CONE PENETROMETER TECHNOLOGIES FOR SUBSURFACE MGP SITE CHARACTERIZATION

Prepared for:

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Contract No. 99-010

October 25, 1999

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INTRODUCTION

There are over 3000 former Manufactured Gas Plant (MGP) sites in the U.S. Many of these sites are contaminated with the products of operations such as aliphatic, olefinic and aromatic hydrocarbons. Of particular concern is heavy oil, tar, and creosote present as Dense NonAqueous Phase Liquid (DNAPL) in the subsurface.

Characterization of MGP sites to date has generally followed conventional practices such as test pits, soil borings, monitoring wells, and laboratory sample analysis. This approach is invasive, slow and expensive, and new technologies that can speed up and reduce the cost of characterization are sought.

Our objective in this project was to demonstrate several new technologies being developed by Applied Research Associates (ARA) for geophysical and chemical characterization of the subsurface using cone penetrometer (CPT) delivery. Due to limitations in funding and duration of the demonstration, emphasis was placed on demonstrating our newest optical technologies for characterizing subsurface soils, detecting contamination and locating DNAPLs. The use of CPT to perform subsurface hydrogeologic surveys is already well established, and was therefore a lesser goal of the project.

SITE DESCRIPTION

The demonstration was conducted at New York State Electric and Gas Corporation's (NYSEG) former MGP site located on Court Street in Binghamton, NY. The site was fully dismantled and no permanent surface structures were present in the characterization area at the time of the demonstration. Most of the area, which was level, was covered with small crushed stone and cinders. This provided facile access for the CPT truck. A nearly square grid zone covering approximately 15% of the site was designated for the demonstration. The only immovable obstruction in the designated test zone was a large debris container approximately centered on the East boundary of the area. Participants in the demonstration were specifically requested to perform a series of characterizations along a transect running from the SW corner to the NE corner of the grid zone.

TECHNOLOGIES

ARA CPT technologies demonstrated at the MGP site included the piezocone, fuel fluorescence detector (FFD), and videocone. A new, digital CPT system was used with the combined piezocone/FFD probe. The digital CPT utilizes miniature PCB modules placed downhole in the probe. The electronic boards deliver conditioned power to the sensors, control data collection and storage, and provide bi-directional RS-232 serial communication between the sensors and the host computer in the CPT truck. A major advantage of the digital approach is that many more sensors can be deployed simultaneously without the need for running multiple cables through the rod string. A single, strong 10-conductor cable can deliver up to 8 single-ended sensor acquisition channels to the host computer.

Fuel Fluorescence Detector

The FFD is a versatile, low cost, real-time measurement sensor developed by ARA as an alternative to expensive Laser Induced Fluorescence (LIF) systems. Like LIF, the FFD detects aromatic hydrocarbons (BTEX, PAH, etc.) which are the primary fluorescent components of fuels and oils. Designed to be deployed in the CPT, the FFD uses a filtered, low pressure mercury arc lamp emitting at 254nm to excite fluorescence of aromatic contaminants in both saturated and unsaturated zone soils. In our first versions of the device, the fluorescence was collected with a fiber optic bundle and delivered to an up-hole, solid-state photomultiplier detector. An optical filter placed in front of the photomultiplier was used to discriminate against "background" interference while transmitting the desired fluorescence wavelengths for detection. All FFD work conducted to date by ARA and others using our equipment has employed a 150nm wide (full width at half maximum transmission) bandpass filter centered at 360nm in front of the detector. This filter works well for detecting light fuels such as gasoline and diesel because BTEX and low molecular weight PAH such as naphthalenes and 3-ring aromatics fluoresce in this spectral region. However, at MGP sites and other locations suspected to be contaminated with creosotes, tars, and other heavy materials, a longer detection wavelength would be more suitable because heavy materials fluoresce at longer wavelengths.

For the MGP demonstration, our latest version of the FFD was deployed. In this device, the long fragile fiber optic cable delivering fluorescence to an uphole detector was eliminated by configuring the photomultiplier downhole in the sensor module. This approach reduces the cost and complexity of the sensor while at the same time improving sensitivity by reducing light attenuation in the optical fibers. Prior to the demonstration, we performed FFD measurements on a dark, viscous liquid product supplied to us from the Binghamton Court Street site. The tests were conducted with the aforementioned "standard" short wavelength 360nm bandpass filter as well as a longer wavelength 475nm^{+} long pass filter.

As shown in Figure 1, response to the heavy creosote-tar product from the Court Street site was much stronger with the longer wavelength filter than the shorter wavelength filter. A lower detection limit of 7 ppm (signal-to-noise ratio = 3) was measured for the MGP product spiked into clean, dry sand using the long wavelength filter. With the low wavelength filter, the lower detection limit was 5-fold higher (35ppm). Therefore, the 475nm^{+} filter was configured in front of the downhole photomultiplier detector for the demonstration.

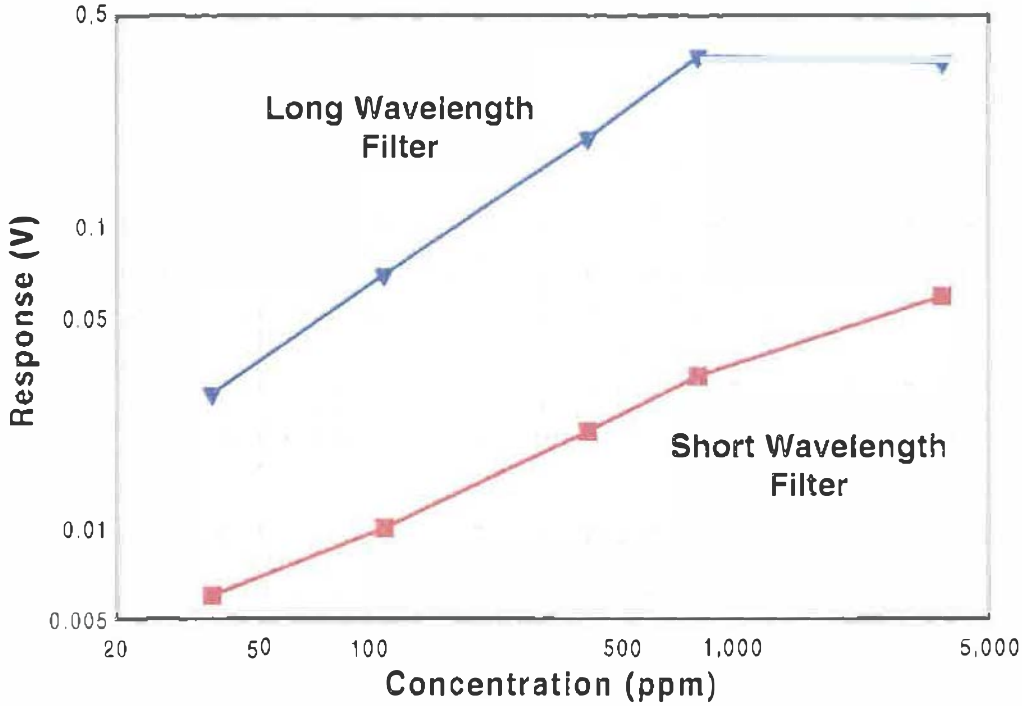


Figure 1. Response of the ARA Fuel Fluorescence Detector to product from the Court Street MGP site in clean sand using two different detection wavelength ranges.

Videocone

The videocone is ARA's latest CPT sensor and consists of a downhole color video camera and white light source. Control of the light intensity is provided to the operator through an uphole variable power supply. For the demonstration, the videocone was configured as a stand-alone sensor with a "dummy" tip (no piezocone). The camera optics are adjustable to provide magnifications suitable for particular applications of the probe. For example, for fine soil grain size analysis, high magnifications are required. Our primary objective for the videocone at the MGP demonstration was to confirm the presence of DNAPL at locations wherre the FFD has produced a strong response. Therefore, the magnification of the video system was set to provide a 7mm field-of-view. This ensured that even sub-millimeter size DNAPL "globules" could be easily viewed in real-time during deployment. Other goals for the videocone were to identify major geologic discontinuities and soil stratigraphy as well as detect water-saturated zones.

The video camera output was viewed in real-time on a TV monitor and recorded with a standard VHS format VCR. A text inserter was interfaced between the camera and TV-VCR. The text inserter overlaid the push location and depth on the TV screen and permanent video record. In order to easily follow the video in real-time, the videocone was deployed at about 1/4 the rate of the FFD-piezocone.

Demonstration Strategy and Difficulties Encountered

One of the advantages of CPT is the ability to conduct "dynamically directed" site characterization based on real-time feedback information. For example, preliminary characterization over a wide area of a site often indicates large regions where there is no contamination. Further efforts can then be directed to performing additional pushes in the regions of contamination in order to better characterize the plume. At MGP sites, the FFD-piezocone can be used to delineate creosote-tar plumes using this method. In areas where the FFD indicates the highest contamination, the videocone can then be deployed to determine if DNAPL is present. The dynamically-directed approach is far more efficient, cost-effective, and less intrusive than performing characterizations based on pre-defined penetration grids of increasing density. It also provides much more thorough and timely characterization than trenching and groundwater wells installed at arbitrarily selected locations.

