

Harmony Solar ND, LLC
Harmony Solar Project
Docket No. PU-18-219

Late-Filed Exhibit No. 14 – Geotechnical Report

At the public hearing, a request was made for a copy of the Harmony Solar Project's Geotechnical Report. A copy of the requested report is provided herewith.

Geotechnical Engineering Report

Harmony Solar Project

Cass County, North Dakota

Prepared for
Geronimo Energy

May 2017



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Certification

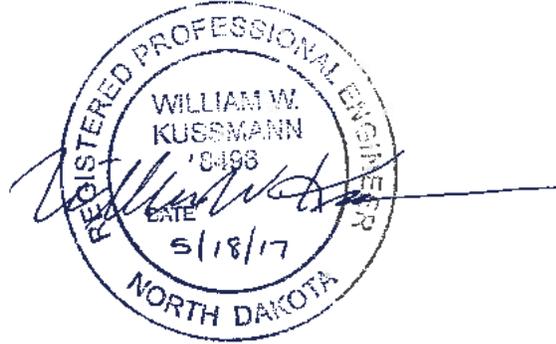
I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly licensed Professional Engineer under the laws of the State of North Dakota.



William W. Kussmann, P.E.

Date: May 18, 2017

License No.: PE8498



1.0 Introduction

Barr Engineering Co. (Barr), under authorization and contract by Geronimo Energy (Geronimo), completed a geotechnical investigation of the Harmony Solar Project site in Cass County, North Dakota. The Harmony Solar Project site is a proposed solar power facility, and will cover an area of approximately 1,600 acres. The site investigation was performed in December of 2016, and associated laboratory testing was performed in January 2017.

This report describes the investigation and testing performed, presents the results of this work, and provides geotechnical analyses and conclusions for foundations of the proposed solar panel arrays.

1.1 Site Location

The proposed Harmony Solar Project site is located in Cass County, North Dakota, northwest of Fargo, as shown on [Figure 1](#). [Figure 2](#) indicates current site layout and extents. Barr selected the geotechnical locations for testing and provided them to Geronimo for approval prior to the beginning of the geotechnical investigation. The coordinates of the geotechnical field test locations are provided in [Appendix A](#).

1.2 Site Geology

Surficial soils within the project area are typically mapped as units of glacial lake deposits. The soils map on [Figure 3](#) indicates that the surficial soils are likely to consist of high plasticity silt, but based on the results of this investigation, the soil behavior is more consistent with a high plasticity clay. A drainage ditch runs northwest to southeast across the north half of the project site, and mapped soil units indicate that silt is present near the ditch, identified as miscellaneous silt loams on [Figure 4](#).

[Figure 4](#) indicates that the majority of the site consists of Fargo and Bearden silty clay loams, which are Pleistocene aged glacial lake deposits from the historical Glacial Lake Agassiz. According to Klausning, (1968), the Fargo and Bearden units cover the majority of the lake plain, and generally consists of fine-grained soil deposits. The Glacial Lake Agassiz plain is a flat, relatively featureless plain that slopes to the north and has relief typically less than 10 feet (Klausning, 1968). Drainage in the project area is directed towards the Maple River (just southeast of the project site) and Red River (east of the project site).

[Figure 5](#) indicates that the surficial geology consists primarily of the Oahe Formation, which was deposited as a windblown silt and commonly includes paleosols or as alluvial/slough deposits. The Coleharbor Formation is present in the very southwest corner of the site, and typically consists of glacial silts and clays.

According to the Geologic Bedrock Map of North Dakota (Bluemle, 1983 and [Figure 6](#)), the shallowest bedrock is likely Mesozoic in age, consisting of massive sandstones and siltstones. Mapped bedrock in the vicinity of the site is estimated at depths greater than 200 feet (Anderson, 2011).

Based on a review of the mapped karst landforms across the United States ([Veni, 2002](#)), the proposed site is not underlain by potentially karstic bedrock. Therefore, karst will likely not be an issue for this project.

Mining and oil and gas extraction are also not anticipated in the vicinity of the site.

1.3 Previous Investigations

To Barr's knowledge, there were no geotechnical investigations performed within the boundaries of the proposed Harmony Solar project site.

2.0 Geotechnical Investigation Methods

As a part of the geotechnical investigation, cone penetration testing (CPT), flat plate dilatometer testing (DMT), test pit excavations, laboratory testing, and thermal resistivity testing were performed. Electrical testing was performed in May 2017 after snow melt. The scope of work was defined by Geronimo while Barr selected the testing locations which were subsequently approved by Geronimo. Barr verified the locations with a standard handheld GPS.

Figures 7 through 9 show the plan location of all explorations completed for the geotechnical investigation. Geographic coordinates for the field testing are indicated in Appendix A. The geotechnical investigation was largely performed in December 2016 and laboratory testing was completed in January 2017. Electrical resistivity testing was completed in May 2017.

2.1 Field Work

2.1.1 CPT Soundings

CPT soundings were performed at 41 locations in accordance with ASTM D5778, "Standard Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils" (Figure 7). A total of 28 soundings were performed to a target depth of 20 feet, and 13 soundings extended to a depth of 30 feet due to relatively low strength soils encountered at the site. All soundings reached the target termination depths of either 20 or 30 feet (i.e. shallow refusal was not encountered). Graphical logs of the CPT soundings are included in Appendix B.

CPT soundings were conducted by Conetec, of Salt Lake City, Utah. The CPT testing was performed with a 20-ton track-mounted all-terrain rig with an enclosed work space. For the CPT test, a cylindrical cone is pushed vertically into the ground at a constant penetration rate of 20 mm/sec. During penetration, measurements are made at 5-cm intervals of the cone tip resistance (q_c), the side friction of the cylindrical shaft (f_s) just above the tip, and pore water pressure generated by cone penetration (u_2).

The cone used in the investigation had a 15 cm² base area and an unequal end area ratio of 0.80. The sleeve area of the cone was 225 cm². The fluid used for saturation of the filter was silicone. The CPT contractor provided Barr with complete records of tip resistance, sleeve friction, pore pressure, and friction ratio of all CPT soundings. These records included graphical plots and tabular data of all readings with depth, including an interpreted soil classification. Copies of the data plots and analyzed data are included in Appendix B.

The following describes the procedures used to interpret the CPT data and the interpreted lithology.

