U.S. Department of Energy
Grand Junction Office
2597 B¾ Road
Grand Junction, CO 81503

MAR 2 2 2002

Madeline Roanhorse, Director
Navajo UMTRA Program
Division of Natural Resources
P.O. Box 1875
Window Rock, Arizona 86515

Subject: Shiprock, New Mexico, Disposal Cell Investigation Results

Dear Ms. Roanhorse:

During the last few years, the Navajo Nation has expressed concerns over the UMTRA Shiprock disposal cell performance. These concerns have been identified in the following Navajo UMTRA correspondence to DOE:

1. Shiprock UMTRA Site, April 6, 1999
2. Data Requirements for the Disposal Cell Investigation

The DOE–GJO has taken your concerns and suggestions seriously, and, as a result, has performed additional studies of the Shiprock disposal cover and cell. Results of these DOE studies are presented in two separate reports:

1. Environmental Sciences Laboratory *Disposal Cell Cover Moisture Content and Hydraulic Conductivity*, March 2002
2. *Results of a Piezocone Investigation, Shiprock, New Mexico*

I am enclosing five copies each of these reports. If DOE–GJO gains evidence in the future, through implementing the ground water remedial action project, that indicates the disposal cell is contributing contaminant seepage to the floodplain, then further disposal investigations will be planned and implemented.

If you have any questions, please call me at 970/248-7612.

Sincerely,

Donald R. Metzler
Program Manager

Enclosures

NM5508
WM-58

cc w/enclosures:
L. Breckenridge, Knight Piesold
B. Von Till, NRC

cc w/o enclosures:
M. Kautsky, MACTEC-ERS
M. Madril, MACTEC-ERS
S. Marutzky, MACTEC-ERS
J. Waugh, MACTEC-ERS
Project File GWSHP 3.5 (DOE)

drm\3-5mr.doc

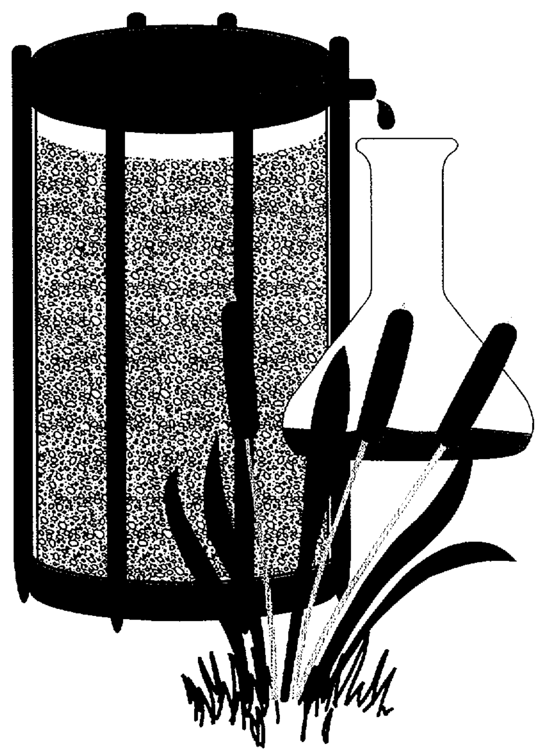
GJO-2001-204-TAR
ESL-RPT-2001-04

Environmental Sciences Laboratory

Disposal Cell Cover Moisture Content and Hydraulic Conductivity

Long-Term Surveillance and Maintenance Program Shiprock, New Mexico, Site

May 2001



Prepared for
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado

Work Performed Under DOE Contract No. DE-AC13-96GJ87335
DOE Task Order No. MAC01-05

MAC–UGWSHP 13.1

Disposal Cell Cover Moisture Content and Hydraulic Conductivity

Long-Term Surveillance and Maintenance Program Shiprock, New Mexico, Site

May 2001

Prepared for
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado

Project Number UGW–511–0020–08–000
Document Number U0103700

Signature Page

Disposal Cell Cover Moisture Content and Hydraulic Conductivity

Long-Term Surveillance and Maintenance Program
Shiprock, New Mexico, Site

May 2001

Prepared By: ______________________
Ed Glenn, Professor
Environmental Research Laboratory
University of Arizona

Prepared By: ______________________
Jody Waugh, Principal Scientist
Environmental Sciences Laboratory

Reviewed By: ______________________
Stan Morrison, Manager
Environmental Sciences Laboratory

Reviewed By: ______________________
Carl Jacobson, Manager
Long-Term Surveillance and Maintenance Program

Approved By: ______________________
Art Kleinrath, Project/Technical Manager
U.S. Department of Energy Grand Junction Office

Contents

Tables

Figures

Acronyms

AEP	air-entry permeameter
ANOVA	analysis of variance
cm	centimeters
cm^3	cubic centimeters
cm/d	centimeters per day
cm/s	centimeters per second
CPN	Campbell Pacific Nuclear
CSL	compacted soil layer
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
g/cm^3	grams per cubic centimeter
GJO	Grand Junction Office
hr	hours
in	inches
kg	kilograms
K_{sat}	saturated hydraulic conductivity
LTSM	Long-Term Surveillance and Maintenance
m	meter
pCi/l	picocuries per liter
NRC	U.S. Nuclear Regulatory Commission
RRM	residual radioactive material
SEM	standard error of the mean
UMTRA	Uranium Mill Tailings Remedial Action
UMTRCA	Uranium Mill Tailings Radiation Control Act

End of current text

Executive Summary

The Shiprock, New Mexico, Uranium Mill Tailings Remedial Action (UMTRA) disposal cell was constructed by the U.S Department of Energy (DOE) to isolate uranium mill tailings and contaminated soil in order to minimize radon emanation and moisture infiltration. The purpose of this study, conducted by the Environmental Sciences Laboratory for the DOE Long-Term Surveillance and Maintenance (LTSM) Program, was to evaluate evidence of water movement through the Shiprock UMTRA disposal cell cover as requested by the Navajo Nation. Percolation of precipitation through the cover and tailings is a potential source of ground water contamination. This report presents methods and results of physical property tests of cover materials, hydroprobe monitoring of soil moisture profiles in the cover from June 1999 through September 2000, and in situ measurements of the saturated hydraulic conductivity. A barrel calibration method was used to calculate volumetric moisture content as a function of neutron counts.

A summary of the conclusions and recommendations follows:

- The compacted soil layer (CSL or radon barrier) consists of highly compacted silt loam soil.
- Voids in a surface rock layer have half filled with windblown silt and fine sand since construction of the disposal cell in 1986.
- The CSL in the cover was essentially saturated in 2000.
- CSL moisture content measurements show minimal variation from one location to another, with depth or over time.
- Hydroprobe monitoring indicates that the top of the tailings was also essentially saturated in 2000. The saturation of the tailings was confirmed. The neutron hydroprobe was consistently dripping wet when extracted from probe ports into the tailings, even after the ports had been bailed.
- The in situ saturated hydraulic conductivity of the CSL, measured on the north side slope as part of a 1998 root intrusion study, was highly variable and significantly greater than the design target of 1.0×10^{-7} cm/s.
- A 1988 laboratory measurement of the saturated hydraulic conductivity (K_{sat}) of the tailings suggests that the upper tailings layer may have a much lower K_{sat} than the CSL, possibly causing water percolating through the cover to perch on the tailings. This may be the reason for standing water in the bottom of the hydroprobe ports.
- Given apparently high variability in the K_{sat} of the CSL and apparently low K_{sat} of the tailings, conclusions of this study are the basis for a recommendation to DOE to conduct representative tests of the physical and hydraulic properties of the CSL <u>and</u> tailings layer to evaluate water flux through the disposal cell.

End of current text

1.0 Introduction

The U.S. Department of Energy Grand Junction Office (DOE–GJO) Long-Term Surveillance and Maintenance (LTSM) Program provides stewardship services for DOE sites across the country containing low-level radioactive materials (*www.doegjpo.com/programs/ltsm/*). Included in the LTSM Program are uranium mill tailings disposal cells constructed under the auspices of the Uranium Mill Tailings Radiation Control Act (UMTRCA) to contain contaminants for 1,000 years. In 1998, the LTSM Program initiated the Cover Monitoring and Long-Term Performance Project to evaluate how changes in UMTRCA disposal cell environments, both observed changes and changes projected over hundreds of years, may alter the performance of disposal cells (DOE 2001). The LTSM Program and the DOE Environmental Sciences Laboratory are evaluating the hydrologic performance of the Shiprock, New Mexico, uranium mill tailings disposal cell in response to a request by the Navajo Nation. This report presents the results of recent soil moisture and soil hydraulic property sampling in the disposal cell cover for comparison with sampling data from the late 1980s.

Five neutron hydroprobe access tubes were installed in the cover of the Shiprock disposal cell in 1988, penetrating approximately 325 centimeters (cm) through the rock layer, sand layer, and compacted soil layer (CSL) or radon barrier, and into the upper part of the interred tailings (Figure 1). We used four of these probe ports (the fifth port was blocked) to monitor moisture levels in the rock layer and CSL from June 1999 through November 2000. We also conducted a calibration study to relate neutron counts per minute, measured in the disposal cell cover profile using a neutron hydroprobe, to volumetric water content. Results of this recent monitoring period were compared with data on physical and hydraulic properties of the CSL acquired (1) in 1988 shortly after the disposal cell cover was constructed and (2) during a root intrusion study conducted in 1998.

The objectives of the current hydroprobe monitoring study at Shiprock were

- to evaluate moisture contents in the cover and tailings,
- to report any changes in the physical or hydraulic properties of cover materials, and
- to evaluate evidence for infiltration of a significant volume of water through the disposal cell cover and tailings.

End of current text

2.0 Background Information

The Shiprock, New Mexico, disposal cell was constructed in 1986 before the U.S. Environmental Protection Agency (EPA) proposed ground water quality standards for uranium mill tailings sites. The disposal cell cover was designed to address performance standards concerned with radon flux and longevity. The design standard for radon (40 CFR 192.02[b]) states that the remedial action should provide reasonable assurance that releases of radon-222 to the atmosphere will not (1) exceed an average surface flux rate of 20 $pCi/m^{-2}/s^{-1}$, or (2) increase the annual aver concentration of radon-222 in the air at or above any location outside the disposal site by more than 1/2 pCi/l^{-1}. EPA established a design life standard of 1,000 years whenever reasonably achievable (EPA 1983). In any case, a minimum performance period of 200 years must be achieved.

No ground water quality standards existed at the time the Shiprock disposal cell was constructed in 1986. In 1995 EPA published 60 FR 2854, the Final Rule for the control of residual radioactive materials (RRM) from inactive uranium processing sites. The Final Rule requires that remedial action be conducted to assure that amounts of RRM and associated hazardous constituents in ground water meet certain concentration standards. At sites like Shiprock where tailings were stabilized in place, compliance with groundwater standards may depend on an engineered cover that limits infiltration of meteoric water into buried RRM (DOE 1989). This may be achieved by maintaining unsaturated conditions in the cover, by including a highly permeable bedding or drainage layer in the cover, and/or by including a compacted, low-permeability soil layer in the cover. In 1988, DOE began an evaluation of the hydrological performance of the existing disposal cell cover at Shiprock (DOE 1989, 1991).

2.1 Shiprock Cover

The cover design used at Shiprock consists of three layers: a CSL or radon barrier to control radon releases and water infiltration, a sand or drainage/bedding layer overlying the CSL, and rock armor as the top layer. As with Resource Conservation and Recovery Act covers, the target saturated hydraulic conductivity for the CSL is 1×10^{-7} cm/s (Caldwell 1992). A CSL thickness adequate to meet the radon flux standard was calculated using an early version of the U.S. Nuclear Regulatory Commission (NRC) RADON model (NRC 1989). A sand drainage or filter layer also serves as a bedding layer for the rock armor. The rock armor is sized to prevent erosion of underlying layers given a probable maximum precipitation event, the most severe combination of meteorological and hydrological conditions possible at a site. The Shiprock top slope cover design consists of a 198-cm CSL overlying the tailings, a 15-cm sand drainage/bedding layer overlying the CSL, and a 30-cm cobble riprap layer overlying the bedding layer. The CSL is 214-cm thick on the side slopes of the disposal cell.

2.2 Neutron Hydroprobe Operation

Neutron hydroprobes, or neutron thermalization gauges, consist of a probe containing a source of high-energy neutrons and a detector for slow neutrons; a cable to lower the probe down access tubes; a probe housing with lead and polyethylene shields to absorb gamma rays and neutrons, respectively; and a scaler to display slow neutron counts. High-energy neutrons released from an americium-beryllium source in the probe are scattered and slowed (thermalized) by elastic collisions with hydrogen nuclei in the soil water. The slow neutrons interact with gases in the

probe detector, releasing an alpha particle that causes an electric pulse recorded as a count in the scaling unit (Gardner 1986). The volume of soil measured by the probe varies depending on the concentration of hydrogen nuclei and, thus, primarily on soil water content. Since the development of neutron thermalization methods for measuring soil moisture (Gardner and Kirkham 1952: Van Bavel et al., 1956), advances in electronics and the use of less radioactive sources have improved efficiency, portability, safety, and precision. The standard error of estimated volumetric soil water content is often less than 0.01 cm^3 water per cm^3 dry soil (Gardner 1986). Details concerning the theory and operation of neutron thermalization gauges can be found elsewhere (Greacen 1981; Gardner 1986).

3.0 Methods

3.1 CSL Physical Properties

Soil bulk density, soil texture, soil water content, and porosity of the CSL and of soils in the borrow area used to construct the CSL were determined in the field. Adequate field sampling of these soil properties was necessary to design physical models for the hydroprobe calibration.

Three soil pits were excavated in the Shiprock cover adjacent to hydroprobe ports 205, 206a and 206b, and 208 on July 25, 2000 (Figure 1). Excavated rock and sand drainage-layer materials from the pit were separated on a tarp. The upper 10 to 15-cm excavated portion of the CSL was removed and piled separate from the rock and sand. Volume samples for bulk density analyses were retrieved with a double cylinder, hammer-driven core sampler. A hand-driven bucket auger was used to obtain bulk samples for analyses of soil texture and water content. Bulk samples of windblown soil deposited in the rock cover were also collected for textural analysis. Bulk soil samples were collected from eight random locations in the CSL borrow pit area for analysis of particle size distribution. Table 1 lists the laboratory methods used for analyses of gravimetric water content, dry-weight bulk density, soil porosity, and particle size distribution (texture). After the samples were collected, rock, gravel, and CSL materials were placed back in the pit in a layer sequence that closely matched the predisturbed condition.

3.2 Hydroprobe Calibration

A combination of an in situ field method and a barrel calibration method was used to determine volumetric soil moisture content as a function of neutron counts per minute measured by a Campbell Pacific Nuclear (CPN) neutron hydroprobe supplied by the Environmental Research Laboratory (Campbell Pacific Nuclear 503 DR, Serial No. 1475). Neutron counts (counts per minute) were recorded in hydroprobe ports 205, 206a, 206b, and 208 just before the pits were excavated to sample soil physical properties. Simultaneous readings of soil density using a CPN density-moisture meter were attempted, but the aluminum probe ports were not wide enough for the probe to pass freely into the tube. Micrometer measurements showed that the exposed portions of the probe ports were slightly out of round, varying from 4.75 –5.41 cm, while the probe diameter was 4.83 cm.

A barrel calibration was performed using the borrow area soil to simulate the CSL. The soil was air dried and then placed in a 210-l (50-cm-diameter) barrel. An aluminum neutron hydroprobe port of the same wall thickness (0.124 cm) and internal diameter (5.08 cm) as the Shiprock ports was installed in the center of the barrel. Soil was placed in the barrel and compacted in an attempt to achieve the same bulk density as measured in the Shiprock cover CSL. Exactly 198.85 kg of dry soil was layered into the barrel in 10-cm lifts and compacted with a metal tamper. The bulk density of the soil (ρ_b, grams of soil per cubic centimeter of soil) in the barrel was determined by calculating the depth of soil (d in centimeter) in the barrel (measured at 10 or more points on the soil surface), the oven-dry weight of soil placed in the barrel (m_s in grams), and the cross sectional area (a, in square centimeters) of the barrel:

$$\rho_b = m_s/(d)(a) \tag{1}$$

The barrel was filled to within about 40 cm of the top with compacted soil. A bulk density of 1.90 grams per cubic centimeter (g/cm^3) was measured for the dry soil. The neutron count (counts per minute) of the dry soil was measured with the neutron hydroprobe lowered down the aluminum port to the center of the barrel. Sufficient water to bring the moisture content to 0.15 cm^3/cm^3 was added to the top of the soil. After allowing this water to infiltrate for 48 hours (hr), the soil was compacted further by tamping. The addition of moisture allowed the soil to be compacted to a final dry-weight bulk density of 1.98 g/cm^3.

When a neutron hydroprobe measurement of 0.15 cm^3/cm^3 moisture was achieved, 15 cm of additional water was added to the top of the soil and allowed to infiltrate. Neutron counts in the barrel were recorded periodically over 290 hr as the water infiltrated the soil. A control barrel filled with water was used to account for evaporation rate (ca. 0.2 cm/day). After approximately 100 hr, water began to drain from the bottom of the calibration barrel, indicating that the soil was saturated. At 290 hr, the initial volume of water added to the barrel had completely infiltrated into the soil or evaporated. An additional 5 cm of water was added to the surface and allowed to infiltrate and drain to ensure even wetting. When no further water drained from the barrel for 24 hr, considered to be the field capacity of the soil, the neutron hydroprobe was lowered to the center of the barrel to record neutron counts. Three 60-g soil samples were taken from the barrel for a gravimetric determination of water content. Results were recorded as volumetric or volumebasis water content (θ_{vb}, cubic centimeters of water per cubic centimeter of soil) using the equation (Gardner 1986)

$$\theta_{vb} = (\rho_b/\rho_w)\theta_{dw} \qquad (2)$$

where

ρ_b = dry-weight bulk density of the soil (g soil/cm^3 soil),
ρ_w = density of water (1.0 g water/cm^3 water), and
θ_{dw} = dry-weight or gravimetric soil moisture content (g water/g dry soil).

3.3 Hydroprobe Monitoring in Cover

Neutron counts (counts/minute) were monitored monthly in hydroprobe access ports 205, 206a, 206b, and 208 in the Shiprock cover from June 1999 through September 2000 (Figure 1). Use of the neutron hydroprobe followed the procedures of Gardner (1986). Figure 2 shows the depth of neutron probe ports relative to cover and tailings layers. Port 207 was blocked with debris at a depth of about 80 cm and was not monitored regularly. Port 206b was blocked initially, but the obstruction was removed in September 1999. Counts were recorded at 15.24-cm (6-in.) increments from the top of the hydroprobe access ports to a depth of 351 cm (138 in.). The 15-cm counts were above the ground surface, the 30-cm counts were near the top of the rock layer, the 46-cm counts were near the bottom of the rock layer, and the 61-cm counts were in the sand drainage layer. Data for 76-cm to 259-cm depths were from the CSL and counts at 274 cm and below were in the tailings.

3.4 In Situ Hydraulic Conductivity

In 1998, DOE evaluated the effects of root intrusion on the saturated hydraulic conductivity (K_{sat}) of the CSL. Air-entry permeameters (AEPs) were used to estimate in situ K_{sat} in areas on

the north side slope of the disposal cell cover where several typically deep-rooted plant species were growing (Figure 1). The AEPs were designed and manufactured by Daniel B. Stephens and Associates, Inc. (Stephens et al. 1988; Havlena and Stephens 1992). The AEP, based on a design by Bouwer (1966), consists of a round, 30-cm-deep permeameter ring, air-tight cover, standpipe, graduated water reservoir, and vacuum gauge.

Three pits were excavated where three different species were rooted into the CSL (Figure 1): tamarisk (*Tamarix ramosissima* Ledeb.), rubber rabbitbrush (*Chrysothamnus nauseosus* [Pall. ex Pursh] Britton), and Russian thistle (*Salsola kali* L.). AEP measurements were made within each pit where roots penetrate the CSL and in an adjacent location where plant root intrusion was not observed. After installing the permeameter ring, we sealed polycarbonate plates to the top of the ring, attached standpipes and water reservoirs, and filled the reservoirs. Reservoir water was dyed to trace wetting fronts and preferred flow paths. The two-stage test consisted of (1) measuring the rate of water-level drop in the reservoir and (2) measuring the pressure (tension) with the vacuum gauge after shutting off the water supply and allowing time for water to redistribute. The vacuum gauge measurement was used to calculate the air-entry or bubbling pressure of the soil (ASTM D5126–90). Within each of the three test pits, core samples of the CSL were taken to determine soil moisture content, bulk density, and porosity using the methods described in Section 3.1.

Using the AEP method (Bouwer 1966; Havlena and Stephens 1992), saturated conductivity (K_{sat} in cm/s) was calculated as

$$K_{sat} = [2 * dH/dT * L * (R_{ws}/R_{sr}) * 2]/[H_f + L - (0.5 * P_a)] \quad (3)$$

where

dH = change in head,
dT = change in time,
L = depth of soil surface to wetting front,
R_{ws} = radius of water supply reservoir,
R_{sr} = radius of AEP soil ring,
H_f = last head reading,
P_a = $P_{min} + G + L$,
P_{min} = gauge pressure at air entry (negative value), and
G = height of gauge above the soil surface

End of current text

4.0 Results and Discussion

4.1 Physical Properties of CSL and Borrow Soils

The cover CSL and most of the borrow area soils are classified as silt loam. However, the borrow area samples tend to have higher sand splits and lower clay splits than the cover CSL. On the basis of this comparison, we selected sample location SBA–7 in the soil borrow area to build the hydroprobe calibration barrel. Sand-silt-clay splits at sample location SBA–7 are 23-58-19 compared to an average of 19-58-22 in the cover CSL. Table 2 presents soil particle-size distribution and texture results for the Shiprock cover CSL and borrow area soils.

Table 3 shows gravimetric moisture content of drainage layer sand, gravimetric moisture content of the CSL, dry-weight soil bulk density and calculated porosity of the cover CSL, and the calculated percent saturation of the CSL. Cover CSL samples were removed from a depth of approximately 30 cm below the sand-CSL contact. The mean bulk density of the CSL (1.98 g/cm^3) was used as the target for soil compaction in the calibration barrel.

Percent saturation (mean = 97.1, Standard error of the mean [SEM] = 5.16) was calculated using bulk density of the CSL (mean = 1.93 g/cm^3, SEM = 0.012 g/cm^3, n = 71) and the mean particle density of the CSL (mean = 2.72, SEM = 0.003, n = 93) from the 1988 study. The 1988 bulk density values were less than those measured in the current study (mean = 1.98 g/cm^3, SEM = 0.04 g/cm^3, n = 3). Using the 1988 mean bulk and particle density values, the equivalent mean porosity is 29.04 percent.

Table 4 presents soil particle-size distribution for fines sampled from the rock layer in the three pits. These materials filled approximately half of the interstitial voids in the rock layer and are assumed to be windblown soil from surrounding areas. If, indeed, most or all of the fines in the rock layer are windblown, then complete filling of the interstitial voids during the first decades of the 21st century is a reasonable projection. Two consequences are likely: establishment of a contiguous plant cover and greater water retention above the CSL.

4.2 Hydroprobe Calibration

Soil moisture content of samples taken from the calibration barrel was correlated with counts-per-minute data recorded with the neutron hydroprobe in the barrel. A strong linear relation was identified between volumetric soil moisture and counts recorded with the hydroprobe (Figure 3). The equation of best fit had a high coefficient of determination (r^2 = 0.99); neutron hydroprobe and soil moisture data from the cover clustered at the wet end and were omitted from the calibration. This equation was used to convert monthly count data at different soil depths to estimates of volumetric soil moisture content. The moisture content of the three samples taken from the calibration barrel at field capacity was 0.301 cm^3/cm^3 (SEM = 0.006, n = 3). Given a dry-weight bulk density range of 1.90 to 1.98 g/cm^3 from Equation (1) and a measured particle density range of 2.66 to 2.78 g/cm^3 from the 1988 data, then the equivalent range of porosity values is 0.26 to 0.32. Therefore, we assume that for the wet point measurements in the calibration barrel, soil samples were 94-percent saturated, at a minimum, and likely close to 100-percent saturated. The rate of water infiltration into this saturated or near saturated soil in the calibration barrel was 3.84×10^{-2} cm/hr or 1.07×10^{-5} cm/s as indicated by the slope in Figure 4.

4.3 Moisture Levels in Shiprock Cover

Figure 5 presents moisture content in the disposal cell by depth from the top to the bottom of the hydroprobe ports averaged for data from all probe ports and for all dates. The sand drainage layer ended and the CSL layer began between the 60 and 76 cm depths. Moisture content increased from the top of the hydroprobe ports in the rock layer, reaching 35-percent volume in the sand layer, then remained at approximately 28-percent volume to the bottom of the probe ports. Variability was much greater above the CSL in the sand and rock layers than within the CSL.

Data were analyzed utilizing Statistix 7, a package of statistical programs from Analytical Software (P.O. Box 12185, Tallahassee, FL, 32317–2185). Data from the sand and rock layers (less than 76 cm depth) and the CSL were analyzed separately. For each group, we conducted a one-way analysis of variance (ANOVA) for each of three factors: probe, date, and depth. The dependent variable was soil water content (cm^3/cm^3) in each case. Each result shown in Table 5 was a one-way ANOVA. The subscript numbers in the ANOVA F value column indicate the degrees of freedom among and within groups. The rock layer in Table 5 represents soil depths to 76 cm, and the CSL layer represents greater depths including the tailings. All the factors had statistically significant effects, with the exception of the probe factor for the rock layer samples. Although the differences among groups in the other analyses were statistically significant, the powers of the tests were high because of the larger sample size, and, in most cases, the differences were not relevant. However, it was evident, even without a confirmatory statistical test, that soil water content increases with depth from the rock layer to the sand layer.

4.4 CSL Saturated Hydraulic Conductivity

Results of the 1998 K_{sat} study contrast sharply with other physical and hydraulic property data from the site (Table 6). The in situ K_{sat} values for the CSL were highly variable, with a range of nearly 4 orders of magnitude and a high of 1.29×10^{-4} cm/s. In contrast, DOE (1989) reported a much lower laboratory K_{sat} for CSL (mean = 5.6×10^{-7} cm/s; range = 2.3×10^{-6} to 6.4×10^{-8} cm/s). Contrary to our expectations, CSL K_{sat} values were actually lower in locations where roots penetrated the CSL than in locations with no observed root intrusion.

4.5 Physical and Hydraulic Properties of Tailings

This section summarizes the tailings data acquired during the 1988 study (DOE 1989). Tailings samples were taken at various depths during installation of hydroprobe ports 203, 206a, 206b, 207, and 208 (Figure 1). Soil moisture content, bulk density, particle density, and saturated hydraulic conductivity were measured; the saturated conductivity was reported as 3.5×10^{-8} cm/s (Table 7).

5.0 Conclusions

DOE is developing ground water restoration plans for the former uranium-ore processing site at Shiprock. DOE recognizes that containment of sources of ground water contamination is an important element of a successful environmental restoration effort at Shiprock. Evaluations of possible rates of water movement through the disposal cell cover and tailings, potential seepage rates out the bottom of the disposal cell, and effects of seepage mixing in the saturated zone may be needed to assure that long-term ground water cleanup goals will be achieved. As part of DOE's evaluation of the performance of the Shiprock disposal cell, this study compared recent soil moisture and hydraulic conductivity monitoring data of the disposal cell cover with monitoring data from a 1988 study.

5.1 Soil Physical Properties

The cover CSL consists of highly compacted silt loam soil. Soils sampled in the CSL borrow pit area were also a silt loam and, therefore, suitable for construction of a neutron hydroprobe calibration model for the CSL. Voids in the 30-cm-thick rock layer have half filled with windblown silt and fine sand since construction of the disposal cell in 1986. Over time this infilling will create a more favorable habitat for plant establishment.

5.2 Hydroprobe Calibration

The soil texture and bulk density of the hydroprobe calibration barrel almost matched the actual Shiprock CSL. Therefore, the linear calibration ($r^2 = 0.99$) produced volumetric soil moisture data with relatively low measurement error.

5.3 Cover and Tailings Moisture Content

The CSL in the Shiprock cover was essentially 100-percent saturation in 2000. Therefore, saturated flow is most likely occurring in the CSL. Although some seasonal wetting and drying of the sand drainage layer occurs, the sand layer remains relatively wet (mean = 35 percent by volume) all year.

The moisture content of the CSL changed little from one hydroprobe port location to another, with depth, or over time. The moisture content of the CSL (mean = 28.8 percent by volume, SEM = 0.6) and the porosity of the top of the CSL (27.1 percent, SEM = 1.7) are statistically the same; therefore, the CSL is essentially 100-percent saturated. The moisture content of the top of the tailings (mean = 27.9 percent by volume, SEM = 0.9) and the calculated porosity of the tailings from the 1988 data (29.4 percent, SEM = 2.4 percent) are also statistically the same. Thus, we can infer that the top of the tailings is also 100-percent saturated. The fact that the neutron hydroprobe comes up dripping wet when lowered into the tailings, even after the port has been bailed, confirms this.

5.4 Saturated Hydraulic Conductivity of CSL and Tailings

The in situ saturated hydraulic conductivity of the CSL, measured on the north side slope as part of a 1998 root intrusion study, was highly variable (range = 4.8×10^{-8} to 1.2×10^{-4} cm/s) and significantly greater (mean = 4.4×10^{-5} cm/s, SEM = 2.5×10^{-5}) than the design target of 1.0×10^{-7} cm/s. One 1988 laboratory measurement of the K_{sat} of the top layer of tailings (3.5×10^{-8} cm/sec) suggests that top layer may have a much lower K_{sat} than the CSL. If true, water percolating through the cover may perch on the tailings. This may be the reason for the standing water in the bottom of the hydroprobe ports.

5.5 Water Flux

If the CSL is continuously saturated, as neutron hydroprobe data indicate, then the passage of water through the CSL and tailings would be greatly influenced by the K_{sat} of both. Under saturated conditions, the hydraulic gradient is approximately 1 and water flux through the cover can be estimated with Darcy's law. Given apparently high variability in the K_{sat} of the CSL and apparently low K_{sat} of the tailings, it is recommended that DOE conduct representative tests of the physical and hydraulic properties of the CSL and tailings layer to evaluate water flux through the disposal cell.

6.0 References

ASTM (American Society for Testing and Materials), 1998. "Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone," (ASTM D5126–90) West Conshohocken, Pennsylvania.

Bouwer, H., 1966. "Rapid Field Measurement of Air Entry Value and Hydraulic Conductivity of Soil as Significant Parameters in Flow System Analysis," *Water Resources Research* 2:729–738.

Caldwell, J.A. 1992. Engineering perspectives for near-surface disposal, pp. 161-198. in Deserts as Dumps? The Disposal of Hazardous Materials in Arid Ecosystems, C.C. Reith and B.M. Thompson (eds.). University of New Mexico Press, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1989. Moisture Contents and Unsaturated Conditions in UMTRA Radon Barriers. UMTRA–DOE/AL, Uranium Mill Tailings Remedial Action Project, United States Department of Energy, Albuquerque, New Mexico.

———, 1989. Technical Approach Document, Revision II, UMTRA–DOE/AL 050425.0002. Uranium Mill Tailings Remedial Action Project, U.S. Department of Energy, Albuquerque, New Mexico.

———, 1991. Analysis of Infiltration Through a Clay Radon Barrier at an UMTRA Disposal Cell. UMTRA–DOE/AL 400667, Uranium Mill Tailings Remedial Action Project, United States Department of Energy, Albuquerque, New Mexico.

