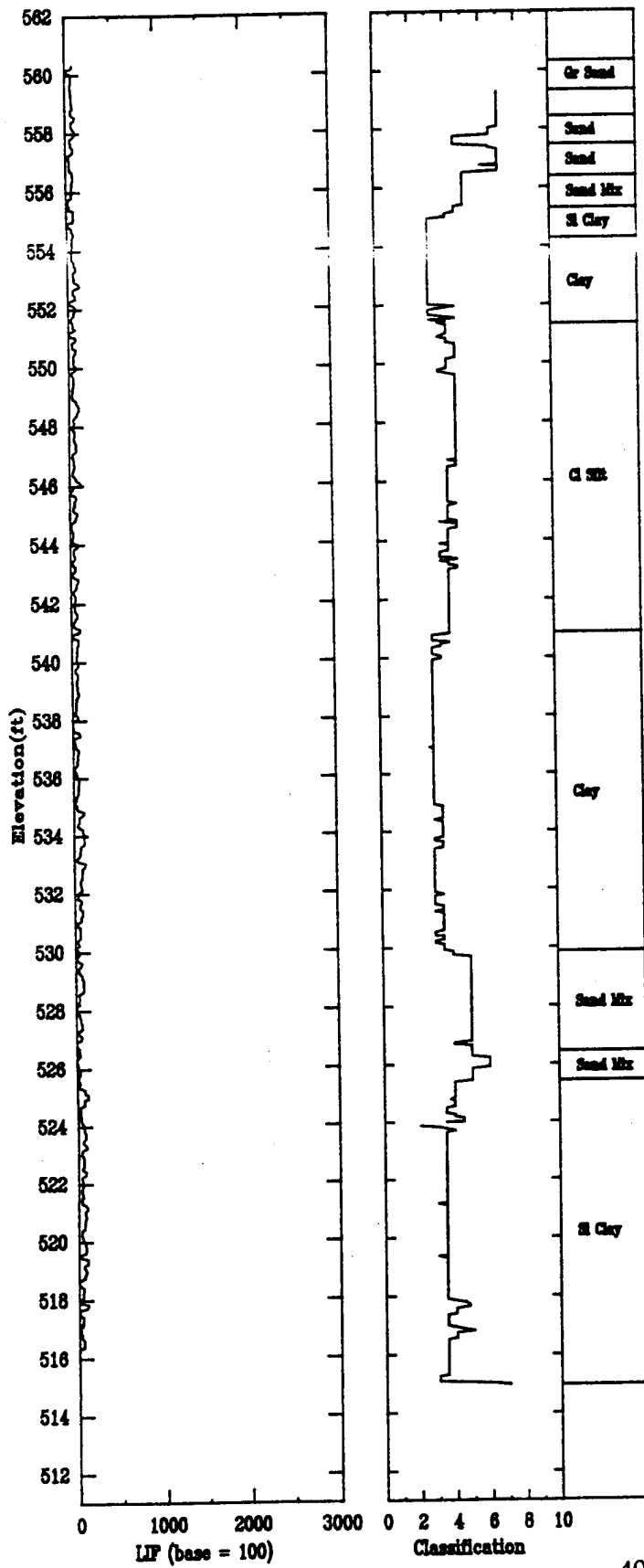
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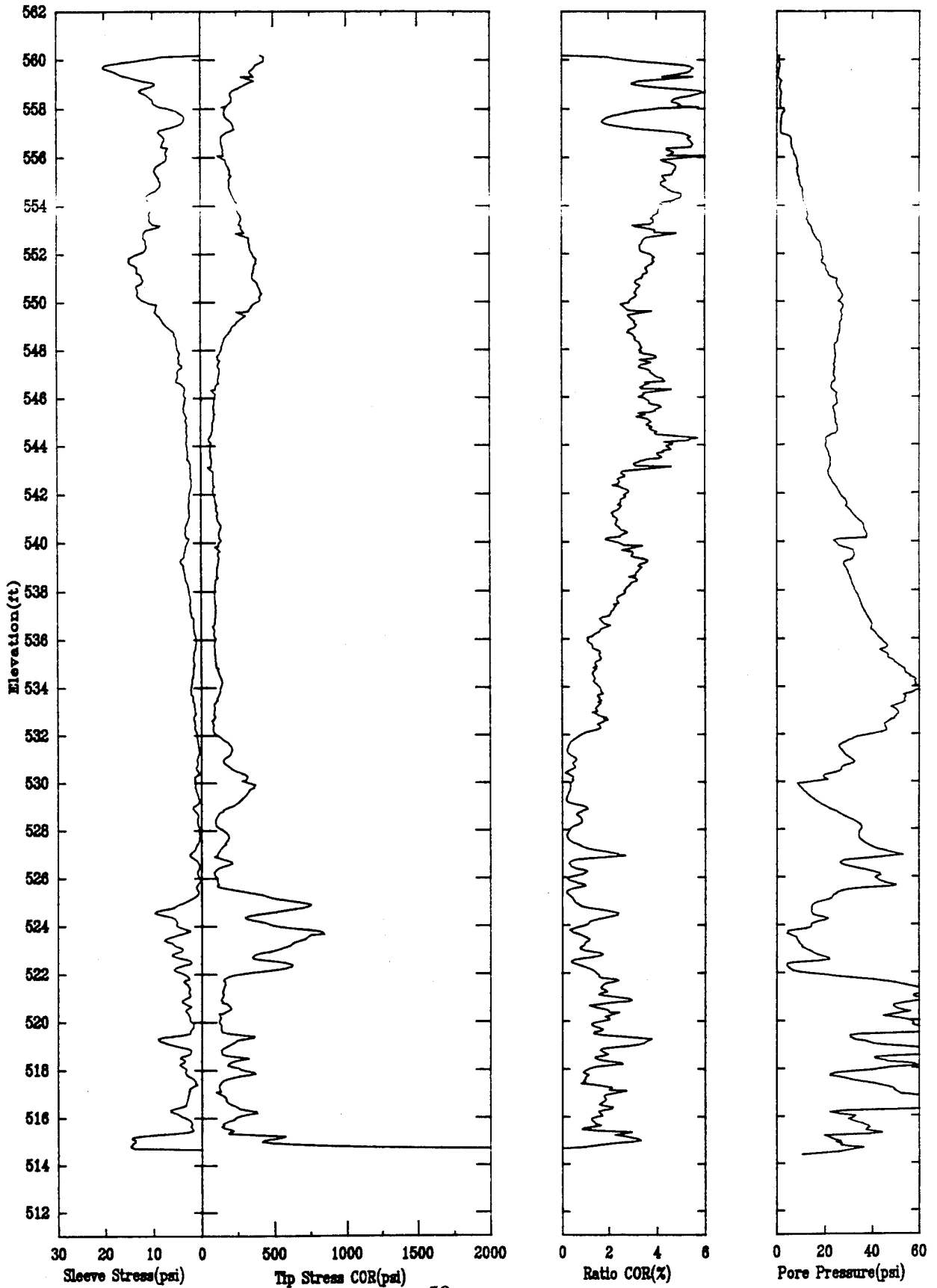
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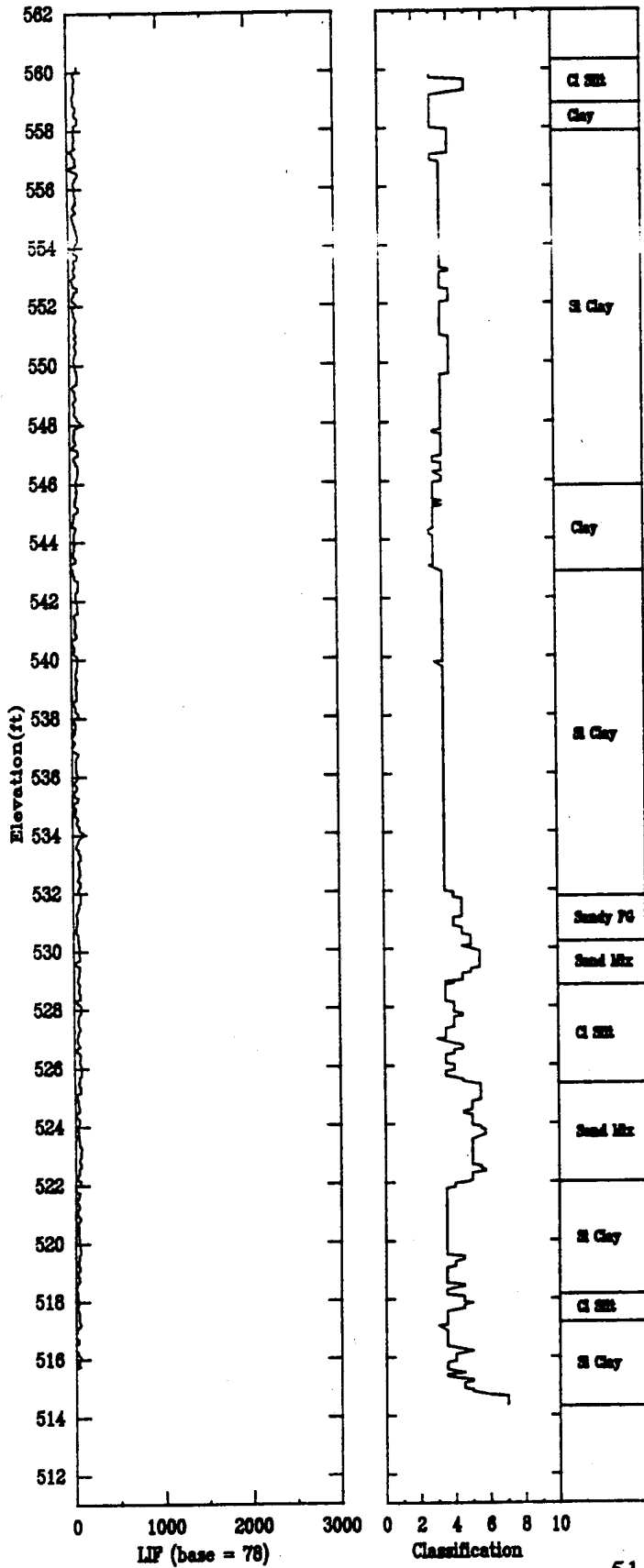
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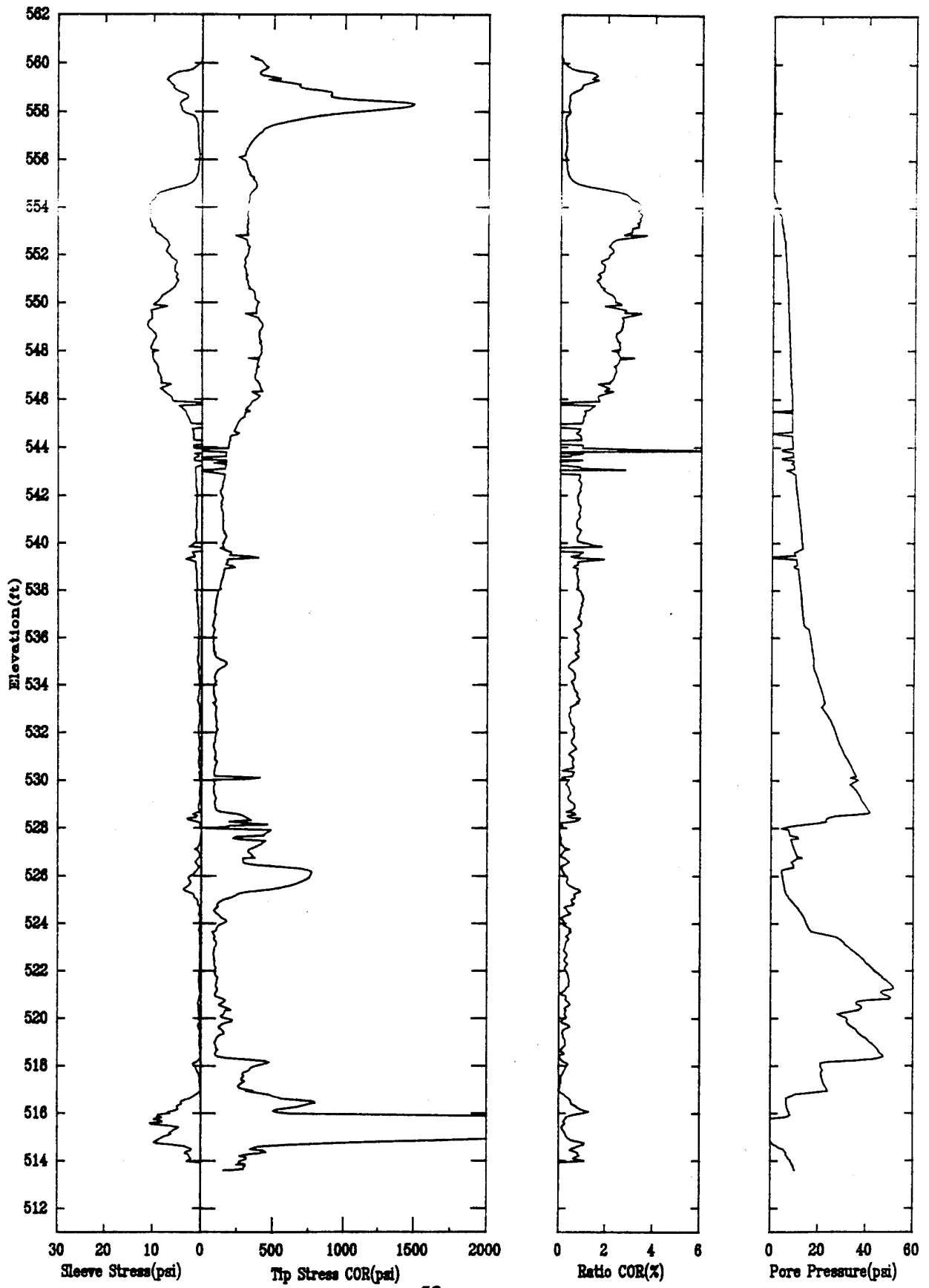
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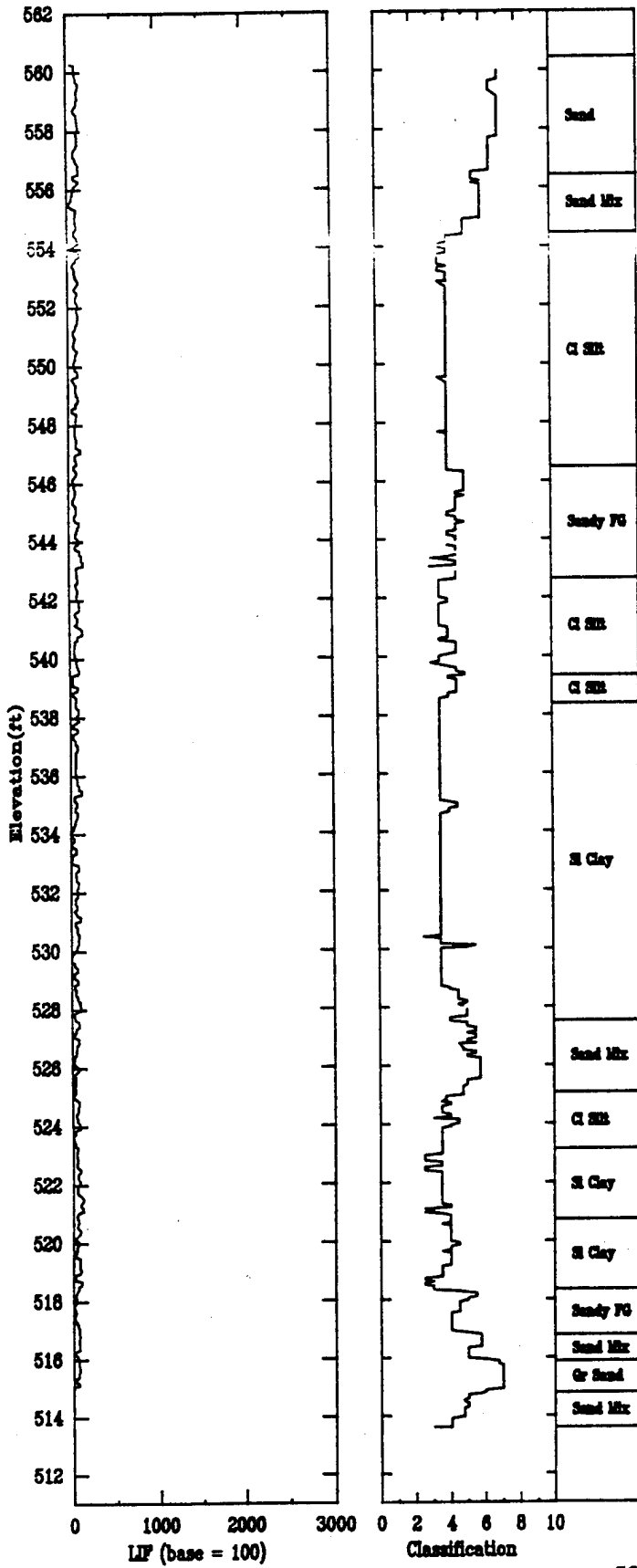
Elevation 560.352