The CPT data interpretation was performed using an in-house program designed by Barr. The in-house program has been crosschecked with commercially available CPT analysis software for quality assurance and has been found to be compliant. The program uses the soil behavior type classification system from CPT data proposed by Robertson (1990). The classification system is based on the corrected tip resistance

(q_t), the friction ratio (R_f), and pore-water pressure parameter (B_q), and includes a total of nine soil behavior types. These cone parameters are defined as follows:

$$q_t = q_c + (1 - a) u_2 \quad (\text{Robertson, 1990})$$

$$R_f = \frac{f_s}{q_t} 100\% \quad (\text{Robertson, 1990})$$

$$B_q = \frac{u_2 - u_0}{q_t - \sigma_{vo}} \quad (\text{Robertson, 1990})$$

where:

q_c = tip resistance measured by the cone, load per area

a = unequal end area ratio of the cone

u_2 = measured pore-water pressure during cone penetration, load per area

f_s = unit sleeve friction resistance, load per area

σ_{vo} = total overburden stress, load per area

u_0 = in-situ pore water pressure, load per area

2.1.2 DMT Soundings

A total of five DMT soundings were performed at selected locations across the project site. These locations were chosen for DMT testing to represent the settlement and horizontal resistance characteristics of the soils across the site. [Figure 7](#) shows the plan location of the DMT testing locations, which coincide with CPT soundings performed at the same location. The results of the DMT soundings performed during this investigation are included in [Appendix C](#).

The Marchetti Dilatometer consists of a 95-mm stainless steel blade with a thin, flat, expandable steel membrane (60-mm diameter) on the side. Performing a DMT test consists of pushing the dilatometer blade into the ground vertically to a desired test depth, measuring the thrust necessary to accomplish this penetration, and then using gas pressure to expand the circular steel membrane against the soil. The test operator obtains three readings: the A-pressure required to initiate movement of the membrane against the soil; the B-pressure required to move its center 1 mm into the soil; and the C-pressure during deflation of the membrane, which is related to the in-situ pore-water pressure in sands and penetration pore-water pressure in clays. The operator then pushes the blade to the next depth and repeats the test. A dilatometer sounding log consists of the results from all the measured and correlated parameters with depth.

The DMT parameter generally includes the measured material index I_d , dilatometer modulus E_d , horizontal stress index K_d , constrained modulus of soil compressibility M , and undrained shear strength s_u . The main

objective for performing the DMT soundings was the determination of the constrained modulus of soil compressibility in order to evaluate settlements, and to determine horizontal resistance properties of the soil on the anticipated foundation type. The DMT has the advantage of providing quasi-continuous soil compressibility information as part of the field investigation. Traditionally, the compressibility soil parameters are obtained by performing a soil boring, taking an undisturbed Shelby tube sample, and performing a consolidation test in the laboratory. The use of the DMT obtains required compressibility parameters much more quickly and comprehensively. The DMT test also is an in-situ test method which does not require sampling and transportation of soils to a testing laboratory.

2.1.3 Test Pit Excavations

A total of five test pit excavations were conducted as part of the geotechnical investigation. The test pits were completed to depths of 10 feet below existing grade. All test pits were completed within the solar array area to evaluate subsurface conditions and obtain samples for laboratory testing, although through discussions with Geronimo, the test pits were performed towards the outer edges of the farm fields near the county roadways, so that any disturbance from test pit excavations would not impact farming equipment in the spring. The test pit excavations were completed in December 2016.

Samples obtained from the test pit excavations included bulk samples and grab samples from various depths. All samples were sealed in the field to preserve their in-situ moisture content. The samples were shipped to Soil Engineering Testing, Inc., (SET) or Bloomington, Minnesota for laboratory testing.

Test pits were performed by Earthwork Services, Inc., with a rubber-tired mini-excavator. The backhoe used an 18-inch bucket equipped with ripping teeth capable of penetrating the frost. The test pit locations are indicated on [Figure 8](#). Test pit logs from the geotechnical investigations are provided in [Appendix D](#). Photos of the test pit excavations from the investigation can be found in [Appendix E](#). All test pits utilized the same excavating equipment, and were backfilled and compacted with the backhoe bucket upon completion.

2.2 Laboratory Testing

The following tests were performed by SET:

- Moisture content testing in accordance with ASTM D2216, "Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass"
- Atterberg Limit determinations in accordance with ASTM D4318-05, "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils"
- Standard proctor density testing in accordance with ASTM D698, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600 kN-m/m³))"
- Soil thermal resistivity in accordance with ASTM D5334-08 "Guide to Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure"

- Soil pH tests in accordance with ASTM D4972-01 “Standard Test Method for pH of Soils”
- Soil soluble chloride content in accordance with SM 4500-Cl E-97 OL, “Coloimetric, manual or Automatic (Ferricyanide) Potentiometric Titration Method”
- Soil soluble sulfate content in accordance with EPA 300.0 Rev. 2.1, “Ion Chromatography Method.”

All physical laboratory test results are provided in [Appendix F](#). Chemical laboratory test results are included in [Appendix G](#).

2.3 Soil Electrical Resistivity Testing

Soil resistivity testing was completed by Barr personnel in accordance with ASTM method G57 “Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method” (equivalent to IEEE Std. 81). Testing was performed at four locations selected for spatial variation within the project layout, and one test was performed near an existing substation which is anticipated to be near the interconnect point for the project ([Figure 9](#)). At each location, measurements were taken to determine average soil resistivity in two perpendicular arrays. Electrode “a”-spacings of 2, 5, 10, 20, and 40 feet were used during the testing.

The electrical resistivity report is included as [Appendix H](#).

2.4 Soil Thermal Resistivity Testing

Three bulk soil samples were collected at the test pit locations by Barr personnel for thermal resistivity testing ([Figure 9](#)). The bulk sample was obtained from a depth of approximately 1 to 5 feet below ground surface and placed in a sealed 5-gallon bucket to maintain in-situ moisture content. The sample was transported to SET for testing. SET completed the testing in accordance with ASTM D5334-05, “Standard Test Method for Determination of Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure”. Laboratory tests included measurement of the soil’s moisture content, maximum dry density, and thermal dryout characteristics, which is a function of moisture content.

The thermal resistivity report is included in [Appendix I](#).

3.0 Results

A description of the field and laboratory investigation procedures is provided in [Section 2.0](#). [Section 3.0](#) presents the data from testing and investigation and provides further analysis of these results.

3.1 Soil Lithology

The results of the CPT soundings ([Appendix B](#)), test pits ([Appendix D](#)) and laboratory test results ([Appendix F](#)) were compiled to obtain an understanding of the lithology of the study area.

In general, the site consists of a relatively flat agricultural field used for crops with some drainage ditches running generally east to west across the site. At the time of the geotechnical investigation, the field was observed to be tilled, and the top 18 inches was frozen.