———, 2001. Long-Term Surveillance and Maintenance Program 2000 Report. GJO–2000–181–TAR, U.S. Department of Energy Grand Junction Office, Grand Junction, Colorado.

EPA (U.S. Environmental Protection Agency), 1983. Health and Environmental Protection Standards for Uranium Mill Tailings. 48 FR 602, 40 CFR 192, Washington, D.C.

Gardner, W., and D. Kirkham. 1952. Determination of soil moisture by neutron scattering. Soil Science 73:391-401.

Gardner, W.H. 1986. Water Content, pp. 493-544, in A. Klute, ed., Methods of soil analysis, Part I, 2nd ed. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin.

Greacen, E.L. 1981. Soil water assessment by the neutron method. CSIRO, Melbourne, Australia.

Havlena, J.A., and D.B. Stephens, 1992. "Vadose Zone Characterization Using Field Permeameters and Instrumentation," in *Proceedings of the Symposium on Groundwater and Vadose Zone Investigations*, American Society for Testing and Materials, San Diego, California, January 30 through February 1, 1991.

Klute, A. ed. 1986. Methods of soil analysis, Part I, 2nd ed. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin.

NRC (U.S. Nuclear Regulatory Commission), 1989. Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers. Regulatory Guide 3.64 (Task WM 503-4).

Stephens, D.B., M. Unruh, J. Havlena, R.G. Knowlton, Jr., E. Mattson, and W. Cox, 1988. "Vadose Zone Characterization of Low-Permeability Sediments Using Field Permeameters," *Ground Water Monitoring Review* 8:59–66.

Van Bavel, C.H.M., N. Underwood, and R.W. Swanson. 1956. Soil moisture measurement by neutron moderation. *Soil Science* 82:29-41.

Table 1. Summary of Laboratory Methods for Soil Analyses

Soil Property and Method	Reference
Gravimetric Water Content	Klute (1986), Chapter 21, pp. 493-544
Dry-Weight Bulk Density	Klute (1986), Chapter 13, pp. 363-367
Soil Porosity	Klute (1986), Chapter 18, pp. 444-445
Particle Size Distribution	
Sieve	Klute (1986), Chapter 15, pp. 383-442
Hydrometer	Klute (1986), Chapter 15, pp. 383-442

Table 2. Soil Particle Size and Texture Classification for Shiprock Cover CSL and Borrow Area

Sample Location	Sample Number	Sand (%)	Silt (%)	Clay (%)	USDA Classification[a]
Cover CSL	CSL–205	20	59	21	Silt loam
	CSL–206[b]	16	58	26	Silt loam
	CSL–208	22	58	20	Silt loam
	Mean	19	58	22	Silt loam
	SEM[c]	2	0	2	
Soil Borrow Area	SBA–1	32	60	8	Silt loam
	SBA–2	40	44	15	Loam
	SBA–3	38	42	16	Loam
	SBA–4	34	69	3	Silt loam
	SBA–5	40	50	10	Silt loam
	SBA–6	32	63	2	Silt loam
	SBA–7	23	58	19	Silt loam
	SBA–8	38	46	16	Loam
	Mean	35	54	11	Silt loam
	SEM	2	3	2	

[a]USDA soil classification system.
[b]Sample pit was excavated adjacent to ports 206a and 206b.
[c]Standard error of the mean.

Table 3. Gravimetric Moisture Content, Dry-Weight Soil Bulk Density, Porosity, and Saturation for the Shiprock Cover CSL

Sample Number	Description	Moisture Content (wt. %)	Dry Bulk Density (g/cm^3)	Porosity[a] (%)	Water Content (vol. %)	Saturation (%)
205s	Sand drainage layer	2.48				
205csl	Bulk CSL sample	15.28				
205csl(v)	Volume sample of CSL	14.38	1.99	26.8	28.66	(107.3)
206s	Sand drainage layer	2.56				
206csl	Bulk CSL sample	13.32				
206csl(v)	Volume sample of CSL	14.32	1.90	30.1	27.23	90.5
208s	Sand drainage layer	2.41				
208csl	Bulk CSL sample	11.77				
208csl(v)	Volume sample of CSL	11.18	2.04	25.0	22.75	93.5
Mean			1.98	27.1	26.21	97.1
SEM[b]			0.04	1.66	1.78	5.16

[a]A mean particle density of 2.72 g/cm^3 from DOE (1989) was used to calculate porosity.
[b]Standard error of the mean.

Table 4. Soil Particle Size and Texture Classification for Windblown Dust Accumulating in Rock Layer

Sample Location	Sample Number	Sand (%)	Silt (%)	Clay (%)	USDA Classification[a]
Disposal Cell	RD-205	20	75	5	Silt loam
Cover	RD-206	25	66	9	Silt loam
	RD-208	28	65	7	Silt loam
	Mean	24.3	68.7	7.0	Silt loam
	SEM[b]	4.0	5.5	2.0	

[a]USDA soil classification system.
[b]Standard error of the mean.

Table 5. Summary of Analysis of Variance of Data From Hydroprobe Ports in Subsurface Soil at Shiprock Disposal Cell

Layer	Factor	ANOVA *F* Value[a]	*P* Value
Rock	Probe	$F_{3,168} = 1.08$	0.3604
Rock	Date	$F_{8,163} = 2.03$	0.0458
Rock	Depth	$F_{5,166} = 173.24$	0.0000
CSL	Probe	$F_{3,494} = 3.90$	0.0090
CSL	Date	$F_{8,489} = 6.38$	0.0000
CSL	Depth	$F_{17,480} = 4.45$	0.0000

[a]ANOVA = analysis of variance.

Table 6. Results of In Situ Saturated Hydraulic Conductivity Sampling on North Side Slope of Shiprock Disposal Cell Cover Using Air-Entry Permeameters

Site Description	Moisture Content (%)			Dry Bulk Density (g/cm^3)	Wet Bulk Density (g/cm^3)	Calculated Porosity (%)	Air-Filled Porosity (%)	Saturated Conductivity (cm/s)
	g/g (%)	cm^3/cm^3 (%)	Saturation (%)					
Tamarix (*no roots)*	14.8	27.1	87.4	1.83	2.10	31.0	3.9	1.29×10^{-4}
Tamarix (roots)	12.8	24.7	90.1	1.92	2.17	27.4	2.7	4.76×10^{-8}
Chrysothamnus (no roots)	12.3	22.4	71.6	1.82	2.05	31.3	8.9	6.12×10^{-6}
Chrysothamnus (roots)	12.2	22.7	75.7	1.86	2.08	30.0	7.2	5.34×10^{-6}
Salsola (*no roots)*	14.7	24.3	64.3	1.65	1.89	37.8	13.5	1.19×10^{-4}
Salsola (roots)	8.6	15.2	45.9	1.77	1.93	33.1	17.9	5.12×10^{-6}

Table 7. Summary of Physical and Hydraulic Properties of Tailings From the 1988 Study (DOE 1989)

Summary Statistics	Moisture Content (%)			Dry Bulk Density (g/cm^3)	Particle Density (g/cm^3)	Calculated Porosity (%)	Saturated Conductivity (cm/s)
	g/g (%)	cm^3/cm^3 (%)	Saturation (%)				
Mean	12.6	23.3	78.4	1.91	2.72	29.4	3.5×10^{-8}
SEM[a]	2.14	3.23	7.47	0.057	0.014	2.40	NA
Maximum	21.0	36.5	(108.6)	2.06	2.78	41.4	NA
Minimum	5.7	11.7	51.1	1.63	2.67	22.9	NA
n	8	8	8	8	9	8	1

[a]Standard error of the mean.

End of current text

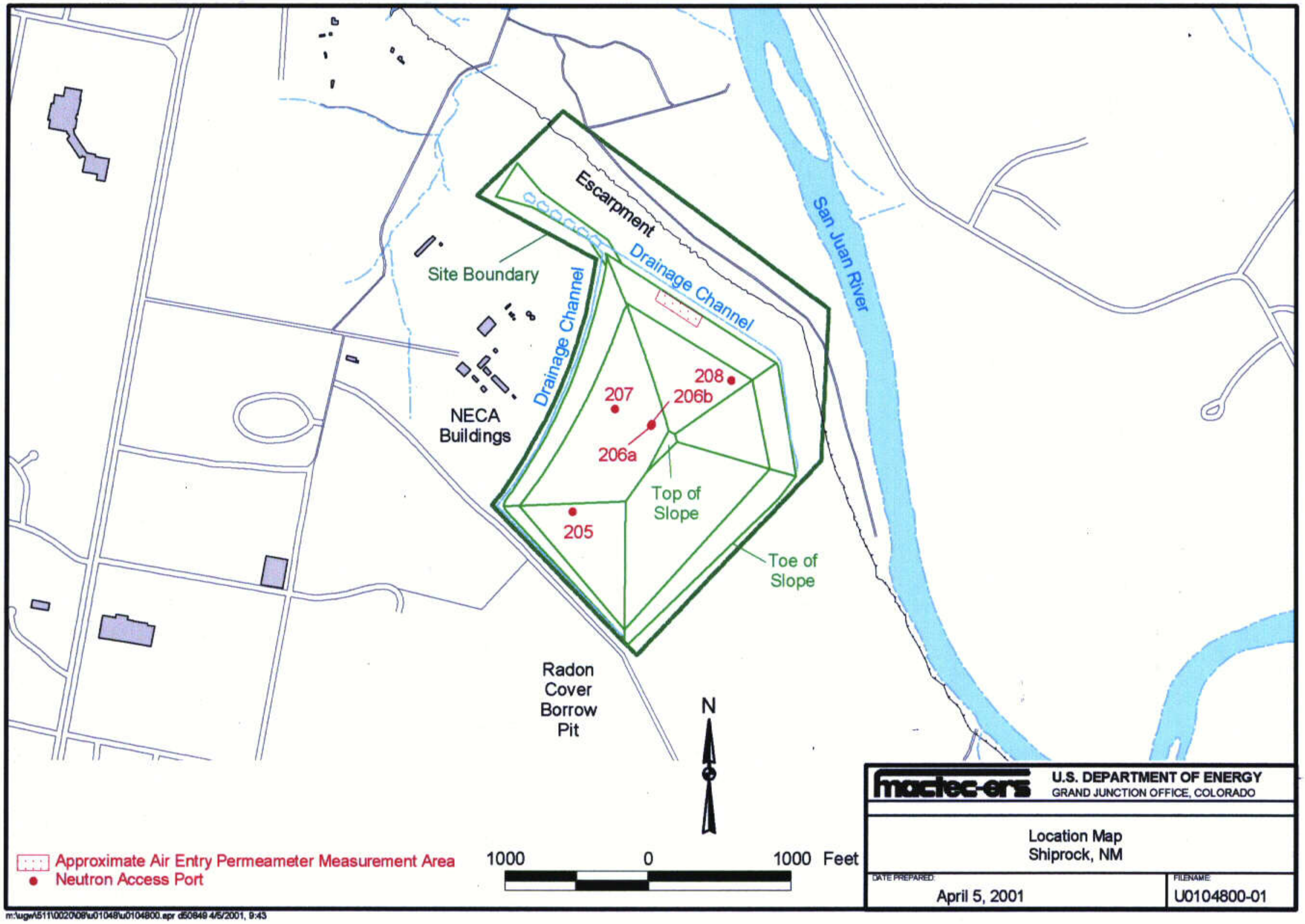
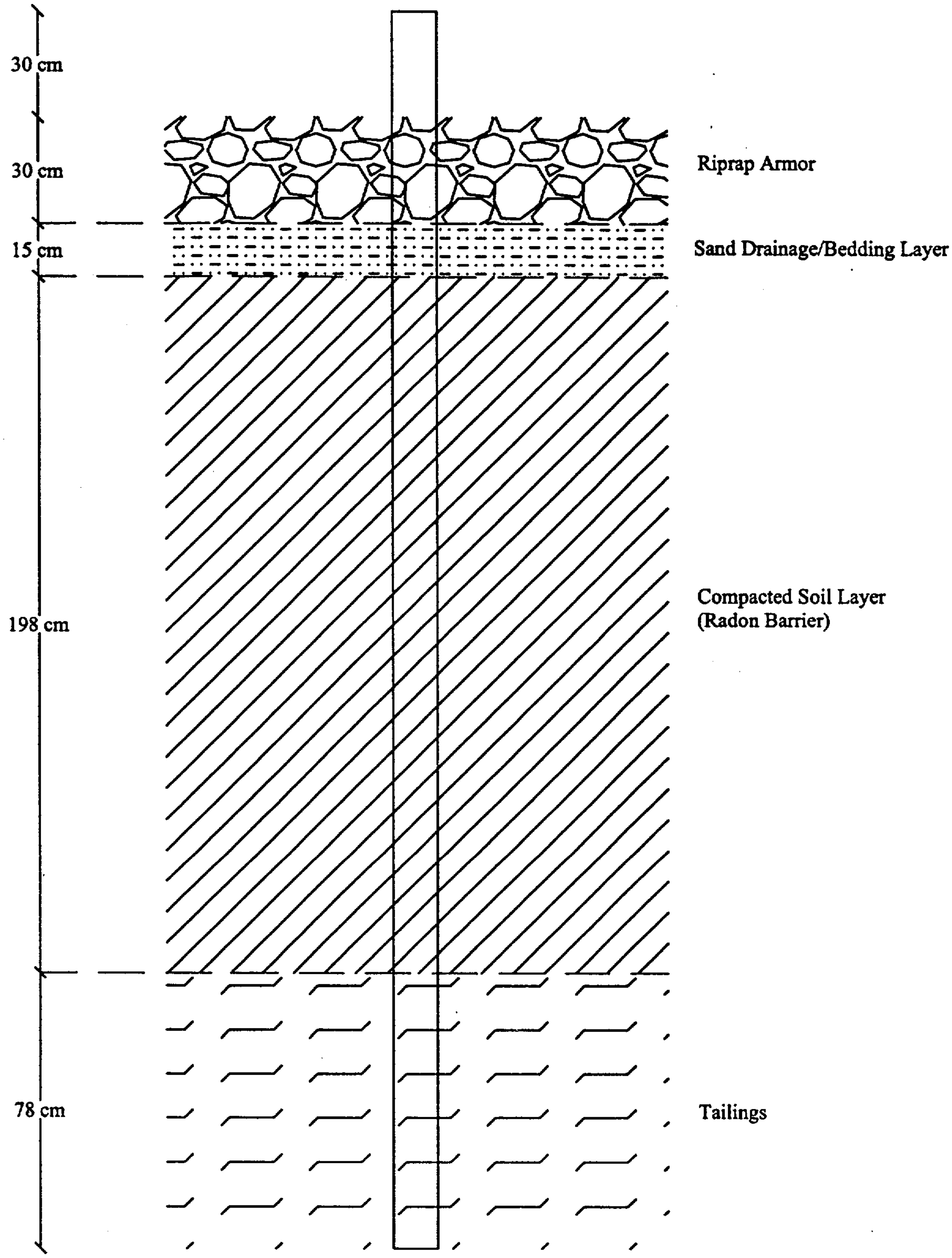


Figure 1. Sampling Locations

C01



K:\ENGR\GWUMTRA\SHIPROCK\511.0020.08\U01037\HYDPORT.DWG

Figure 2. Neutron Hydroprobe Port Depths in the Shiprock Disposal Cell Cover

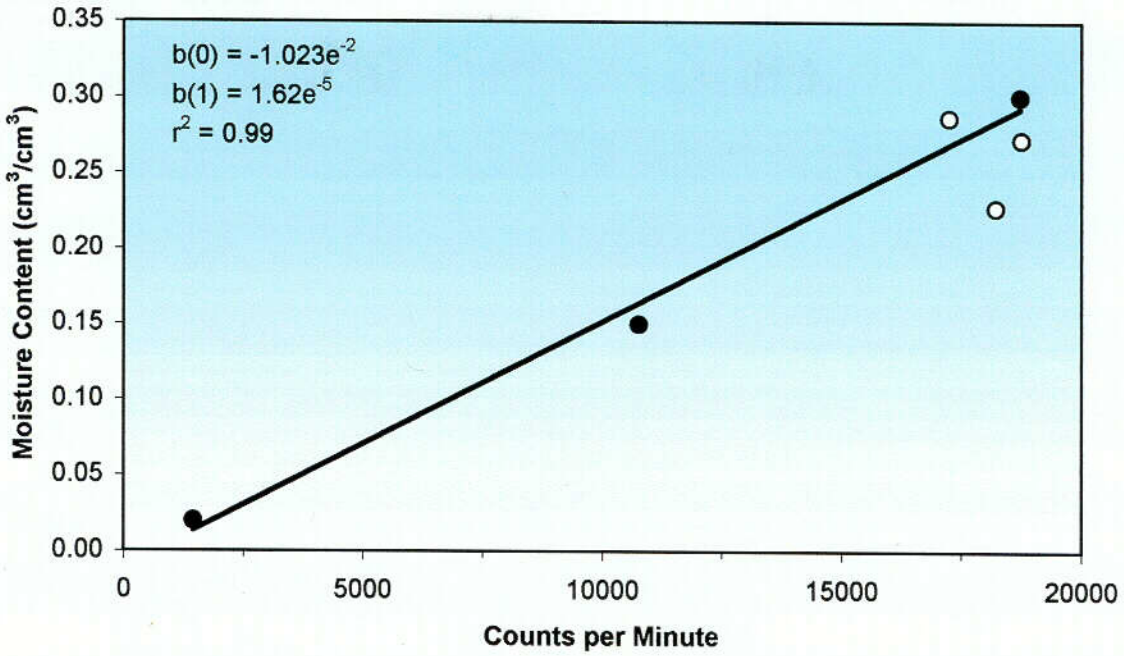


Figure 3. Calibration to Determine Volumetric Moisture Content in Shiprock CSL From Neutron Hydroprobe Data

Note: The calibration included data from barrel measurements only (closed circles). Open circles are results of field measurements.

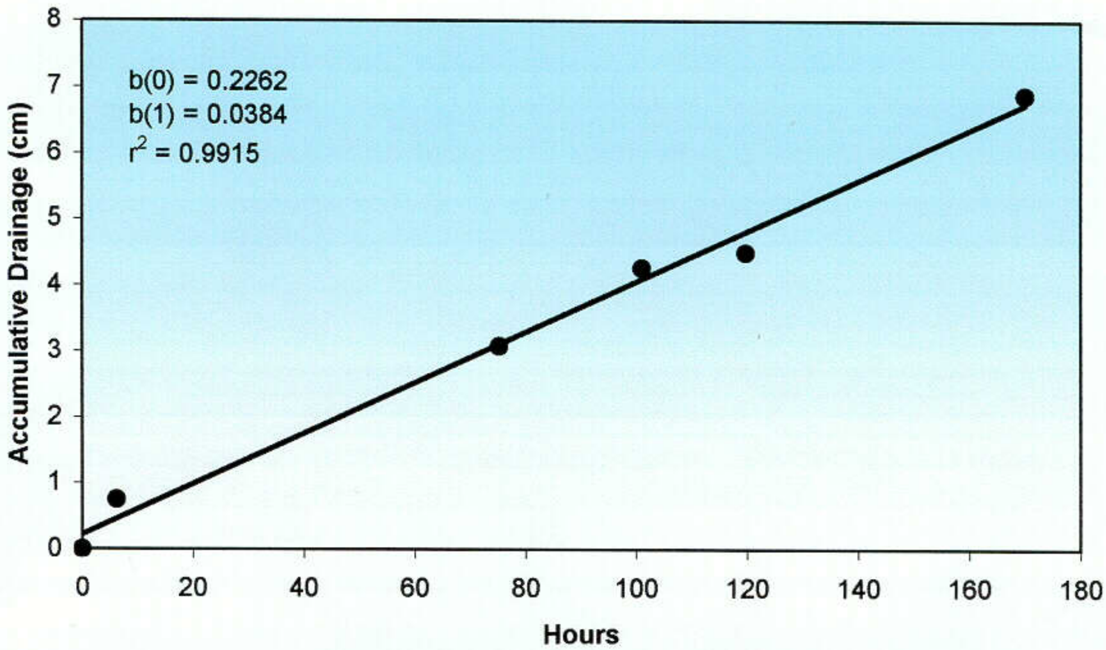


Figure 4. Infiltration of Water Into CSL Soil in a Barrel From Neutron Hydroprobe Data

C02

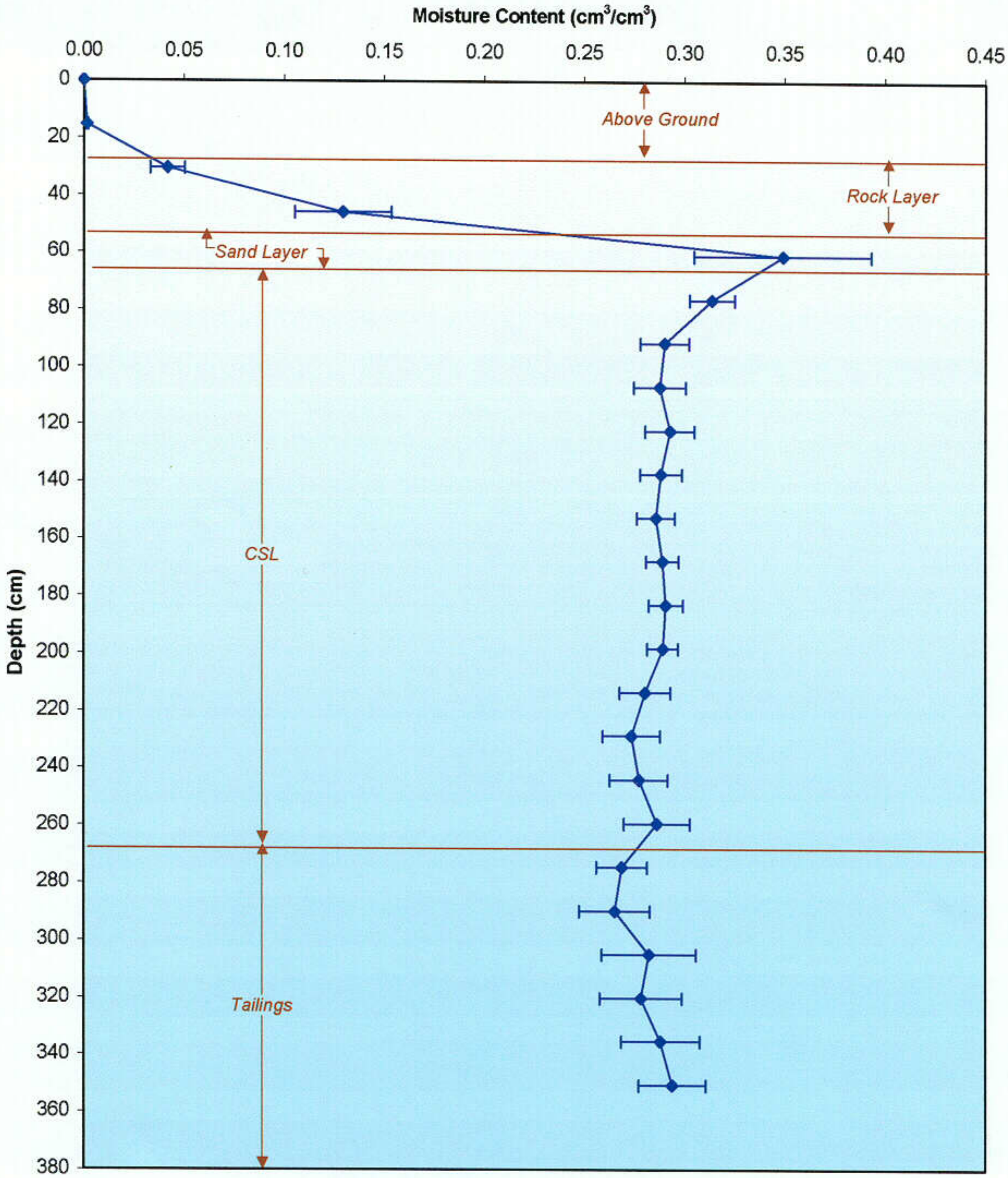


Figure 5. Profile of Volumetric Soil Moisture Content in Disposal Cell Cover and Upper Tailings Averaged for Data From all Probe Ports and Sampling Dates (error bars are 2 SEM)

C03

GJO–2001–276–TAR
MAC–GWSHP13.3–1

UMTRA
Ground Water Project

Results of A Piezocone Investigation Shiprock, New Mexico

February 2002

Prepared by the
U.S. Department of Energy
Grand Junction Office

Work Performed Under DOE Contract No. DE–AC13–96GJ87335 for the U.S. Department of Energy
Approved for public release; distribution is unlimited.

GJO-2001-276-TAR
MAC-GWSHP13.3–1

UMTRA Ground Water Project

Results of A Piezocone Investigation Shiprock, New Mexico

February 2002

Prepared by
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado

Project Number UGW–511–0020–28–003
Document Number U0145400

Work Performed Under DOE Contract Number DE–AC13–96GJ87335

Executive Summary

A piezocone study was performed at the Shiprock, New Mexico, UMTRA disposal cell as a screening-level investigation of in situ moisture conditions within the disposal cell. The purpose of the investigation was to determine if moisture conditions within the cell are saturated, unsaturated, or some proportion of each. Accordingly, 29 piezocone soundings were made on the disposal cell, with three additional attempts made in surrounding drainage channels. Results of the investigation indicate that moisture is present in both saturated and unsaturated conditions.

A majority of the soundings conducted over the southern two-thirds of the disposal cell refused at relatively shallow depths on a dense layer immediately beneath the cover system. Approximately one-half of the soundings advanced in the northern third of the disposal cell extended through the tailings to the underlying alluvial terrace deposit. Soundings advanced in the drainage channels refused at shallow depths on the alluvial terrace deposit. The piezocone tool used in this investigation was equipped with an electrical resistivity module to measure bulk soil electrical resistivity. Depending on chemistry of the pore fluid and soil solids, saturated soils result in very low resistivities when compared to unsaturated soils. The resistivity module was not calibrated for moisture contents of Shiprock tailings or cover soils, so results only indicate relative moisture contents and trends as opposed to absolute values.

Overall, the disposal cell cover is partially saturated as indicated by bulk electrical resistivity measurements. Multiple soil lenses within the disposal cell cover have resistivity readings less than 100 ohm-meters. These lenses indicate saturated zones throughout the entire cover thickness. Such saturated lenses suggest preferential flow through the cover system and that moisture is possibly infiltrating through the disposal cell cover. Likewise, the majority of tailings are partially saturated because of similar occurrence of tailings with bulk electrical resistivities less than 100 ohm-meters. A phreatic surface is not present due to a lack of continuous saturation. Partially saturated soil materials, i.e. tailings, drain in an unsaturated mode for a long, but unknown period of time. Unsaturated drainage is characterized by relatively large drainage volumes initially, but decrease and become asymptotic with time. Tailings deposition was more than 30 years ago, and disposal cell construction was completed 16 years ago, thus the greatest quantity of fluids have drained from the cell. A relatively small quantity of saturated slime tailings exists beneath the northeast facet of the disposal cell. Maximum saturated thickness is approximately 10 feet (ft), with approximately 5.5 ft of excess water pressure creating a minor potentiometric surface in these slimes. Since the majority of tailings are unsaturated the disposal cell is not considered a major continued source of contamination.

Based on results from this investigation a second investigation phase is suggested: (1) to quantify the extent of the saturated slimes, (2) to obtain physical samples of unsaturated soils to develop soil moisture characteristics of the cover and tailings, and (3) to physically measure in situ moisture conditions. Both piezocone soundings and a conventional drilling program are required to obtain this information. Additional piezocone soundings are proposed to delineate the extent of the slimes and will require pre-punching through expected dense layers. Physical samples will be obtained of the cover and tailings materials to determine volumetric moisture contents. Borings will be advanced to obtain continuous samples through the cover and tailings. Installation of a minimum of two pore pressure transducers in a vertical plane in the saturated slimes will quantify the actual hydraulic gradient. Installation of tensiometers will be used to quantify negative pore pressures in unsaturated regions. Results of these investigations will be used to numerically model moisture movement within and from the disposal cell.

1.0 Introduction

As part of the Uranium Mill Tailings Remedial Action (UMTRA) surface project, radioactive surface contamination consisting of tailings and other contaminated soils were encapsulated in a uranium mill tailings disposal cell at Shiprock, New Mexico. Construction of the disposal cell was completed in 1986. The objective of the UMTRA surface program was to mitigate exposure of radon and radon progeny to humans and the environment. Results of analysis of ground water collected from ground water systems at the Shiprock site indicate that contamination from former milling processes has occurred. The U.S. Congress authorized the UMTRA ground water project in the early 1990's charging the DOE with the cleanup of contaminated ground water at UMTRA sites. Thus, cleanup of ground water systems at Shiprock is required under law.

The ground water regime at the Shiprock site has been divided into two components, a terrace ground water system and a floodplain ground water system. These ground water systems appear to be connected, the terrace ground water system flowing slowly into the floodplain ground water system. Contaminated ground water in the terrace system is hypothesized to be a continued source of contamination for the floodplain ground water system. The disposal cell has been suggested as a continuing source of contamination to the terrace ground water system.

Indirect evidence supporting the hypotheses that the disposal cell is the source of the continued contamination include: (1) monitoring data from neutron hydroprobes installed in the cover, (2) results of limited testing of saturated hydraulic conductivity with air-entry permeameters, and (3) numerical modeling results. Hydroprobe monitoring results taken in the year 2000 indicate that the compacted soil barrier layer (radon barrier) of the cover was essentially saturated (Environmental Sciences Laboratory 2001). Air-entry permeameter testing coupled with results from hydroprobe measurements suggest a source of water may be passing through the cover and recharging the tailings. Ground water modeling also provides evidence that the disposal cell may be a continuing source of contamination (DOE 2000)

Determination of moisture flux coming from the disposal cell requires an understanding of the disposal cell's internal moisture condition. Relative moisture content determination of the tailings is possible with a piezocone investigation which does not expose contaminated materials.

This report presents results of a piezocone investigation performed September 21 through 24, 2001, at the Shiprock disposal cell by MACTEC–ERS for the U.S. Department of Energy Grand Junction Office. The report from the piezocone subcontractor, ConeTec, as well as an independent review of ConeTec results performed by Dr. P.K. Robertson, are provided in Appendix A and Appendix B, respectively. Dr. Robertson is a leader and developer in the field of in situ investigations and has developed many geotechnical relationships for the piezocone that are in common use today. Dr. Robertson is a professor in the Department of Civil Engineering, University of Alberta, Edmonton, Alberta, Canada.

2.0 Purpose

The purpose of this investigation was to perform a screening-level determination of internal moisture conditions within the disposal cell. Results can be used to infer if the cell is a continuing source of contamination to the terrace ground water system.

A piezocone was selected for the investigation tool because of its ability to identify material types zones of regions and elevated soil moisture content. Additionally, in zones of saturation, consolidation properties and saturated conductivities are estimated.

Twenty-nine piezocone soundings were made into the disposal cell. Soundings were spaced more-or-less evenly across the surface of the cell; the sounding locations are shown on a site map provided on Figure 1. Three additional soundings were made in the drainage channels along the east, north, and west sides of the cell.

3.0 Methods

Piezocone soundings were used to determine the disposal cell stratigraphy and detect zones of saturation. Higher moisture contents are expected in fine-grain slime tailings compared to other tailing soils. Information provided in preconstruction characterization reports (U.S. DOE 1984) indicated a greater occurrence of slime deposition in the northern portion of the disposal cell, thus more soundings were pushed there.

