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UMTRA Ground Water Project

Results of A Piezocone Investigation Shiprock, New Mexico

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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.

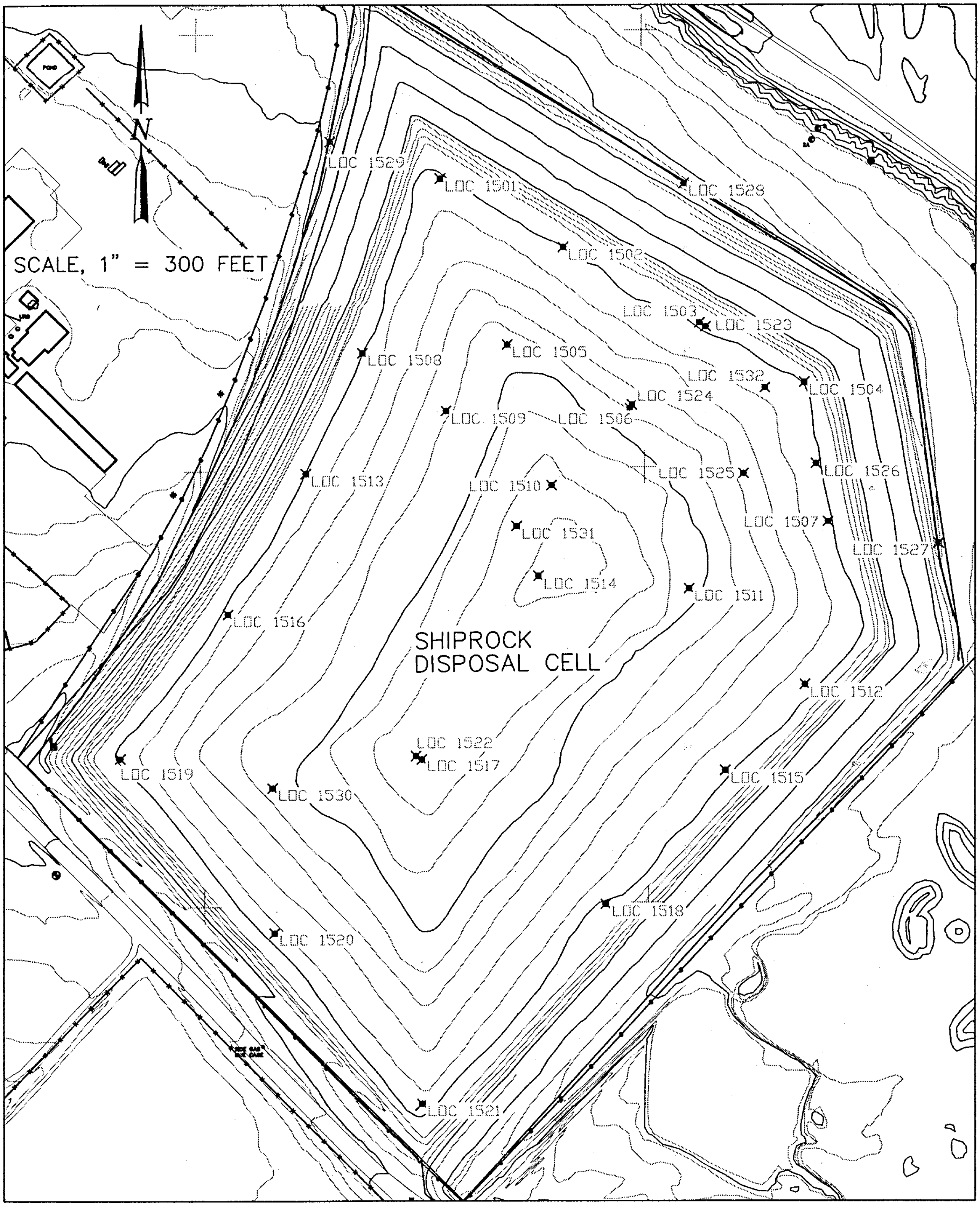
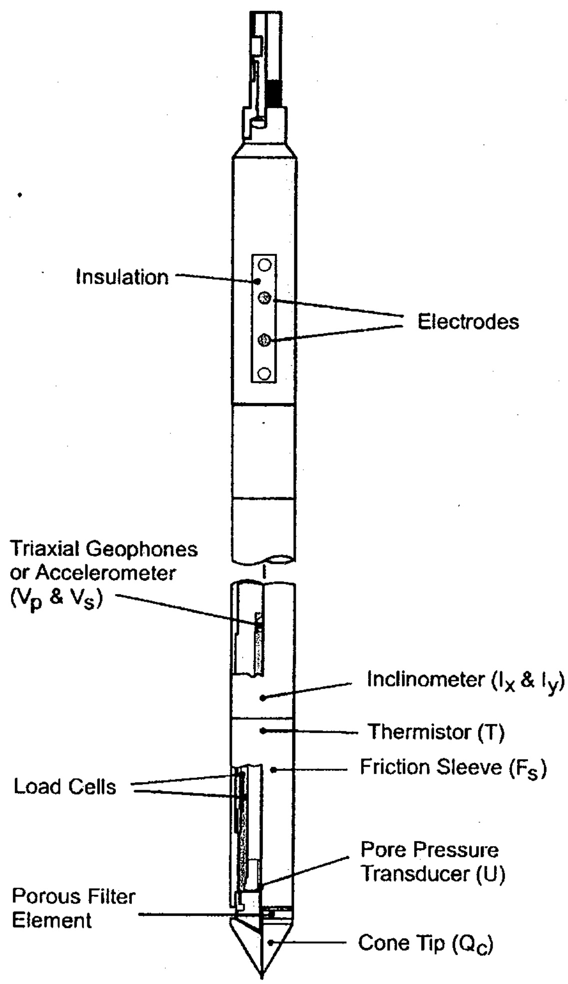


Figure 1. Shiprock Disposal Cell Piezocone Investigation Sounding Location

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

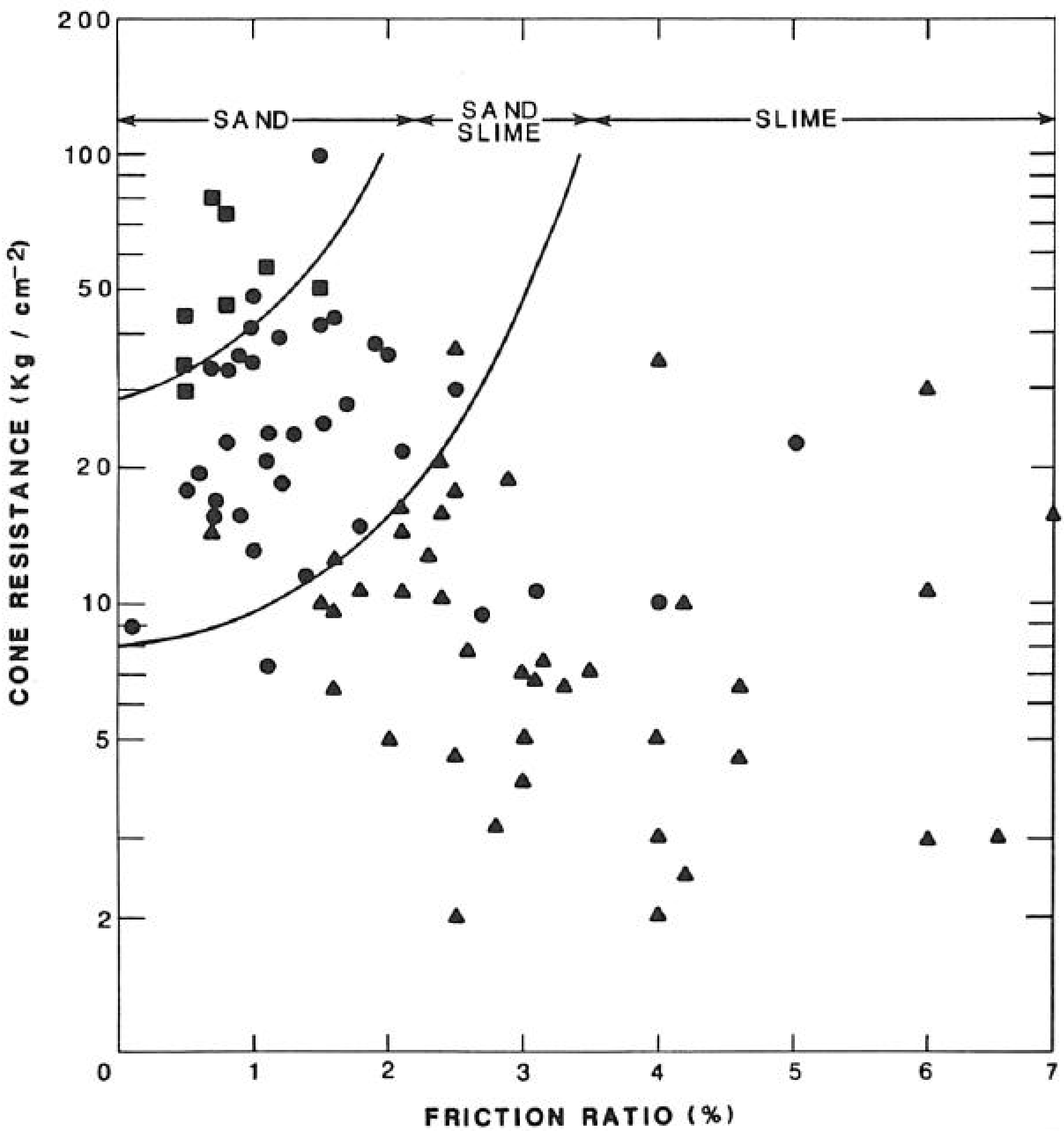


Figure 3.Piezocone Classification Chart Used for Uranium Mill Tailings

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.

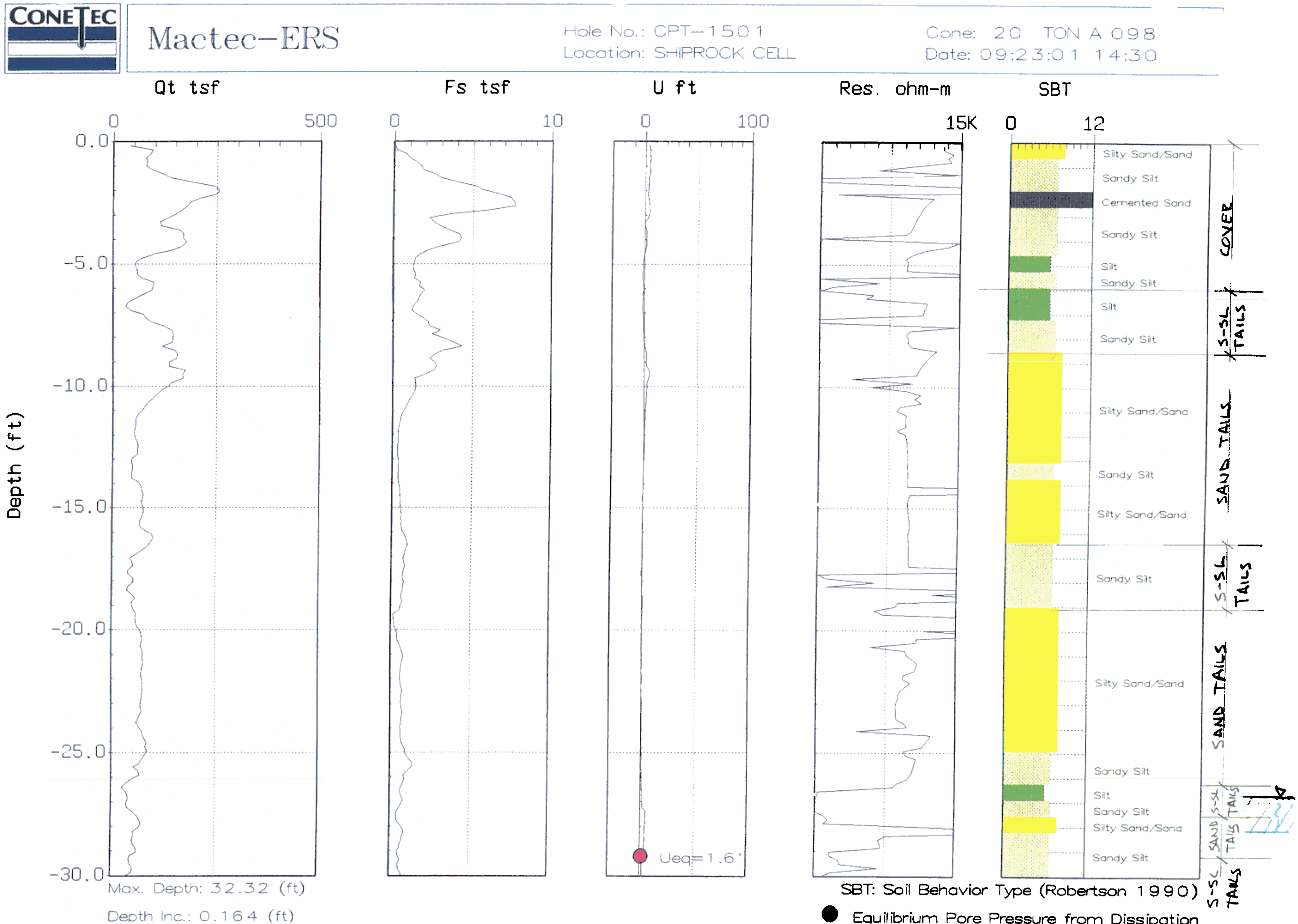
7.0 Pore Pressure Dissipation Tests

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)
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Silty Sand/Sand
Sandy Silt
Cemented Sand
Silt
Ueq=1.6'
COVER
S-SL TAILS
SAND TAILS
Max. Depth: 32.32 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 4

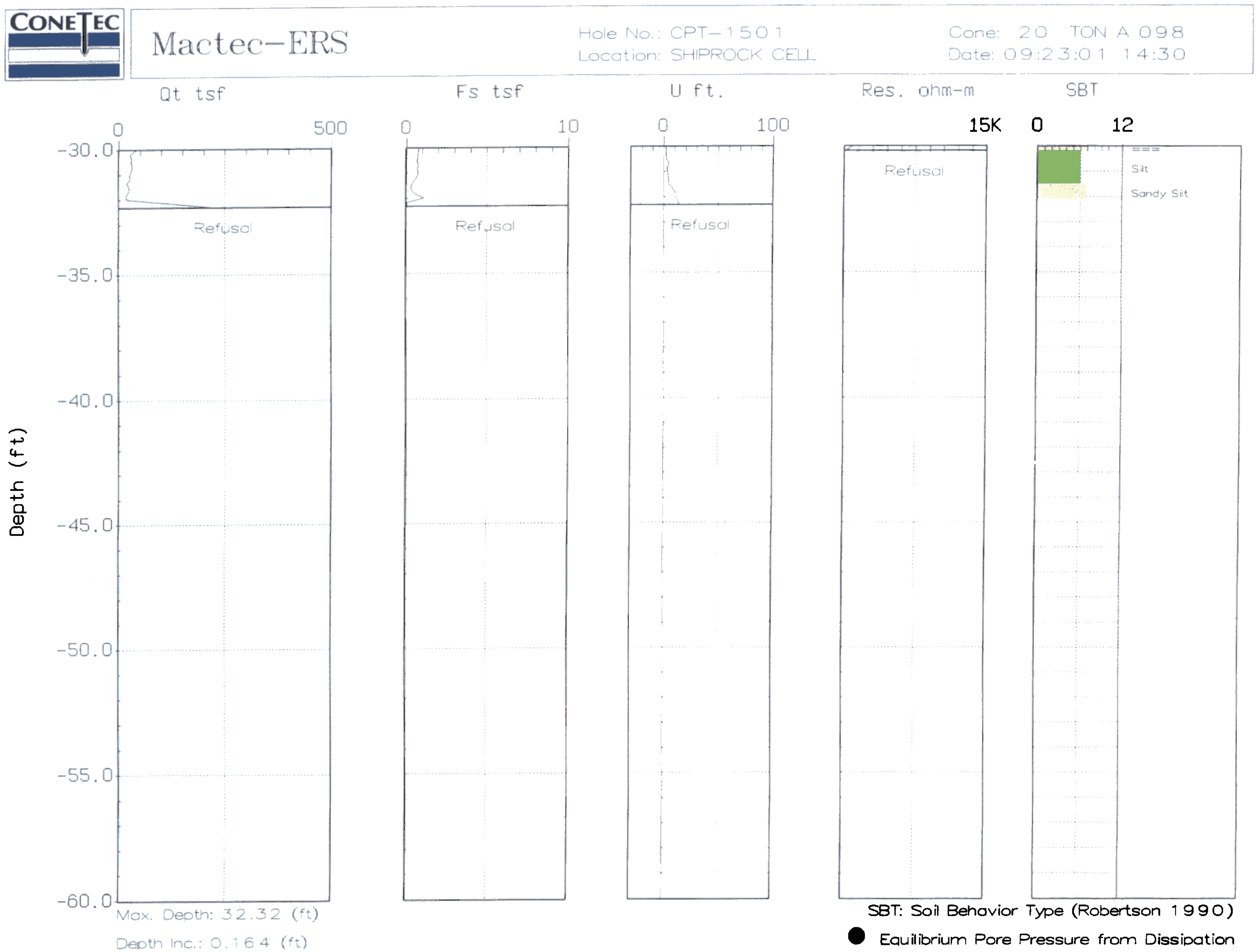


Figure 4 (continued)