As stated previously, our primary objective in this project was to demonstrate the applicability of FFD-piezocone and videocone CPT technologies to MGP site characterization and this goal was achieved. However, it was also our intention to demonstrate the dynamically directed approach to characterization at the Court Street site. A third goal of the demonstration was to achieve "production mode" operation where characterization was performed at maximum efficiency (speed).

The latter two goals were achieved in the course of the demonstration, although not to the extent we had originally anticipated. Several persistent electrical problems encountered with our new equipment led to considerable downtime during the first several days of the demonstration period. Overall, our manpower effort was over twice that budgeted for the project, which was due largely to the instrument repair efforts. Since the demonstration, we have identified the source of the electrical problems as improper grounding of the CPT truck power supply as well as the FFD power supply. Both problems have been corrected and the system has performed well in subsequent projects. However, during the demonstration, three computers and two FFD detectors were damaged as a result of the grounding problems. It is important to note that the considerable downtime we experienced at the NYSEG site was atypical and a result of deploying our latest, minimally tested technologies. *Since the MGP demonstration, the corrected equipment has been tested extensively at our VT office and deployed at two sites without any downtime.*

RESULTS AND DISCUSSION

A total of 19 FFD-piezocone and 4 videocone deployments were completed during the demonstration. The FFD-piezocone results are included as Appendix A to this report. The first 11 of these deployments were conducted with the fully functioning digital FFD-piezocone system, although the first push (AF-1) was repeated at an adjacent location (AF-2) due to a data recording error. For the final 8 pushes of the demonstration, the digital system (including the piezocone) was disabled and only analog FFD data was collected. This was due to repeated computer damage experienced when the digital system was connected to the computer's serial port. As noted previously, this problem has been rectified.

The videocone results are included in the VHS format VCR tape accompanying this report. Maximum depth of penetration for all videocone and FFD-piezocone deployments was limited to 18 ft due to concerns about penetrating DNAPL confining layers. A damaged computer serial port prevented depth encoding on the first two videocone recordings. However, depth was encoded on the final two videocone deployments which were most important because they were conducted proximate to locations which produced high FFD readings. An error in the digital FFD-piezocone computer program resulted in an incorrect depth display on the screen during deployment. Therefore, the actual maximum depth of deployment for the digital system deployments was 12.5 ft.

FFD Results

Table 1 summarizes the depth of penetration and FFD results for each CPT deployment. At over half the push locations, refusal was met at 8.5 ft or less due to the presence of concrete pads, building foundations, and other impenetrable structures. The two major regions where refusal was not encountered were the NW corner and along the South edge of the demonstration area. The FFD window was 2.5 ft behind the piezocone tip; therefore, FFD data could not be collected for pushes meeting refusal at depths of 3 ft or less. However, at two shallow push locations, AF-11 and AF-19 which were near one another, creosote-tar product was observed on the piezocone tip after retraction, indicating that free product was trapped on top of the impermeable structure. For those deployments where refusal was met at 8.5 ft, FFD data was collected to 6.0 ft.

Figure 2 is a map of the CPT push locations indicating the contamination level at each location as measured by the FFD. The level rankings (High, Medium, Low, and None in Table 1) were determined from the peak FFD response over baseline. "High" responses were a strong indicator of possible DNAPL to be further probed with the videocone. Overall, the FFD results indicate contamination across the entire demonstration area, including the full distance of the transect test line. The only region of *relatively* low contamination was in the region bounded AF-3, AF-7, AF-13, AF-6, and AF-15. In nearly every push location a zone of contamination was detected between 4 ft and 8 ft below ground. A thin, 1 ft to 2 ft zone of significant contamination was generally observed in softer materials (sands and silts) above a confining layer (clay) in push locations such as AF-2, AF-4, AF-8, and AF-9. As the soil stratigraphy plots for deployments AF-2 to AF-10 show, the presence of clay throughout the demonstration area was variable and much less prevalent than thicker, interspersed layers of sand and silt found in each push location. Locations without a confining layer generally showed a thicker zone (up to 4 ft or more) of lower level contamination (e.g., AF-5 and AF-6).

Along the North central edge of the demonstration area, a second zone of contamination was detected at about 10 ft to 12 ft in both AF-17 and AF-18 which were able to reach 18 ft (15.5 ft for the FFD window) without refusal. This deeper zone of contamination was not detected in the other 18 ft deployments on the South boundary of the demonstration area (AF-12 and AF-13), which also showed comparatively less upper level contamination.

Table 1. FFD-Piezocone Deployment Summary

Push ID	*Max. Depth (ft)*	*Contaminant Zones (ft)*	*Contaminant Level*
AF-1	---	---	---
AF-2	8.5 (refusal)	4.8 - 6	Medium
AF-3	8.5 (refusal)	None	None
AF-4	11.25	4.8 - 7	High
AF-5	12	2.5 - 4, 5 - 7, 9 - 9.5	Medium
AF-6	8.5 (refusal)	1 - 6	Low
AF-7	8.5 (refusal)	2 - 3, 4 - 6	Low
AF-8	8.5 (refusal)	3.5 - 4.5	High
AF-9	11.75	6 - 7	Medium
AF-10	12.5	5 - 7	Low
AF-11	3 (refusal)	---	---
AF-12	18	5.5 - 8	Low
AF-13	18	2.5 - 3.5, 5.5 - 8	Low
AF-14	8 (refusal)	4 - 5	Medium
AF-15	8.5 (refusal)	4 - 5.5	Low
AF-16	3 (refusal)	---	---
AF-17	18	6 - 12.5	High
AF-18	18	5.5 - 8.5, 10 - 12	High
AF-19	1 (refusal)	---	---

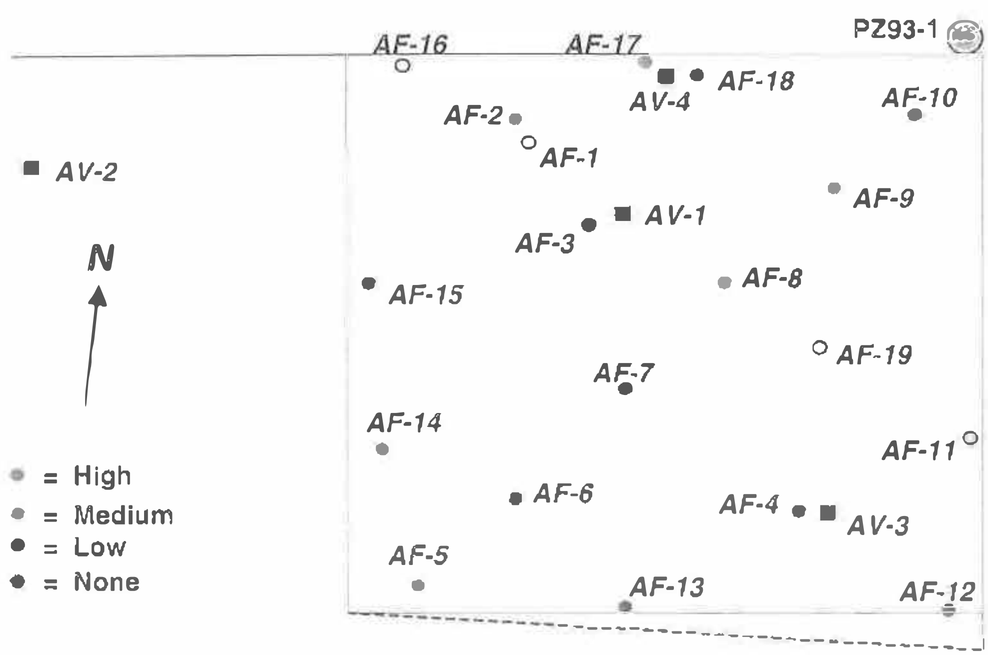


Figure 2. Map of CPT deployment locations in the demonstration zone and peak contamination levels measured with the FFD.

Videocone Results

The videocone was deployed adjacent to several locations where "High" FFD responses were obtained, indicating the possible presence of DNAPL. Depth-encoded video data were recorded adjacent to push AF-4 (video AV-3) and between AF-17 and AF-18 (video AV-4). The video recordings provided valuable information about creosote-tar contamination, as well as soil stratigraphy and water content.