A piezocone is an in situ soil testing tool that can be described as an instrumented drill rod with a pointed tip. For this investigation, the piezocone tool used was approximately 60 centimeters (2 ft) long with an approximate 4½ cm (1¾ inch) diameter tip (15 square centimeter surface area). A piezocone sounding, or cone penetration test (CPT), is obtained by hydraulically pushing the cone into the soil at a constant rate of 2 centimeters per second. Piezocone instrumentation includes load cells to measure tip resistance or cone bearing pressure, sleeve resistance, a porous element located immediately behind the tip to measure pore pressure, and two electrodes spaced 5 centimeters (cm) apart measuring electrical resistance. Figure 2 in the ConeTec report (provided as an Appendix) illustrates the instrument used, and is reproduced herein as Figure 2. Both dynamic pore pressure and static pore pressures are measured by the piezocone. Dynamic pressures are measured during the push, and static pore pressure is measured after stopping advancement of the cone and allowing dynamic pore pressures to dissipate until an equilibrium state is reached. Measurement of pore pressure decay is called a pore pressure dissipation (PPD) test.

The relationship between the cone bearing pressure, sleeve friction and dynamic pore pressure is used to indicate material type. The quotient of sleeve friction divided by the cone bearing pressure produces the friction ratio. Natural or native soil types have been inferred to relationships between cone bearing pressure and friction ratio (Robertson, 1990). An example of soil behavior types that are indicated by a piezocone are shown on Figure 1 of the ConeTec report for natural soils. Cone data reduction for all soundings is provided by ConeTec in the attached report. Additional classification relationships between cone bearing pressure and friction ratio for uranium mill tailings have been derived by Larson and Mitchell (1986). Figure 3 illustrates these relationship which are based on grain-size fractions listed in Table 1. The computer program "Piezo" (Larson and Mitchell 1986) was used to classify the uranium tailings.

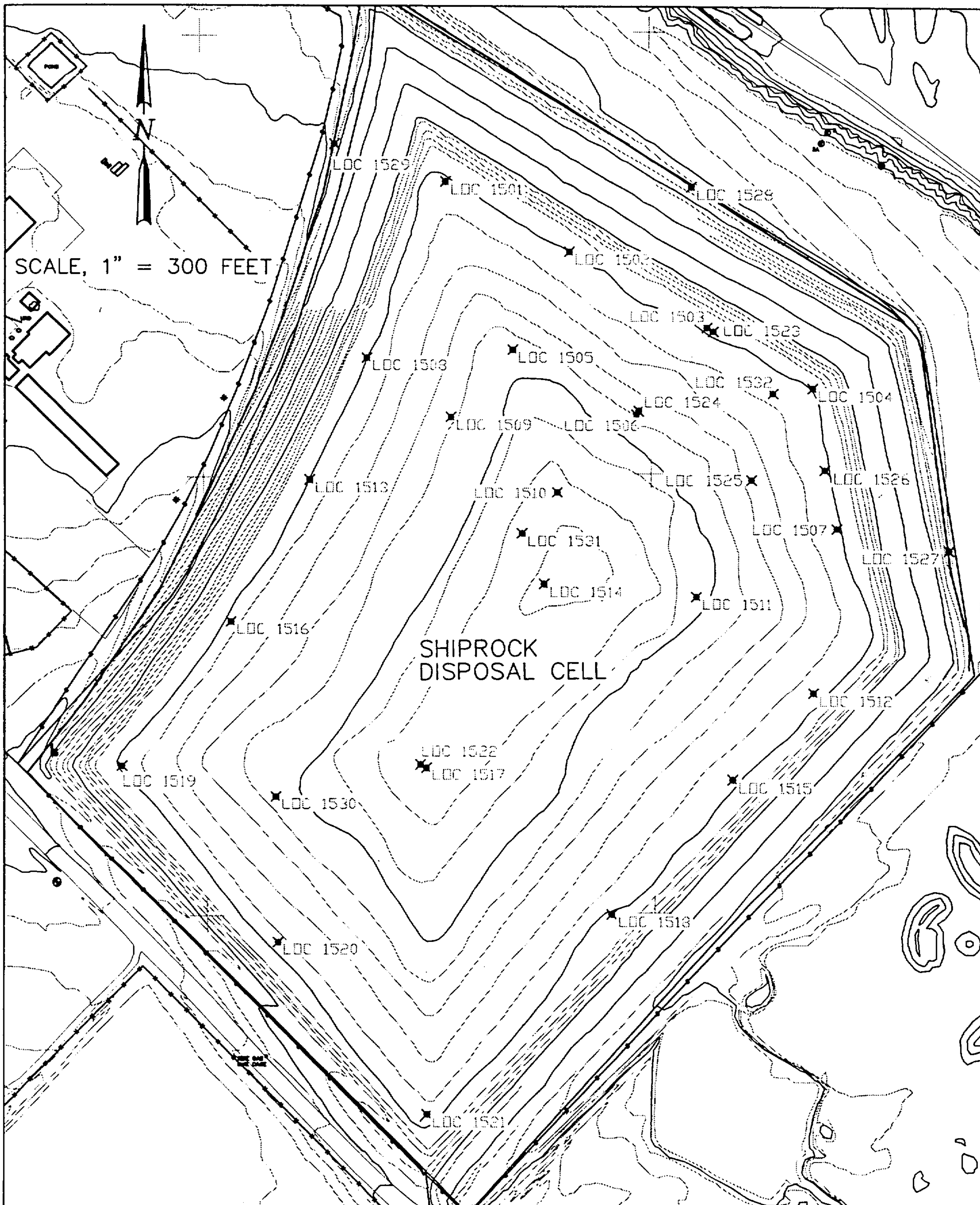
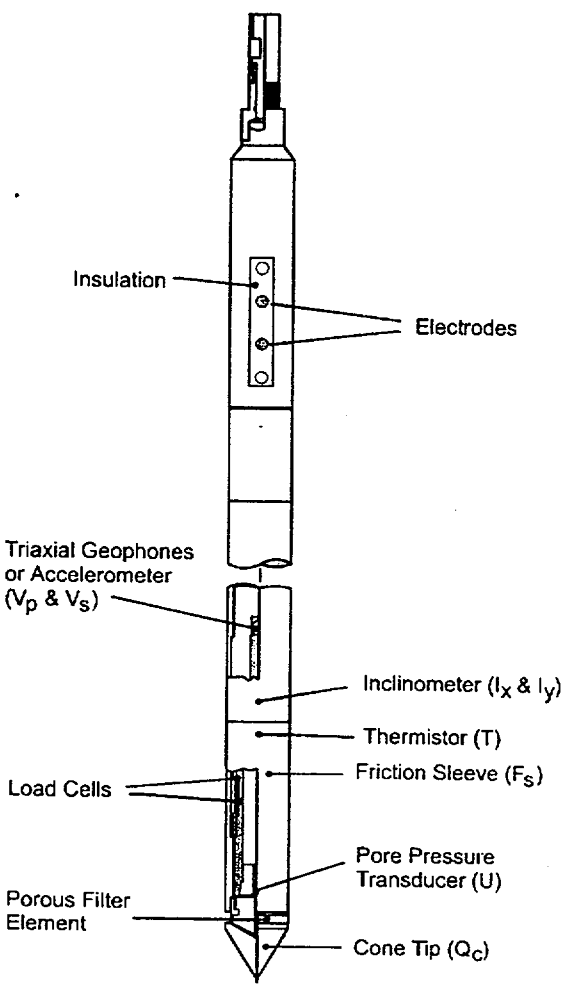


Figure 1. Shiprock Disposal Cell Piezocone Investigation Sounding Location

THE ELECTRICAL RESISTIVITY CONE



The resistivity cone penetration test (RCPTU) combines the downhole analysis of soil resistivity and the logging capabilities of the cone penetration test (CPTU). The RCPTU provides a rapid, reliable and economic means of determining soil permeability, stratigraphy, and strength in addition to providing relative measurements of electrical resistivity. The ability to determine groundwater and soil resistivity and various other soil parameters in one operation on a near continuous basis allows for the accurate profiling of contaminated groundwater plumes as well as some estimate of the rate and direction of groundwater flow through the soil. Identification of the lateral and vertical extent of contaminants enables the engineer/scientist to rapidly implement a remedial works or recovery program thereby mitigating the potential damage caused by contaminated groundwater seepage. To the left is an illustration of ConeTec s resistivity cone.

Ref: ConeTec, Geotechnical and Environmental Site Investigation Contractors

Figure 2. The Electrical Resistivity Cone

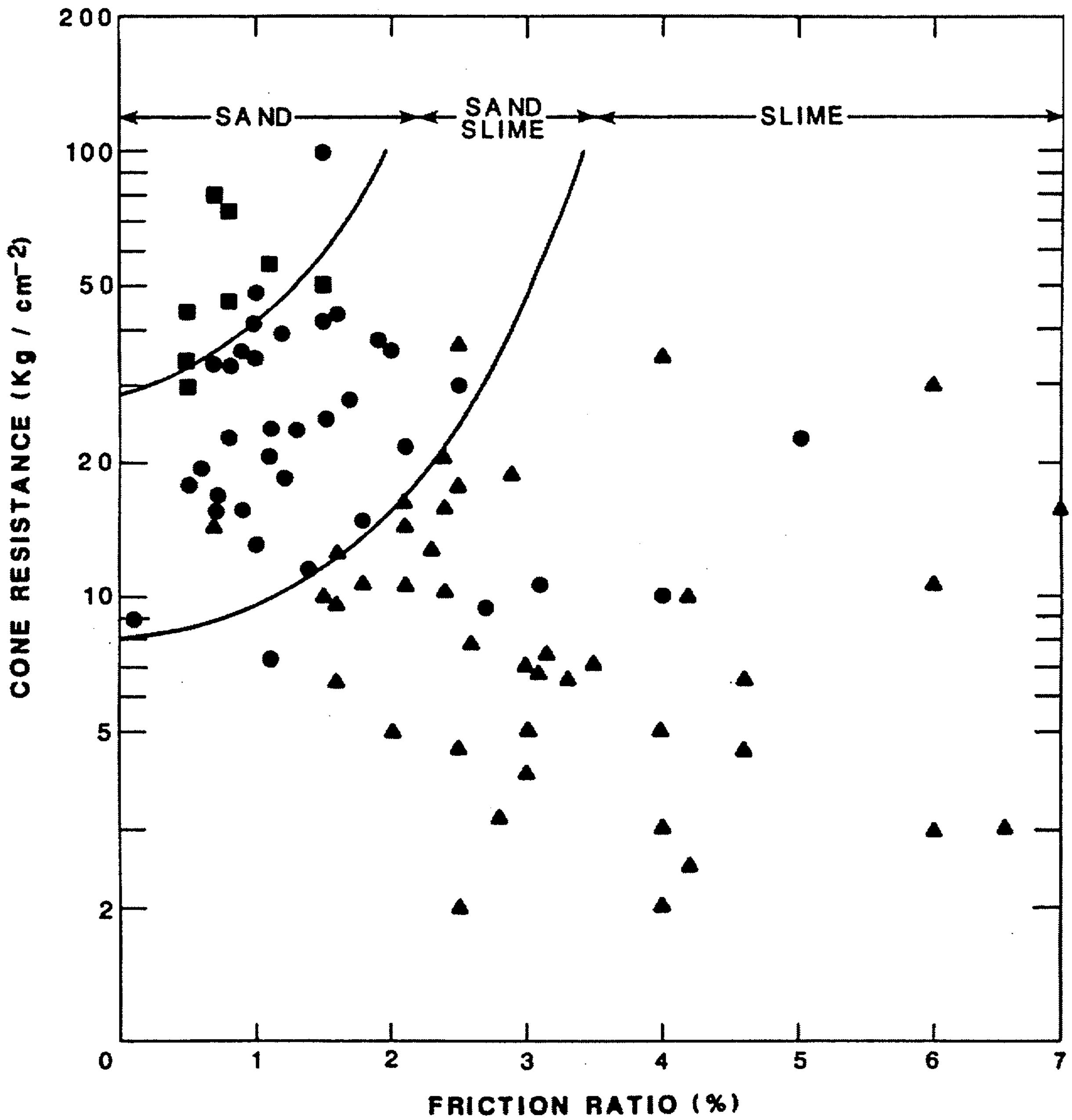


Figure 3.Piezocone Classification Chart Used for Uranium Mill Tailings

Table 1. Uranium Mill Tailings Classification

Description	Percent Passing #200 Sieve
Sand	0 to 30
Sand-slime	30 to 70
Slime	70 to 100

Cover soils are identified with relationships provided by ConeTec, and tailings stratigraphy is determined with relationships from "Piezo". An interpretation of disposal cell stratigraphy is shown on copies of sounding logs presented in the Results section (4.0). Bulk electrical resistivity measurements were made and recorded in conjunction with each sounding to indicate zones of saturation. Measurements were obtained with a separate resistivity module that is attached approximately 0.7 meter (2.3 ft) behind the cone tip as shown on Figure 2. Measurements are made across two electrodes spaced approximately 5 cme (approximately 2 inches) apart. Thus, resistivity measurements were not recorded 0.7 m above refusal depth or at the termination of the push. As the electrodes pass through a saturated or nearly saturated soil, a low resistance is recorded. Passing the probe through unsaturated soils results in higher resistances measured. As indicated by Dr. Robertson, saturated tailings can have bulk electrical resistivities less than 100 ohm-meters, while unsaturated tailings will have bulk electrical resistivities greater than 10,000 ohm-meters. When a rock is present and the electrodes pass by it, a high resistance will be recorded even though the soil is saturated. A slightly higher moisture condition than is present prior to the sounding will be measured in partially saturated soils because the cone will compact soils immediately in front and to the side of the cone during penetration. Therefore, nearly saturated soils will become saturated because of the void ratio decrease the soils experience during the test. This does not pose a practical problem because soils near saturation will behave much as saturated soils.

4.0 Results

Graphical output provided by ConeTec for each sounding, along with MACTEC–ERS interpretations, are given on Figures 4 through Figure 35. Soundings and cross-section locations are shown on Figure 36. Soundings were advanced to refusal at all locations. In situ moisture conditions are shown by bulk electrical resistivity measurements that indicate relative moisture trends; unfortunately, absolute moisture contents are not available. For use in this report, in situ moisture conditions are grouped into the following categories:

1. Unsaturated moisture conditions – materials that exhibit moderate to high bulk electrical resistivities greater than 10,000 ohm-meters,

2. Partially saturated moisture conditions – materials that have multiple internal soil lenses with bulk electrical resistivities less than 100 ohm-meters, and

3. Nearly saturated to saturated moisture conditions – complete soil thickness with bulk electrical resistivities less than 100 ohm-meters.

5.0 Cover

In this report, the cover is defined as the radon barrier layer that is beneath the erosion control rock and sand bedding layers. Results indicate an average cover thickness of 6.7 ft. Native soil behavior types are used to describe the cover. Soil types include sands, silts, sandy silts, silty sands, and clayey silts. A dense gravelly zone at the base of the radon barrier stopped many penetrations of the piezocone probe. Refusal was indicated by high point resistance and high sleeve resistance. Across the southern portion of the disposal cell, this layer is indicated on the logs as cemented sand as shown on cross-section A – A', Figure 37. These cemented sands are

nearly saturated. Piezocone results show numerous lenses of soil possessing bulk electrical resistivities less than 100 ohm-meters throughout the entire cover thickness across the pile. For example, zones with bulk electrical resistivities less than 100 ohm-meters occur within the upper 2 ft of the cover at some locations, (soundings 1501 and 1508); at the base of the cover, (soundings 1503 and 1508); and below the cover (soundings 1501 and 1516). However, attempt to correlate these lenses between soundings was unsuccessful.

6.0 Tailings

As shown on cross-sections B–B' on Figure 38, the tailings materials typically consist of sands, sand-slimes, and slimes. Soundings advanced across the southern portion (southern two-thirds) of the disposal cell, 1513 through 1522 and 1530 reveal sand-slime tailings exclusively except for 1516, which is all sand tailings. Slimes were not encountered in any soundings. Refusal of these soundings consistently occurred within tailings fill, above the projected alluvial terrace surface. Approximate elevation and depth to the terrace alluvium was determined from boring logs of ground water monitor wells installed around the disposal cell. Unsaturated moisture conditions prevail in tailings in the southern two-thirds of the disposal cell.

Sand-slime and slime tailings dominate tailings materials in the northern one-third of the disposal cell. Slimes are interspersed in sand-slimes on the western half of this northern one-third. Forty seven percent of the soundings advanced in the northern one-third refused on the projected alluvial terrace surface, and the remainder refused within the tailings fill. Partially saturated moisture conditions dominate the tailings with saturation occurring in perched lenses in sands and slimes on the western side. An approximate 10-foot maximum thickness of saturated slimes is present beneath the northeastern facet of the cell as shown on cross-sections A–A' and B–B', Figure 37 and Figure 38, respectively. Saturated slimes occur along the north and northeast portion of the disposal cell as shown in Figure 36.

7.0 Pore Pressure Dissipation Tests

Eight PPD tests were performed in the investigation for times varying from 600 to 5200 seconds. Static pore pressures achieved during PPD testing are provided on Table 2. Copies of PPD plots are provided in the ConeTec report and are analyzed to estimate the degree of consolidation. Time to reach 50 percent consolidation [t_{50}] are determined from PPD plots and are listed on Table 2. Coefficient of consolidation values are estimated from relationships presented by Robertson et al., (1992).

Table 2. Summary of PPD, Estimated Time to 50% Consolidation [t_{50}] and Horizontal Coefficient of Consolidation [c_h]

Sounding	Material[a]	Depth of Test (ft)	Static Pore Pressure (ft)	t_{50} (min)	c_h (cm^2/min)
1501	S-SL tails	29.2	1.6	0.7	11.3
1502	SL tails	30.2	8.8	8.3	1.1
1504	SL tails	25.6	13.0	2.6	3.0
1507	SL tails	25.6	14.3	5.6	1.5
1513	S-SL tails	15.1	0.0	0.8	10.5
1519	S-SL tails	12.6	0.7	28.6	1.3
1523	SL tails	30.8	2.7	1.6	4.8
1526	S-SL tails	25.4	18.0	6.7	1.2

[a]S-SL tails are sand- slime tailings; SL tails are slime tailings.

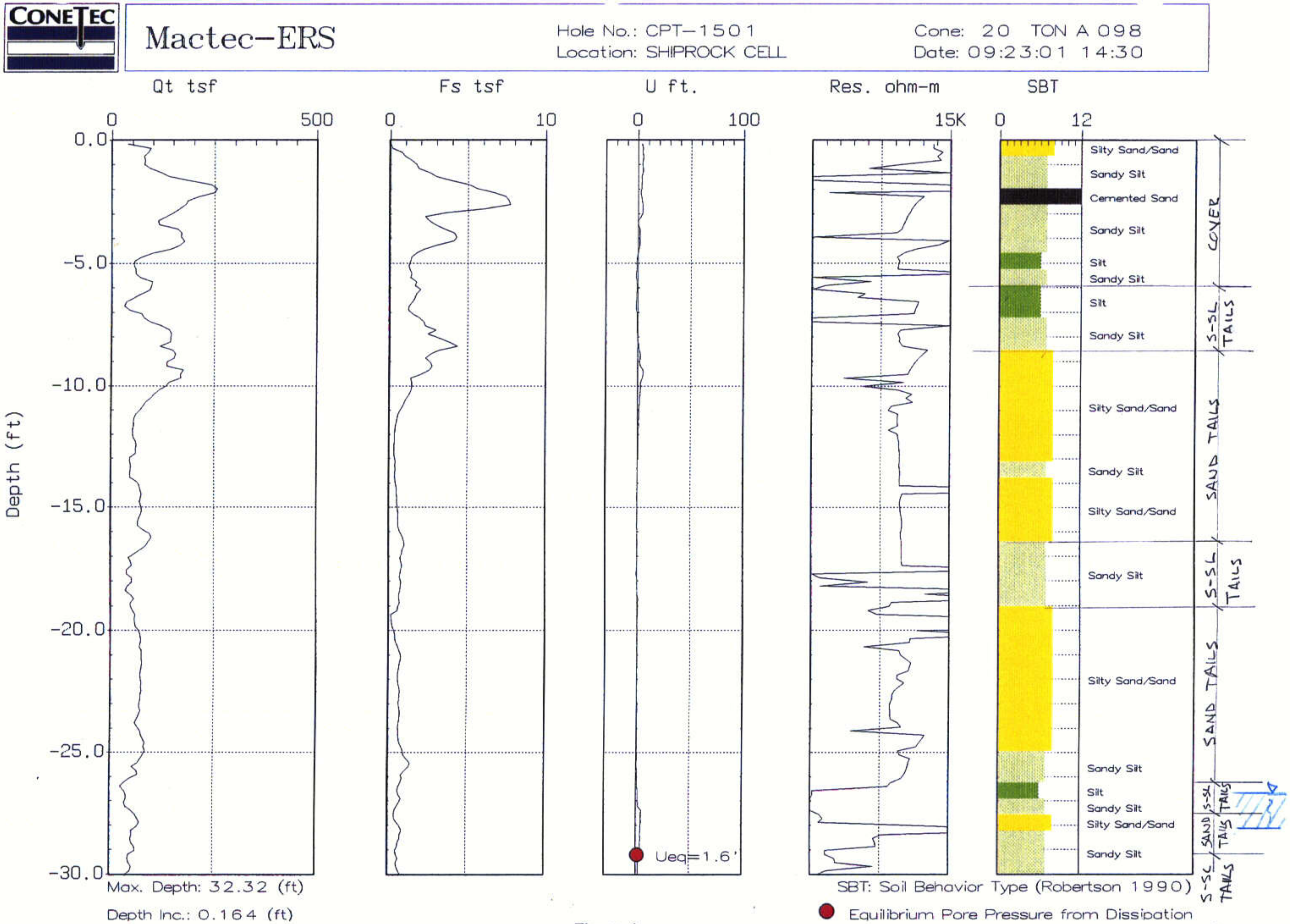

CONETEC
Mactec-ERS
Hole No.: CPT-1501
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:23:01 14:30
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Ueq=1.6'
Silty Sand/Sand
Sandy Silt
Cemented Sand
Sandy Silt
Silt
Sandy Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
COVER
S-SL TAILS
SAND TAILS
S-SL TAILS
SAND TAILS
S-SL TAILS
SAND TAILS
S-SL TAILS
Max. Depth: 32.32 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 4

C04

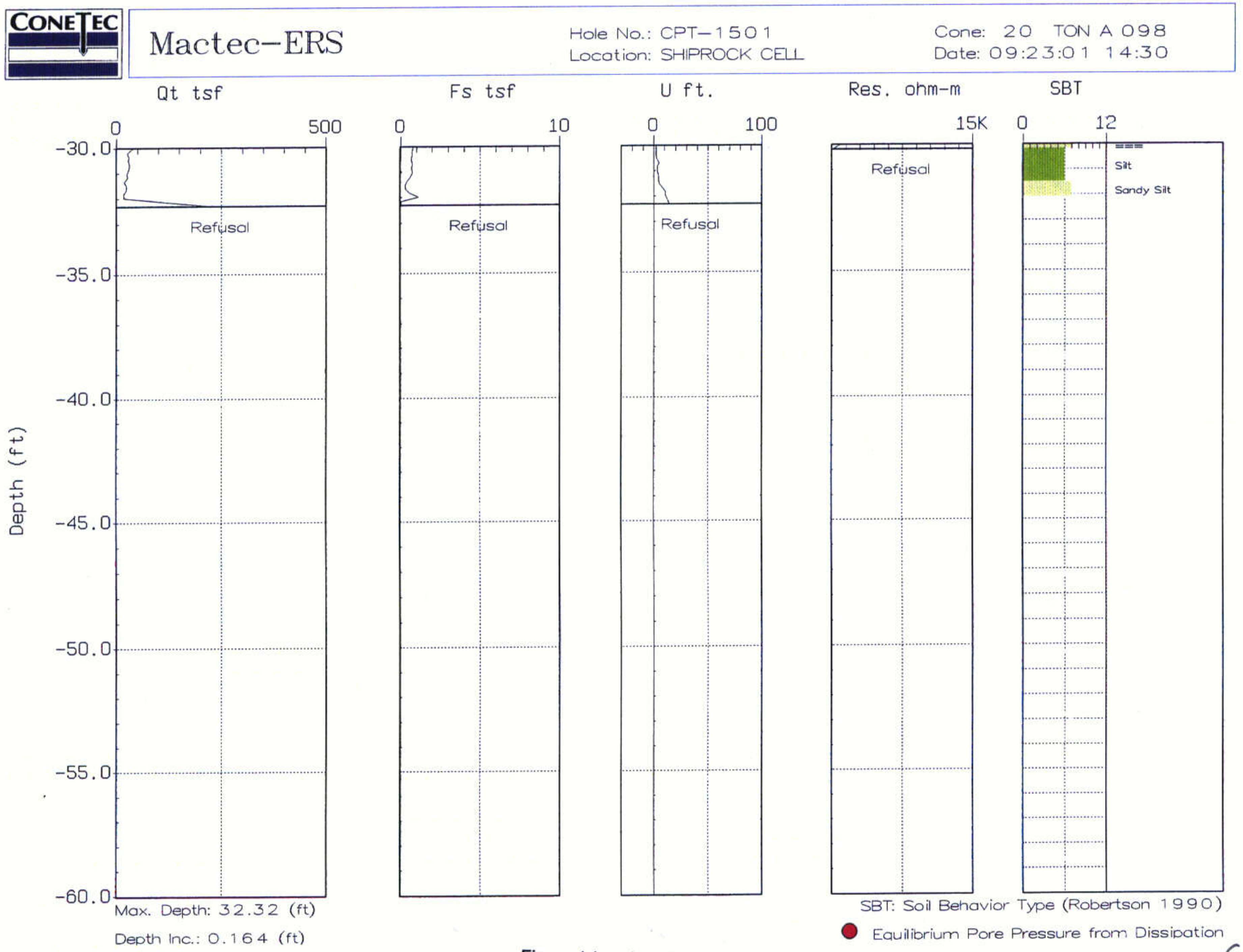
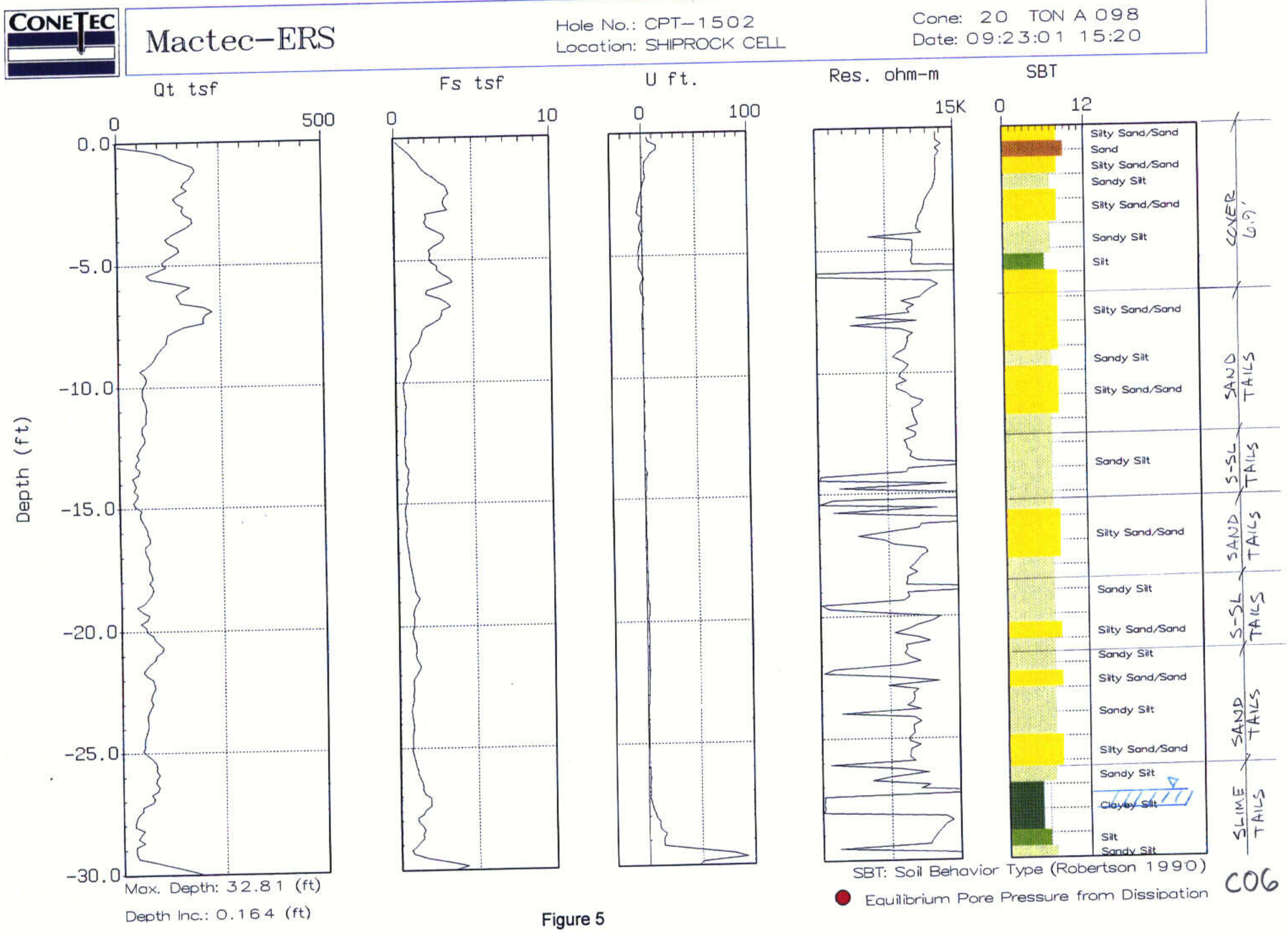


Figure 4 (continued)

C05



CONETEC
Mactec-ERS
Hole No.: CPT-1502
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:23:01 15:20
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Silty Sand/Sand
Sand
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Clayey Silt
Silt
Sandy Silt
COVER 6.9'
SAND TAILS
S-SL TAILS
SAND TAILS
S-SL TAILS
SAND TAILS
SLIME TAILS
Max. Depth: 32.81 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C06