The existing conditions consist of a topsoil layer (frozen at the time of investigation) approximately 8 to 18 inches in thickness underlain by moderate to high plasticity clay (fat clay) soils which extended to the termination depth of the test pits and CPT soundings. Trace amounts of sand were observed in the clays, but boulders and cobbles were not observed. Thinner zones of lean clay were observed in a few of the test pits.

The CPT data was analyzed to infer lithology. The analyses utilized the soil behavior type classification system from CPT data proposed by Robertson et al (1990). The classification system is based on the corrected tip resistance (q_t), friction ratio (R_f), and pore-water pressure parameter (B_q); the classification includes a total of nine soil behavior types. Results of the CPT soil behavior identification indicate that the primary soil type at the site is predominantly cohesive, consisting of clay, silt, and clayey silt, consistent with the anticipated geologic conditions and the results of the test pit excavations.

The conditions encountered during the geotechnical investigation generally agreed with the geologic summary included in [Section 1.2](#) of this report.

3.1.1 Topsoil

The topsoil consists primarily of lean to fat clay with various amounts of organic material, roots, and sand. The topsoil was observed to be dark brown to black in color. The topsoil thickness varied from approximately 8 to 18 inches across the site, but may vary locally between the investigated locations.

3.1.2 Fat Clay

Fat clay was observed in all five test pits underlying the topsoil and extended to the termination depth. The fat clay ranged in color from brown to dark brown to black, and was in a moist to wet condition. The clay was observed to have trace amounts of sand, and occasional silt laminations. Cobbles and boulders were not noted within the fat clay layers during the test pits.

Moisture contents in the fat clay soils ranged from 25.2 to 45.3 percent, with an average of 33.3 percent.

Atterberg Limits testing on samples of the fat clay indicated a Liquid Limit ranging from 52.1 to 114.7 percent, a Plastic Limit ranging from 19.1 to 27.3 percent, and a Plasticity Index ranging from 33 to 87.4 percent. According to the Plasticity Chart (NAVFAC, 1986), these soils plot as fat clay (CH) type soils.

3.1.3 Silty Lean Clay

Silty lean clay soils were observed interbedded with the fat clay soils at TP03 (5 to 8 feet) and TP05 (4 to 6 feet). The silty lean clay soils were observed to be dark brown in color, and were generally in a moist condition.

Moisture contents in the lean clay soils were approximately 31.3 percent.

Atterberg Limits testing on one sample of the lean clay indicated a Liquid of 40.5 percent, a Plastic Limit of 19.7 percent, and a Plasticity Index of 20.8 percent. According to the Plasticity Chart (NAVFAC, 1986), these soils plot as lean clay (CL) type soils.

3.2 Groundwater Conditions

The groundwater levels were measured during the test pits. Groundwater was observed in three test pits around a depth of 7 feet as indicated in [Table 1](#).

Many factors contribute to water level fluctuations, such as heavy rainfall events, dry periods, sand seams, etc. Encountering groundwater at a small number of boring locations indicates that other proposed sites around the project site may also encounter groundwater at similar depths. Based on the depth of water observed during drilling, it appears that the static water levels may be present above the anticipated embedment depth. Should deeper foundations such as drilled shafts or driven piles be used, the contractor should be prepared to utilize casing to maintain hole stability.

3.3 General Laboratory Testing

All laboratory test results are summarized in [Table 2](#) and included in [Appendix F](#).

3.3.1 Moisture Content Testing

A total of 12 moisture content tests were performed. The results indicate that the natural moisture content ranges from 25.2 to 45.3 percent, with an overall average of 33.2 percent.

3.3.2 Atterberg Limits Testing

Atterberg Limits testing on four samples of the lean and fat clay indicated a Liquid Limit ranging from 40.5 to 114.7 percent, a Plastic Limit ranging from 19.1 to 27.3 percent, and a Plasticity Index ranging from 20.8 to 87.4 percent. According to the Plasticity Chart (NAVFAC, 1986), these soils plot as fat clay (CH) and lean clay (CL) type soils.

3.4 Shear Strength

The results of the geotechnical investigation indicate that the primary soil type at the site is cohesive. The undrained shear strength of the soil was evaluated using the results of CPT testing correlations.

3.4.1 Design Value Determination for Cohesive Soils

The undrained shear strength of cohesive soil at various depths is calculated based on CPT data using the following equation:

$$s_u = \frac{q_t - \sigma_{vo}}{N_{kt}} \quad (\text{Lunne et al, 1997})$$

where:

s_u = undrained shear strength

N_{kt} = empirical cone factor (16 was used for this project based nearby project experience)

σ_{vo} = total in-situ vertical stress = varies (from CPT data)

q_t = corrected cone tip resistance = varies (from CPT data)

Table 3 summarizes the average undrained shear strength calculated from CPT data for each proposed CPT sounding. The values reported in Table 3 correspond to the average undrained shear strength from below the frost depth to the bottom of the sounding. Figures 10 through 14 indicate the undrained shear strength and friction angle for each sounding location versus depth for all tested locations. Average soil undrained shear strengths, determined from the entire CPT sounding, ranged from 1,161 to 1,604 psf, with an overall project average of 1,404 psf (Table 3). For the individual soil layers, the undrained shear strengths from CPT testing ranged from about 500 to greater than 4,000 psf, with the majority of the measurements exceeding 1,100 psf.

In general, the undrained shear strength of the clay soils at the site appeared to be variable in the upper 7 feet of soil. The undrained shear strength tended to be less in some locations and higher in others. Below a depth of 7 feet, the undrained shear strength was generally higher, and was relatively consistent extending to the termination depth of the sounding.

For the upper 7 feet of soil, a design undrained shear strength of 500 psf is recommended for the cohesive soils. A design undrained shear strength of 1,100 psf is recommended for the cohesive soils below the frost depth of 7 feet based on the results of the field testing. This design value was derived from CPT testing across the project site.

3.4.2 Lower Undrained Shear Strength Zones

Lower undrained shear strength zones were observed in 16 CPT soundings (Table 4). In general, the low strength zones did not have any spatial correlation across the project site. In addition, the low strength

zones were observed in thicknesses of 3 feet or less, and the measured undrained shear strength was not significantly below the recommended design undrained shear strength of 1,100 psf.

3.5 Standard Proctor Testing

Standard Proctor density tests were performed on five samples collected as part of the thermal resistivity testing. The results of the test are indicated in [Table 5](#). The resulting maximum dry density for the soils tested ranged from 85.6 to 99 pcf. The corresponding optimum moisture contents ranged from 22.5 to 31.1 percent. Standard Proctor test results are included in [Appendix F](#).

