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# Correct use of cone penetrometer sensors to predict subsurface conditions

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ABSTRACT: When cone penetrometer testing (CPT) technology is used with in-situ sensors and probes to characterize subsurface conditions in environmental investigations, each sensor must be calibrated with high-quality, site-specific data to establish essential interpretation criteria. Mechanical, geophysical, and chemical sensor data collected for a site in South Carolina without such controls were misleading. Core logs obtained subsequently had major lithologic discrepancies with the soil classification based on the CPT sensor data. In addition, detailed core sampling and laboratory analysis showed that the sensor data on chemical contaminants included false-positive and false-negative results. In contrast, for a site in Nebraska, CPT data calibrated with high-quality site controls provided a detailed interpretation of subsurface conditions relevant to contaminant fate and transport. On the basis of the work in Nebraska, Argonne scientists are continuing to develop criteria to improve the interpretation of complex subsurface stratigraphy.

## 1 INTRODUCTION

Since the early 1970s, CPT technology has gained wide acceptance for use in environmental investigations. New and improved sensors for collecting in-situ geologic, hydrogeologic, and chemical data have made the CPT highly useful as an investigative and monitoring tool. The ability to collect subsurface data faster, cheaper, and more safely has fueled research to further advance CPT technologies.

Although most professionals warn that interpretation of CPT data must be based on and integrated with existing site controls (such as core holes, laboratory samples, and hydrogeologic testing), CPT is too frequently the only site investigative tool. Because the soil classification systems currently in use are empirical and because knowledge about the in-situ behavior of many environmental contaminants is limited, caution must be exercised in interpreting data collected with CPT technology. This paper discusses two cases where CPT data were used for site characterization. In the first case, the entire site was characterized geologically and for petroleum hydrocarbon contamination by using only CPT technology. A later study at this site determined that the interpretation of the CPT data was flawed. Had site controls been used, much time and money would have been saved. In the second case, existing geologic information and site controls (such as geologic core holes, surface and downhole geophysics, and sampling and analysis) were integrated with the CPT data. In this case, use of CPT technology to supplement and augment the existing data proved to be extremely valuable and highly cost-effective.

## 2 FIRST CASE HISTORY: SOUTH CAROLINA

A small land area (24.6 m by 18.0 m [75 ft by 55 ft]) owned by the U.S. Department of Energy (DOE) historically housed two aboveground diesel fuel tanks. Because of suspected fuel contamination, the subsurface was characterized in August 1995 by using CPT and the Rapid Optical Screening Tool (ROST™), a laser fluorescence technology developed as an in-situ method of investigating sites for petroleum contamination. Laser-induced fluorescence (LIF) has been used for a number of years in the laboratory to detect and analyze petroleum products. In LIF, a fiber-optic spectroscopic sensor measures the fluorescence generated when petroleum hydrocarbons are excited with ultraviolet laser energy. The screening-level data produced are expected to be supported by traditional sampling and analytical methods. At the DOE site, tip, sleeve, pore pressure, and ROST™ readings were collected at 14 locations (Figure 1) in and around the storage tank area. The CPT operator

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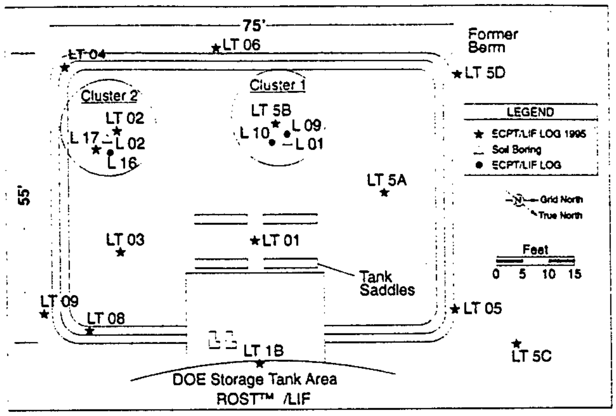


Figure 1. Locations of CPT sampling and sensor data collection and of soil core holes at the DOE site.

stressed, in the cover letter accompanying the final report (Fugro 1995), that because the soil behavior chart was empirical, the soil identification should be verified locally. Nevertheless, the only additional work performed was the collection of 23 soil samples for laboratory analysis for total petroleum hydrocarbon (TPHs) (Burbage et al. 1996). Soil sample locations were selected on the basis of peak signal responses by the ROST™ sensor. Figure 2 shows 4 of the 14 data logs produced for the CPT-ROST™ sensors and the results of chemical analysis of the soil samples collected at those three locations.