Certainly most significant was the unequivocal observation of creosote-tar DNAPL "globules" in both AV-3 and AV-4 videocone deployment locations. Figure 3 is a still image captured during push AV-4 which clearly shows the presence of DNAPL at a depth of 8.02 ft. The largest "globules" observed at the site were about 20 mm diameter, with sizes ranging down to about 30 μm diameter (the resolution limit of the camera system as configured for the demonstration). Most of the DNAPL was observed to be in the 0.1 to 1 mm diameter range. Comparison of the AV-3 and AV-4 video records with the corresponding FFD traces for adjacent locations (AF-4 and AF-17/AF-18, respectively) showed excellent agreement between the two techniques. DNAPL was observed with the videocone at depths where the FFD produced the strongest responses. Conversely, DNAPL was not observed at depths where the FFD registered little or no response. Thus, it has been demonstrated that the FFD can be used to quickly delineate creosote/tar contamination plumes and identify *potential* DNAPL locations that can be probed in detail with the videocone. In addition to free phase product (i.e., the liquid DNAPL "globules"), the videocone also revealed the presence of creosote-tar covered (stained) soil particles in the subsurface. The stained soil also produced strong FFD responses. Therefore, the videocone was able to provide invaluable confirmation and differentiation of creosote-tar coated particles and free phase liquid that could not be achieved with the FFD (or LIF) alone.

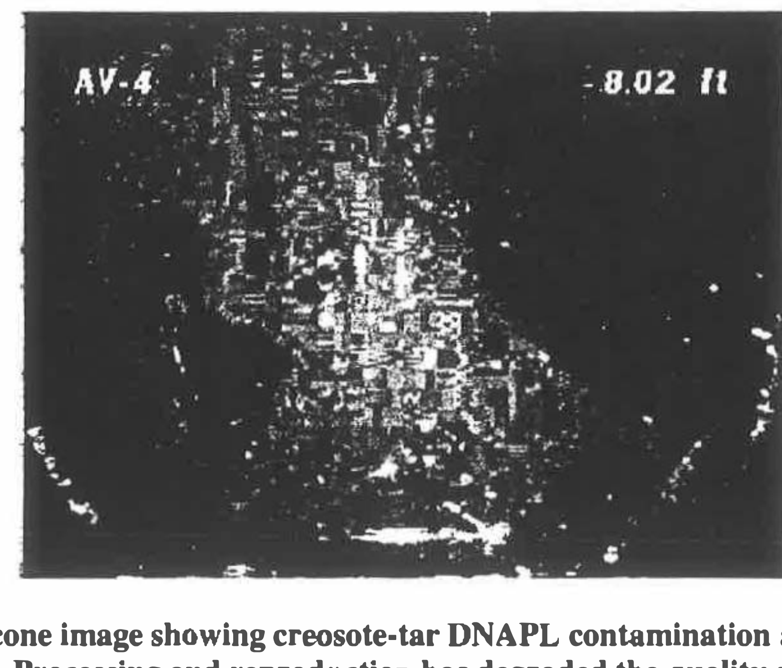


Figure 3. Videocone image showing creosote-tar DNAPL contamination at the Court Street MGP site. Processing and reproduction has degraded the quality of the image from the original tape.

The videocone also provided a detailed "look" at soil stratigraphy at the Court Street site, confirming and supplementing the stratigraphic information provided by the piezocone. To gain a full appreciation of the videocone's capabilities in this area it is recommended that the videotape accompanying this report be viewed. However, several key stratigraphic features observed with the videocone are worthy of mention here. First, the presence of fill material and debris in the first two to four feet below ground surface was observed. This stratum was generally classified by the piezocone as a stiff, consolidated layer (as a result of significant tip and sleeve stresses) which is typical of native surface soils. The videocone confirmed the general presence of fine grained consolidated material, but also revealed larger concrete chips, cinders and pieces of brick (e.g., at 3.40 ft in AV-3) indicating the presence of fill, rather than native soil. In each videocone push, the first native soil stratum (sand) was reached by 5 ft.

Deeper strata observed in the video record generally consisted of light-colored sands and silty sands, as well as layers of dark colored silty clays. Several highly mixed zones of dark silt and light colored sand particles were observed in both AV-3 and AV-4. Again, the video results were in excellent agreement with the piezocone classifications. Especially notable in AV-3 was a thin, dark clay layer observed at about 9 ft., below the DNAPL in a clayey-silt. This stratum was also detected by the piezocone.

Soil water content was also readily observed with the videocone, providing useful hydrologic information. In both AV-3 and AV-4, discrete zones of water saturation were visible. For example, in AV-4 several thin saturated zones were observed at depths of 1.3 to 5 ft. At 6.25 ft, the probe entered a saturated zone about 5 ft thick. Saturated zones of high hydraulic conductivity were also visible in AV-3 and AV-4. Information such as this provided by the videocone can supplement water table information (depth) gathered through dissipation tests performed with the piezocone.

Production Mode Operation Results and Costs

During two periods of the demonstration, the afternoons of May 13 and May 14, 1999, we conducted CPT operations at a typical production level. At those times, the FFD-piezocone was deployed at the maximum 20 mm/sec rate recommended by ASTM (Standard D5778-95) and no technical difficulties were encountered. In production mode, our two-person crew was able to conduct an average of two 18-ft. deployments per hour, including grouting the CPT holes after retraction of the rod string. This level of production is equivalent to a penetration rate of 300 ft per day. Daily CPT operation costs are about $3,000.00 per day or $10.00 per ft, which is consistent with the demonstrated production rate. The videocone is typically deployed at about 1/4 the rate of the FFD-piezocone so that subsurface features can be observed in real-time. Faster deployments are difficult to follow on the video monitor. Slower deployment also limits the footage production rate, increasing videocone deployment costs to about $13.00 per ft. However, the videocone is intended to be used only at select locations (i.e., in locations of high FFD response) and can often be deployed quickly through depths known to have few interesting features (e.g., a 30 ft clean sand stratum). Thus, the higher unit cost for videocone deployment will have little impact on the overall cost of characterizing MGP sites.

CONCLUSIONS

The major objectives of the NYSEG MGP site demonstration have been achieved. A FFD-piezocone was deployed with a CPT to provide real-time hydrogeologic and creosote-tar contamination characterization of the subsurface over a designated area of the site. The dynamically-directed method was used to characterize the demonstration zone, which turned out to be contaminated throughout its area. To more fully demonstrate the efficiency advantage of the dynamically-directed approach to CPT characterization, it would be desirable to expand characterization beyond the demonstration zone into uncontaminated areas of the site.

In a production mode of operation, the CPT system was demonstrated to be able to perform 16 penetrations per day to a depth of 18 ft at a cost of approximately $3,000.00 per day or $10.00 per ft ($13.00 per ft for the videocone). At this production level, a full one-day effort is sufficient to extensively characterize an area the size of the zone designated for the demonstration. The major challenge to delineating creosote-tar contamination at the Court Street site was the presence of numerous buried anthropomorphic structures which were impervious to CPT penetration.

ARA's videocone CPT probe was also demonstrated at the site and provided direct confirmation of free-phase DNAPL present as small "globules" in the subsurface. The videocone was further able to provide a view of soil stained with creosote or saturated with water, differentiate fill from native soils, as well as give a detailed "look" at stratigraphic features more generally identified and classified with the piezocone.

Overall, the ARA CPT system was demonstrated to be a rapid and cost-effective tool for providing extensive, minimally invasive characterization of MGP sites. When fully implemented, the dynamically-directed CPT method should prove to be better (i.e., producing more complete, higher quality data), faster, and less expensive than conventional methods for MGP site characterization.

APPENDIX A

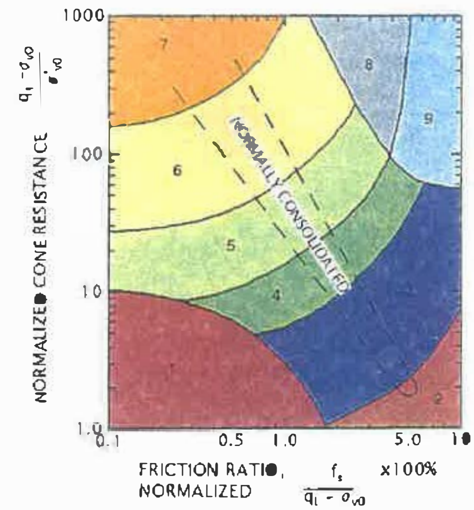
FFD-Piezocone Data

CPT Soil Classification Legend

Zone		Q_t/N	Description
1		2	Sensitive, Fine Grained
2		1	Organic Soils-Peats
3		1.5	Clays-Clay to Silty Clay
4		2	Silt Mixtures-Clayey Silt to Silty Clay
5		3	Sand Mixtures-Silty Sand to Sandy Silt
6		4.5	Sands-Clean Sand to Silty Sand
7		6	Gravelly Sand to Sand
8		1	Very Stiff Sand to Clayey Sand *
9		2	Very Stiff, Fine Grained *

(*) *Heavily Overconsolidated or Cemented*

Normalized Friction Ratio Classification Chart



(Ref. Robertson, 1990)

Coefficient of Permeability (cm/s)

Zone	Description	Permeability
1	Sensitive Fines	10^{-5}
2	Organic Soils-Peats	10^{-5}
3	Clays	10^{-7}
4	Silt Mixtures	10^{-6}
5	Sand Mixtures	10^{-4}
6	Sands	10^{-2}
7	Gravelly Sands	10^{-1}
8	Very Stiff Sands	10^{-5}
9	Very Stiff Fines	10^{-6}