3.6 Chemical Testing

Chemical testing was performed on four samples of soil collected from the test pits. Results of the chemical testing indicate that the pH ranged from 7.6 to 8.1, soluble chloride content ranged from below the detection limit of 10 mg/kg to 42 mg/kg, and soluble sulfate content ranged from 32.2 to 23,700 mg/kg. Results of the chemical testing are summarized in [Table 6](#) and provided in [Appendix G](#).

3.7 Shrink/Swell Potential

The shrink/swell potential of a soil is related to its liquid limit and plasticity index. Soils with Liquid Limit values less than 50 and Plasticity Index values less than 25 are considered to have low shrink-swell potential. Soils with Liquid Limit values of 50 to 60 and Plasticity Index values of 25 to 35 are considered to have moderate shrink-swell potential. Soils with Liquid Limit values greater than 60 and Plasticity Index values greater than 35 are considered to have high shrink-swell potential ([Das, 1994](#)).

The results of the Atterberg limits testing indicate that the fat clay at the project site is of high plasticity. Therefore, the cohesive soils are anticipated to have a high shrink-swell potential, and may affect foundation design. Further discussion of the shrink-swell potential of soils is provided in [Section 4.8](#).

3.8 DMT Interpretations

3.8.1 Compressibility Characteristics from DMT

Flat-blade dilatometer testing (DMT) was performed at five sounding locations. The DMT data was used to obtain the one-dimensional constrained modulus M .

$$M = R_M * E_D \quad (\text{Totani, 2001})$$

where,

M = constrained modulus from DMT testing

R_M = Marchetti ratio factor relating M to E_D (calculated from horizontal stress index, K_D)

E_D = Dilatometer Modulus (calculated from DMT readings)

The one-dimensional constraint modulus M is related to the one-dimensional coefficient of volume compressibility m_v by the following equation:

$$M = 1/m_v$$

Based on correlations to the preconsolidation pressure, the soils at the project site have an overconsolidation ratio ranging from 1.3 to 8.9, with all but two measurements indicating an overconsolidation ratio greater than 2, indicating that the soils are overconsolidated, and will experience recompression rather than virgin compression when loaded ([Figure 15](#)).

3.8.2 Dilatometer Modulus Correlations from DMT

Results of correlated dilatometer moduli (E_D) from all DMT soundings ranged from 46 to 618 kips per square foot (ksf), with an average of about 168 ksf. However, below a depth of 7 feet (the frost zone), the average decreased slightly to about 153 ksf. Results of the correlated dilatometer modulus correlations are indicated on [Figure 16](#).

4.0 Foundation Analysis and Recommendations

Results of the geotechnical investigations are presented in [Section 3.0](#). Based on these results, [Section 4.0](#) provides general analysis, conclusions and recommendations for foundation design, as well as general construction considerations.

4.1 Recommended Geotechnical Parameters

The following parameters are recommended for design based on the results of the geotechnical investigation. The parameters are summarized in [Table 7](#).

4.1.1 In-Situ Moisture Content

For design purposes, a long-term in situ moisture content of 20 percent for the cohesive soils is recommended.

4.1.2 In-Situ Density

For design purposes, a moist density of 95 pcf for the clay soils at the site is recommended.

4.1.3 Undrained Shear Strength

Based on the results of the test pits and CPT soundings, the foundations will likely be embedded within cohesive soils consisting of fat clay. A reduced design undrained shear strength of 500 psf is recommended for soils above the frost zone (7 feet), and a design undrained shear strength of 1,100 psf is recommended for soils below the frost zone.

4.2 Solar Module Foundation Design Recommendations

Solar modules are typically supported on some form of a deep foundation system. Typical deep foundation systems include driven and vibrated steel piles, helical piers (ground screws), and drilled piers (caissons). In some cases, the solar modules have also been supported by a shallow spread footing (ballasted) foundation system that can be cast-in-place or precast.

The results of the geotechnical investigation indicate that there may be design challenges for different types of foundations. The following sections provide a summary of potential geotechnical issues for design and construction of the foundations at this project site.

4.2.1 Foundation Design Considerations

Based on the results of the geotechnical investigation, all foundation systems appear to be suitable for the project site, although some may be more costly than others. It is Barr's understanding that a steel pile foundation system is commonly the most economical and, thus, the most desirable foundation system to support the solar modules.

Of primary concern for the pile option is the presence of weak fat clay soils, shrink-swell, or frost heave. The results of the site reconnaissance did not indicate a presence of cobbles or boulders, and only trace

amounts of sand were observed in the test pits. Therefore, there is a relatively low risk of cobbles and boulders impeding pile installation based on the findings of this geotechnical investigation. However, because the investigation locations were spread out across the project site, the potential for variation in ground conditions is possible, and pile refusal may be encountered. Frost heave can affect pile uplift and heave through adfreeze forces in the frost zone. Shrink-swell also could cause potential vertical movements with significant moisture changes in the soils.

It is recommended that a test pile program be implemented to observe and document installation procedures, develop pile driving criteria for production phase piles to verify required capacity, and determine pile capacity for various installation depths and pile sizes. For driven piling, it is recommended that the foundation designer and/or contractor evaluate the results of the geotechnical investigations with respect to pile drivability and energy required. Should undesirable soil conditions be encountered during pile installation (such as the presence of loose or soft soils), the piles could be extended to deeper into the ground to develop the necessary capacity.

If drilled shafts are considered, there is a relatively low risk of auger refusal across the project site, although isolated zones may be encountered where impedance of installation is possible. Belled drilled shafts are not required, but may provide additional uplift capacity against frost heave and shrink-swell of soils. If belled drilled shafts are used, the bells should be placed entirely below the extreme frost depth. Helical piles also may assist with design for frost heave or shrink-swell potential and the bearing plates also should be placed below extreme frost depth.

This geotechnical investigation was performed at selected locations spread across the project site. The potential exists for loose, soft, or otherwise undesirable soil conditions in between the geotechnical test locations.

4.2.2 Deep Foundations

Special considerations for deep foundation systems at this project site include:

- Driving or installation refusal on cobbles, boulders, and/or dense gravel layers. Based on the results of the explorations, the likelihood of pile or shaft refusal appears relatively low, but may be encountered in isolated areas of the site.
 - In cases of shallow refusal during pile installation, remedial options to be considered include removal and/or extraction of the obstruction and replacement with compacted engineered fill and then re-driving the pile.
 - Pre-drilling through obstructing layers is another option which can be considered for pile installation.
- Evaluation of the suitability and constructability of various pile type/configurations should be performed by the foundation engineer taking into account the subsurface conditions and potential for vertical movement as described in this report.