Figure 5

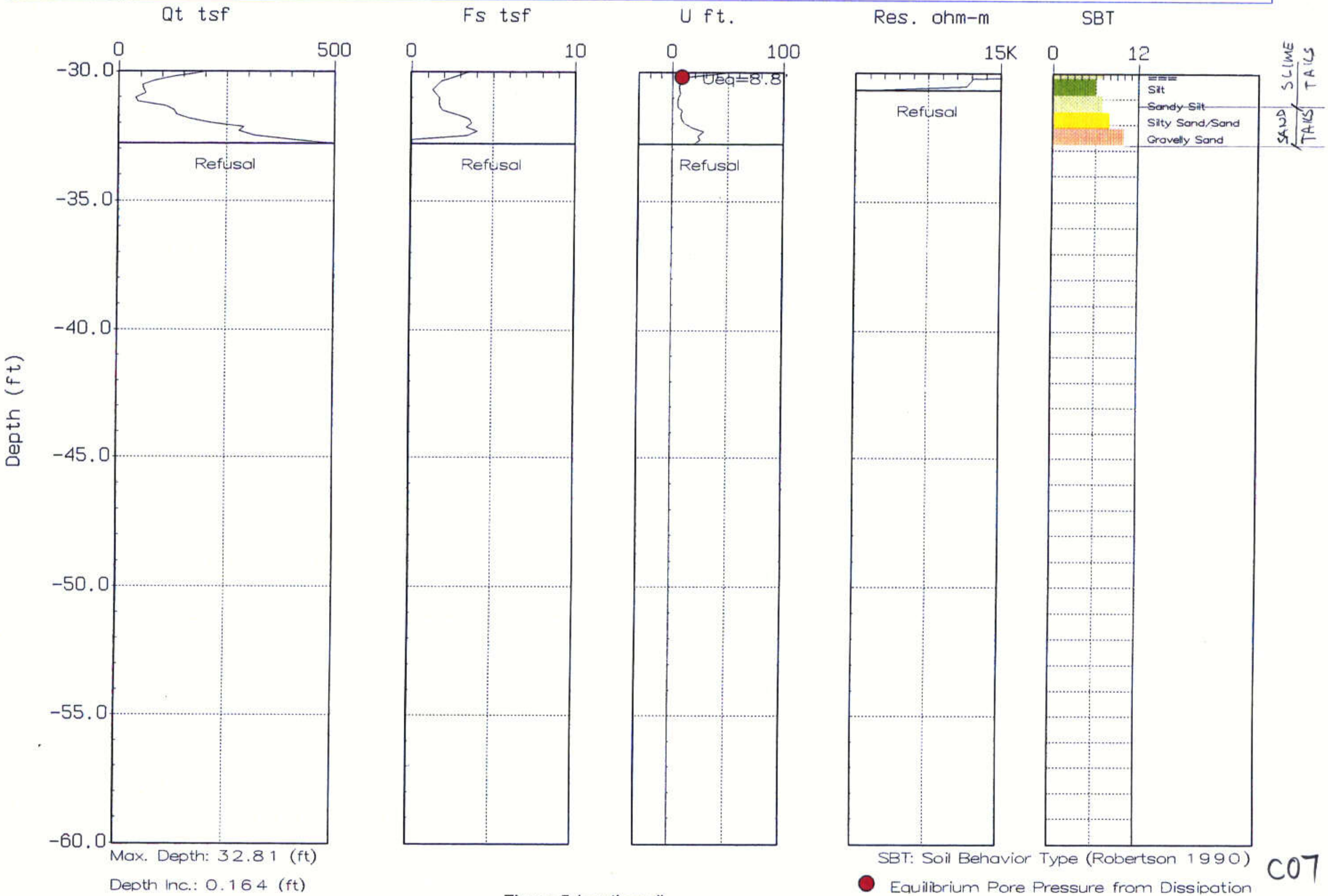


Figure 5 (continued)

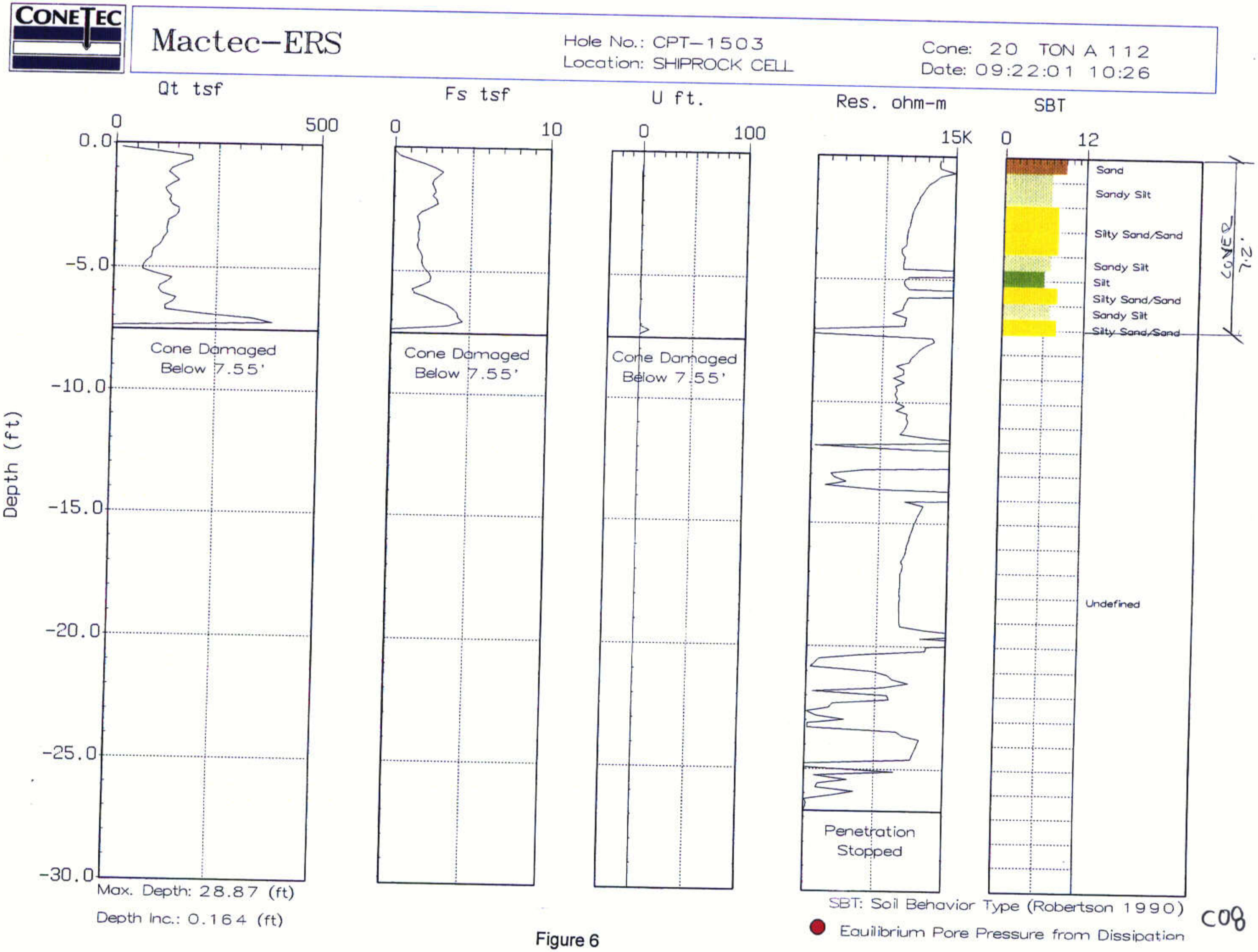
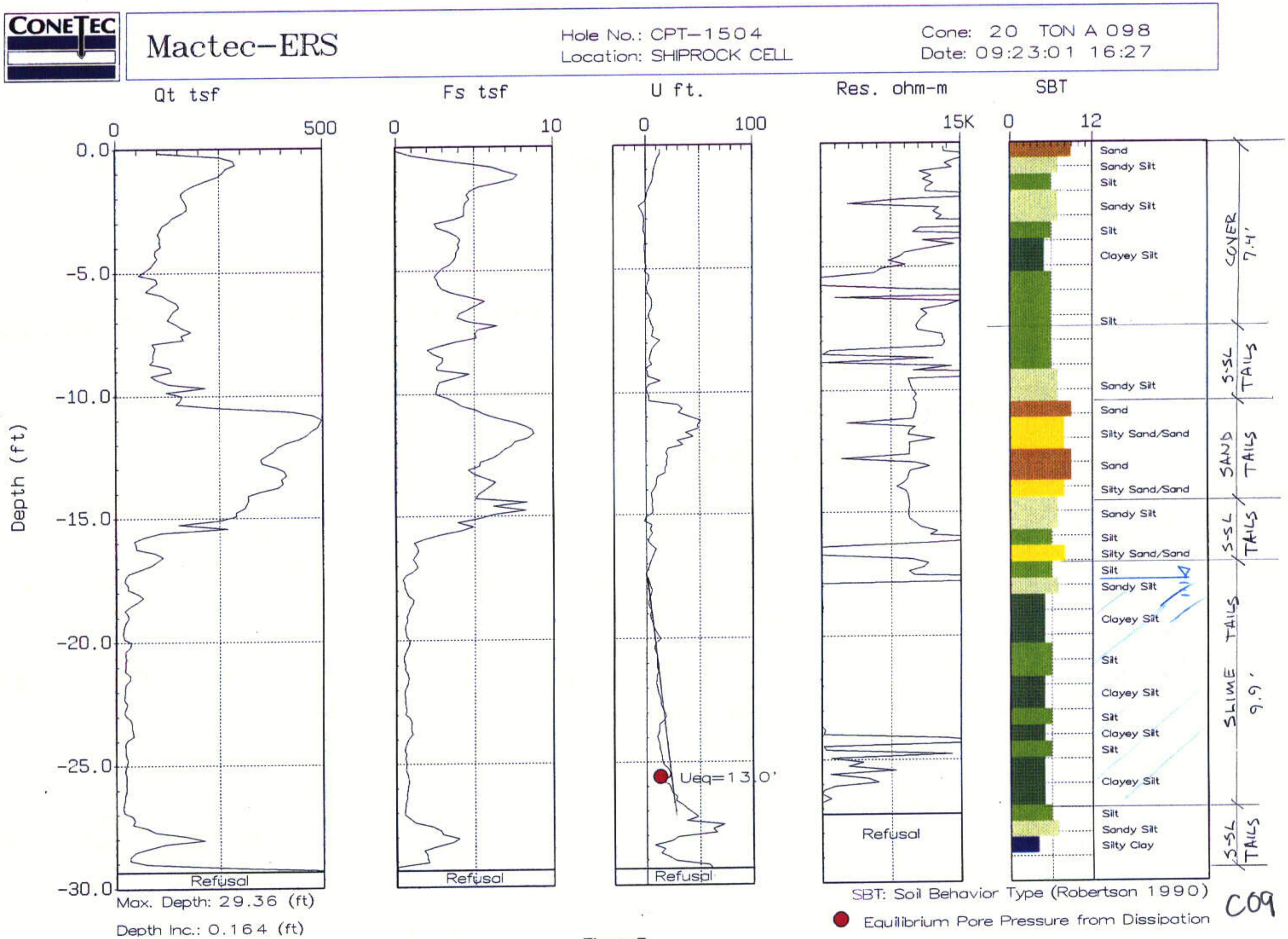
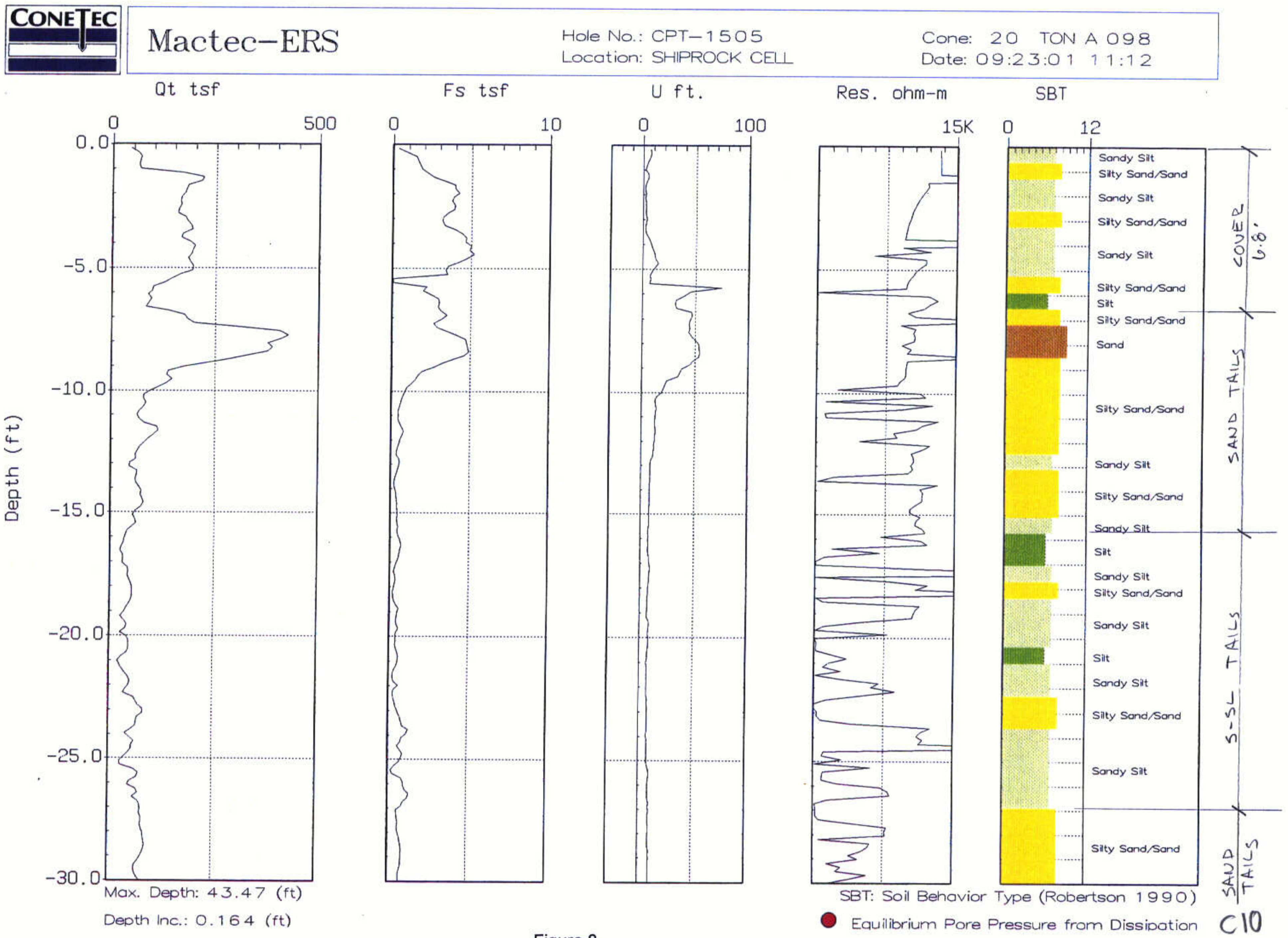

CONETEC
Mactec-ERS
Hole No.: CPT-1503
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:22:01 10:26
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Cone Damaged Below 7.55'
Penetration Stopped
Sand
Sandy Silt
Silty Sand/Sand
Silt
Undefined
COVER 7.2'
Max. Depth: 28.87 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C08

Figure 6



CONETEC
Mactec-ERS
Hole No.: CPT-1504
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:23:01 16:27
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Refusal
Ueq=13.0'
Sand
Sandy Silt
Silt
Clayey Silt
Silty Sand/Sand
Silty Clay
COVER 7.4'
S-SL TAILS
SAND TAILS
SLIME TAILS 9.9'
Max. Depth: 29.36 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C09

Figure 7



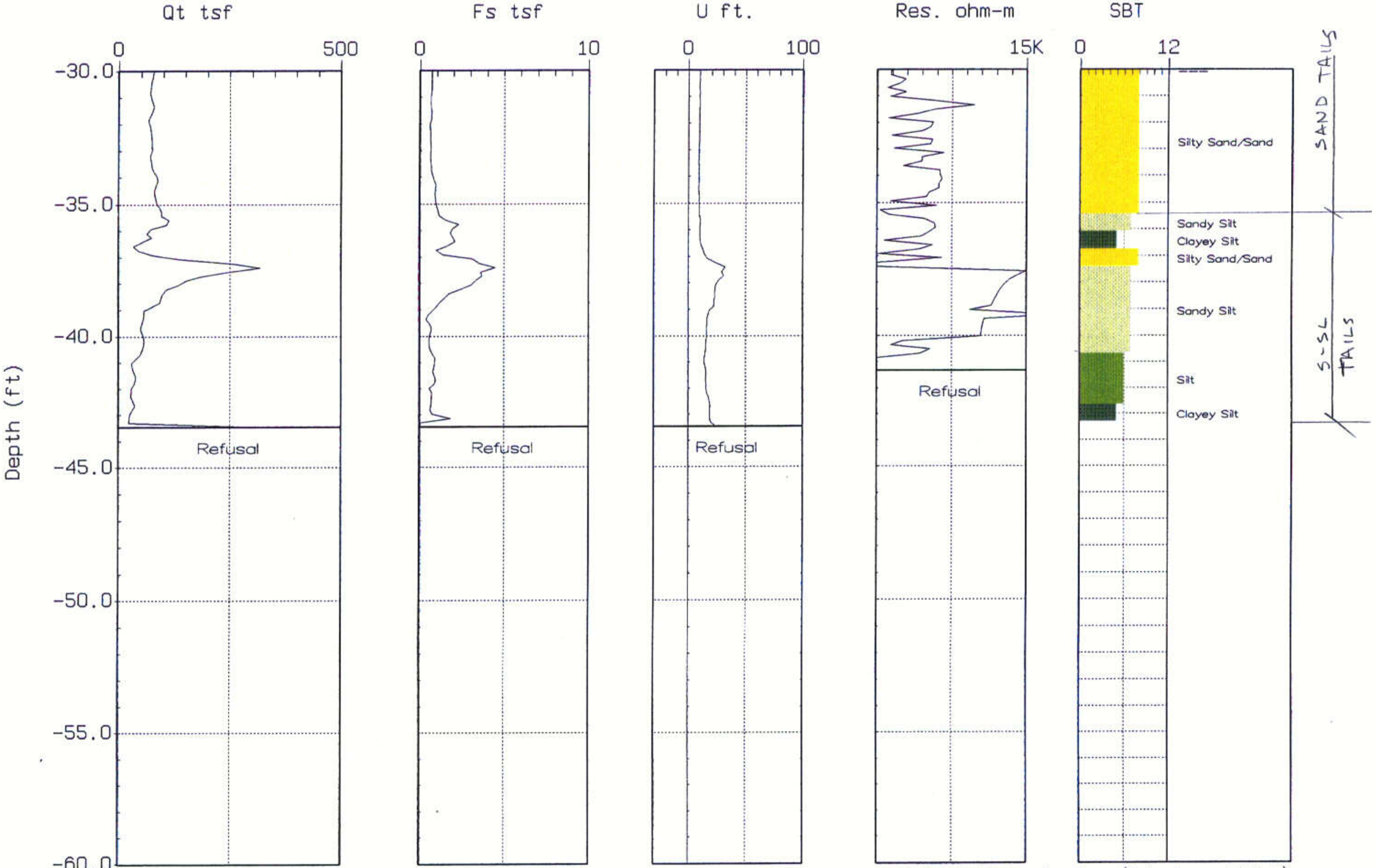
CONETEC
Mactec-ERS
Hole No.: CPT-1505
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:23:01 11:12
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Sandy Silt
Silty Sand/Sand
Silt
Sand
COVER 6.8'
SAND TAILS
S-SL TAILS
SAND TAILS
Max. Depth: 43.47 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C10

Figure 8

Mactec-ERS

Hole No.: CPT-1505
Location: SHIPROCK CELL

Cone: 20 TON A 098
Date: 09:23:01 11:12



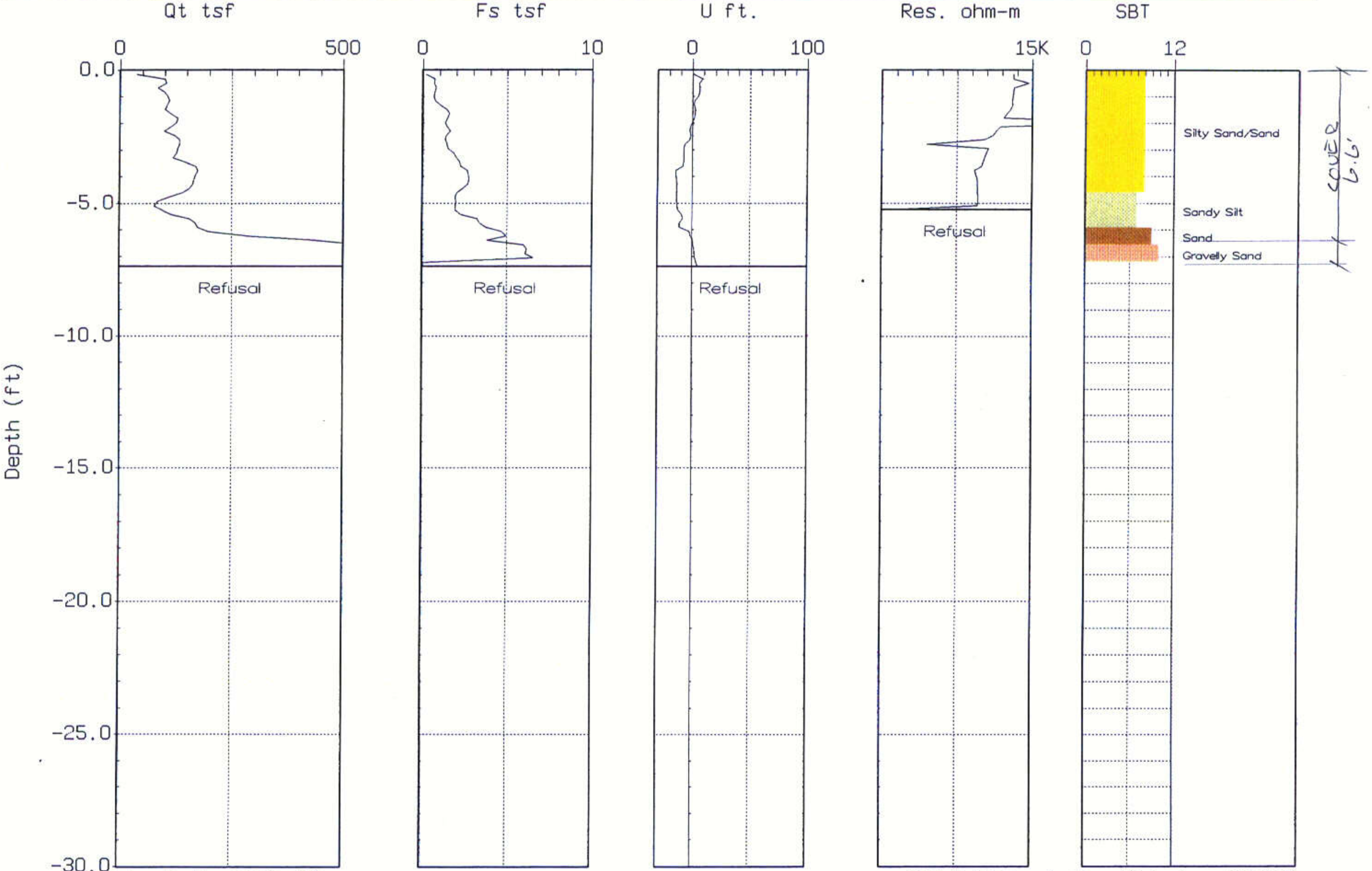
Max. Depth: 43.47 (ft)
Depth Inc.: 0.164 (ft)

SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

C11

Figure 8 (continued)

Mactec-ERS	Hole No.: CPT-1506 Location: SHIPROCK CELL	Cone: 20 TON A 112 Date: 09:22:01 10:07



Max. Depth: 7.38 (ft)

Depth Inc.: 0.164 (ft)

SBT: Soil Behavior Type (Robertson 1990)

Equilibrium Pore Pressure from Dissipation

C12

Figure 9

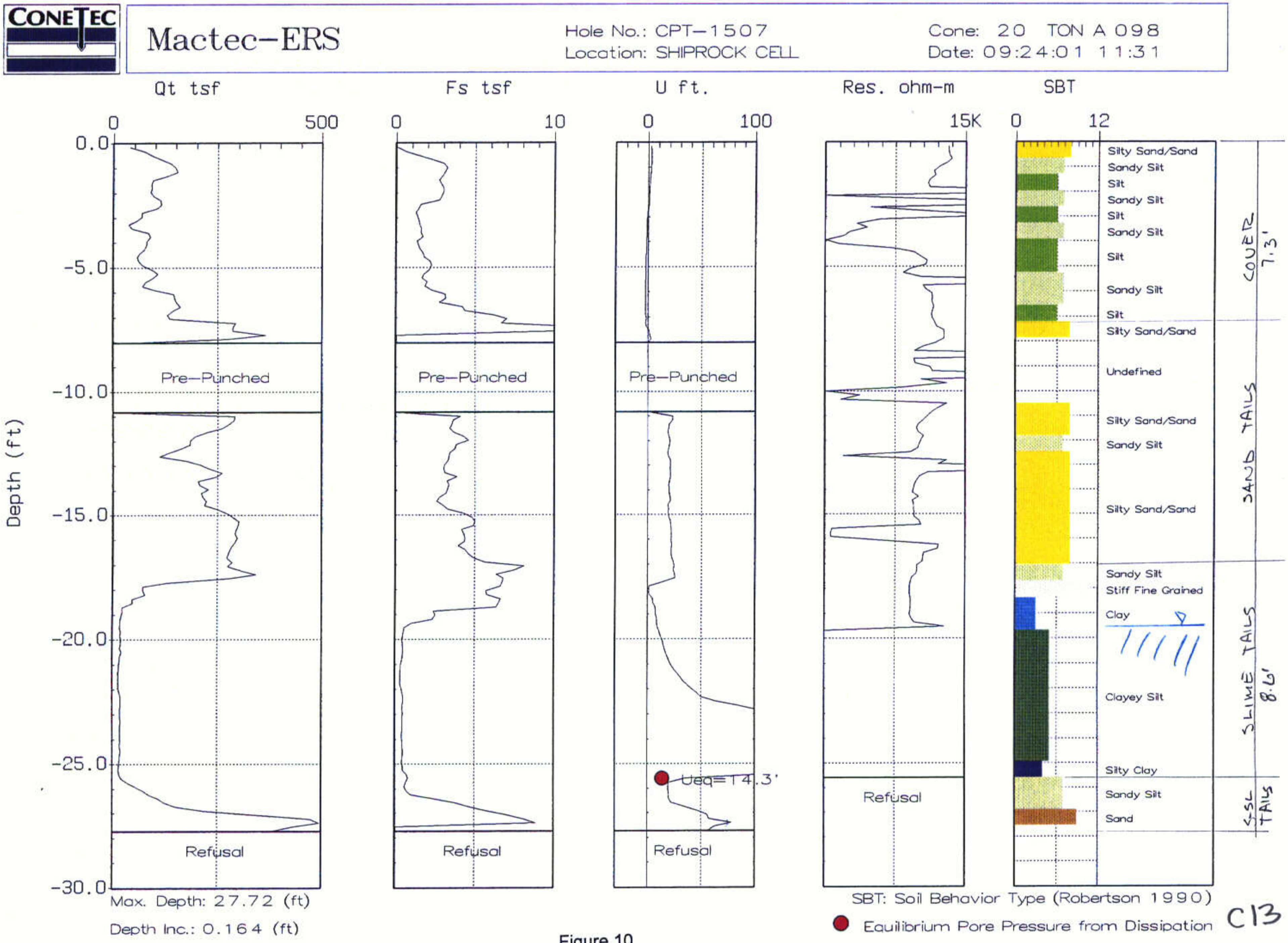

CONETEC
Mactec-ERS
Hole No.: CPT-1507
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:24:01 11:31
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Pre-Punched
Refusal
Ueq=14.3'
Silty Sand/Sand
Sandy Silt
Silt
Undefined
Stiff Fine Grained
Clay
Clayey Silt
Silty Clay
Sand
COVER 7.3'
SAND TAILS
SLIME TAILS 8.6'
S-SL TAILS
Max. Depth: 27.72 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C13