Applied Research Associates South Royalton, VT 05068 802-763-8348 Email: cpt@ned.ara.com http://www.ara.com	Northing: Easting: Elevation:	Date: 13/May/1999 Test ID: AF-2 Project: NYSEG
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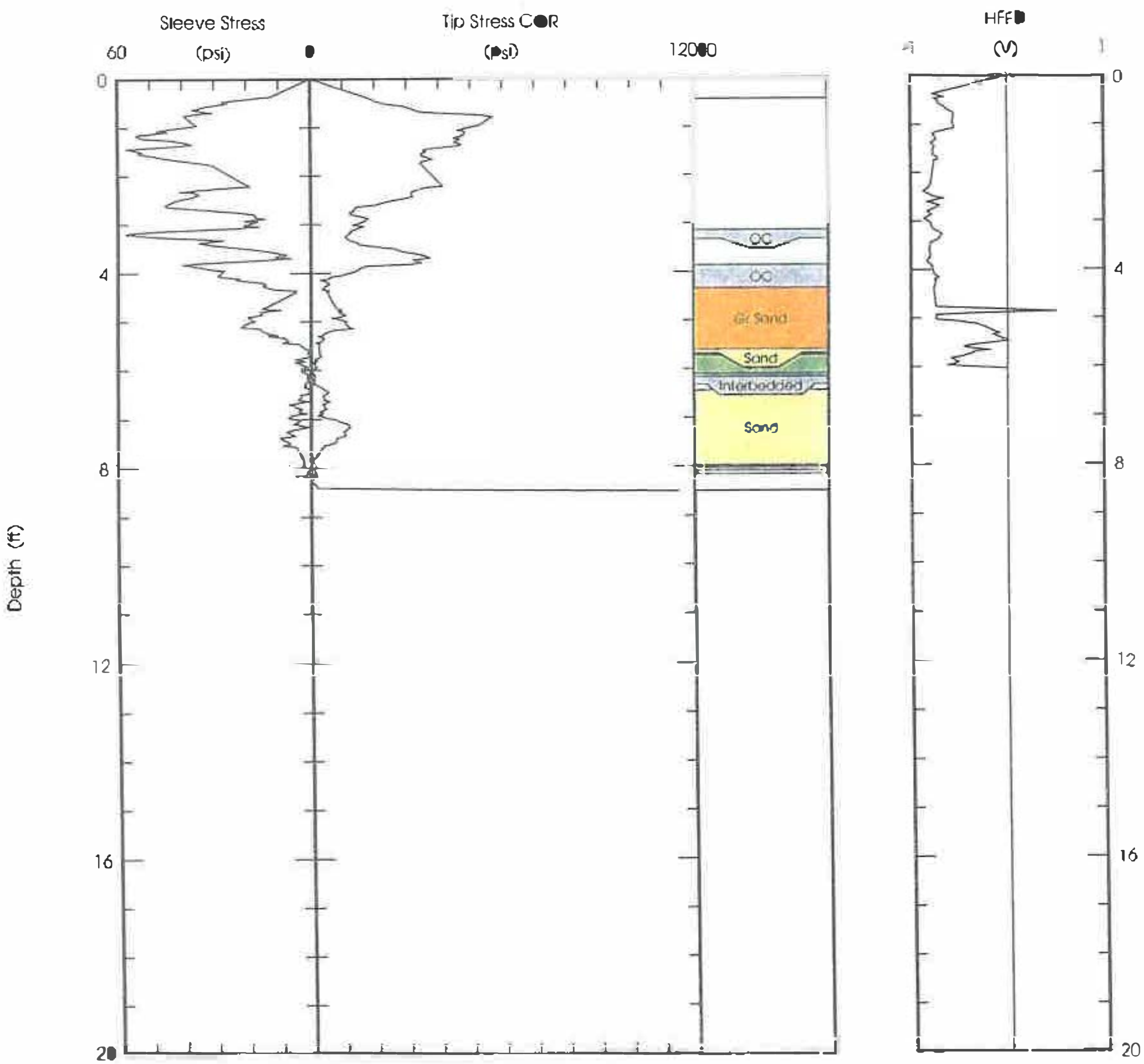

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Email: cpt@ned.ara.com
http://www.ara.com

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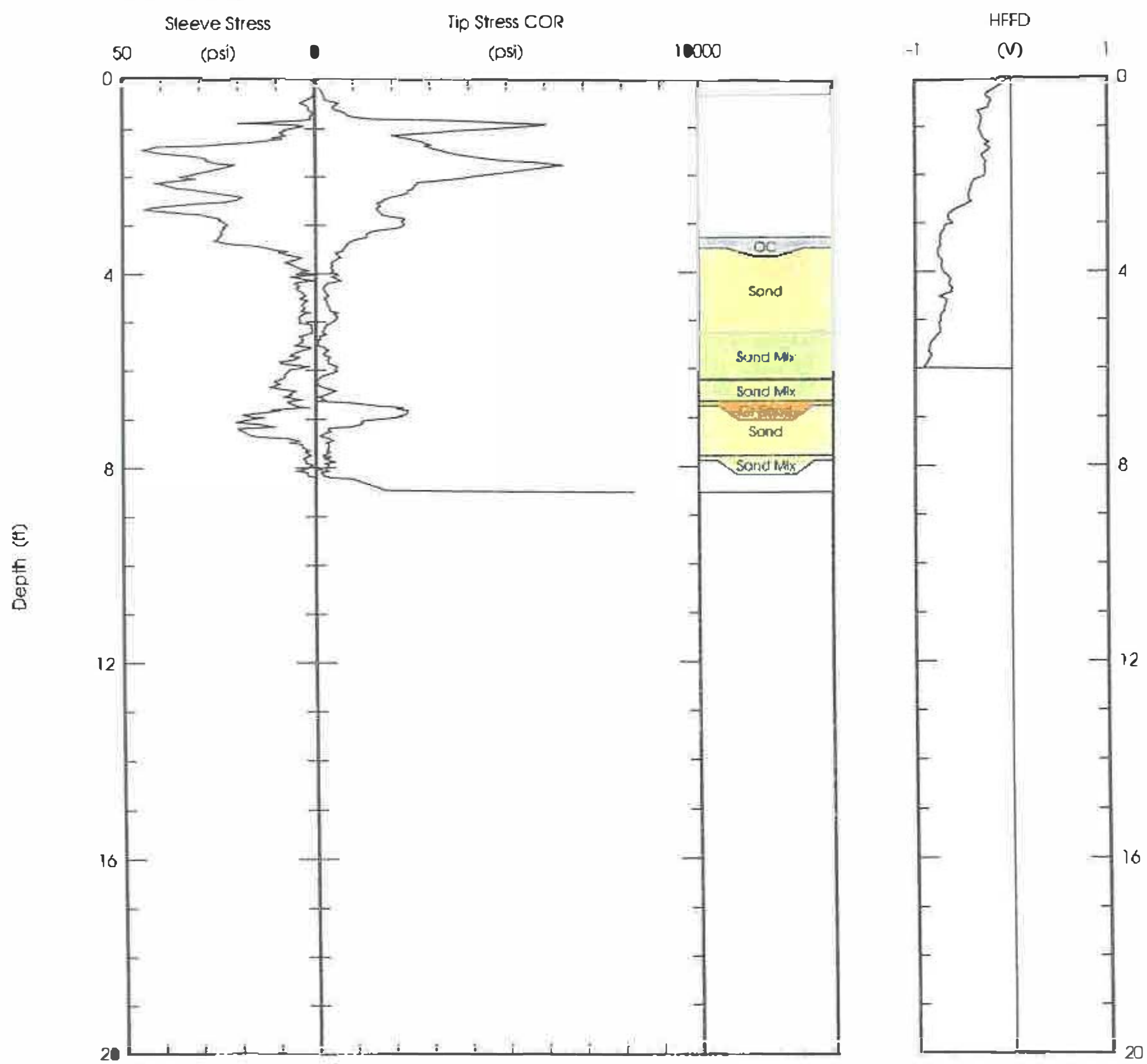
Site: Binghamton, NY	