- Frost heave forces contributing to uplift on the piles.
- Vertical movement of the piles from shrink-swell.
- For unprotected steel driven piling, evaluation of higher corrosion potential for steel foundations in contact with site soils should be considered. Typically fat clay soils have relatively low apparent resistivity values and accelerated corrosion of the metal may be a concern. This will be further evaluated upon completion of the electrical resistivity testing.
- For drilled shaft foundations or other concrete pile types in contact with the site soils, evaluation of cement type based on the potential for high sulfate levels in the soil.

4.2.3 Shallow Foundations

Typically, shallow spread foundations are not used for the solar arrays, but likely will be used for substation structures or O&M building foundations. Special considerations for shallow foundation systems at this project site include:

- Low strength soils at shallow depths were observed at various locations across the site.
 - The presence of relatively low strength soils may lead to larger foundations which spread the imposed load over a larger area.
 - Overexcavation and replacement with engineered fill may be required in localized areas of the site in order to extend the foundation to suitable soils.
- Evaluation of soils with potentially high sulfate levels in surficial soils, which may require different cement type for concrete elements in contact with the soil.
- Frost depth.
 - The deep frost depth will require consideration for how to design the foundations (i.e. design for foundations to extend to frost depth or protection of foundations placed shallower than the frost depth).
 - Frost heave forces contributing to uplift on the foundations. Because the frost depth is so deep, the potential for lateral heave on foundations embedded to frost depth may need to be evaluated if not properly protected.

4.2.4 Other Foundation System Options

Other foundation types that can be considered based on the results of the investigation include:

- Helical Piles

- Helical piles are a deep foundation system that is “screwed” into the soil to the design depth. Helical piles typically have small shaft diameters and larger helical plates at depth to provide the necessary base resistance.
- Due to the smaller shaft diameters, lateral load resistance will need to be specifically considered in the foundation design.
- Helical piles may not be feasible in ground containing cobbles, boulders, or very dense soil.
- Helical piles may provide more resistance to frost jacking and shrink-swell.
- Helical piles also may need to be founded deeper to achieve required capacity.
- Augercast Piles
 - Augercast piles are a deep foundation system that is cast-in-place using a hollow-stem auger drilled to the design depth.
 - Augercast piles can be installed to depths needed to reduce potential vertical movements from frost heave and/or shrink-swell of soils.
 - Augercast piles may not be economically feasible in ground containing cobbles, boulders, or hard or very dense soils due to lack of penetration with the auger.
- Micropiles
 - Micropiles are high-capacity drilled and grouted small diameter piles (typically 5 to 12 inches in diameter).
 - Micropiles can be drilled through a wide range of materials and obstructions.
 - Based on the site conditions, micropiles do not appear warranted, and likely will be a higher cost.

4.3 Deep Foundation Design Parameters

A pile or drilled shaft foundation system will develop capacity through a combination of end bearing and skin friction. Lateral capacity is also taken into consideration in the design. The allowable bearing capacity can be determined from the soils design shear strength. The frost zone should be reduced in bearing capacity calculations for deep foundations. Suitable end bearing material was generally observed in CPT soundings below a depth of 10 feet. The following sections describe geotechnical recommendations for the design of pile foundation systems.

4.3.1 Axial Capacity

The axial capacity of pile or drilled shaft foundation systems is based on the contribution of the skin friction and the end bearing that the soil provides. The design values established in [Section 4.1](#) of this report are recommended for use in design of pile foundation systems.

The ultimate bearing capacity of the soil supporting a deep foundation can be determined from the end bearing of the pile (first term of the equation) and the sum of the downward skin friction resistance along the individual soil layers into which the pile is embedded (second term of the equation).

$$Q_{all} = q_{p(all)} A_b + \sum q_{s(all)} A_s$$

where:

A_b = base area of the pile

A_s = pile shaft area along soil embedment layer

$q_{p(all)}$ = unit end bearing resistance of the pile

$q_{s(all)}$ = unit skin friction resistance of the pile

Calculation of the allowable end bearing pressure in cohesive soils (clays) may be performed through the use of the following equation. Calculation of the allowable force in end bearing in cohesive soils is determined by multiplying the pressure computed below by the base area of the pile.

$$q_{p(all)} = \frac{s_u N_c^*}{FS} \quad (\text{Das, 2007})$$

where:

s_u = undrained shear strength ([Section 4.1.3](#))

N_c^* = bearing capacity factor = 9 (if depth/diameter is greater than 3) ([Das, 2007](#))

FS = factor of safety = 2

Calculation of the allowable skin friction pressure in cohesive soils (clays) may be performed through the use of the following equation. Calculation of the skin friction force is determined by multiplying the allowable pressure (using the equation below) by the length of the pile and circumference of the pile.

$$q_{s(all)} = \frac{\alpha s_u}{FS} \quad (\text{Das, 2007})$$

where:

α = factor correlating soil cohesion to adhesion = 0.7 ([NAVFAC, 1986](#))

s_u = undrained shear strength

FS = factor of safety = 2.5

Final axial design capacity will depend on the depth of the pile, diameter of the pile, and installation methods. It should be noted that values of end bearing and skin friction will not increase with depth beyond a depth equivalent to 20 times the pile diameter (USACE, 1991). If the depth/diameter ratio is less than 4, a reduction in the end bearing capacity factor (N_{cs}) will be required, as the foundation will act more as a column footing than a deep foundation. Ideally the base of the drilled shaft foundation should not be placed within one foundation diameter of the transition to the lower strength clay soil. It is recommended to use reduced resistance from the frost zone in performing pile capacity calculations, as indicated in Table 8.

4.3.2 Uplift from Frost Heave and Swell Potential

The contribution to uplift forces from frost heave should be included in the foundation design for pile foundations. The adfreeze value for uplift between the clay (fine-grained soils) and steel should be taken as approximately 1 ton per square foot (tsf), and the adfreeze value for uplift between clay and concrete should be taken as 0.68 tsf (Canadian Foundation Design Manual, 2006). Based on the size of piling selected for the foundations, this frost heave force should be computed to ensure that uplift forces will be overcome by the weight of the structure combined with the pullout resistance of the foundation below frost depth.

It should be noted that the extreme frost depth at the project site (described further in Section 4.5) will likely lead to longer pile depths due to the depth of soils affected by frost.

It is recommended that the skin friction contributing to uplift resistance should be taken as the skin friction used in compression (below the frost zone) minus a 10 percent reduction applied to account for the potential loss of lateral earth pressure in uplift (FHWA, 1999).

The use of in situ pull out testing of either test piles or representative bench scale alternatives would likely result in confirmation of considerably higher uplift capacity. Alternatively, and isolated or sleeved pile through the frost zone could be considered to remove the adfreeze forces and frost heave potential.