In June 1996, Argonne National Laboratory, under contract with DOE, used the same area for an evaluation of LIF sensor technology (Argonne 1996). The site was selected for Argonne's work because it was believed to be fully characterized for fuel contamination and to contain the contaminant concentrations needed for the evaluation. However, Argonne's review of the previous CPT, ROST™, and soil sampling data revealed that the results of the soil sample collection did not support the ROST™ sensor data, which had produced both false-negative and false-positive readings (Figure 2). Therefore, during Argonne's evaluation, two core holes were drilled and logged in detail by a geologist, then sampled continuously for petroleum hydrocarbon analyses (PAHs [polynuclear aromatic hydrocarbons] and BTEX [benzene-toluene-ethylbenzene-xylene]) to establish site control. After samples were collected for chemical analysis, the remaining core was sent to a geotechnical laboratory for grain analysis with a microscope. Each core hole was placed immediately adjacent to a CPT-ROST™ data collection location from the 1995 study in order to confirm earlier results (with core hole L01 adjacent to LT5B and core hole L02 adjacent to LT02).

Argonne began by logging the core. Figure 3 compares the original CPT log as interpreted by the

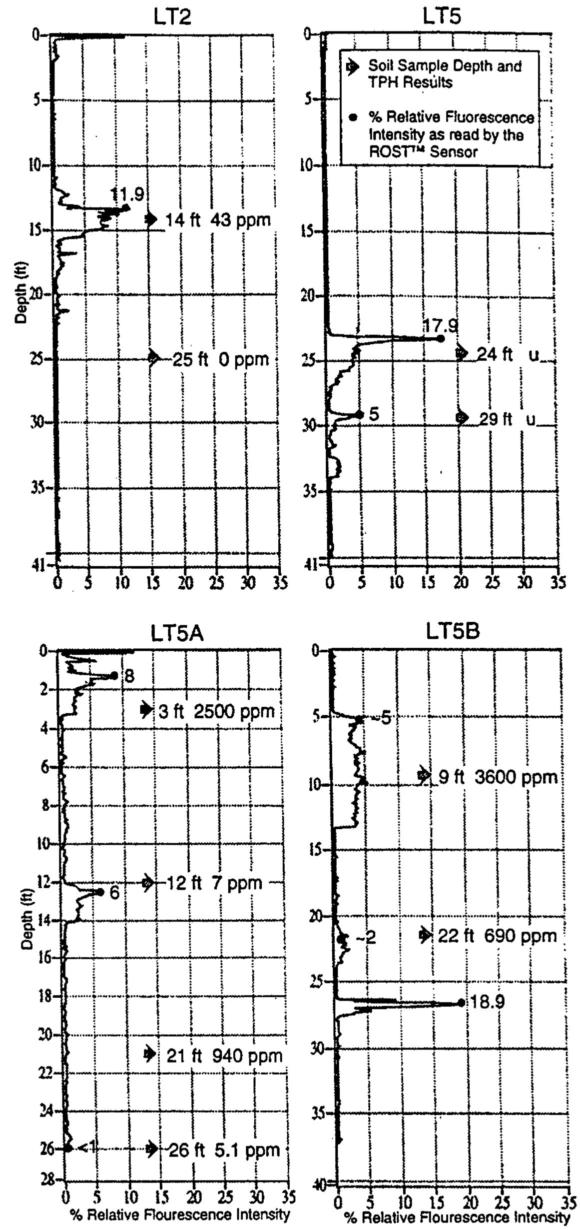


Figure 2. Results from the ROST™ sensor investigation with soil sample results for the DOE site (as modified from Fugro 1995).

soil classification software program on the truck with the core hole log described by the geologist and the laboratory after microscopic examination. Some major discrepancies are apparent. At location L02, the soil boring log was described by the geologist as being dominated by silt and clay in the upper 4.9 m (15 ft) and by sand at 4.9-9.5 m (15-29 ft). The CPT computer-generated soil classification log at this location identified the material at 9.8 m (30 ft) as clay, with sand and silt layers at 6.9-8.2 m (21-25 ft).