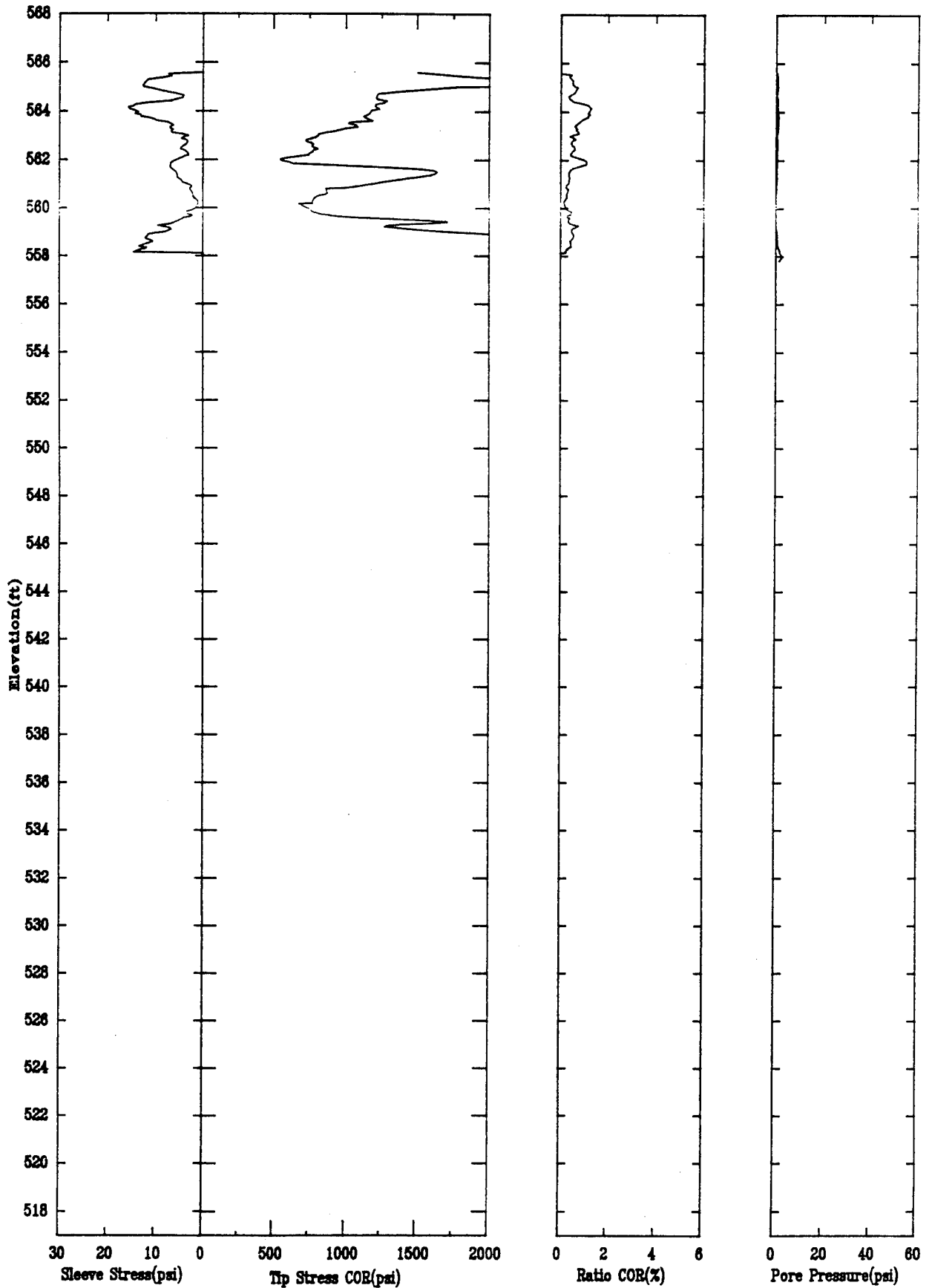


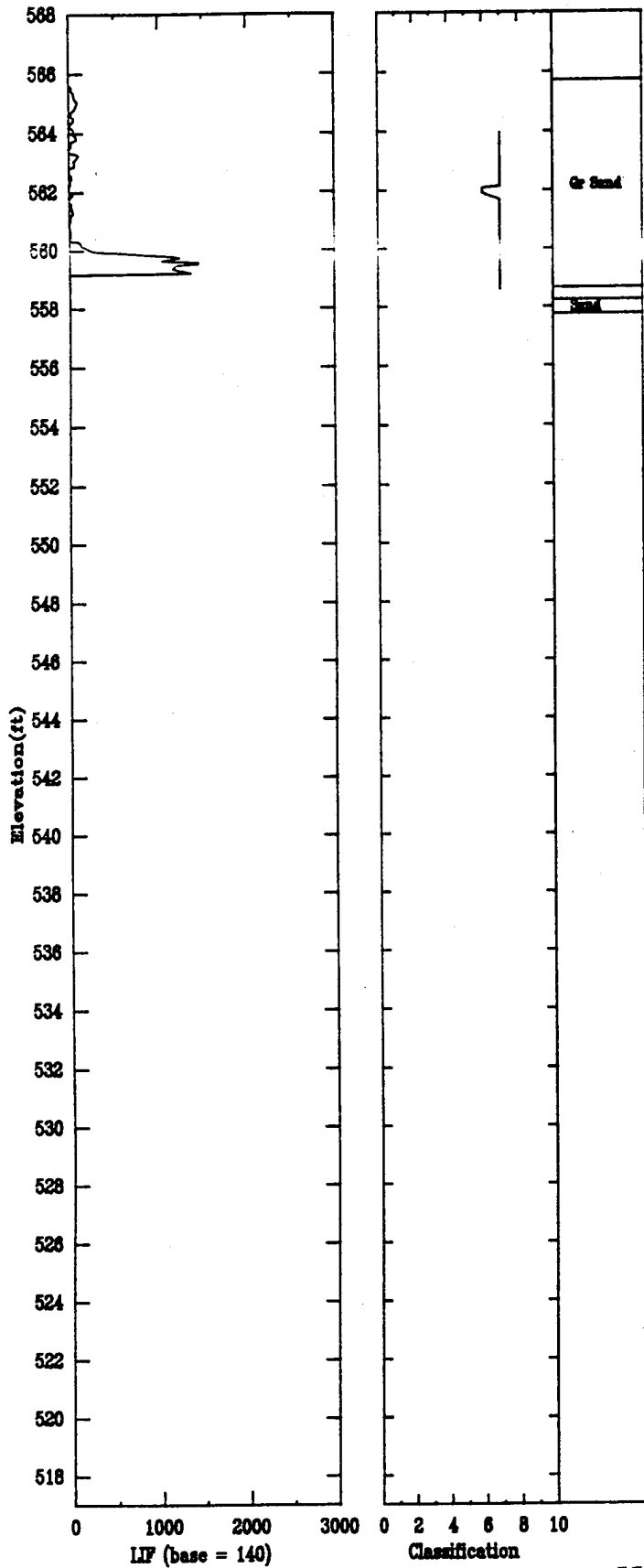


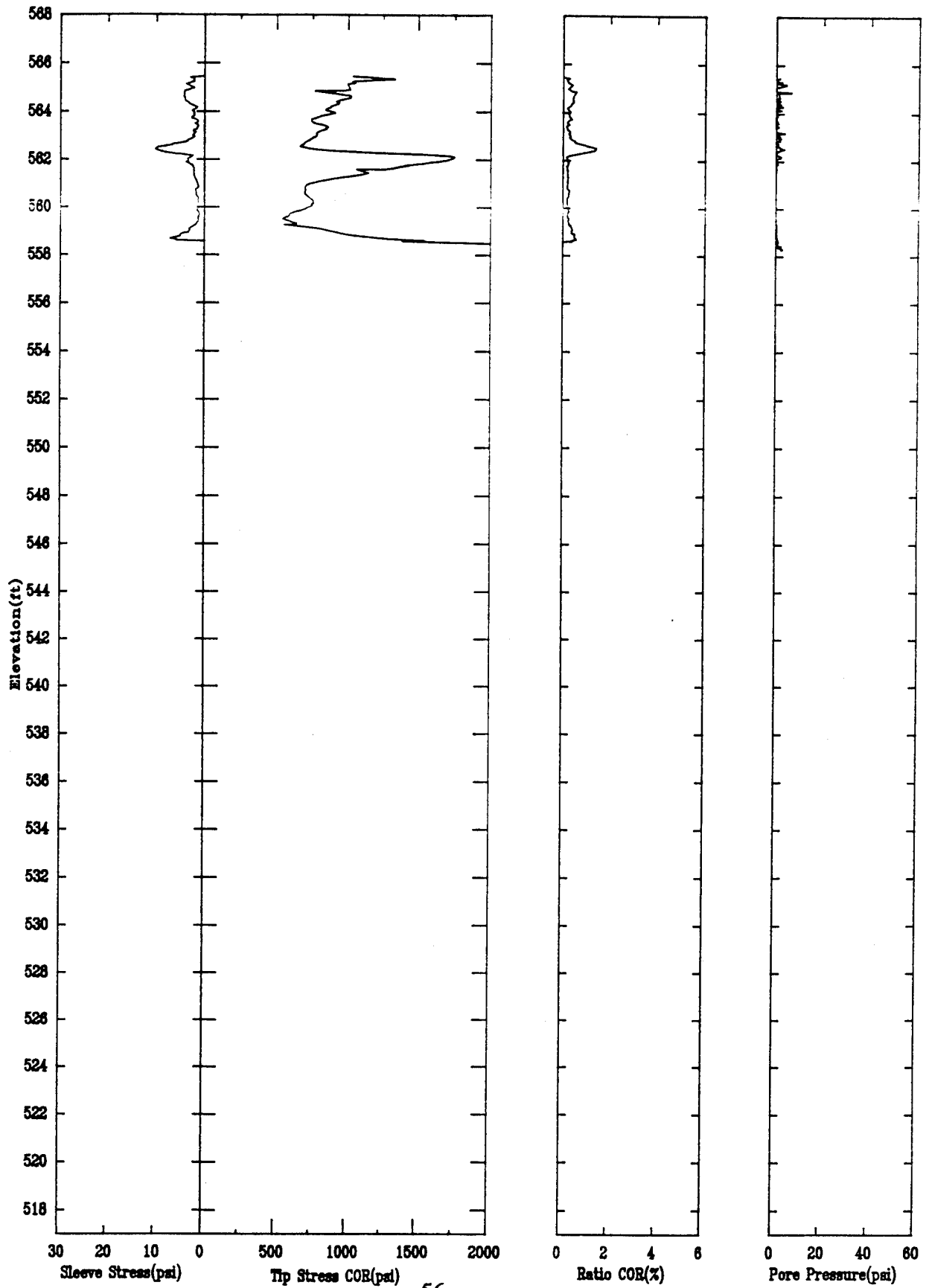












BSS-06

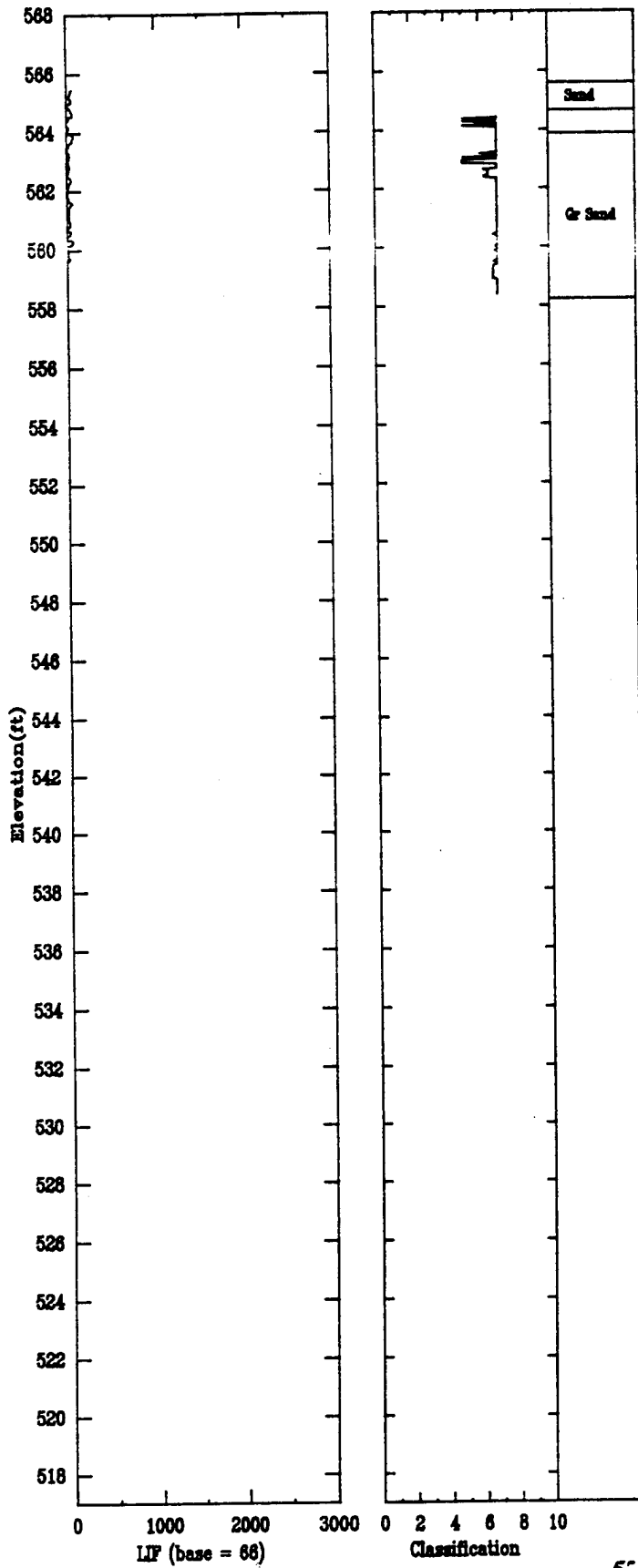
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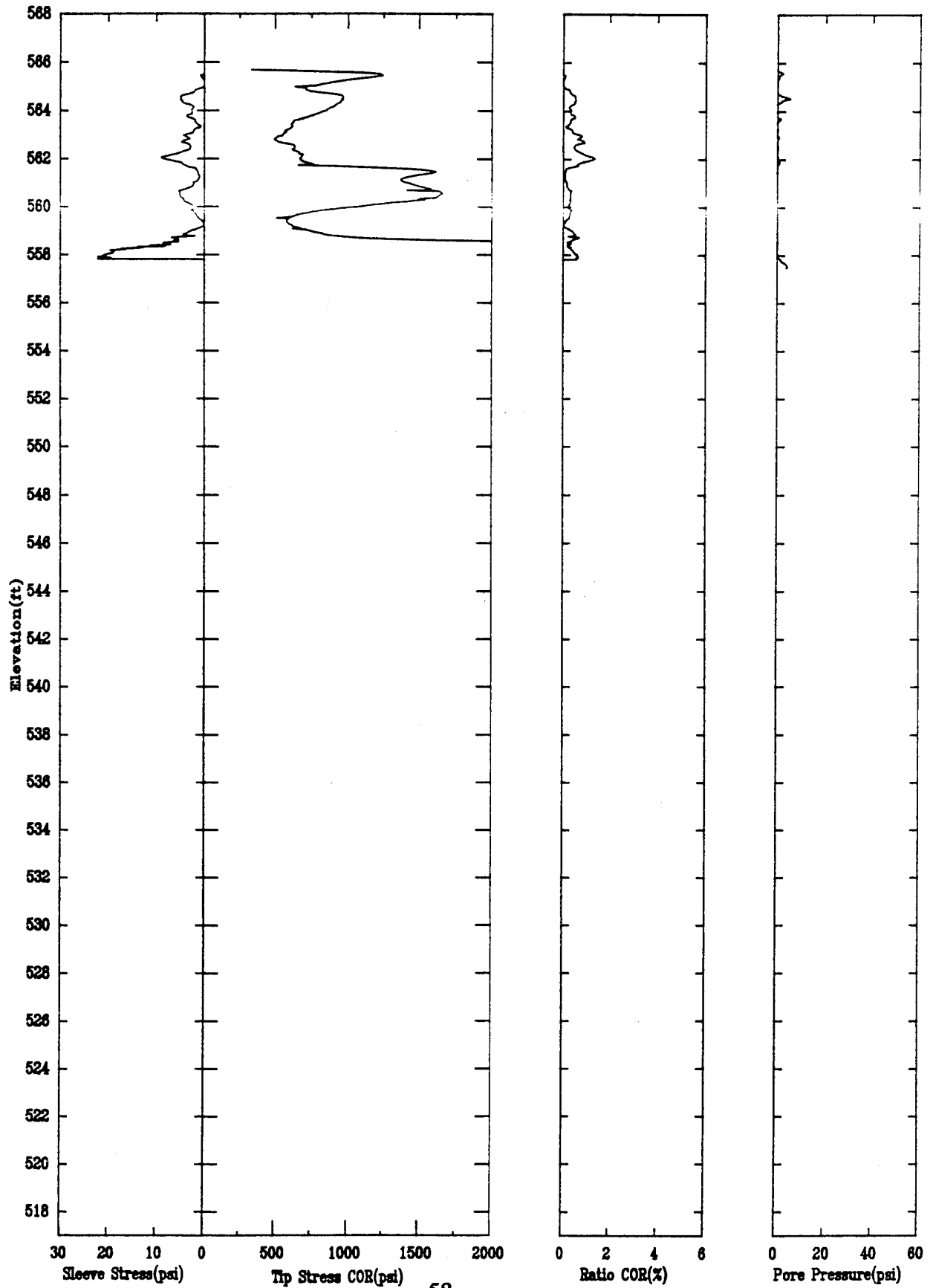
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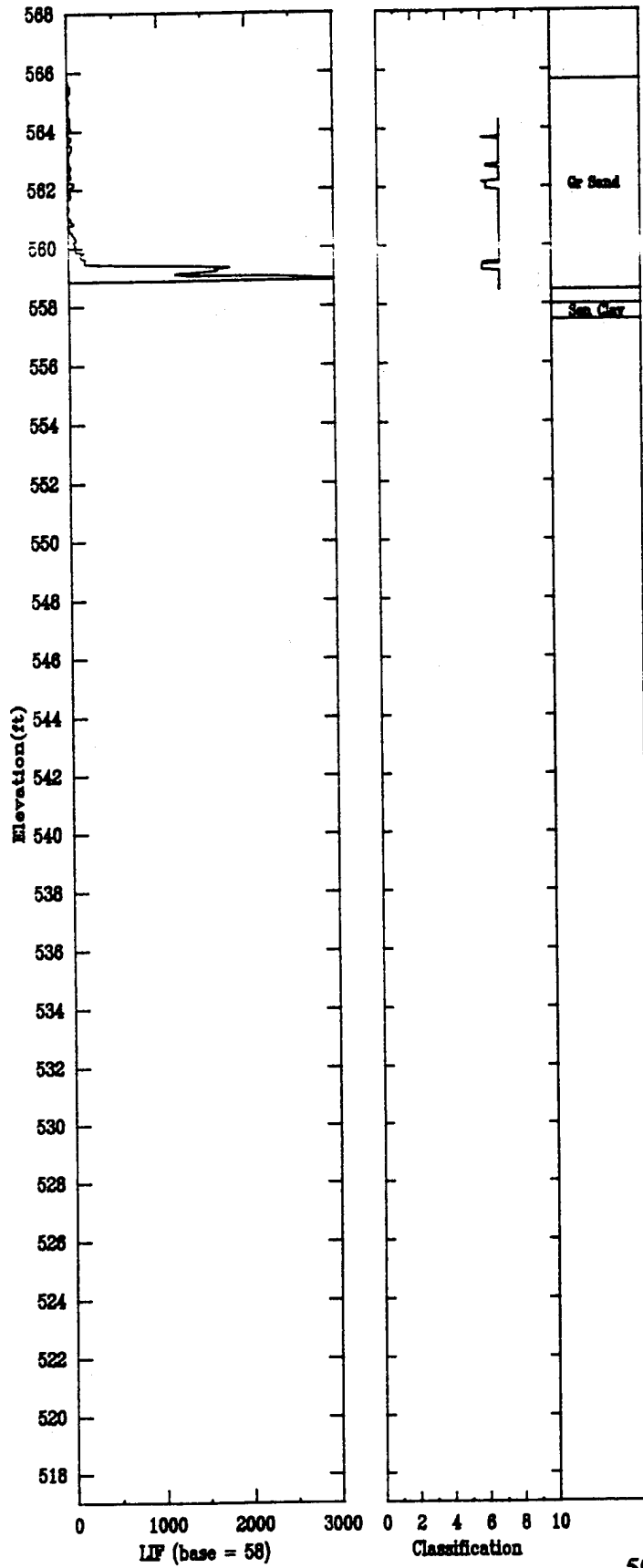
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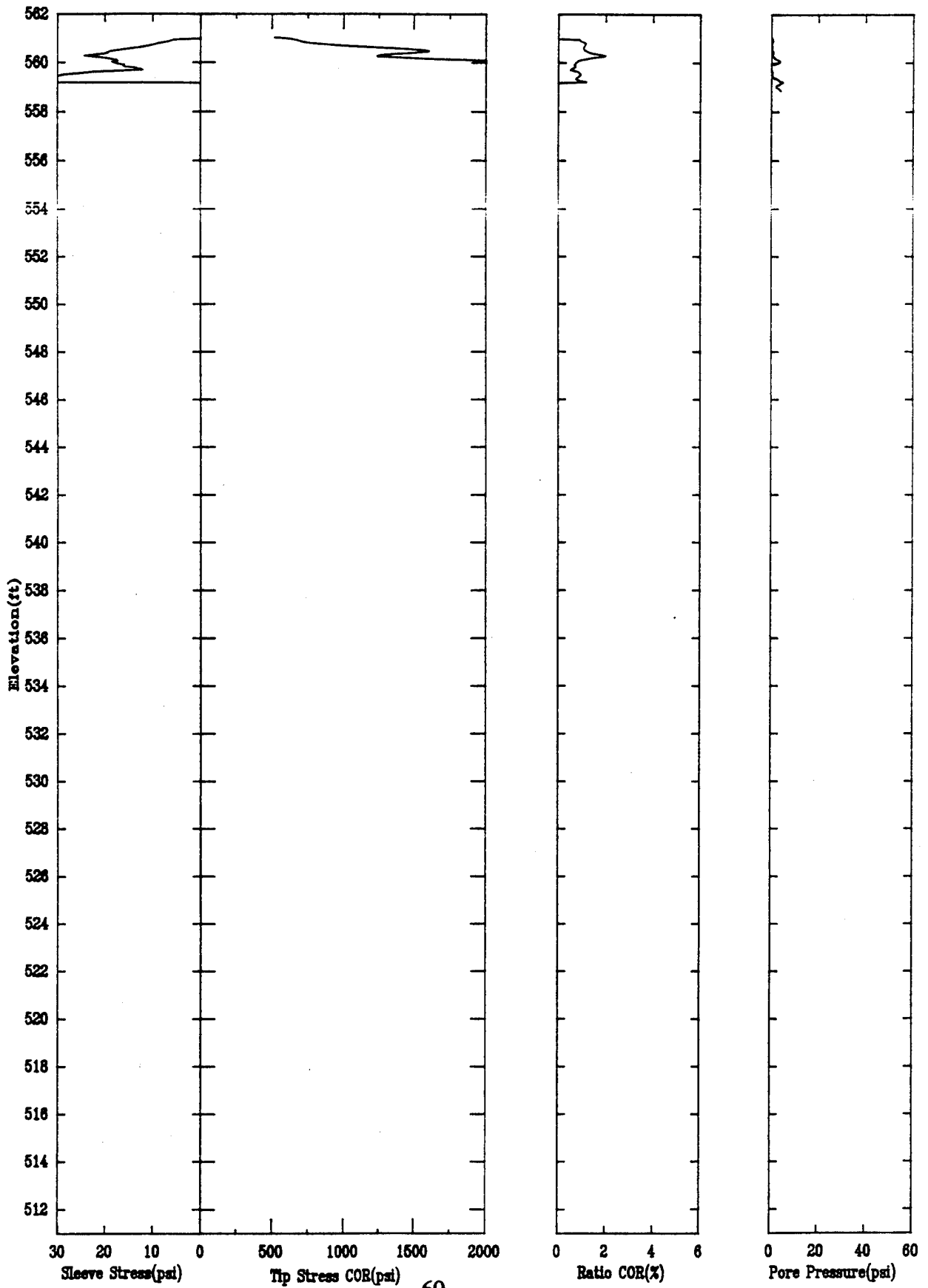
East 2024350