Figure 10

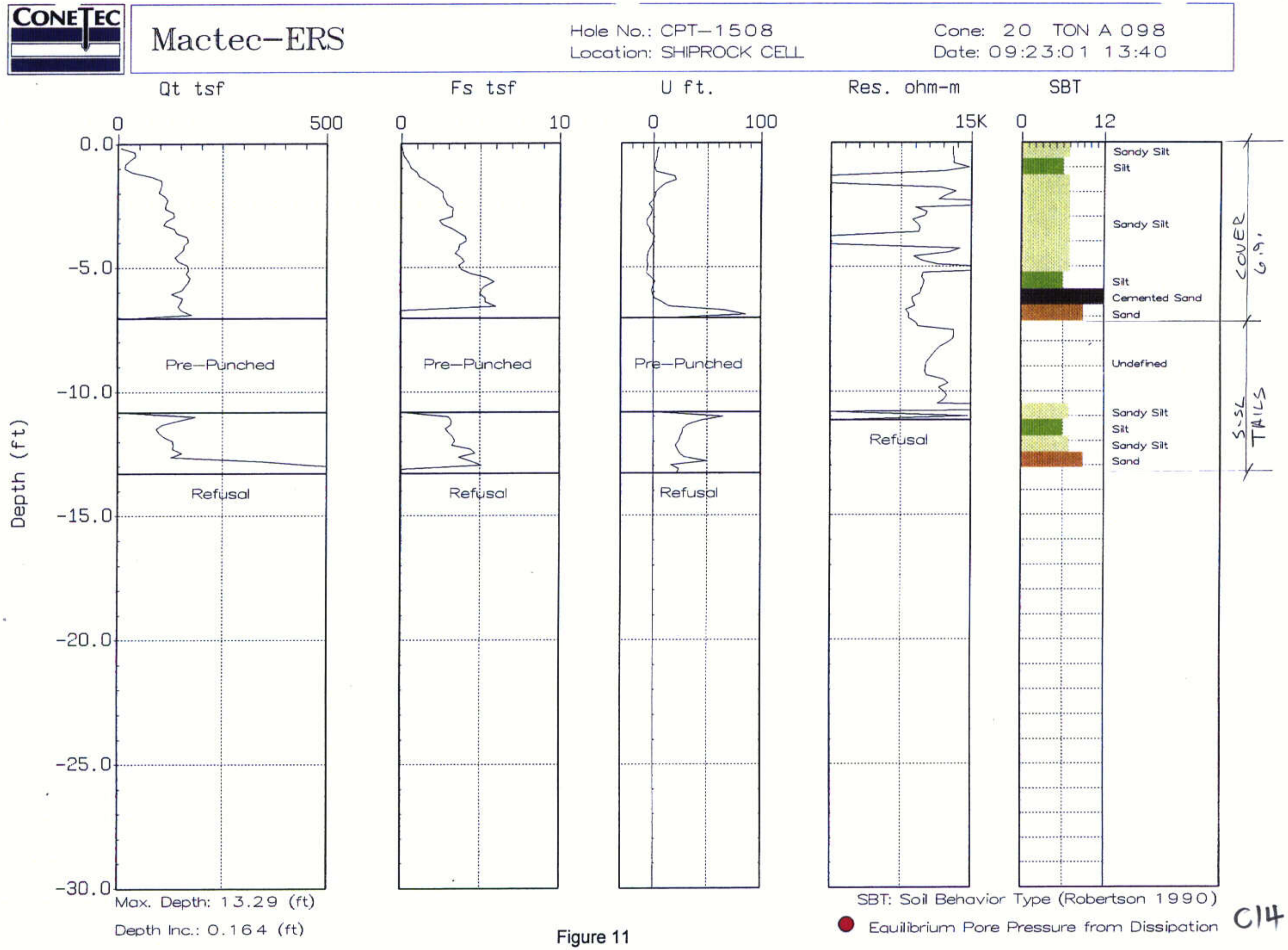


Figure 11

C14

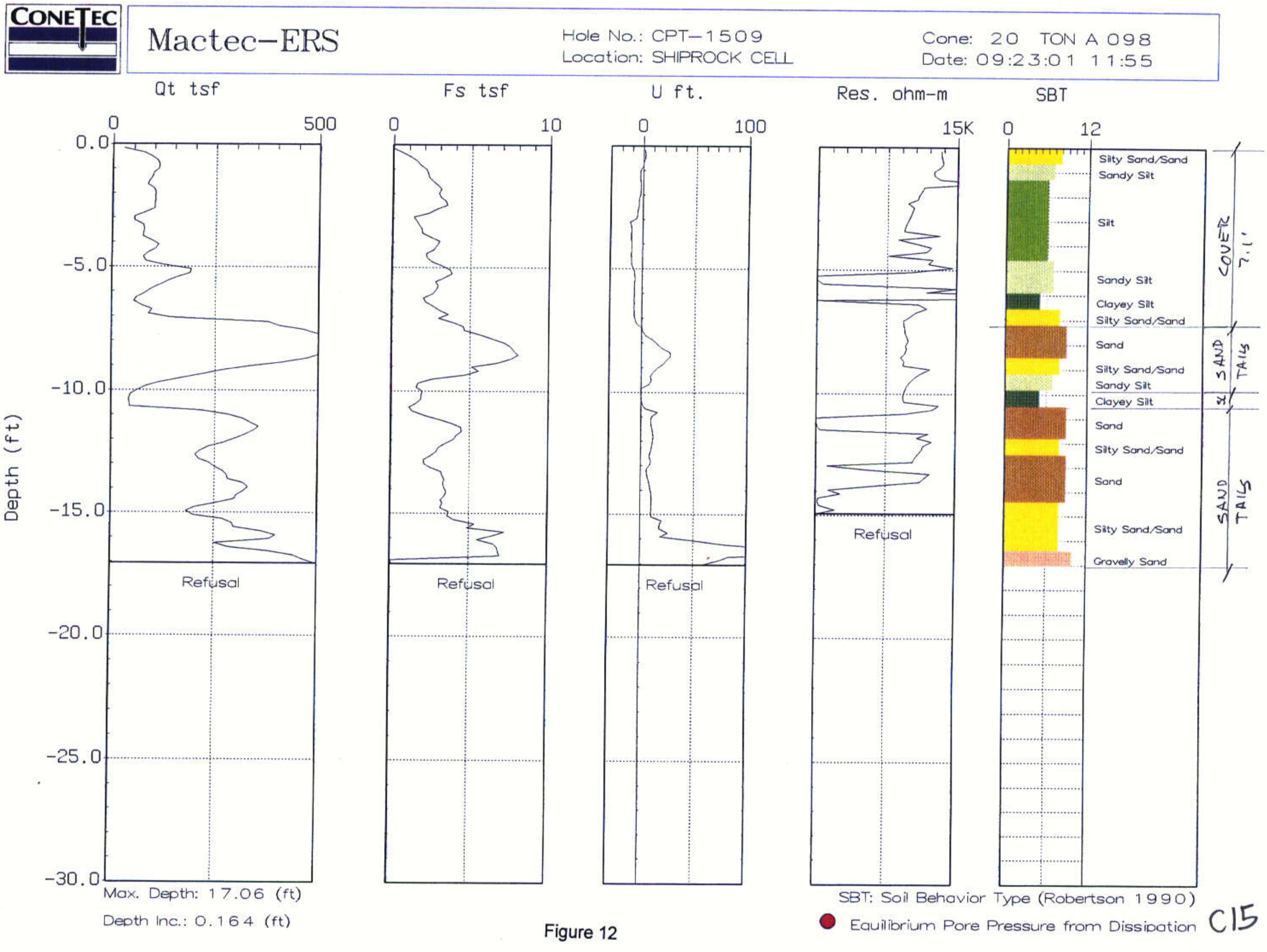


Figure 12

C15

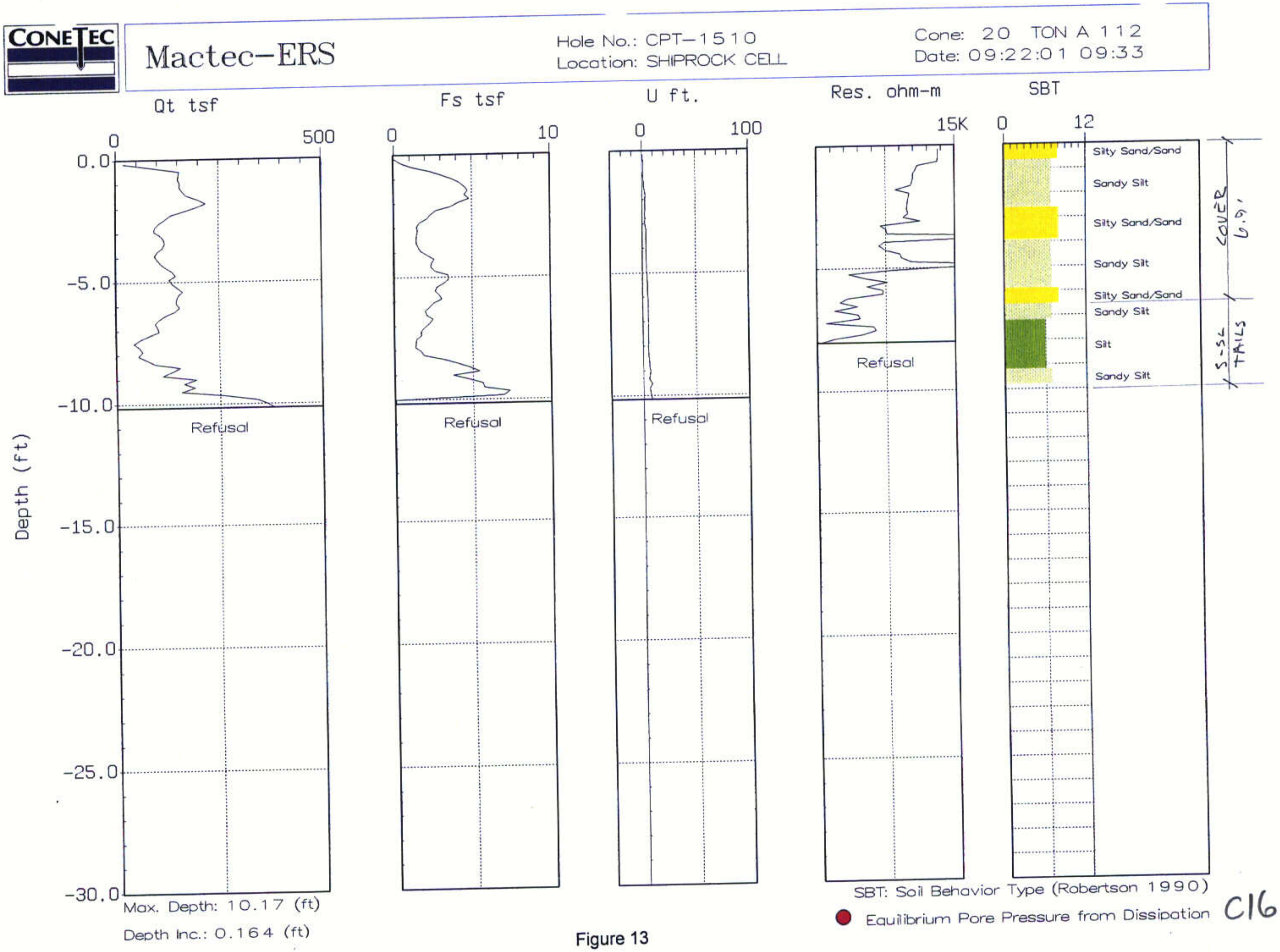
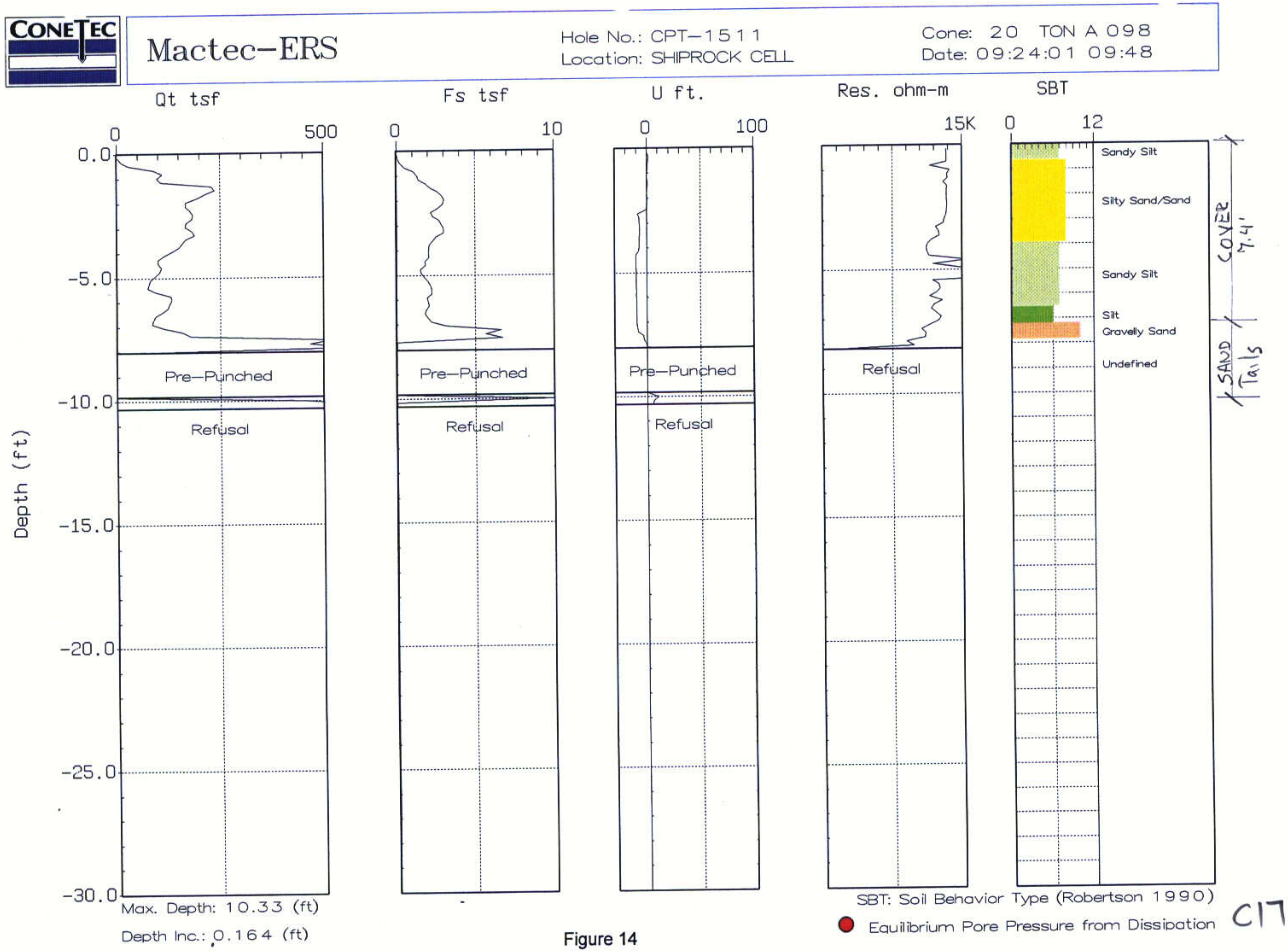

CONETEC
Mactec-ERS
Hole No.: CPT-1510
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:22:01 09:33
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Silty Sand/Sand
Sandy Silt
Silt
Max. Depth: 10.17 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C16

Figure 13



CONETEC
Mactec-ERS
Hole No.: CPT-1511
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:24:01 09:48
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Pre-Punched
Refusal
Sandy Silt
Silty Sand/Sand
Silt
Gravelly Sand
Undefined
COVER 7.4'
SAND Tails
Max. Depth: 10.33 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C17

Figure 14

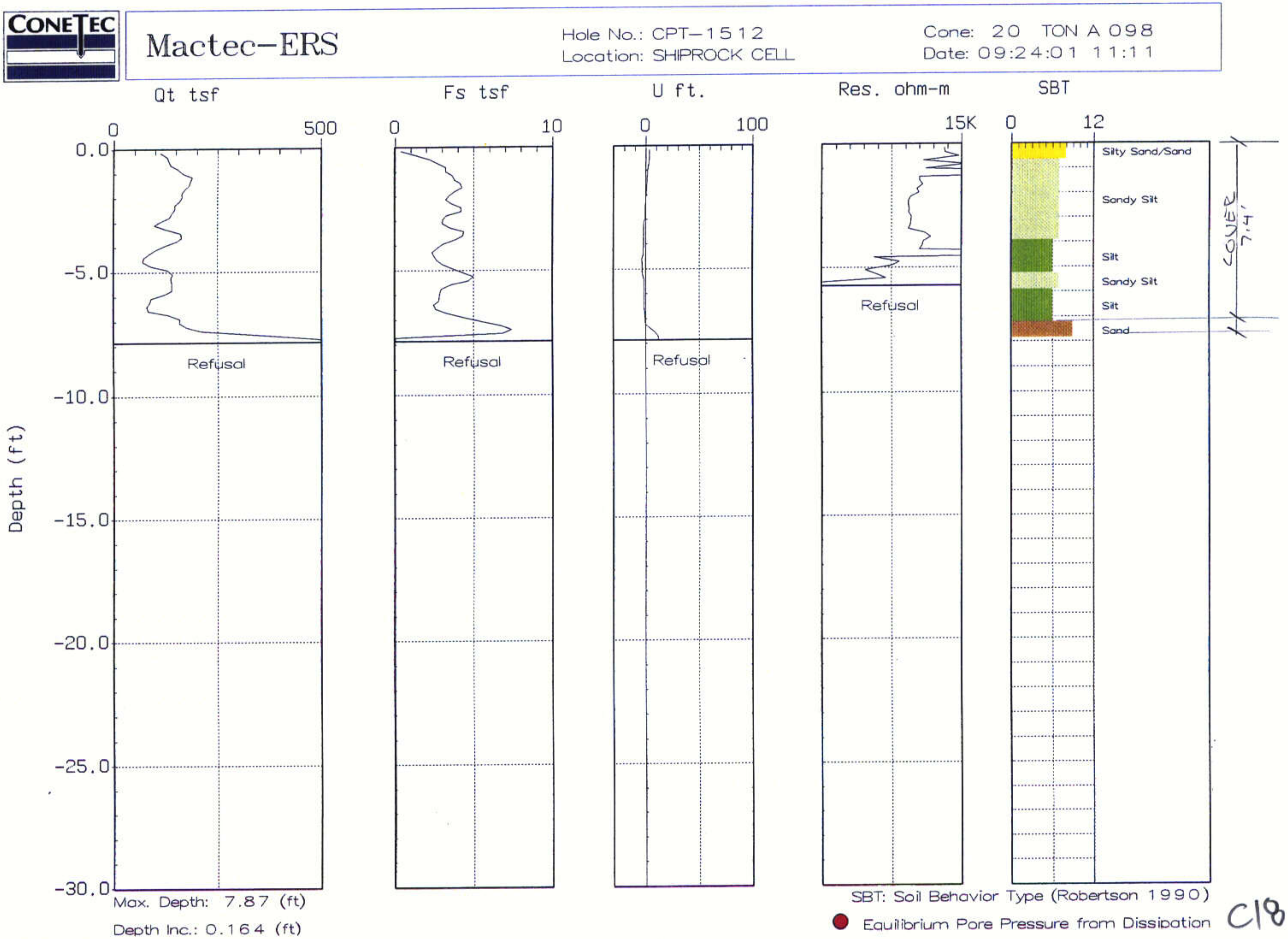
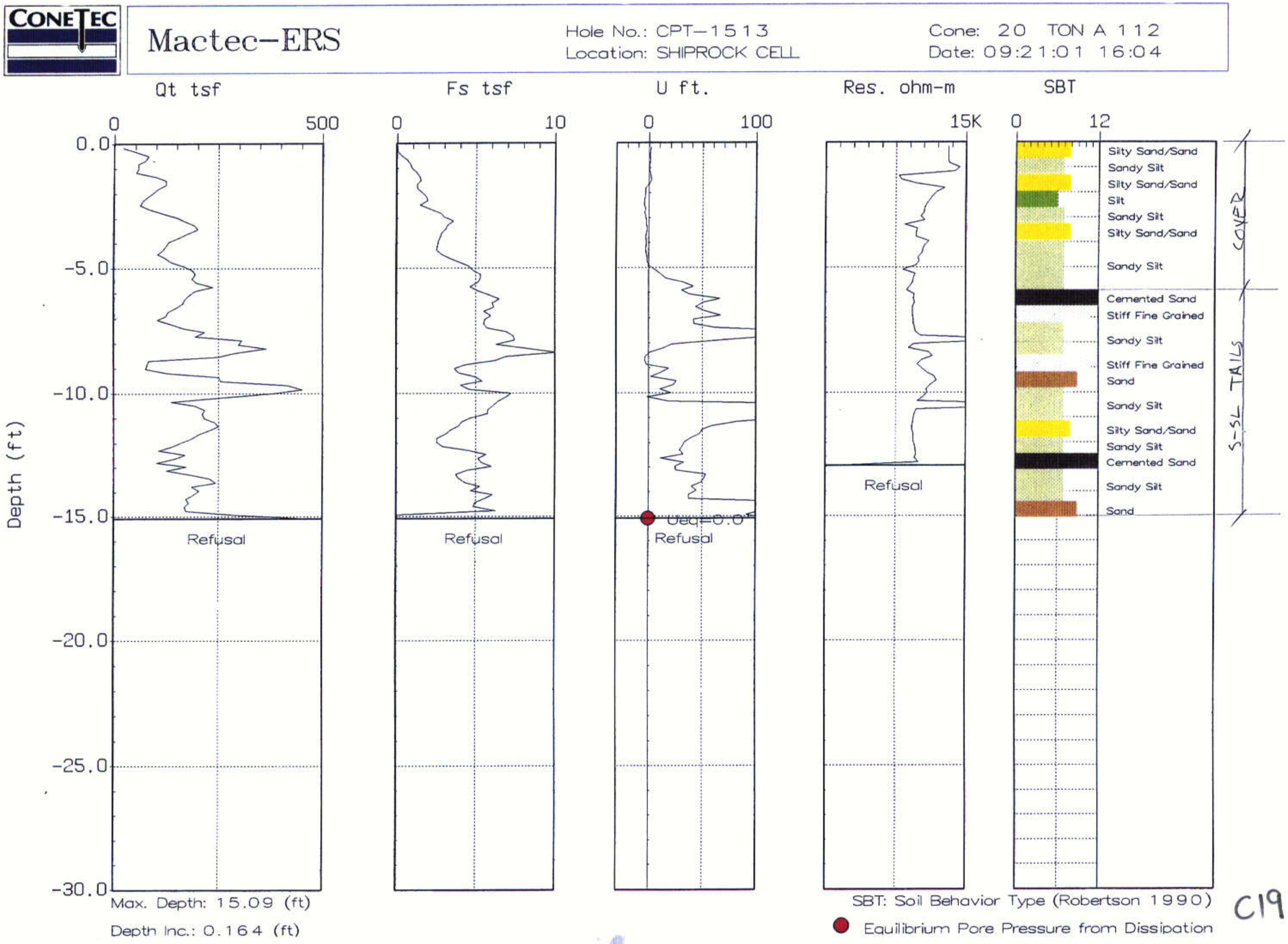

CONETEC
Mactec-ERS
Hole No.: CPT-1512
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:24:01 11:11
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silt
Sand
COVER 7.4'
Max. Depth: 7.87 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C18

Figure 15



CONETEC
Mactec-ERS
Hole No.: CPT-1513
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 16:04
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Refusal
Ueq=0.0
Silty Sand/Sand
Sandy Silt
Silt
Cemented Sand
Stiff Fine Grained
Sand
COVER
5-SL TAILS
Max. Depth: 15.09 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C19

Figure 16

Mactec-ERS

Hole No.: CPT-1514
Location: SHIPROCK CELL

Cone: 20 TON A 112
Date: 09:22:01 09:13

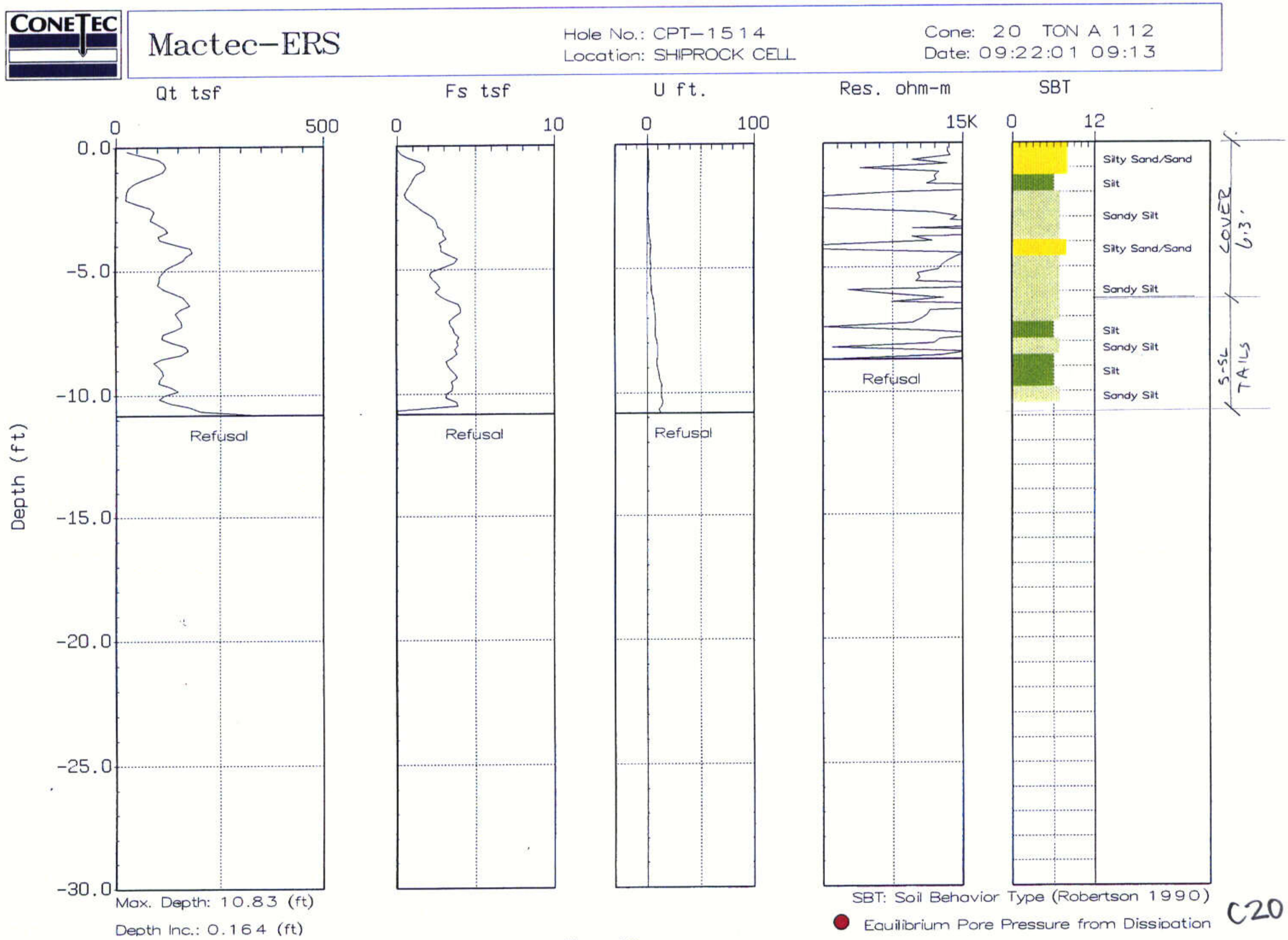


Figure 17

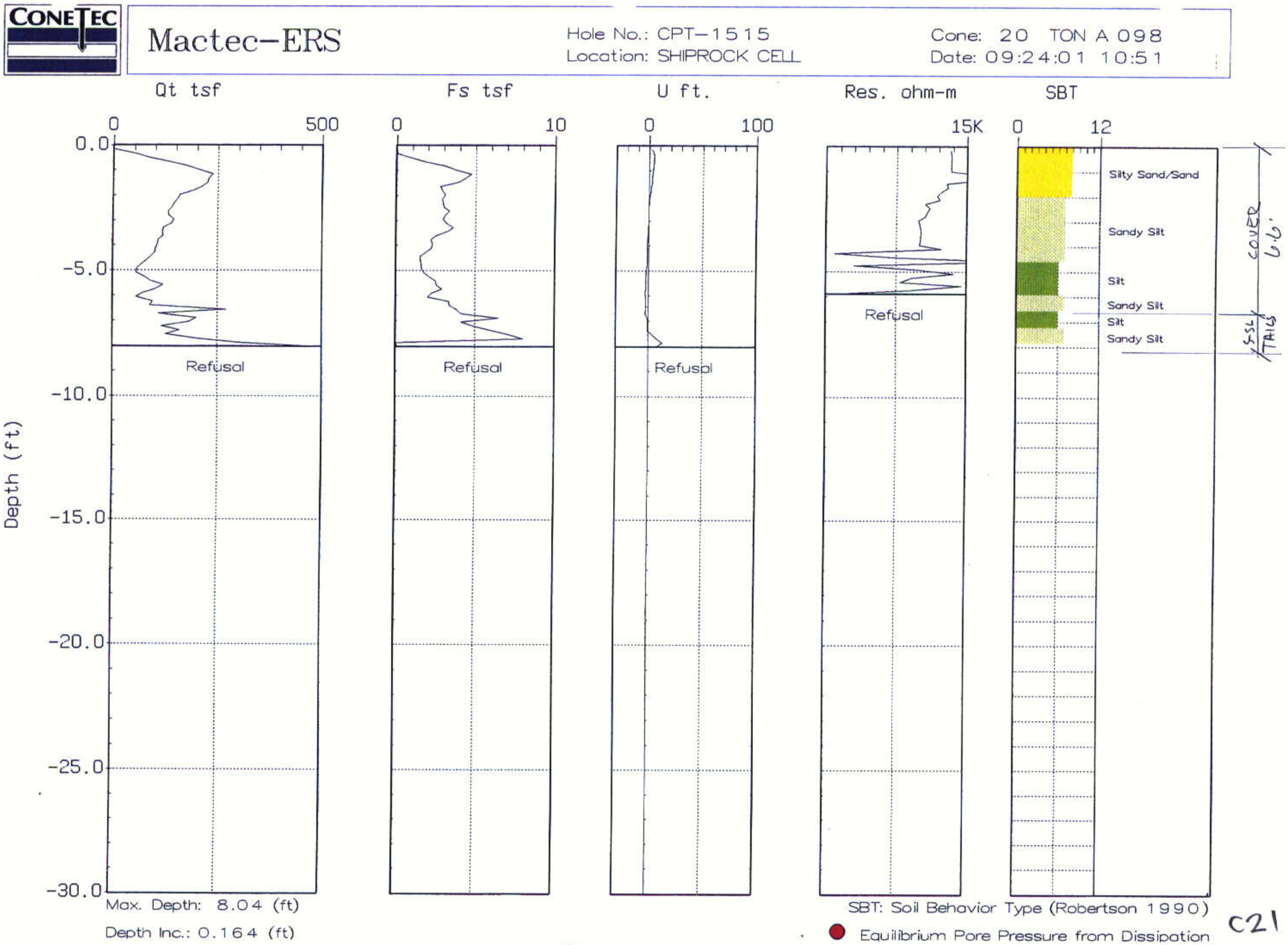
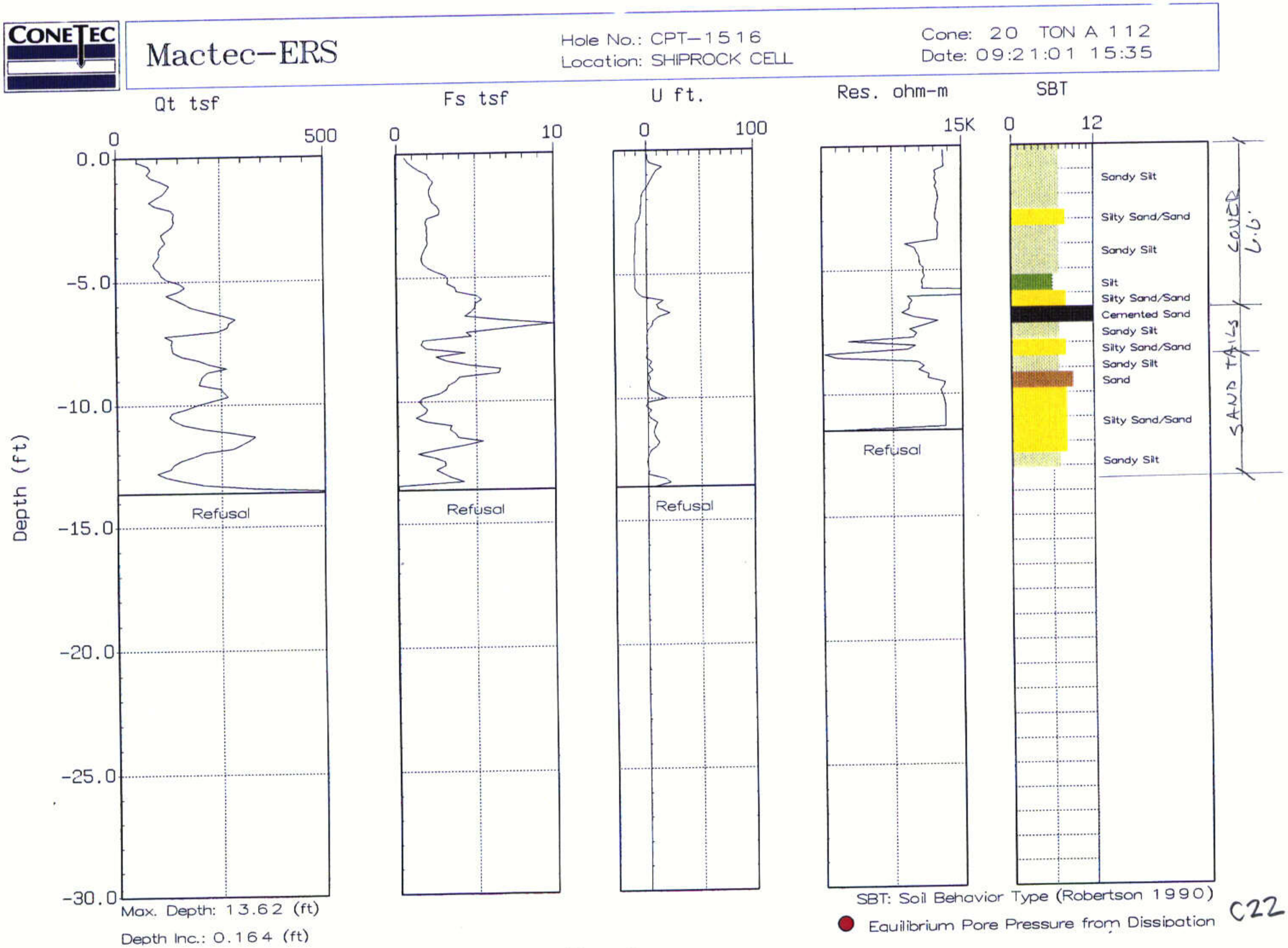