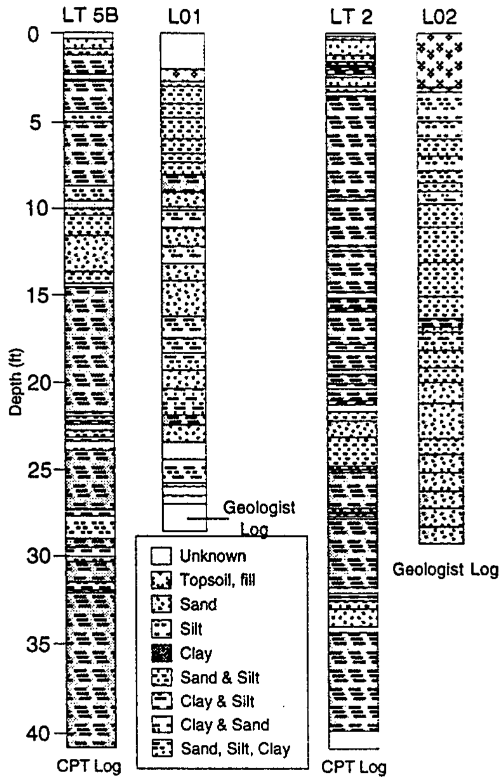


Figure 3. Comparison of the geologist's description of core logs for the DOE site with the CPT interpreted soil classification.

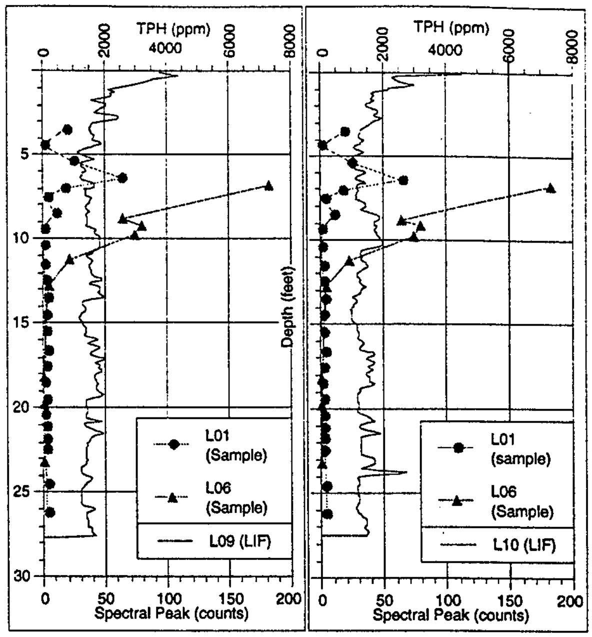


Figure 4. CPT, LIF, and soil sample collection results from Argonne's June 1996 investigation at the DOE site.

The geologist's log at location LT05B/L01 indicates that the upper 4.9 m (15 ft) was dominated by silt and sand, while the interval at 4.9-8.9 m (15-27 ft) was predominantly clay and silt. The CPT log was interpreted as clay with sand and silt layers at 3.3-4.6 m, 7.5 m, and 8.5-9.2 m (10-14 ft, 23 ft, and 26-28 ft).

In addition, during the June 1996 field work, a CPT truck equipped with an LIF sensor was pushed at two locations around core hole L01. The major objective was to evaluate the LIF sensor's ability to detect PAHs accurately in the soil. Figure 4 shows the results for one of the LIF sensor pushes around core hole L01, along with the analytical results for soil samples collected. Cluster 1 data were collected from either side of core hole L01. Additional data collected throughout the site (but not shown here because of space limitations) produced similar results. Little or no correlation between the LIF peaks and the TPH analytical concentrations is apparent. Virtually all of the contamination found at the site during the June 1996 effort was confined to the upper 4.9 m (15 ft) of material. The concentrations of the TPHs may not have been high enough to be detected by the LIF, or chemical complexing interactions with the clay material at the site may have caused erroneous readings from the sensor. The in-situ behavior of most contaminants is not well understood; clay is known to attenuate the signal produce by the LIF, but the reasons for the discrepancies in this study are not known.