CONETEC

Mactec–ERS

Hole No.: CPT–1502
Location: SHIPROCK CELL

Cone: 20 TON A 098
Date: 09:23:01 15:20

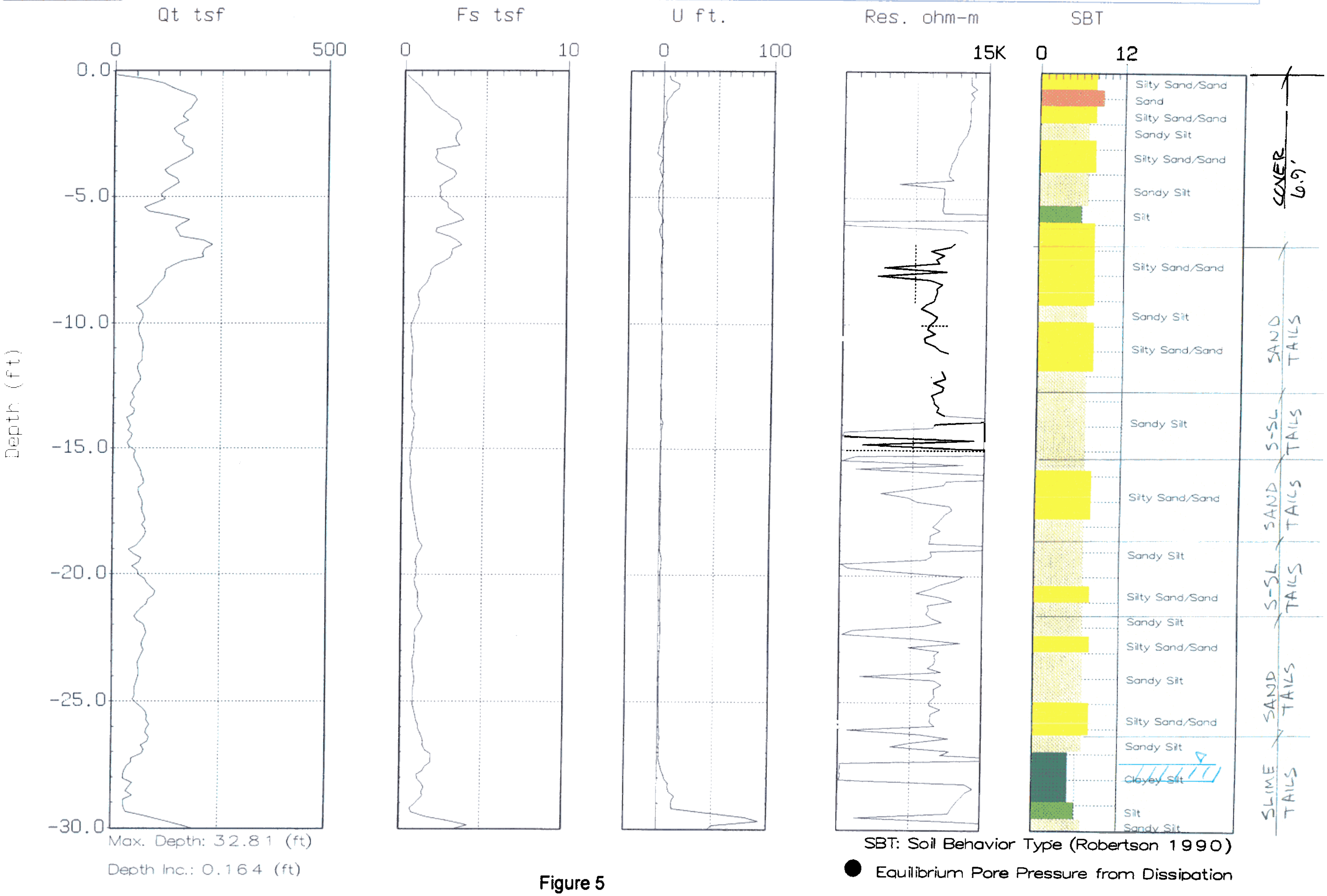


Figure 5

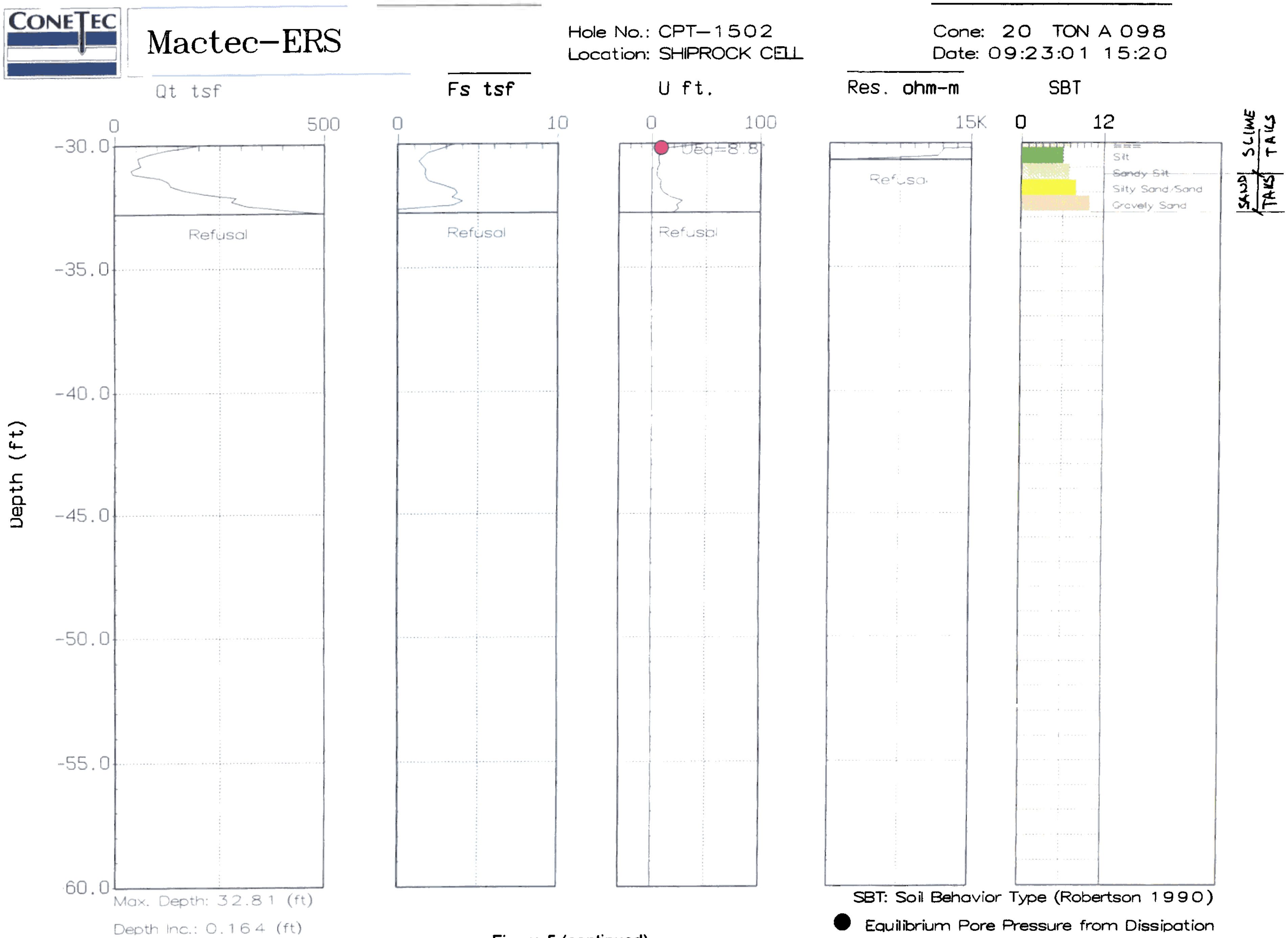


Figure 5 (continued)

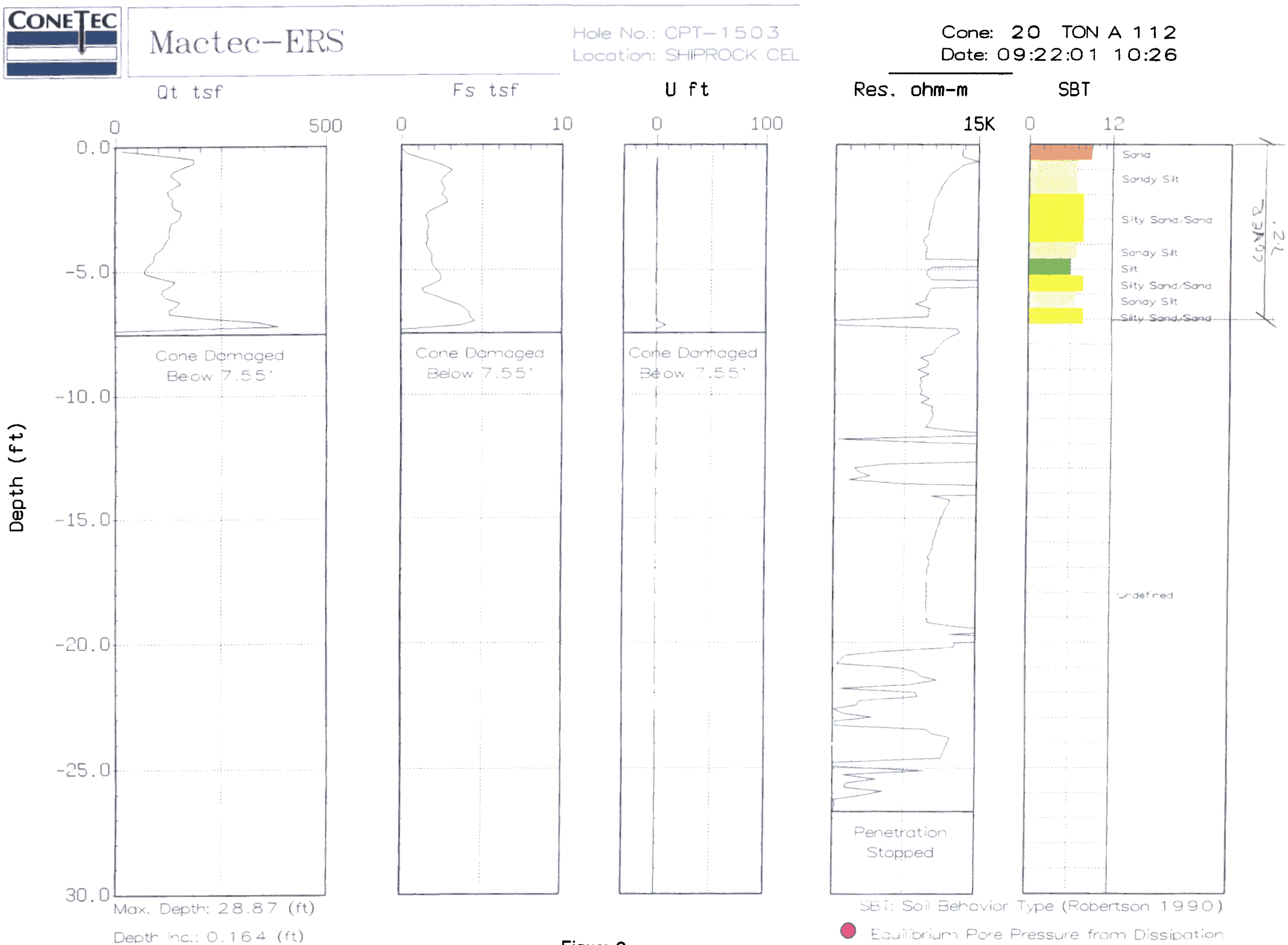
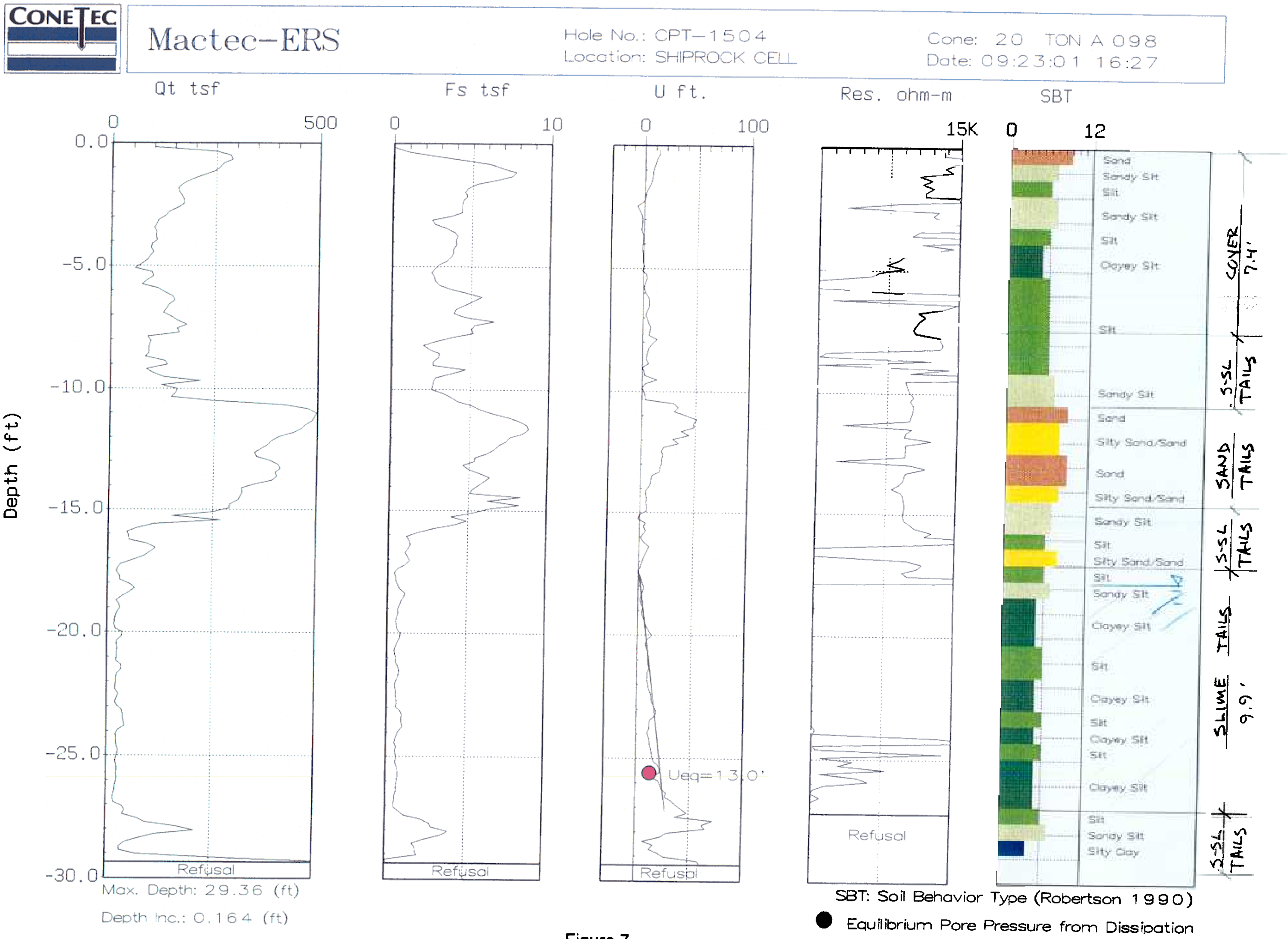

ConeTec
Mactec-ERS
Hole No.: CPT-1503
Location: SHIPROCK CEL
Cone: 20 TON A 112
Date: 09:22:01 10:26
Qt tsf
Fs tsf
U ft
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
30.0
Depth (ft)
Cone Damaged Below 7.55'
Cone Damaged Below 7.55'
Cone Damaged Below 7.55'
Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Undefined
COVER 7.2'
Penetration Stopped
Max. Depth: 28.87 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 6



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
TAILS
SLIME 9.9'
Max. Depth: 29.36 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 7

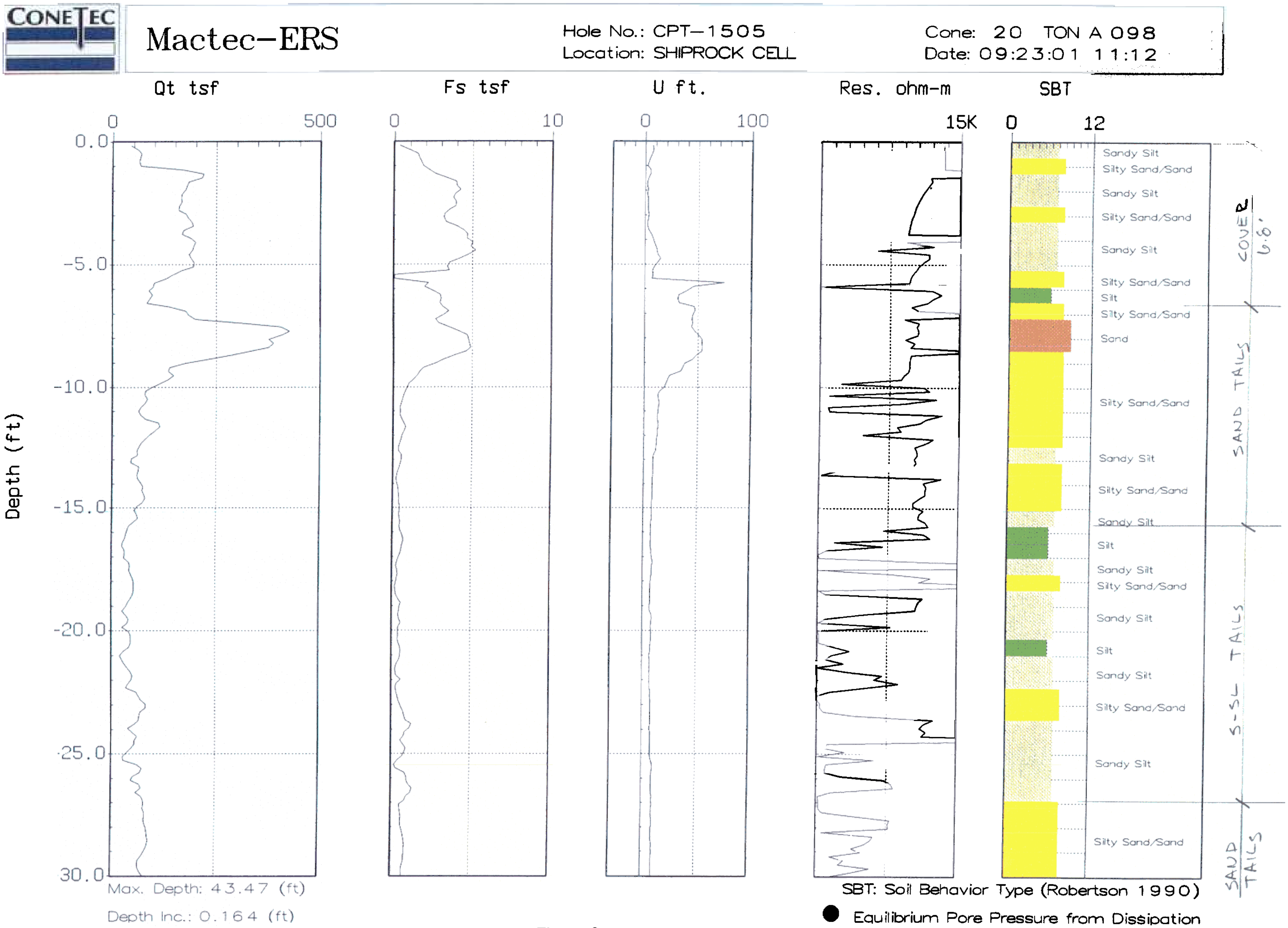

CONETEC
Mactec–ERS
Hole No.: CPT–1505
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:23:01 11:12
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
0
10
0
100
15K
0
12
Depth (ft)
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
30.0
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/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