Figure 18

C21



C22

Figure 19

Mactec-ERS

Hole No.: CPT-1517
Location: SHIPROCK CELL

Cone: 20 TON A 112
Date: 09:21:01 14:32

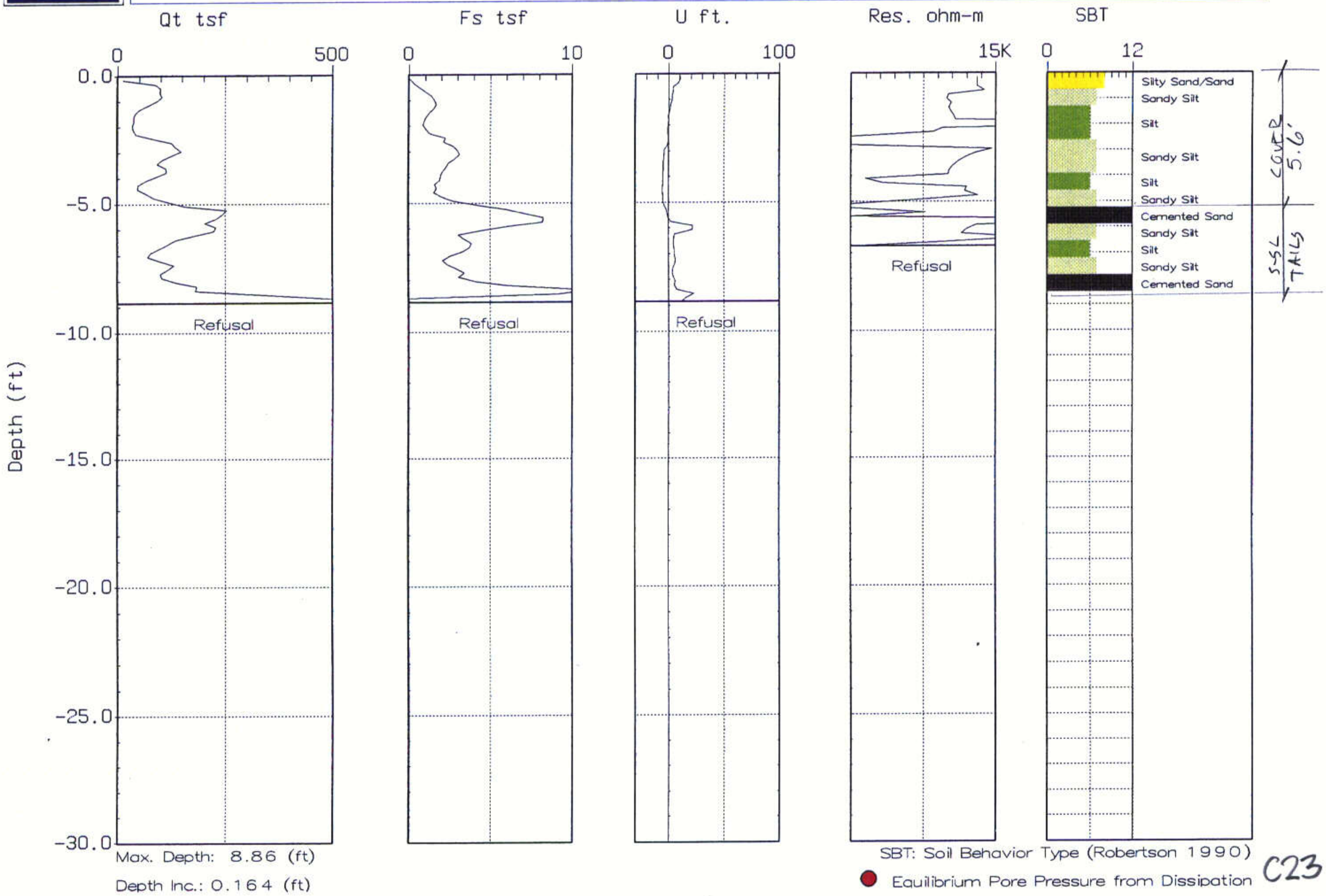


Figure 20

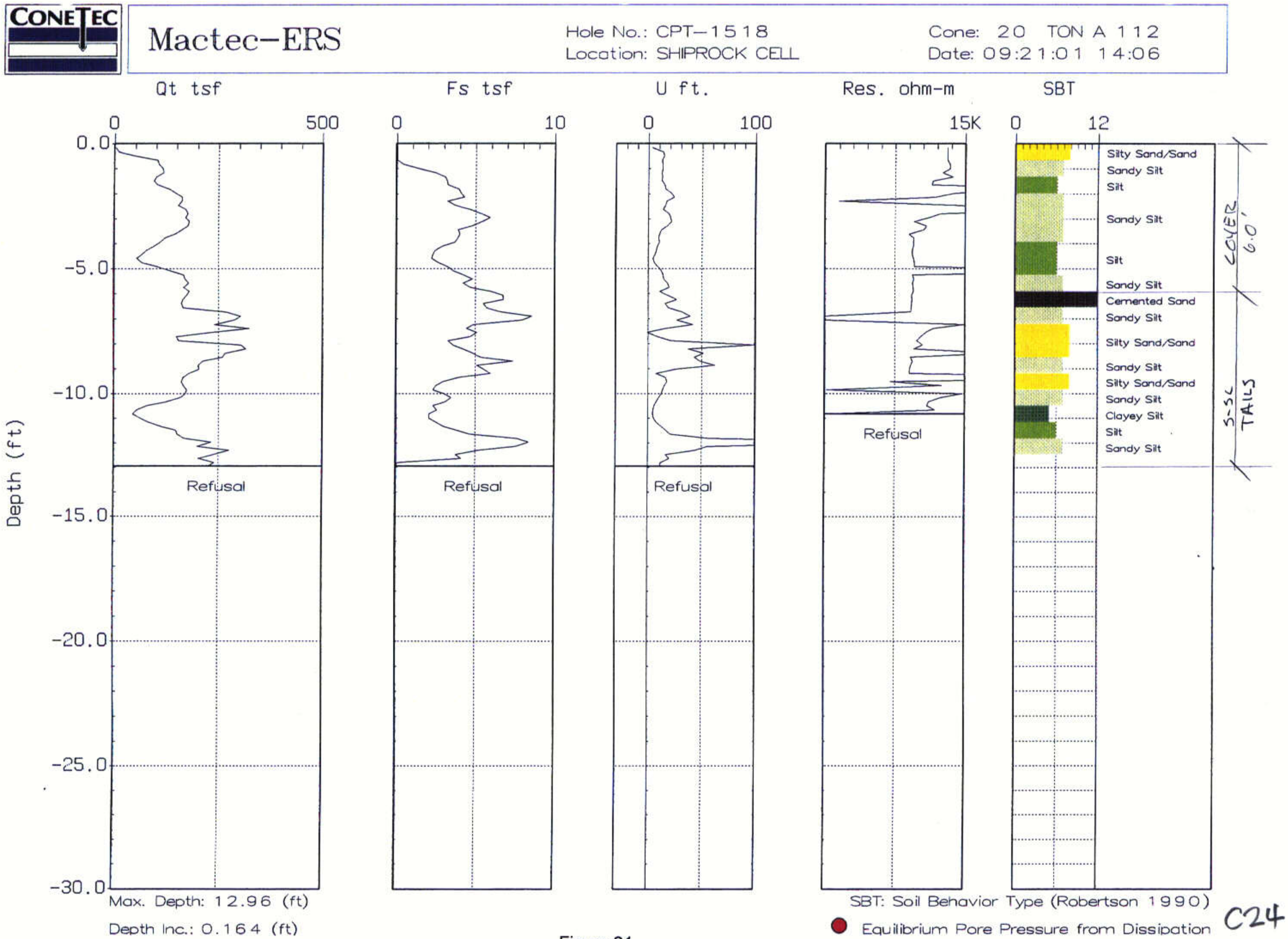

CONETEC
Mactec-ERS
Hole No.: CPT-1518
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 14:06
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Refusal
Silty Sand/Sand
Sandy Silt
Silt
Cemented Sand
Clayey Silt
COVER 6.0'
5-5C TAILS
Max. Depth: 12.96 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C24

Figure 21

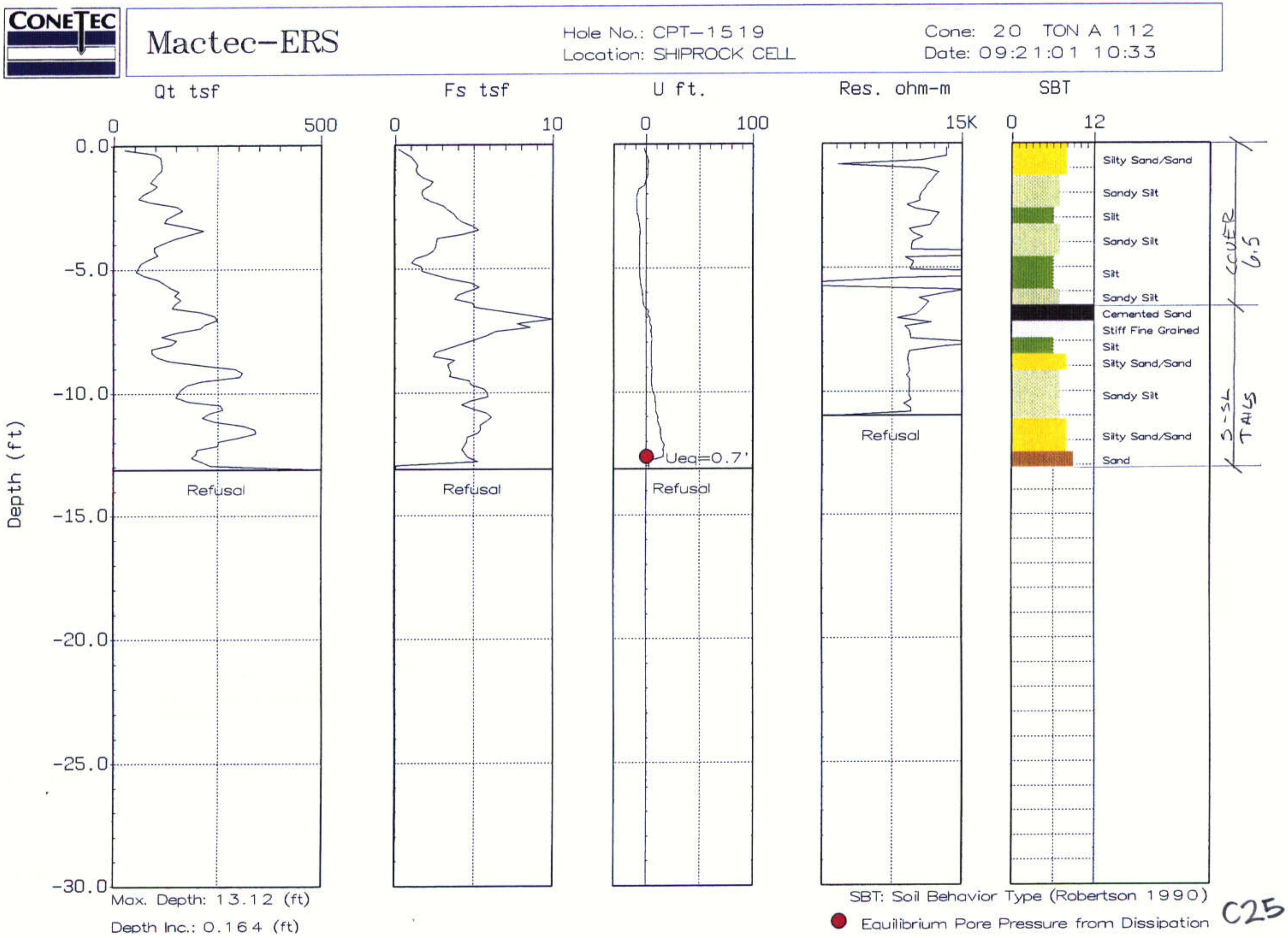
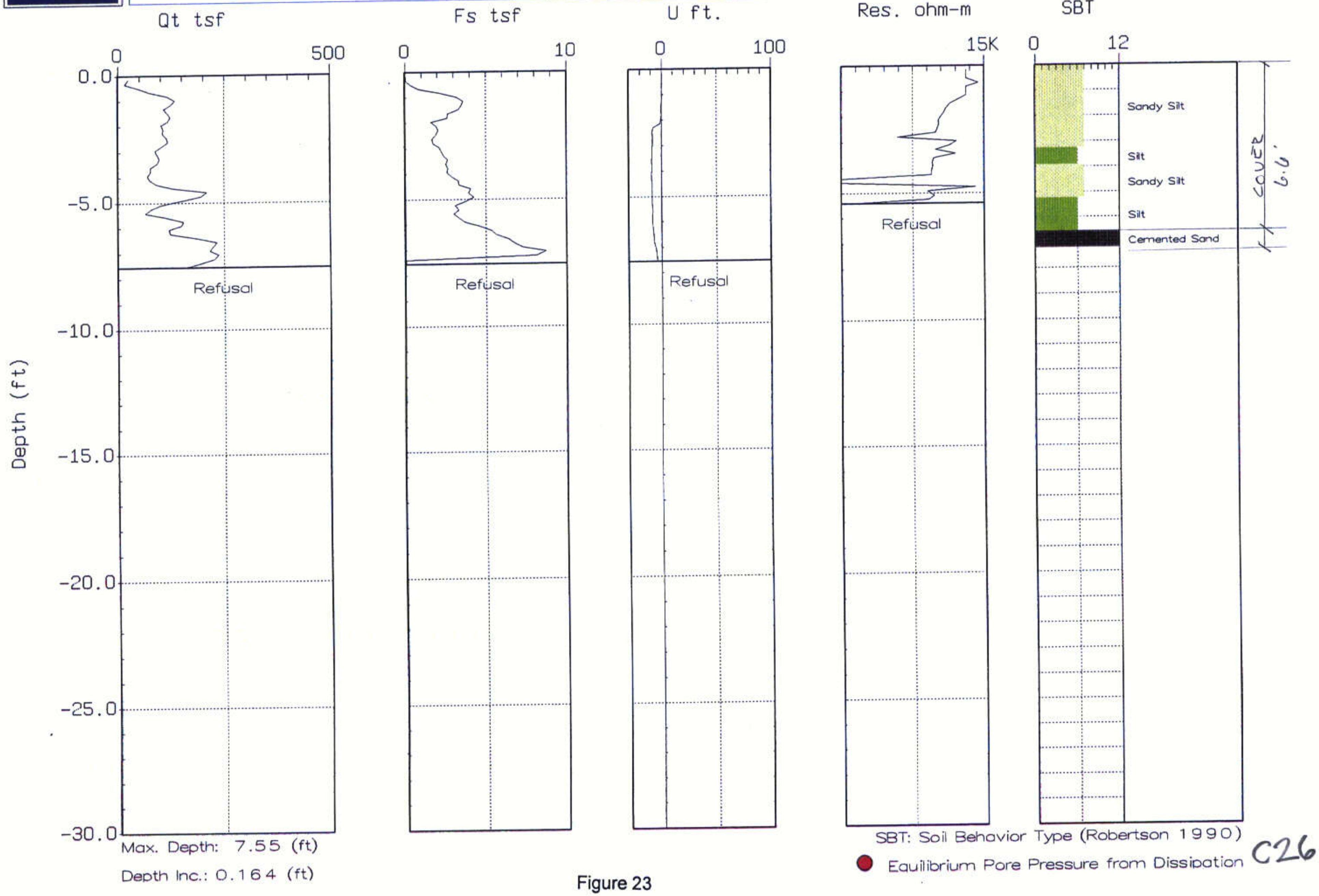

CONETEC
Mactec-ERS
Hole No.: CPT-1519
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 10:33
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silt
Sandy Silt
Cemented Sand
Stiff Fine Grained
Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sand
COVER 6.5
S-SL TAILS
Ueq=0.7'
Refusal
Refusal
Refusal
Refusal
Max. Depth: 13.12 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C25

Figure 22

Mactec-ERS

Hole No.: CPT-1520
Location: SHIPROCK CELL

Cone: 20 TON A 112
Date: 09:21:01 11:58



C26

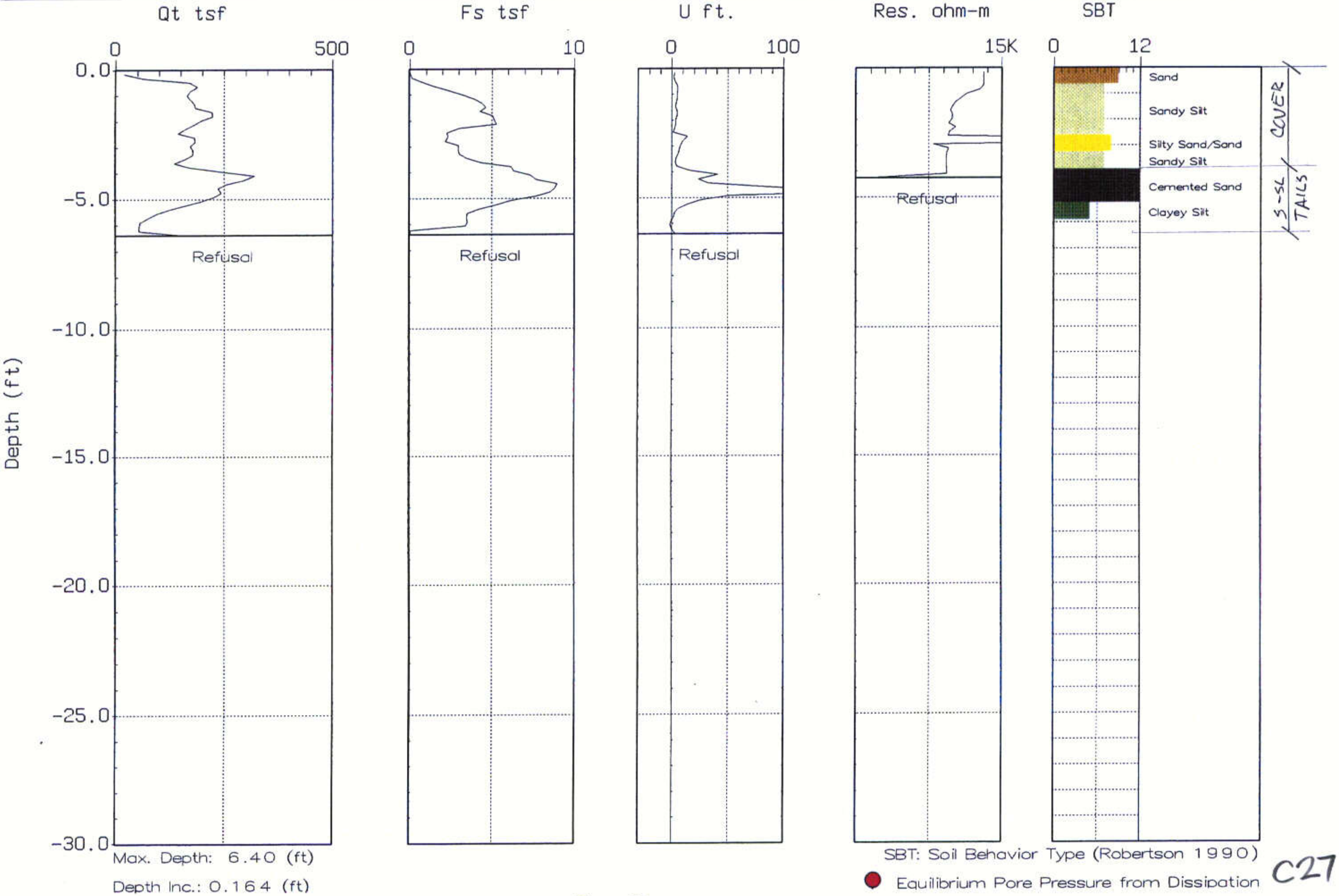
Figure 23

CONETEC

Mactec-ERS

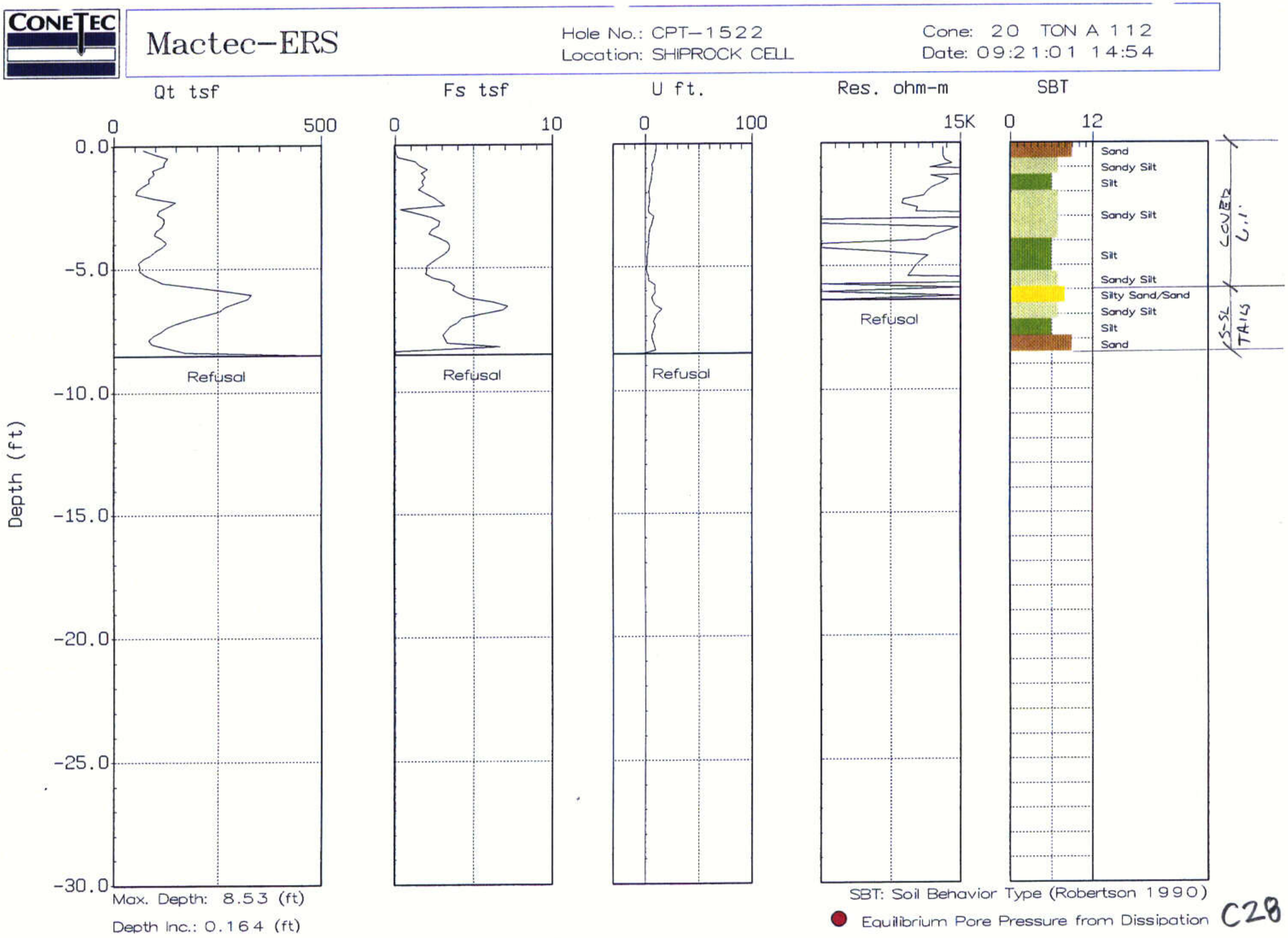
Hole No.: CPT-1521
Location: SHIPROCK CELL

Cone: 20 TON A 112
Date: 09:21:01 13:34



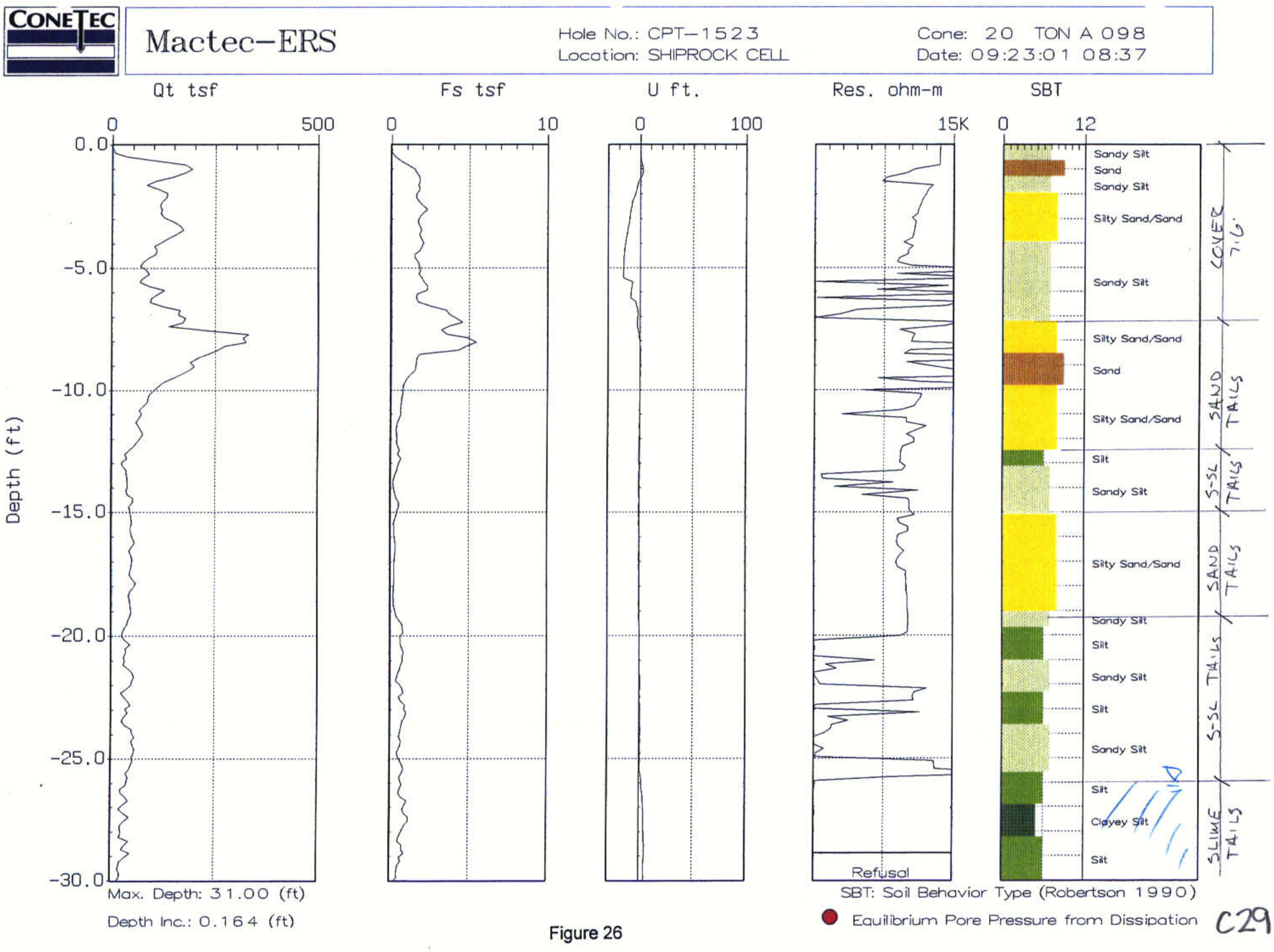
C27

Figure 24



CONETEC
Mactec-ERS
Hole No.: CPT-1522
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 14:54
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Refusal
Sand
Sandy Silt
Silt
Sandy Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Sand
Max. Depth: 8.53 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C28

Figure 25



CONETEC
Mactec-ERS
Hole No.: CPT-1523
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:23:01 08:37
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Sandy Silt
Sand
Silty Sand/Sand
Silt
Clayey Silt
Refusal
COVER
SAND TAILS
S-SL TAILS
SLIME TAILS
Max. Depth: 31.00 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C29

Figure 26

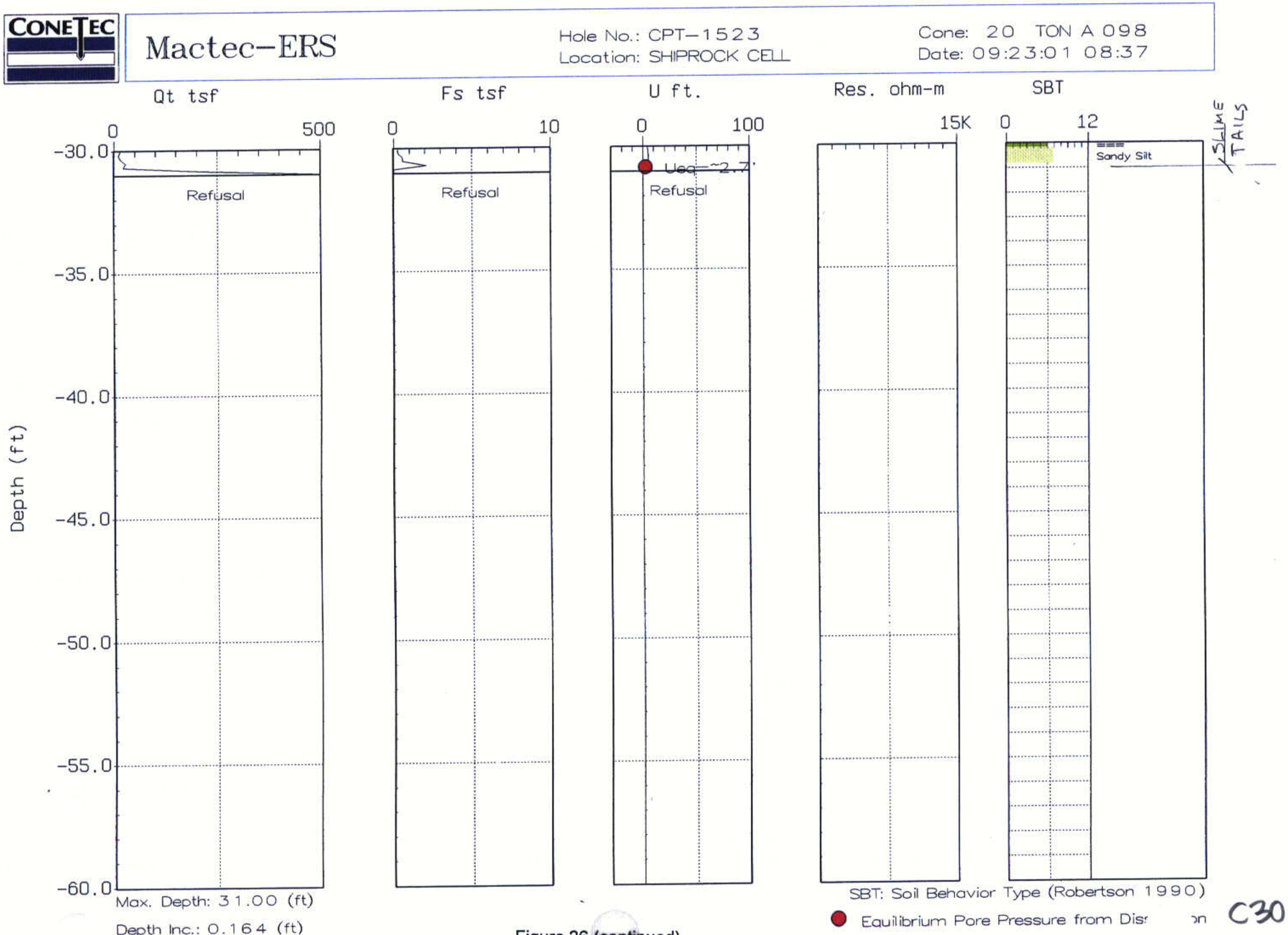


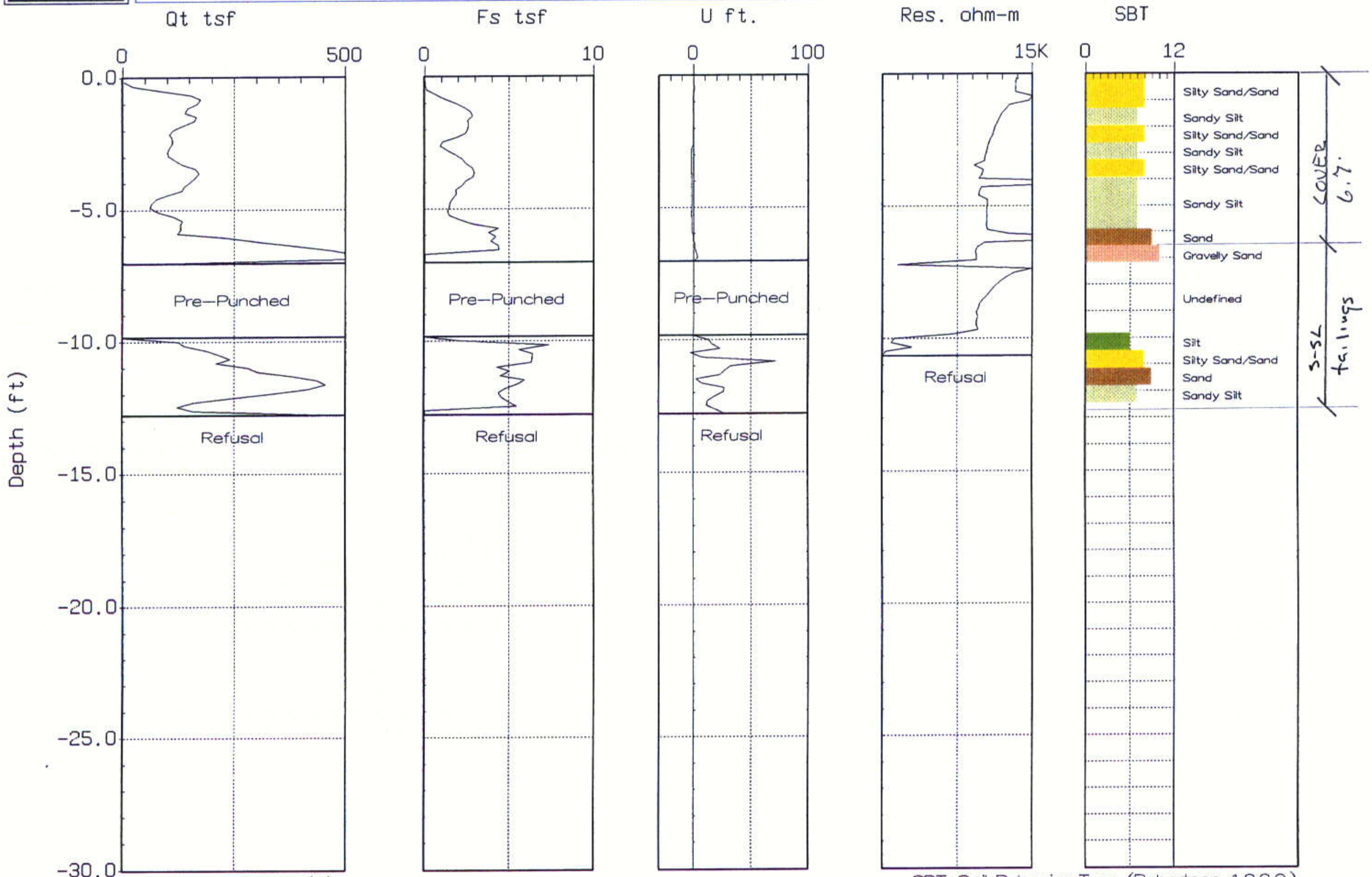
Figure 26 (continued)