This study clearly shows the importance of establishing good site control, both stratigraphic and chemical, when CPT sensor technology is used. In-situ sensor readings can rapidly identify problem areas without producing wastes. However, the interpretation of data generated can be meaningless without a thorough understanding of the site and the contaminants of concern.

## 3 SECOND CASE HISTORY: HUMPHREY, NEBRASKA

Humphrey is a small farming community (population 750) in northern Nebraska. The town's drinking water supply is contaminated with carbon tetrachloride. Figure 5 shows the town and the study areas. In June of 1995, Argonne began a site characterization at Humphrey to define the geologic and hydrogeologic regime and to determine the nature and extent of the carbon tetrachloride plume. During this investigation, CPT technology was successfully integrated with traditional technologies (drilling, sampling, geophysics, monitoring well installation) to meet these objectives.

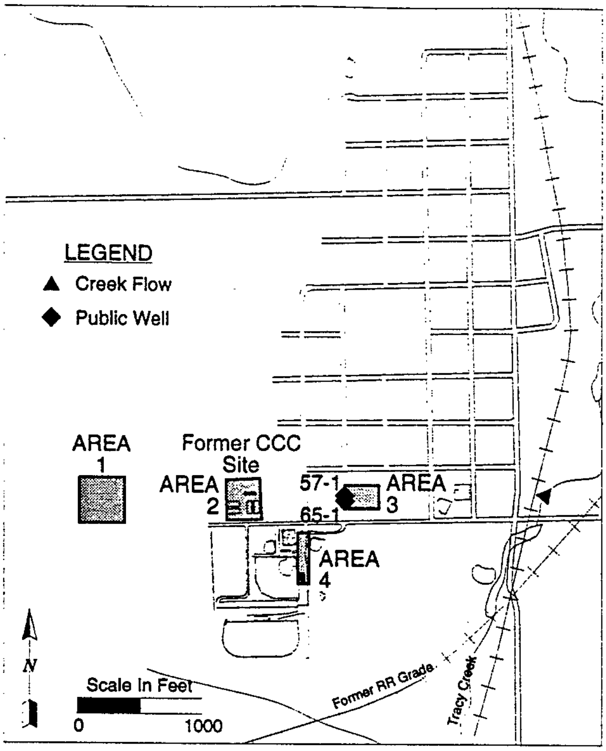


Figure 5. Locations of the four sample areas at Humphrey, Nebraska.

The work at Humphrey began with construction of a conceptual model of the subsurface from data in existing borehole geologic logs. Test holes drilled and logged by the Nebraska Geological Survey were used to develop the geologic framework for the region. Local and on-site private and public wells logged by the drillers were matched, where possible, with the regional geologic logs to develop the preliminary conceptual model of the site's subsurface. The initial field work was designed to test and support the model.

In the field, the CPT sensor response was calibrated with a continuously cored drill hole installed to test the conceptual model and to establish the lithologic units in the stratigraphic sequence. The drill hole was logged for moisture content, and the saturated zones were identified. Downhole and surface geophysics were also used to map some of the major subsurface features; the geophysical data were integrated with the core hole geology and CPT sensor profiles.

Figure 5 shows the location of Area 1, where the initial calibration was performed, as well as the three areas where additional subsurface stratigraphy and hydrostratigraphy were required. Area 2 is believed to be the source area for the carbon tetrachloride contamination. Area 3 is immediately east of the contaminated public wells. Area 4 is southeast of the source, along the regional flow direction (E&E/FIT 1988).

Figure 6 shows the responses of the CPT sensors and the major lithologies described from the core at SB01. The CPT truck was unable to penetrate into the main aquifer (a gravel with some boulders) at this location. Therefore, the CPT application was limited to investigation of the upper formations and the associated waters above the main aquifer. The water-bearing zones were identified as (1) a zone associated with the paleosol at 542.6-538.7 m (1,654-1,642 ft) above mean sea level (AMSL), (2) a sandy layer at 530.2-527.2 m (1,616-1,607 ft) AMSL, and (3) the top of the main aquifer at 510.2 m (1,555 ft) AMSL.

The CPT sensor data collected at Area 2 correlate closely with the geology described at Area 1. Although some variations were noted, the main lithologic changes and the major groundwater zones were identified. Chemical and isotopic analyses of samples from the groundwater zone at 530.8-532.2 m (1,618-1,622 ft) AMSL at Area 2 proved that this groundwater is the same as that present at similar depth at Area 1. The CPT truck penetrated the main aquifer at this location at approximately 508.5 m (1,550 ft) AMSL and continued to 503.6 m (1,535 ft) AMSL before refusal.