Figure 8

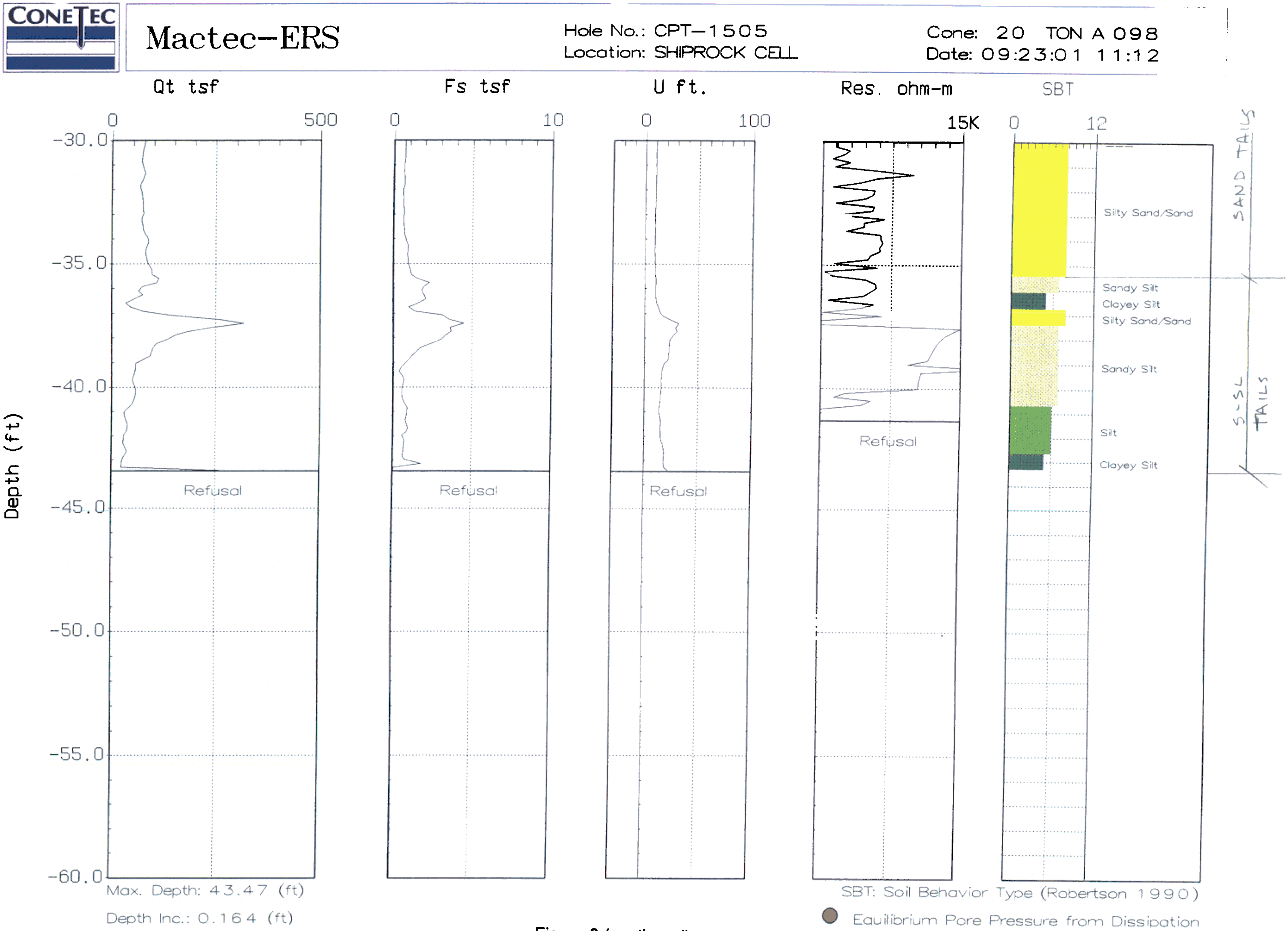
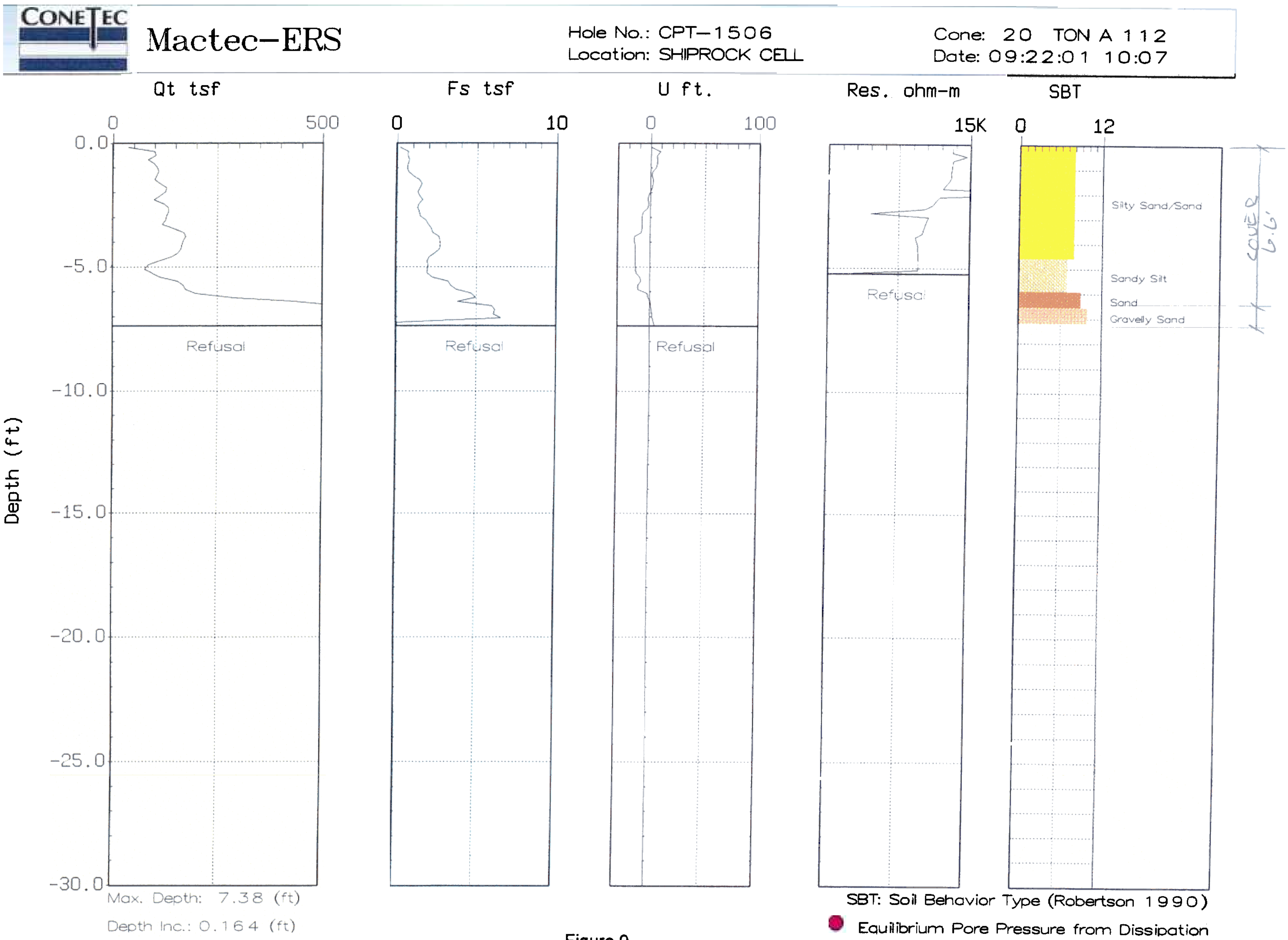
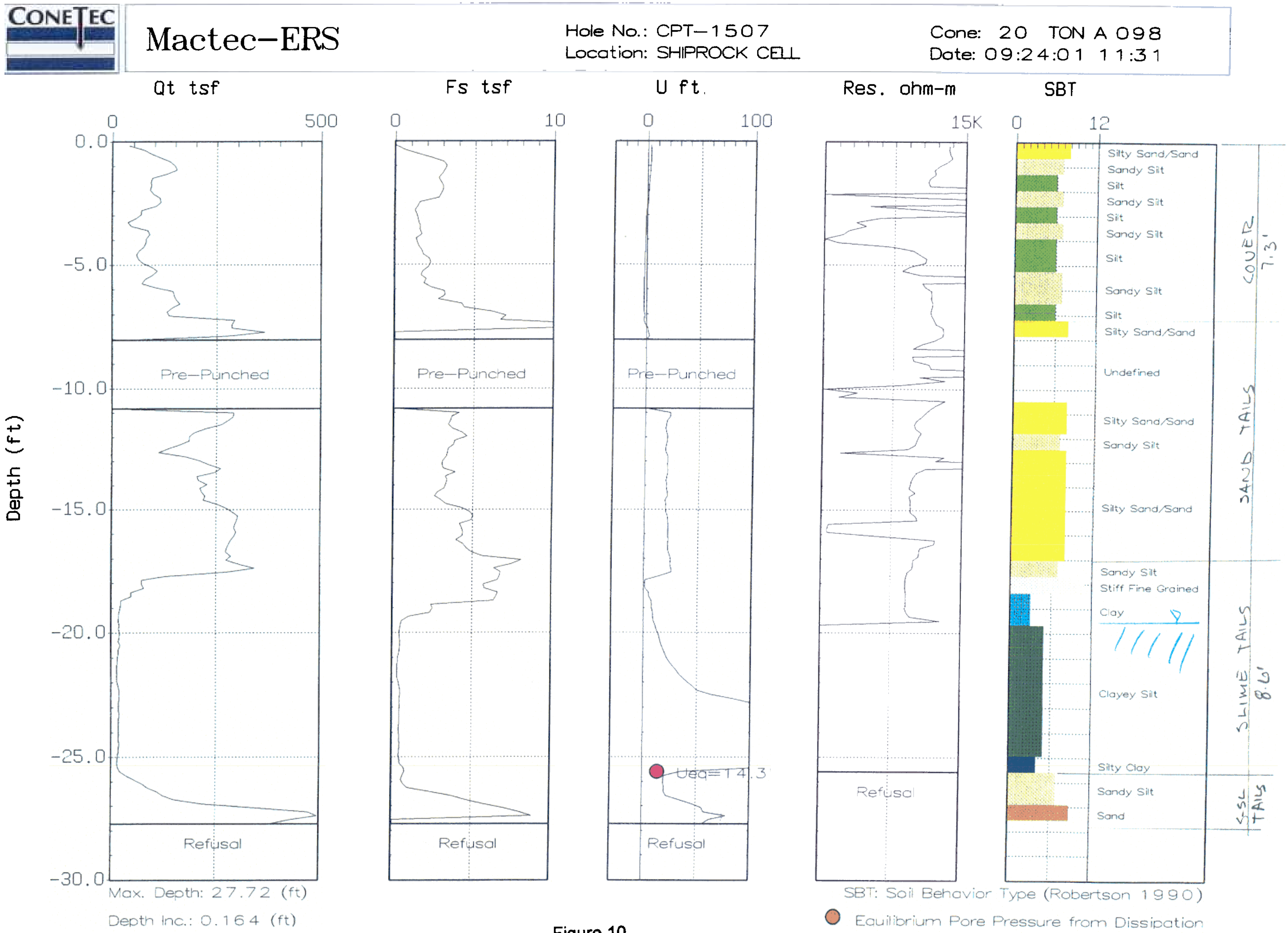


Figure 8 (continued)



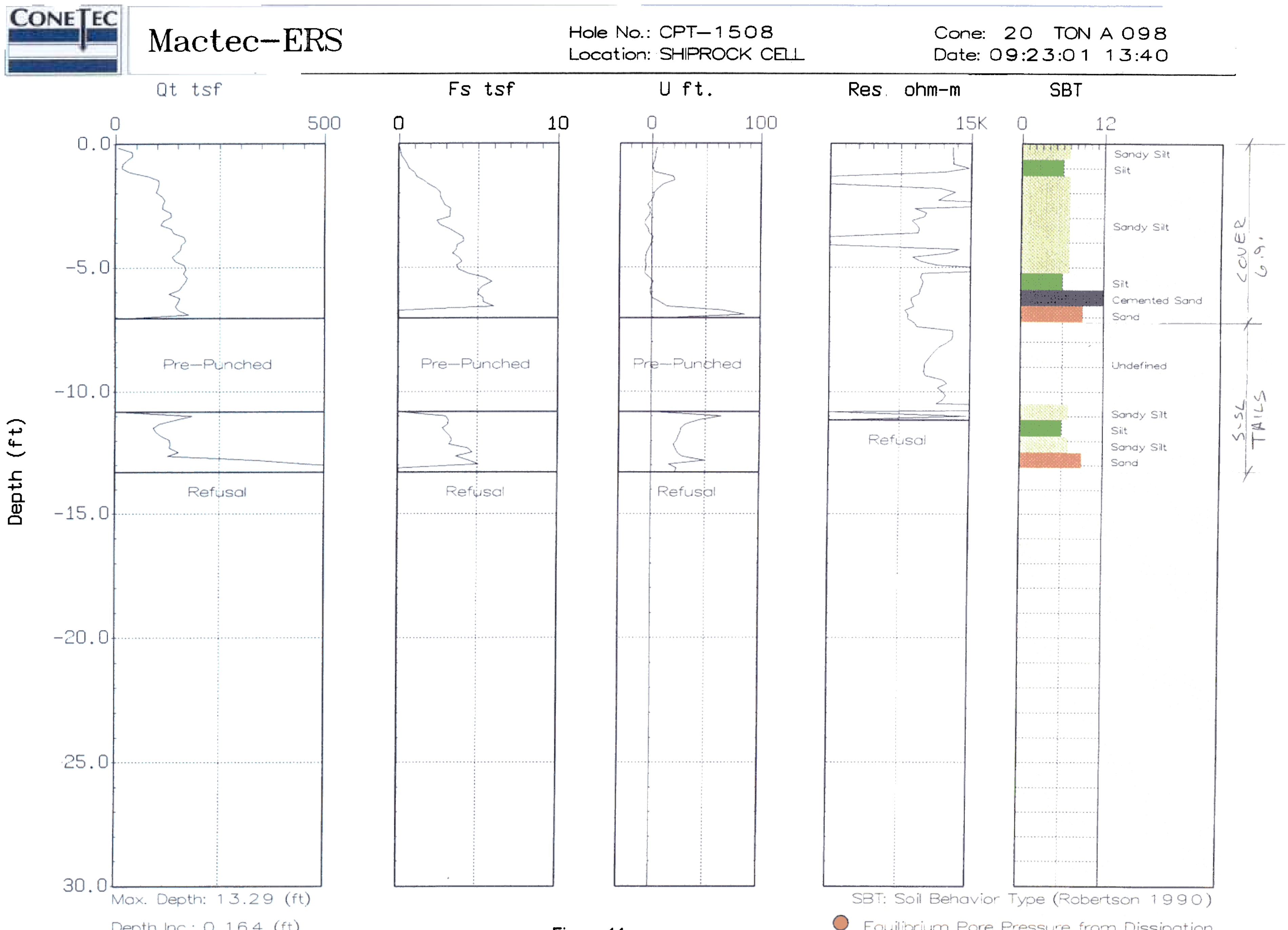
ConeTec
Mactec-ERS
Hole No.: CPT-1506
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:22:01 10:07
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Silty Sand/Sand
Sandy Silt
Sand
Gravelly Sand
Max. Depth: 7.38 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

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
Depth (ft)
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
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

Figure 10



CONETEC
Mactec–ERS
Hole No.: CPT–1508
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:23:01 13:40
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
0
10
0
100
15K
0
12
Depth (ft)
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
30.0
Pre–Punched
Refusal
Sandy Silt
Silt
Sandy Silt
Silt
Cemented Sand
Sand
Undefined
Sandy Silt
Silt
Sandy Silt
Sand
COVER
6.9'
S-SL
TAILS
Max. Depth: 13.29 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 11

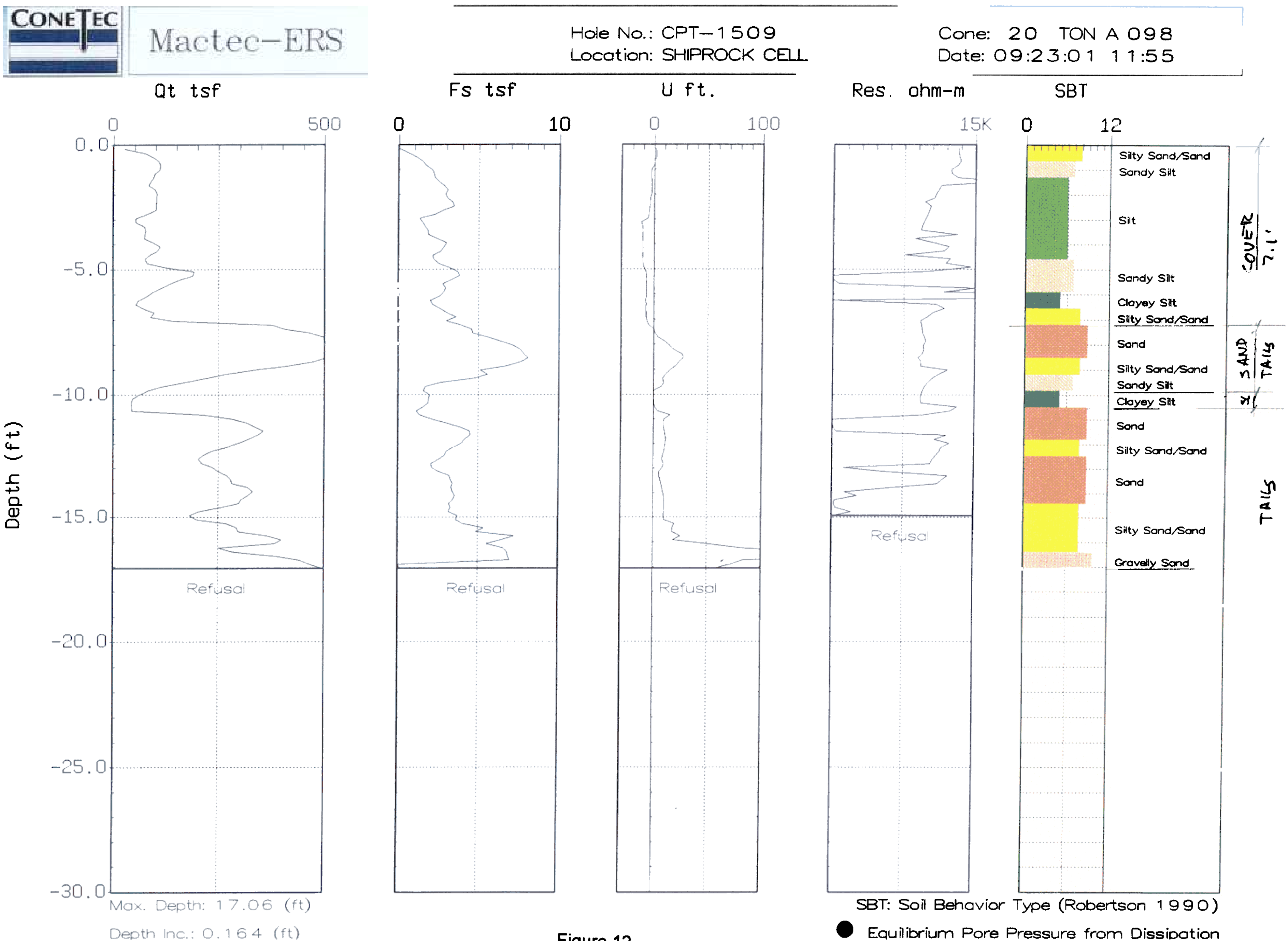

ConeTec
Mactec-ERS
Hole No.: CPT-1509
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:23:01 11:55
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Clayey Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Sandy Silt
Clayey Silt
Sand
Silty Sand/Sand
Sand
Silty Sand/Sand
Gravelly Sand
COVER 7.1'
SAND TAILS
TAILS
Max. Depth: 17.06 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

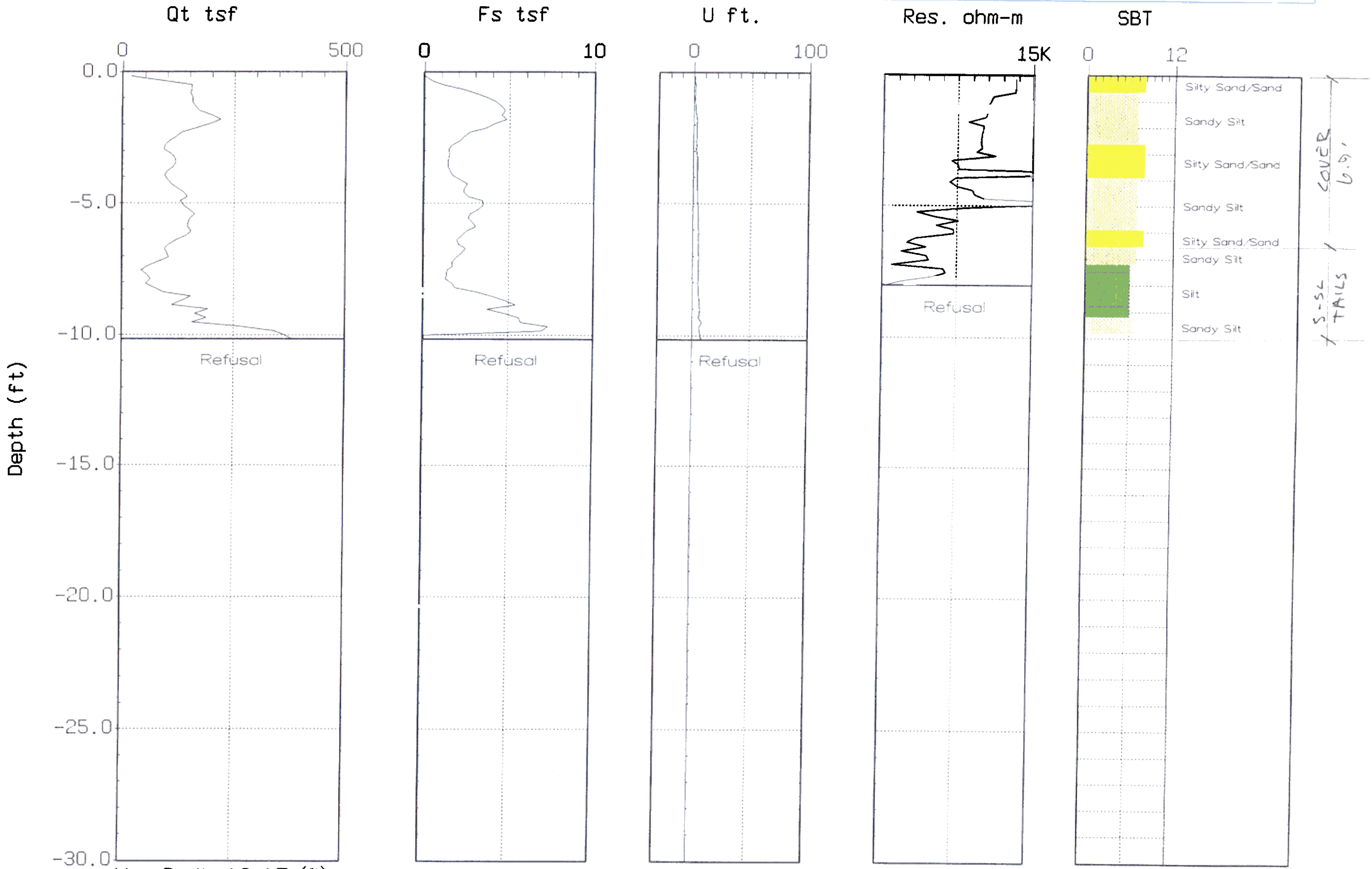
Figure 12

CONETEC

Mactec–ERS

Hole No.: CPT–1510
Location: SHIPROCK CELL

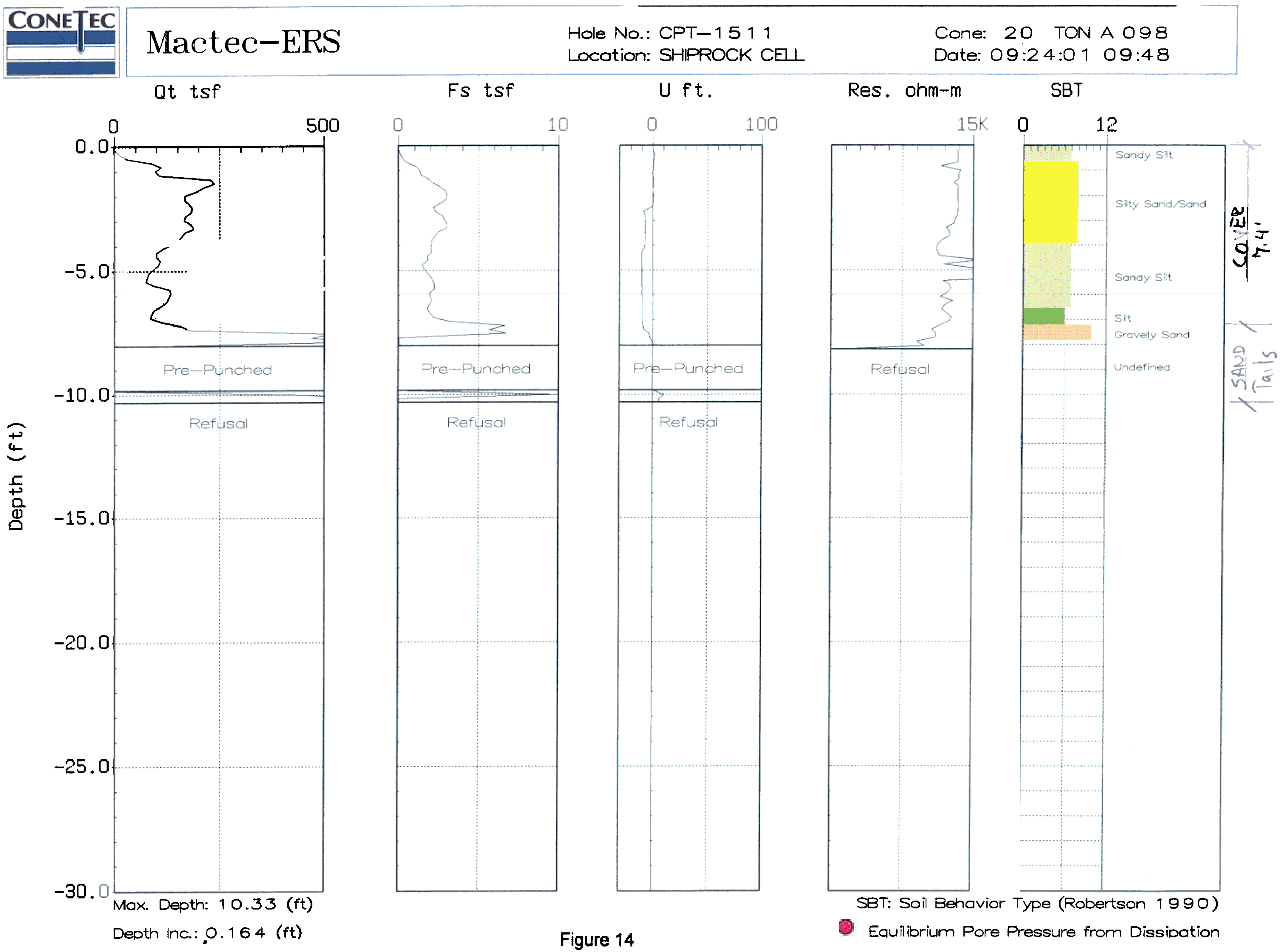
Cone: 20 TON A 112
Date: 09:22:01 09:33



Max. Depth: 10.17 (ft)
Depth Inc.: 0.164 (ft)