Elevation 565.647









BSS-08

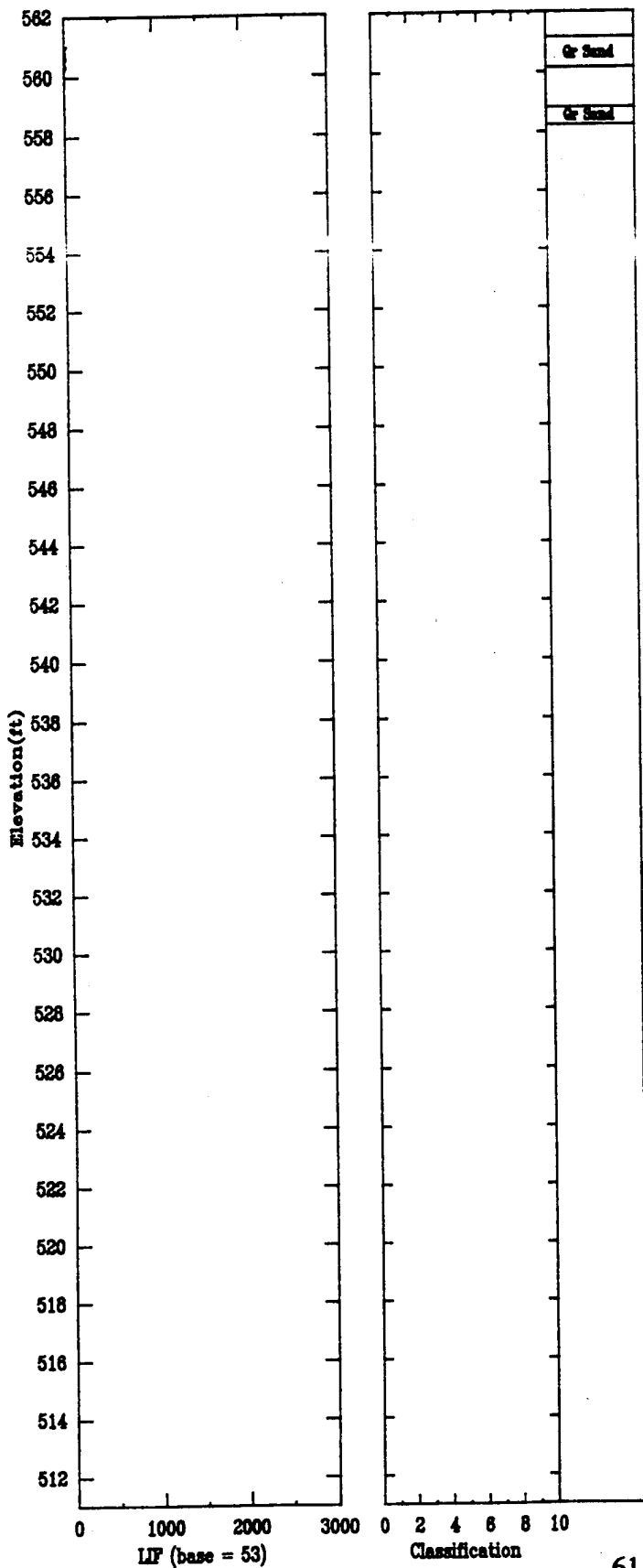
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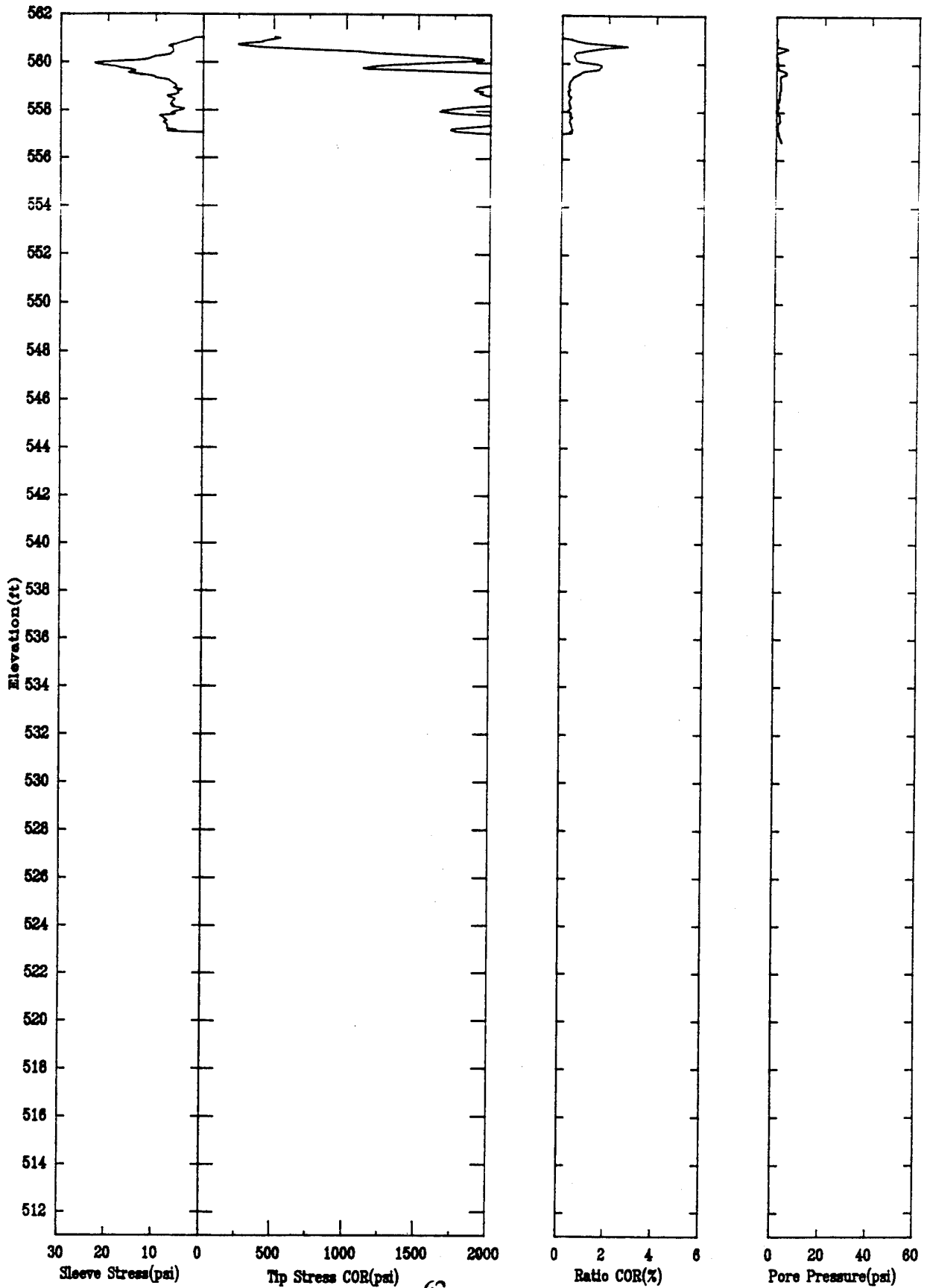
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East 2024395

Elevation 561.177





BSS-09

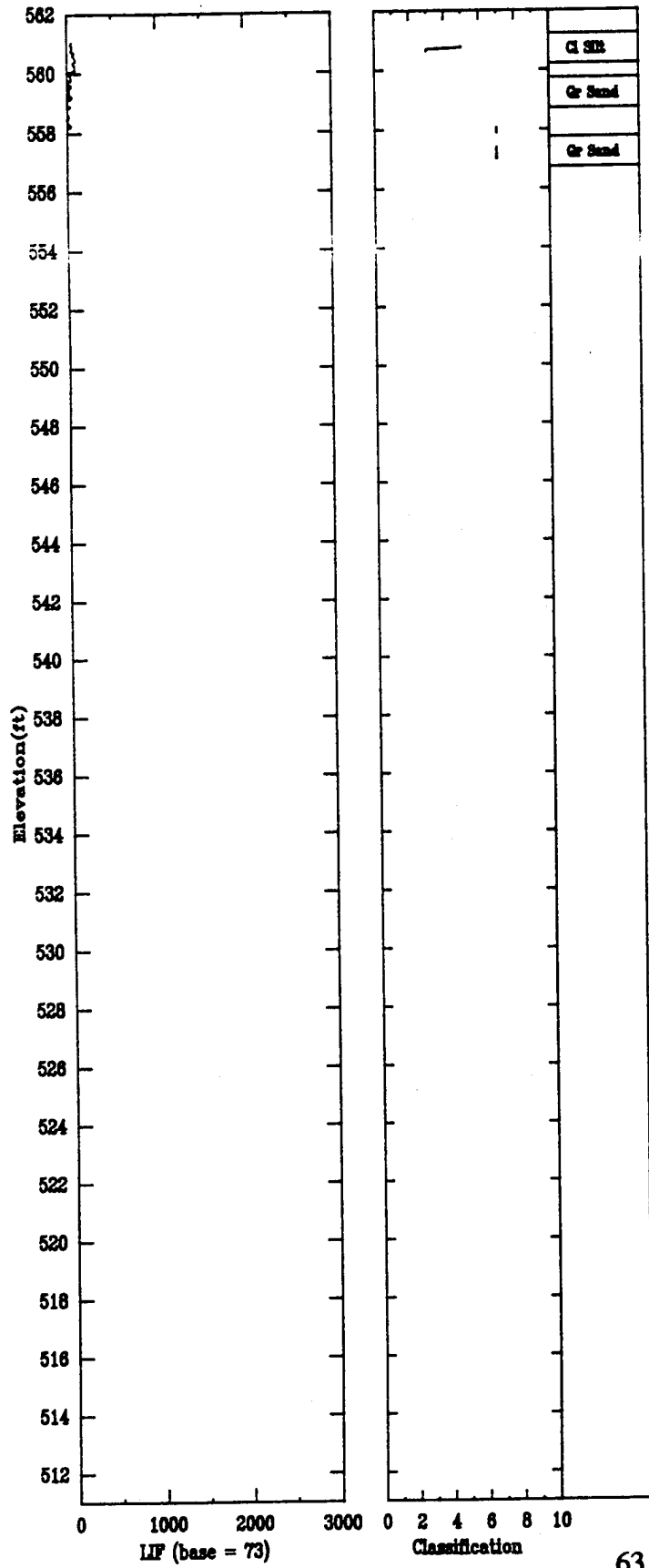
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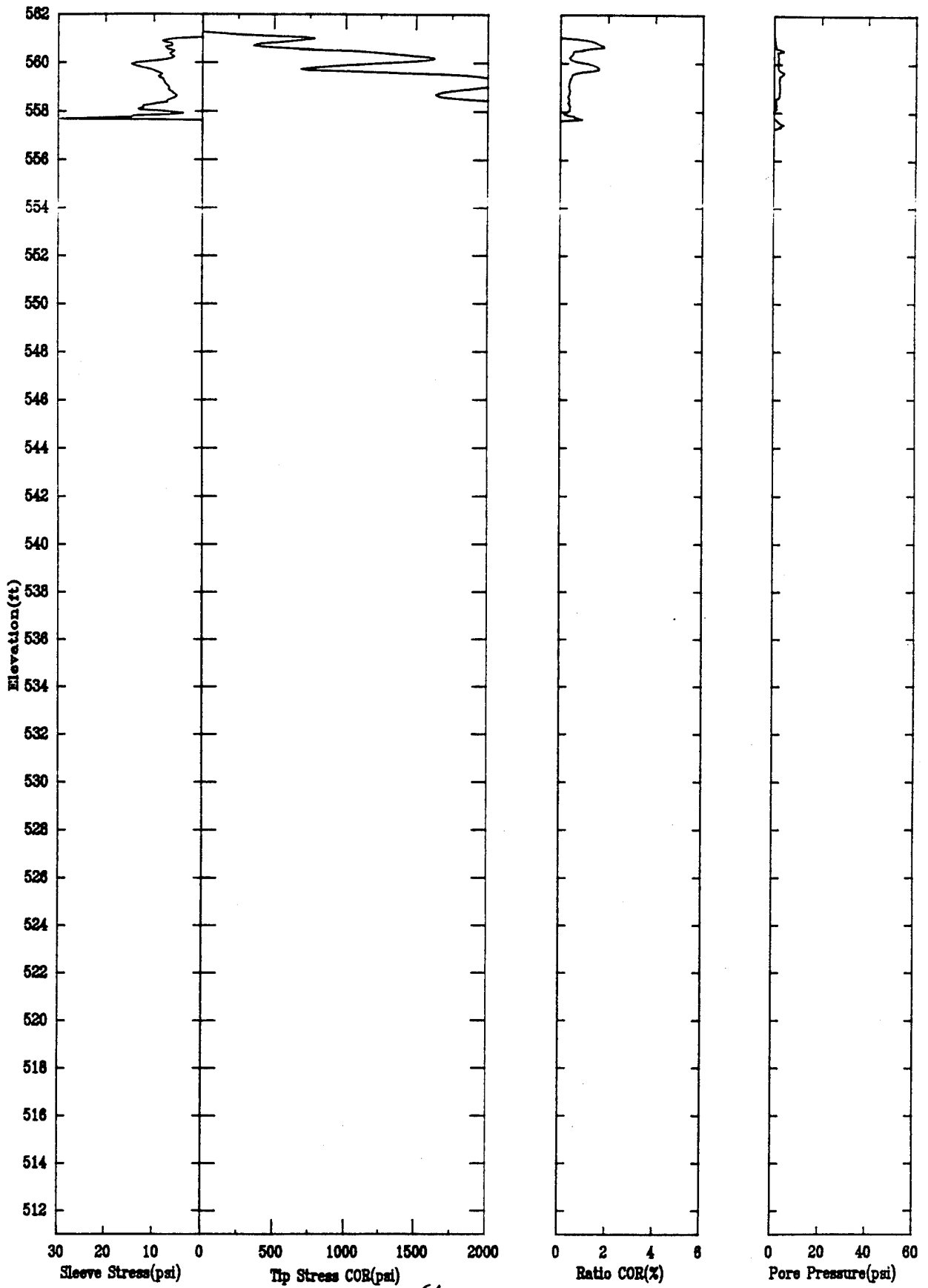
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East 2024385