CONETEC

Mactec-ERS

Hole No.: CPT-1524
Location: SHIPROCK CELL

Cone: 20 TON A 098
Date: 09:23:01 09:40



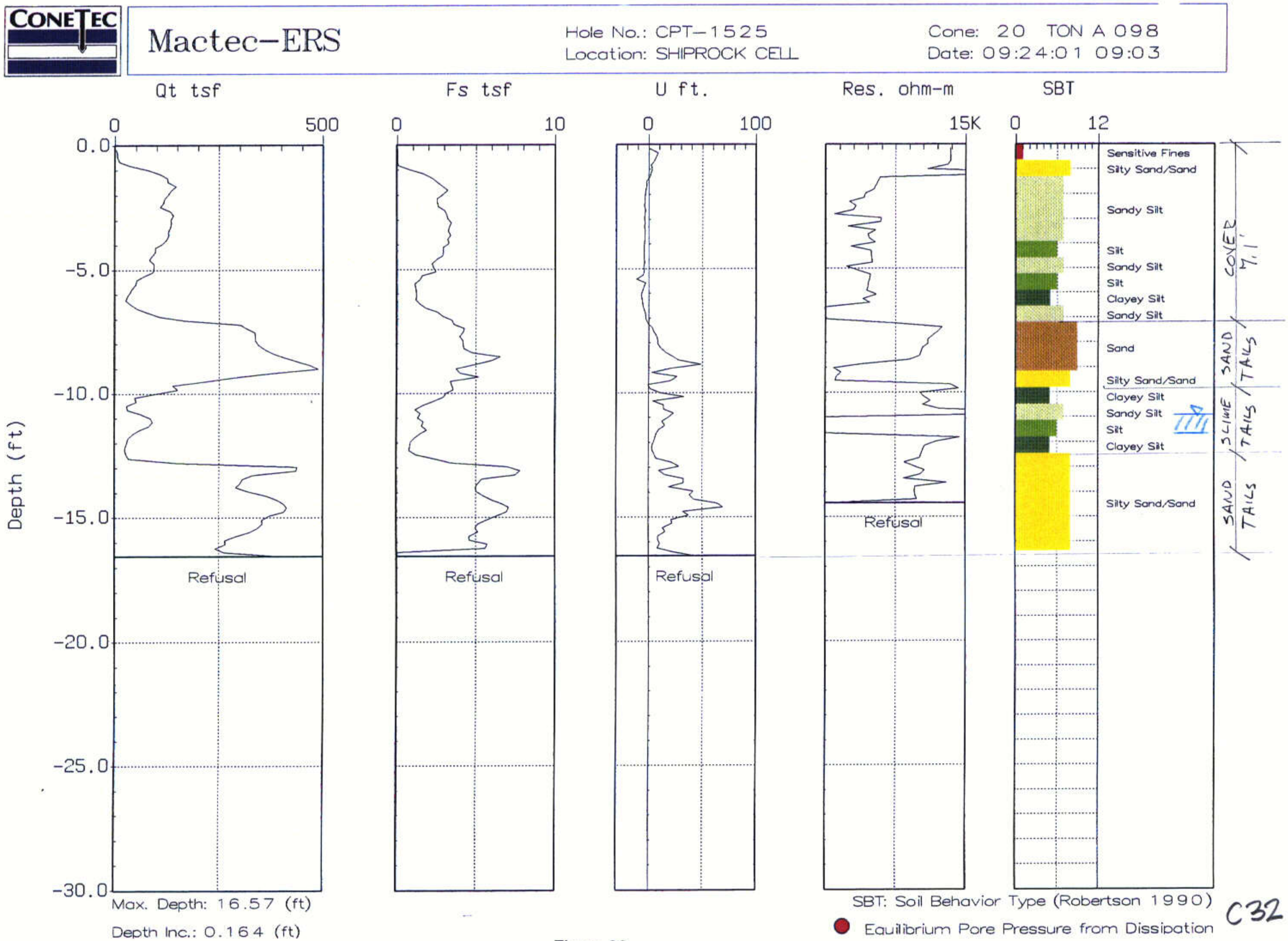
Max. Depth: 12.80 (ft)
Depth Inc.: 0.164 (ft)

SBT: Soil Behavior Type (Robertson 1990)

● Equilibrium Pore Pressure from Dissipation

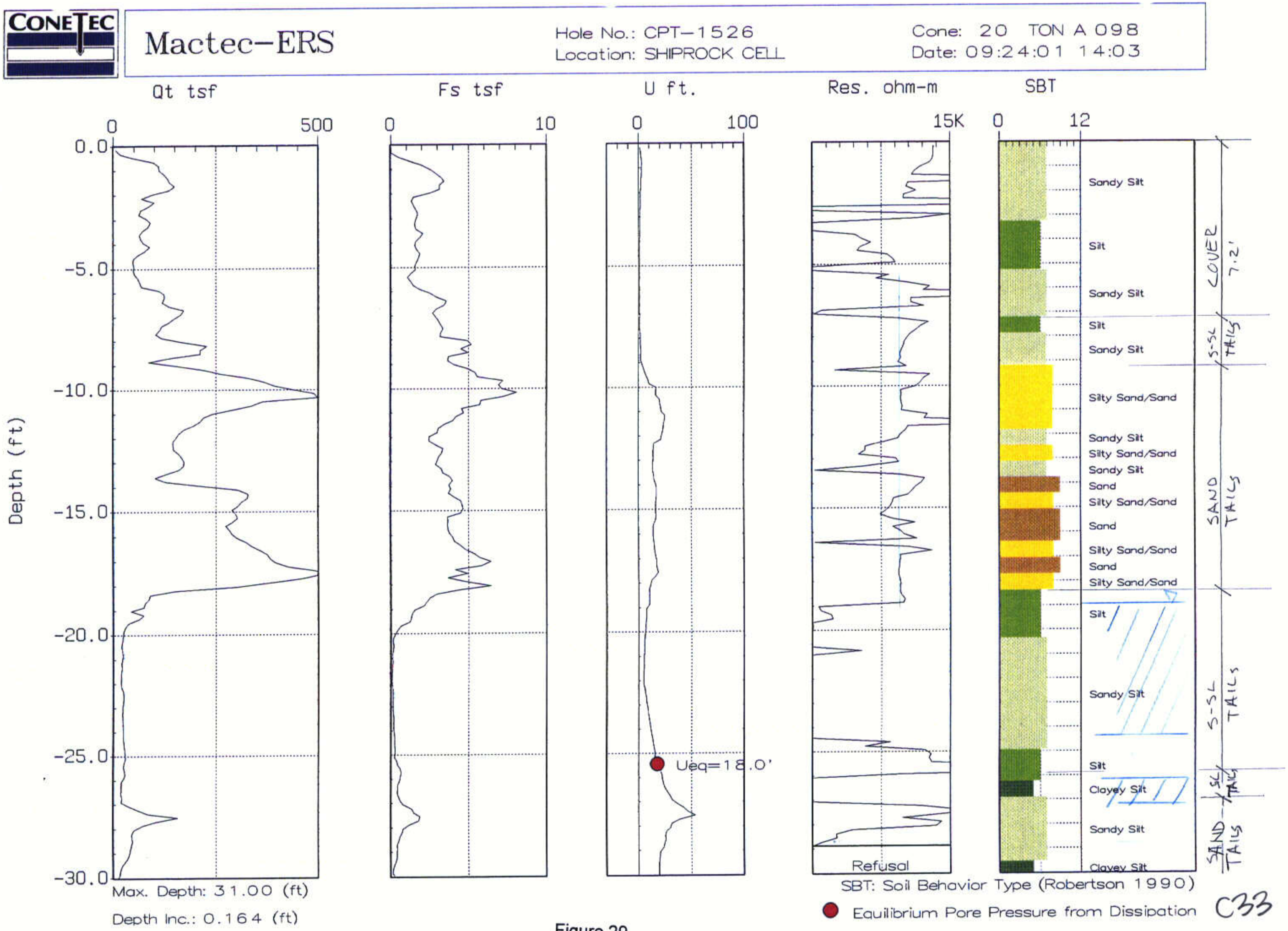
C31

Figure 27



CONETEC
Mactec-ERS
Hole No.: CPT-1525
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:24:01 09:03
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
Depth (ft)
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Refusal
Sensitive Fines
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silt
Clayey Silt
Sandy Silt
Sand
Silty Sand/Sand
Clayey Silt
Sandy Silt
Silt
Clayey Silt
Silty Sand/Sand
COVER
7.1'
SAND TAILS
SLIME TAILS
SAND TAILS
Max. Depth: 16.57 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C32

Figure 28



CONETEC
Mactec-ERS
Hole No.: CPT-1526
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:24:01 14:03
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Ueq=18.0'
Refusal
Sandy Silt
Silt
Sandy Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Silt
Sandy Silt
Silt
Clayey Silt
Sandy Silt
Clayey Silt
COVER 7.2'
SAND TAILS
Max. Depth: 31.00 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C33

Figure 29

Mactec-ERS

Hole No.: CPT-1526
Location: SHIPROCK CELL

Cone: 20 TON A 098
Date: 09:24:01 14:03

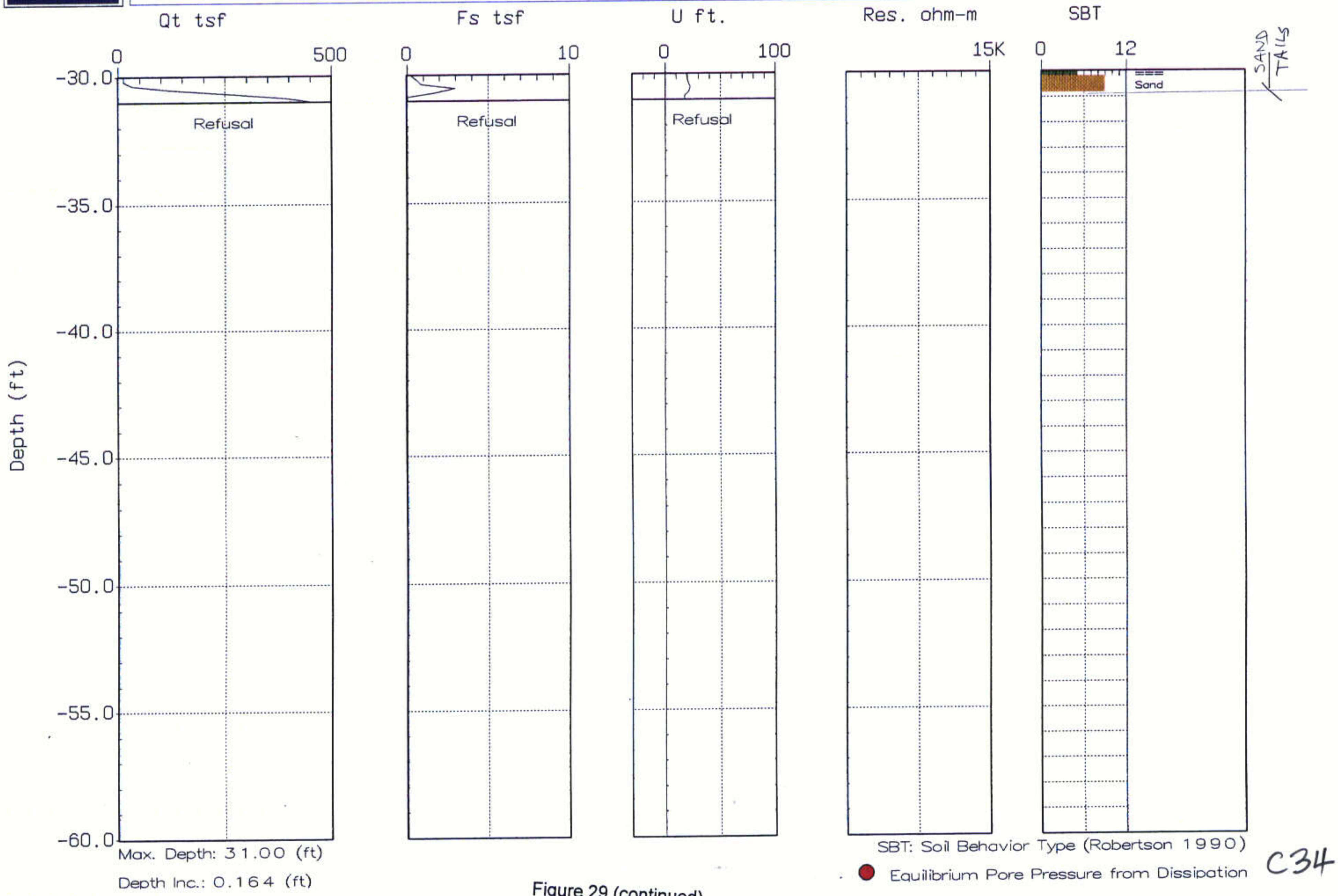


Figure 29 (continued)

C34

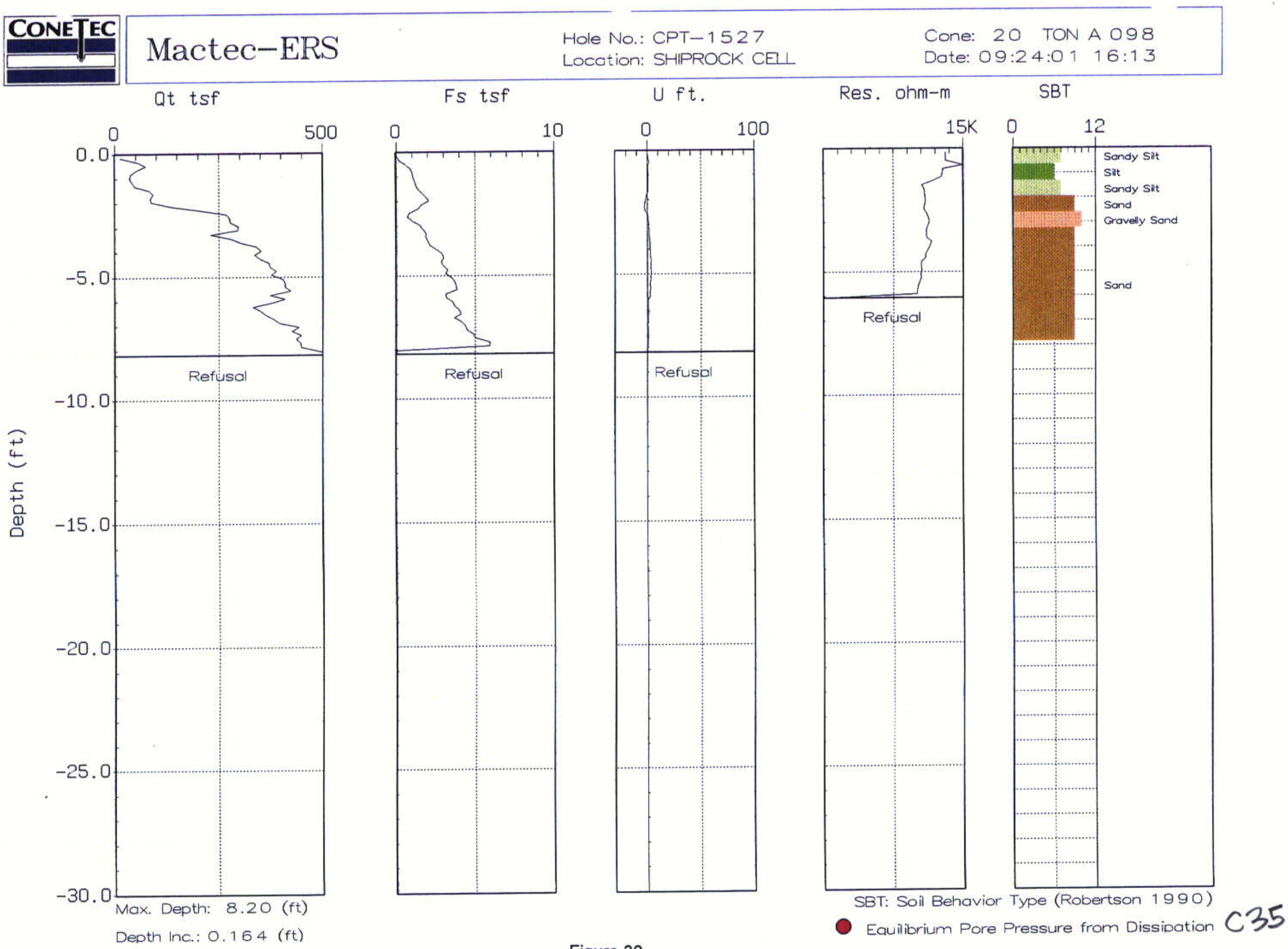
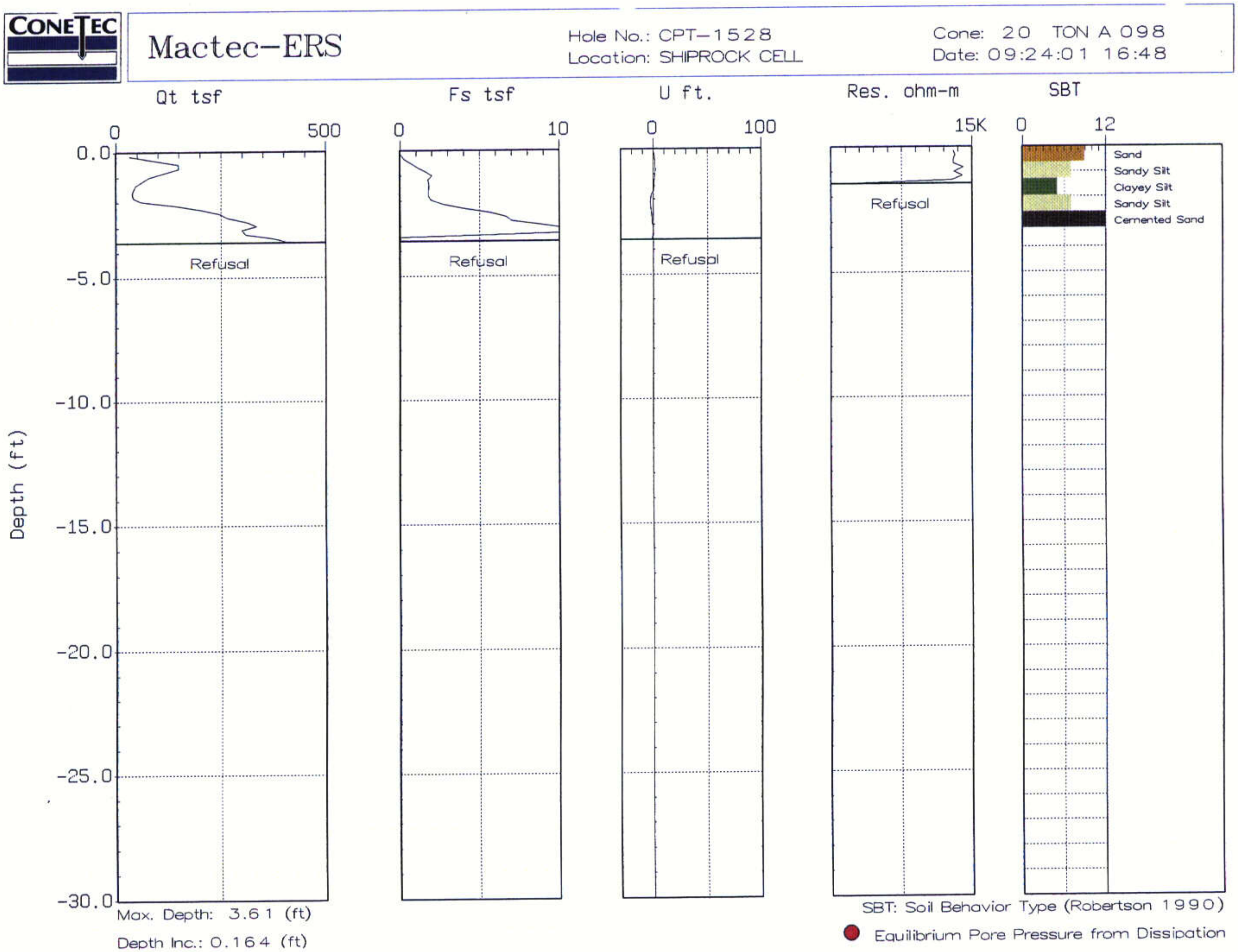

CONETEC
Mactec–ERS
Hole No.: CPT–1527
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:24:01 16:13
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Sandy Silt
Silt
Sandy Silt
Sand
Gravelly Sand
Sand
Max. Depth: 8.20 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C35

Figure 30



C36

Figure 31

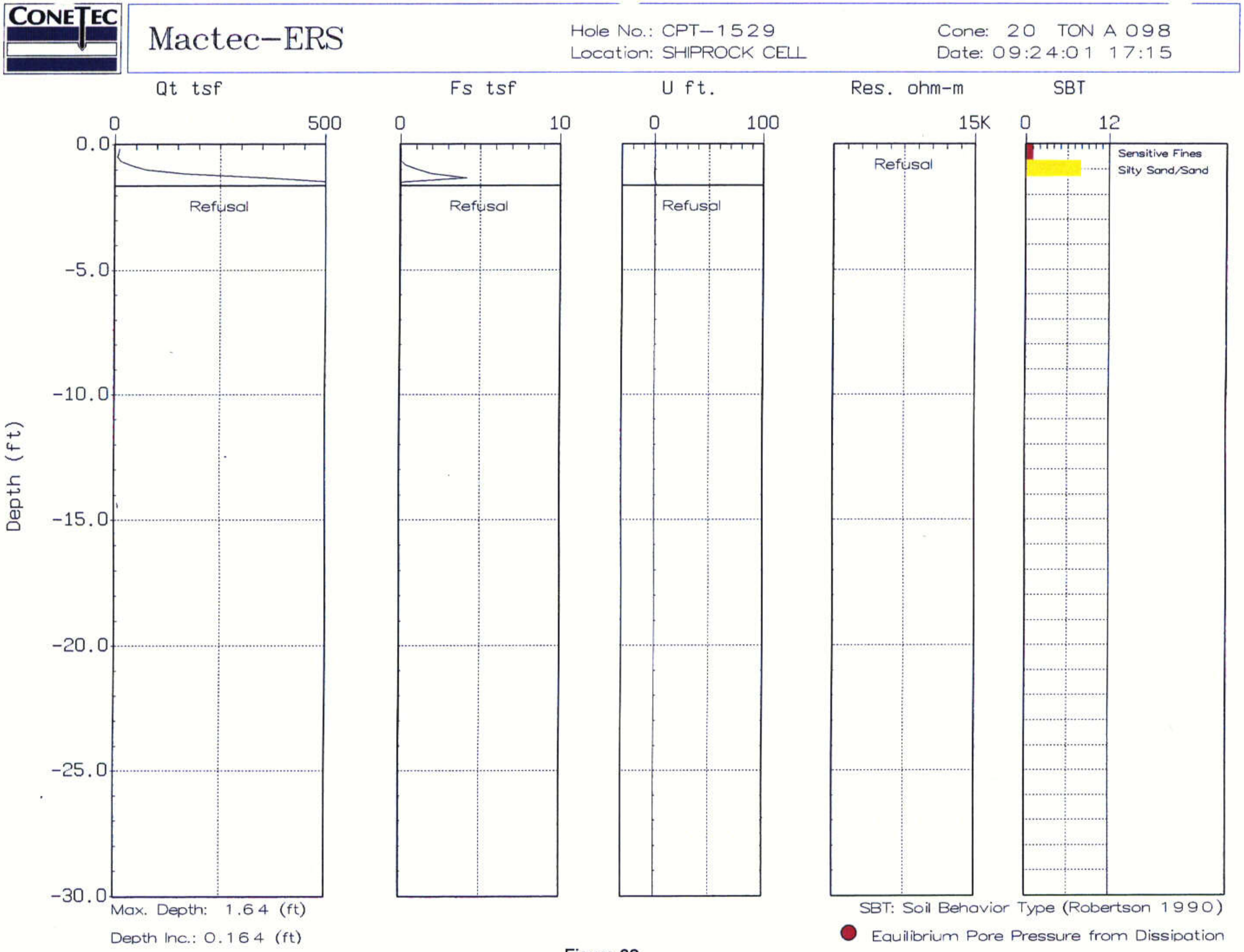
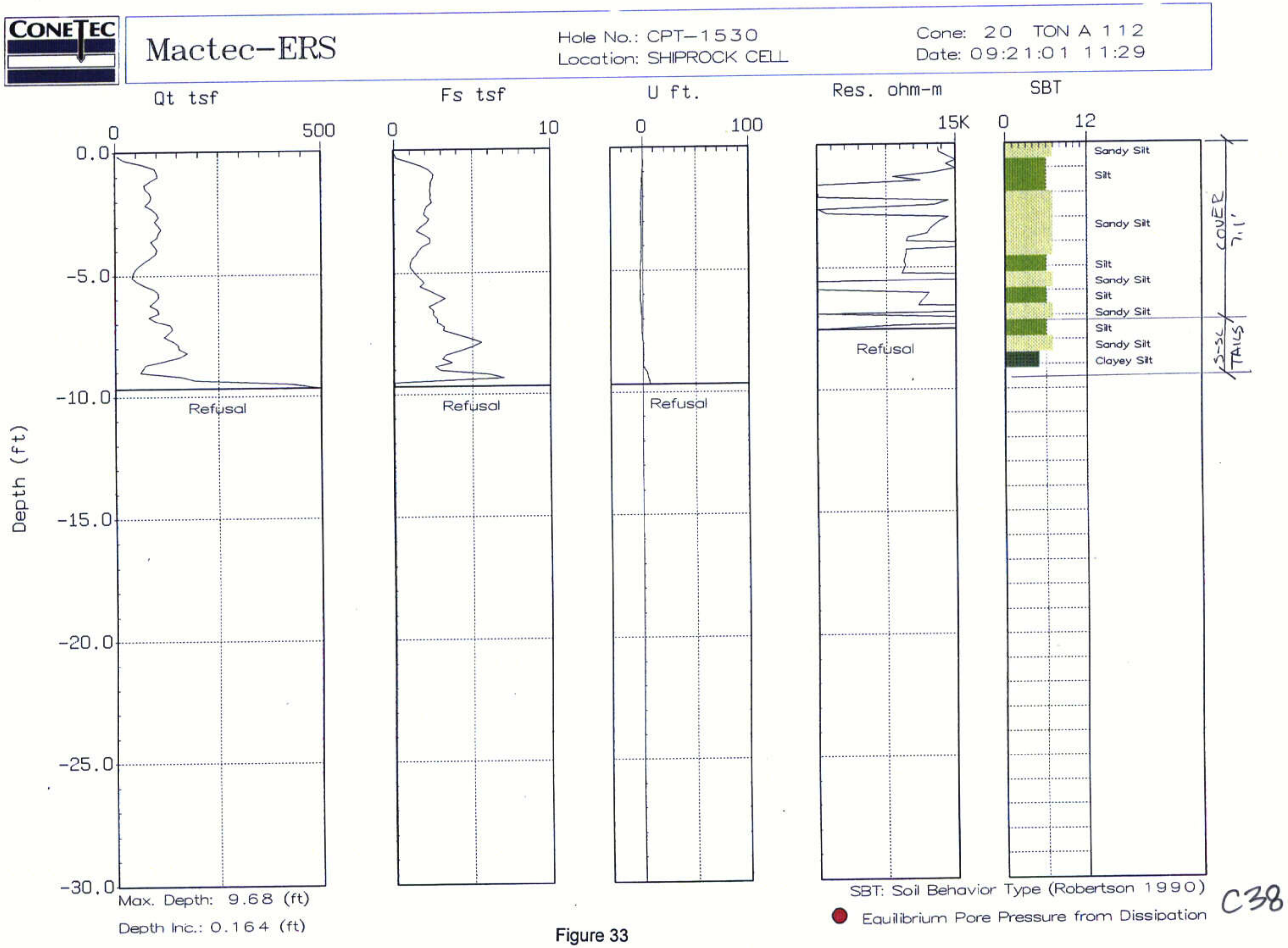