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

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
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
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

Figure 14

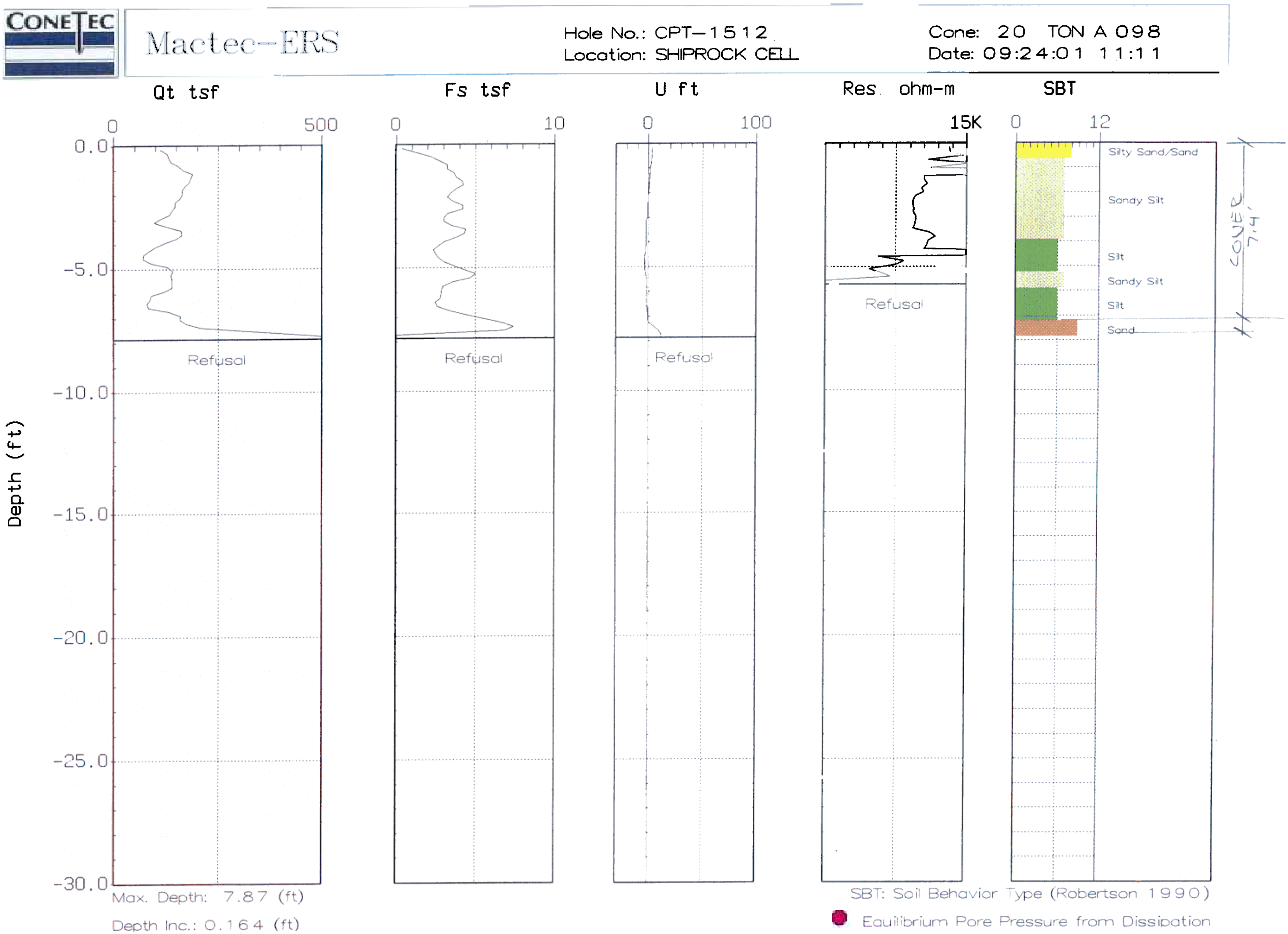

CONETEC
Mactec-ERS
Hole No.: CPT-1512
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:24:01 11:11
Qt tsf
Fs tsf
U ft
Res ohm-m
SBT
Depth (ft)
Refusal
Refusal
Refusal
Refusal
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silt
Sand
COVER 7.4'
Max. Depth: 7.87 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 15

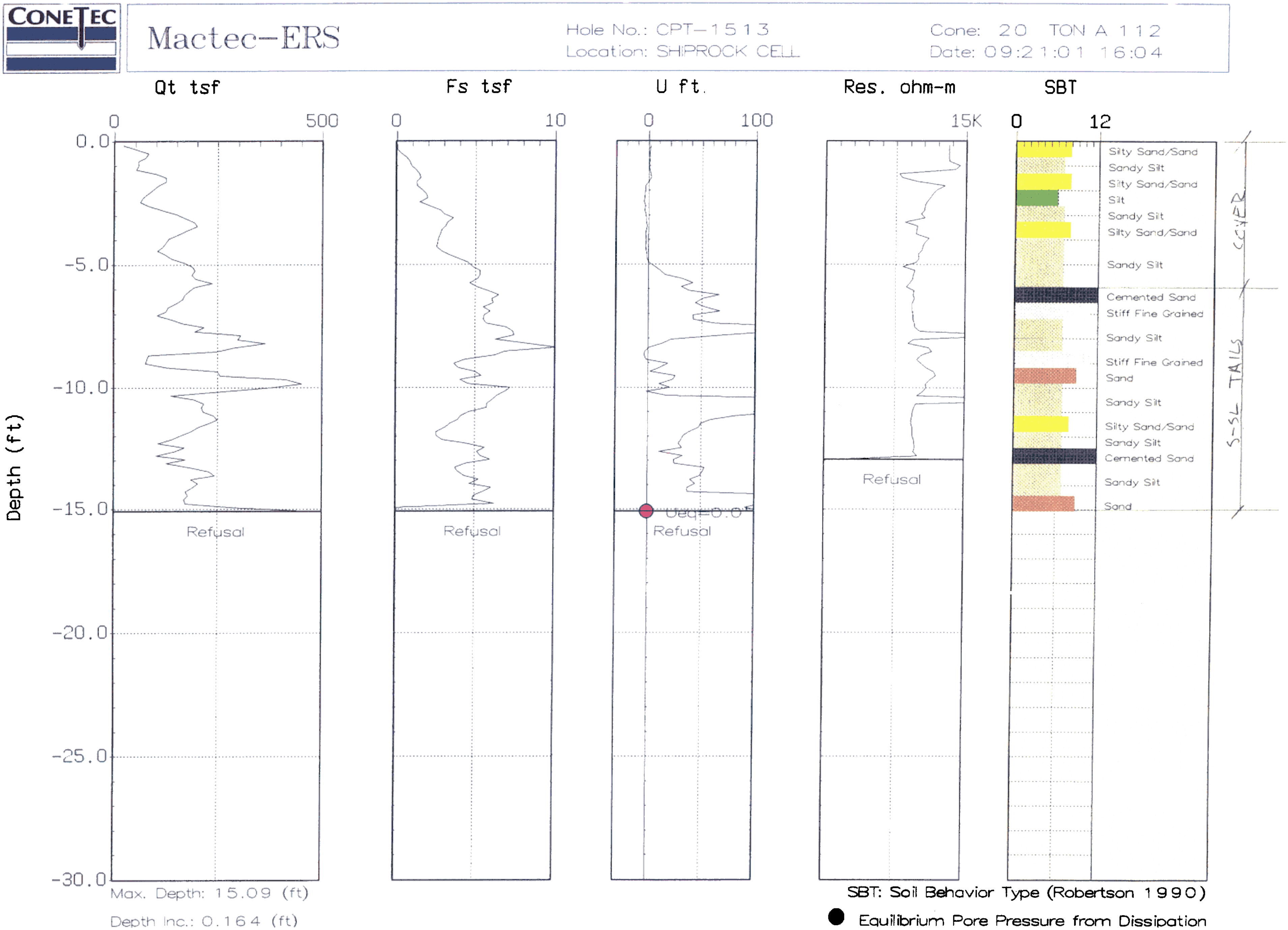

CONETEC
Mactec-ERS
Hole No.: CPT-1513
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 16:04
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Cemented Sand
Stiff Fine Grained
Sandy Silt
Stiff Fine Grained Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Cemented Sand
Sandy Silt
Sand
COVER
S-SL TAILS
Refusal
Refusal
Ueq=0.0
Refusal
Refusal
Max. Depth: 15.09 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 16

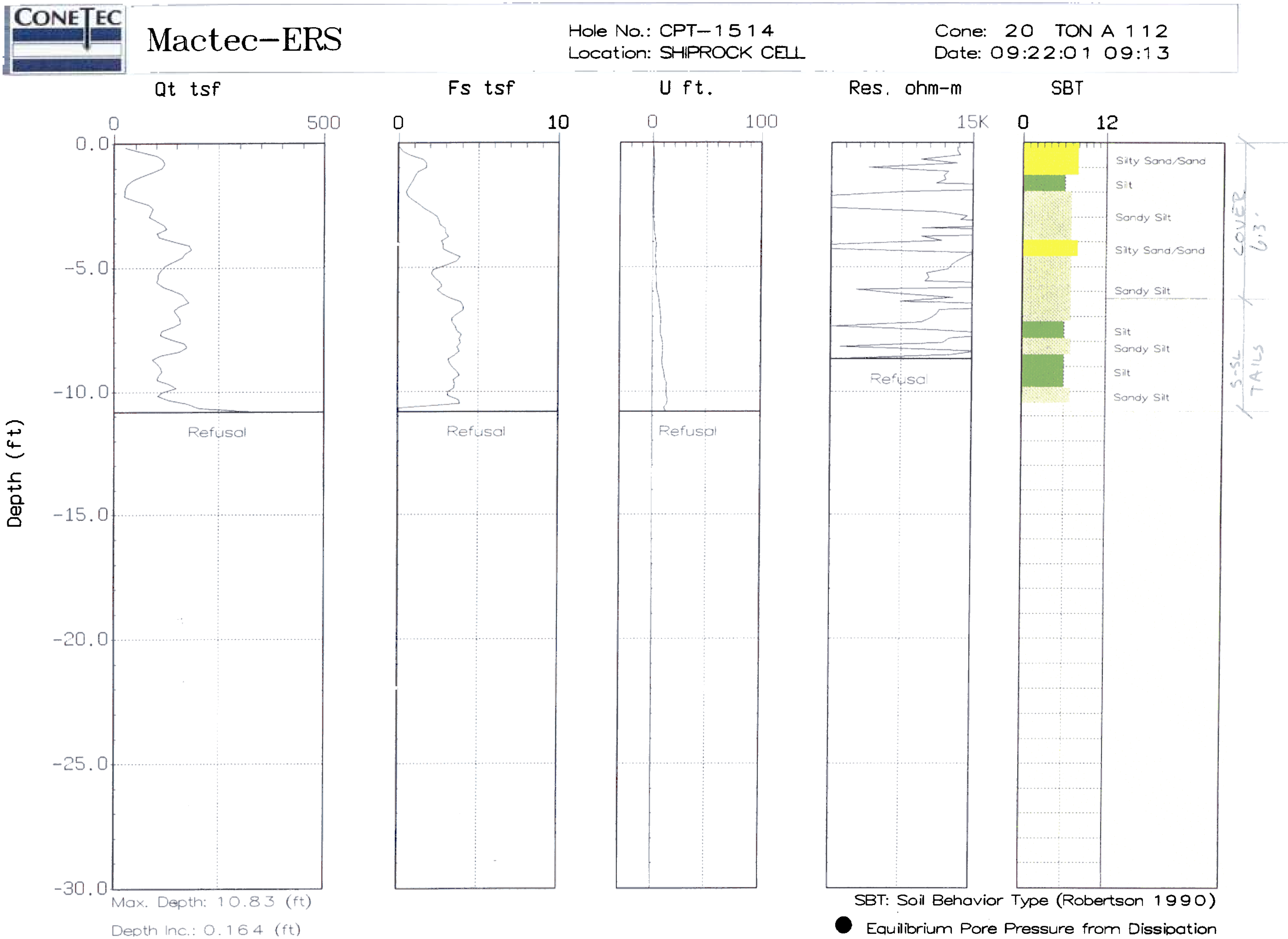

CONETEC
Mactec-ERS
Hole No.: CPT-1514
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:22:01 09:13
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Silty Sand/Sand
Silt
Sandy Silt
Max. Depth: 10.83 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 17

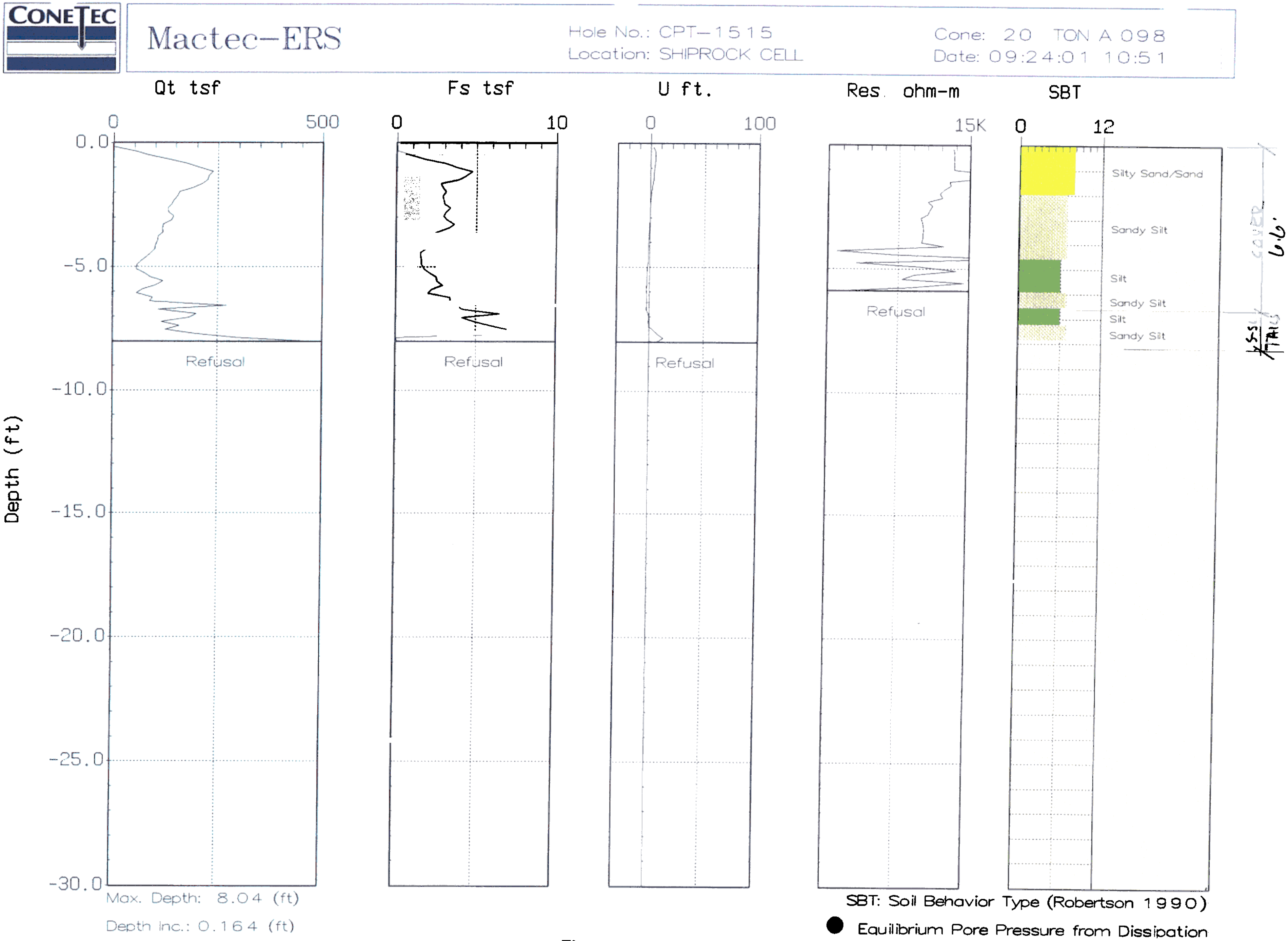

CONETEC
Mactec-ERS
Hole No.: CPT-1515
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:24:01 10:51
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Refusal
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silt
Sandy Silt
Max. Depth: 8.04 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 18