It is assumed that piles designed to resist frost heave will be founded below the frost depth, which should be below the active moisture content change zone at the site. Therefore, provided the piles can generate enough resistance to vertical movement from frost heave, this will also reduce the potential for vertical movement from shrink-swell.

4.3.3 Lateral Capacity

It is assumed that the computer program LPile will be used for the design of driven pile foundations to evaluate the lateral capacity of the soil system supporting the foundations. Lateral load resistance can be calculated for the native clayey soils using a modulus of horizontal subgrade value, and is dependent on whether the soils are exposed to a static or cyclic load, and the stiffness of the soil. Parameters for lateral capacity design were taken from Meyer and Reese (1979). A summary of the recommended values for lateral resistance related to foundation design, including soil density, soil shear strength and LPile design parameters is included in Table 8.

4.3.4 Settlement

It is anticipated that the driven piles will be founded within the clay soils at the site. Total settlement for driven piles could not be explicitly calculated because the foundation loads and dimensions are not available at this time. Typically, settlement is tolerable for pile-type foundations and it is not anticipated that settlement will govern the solar array foundation design.

4.4 Shallow Foundations

Shallow foundations at the site will likely be embedded in cohesive soil. Therefore, the bearing capacity for shallow foundations was evaluated for undrained conditions. It is recommended to design the bearing elevation for shallow foundations below the frost zone.

4.4.1 Allowable Bearing Capacity

The ultimate bearing capacity of the soil supporting a spread footing can be determined using the Terzaghi-Meyerhoff equation as follows:

$$q_{ult} = \frac{1}{2}\gamma'BN_{\gamma} + qN_q + s_uN_c \quad (\text{Das, 2007})$$

The first and second terms of the general bearing capacity equation are associated with granular soils which typically exhibit drained modes of failure (except under earthquake loading) and where excess pore pressures cannot build up in the soil when sheared. These terms represent the ultimate drained bearing capacity.

The third term of the equation is associated with fine-grained/clayey soils which typically exhibit an undrained mode of failure and where excess pore pressures can build up in the soil when sheared. To calculate the net ultimate bearing capacity, the first and second terms drop off and only the third term remains in the equation. As a result, the equation representing the ultimate net undrained bearing capacity is as follows:

$$q_{ult} = s_uN_c$$

where:

s_u = undrained shear strength

N_c = bearing capacity factor = 5.14 (Das, 2007)

It is recommended that shallow foundations be founded at or below the extreme frost depth of 7 feet. Using the minimum design undrained shear strength below the frost zone of 1,100 psf (Section 4.1.3), the ultimate undrained bearing capacity is calculated to be approximately 5,650 psf. A factor of safety of 3 is recommended for bearing capacity calculations. Therefore, the recommended allowable bearing capacity is approximately 1,850 psf for shallow foundations. This value is the minimum recommended bearing capacity for shallow foundations placed on the shallow clay soils.

The foundation designer should determine the appropriate bearing capacity for shallow foundations in accordance with the allowable settlement tolerances for the foundations. Settlement estimations are provided in the following sections.

4.4.2 Settlement

4.4.2.1 Elastic Settlement

The immediate or elastic settlement of shallow foundations on native clayey soils must be taken into account when establishing the allowable bearing capacity. The following equation was used to evaluate the immediate settlement of shallow foundations.

$$S = \frac{B q_o}{E_s} (1 - \nu^2) I \quad (\text{Das, 1994})$$

where:

S = elastic settlement

q_o = net increase in contact pressure

B = effective foundation width

ν = Poisson's ratio = 0.3 (assumed from [Das, 1994](#))

E_s = elastic soil modulus = 1,000 ksf (for medium clay, from [USACE EM 1110-1-1904](#))

I = shape factor = 1.65 (under center of rigid foundation, linear interpolation from [USACE EM 1110-1-1904](#))

Assuming a typical foundation for an inverter pad, with dimensions of 40 feet by 15 feet and a net bearing pressure increase of 1,850 psf, the total immediate settlement is estimated to be on the order of 0.5 inches.

4.4.2.2 Long-Term Settlement

The long-term settlement of a shallow foundation can be computed using the data collected from the DMT test. The long-term settlement of the foundation can be computed using the data collected from the DMT test data. The procedure proposed by Schmertmann, which uses the one-dimensional constrained modulus, M_i , was used to calculate the settlement. In this procedure, the soil strata under the proposed foundation are subdivided into several layers. The stress increment induced by the foundation load is then calculated at the mid-point of each layer. The compression of each layer can be computed using the following equation:

$$s_t = \sum_i \Delta\sigma' \frac{\Delta H_i}{M_i}$$

where:

s_t is the total settlement of all soil layers

$\Delta\sigma'$ is the applied stress at the mid-point of the soil layer

ΔH_i is the thickness of layer i

M_i is the average one-dimensional constraint modulus of the layer i

M values derived from the DMT are discussed in [Section 3.8.1](#). The settlement from the DMT results can be calculated based on the application of the normal operating load at the midpoint of each layer. An assumed normal operating load was used in this report. To calculate the consolidation settlement, the soil should be split into several layers, with the total settlement calculated as the sum of the individual layer settlements.

Considering the time required for long-term settlement from cohesive soils, differential settlement will be realized as a function of the applied foundation load during mean operating conditions at the center of the effective bearing area and at the loaded edge of the foundation.

The soil parameters over the footing width should remain constant, so only the applied load differs from the center of the affective area to the edge foundation. The soil stress from foundation at the center of the effective bearing area and at the edge of the foundation was calculated using the following formula:

$$\Delta\sigma = I * q$$

where,

$\Delta\sigma$ = soil stress at midpoint of soil layer (variable with depth and location)

I = Influence factor varying with depth and location beneath foundation

q = foundation bearing pressure for mean operating load condition

The influence factors for the center and edge of the foundations were calculated using Boussineq's solution for vertical stress dissipation caused by a rectangular loaded area ([Das, 2007](#)). Influence values at the center of the area and at the edge of the foundation were calculated for the midpoint of each layer where DMT data was analyzed.

Using assumed dimensions of a 40-foot by 15-foot pad with a working load of 1,850 psf, the long-term settlement at the center of the loaded area is estimated through DMT correlations to range from 0.78 to 1.30 inches, and differential settlement between the edge and center of the loaded area is estimated to range from 0.3 to 0.6 inches.

Once the final foundation design information is available, this procedure should be utilized to evaluate the final settlement estimations if the foundation is different from that assumed herein.