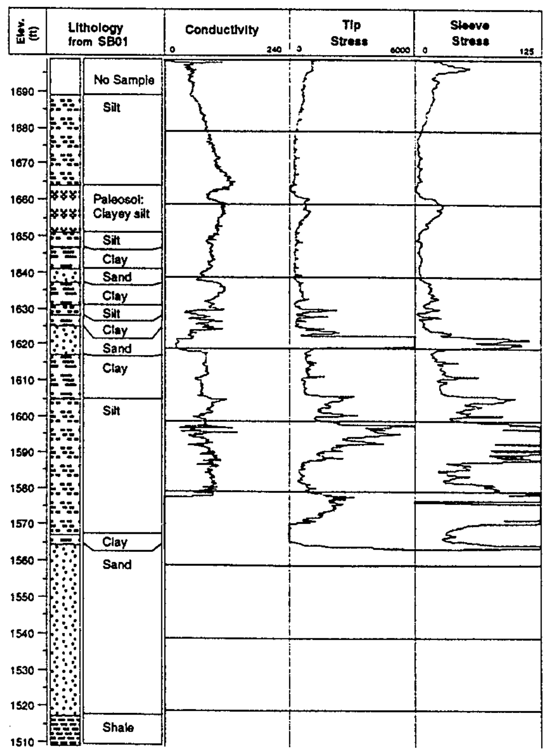


Figure 6. CPT sensor data and soil core description for Area 1 at Humphrey.

Because of the excellent correlation between the CPT logs and the core hole logs at Areas 1 and 2, the CPT was used to collect data at Areas 3 and 4. The CPT logs (Figures 7 and 8, respectively) indicate a significant change in the subsurface stratigraphy at Areas 3 and 4. Results of the geophysical survey were used in an effort to understand these changes. However, surface seismic data did not reveal any major change in the profile at Area 3 (Figure 7). Therefore, minor conductivity responses produced by the CPT sensor at 528.2-526.6 m (1,610-1,605 ft) AMSL were interpreted as groundwater saturation. However, groundwater samples could not be collected at this elevation. A gravel unit was indicated by the CPT log at 507.9-505.2 m (1,548-1,540 ft) AMSL, and a groundwater sample was collected at this elevation. The material underlying this gravel unit was extremely compact, and the CPT truck was unable to penetrate below 495.4 m (1,510 ft) AMSL. Similarly, at Area 4 (Figure 8), a minor conductivity response at 529.9-528.2 m (1,615-1,610 ft) AMSL was interpreted as a saturated unit; however, no groundwater was encountered. Even after a four-hour period, no water was present in the CPT hole at this elevation. The CPT truck met refusal at 512.4 m (1,562 ft) AMSL, short of the main aquifer.

To better understand these variables, two additional core holes were drilled, one at each location. The core was logged in detail. Figures 7 and 8 show the correlation between the core and the CPT logs. At Area 3 (Figure 7), the core log shows the paleosol to be partially saturated, as at Areas 1 and 2. The sandy zone seen at Areas 1 and 2 at approximately 528.2 m (1,610 ft) AMSL is absent at Area 3. The upper 10 ft of the boulder-gravel main aquifer was indicated by the CPT sensor data. However, the deeper portion of the main aquifer, as logged at Area 1, was not logged at Area 3. A compact, firm glacial till occurred under the bolder-gravel unit, overlying the bedrock.

The core log at Area 4 (Figure 8) shows saturation in the paleosol, locally forming a perched aquifer. The groundwater zone at 528.2 m (1,610 ft) AMSL was a clayey silt with little or no sand that was nevertheless saturated. The main aquifer here was a mixed bed of coarse gravel to boulders, again underlain by a glacial till.