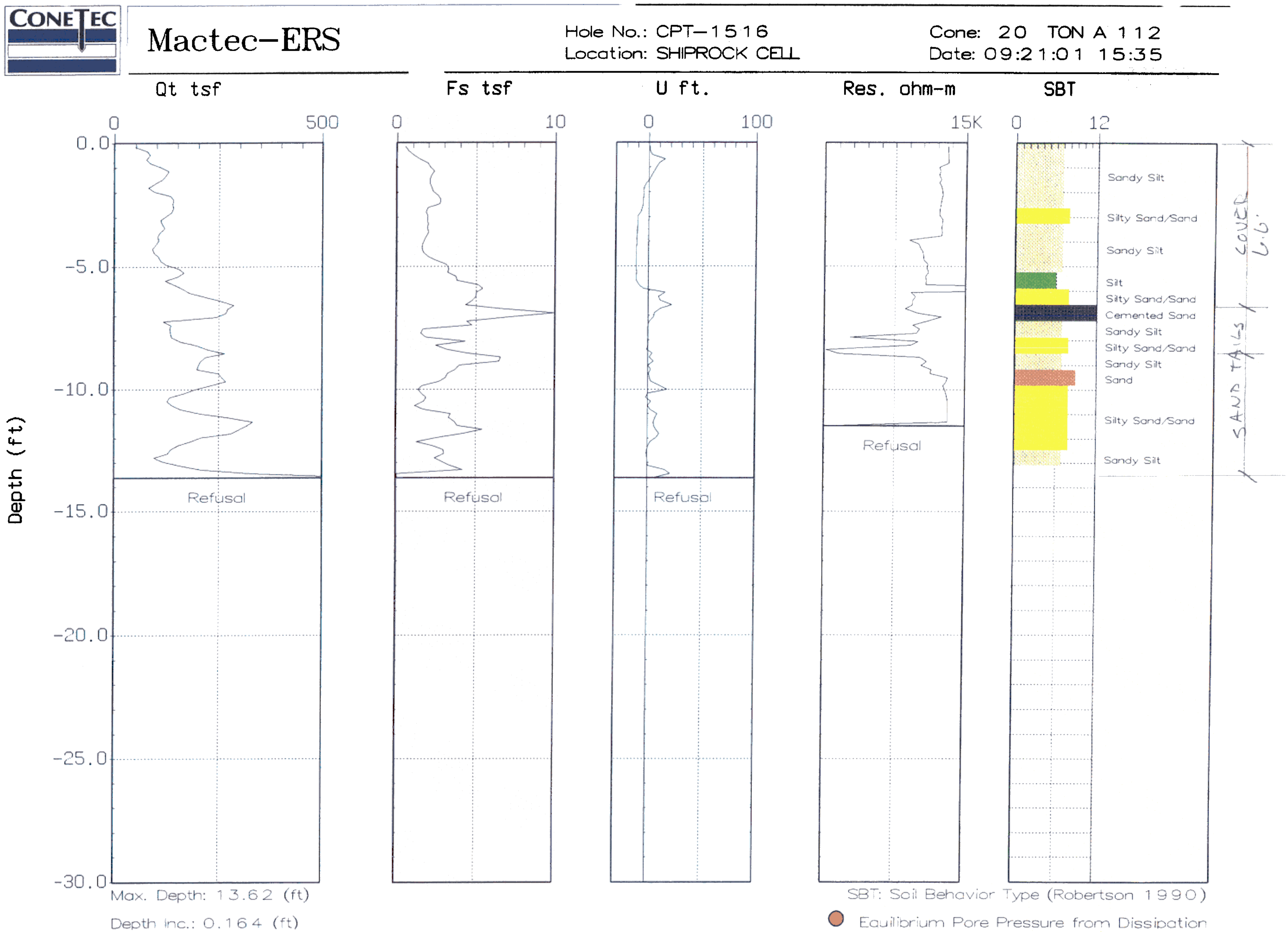
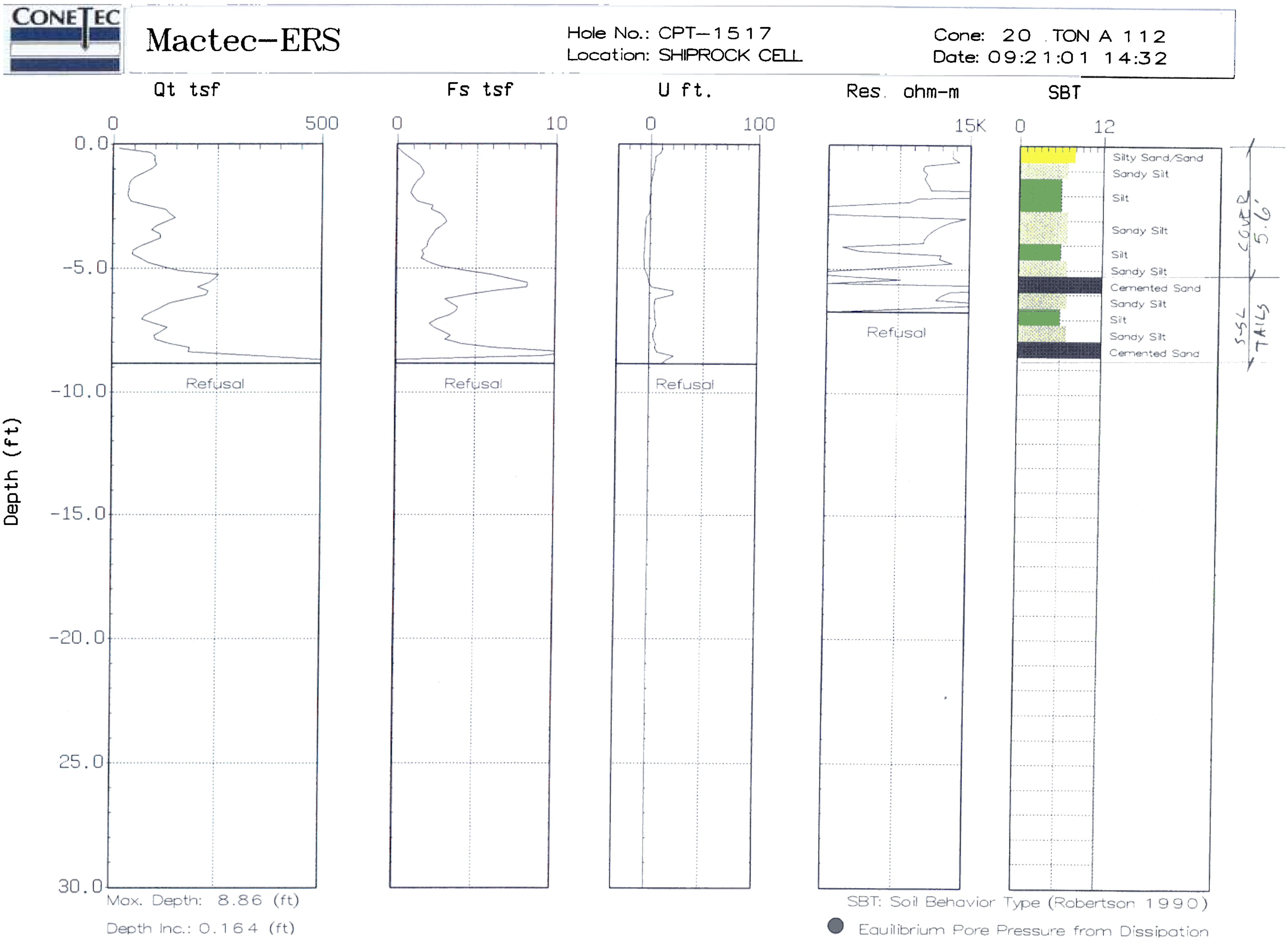

CONETEC
Mactec–ERS
Hole No.: CPT–1516
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 15:35
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Refusal
Sandy Silt
Silty Sand/Sand
Silt
Cemented Sand
Sand
COVER 6.6'
SAND TAILS
Max. Depth: 13.62 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 19



CONETEC
Mactec-ERS
Hole No.: CPT-1517
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 14:32
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
Cemented Sand
COVER 5.6'
TAILS
Max. Depth: 8.86 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 20

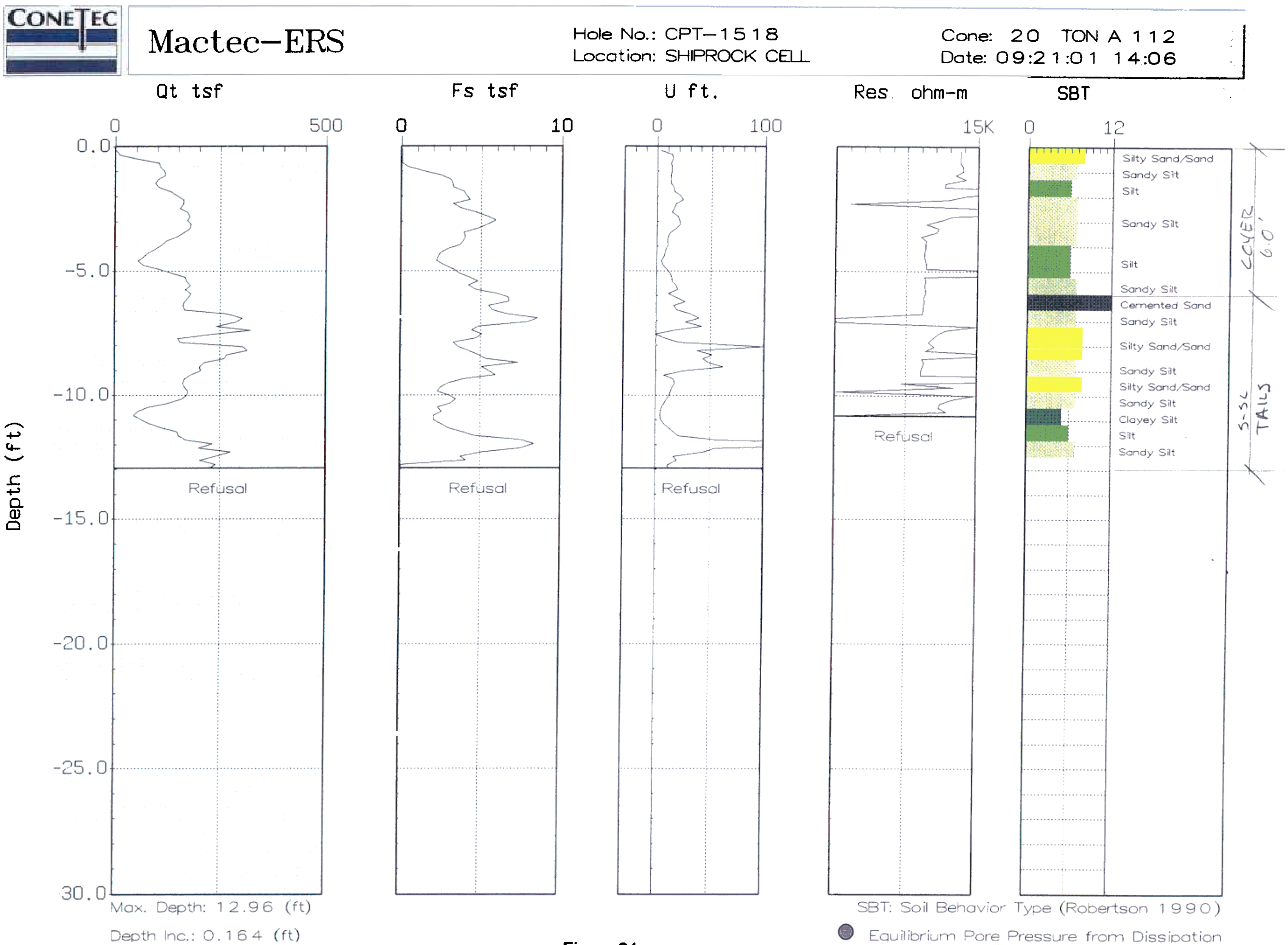

CONETEC
Mactec–ERS
Hole No.: CPT–1518
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 14:06
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Refusal
Silty Sand/Sand
Sandy Silt
Silt
Cemented Sand
Clayey Silt
COVER 6.0'
5-5L TAILS
Max. Depth: 12.96 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior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

Figure 21

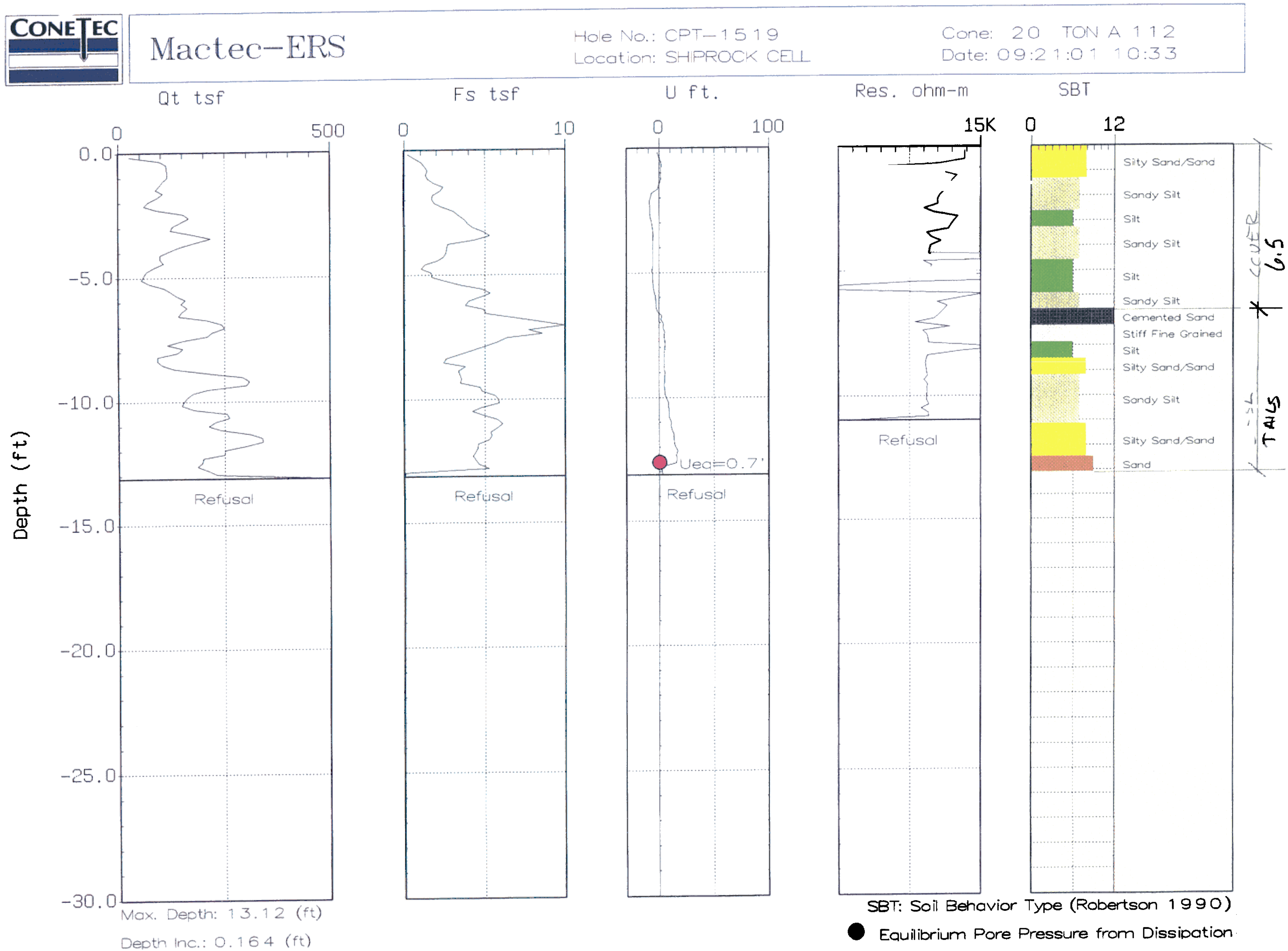
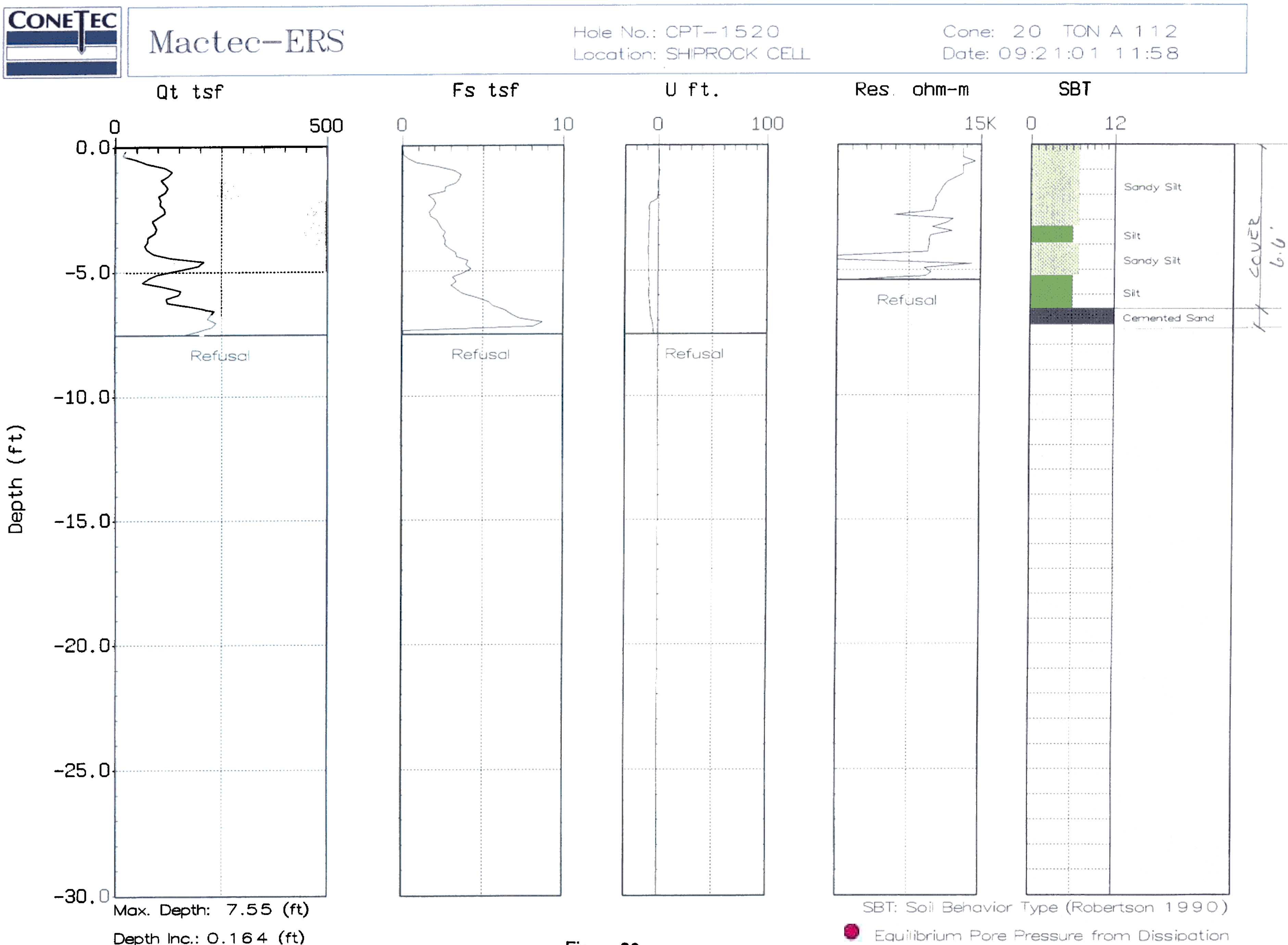

CONETEC
Mactec-ERS
Hole No.: CPT-1519
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 10:33
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Ueq=0.7'
Silty Sand/Sand
Sandy Silt
Silt
Cemented Sand
Stiff Fine Grained
Sand
COVER
6.5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

Figure 22



CONETEC
Mactec-ERS
Hole No.: CPT-1520
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 11:58
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
Silt
Cemented Sand
Max. Depth: 7.55 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 23

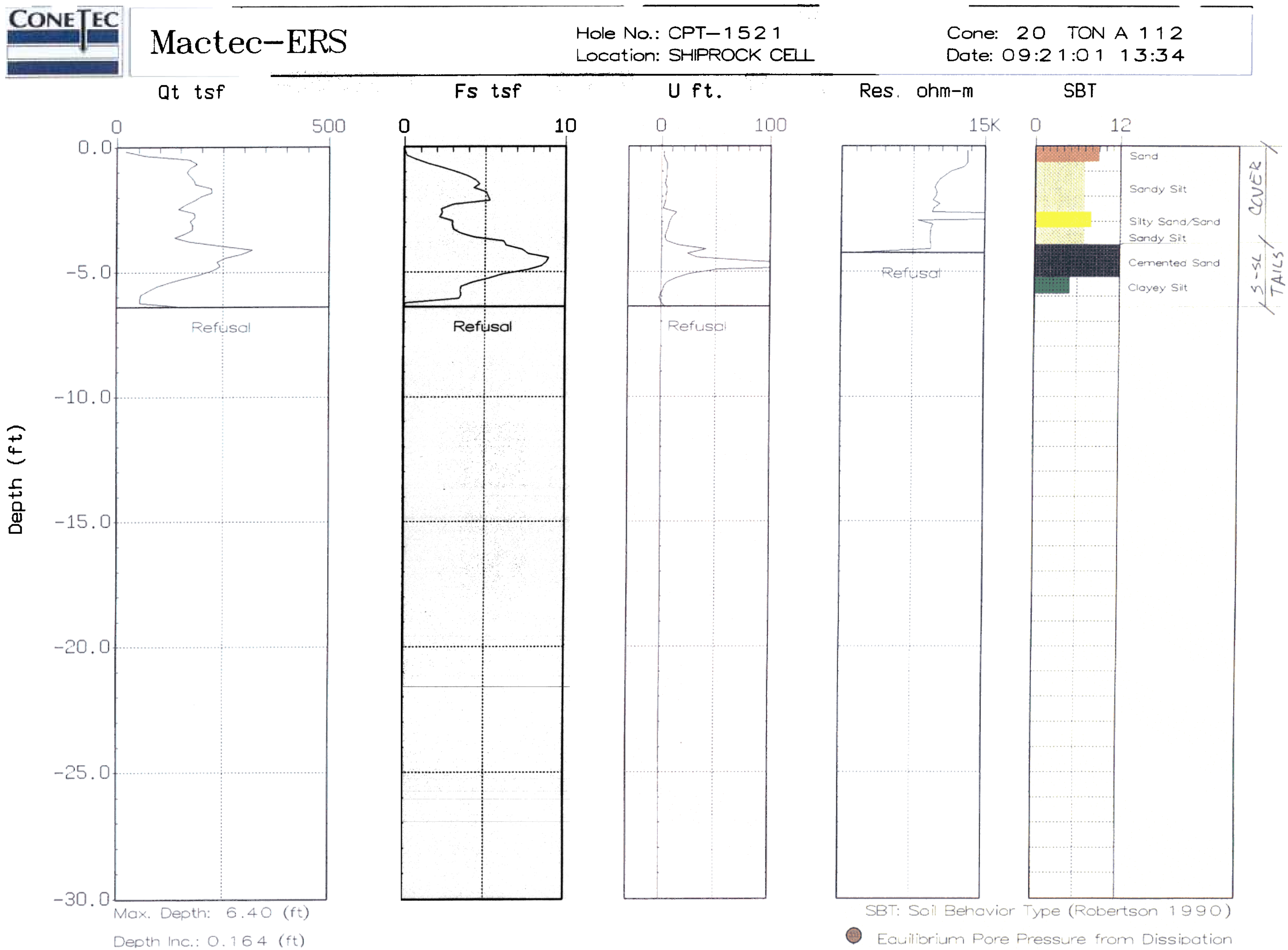

Mactec-ERS
Hole No.: CPT-1521
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 13:34
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
0
10
0
100
15K
0
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Refusal
Refusal
Refusal
Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Cemented Sand
Clayey Silt
COVER
TAILS
Max. Depth: 6.40 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 24