Elevation 561.232





BSS-10

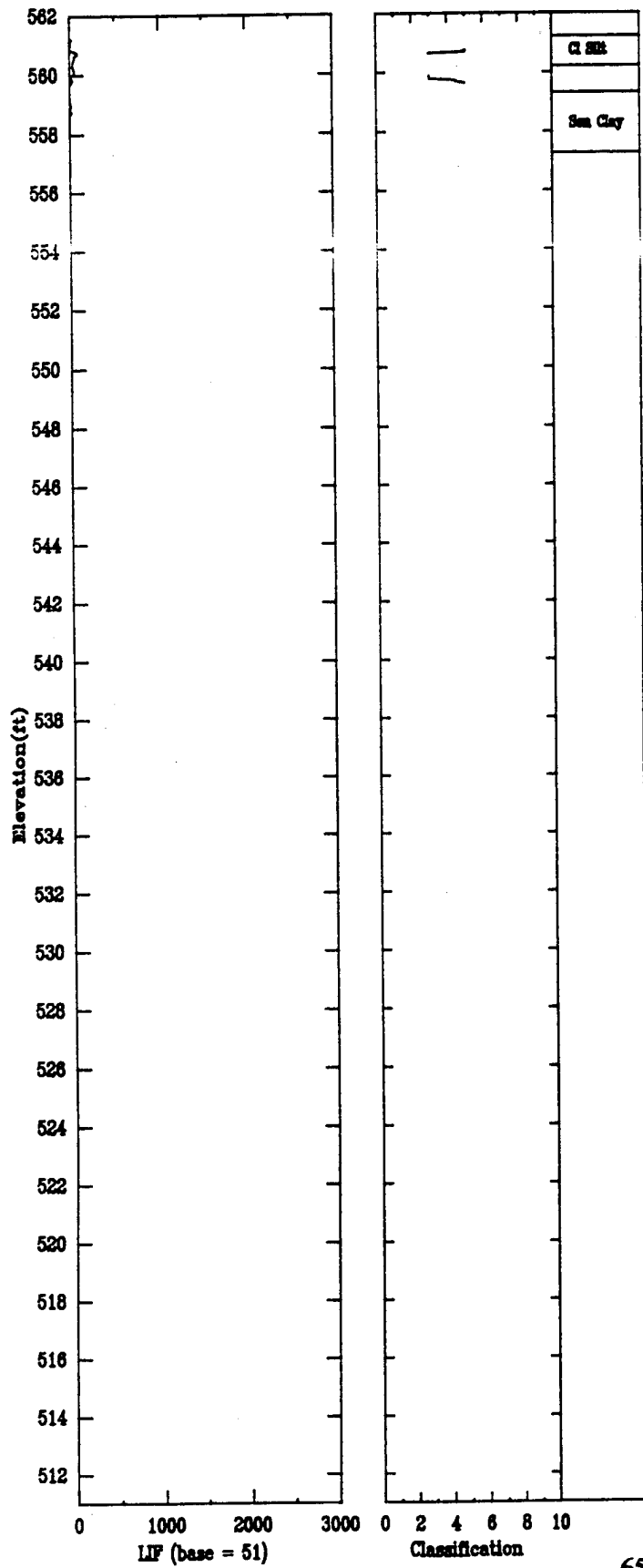
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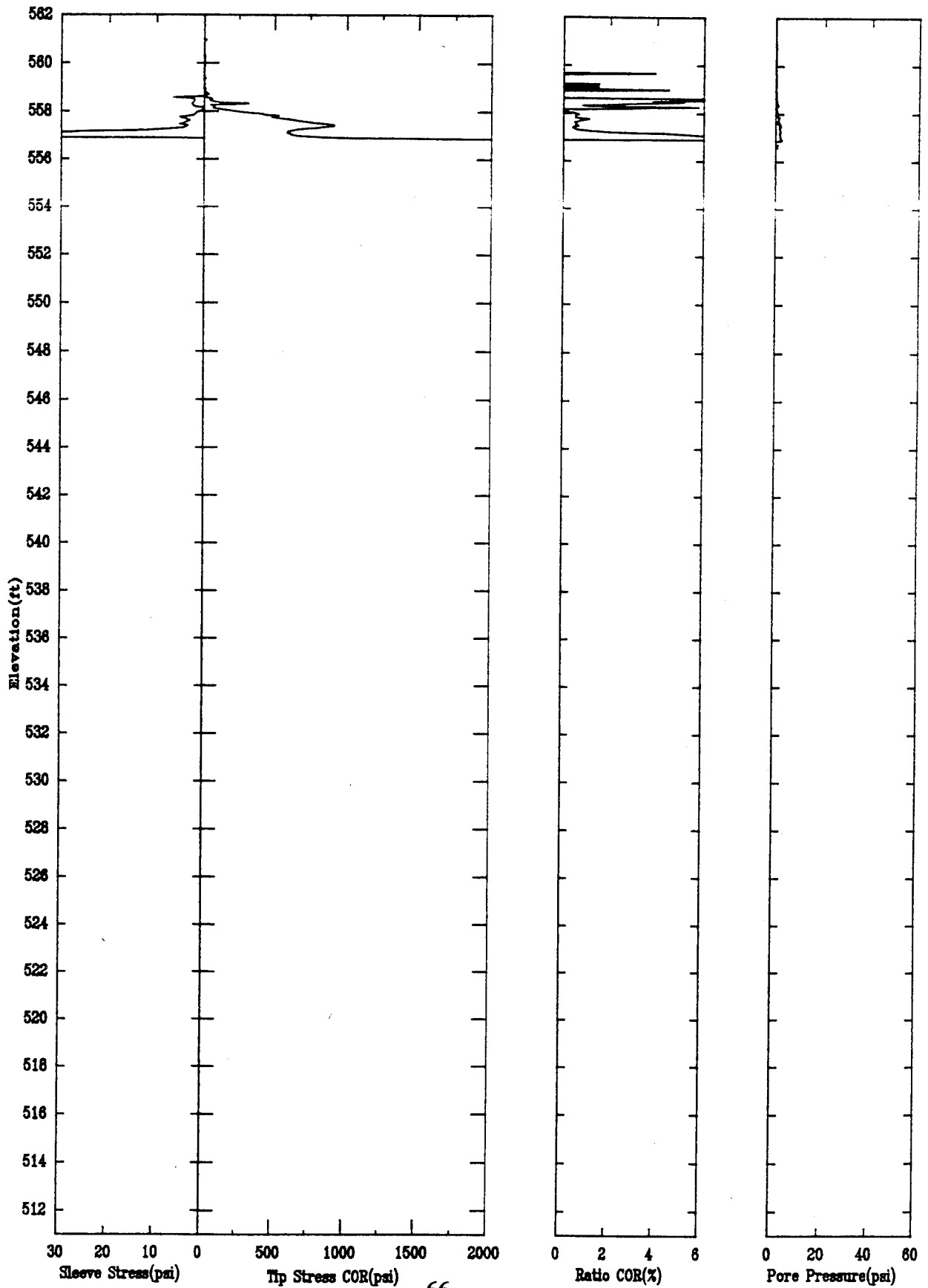
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Elevation 561.247