4.5 Frost Depth

The design frost depth for the project site is approximately 84 inches (NAVFAC, 1986). It is recommended that all foundations for the solar PV modules (assumed to be unheated) extend a minimum of 7 feet below existing grade for protection from frost. Foundations for unheated structures placed at depths shallower than 7 feet, including slabs-on-grade, may be susceptible to frost heave. In addition, deep foundations may be subject to frost jacking through the upper 7 feet of soil, regardless of the total embedment depth of the foundation.

For structures supported by a slab-on-grade foundation system where frost is a concern, there are a number of ways to reduce the risk of frost heave. One method for reducing frost heave is to support the slab on frost-depth footings. Alternatively, the slab could be tied into helical pile foundations placed below frost depth. If this method is utilized, a compressible material shall be placed under the structural slabs or the slabs should be suspended above the subgrade soils to accommodate for frost heave.

A second method to reduce the risk of frost heave is to place extruded polystyrene foam insulation beneath the slabs and extending the foam beyond the slabs or foundations, or as in accordance with the manufacturer's recommendations. Insulation will reduce frost penetration into the underlying subgrade and thereby reduce heave. A leveling course consisting of 12 inches of clean sand with less than 5 percent fines content is generally required to seat the insulation sections. Crushed road base material with a minimum thickness of 12 inches should be placed over the insulation sections for protection during and after construction.

Another method of reducing frost heave is to remove the frost-susceptible soils to below the frost depth and replace with non frost-susceptible sand. Sands with less than five percent passing the number 200 sieve are considered non frost-susceptible. With this method, a drain system that could remove the pooling water within the sand from below the foundation should be considered.

4.6 Seismicity Considerations

It is recommended that a seismic design be performed using the site ground motion procedure prescribed by the International Building Code (2012/15). Seismic design parameters were taken from the USGS Earthquake Hazard Program design maps using standards from the 2012/15 IBC design standard (USGS, 2017). The following parameters may be used in computing seismic base shear forces:

Site Class = B

S_s for site class B = 0.051 g

S_1 for site class B = 0.020 g

The parameters above are for site class B. Barr recommends a site class D is recommended for use in design; therefore, the parameters above should be converted to site class D parameters.

4.7 Sliding Friction

The friction coefficient between the clay soils of the site and construction materials should be taken as 0.4 for steel and concrete foundations (Potyondy, 1961). The friction coefficients recommended are for the case of a relatively smooth construction material surface.

4.8 Dewatering and Erosion Control

Based on the results presented in Section 3.2, groundwater was observed during the geotechnical investigation at depths of 7 feet or greater. It is possible that more permeable seams exist within the clay soils, which could lead to seepage into excavations during construction. Therefore, groundwater may impact construction efforts.

Standard dewatering procedures should be suitable where excavations are exposed to rain or surface water runoff. It is anticipated that excavations will remain open for only short periods of time; therefore special provisions for erosion control of the slopes are not anticipated provided construction is performed during the dry season. Measures should be taken to prevent runoff from depositing sediment in the excavations in case of rain. Where the excavation is to extend to depths below the groundwater table the contractor should be prepared, at a minimum, to remove water from the excavations through the use of a sump and pit.

Long-term erosion control measures for the project site largely consist of revegetation for all areas of the project site where it can be performed following construction. Revegetation will help control erosion from both wind and water. If gravel fill is placed below the solar PV modules as is typically performed, revegetation is not required because the gravel should not lead to a significant amount of erosion. In areas where revegetation is not possible, some wind erosion of the soil may occur but will generally be limited to an inconsequential amount of soil immediately at the ground surface. Temporary erosion controls measures may be required until revegetation is complete. Control of water erosion will generally consist of the design of erosion control structures, berms, diversion devices, and other drainage control measures to limit drainage to confined zones away from the solar structures. The design of specific erosion control structures should be performed by a civil engineer that specializes in this practice. Barr may be able to assist in this design, if requested.

4.9 Liquefaction Potential

Liquefaction of a soil due to seismic loading often occurs in saturated sands and silts when the increase in shear-induced pore-water pressure due to seismic loading decreases the effective stress within the soil, resulting in a temporary loss of strength. The predominant soil type identified was clay, and the seismic activity at the project site is low; therefore, the potential for liquefaction of soils supporting the proposed structures is considered low.

4.10 Shrink-Swell Potential

Soils considered to have shrink-swell potential generally consist of plastic clays subject to changes in moisture content. The results of the Atterberg Limits testing indicates that the fat clay soils underlying the topsoil across the site are of high plasticity, and are considered to have a high shrink-swell potential. If installation of driven piles is performed correctly, and the fat clay soils are protected from additional moisture, specific foundation design considerations are not considered necessary. However, if during the site grading, the topsoil is removed and the fat clays are exposed, they should be protected from significant changes in moisture content until covering materials are restored.

Since the deposits of fat clay are relatively thick at this site, the shrink-swell of the material may impact the structures and may cause vertical movement of piling if the pile is not designed properly. For increased resistance to shrink-swell of the fat clay soils, the piles will likely need to be embedded in the clay soils so that vertical uplift is overcome by the weight of the pile and the skin friction below the assumed normal water level of 7 feet below grade.

4.11 Slope Stability

The results of the investigation indicate generally medium stiff to stiff clay soils. The topography of the site is relatively flat. Slope stability in the area of the proposed solar array locations is not considered a significant risk based on the subsurface conditions encountered and low relief at the site.

4.12 Cement Type

Based on the results of the sulfate testing performed on four soil samples from the site, the soils have sulfate levels at ranging from 32.2 to 23,700 mg/kg, which is considered low to severe exposure (Table 6). Of the four locations tested, three of the sulfate tests indicated soluble sulfate levels less than 1,000 mg/kg, which is considered low sulfate exposure. The soils from test pit TP05 in the northeast part of the site indicated that the sulfate content ranged from about 16,100 to 23,700 mg/kg, which is considered severe sulfate exposure. This sample was tested twice because it was vastly different than the results of the other tests, but the additional testing confirmed the initial results. There was no correlation between the location of the highest sulfate test location (TP05) and the mapped soils at the site or visual observations of the soil across the project site.

Based on recommendations by the American Concrete Institute (2011), Type I cement appears suitable in concrete mix design for the majority of the site, although higher sulfate resistant cement is recommended for the area near TP05. Further testing may be necessary to determine the extent of the high sulfate soils, unless a cement type suitable for use with the highest soil sulfate content is used for the entire site.

4.13 Corrosion Potential

In general, soils with an apparent resistivity less than 2,000 ohm-centimeters are considered to have a severe corrosion potential. Based on the results of the electrical resistivity testing (Appendix H), the soil has an apparent resistivity less than 2,000 ohm-centimeters, and can be considered to have severe corrosion potential when in direct contact with steel foundations. Clay soils of relatively high moisture

content generally tend to exhibit low apparent resistivity values, and protection of steel foundations, if utilized, is recommended.