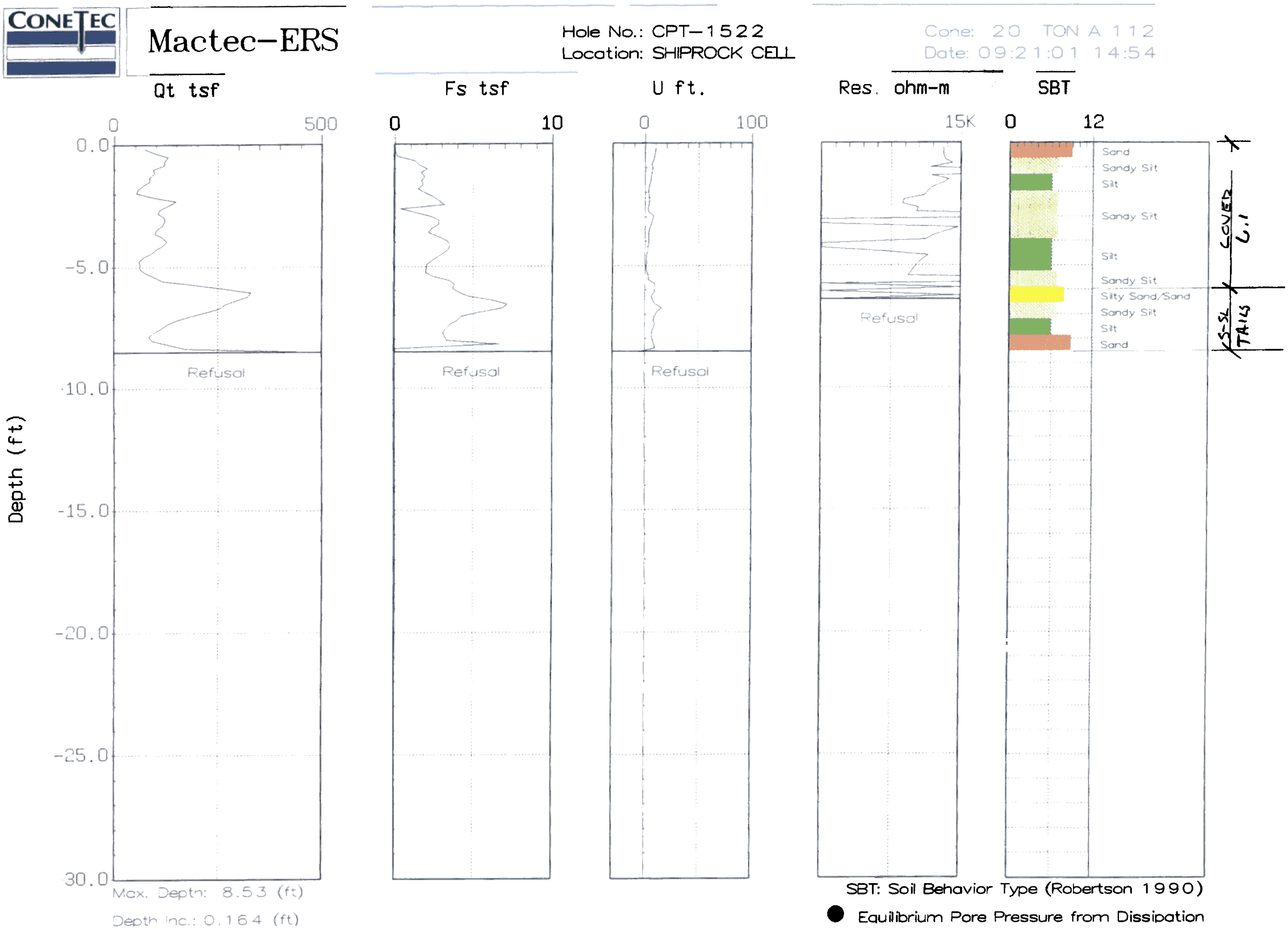
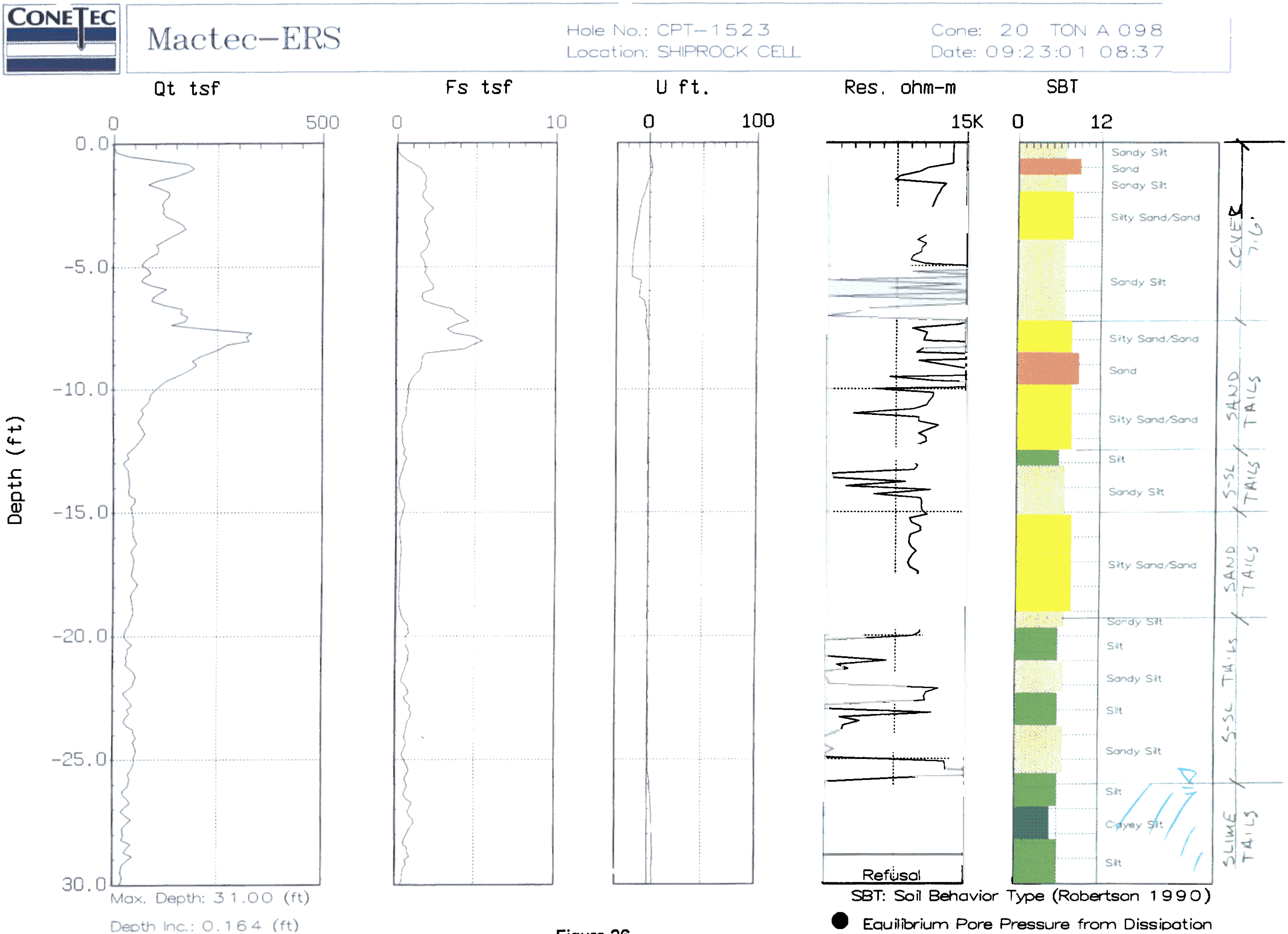

CONETEC
Mactec–ERS
Hole No.: CPT–1522
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 14:54
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Sand
Sandy Silt
Silt
Sandy Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Sand
Max. Depth: 8.53 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

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
0
500
0
10
0
100
15K
0
12
Depth (ft)
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
30.0
Sandy Silt
Sand
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silty Sand/Sand
Sand
Silty Sand/Sand
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silt
Sandy Silt
Silt
Clayey Silt
Silt
Refusal
COVER 7.6'
SAND TAILS
S-SL TAILS
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

Figure 26

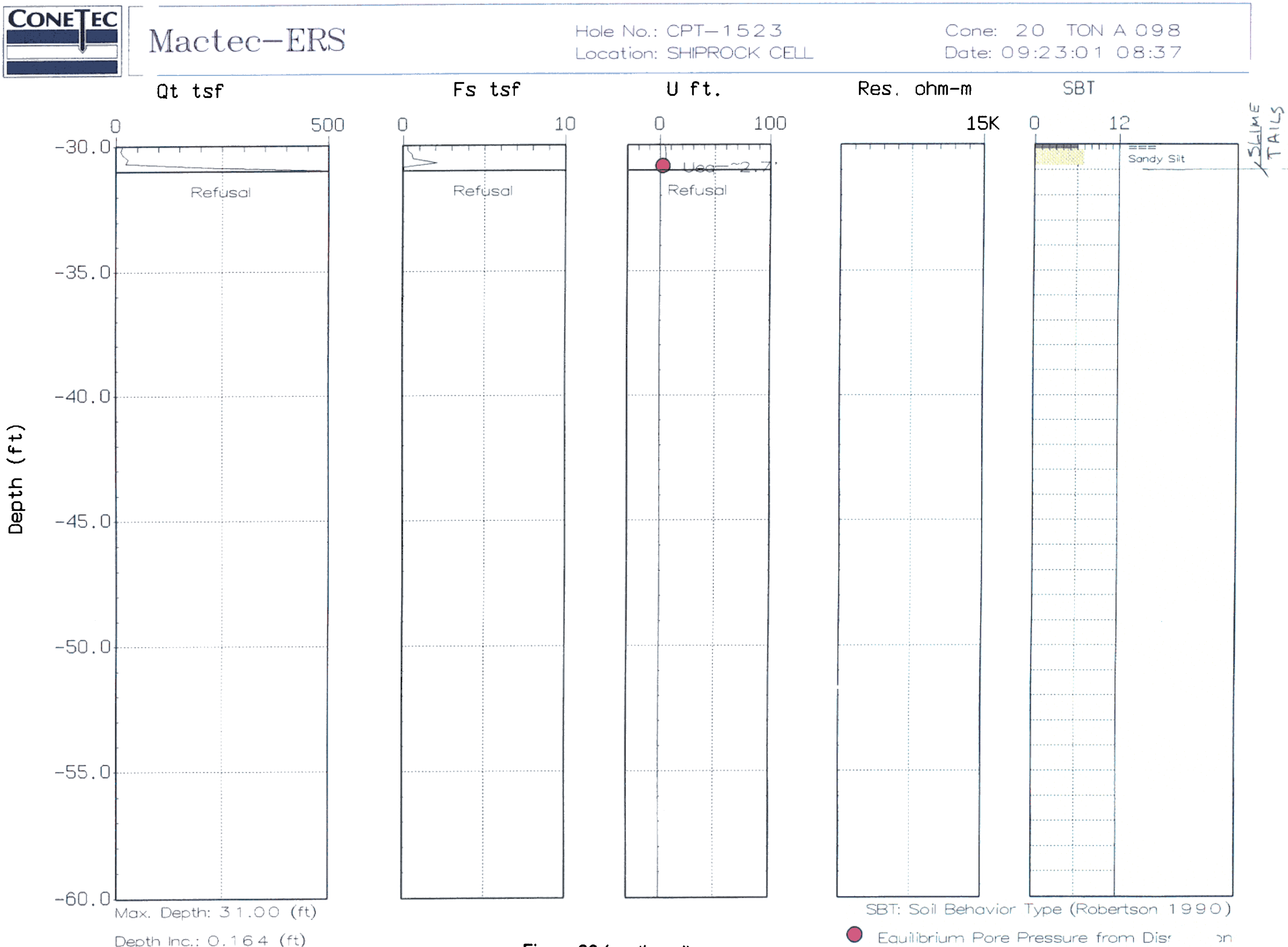


Figure 26 (continued)

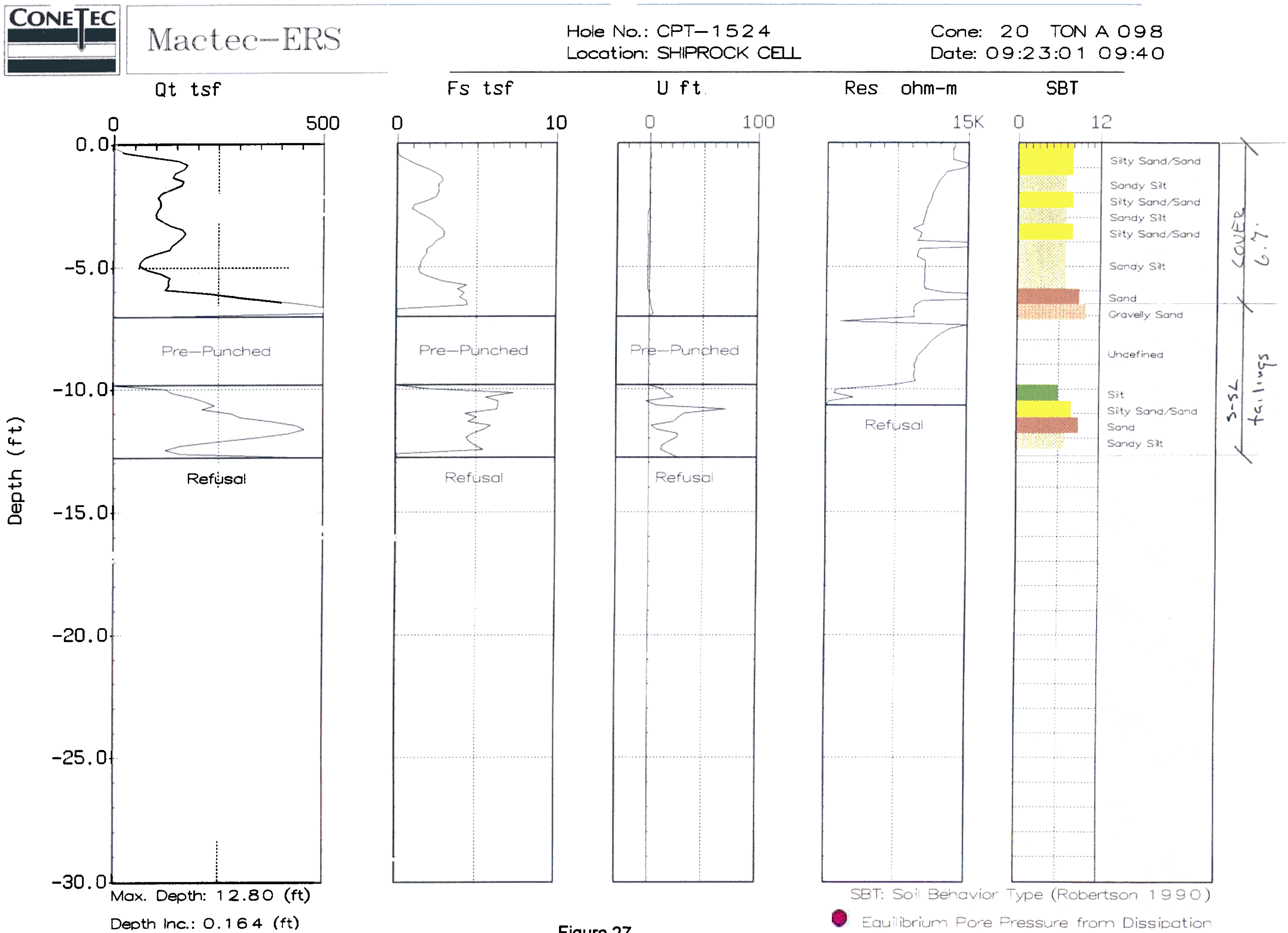
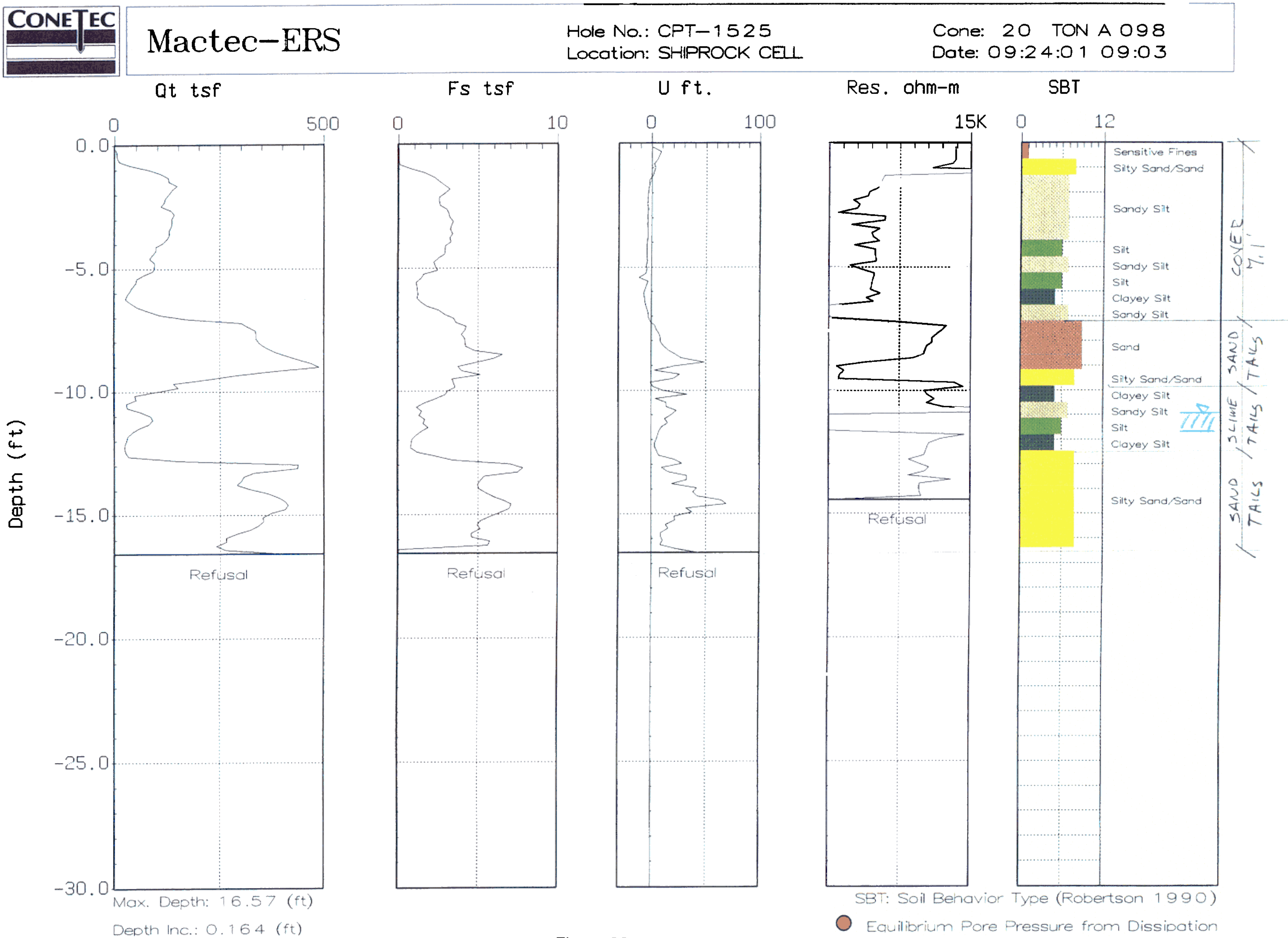
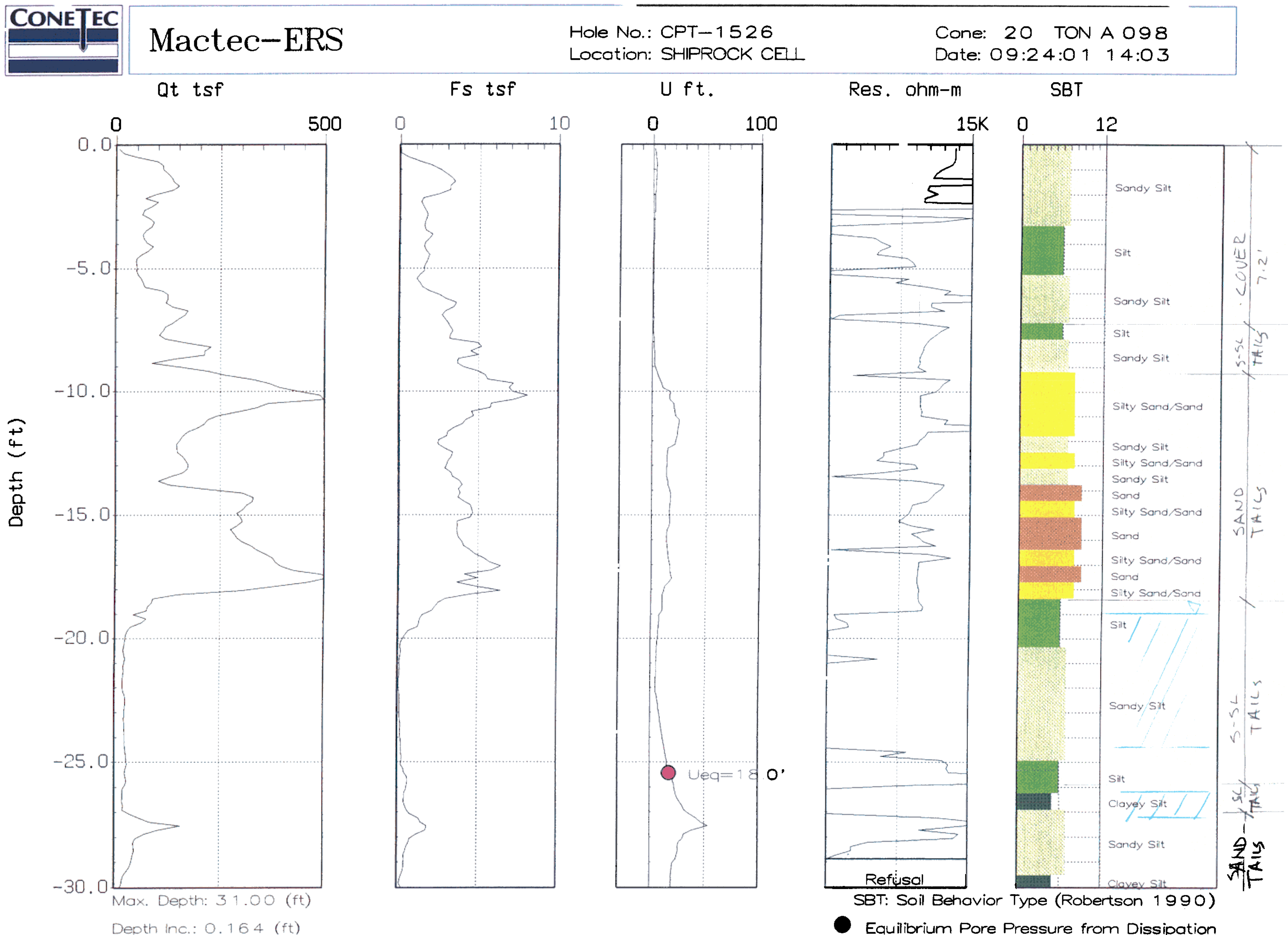