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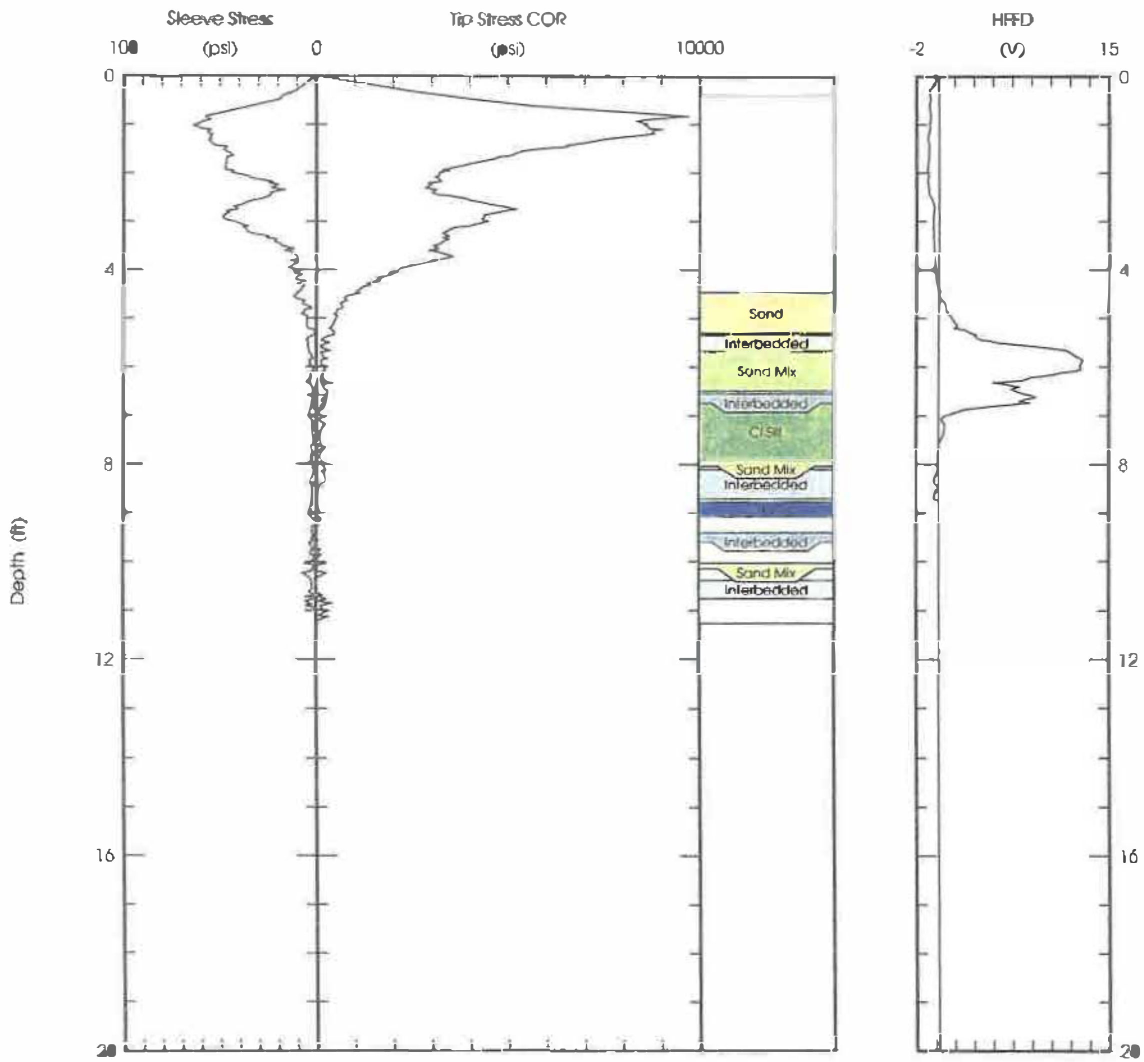

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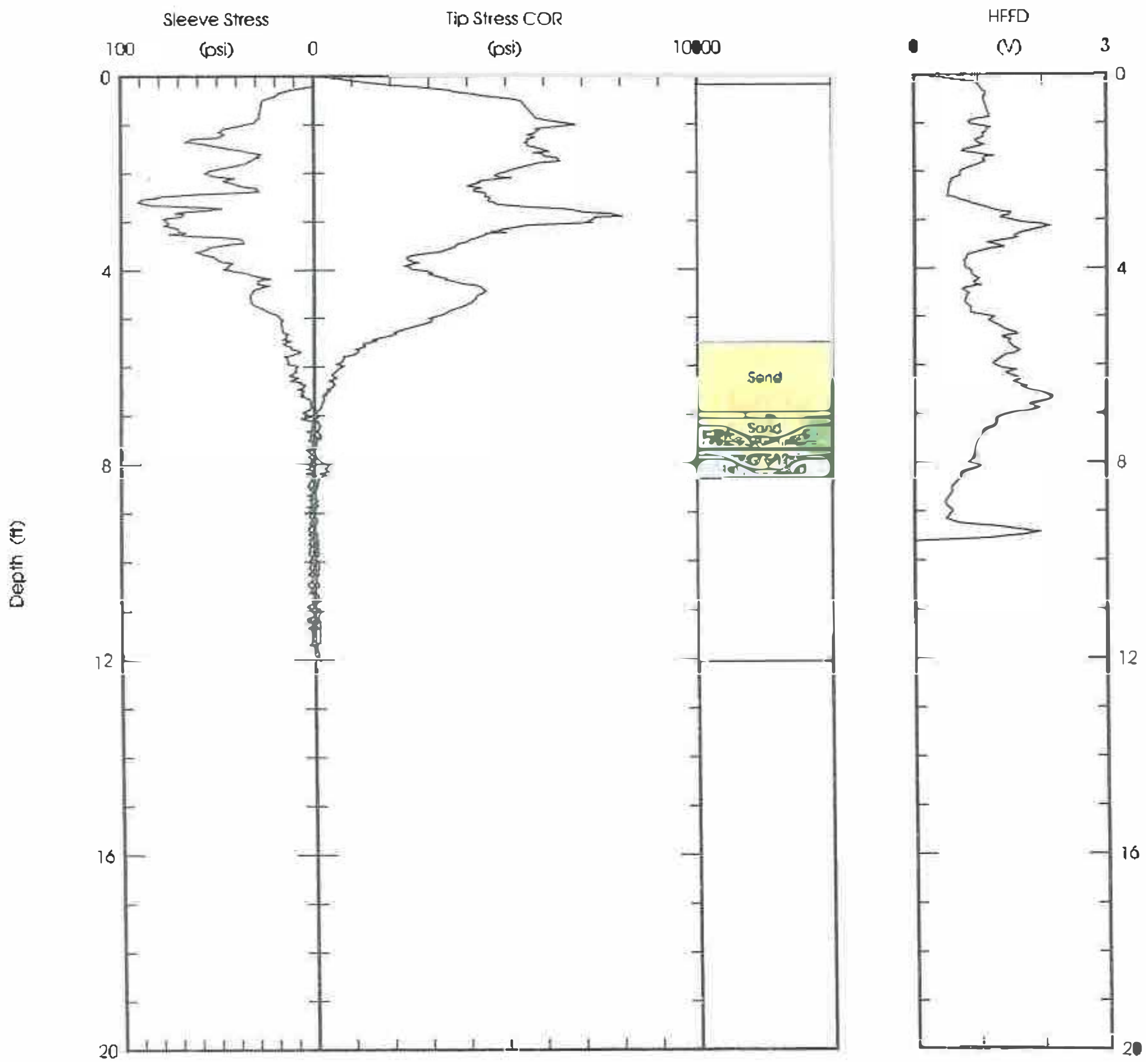

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Test ID: AF-5

Applied Research Associates South Royalton, VT 05068 802-763-8348 Email: cpt@ned.ara.com http://www.ara.com	Northing: Easting: Elevation:	Date: 13/May/1999 Test ID: AF-6 Project: NYSEG
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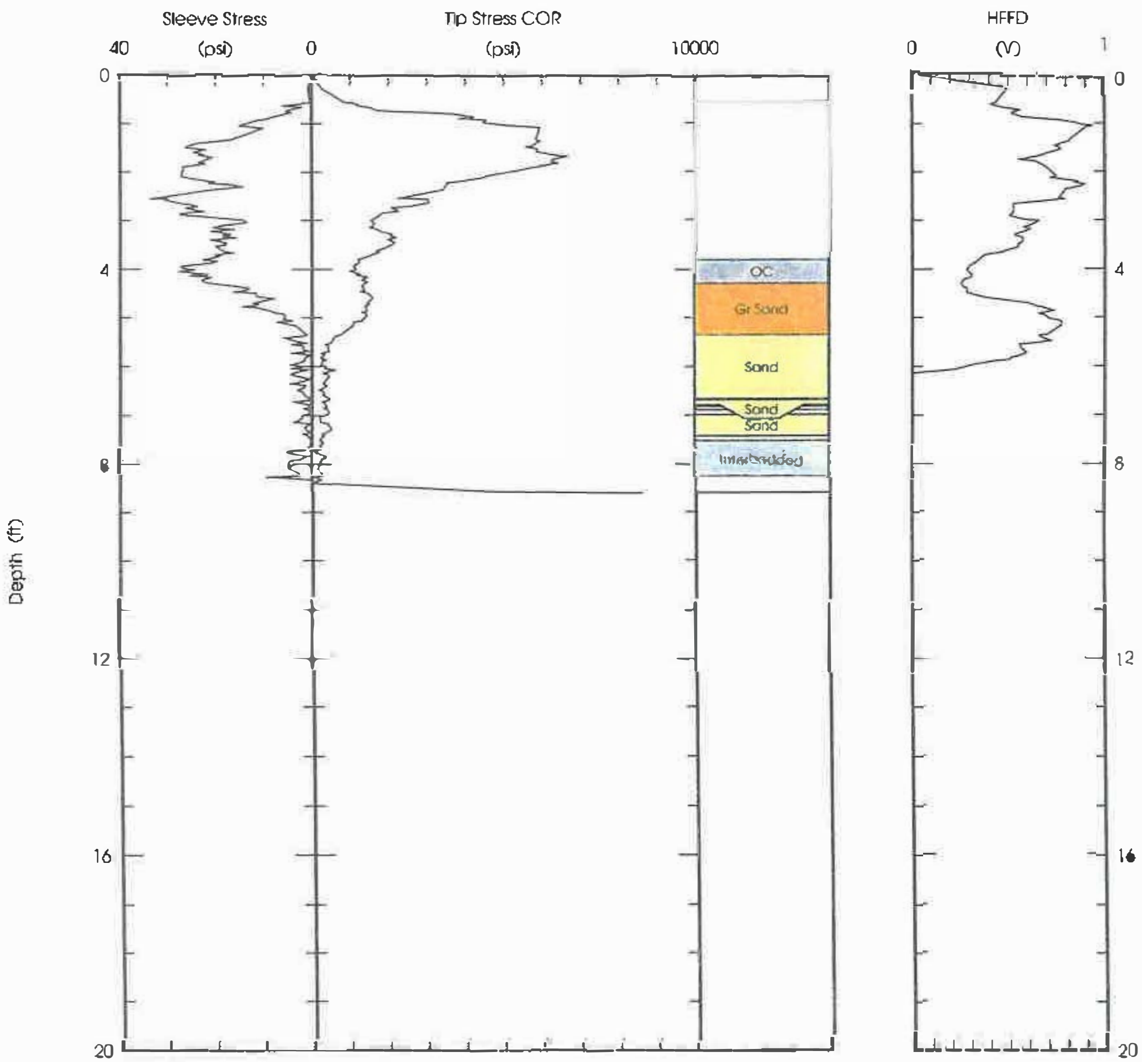