The differences from Areas 1 and 2 to Areas 3 and 4 show that changes in geology can occur over small distances. Without geologic confirmation, CPT logs can easily be interpreted erroneously. Integration and interpretation of the drilling, CPT, and surface geophysics data during the initial stage of the field investigation established the controls required to calibrate the CPT sensor responses with known geology and hydrostratigraphy. The calibrated

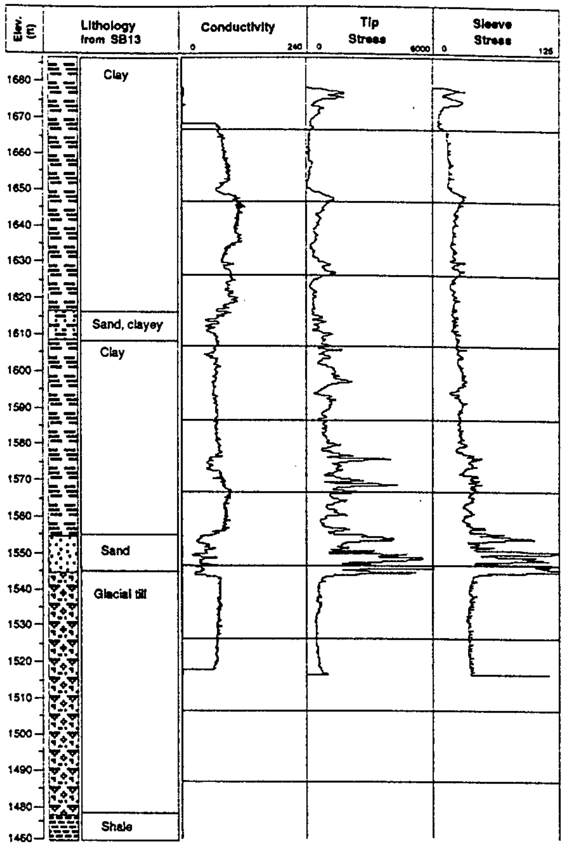


Figure 7. CPT sensor data and lithology for Area 3 at Humphrey.

responses successfully identified the main subsurface features affecting contaminant migration. Optimal sampling sites for determining the horizontal and vertical distribution of contaminants were selected by considering both the core and CPT sensor logs.

## 4 CONCLUSIONS

Using CPT sensor data without the proper site calibration and control can lead to misinterpretations. At times, even with geologic control and initial site calibration of the responses, the data can be misleading or difficult to interpret, leading to improper conclusions about the site, the contaminants, the potential for migration, and the remedial design. When CPT electronic logs are used correctly, no CPT computer-generated soil classification system is needed. The geologist should interpret the site's CPT logs by using controls identified in the characterization program, including soil core logs, grain analysis, soil moisture data, and hydrogeologic data. Even after the initial site control and calibration are established, additional controls

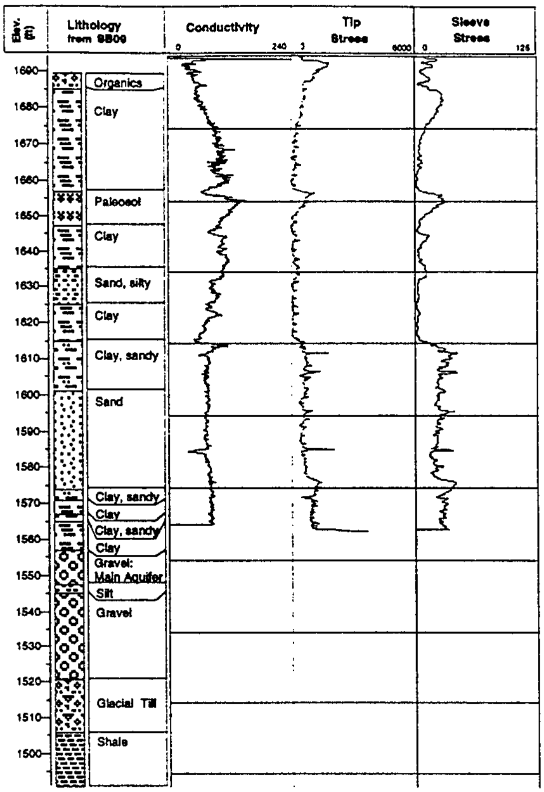


Figure 8. CPT sensor data and lithology for Area 4 at Humphrey.

points may be required as the subsurface conditions change across the site. Conscientious use of CPT technology can save time and costs in many site characterization and monitoring programs. Argonne's approach integrates core hole geology and laboratory sampling with resistivity, tip, sleeve, pore pressure, and analytical data produced by CPT to generate high-quality results.

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