Mactec-ERS
Hole No.: CPT-1524
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:23:01 09:40
Qt tsf
Fs tsf
U ft
Res ohm-m
SBT
Depth (ft)
Pre-Punched
Refusal
Silty Sand/Sand
Sandy Silt
Sand
Gravelly Sand
Undefined
Silt
Max. Depth: 12.80 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

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
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
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

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)
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
0
500
10
100
15K
12
Ueq=18.0'
Refusal
Sandy Silt
Silt
Silty Sand/Sand
Sand
Clayey Silt
COVER 7.2'
S-SL TAILS
SAND TAILS
SC TAILS
Max. Depth: 31.00 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 29

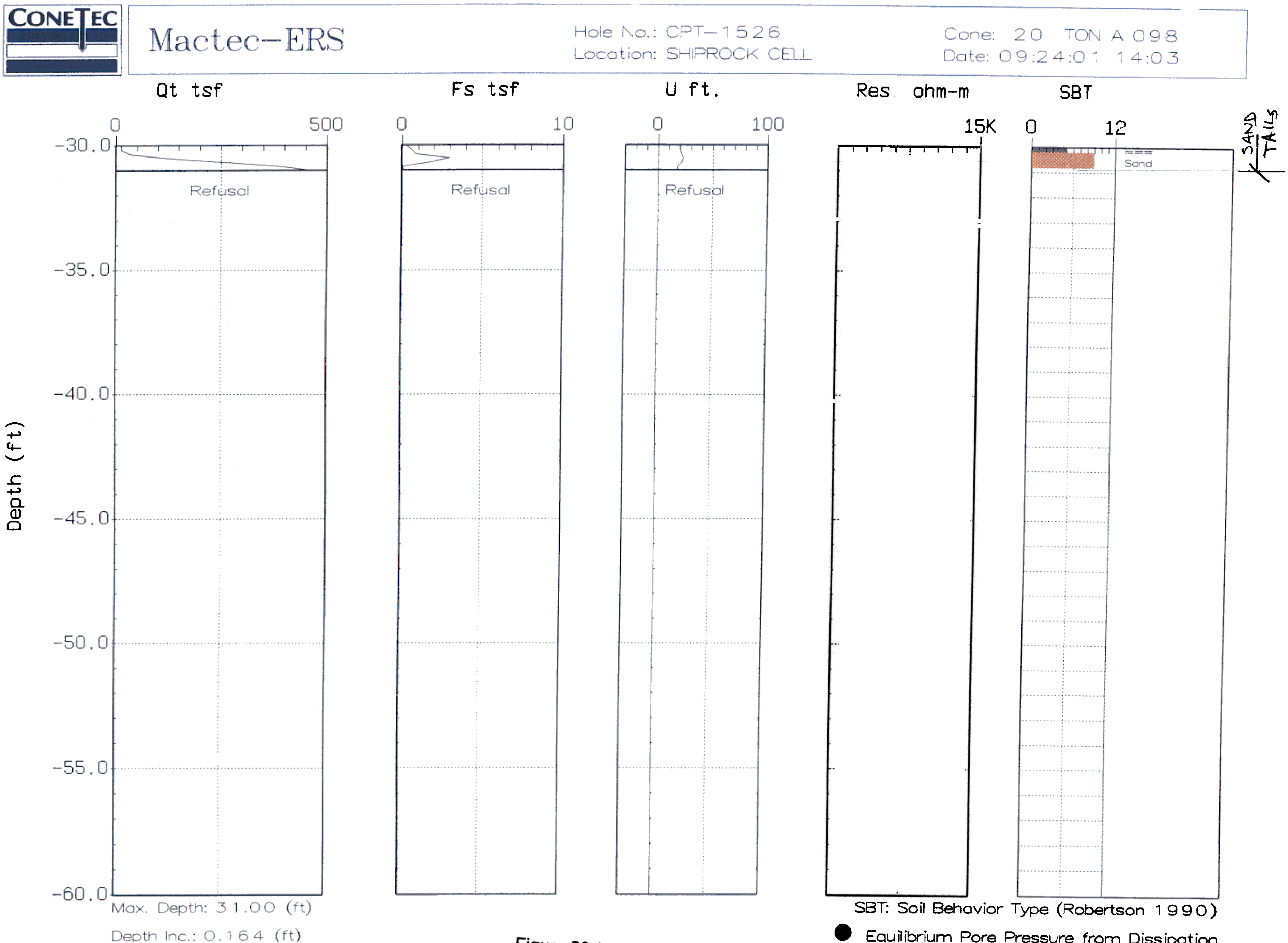
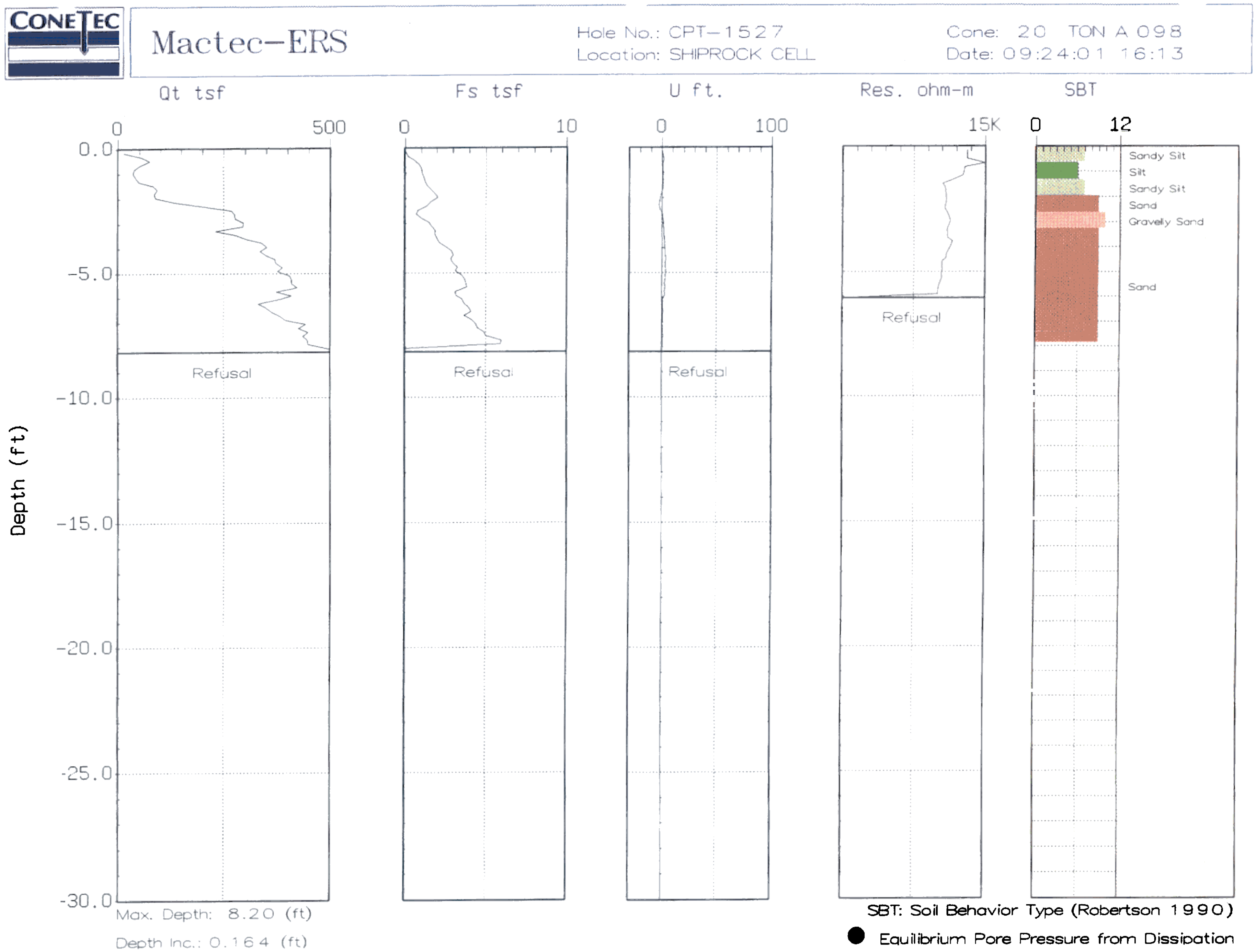
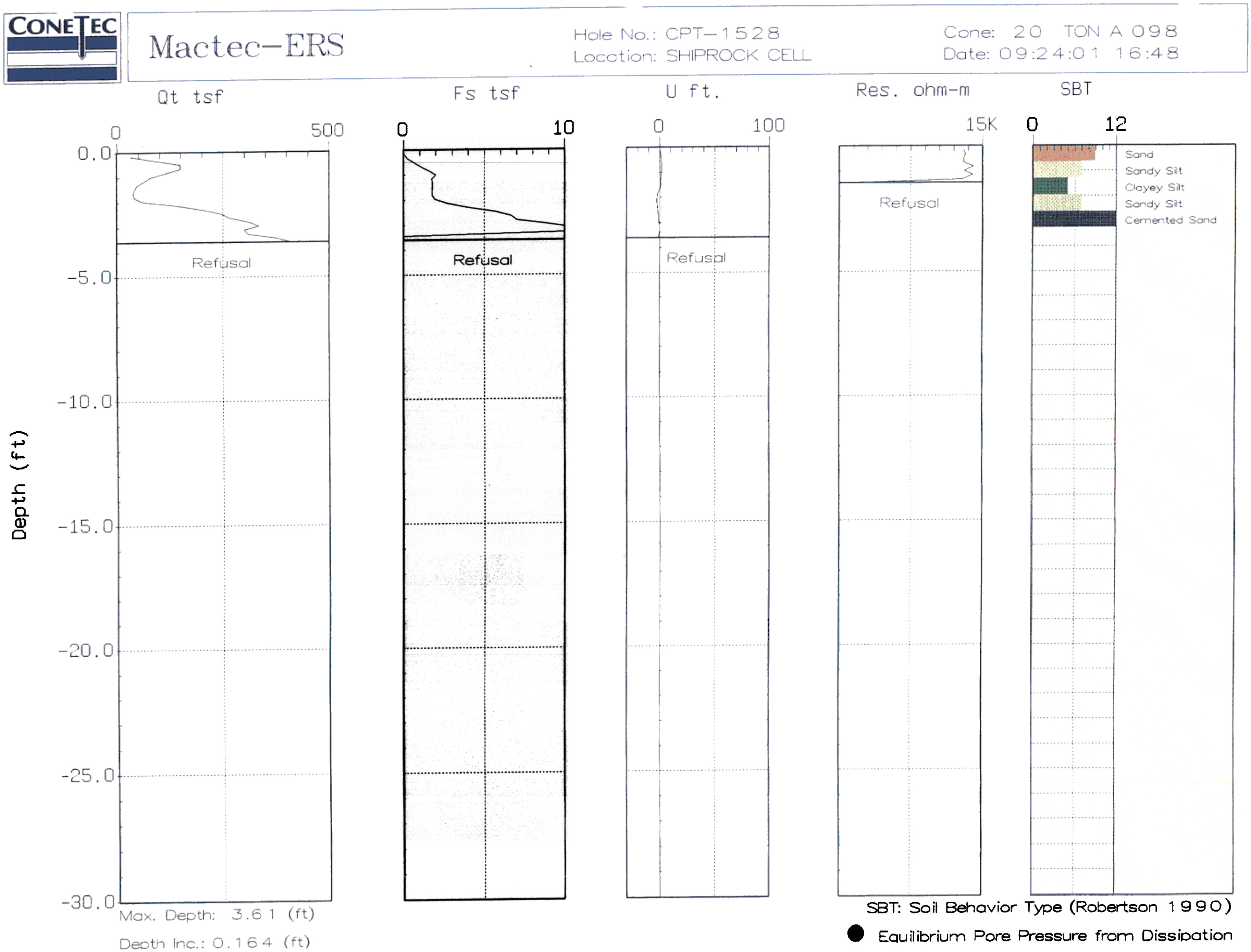


Figure 29 (continued)



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
Sand
Gravelly Sand
Max. Depth: 8.20 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 30



CONETEC
Mactec-ERS
Hole No.: CPT-1528
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:24:01 16:48
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
Sand
Sandy Silt
Clayey Silt
Sandy Silt
Cemented Sand
Max. Depth: 3.61 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 31

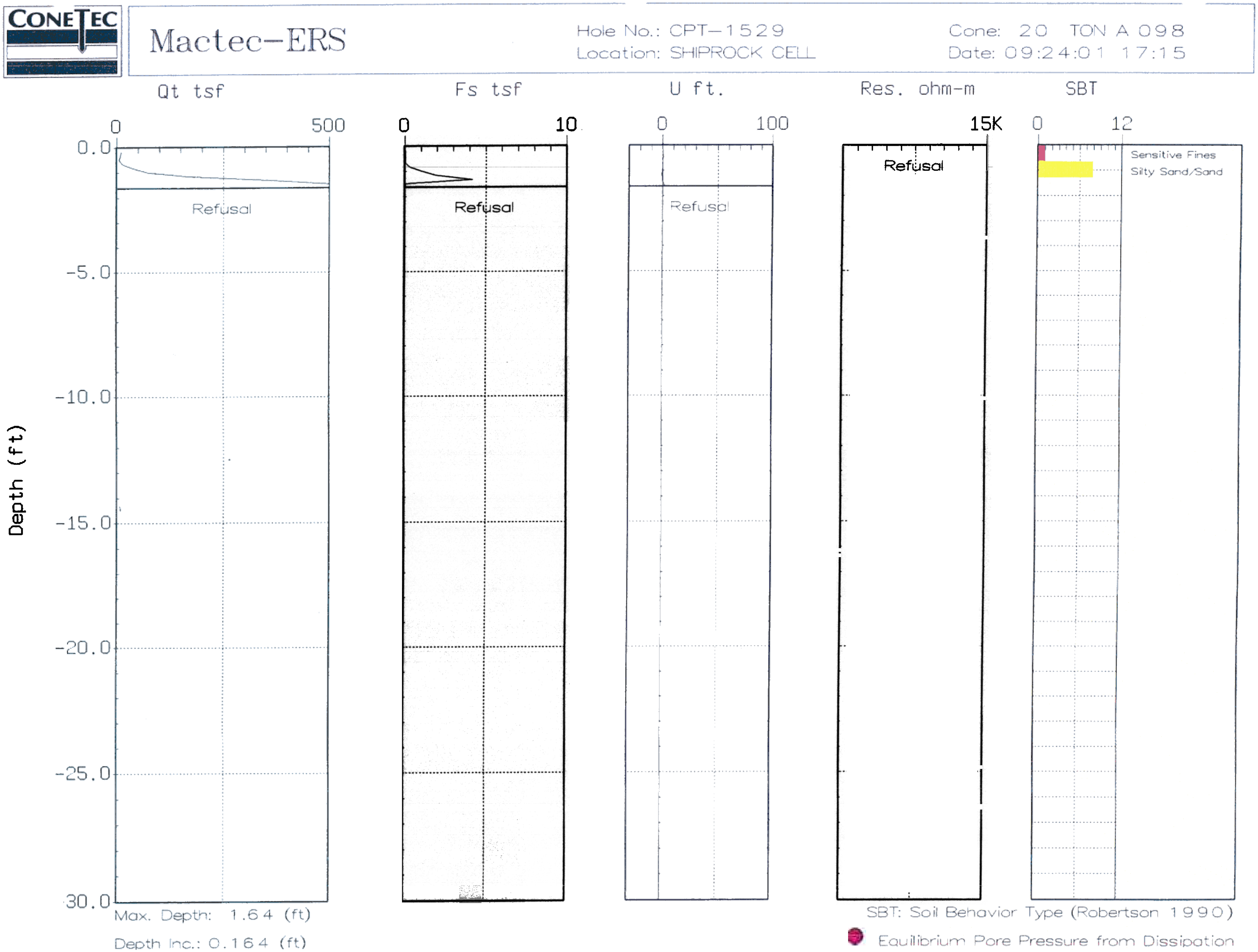

CONETEC
Mactec–ERS
Hole No.: CPT–1529
Location: SHIPROCK CELL
Cone: 20 TON A 098
Date: 09:24:01 17:15
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Refusal
Refusal
Refusal
Sensitive Fines
Silty Sand/Sand
Max. Depth: 1.64 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 32

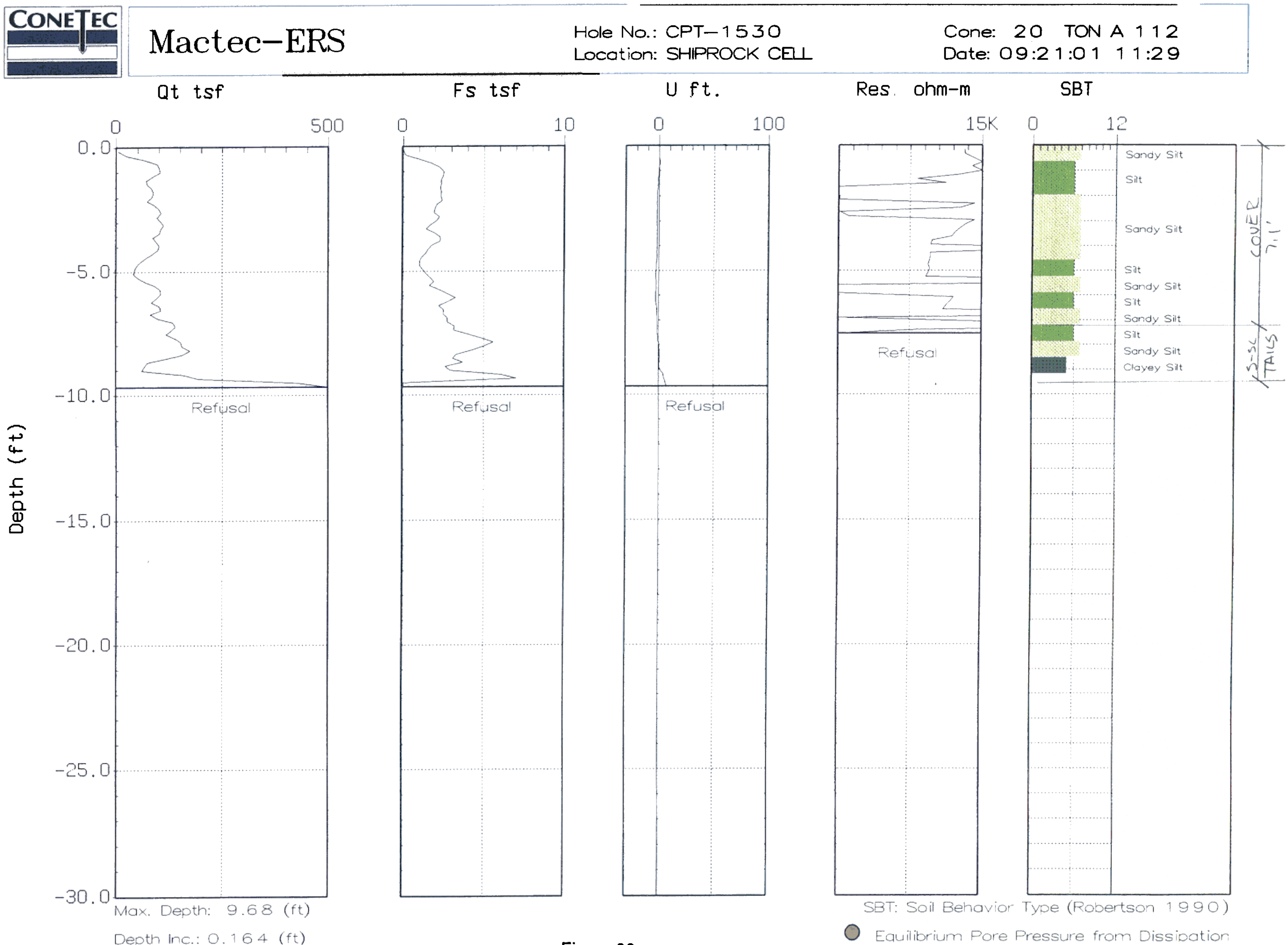

ConeTec
Mactec-ERS
Hole No.: CPT-1530
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:21:01 11:29
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
10
100
15K
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Sandy Silt
Silt
Clayey Silt
COVER
Max. Depth: 9.68 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil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