Maximum depth: 8.62 (ft)

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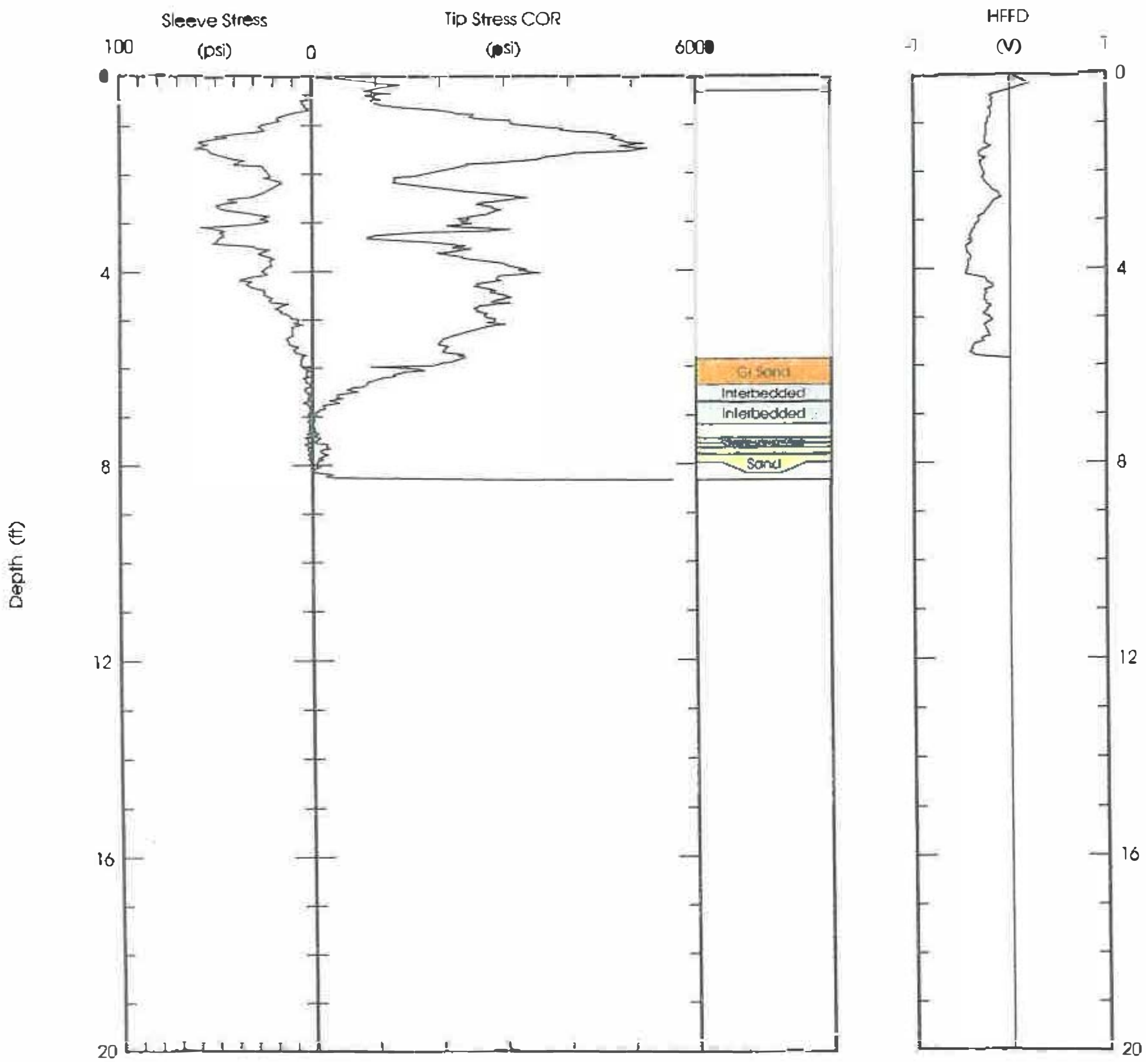
Northing:
Easting:
Elevation:

Client: NYSEG
Site: Binghamton, NY

Date: 13/May/1999
Test ID: AF-7
Project: NYSEG



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Test ID: AF-7
File: AF7a.eep

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Email: cpt@ned.ara.com
http://www.ara.com

Northing:
Easting:
Elevation:

Client: NYSEG
Site: Binghamton, NY

Date: 13/May/1999
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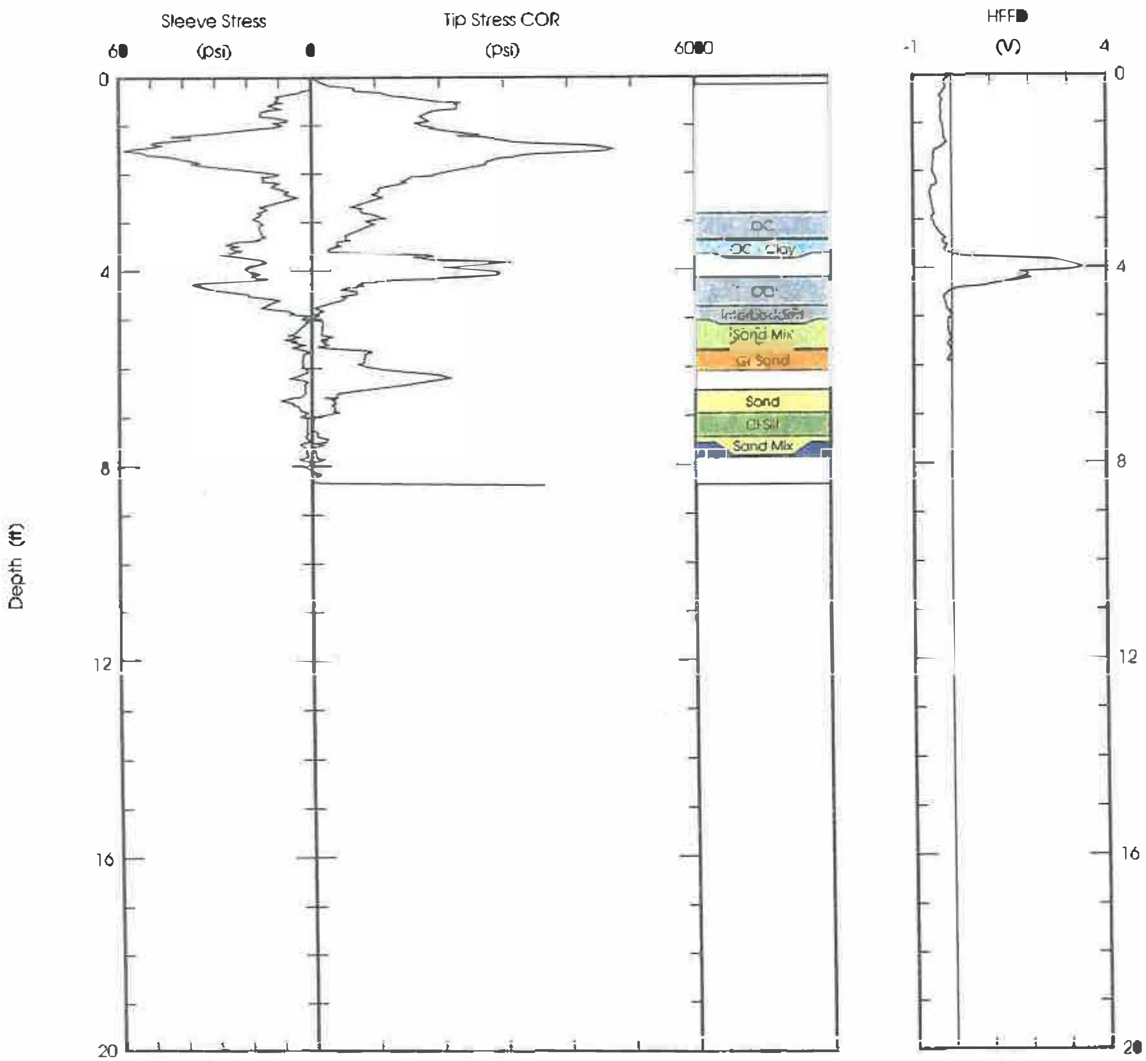
Project: NYSEG