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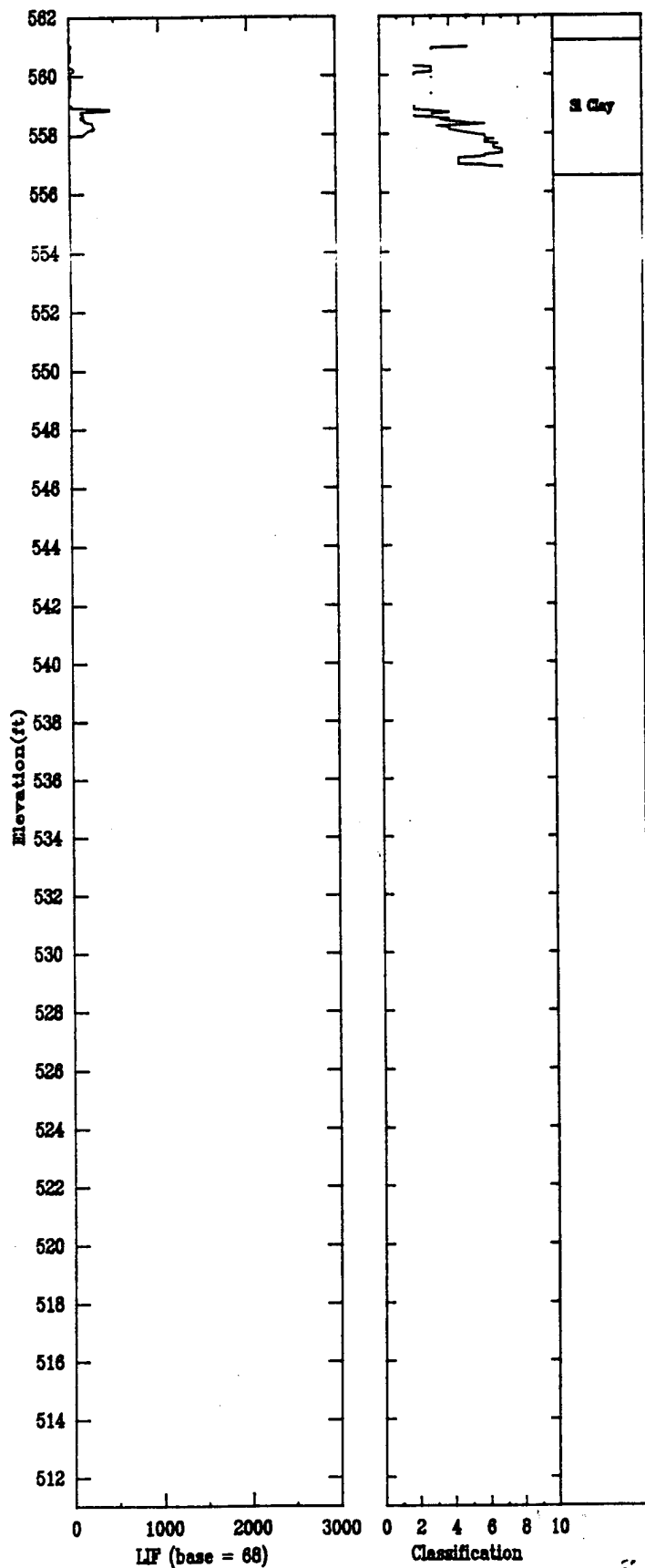
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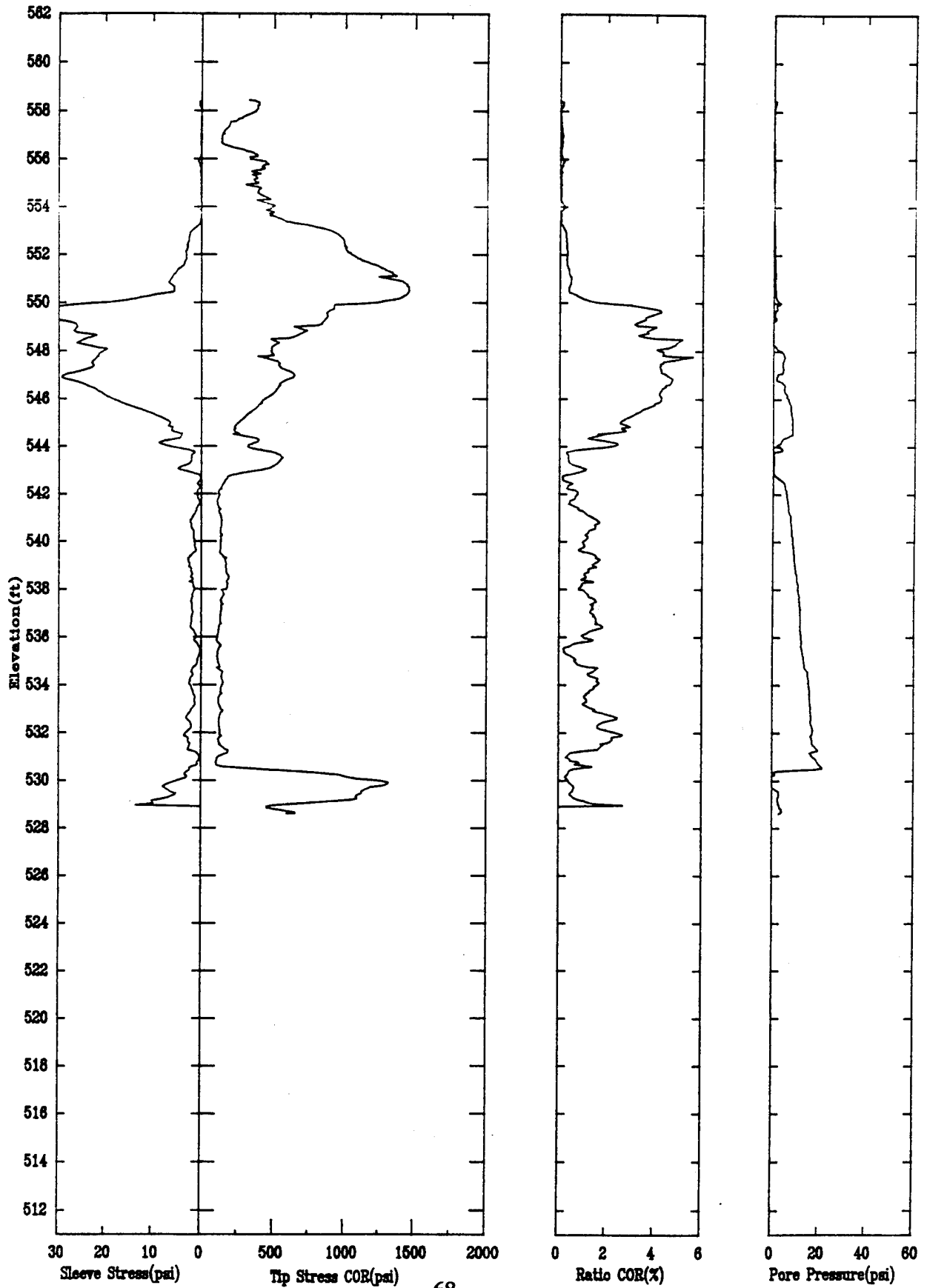
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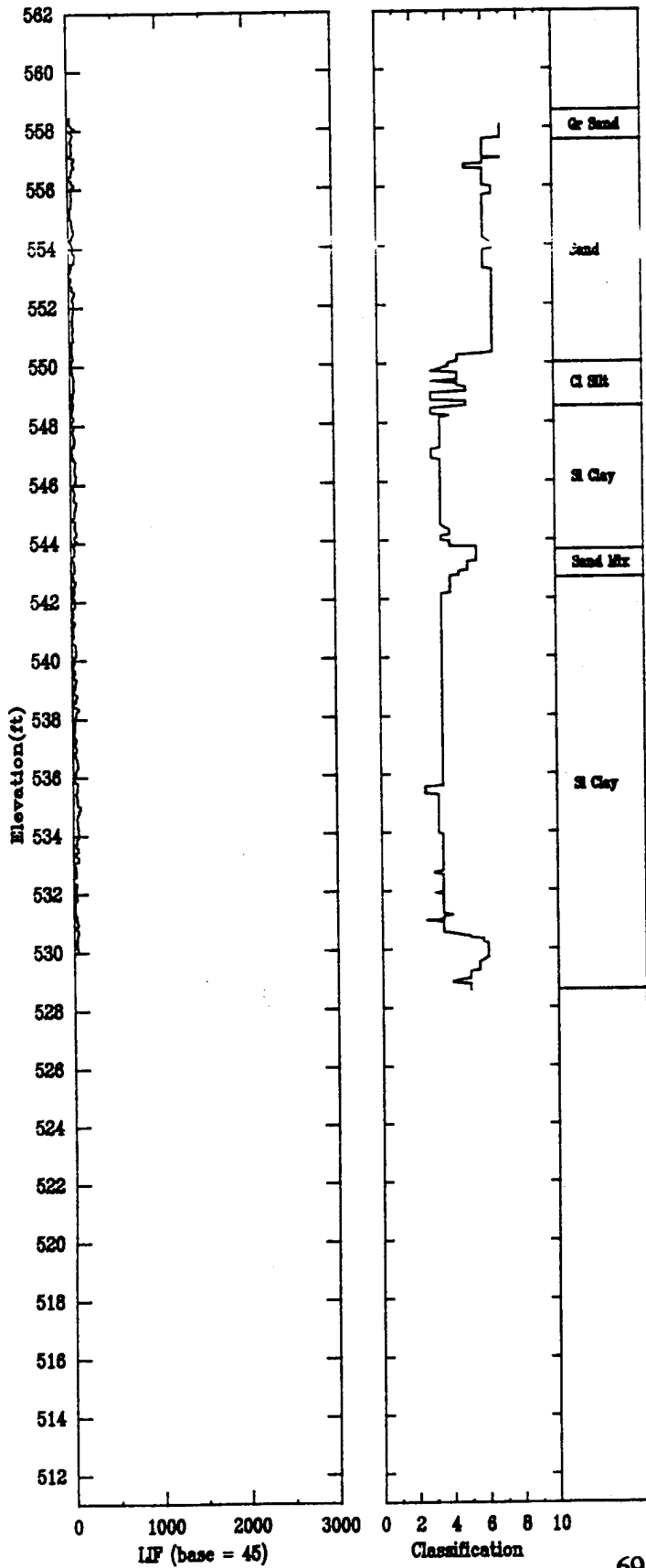
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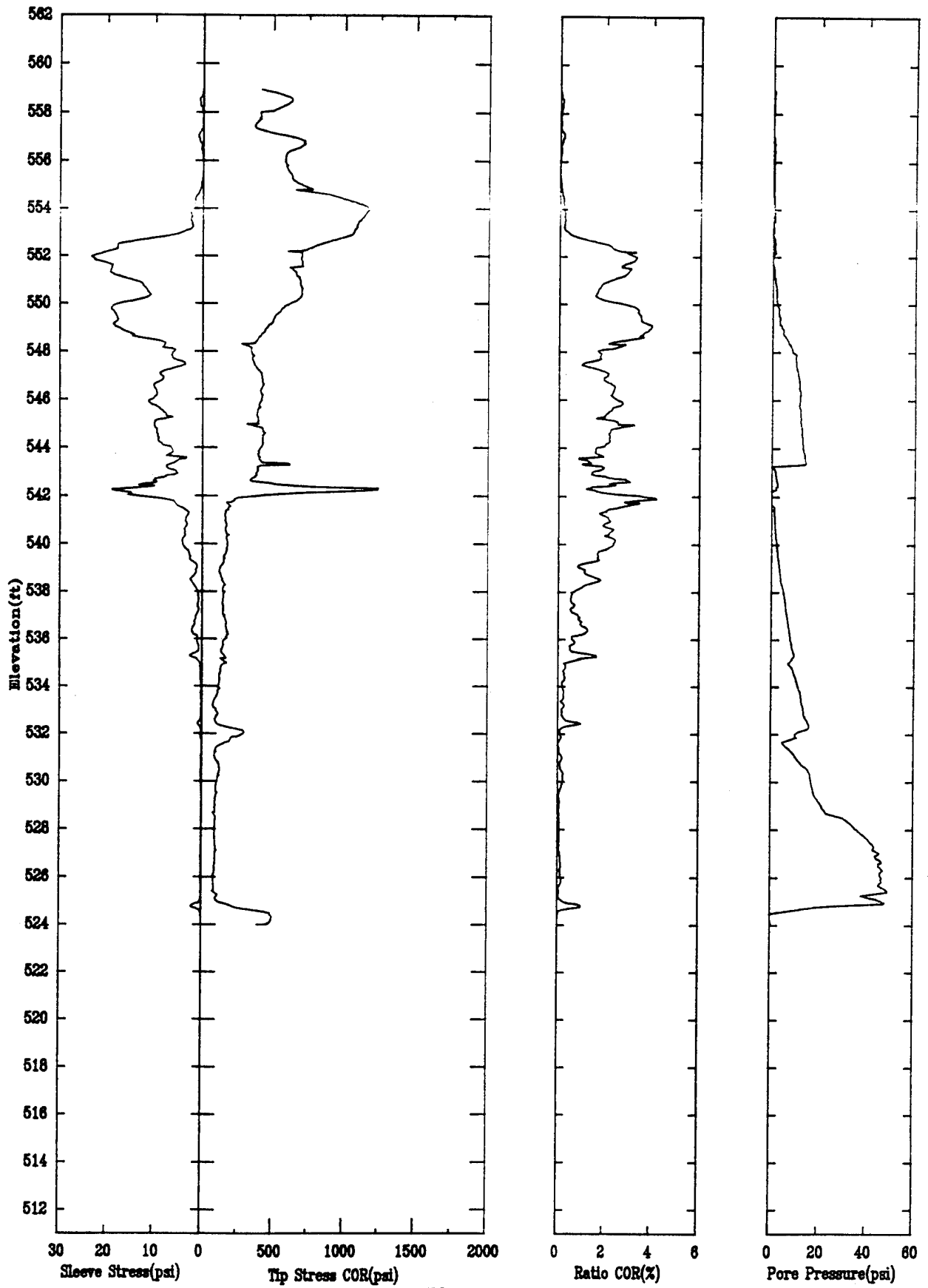
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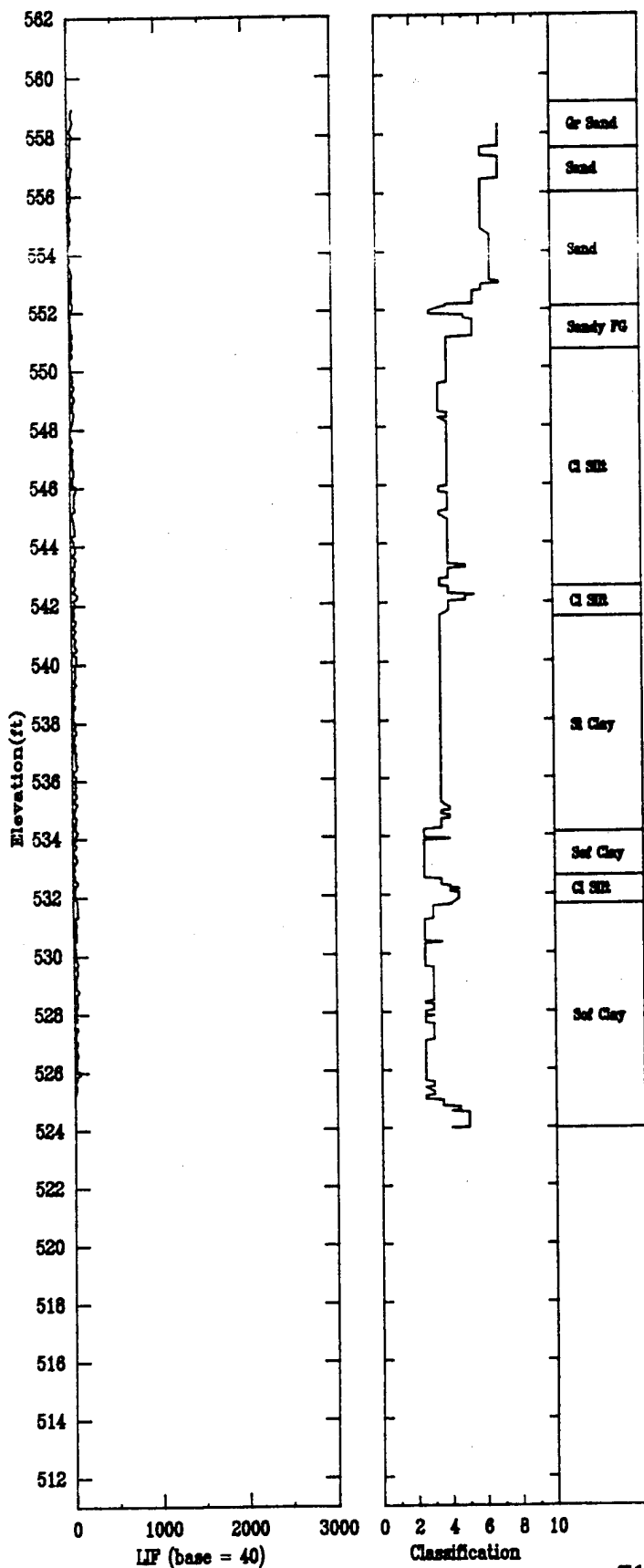
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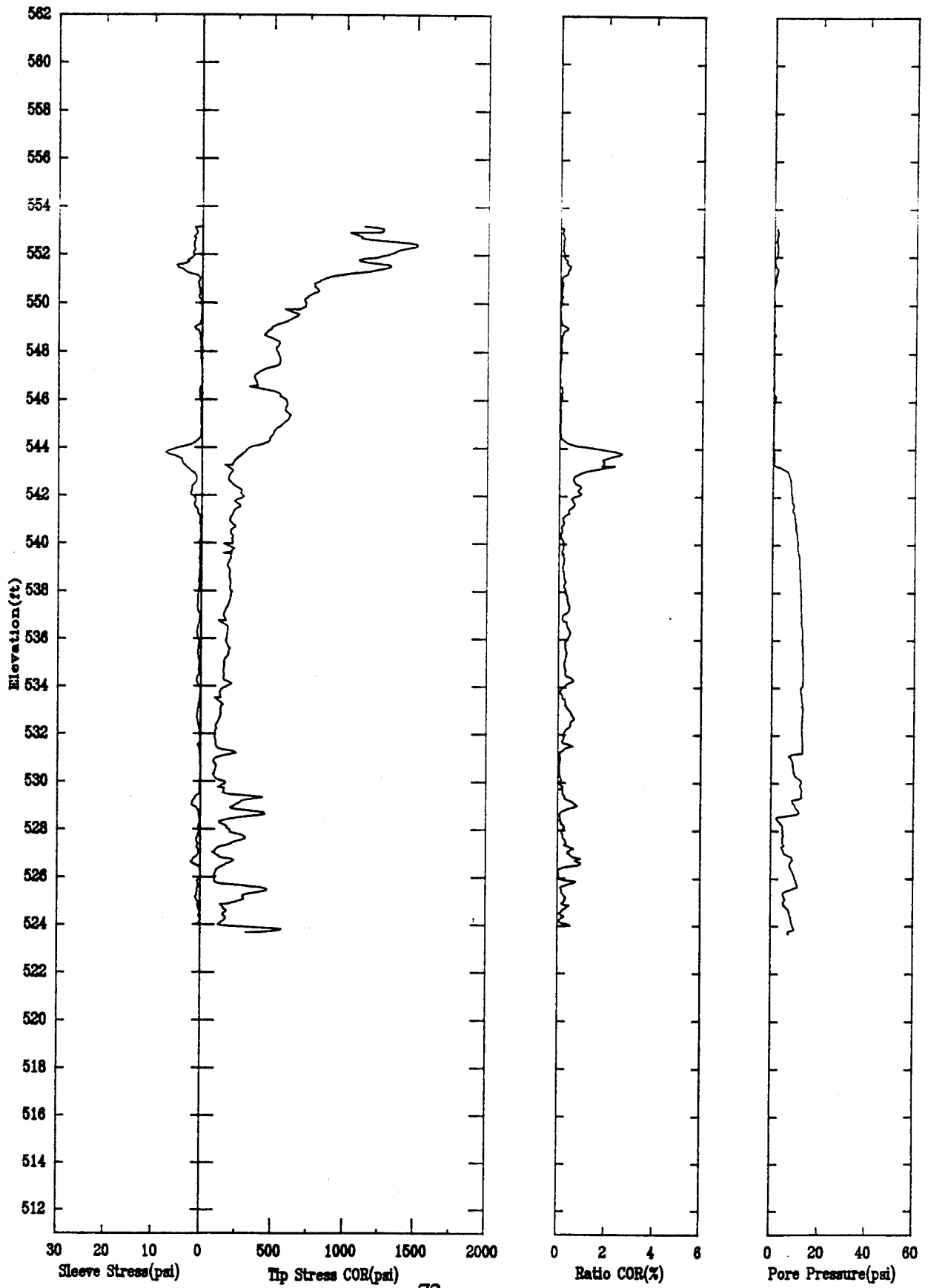