Figure 33

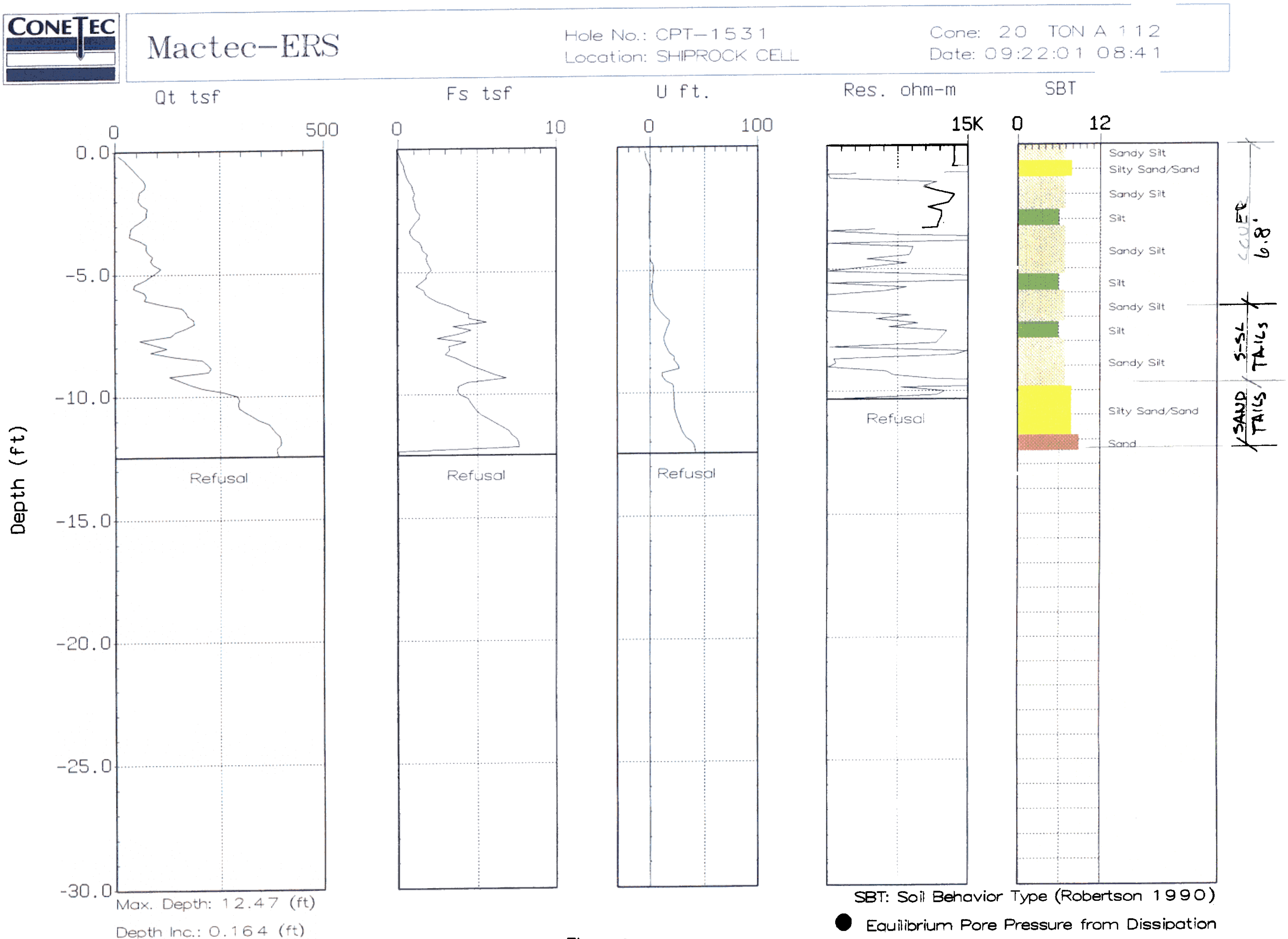

ConeTec
Mactec-ERS
Hole No.: CPT-1531
Location: SHIPROCK CELL
Cone: 20 TON A 112
Date: 09:22:01 08:41
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
0
500
0
10
0
100
15K
0
12
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
Depth (ft)
Refusal
Refusal
Refusal
Refusal
Sandy Silt
Silty Sand/Sand
Sandy Silt
Silt
Sandy Silt
Silt
Sandy Silt
Silt
Sandy Silt
Silty Sand/Sand
Sand
Max. Depth: 12.47 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 34

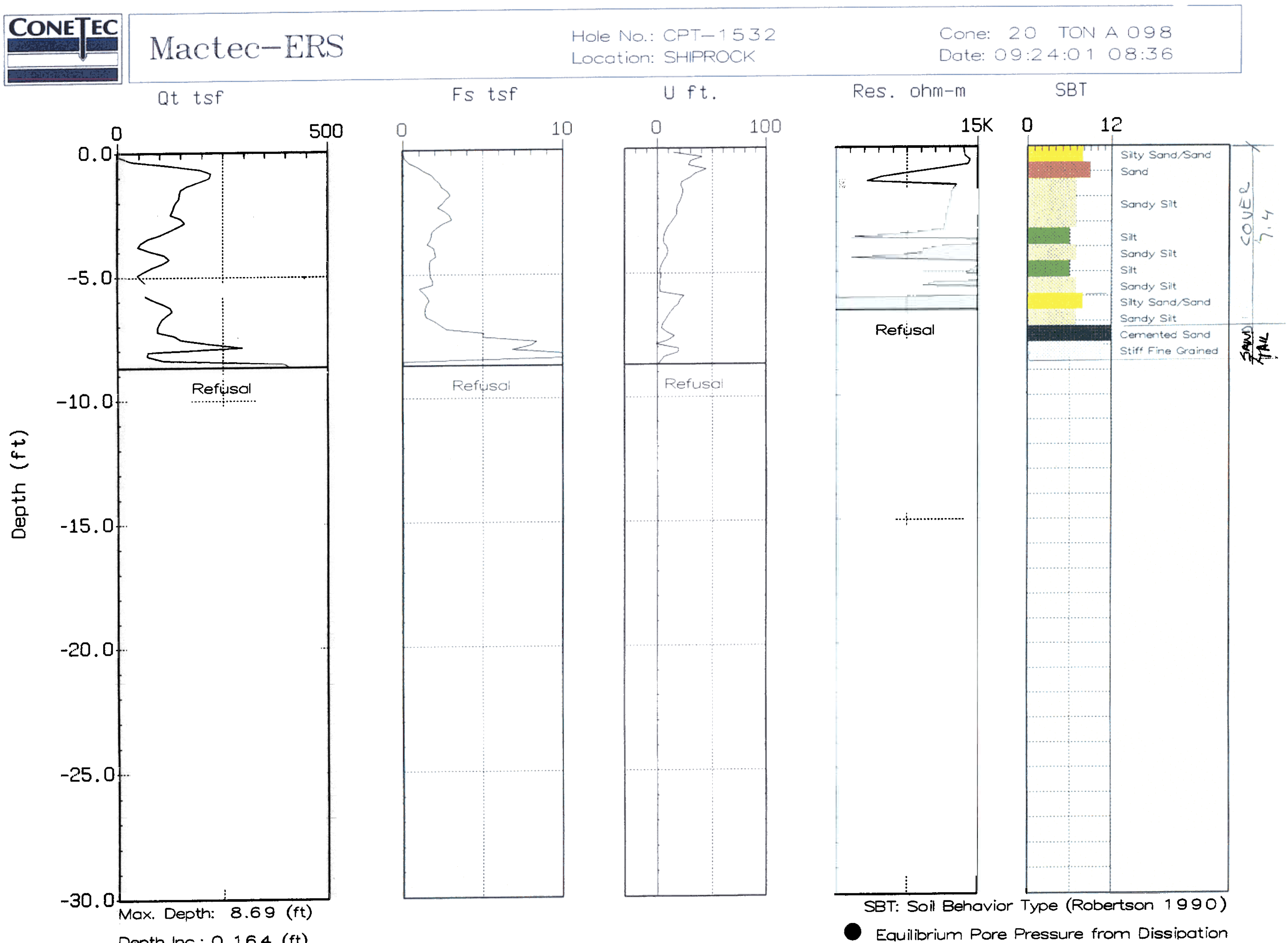

CONETEC
Mactec-ERS
Hole No.: CPT-1532
Location: SHIPROCK
Cone: 20 TON A 098
Date: 09:24:01 08:36
Qt tsf
Fs tsf
U ft.
Res. ohm-m
SBT
Depth (ft)
Refusal
Silty Sand/Sand
Sand
Sandy Silt
Silt
Sandy Silt
Silt
Sandy Silt
Silty Sand/Sand
Sandy Silt
Cemented Sand
Stiff Fine Grained
Max. Depth: 8.69 (ft)
Depth Inc.: 0.164 (ft)
SBT: Soil Behavior Type (Robertson 1990)
Equilibrium Pore Pressure from Dissipation

Figure 35

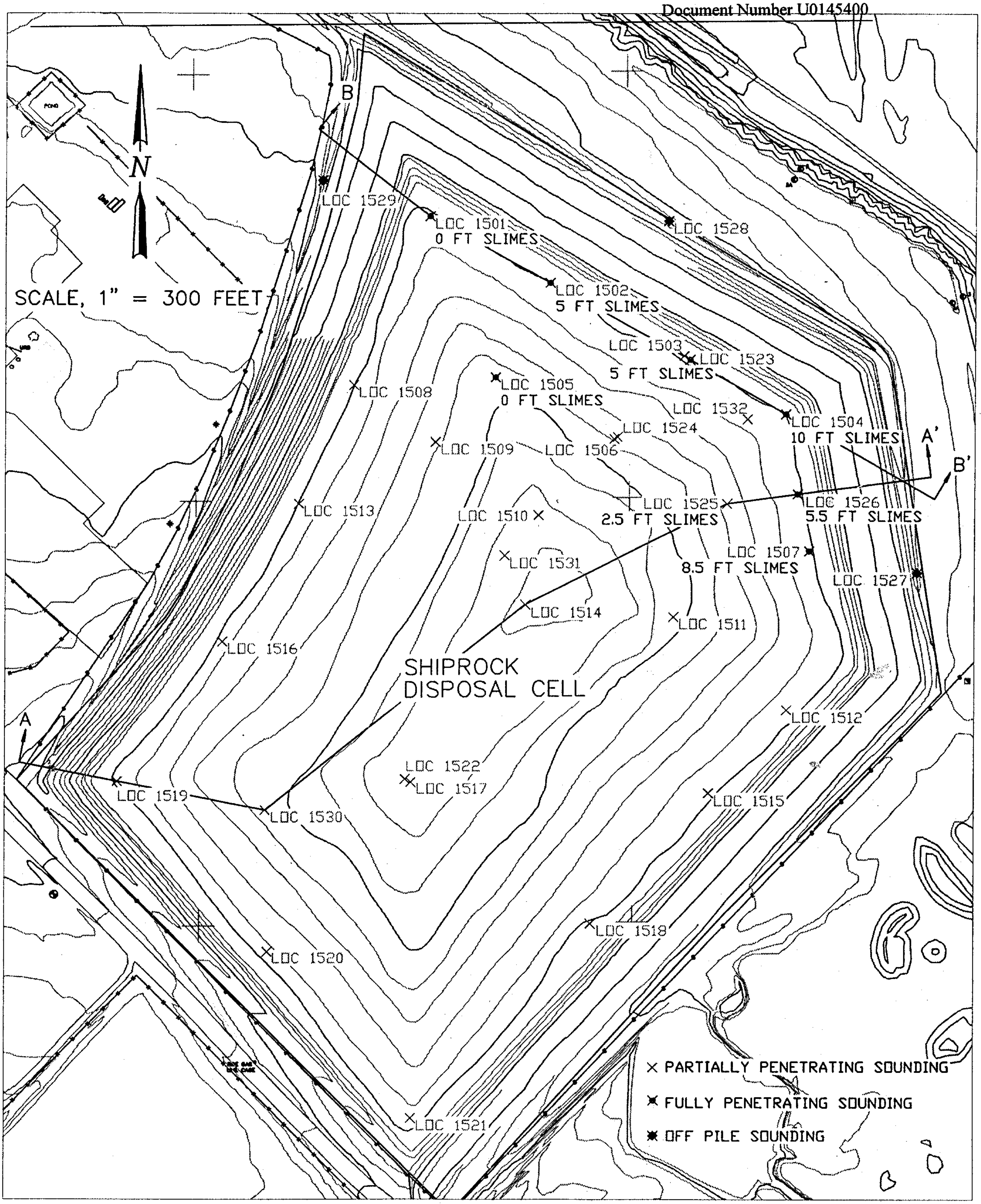


Figure 36. Shiprock Disposal Cell Investigation Cross Sections and Saturated Slimes

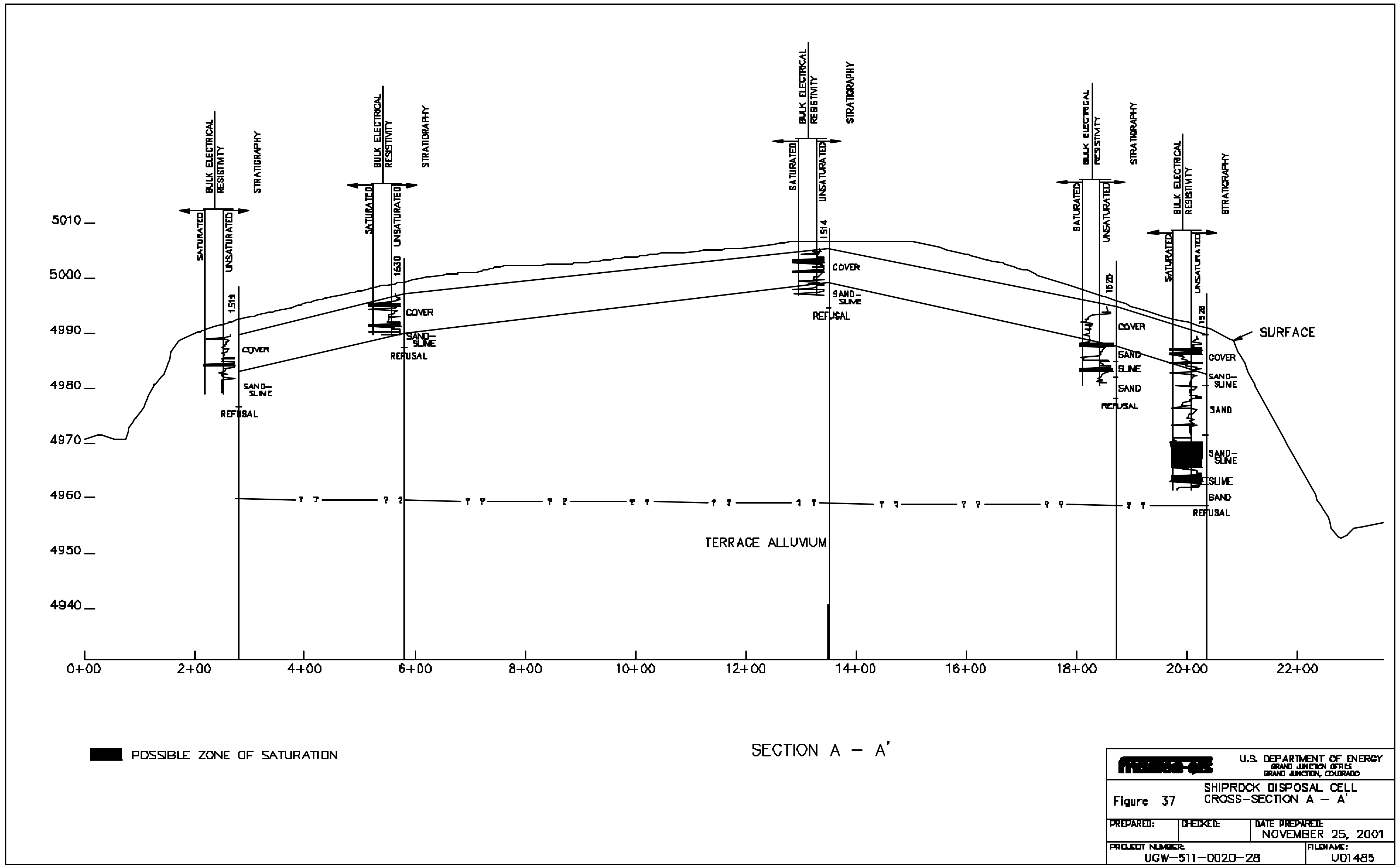


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Figure 37. Cross Section A–A

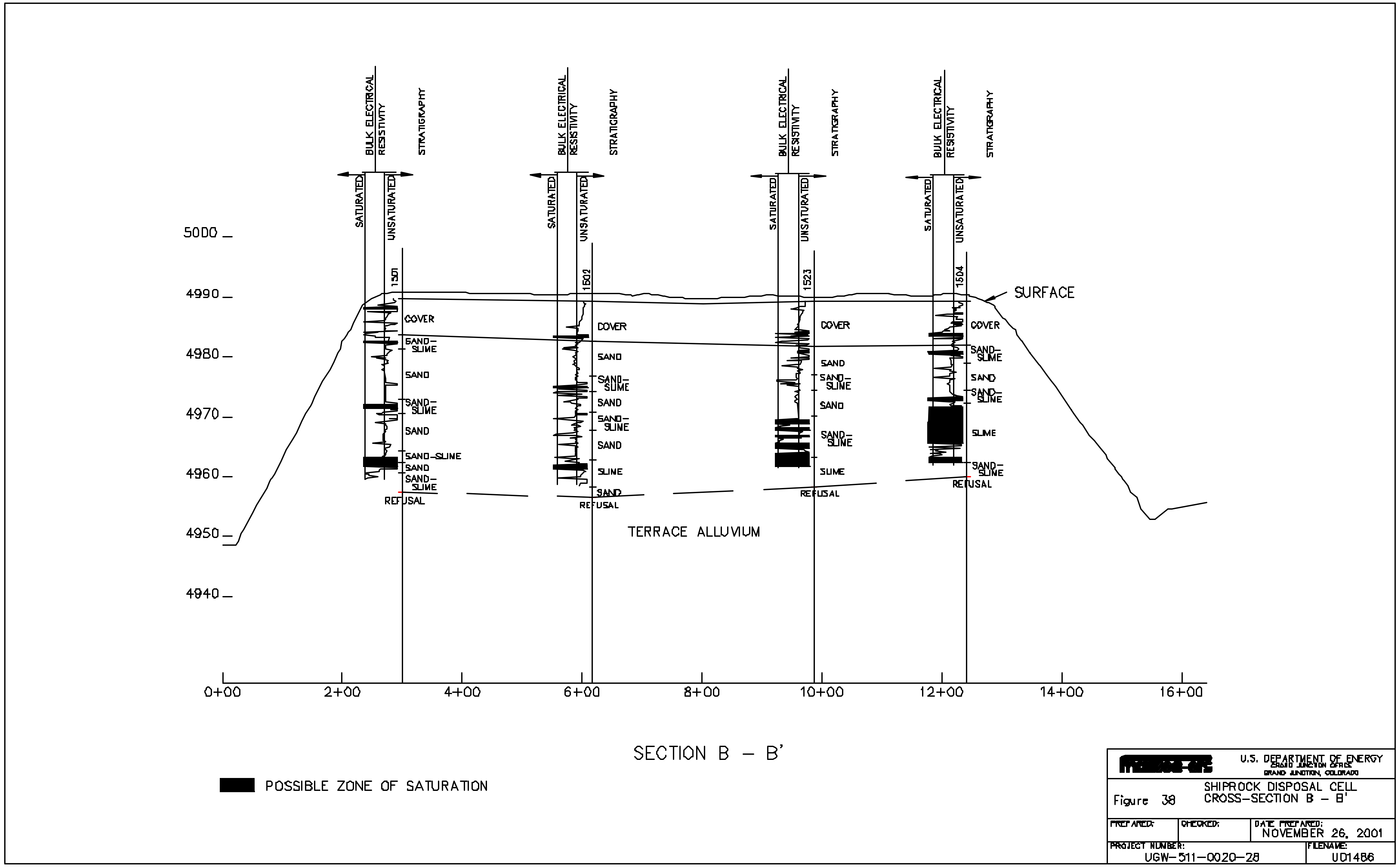

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Figure 38. Cross Section B–B'

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.

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Appendices

Review by P.K. Robertson

ConeTec Report

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Novemeber 5th, 2001

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(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.