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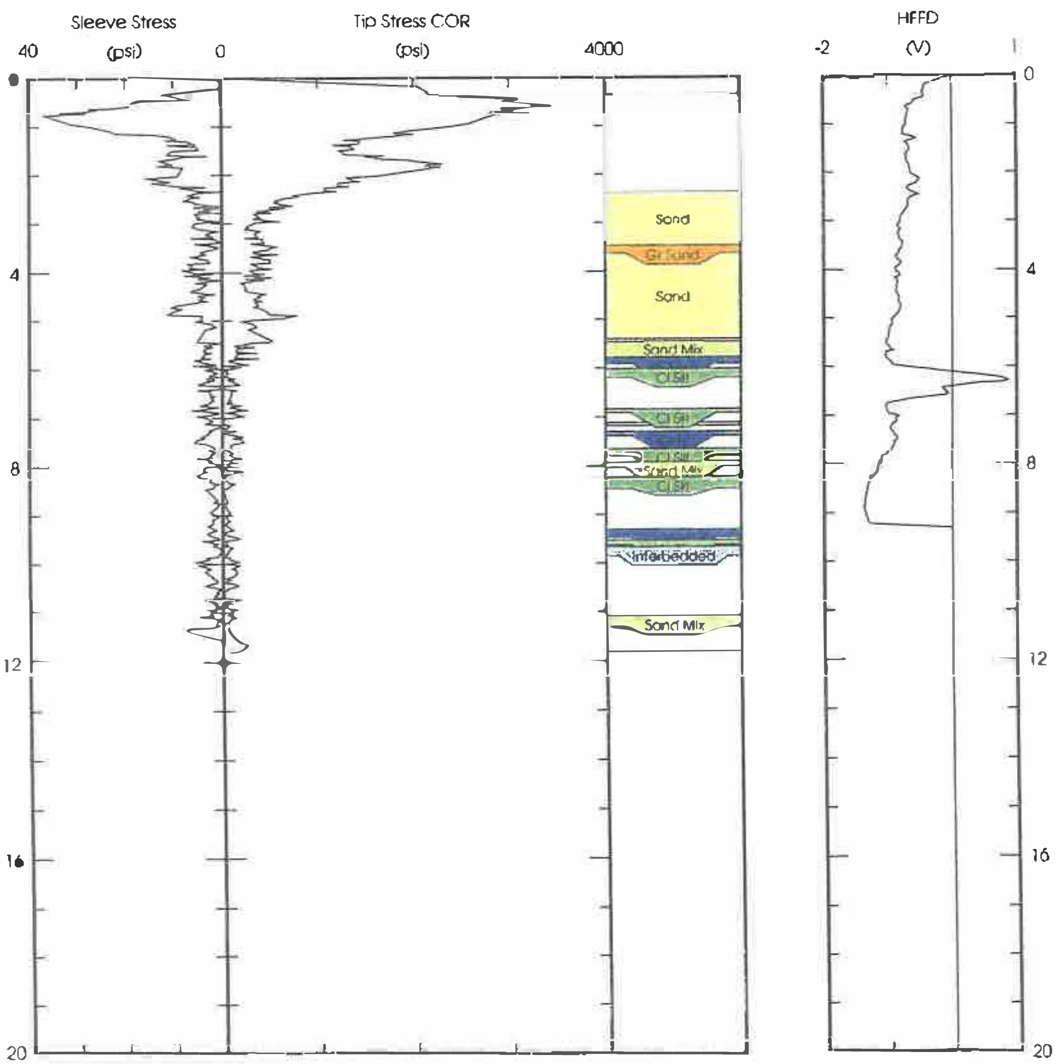
Northing:
Easting:
Elevation:

Date: 13/May/1999
Test ID: AF-9
Project: NYSEG

Client: NYSEG
Site: Binghamton, NY



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http://www.ara.com

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Elevation:

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Project: NYSEG

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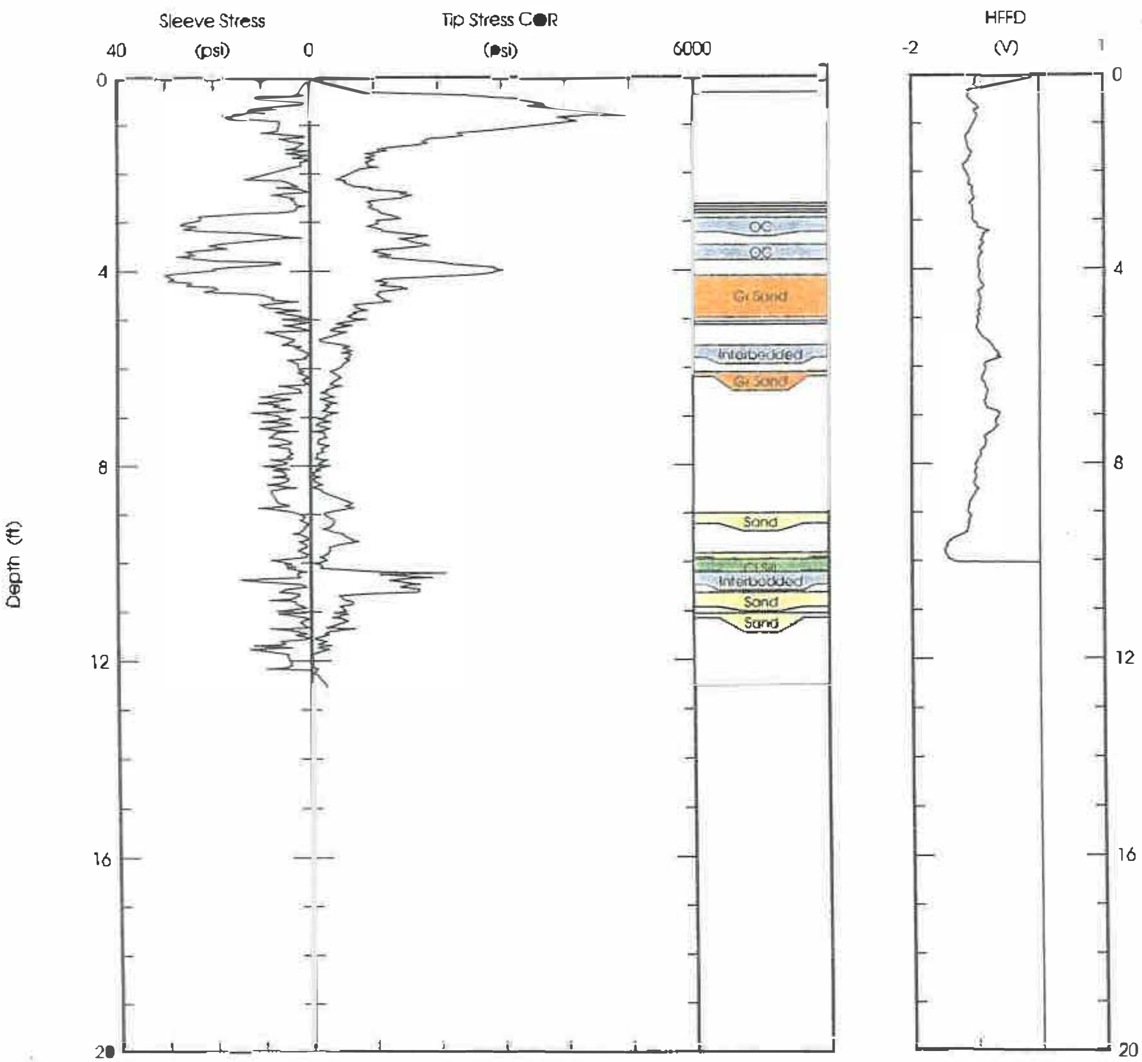
Site: Binghamton, NY