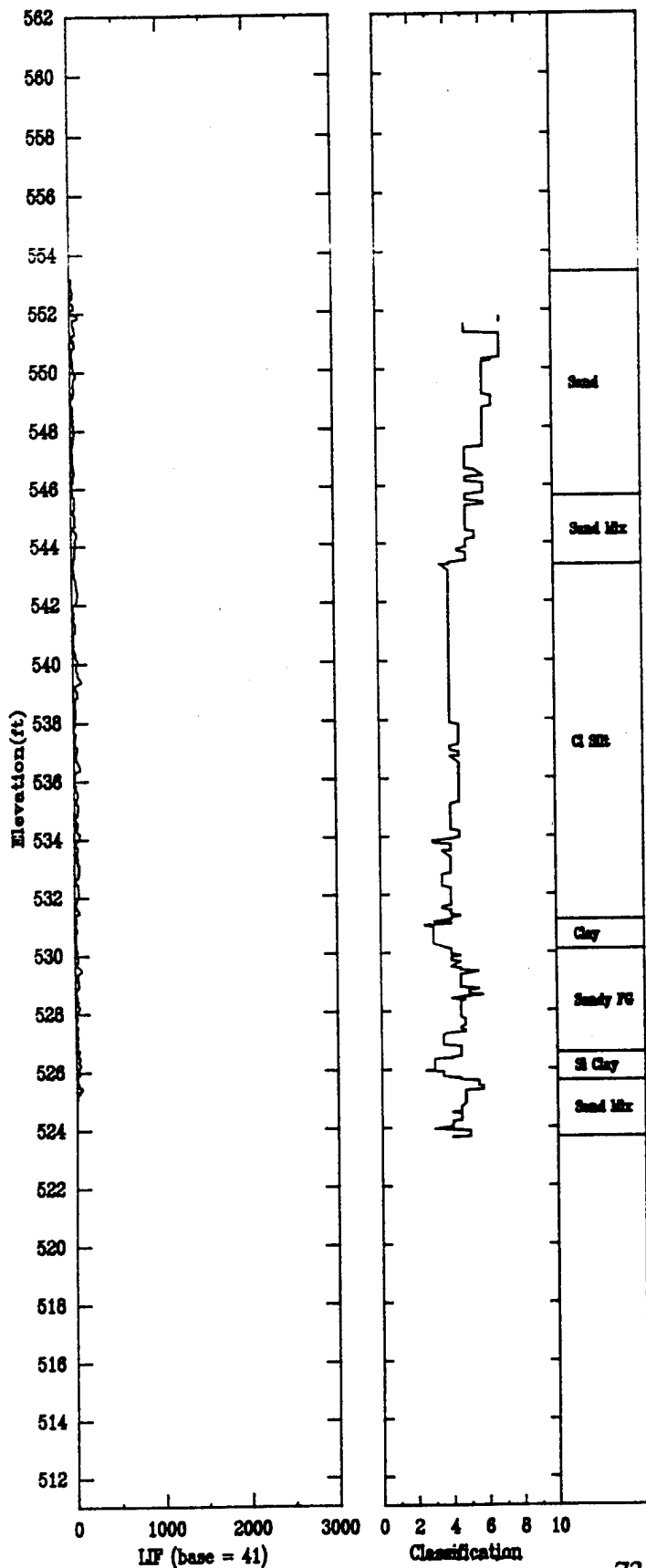












**APPENDIX B**  
**PORE PRESSURE DISSIPATION TESTS**

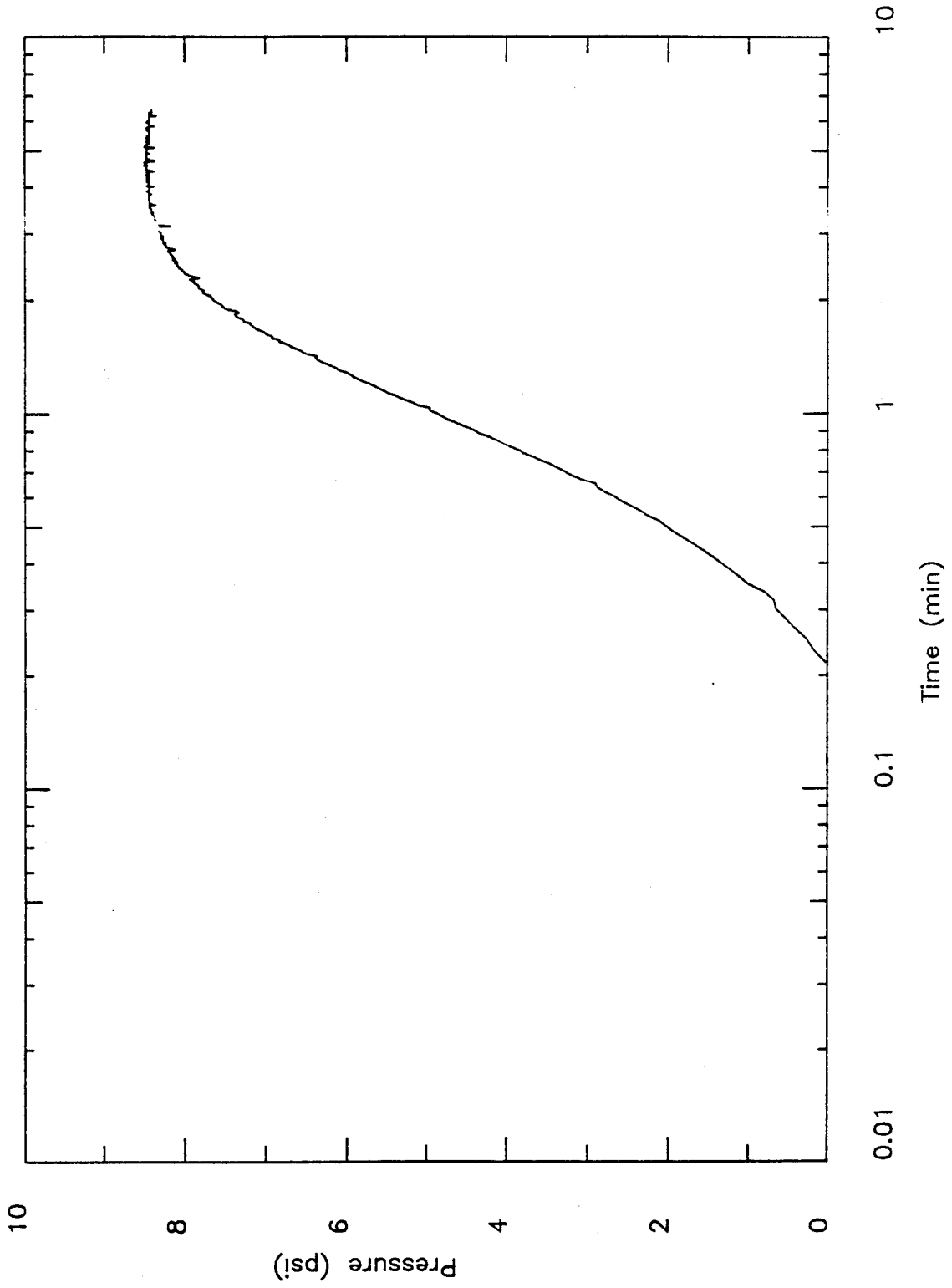
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Pn = 8.42 psi

Depth = 33.13 ft.

Carswell AFB

BSS-02



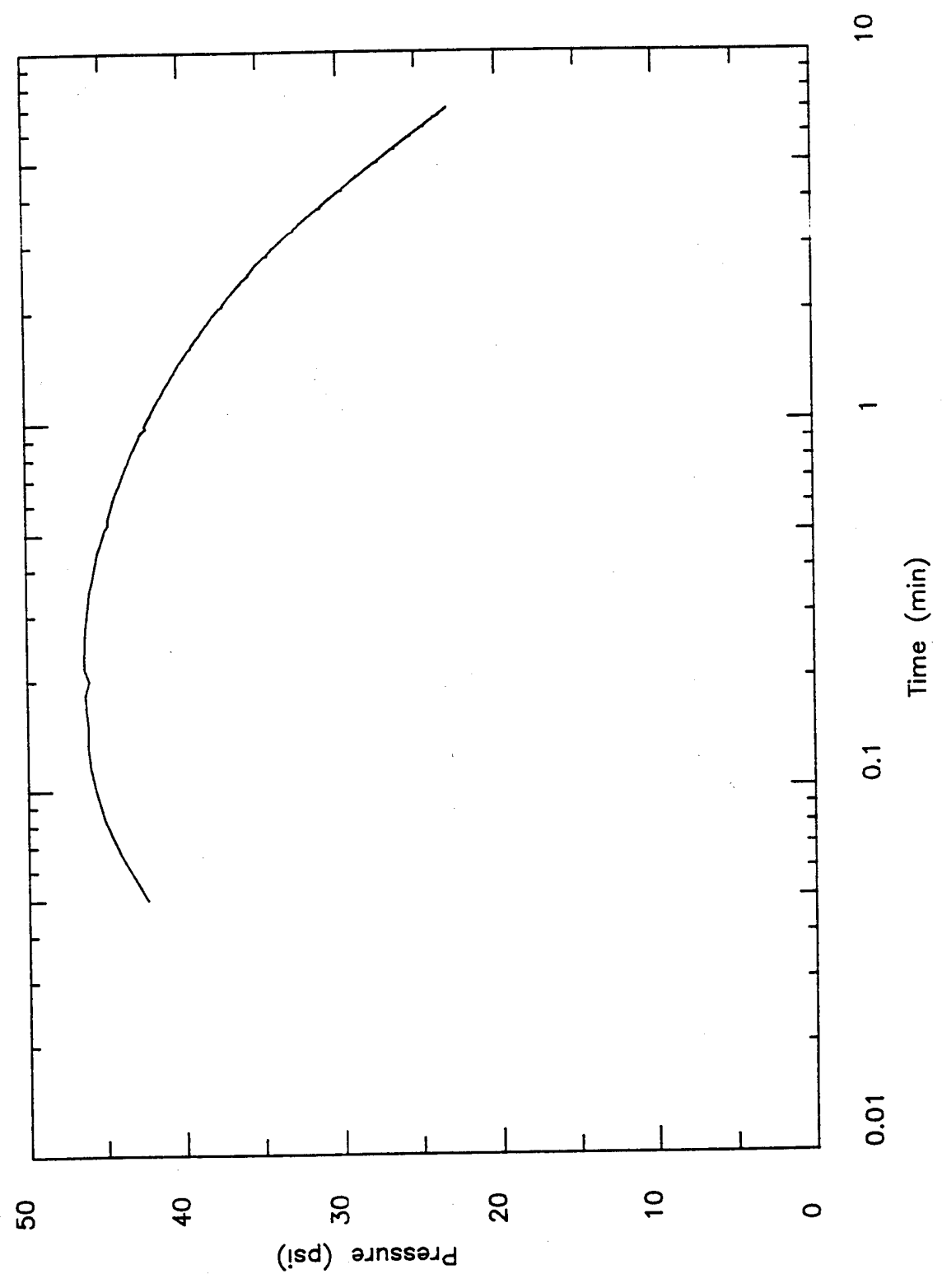
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Carswell AFB

Pn = 23.15 psi

Depth = 45.38 ft.

BSS-02



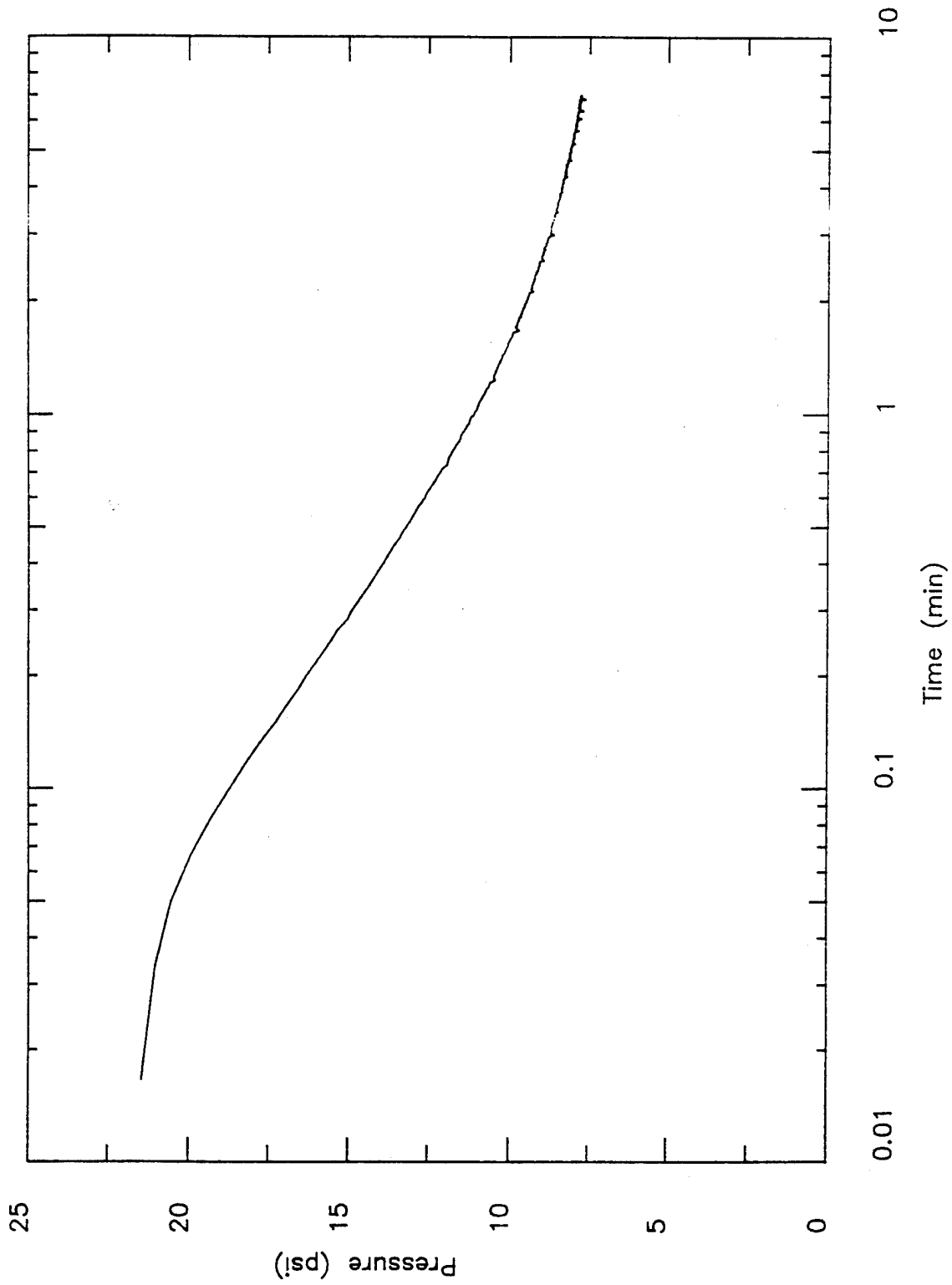
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Pn = 7.77 psi

Depth = 30.29 ft.

Carswell AFB

BSS-03



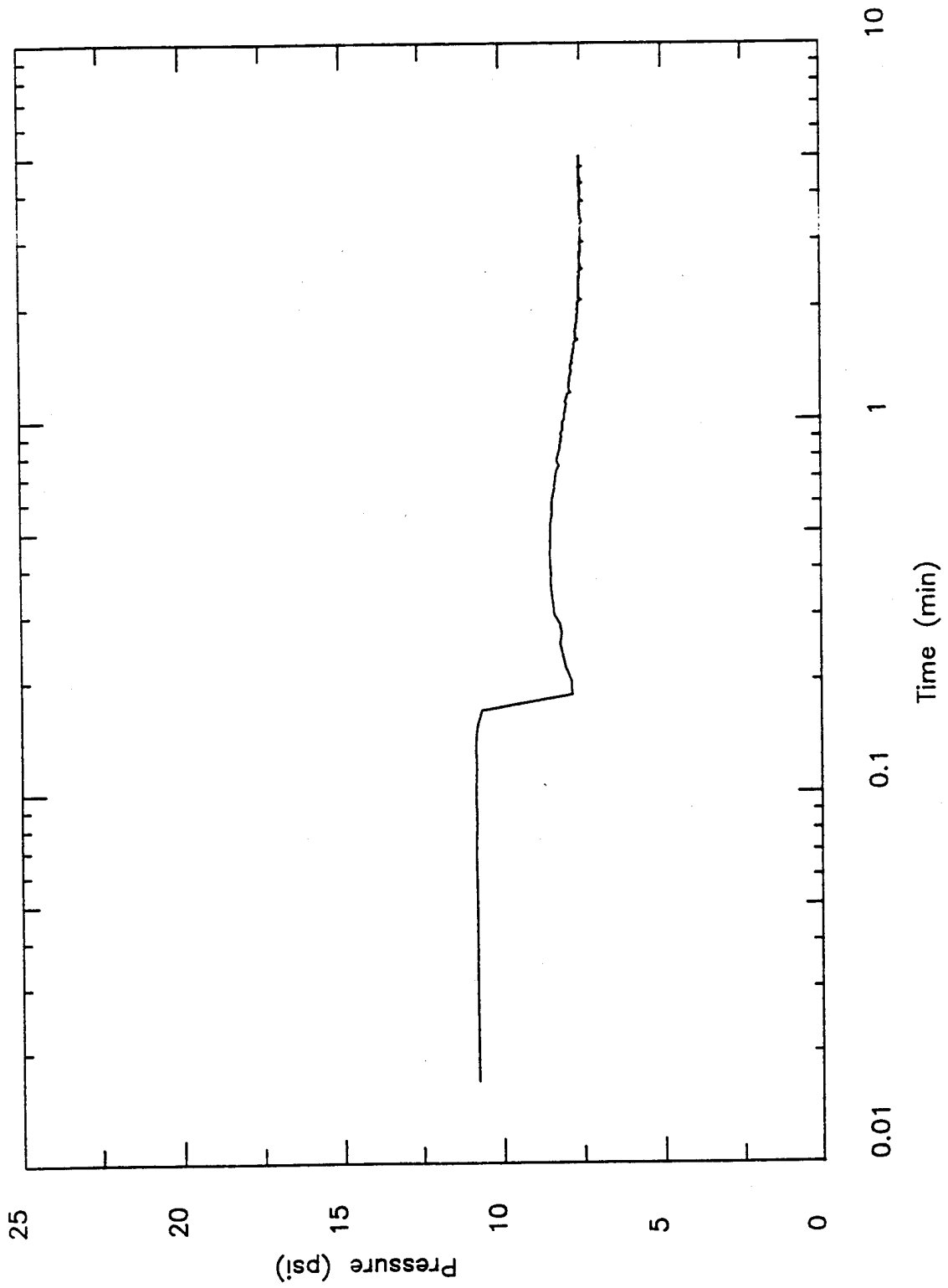
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Carswell AFB

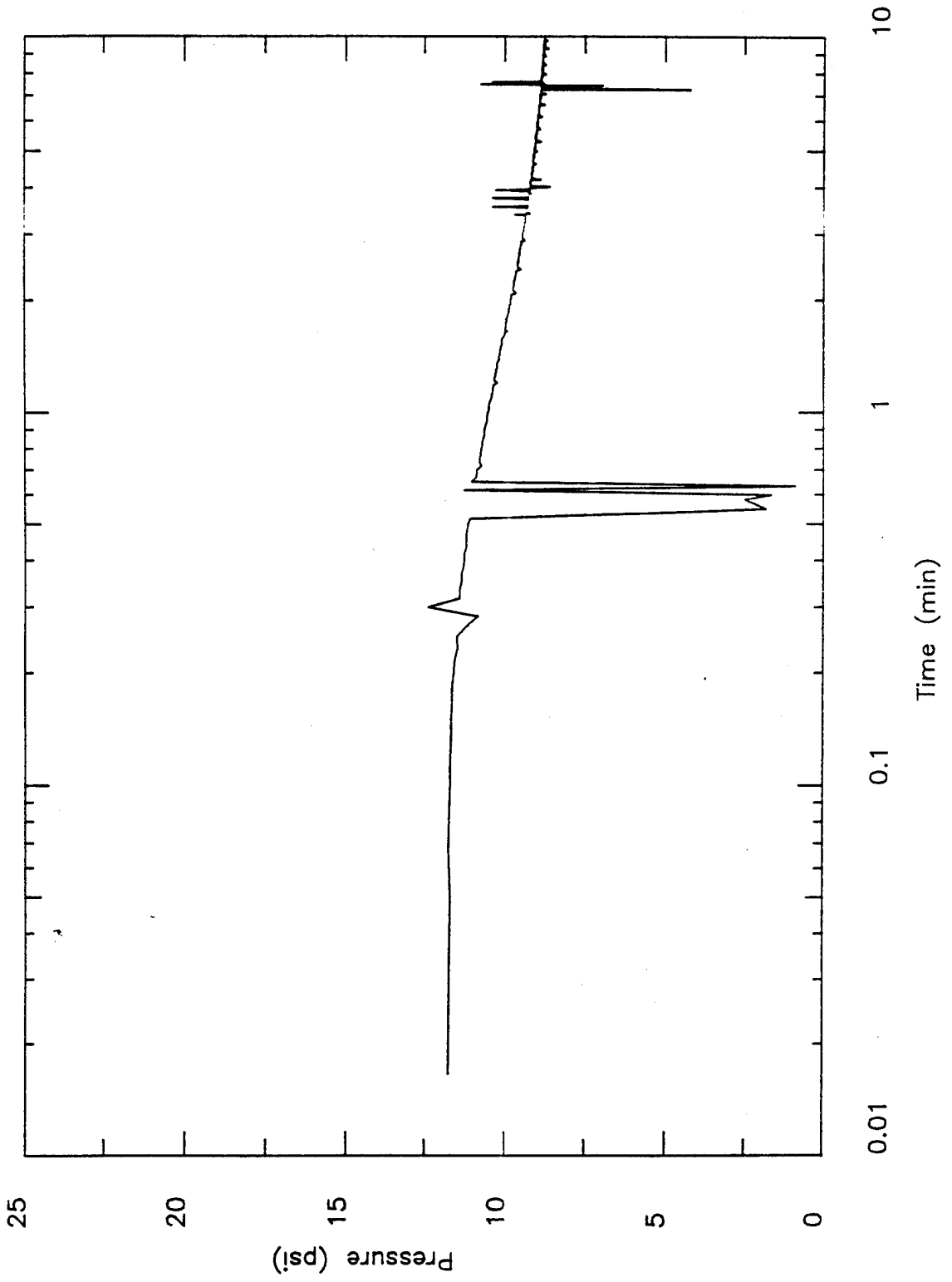
Pn = 7.53 psi

Depth = 45.99 ft.