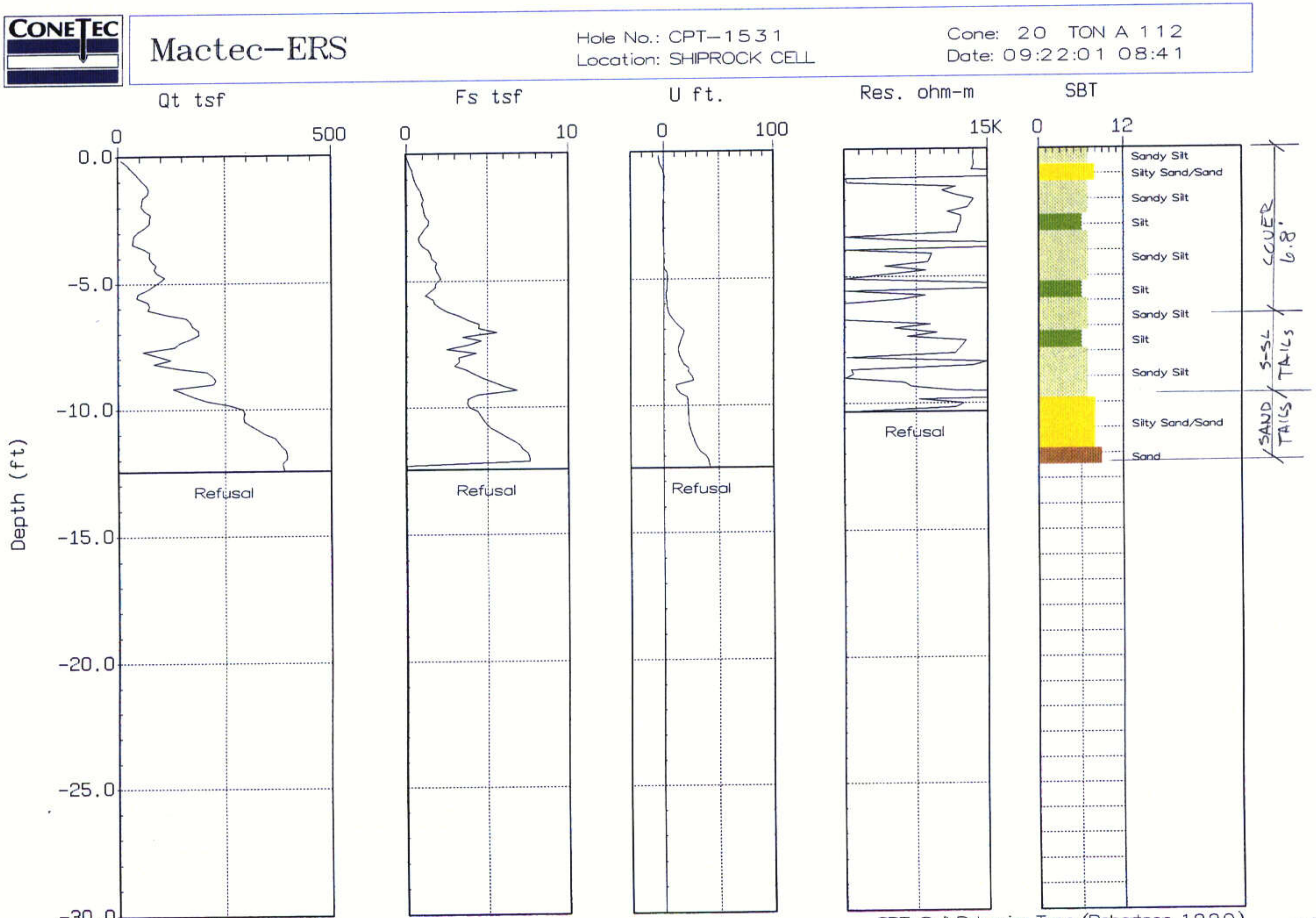
Figure 32

C37



CONETEC
Mactec-ERS
Hole No.: CPT-1530
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 11:29
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Sandy Silt
Silt
Clayey Silt
COVER
TAILS
Max. Depth: 9.68 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation
C38

Figure 33



Max. Depth: 12.47 (ft)

Depth Inc.: 0.164 (ft)

SBT: Soil Behavior Type (Robertson 1990)

Equilibrium Pore Pressure from Dissipation

C39

Figure 34

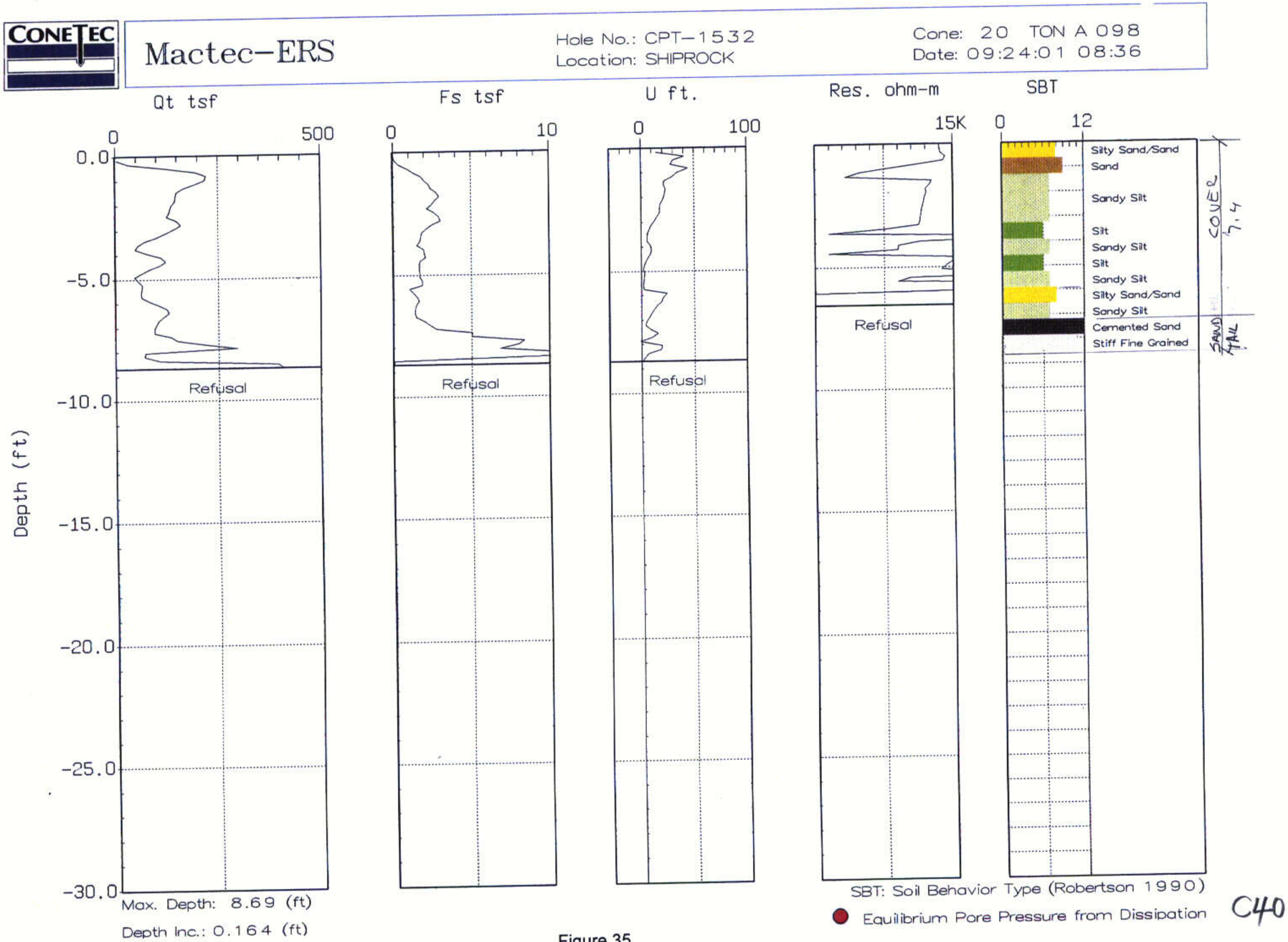


Figure 35

C40

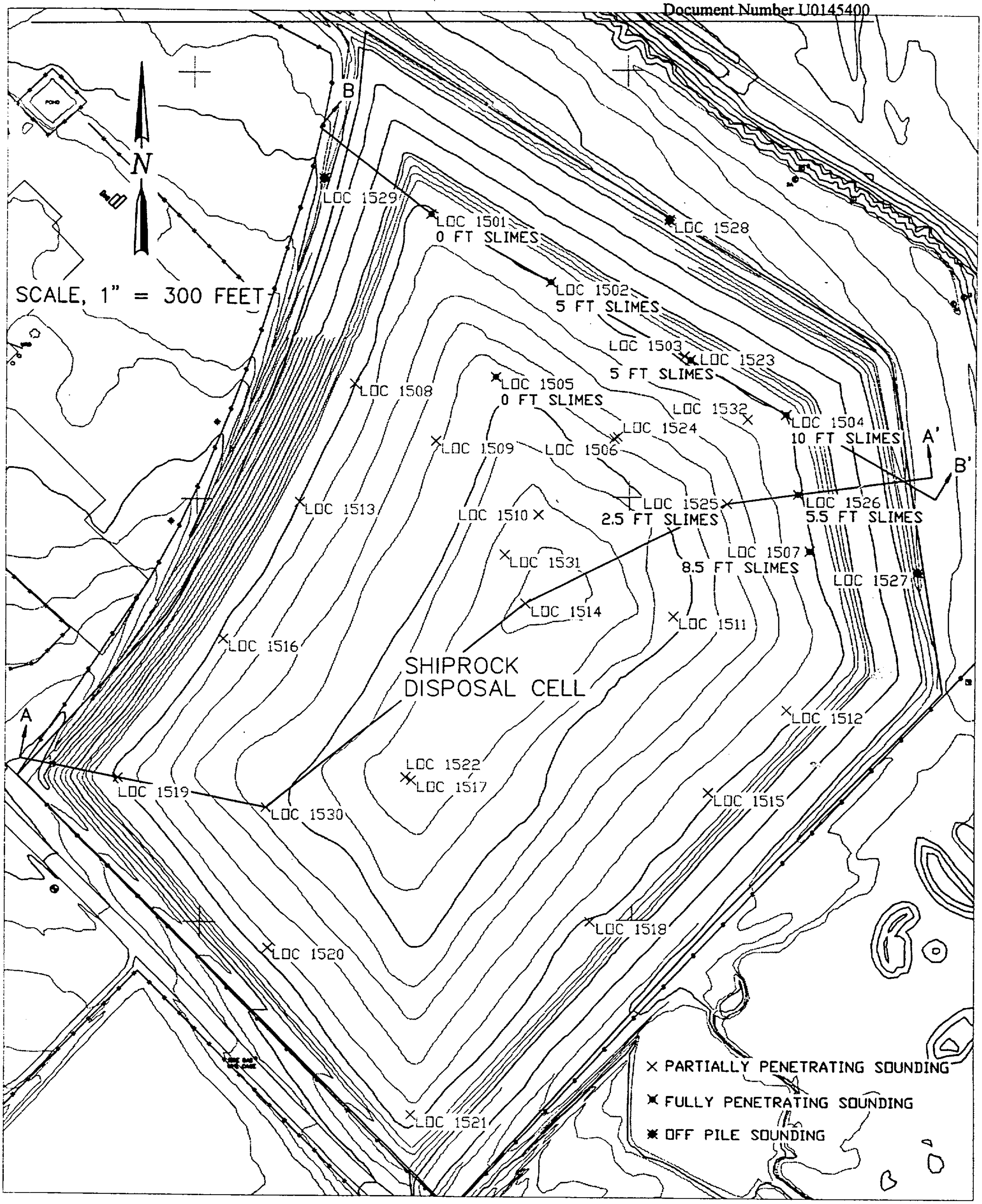


Figure 36. Shiprock Disposal Cell Investigation Cross Sections and Saturated Slimes

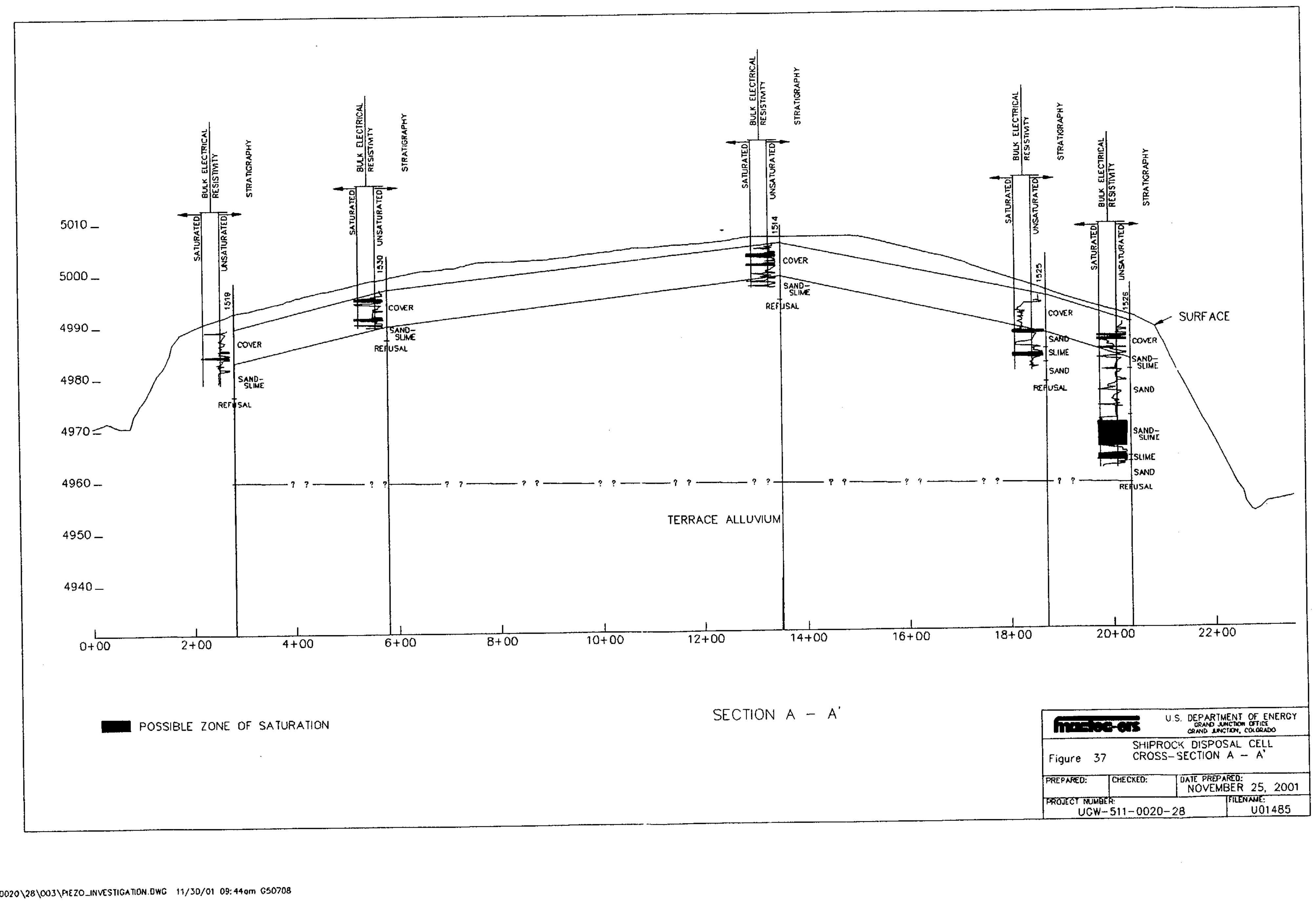
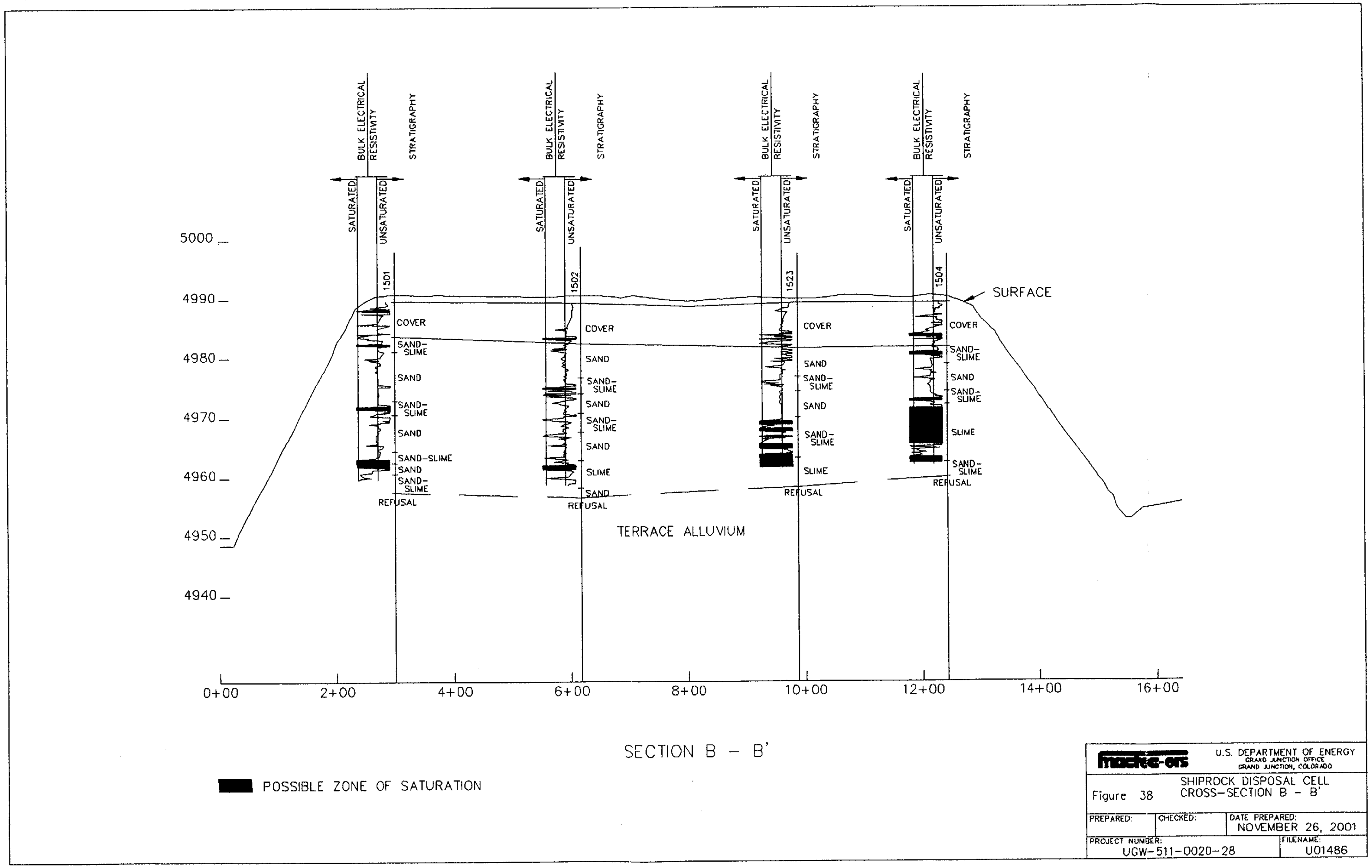


Figure 37. Cross Section A–A



M:\UGW\511\0020\28\003\PIEZO_INVESTIGATION.DWG 11/30/01 09:24am G50708

Figure 38. Cross Section B–B'

The average value of the horizontal coefficient of consolidation for slime tailings is 2.6 cm^2/min (4.3 x 10^{-2} cm^2/sec). Robertson et al. (1992) suggest a factor of approximately 0.33 to convert horizontal coefficient of consolidation to an approximate vertical coefficient of consolidation, or $c_v \approx 1.5 \times 10^{-2}$ cm^2/sec. Keshian and Rager (1988) have published typical values for geotechnical parameters for uranium mill tailings. They report laboratory tested c_v values for tailings slimes range from 2.4 x 10^{-3} to 9.2 x 10^{-3} cm^2/sec. They also report that when tested with a piezocone, the value of c_v was 2 to 8 times greater than laboratory values, or 0.48 x 10^{-2} to 7.4 x 10^{-2} cm^2/sec. Our average value for vertical coefficient of consolidation of 1.5 x 10^{-2} cm^2/sec for this investigation falls within published values. This coefficient of consolidation is relatively fast, indicating that the slimes encountered should consolidated rapidly.

8.0 Summary of Findings and Recommendations

8.1 Findings

8.1.1 Cover

Cover soils are dense – average estimated relative density is greater than 90% of maximum density. A very dense and hard soil layer exists at the base of the cover across the southern two-thirds of the disposal cell. CPT results indicate a soil type behavior of cemented sands. This layer caused refusal of the sounding with cone bearing pressures greater than 500 tons per square foot in every case. This layer is hypothesized to be the former interim cover.

Cover soils are considered to be partially saturated moisture condition as defined herein. Elevated moisture contents are indicated by many lenses occurring over a majority of the cell with bulk electrical resistivities less than 100 ohm-meters throughout a vertical profile. Examples taken from across the pile are seen on soundings: 1501, 1514, 1515, 1519, and 1530. Lenses with low bulk electrical resistivity, coupled with results from hydroprobe investigations, and in situ saturated hydraulic conductivity results indicate the potential for preferential flow through the cover system. This further suggests that moisture is possibly infiltrating through the radon barrier cover and recharging the tailings.

8.1.2 Tailings

Tailings are partially saturated. Saturated lenses that occur throughout the tailings system indicate possible moisture movement through the cover into the tailings. Most of the sand-slimes tailings are partially saturated (see CPT logs 1505 and 1523 resistivity plots for examples). It is unknown whether these lenses with elevated moisture contents as indicated by low bulk electrical resistivities, are due to infiltration of precipitation through the cover as moisture moves downward, or if the moisture remains from former slimes deposits that were placed on top of existing slimes during disposal cell construction. Based on the laws of soil physics, moisture present in these tailings will continue to drain from the disposal cell in an unsaturated mode for a long time, asymptotically approaching an extremely low steady-state flux.

Majority of tailings materials are sands and sand-slimes. Slimes exist along the north and northeastern portion of the cell directly overlying the alluvial terrace gravels. Slime thickness varies from less than 5 ft thick (sounding 1523) to around 10 ft thick (sounding 1507), averaging approximately 9 ft. Saturation exists within these materials and exist with an excess pore pressure of approximately 5.5 ft.

8.2 Recommendations

Based on results from this investigation, the disposal cell is considered a potential source of continued contamination. However, the rate of flux from the cell is unknown at this time. To better understand the flux from the cell, a second phase of the investigation is suggested. Further investigations include both additional piezocone soundings and a conventional drilling program to obtain physical samples.

Additional piezocone soundings are proposed to delineate the extent of the slimes. This will require pre-punching through expected dense layers. Multiple pore pressure dissipation tests will be run to better understand the magnitude of excess pore pressures. Installation of a minimum of two pore pressure transducers are proposed in the saturated slimes in a vertical profile to quantify the actual hydraulic gradient within the material can be performed with a piezocone rig.

Physical samples are required of the cover and of tailings to determine volumetric moisture contents. A field program is proposed that includes advancing two borings taking continuous samples through the tailings in the southern two-thirds of the disposal cell to verify the partially saturated moisture condition in the cover, and to penetrate the dense, hard cemented layer. Two borings drilled and sampled in the northwestern portion of the disposal cell are proposed to determine volumetric moisture contents in the partially saturated tailings. Installation of tensiometers in this partially saturated zone is suggested to quantify negative pore pressures. This information will supplement volumetric moisture content determinations to provide a complete understanding of the partially saturated material soil-water characteristic. Results from this second phase of the investigation will be used in an unsaturated flow model to estimate the rate of flux from the cell.

9.0 References

Environmental Sciences Laboratory (ESL), 2001. "Disposal Cell Cover Moisture Content and Hydraulic Conductivity," *Long-Term Surveillance and Maintenance Program*, Shiprock, New Mexico Site, GJO-2001-204-TAR, ESL-RPT-2001-04, prepared for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

Keshian, B. Jr. and Rager, R.E. 1988. "Geotechnical properties of hydraulically placed uranium mill tailings," *in Hydraulic Fill Structures*, edited by D.J.A. van Zyl and Steven G. Vick, Geotechnical Special Publication No. 21, ASCE, Colorado State University, Fort Collins, CO.

Larson, N. and Mitchell, B. 1986. "Cone penetration use on uranium mill tailings," *in Use of In Situ Tests in Geotechnical Engineering Hydraulically Placed Tailings; Hydraulic Fill Structures '86,* Geotechnical Engineering Division, ASCE, June 1986, Blacksburg, VA.

Mitchell, J.K. and Younger, J.S. 1967. "Abnormalities in hydraulic flow through fine-grained soils," from Permeability and Capillarity of Soils, *Special technical Publication No. 417,* American Society of Testing and Materials, pp 106-139.

Robertson, P.K. 1990. "Soil classification using the cone penetration test," *Can. Geotech. J.*, 27:151-158.

Robertson, P.K., Sully, J.P., Woeller, D.J., Lunne, T., Powell, J.J.M. and Gillespie, D.G. 1992. "Estimating coefficient of consolidation from piezocone tests," *Can. Geotech. J.*, 29:539-550.

Silva, A.J., Hetherman, J.R. and Calnan, D.I. 1981. "Low-gradient permeability testing of fine-grained marine sediments", *in Permeability and Groundwater Contaminant Transport, ASTM STP 746,* T.F. Zimmie and C.O. Riggs, Eds. American Society for Testing and Materials, pp. 121-136.

U.S. Department of Energy, (DOE) 1984. "Processing Site Characterization Report for the Uranium Mill Tailings Site at Shiprock New Mexico," UMTRA-DOE/AL, Uranium Mill Tailings Remedial Action Project Office, Albuquerque Operations Office, Department of Energy, Albuquerque, New Mexico.

U.S. Department of Energy, (DOE), 2000. "Final Site Observation Work Plan for the Shiprock, New Mexico, UMTRA Project Site, Revision 2" GJO-2000-169-TAR, prepared for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

Appendices

Review by P.K. Robertson

ConeTec Report

P. K. ROBERTSON Consulting Ltd.
Edmonton, Alberta, T6H 0P6

Telephone Office: (780) 492-8318
Home: (780) 436-5354
Fax: (780) 492-7876

Novemeber 5th, 2001

Mactec-ERS, LLC
2597 B ¾ Road
Grand Junction, CO 81503

Tel: (970) 248-6550
Fax: (970) 248-7628

(3 pages)

Attention: Greg Smith

Re: Shiprock Uranium Mill Tailings Disposal Cell
Shiprock, New Mexico

As per the request of Mactec-ERS, the following are comments on the ground and groundwater conditions at the Shiprock Uranium Mill Tailings Disposal Cell in Shiprock, New Mexico. These comments are based on the results of 32 CPT soundings performed by ConeTec, Inc. during September 2001.

The top of the disposal cell appears to be at an elevation of around 5,000 feet and the surrounding ground at an elevation of around 4,950 to 4,970 feet. The natural ground appears to slope from the south-west (elevation 4,970 feet) toward the north-east (elevation 4,950 feet). Only the CPT soundings in the north-east part of the disposal cell penetrated to any great depth (more than 20 feet) to reveal the soil close to the base of the cell. Hence, much of the interpreation is controlled by the results from CPT soundings 1501, 1502, 1504, 1505, 1507, 1523 and 1526. These CPT profiles show the tailings to be somewhat heterogeneous with depth and to comprise predominately sand mixtures, ranging from silty sands to sandy silts, with a tendancy to become more fine-grained with depth resulting is some clayey silt at depth.

The upper 10 to 18 feet of sandy tailings appear to be cemented resulting in difficult penetration by the CPT. The soundings in the central and southern parts of the disposal cell appear to have experienced difficulty penetrating through this cemented zone and hence, did not penetrate below a depth of around 20 feet. Based on the CPT pore pressure measurements and the bulk electrical resistivity measurements, the upper sandy tailings appear to have little moisture. A saturated tailings sand can have a bulk resistivity of less than 100 ohm-m compared to a dry tailings sand with a bulk resistivity of more than 10,000 ohm-m. The average bulk resistivity in the upper zone is around 10,000 ohm-m which indicates an almost dry sandy soil. However, even in this upper almost dry sandy zone the electrical resistivity measurements show thin zones (less than 12 inches thick) of higher moisture soil where the bulk resistivity drops to values of less than around 100 ohm-m. These thin zones of higher moisture may be the result of seasonal rainfall and downward perculation.

In the north-east part of the disposal cell, the tailings below a depth of 10 to 18 feet appear to be somewhat softer and more fine grained (silts to clayey silts). The CPT pore pressure measurements and the bulk resistivity measurements indicate a higher moisture content in these softer deeper zones. In CPT 1504, 1507 and 1526 (located along the north-east edge of the disposal cell) the bulk resistivity drops to below 100 ohm-m over a depth range of around 18 to 26 feet indicating a possible saturated soil (tailings). In this zone the CPT pore pressure measurements also indicate a near saturated soil with elevated equilibrium pore pressures. The elevated equilibrium pore pressures indicate either an underconsolidated soil or a high watertable. The high watertable is unlikely since the bulk resistivity in the sandy soils above this zone is very high indicating an almost dry soil. The underconsolidated soil interpreation is, however, not fully supported by the somewhat stiff soil response based on the measured CPT penetration resistance. In underconsolidated soils the pentration resistance can be very low, whereas in these zones the cone resistance indicates a slightly overconsolidated soil. The soft, high moisture content zone was only encountered in CPT 1504, 1507 and 1526 from a depth of around 18 to 26 feet (elevation 4,971 to 4,963 feet). The high piezometric pressure maybe due to an essentially enclosed zone of saturated softer tailings surrounded by a dense, almost cemented shell of dry tailings.

Based on the above observation, it would appear that the tailings in the disposal cell have a predominately low moisture content in the upper (and outer) zones above a depth of about 20 feet, with thin zones of higher moisture, possibly due to seasonal influx of rainfall. Below a depth of about 18 feet a zone of softer, finer grained, higher moisture soil was encountered in parts of the disposal cell along the north-east edge (CPT 1504, 1507 and 1526). This softer zone maybe due to a tendency for moisture to collect along the lower elevation north-east edge of the disposal cell. This water may not be able to seep out along the north-east edge due to the dense cemented nature of the near-surface sandy-silty soils (tailings). It is interesting to note that CPT 1527, which was carried out at the toe of the north-east side of the cell below CPT 1507, encountered essentially dry very dense, cemented sand until refusal at a depth of 8 feet (elevation 4,944 feet). This would indicate that little to no water is seeping below the toe of the north-east section of the disposal cell. It would appear that there may be a mound of near saturated softer fine grained tailings below the crest of the north-east portion of the disposal cell. This zone of softer fine grained saturated tailings may extend back below the central portion of the disposal cell. However, no CPT soundings were able to penetrate to a sufficient depth to fully investigate this possibility.

A detailed cross-section of the disposal cell from the south-west corner (CPT 1519) to the north-east corner (CPT 1526) of the disposal cell would be useful to locate and define the extent of this high moisture zone of tailings.

To investigate the possibility of a mound of high moisture tailings below the north-east corner of the disposal cell it would be useful to perform a CPT from the mid-height bench at an elevation of around 4,970 feet (below CPT 1526 and above CPT 1527). It would also be interesting to observe for signs of seepage along the toe of the north-east edge of the disposal cell for signs of any seepage. However, signs of seepage maybe difficult to

observe if the local climate has high evaporation rates. It would also be interesting to install near-horizontal drains into the face of the north-east edge of the disposal cell at an elevation of around 4,955 to 4,970 feet to see if water would be encountered and possibly removed.

I trust this information is helpful. Please contact the undersigned if you require any further assistance.

Yours truly,

P. K. Robertson, Ph.D.

Cc Shawn Steiner, ConeTec, Inc.