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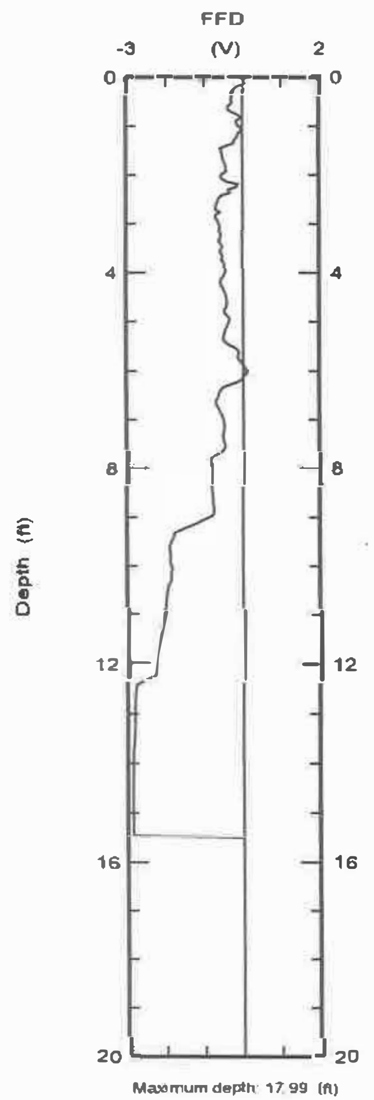

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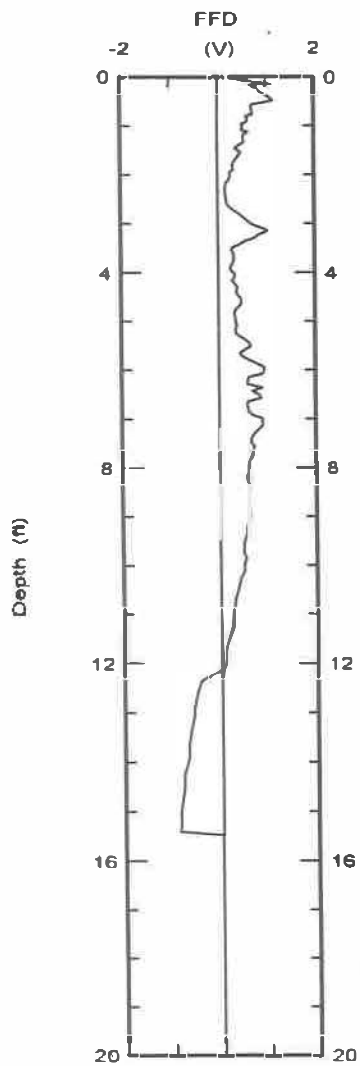
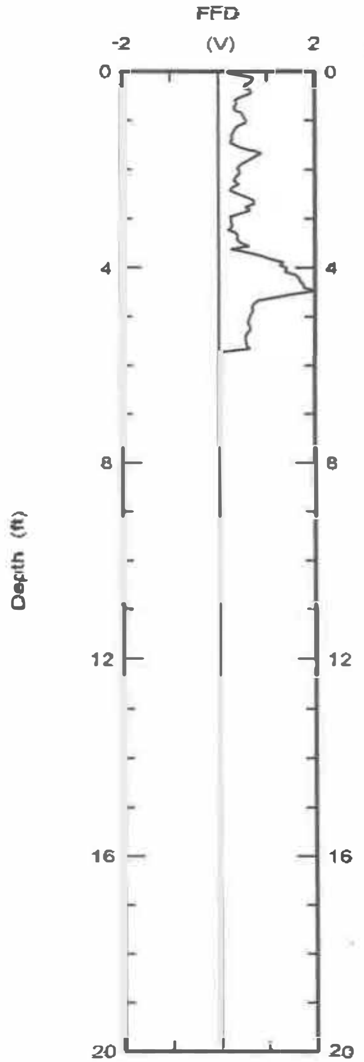
Applied Research Associates South Royalton, VT 05068 802-763-8348 Email: cpt@ned.ara.com http://www.ara.com	Northing: Easting: Elevation:	Date: 05/14/99 Test ID: AF-13 Project: nyseg
	Client: NYSEG Site: NYSEG	



Maximum depth: 17.96 (ft)

Test ID: AF-13
File: z14y907.ecp

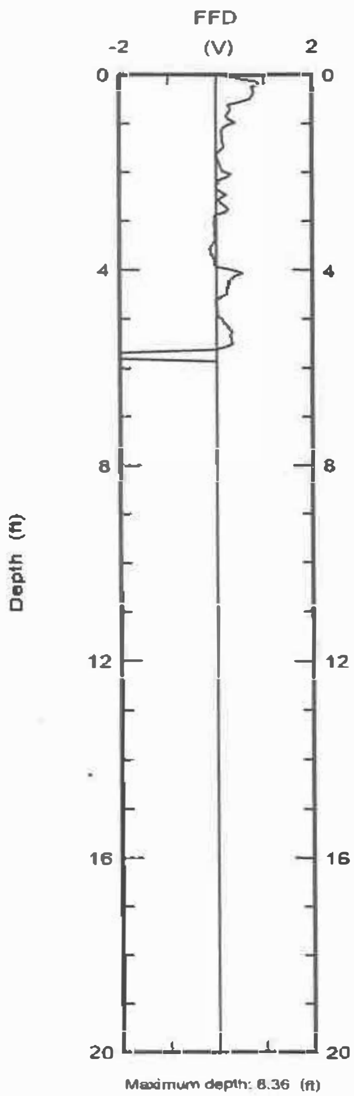
Applied Research Associates South Royalton, VT 05068 802-763-8348 Email: cpt@ned.ara.com http://www.ara.com	Northing: Easting: Elevation:	Date: 05/14/99 Test ID: AF-14 Project: nyseg
	Client: NYSEG Site: NYSEG	



Maximum depth: 8.16 (ft)

Test ID: AF-14
File: x14y900.ecp

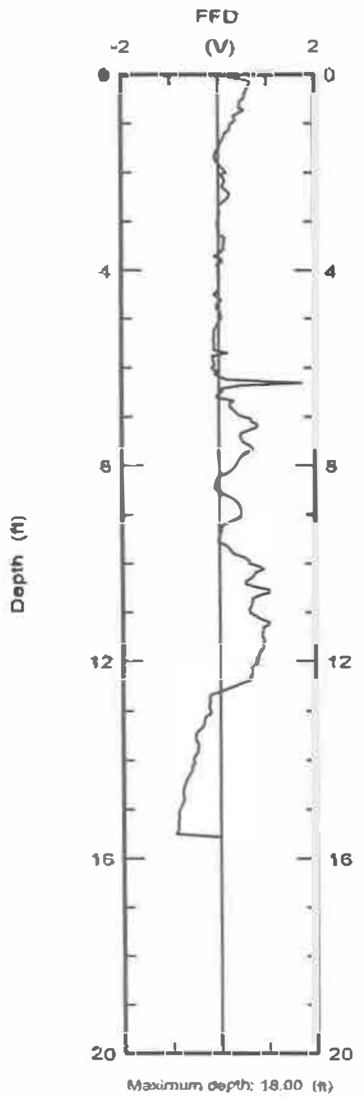
Applied Research Associates South Royalton, VT 05068 802-763-8348 Email: cpt@ned.ara.com http://www.ara.com	Northing: Easting: Elevation:	Date: 05/14/99 Test ID: AF-15 Project: nyseg
	Client: NYSEG Site: NYSEG	



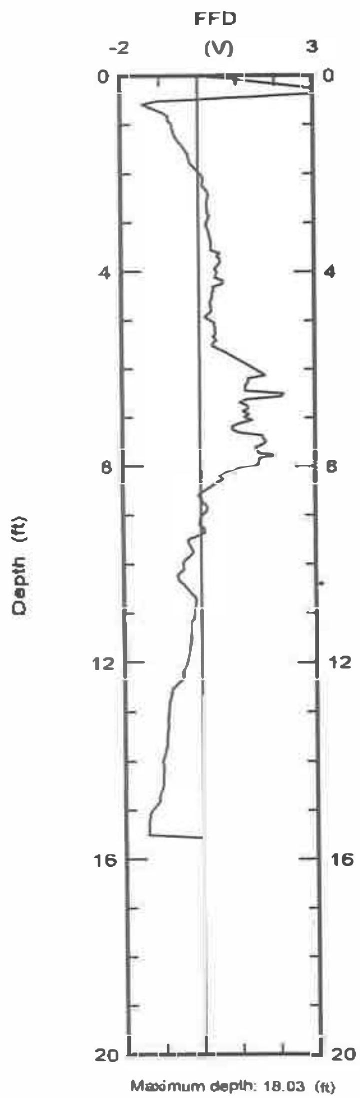
Test ID: AF-15
File: x14y909 ecp

Applied Research Associates
South Royalton, VT 05068
802-763-8348
Email: cpt@ned.ara.com
http://www.ara.com

Northing:	Date: 05/14/99
Easting:	Test ID: AF-17
Elevation:	Project: nyseg
Client: NYSEG	
Site: NYSEG	



Applied Research Associates South Royalton, VT 05068 802-763-8348 Email: cpt@ned.ara.com http://www.ara.com	Northing: Easting: Elevation:	Date: 05/14/99 Test ID: AF-18 Project: nyseg
	Client: NYSEG Site: NYSEG	



Test ID: AF-18
File: x14y912.ecp