BSS-03



Carswell AFB  
BSS-04  
Depth = 33.72 ft.  
Pn = 8.74 psi  
10/05/92



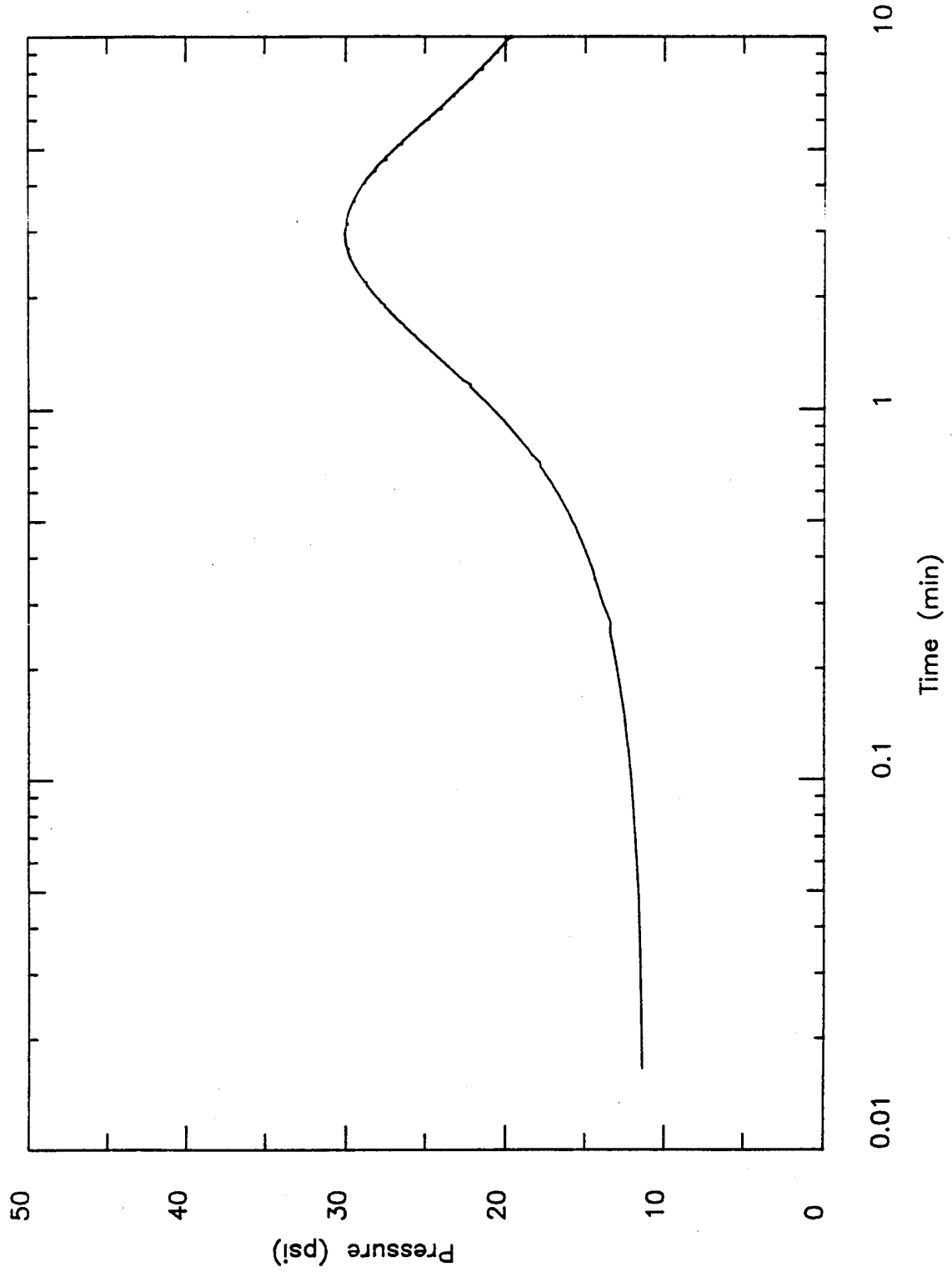
10/05/92

Pn = 19.73 psi

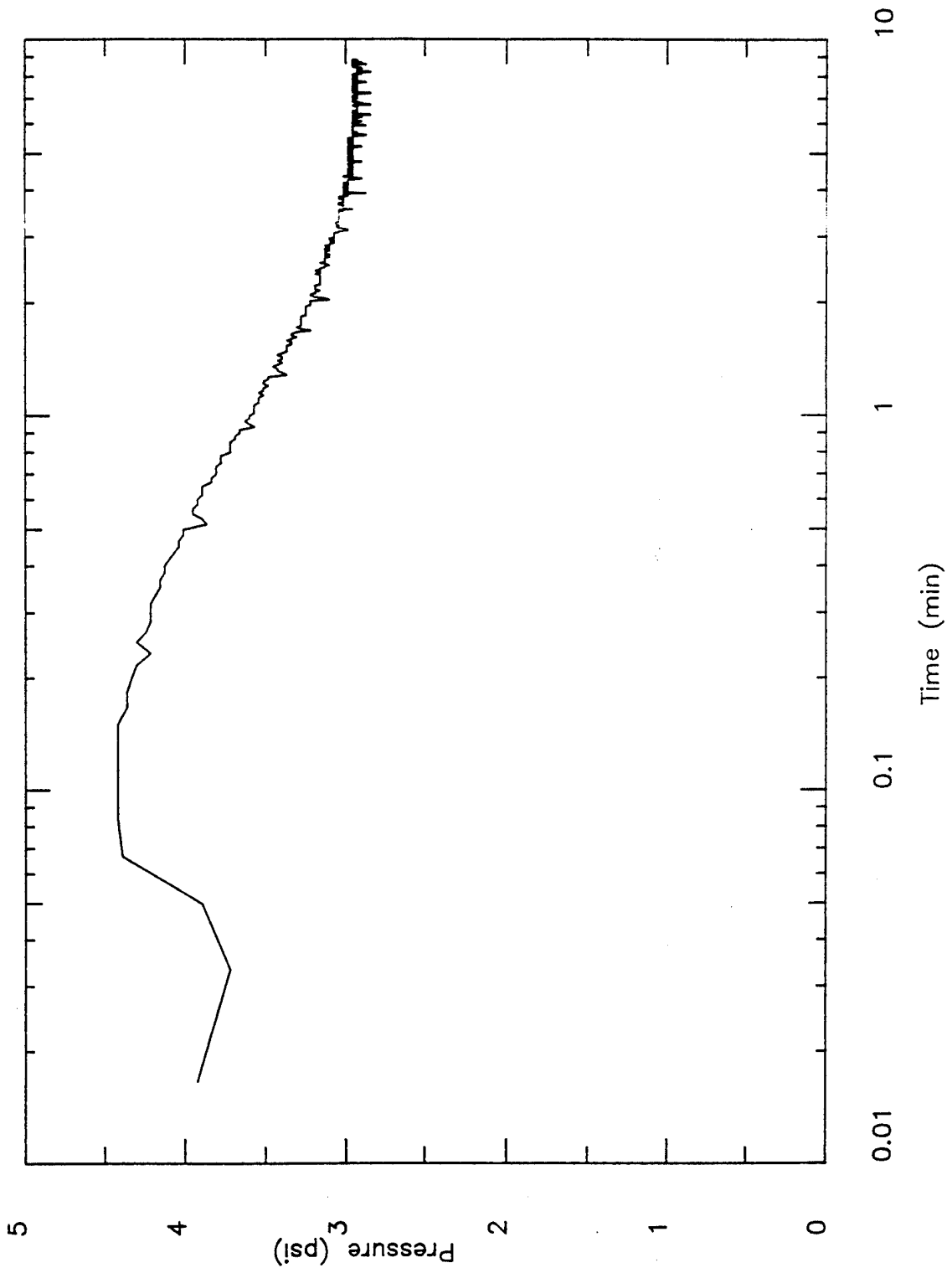
Depth = 46.84 ft.

Carswell AFB

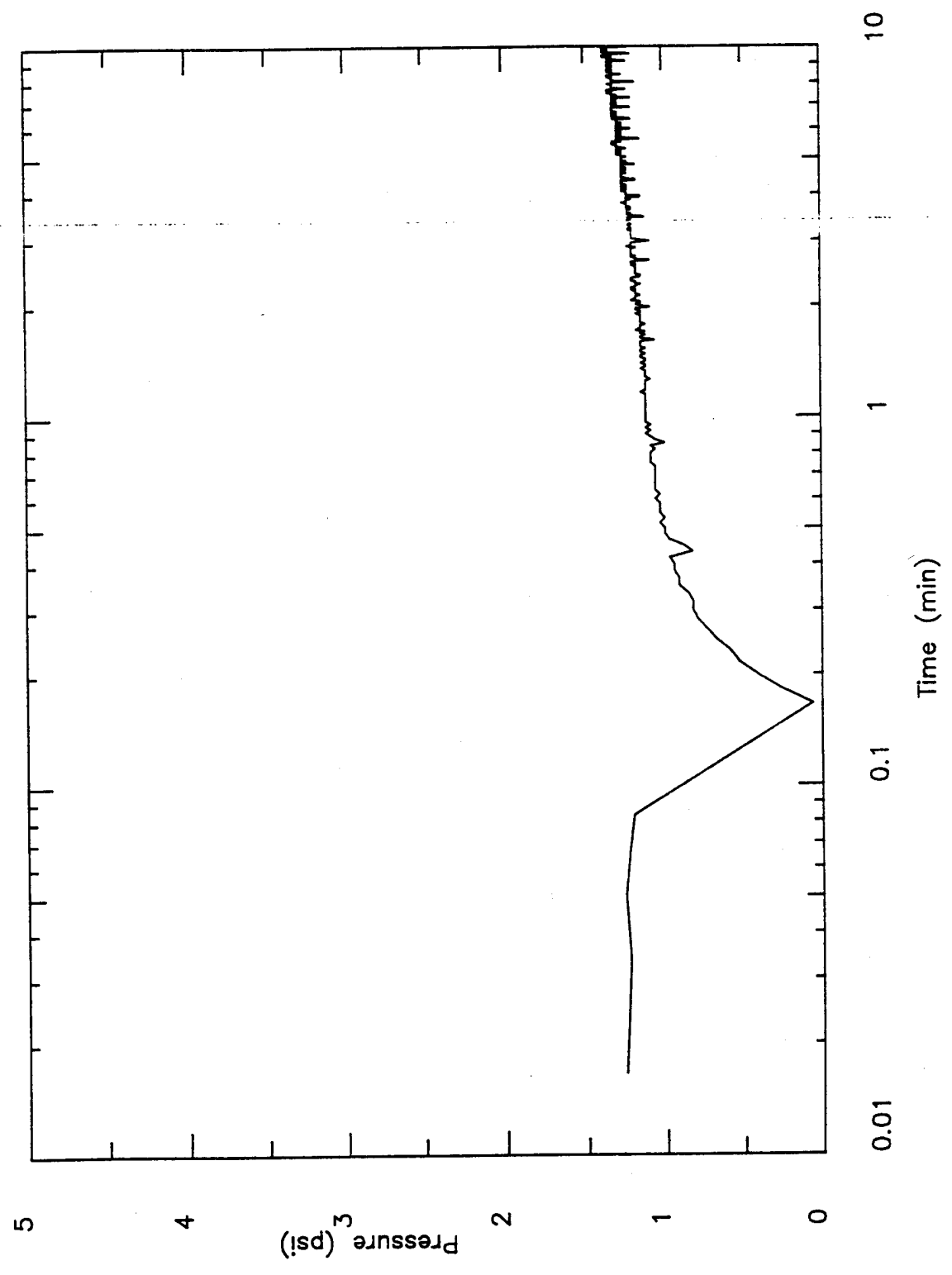
BSS-04



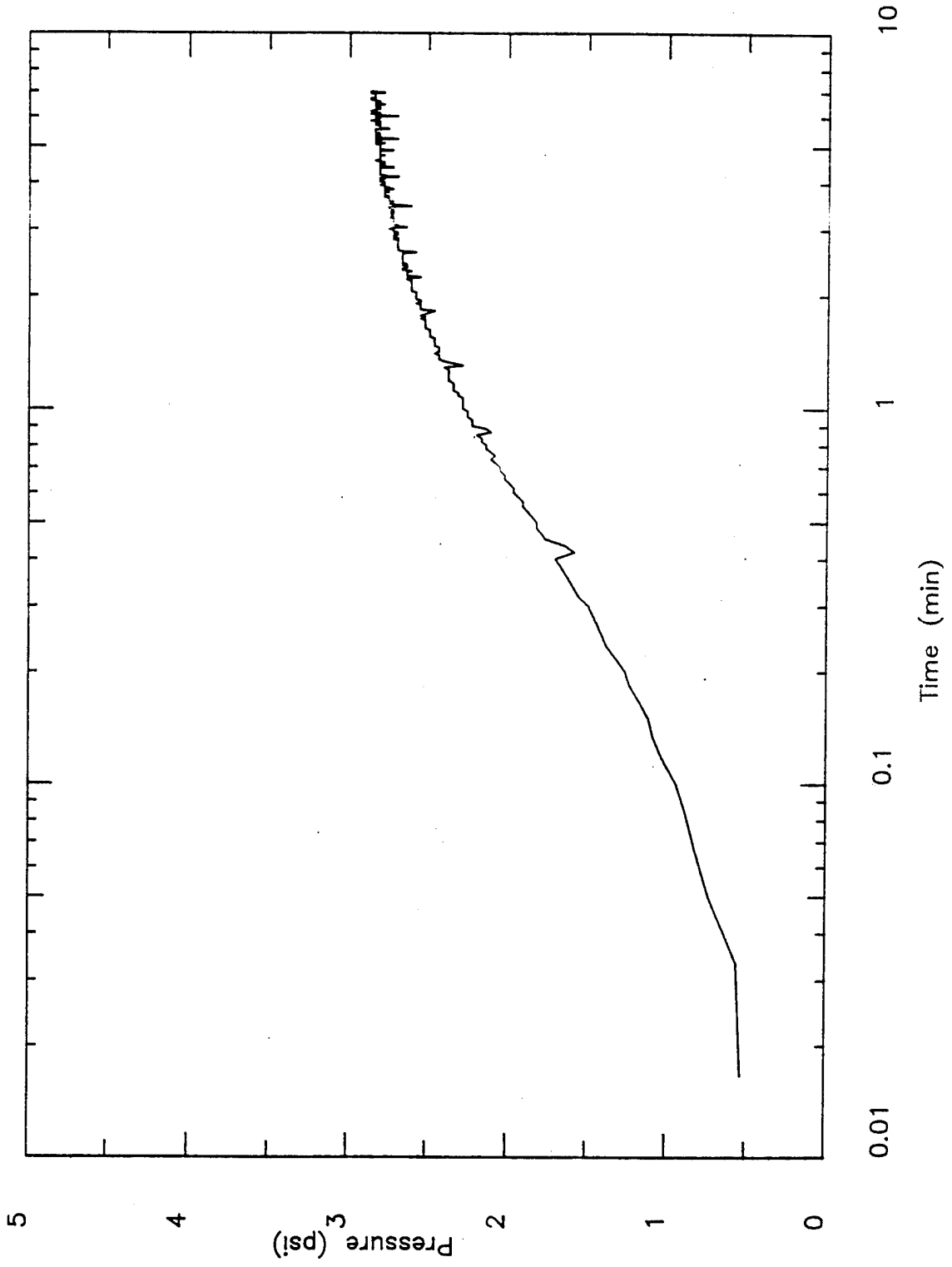
Carswell AFB  
BSS-07  
Depth = 8.21 ft. Pn = 2.94 psi  
10/06/92



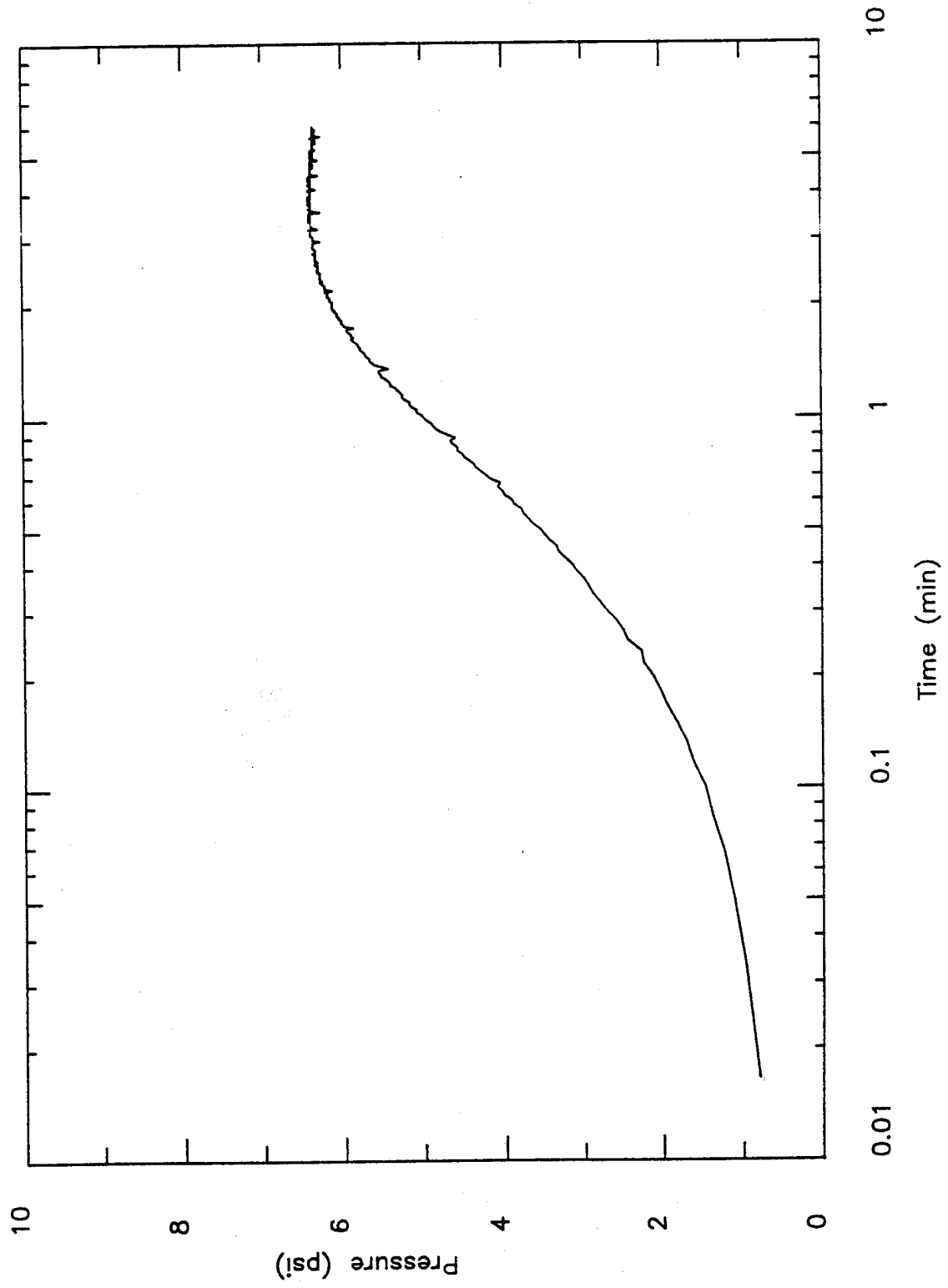
Carswell AFB  
BSS-11  
Depth = 4.68 ft.  
Pn = 1.33 psi  
10/06/92



Carswell AFB  
BSS-12  
Depth = 28.90 ft.  
Pn = 2.84 psi  
10/06/92



Carswell AFB  
BSS-13  
Depth = 35.11 ft.  
Pn = 6.35 psi  
10/06/92



**APPENDIX C**

**CARSWELL ANALYTIC LABORATORY TEST RESULTS**



2600 DUDLEY ROAD — KILGORE, TEXAS 75662 — 903/984-0551 — FAX 903/984-5914

Analytical Chemistry • Utility Operations

11/05/92

Applied Research Associates  
 RR #1, Box 120-A  
 Waterman Road  
 South Royalton, VT 05068-  
 Attention: Jack Jemsek

Sample Identification: SS1 Soil/Gas Mix  
 Collected By: WS  
 Date & Time Taken: 10/05/92 1558  
 Other Data: AFSCAPS Carswell AFB Job #5735  
 Bottle Data: 1 -- 40 ml Glass Vial (Zero Headspace) with a Teflon Lined Lid (04)  
 Lab Sample Number: 222898 Received: 10/09/92

Client: ARS1

PARAMETER	RESULTS	UNITS	ANALYZED	EQL	METHOD	BY
Hydrocarbon Sonication Extract.	Completed		1700 10/12/92		EPA Method 3550 *MOO	TEO
Acrolein	ND	ug/kg	0048 11/05/92	100000	EPA Method 8240	PM
Acrylonitrile	ND	ug/kg	0048 11/05/92	100000	EPA Method 8240	PM
Benzene	220000	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Bromoform	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Bromomethane	ND	ug/kg	0048 11/05/92	10000	EPA Method 8240	PM
Carbon Tetrachloride	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Chlorobenzene	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Chloroethane	ND	ug/kg	0048 11/05/92	10000	EPA Method 8240	PM
2-Chloroethylvinyl ether	ND	ug/kg	0048 11/05/92	10000	EPA Method 8240	PM
Chloroform	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Chloromethane	ND	ug/kg	0048 11/05/92	10000	EPA Method 8240	PM
Dibromochloromethane	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Bromodichloromethane	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
1,1-Dichloroethane	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
1,2-Dichloroethane	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
1,1-Dichloroethene	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM

Continued



222898 Continued

Page 2

PARAMETER	RESULTS	UNITS	ANALYZED	EQL	METHOD	BY
trans-1,2-Dichloroethene	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Dichlorodiflouromethane	ND	ug/kg	0048 11/05/92	1000	EPA Method 8240	PM
1,2-Dichloropropane	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
cis-1,3-Dichloropropene	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Ethyl benzene	930000	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Methylene Chloride	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
1,1,2,2-Tetrachloroethane	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Tetrachloroethene	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Toluene	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
1,1,1-Trichloroethane	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
1,1,2-Trichloroethane	2000000	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Trichloroethene	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Trichlorofluoromethane	ND	ug/kg	0048 11/05/92	10000	EPA Method 8240	PM
Vinyl Chloride	ND	ug/kg	0048 11/05/92	10000	EPA Method 8240	PM
trans-1,3-Dichloropropene	ND	ug/kg	0048 11/05/92	5000	EPA Method 8240	PM
Xylenes	2900000	ug/kg	0048 11/05/92	10000	EPA Method 8240	PM
Total Petroleum Hydrocarbons	4300	mg/kg	1600 10/16/92	30	EPA Method 418.1	TEO

Quality Assurance for the SET with Sample 222898

Sample #	Description	Result	Units	Dup/Std Value	Spk Conc.	Percent	Time	Date	By
<b>Total Petroleum Hydrocarbons</b>									
	Blank	ND	MG/KG				1600	10/16/92	TEO
	Blank	ND	MG/L				1600	10/16/92	TEO
	Blank	ND	MG/KG				1600	10/16/92	TEO
	Standard	156	PPM	150		104	1600	10/16/92	TEO
223027	Duplicate	190	MG/KG	150		124	1600	10/16/92	TEO

I certify that the results were generated using the above specified methods.

*C. H. Whiteside*  
 C.H. Whiteside, Ph.D., President



2600 DUDLEY ROAD — KILGORE, TEXAS 75662 — 903/984-0551 — FAX 903/984-5914

Analytical Chemistry • Utility Operations

11/05/92

Applied Research Associates  
 RR #1, Box 120-A  
 Waterman Road  
 South Royalton, VT 05068-  
 Attention: Jack Jemsek

Sample Identification: BSS-05 7'-8'  
 Collected By: WS  
 Date & Time Taken: 10/06/92 1200  
 Other Data: AFSCAPS Carswell AFB Job #5735  
 Bottle Data: 1 -- Other (13)  
 Lab Sample Number: 222899

Received: 10/09/92

Client: ARS1

PARAMETER	RESULTS	UNITS	ANALYZED	EQL	METHOD	BY
Total Sonic Extr. W/Hex Exch.	30->3	g->ml	1410 10/23/92		EPA Method 3550	GE
Hydrocarbon Sonication Extract.	Completed		1700 10/12/92		EPA Method 3550 *MOD	TEO
Naphthalene	15	mg/kg	2000 10/29/92	1	EPA Method 610	KB
2-Methylnaphthalene	7	mg/kg	2000 10/29/92	1	EPA Method 610	KB
Acrolein	ND	ug/kg	0126 11/05/92	100000	EPA Method 8240	PM
Acrylonitrile	ND	ug/kg	0126 11/05/92	100000	EPA Method 8240	PM
Benzene	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Bromoform	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Bromomethane	ND	ug/kg	0126 11/05/92	10000	EPA Method 8240	PM
Carbon Tetrachloride	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Chlorobenzene	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Chloroethane	ND	ug/kg	0126 11/05/92	10000	EPA Method 8240	PM
2-Chloroethylvinyl ether	ND	ug/kg	0126 11/05/92	10000	EPA Method 8240	PM
Chloroform	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Chloromethane	ND	ug/kg	0126 11/05/92	10000	EPA Method 8240	PM
Dibromochloromethane	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Bromodichloromethane	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM

Continued



PARAMETER	RESULTS	UNITS	ANALYZED	EQL	METHOD	BY
1,1-Dichloroethane	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
1,2-Dichloroethane	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
1,1-Dichloroethene	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
trans-1,2-Dichloroethene	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Dichlorodifluoromethane	ND	ug/kg	0126 11/05/92	1000	EPA Method 8240	PM
1,2-Dichloropropane	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
cis-1,3-Dichloropropene	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Ethyl benzene	41000	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Methylene Chloride	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
1,1,1,2-Tetrachloroethane	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Tetrachloroethene	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Toluene	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
1,1,1-Trichloroethane	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
1,1,2-Trichloroethane	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Trichloroethene	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Trichlorofluoromethane	ND	ug/kg	0126 11/05/92	10000	EPA Method 8240	PM
Vinyl Chloride	ND	ug/kg	0126 11/05/92	10000	EPA Method 8240	PM
trans-1,3-Dichloropropene	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Xylenes	ND	ug/kg	0126 11/05/92	5000	EPA Method 8240	PM
Total Petroleum Hydrocarbons	110	mg/kg	0900 10/13/92	10	EPA Method 418.1	TEO

Quality Assurance for the SET with Sample 222899

Sample #	Description	Result	Units	Dup/Std Value	Spk Conc.	Percent	Time	Date	By	
	<b>Total Petroleum Hydrocarbons</b>									
	Blank	ND	MG/KG				0900	10/13/92	TEO	
	Standard	155	PPM	150		103	0900	10/13/92	TEO	
222878	Duplicate	120	MG/KG	140		115	0900	10/13/92	TEO	

Continued



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Analytical Chemistry • Utility Operations

11/05/92

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Sample #	Description	Result	Units	Dup/Std Value	Spk Conc.	Percent	Time	Date	By
222884	Duplicate	29	MG/KG	27		107	0900	10/13/92	TEO
222886	Duplicate	34	MG/KG	32		106	0900	10/13/92	TEO
222893	Duplicate	32	MG/KG	17		161	0900	10/13/92	TEO

I certify that the results were generated using the above specified methods.

  
C.H. Whiteside, Ph.D., President



2600 DUDLEY ROAD — KILGORE, TEXAS 75662 — 903/984-0551 — FAX 903/984-5914

Analytical Chemistry • Utility Operations

11/05/92

Applied Research Associates  
RR #1, Box 120-A  
Waterman Road  
South Royalton, VT 05068-  
Attention: Jack Jemsek

Sample Identification: River  
Collected By: WS  
Date & Time Taken: 10/05/92 0950  
Other Data: AFSCAPS Carswell AFB Job #5735  
Bottle Data: 1 -- 40 ml Glass Vial (Zero Headpace) with a Teflon Lined Lid (04)  
Lab Sample Number: 222900 Received: 10/09/92

Client: ARS1

PARAMETER	RESULTS	UNITS	ANALYZED	EQL	METHOD	BY
Acrolein	ND	ug/l	1116 10/29/92	100	EPA Method 8240	GO
Acrylonitrile	ND	ug/l	1116 10/29/92	100	EPA Method 8240	GO
Benzene	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Bromoform	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Bromomethane	ND	ug/l	1116 10/29/92	10	EPA Method 8240	GO
Carbon Tetrachloride	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Chlorobenzene	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Chloroethane	ND	ug/l	1116 10/29/92	10	EPA Method 8240	GO
2-Chloroethylvinyl ether	ND	ug/l	1116 10/29/92	10	EPA Method 8240	GO
Chloroform	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Chloromethane	ND	ug/l	1116 10/29/92	10	EPA Method 8240	GO
Dibromochloromethane	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Bromodichloromethane	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
1,1-Dichloroethane	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
1,2-Dichloroethane	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
1,1-Dichloroethene	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
trans-1,2-Dichloroethene	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO

Continued




11/05/92

222900 Continued

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PARAMETER	RESULTS	UNITS	ANALYZED	EQL	METHOD	BY
Dichlorodifluoromethane	ND	ug/l	1116 10/29/92	1.0	EPA Method 8240	GO
1,2-Dichloropropane	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
cis-1,3-Dichloropropene	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Ethyl benzene	50	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Methylene Chloride	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
1,1,2,2-Tetrachloroethane	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Tetrachloroethene	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Toluene	63	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
1,1,1-Trichloroethane	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
1,1,2-Trichloroethane	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Trichloroethene	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Trichlorofluoromethane	ND	ug/l	1116 10/29/92	10	EPA Method 8240	GO
Vinyl Chloride	ND	ug/l	1116 10/29/92	10	EPA Method 8240	GO
trans-1,3-Dichloropropene	ND	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO
Xylenes	200	ug/l	1116 10/29/92	5.0	EPA Method 8240	GO

I certify that the results were generated using the above specified methods.

  
C.H. Whiteside, Ph.D., President



2600 DUDLEY ROAD — KILGORE, TEXAS 75662 — 903/984-0551 — FAX 903/984-5914

Analytical Chemistry • Utility Operations

11/05/92

Applied Research Associates  
 RR #1, Box 120-A  
 Waterman Road  
 South Royalton, VT 05068-  
 Attention: Jack Jemsek

Sample Identification: MW-2  
 Collected By: WS  
 Date & Time Taken: 10/05/92  
 Other Data: AFSCAPS Carswell AFB Job #5735  
 Bottle Data: 1 -- 40 ml Glass Vial (Zero Headspace) with a Teflon Lined Lid (04)  
 Lab Sample Number: 222901 Received: 10/09/92

Client: ARS1

PARAMETER	RESULTS	UNITS	ANALYZED	EQL	METHOD	BY
Acrolein	ND	ug/l	1150 10/29/92	100	EPA Method 8240	GO
Acrylonitrile	ND	ug/l	1150 10/29/92	100	EPA Method 8240	GO
Benzene	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Bromoform	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Bromomethane	ND	ug/l	1150 10/29/92	10	EPA Method 8240	GO
Carbon Tetrachloride	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Chlorobenzene	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Chloroethane	ND	ug/l	1150 10/29/92	10	EPA Method 8240	GO
2-Chloroethylvinyl ether	ND	ug/l	1150 10/29/92	10	EPA Method 8240	GO
Chloroform	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Chloromethane	ND	ug/l	1150 10/29/92	10	EPA Method 8240	GO
Dibromochloromethane	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Bromodichloromethane	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
1,1-Dichloroethane	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
1,2-Dichloroethane	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
1,1-Dichloroethene	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
trans-1,2-Dichloroethene	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO

Continued



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Analytical Chemistry • Utility Operations

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PARAMETER	RESULTS	UNITS	ANALYZED	EQL	METHOD	BY
Dichlorodifluoromethane	ND	ug/l	1150 10/29/92	1.0	EPA Method 8240	GO
1,2-Dichloropropane	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
cis-1,3-Dichloropropene	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Ethyl benzene	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Methylene Chloride	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
1,1,2,2-Tetrachloroethane	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Tetrachloroethene	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Toluene	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
1,1,1-Trichloroethane	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
1,1,2-Trichloroethane	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Trichloroethene	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Trichlorofluoromethane	ND	ug/l	1150 10/29/92	10	EPA Method 8240	GO
Vinyl Chloride	ND	ug/l	1150 10/29/92	10	EPA Method 8240	GO
trans-1,3-Dichloropropene	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO
Xylenes	ND	ug/l	1150 10/29/92	5.0	EPA Method 8240	GO

I certify that the results were generated using the above specified methods.

C.H. Whiteside, Ph.D., President