4.14 General Construction Considerations

The following subsections present general recommendations for site clearing, grading, and compaction for the project site.

4.14.1 Clearing and Grubbing

The project site is an agricultural field used for growing crops, and clearing and grubbing will generally be restricted to the removal of crop remains, root zones, and topsoil. Based on the results of the soil borings, the thickness of this organic material or topsoil is approximately 8 to 18 inches thick on average, but may be thicker or thinner depending on local variations between the completed investigation locations.

The topsoil and organic material is usually mixed during the excavation process, and thus, should not be used for structural fill. This material should be placed separately away from the rest of the excavated material to avoid contamination. Topsoil removed during site stripping should be graded into existing site topography. This material could be used in grading non-structural fill such as fields, or service areas in which compressibility of the material does not have an impact on structures.

4.14.2 General Site Grading

Results of the geotechnical exploration indicate that cut and fill of the soil in the area can be achieved with conventional machinery. For this excavation, tractors of 140 to 223 HP or higher power such as: Caterpillar D7G, D8 and D9; Komatsu D6SE6, D80A18 and D155-1; John Deere 850; Dresser TD15C, TD20E and TD25E; Fiat Allis 14C and FD20 or similar can be used.

After stripping or excavating to rough grade is complete, the exposed subsurface along the entire roadway should be proof-rolled. Proof-rolling should be performed with a fully loaded tandem axle dump truck having a minimum gross weight of 25 tons. Proof-rolling will aid in identifying areas of unstable subgrade. Proof-rolling should be performed in the presence of a geotechnical engineer. Typical standards for proof-rolling should include no rutting greater than 1 inch, and no "pumping" of the soil behind the proof-roll. Proof-rolling is not an indication that the subgrade strength is adequate or that it meets design requirements, but simply highlights potentially unsuitable subgrade conditions. If the graded subgrade soil conditions do not meet the required compaction test results, per the construction specifications, the deficient materials shall be improved as noted below.

Alternatives for subgrade stabilization include the following:

- **Removal and Replacement** – The inadequate materials can be removed and replaced with granular structural fill consisting of well-graded sand and gravel materials with less than 10 percent fines. Compaction of this material is required to achieve a minimum of 95 percent of the laboratory maximum dry density measured according to Standard Proctor. The granular structural

fill can be used in conjunction with a geotextile fabric or geo-grid to potentially reduce depth of overexcavation or to reduce the amount of granular materials required.

- **Scarification and Re-compaction** – It may be feasible to scarify, dry, and re-compact the exposed soils. The success of this procedure would depend primarily upon favorable weather and sufficient time to dry the soils. Even with adequate time and weather, however, stable subgrades may not be achievable if the thickness of the soft soil is greater than 1 to 1-1/2 feet.
- **Soil Stabilization** – The use of cement, lime, or fly-ash as a soil stabilizing agent can be considered in lieu of removal and replacement or scarification and recompaction. The type and quantity of materials used to stabilize the soils will be dependent upon soil type. Design of a soil stabilization program should be performed by a geotechnical engineer in conjunction with laboratory testing to provide the proper stabilizing agent, application rate, and depth of soils stabilized.

Placed fill for subgrade stabilization shall be compacted with a sheepsfoot or pad-foot compactor at sites on cohesive material and a smooth drum roller for granular and gravel fill material. The majority of the native soils near the surface of the substation are clayey soil, indicating the use of a sheepsfoot roller. Vibratory versions of these compactors are acceptable, although not required for cohesive soils. Vibratory rollers may disturb the cohesive soils, especially in the presence of higher moisture content fat clay soils. The number of passes required will vary depending upon the equipment used, fill material type, and moisture condition of the fill.

After completion of proof-rolling, but prior to placement and compaction of granular fill, any soils loosened during the excavation activities should be recompacted as noted in this section of the report.

4.14.3 Grading in Cut

Grading in cut using conventional machinery should be able to remove all topsoil and organic material. The clay soils across the site can be classified as Type B from OSHA soil classifications (29 CFR 1926 Subpart P-Excavations). It is the responsibility of the competent field personnel to verify the in-situ soil classification at each excavation and that the benching or slopes are adequate during construction. The presence of groundwater may complicate shallow excavations, and the side slopes may need to be benched further depending of observations of the competent field personnel for safety.

4.14.4 Shallow Foundation Construction Recommendations

Following excavation, the exposed base should be inspected by the construction phase geotechnical engineer of record or authorized representative. If the excavation base surface is found to contain groundwater or is deemed unsuitable for construction in the opinion of the construction phase geotechnical engineer of record or authorized representative, the conditions shall be noted and communicated to the foundation designer for appropriate foundation modifications.

Any soil placed as engineered fill should be an approved material classified as SM, SC, SP-SM, or SP. It should be free of organic matter or debris, rocks greater than 3 inches in diameter. Clay soils can be used

for general site grading, but should not be used as a structural fill, and should have a Liquid Limit and Plasticity Index less than 45 and 25, respectively. High plasticity silt or clay (MH, CH) soils should not be used as structural fill within 4 feet of footings or within 2 feet of slab or pavement subgrades.

Fill should be placed in lifts not exceeding 8 inches in loose thickness or one third the diameter of the roller, whichever is less, and moisture conditioned to within ± 3 percent of the optimum moisture content. It is recommended that each lift be compacted to a minimum of 98 percent of the maximum dry density obtained in accordance with ASTM Specification D-698, Standard Proctor Method. In areas where the depth of the fill is 5 to 10 feet, the fill should be compacted to 98 percent of the maximum standard Proctor dry density for the entire height of the fill. Fills placed in excess of 10 feet will require further evaluation at the time of the final geotechnical investigation. The backfill surface should be graded such that water is directed away from the foundations to prevent moisture infiltration ($\frac{1}{4}$ " per foot). Backfill density should be checked in the field periodically (approximately one test per 2,500 square feet per lift) to confirm adequate compaction.

4.14.5 Driven Pile Construction Recommendations

Driven piles shall be installed based on driving criteria determined by the foundation engineer of record to support the required loads. Piles should be driven plumb and to the minimum depths specified by the foundation engineer. Based on the results of the field investigation, widespread pile refusal of driven piles is considered a low risk due to the limited gravel and absence of cobbles and boulders observed during the investigation. However, the possibility exists that obstructions are present at the site at locations between the soil borings.

4.14.6 Drilled Shaft Excavations and Recommendations

The base of drilled shaft excavations should be firm and free of loose or disturbed soils. If necessary, any loose or disturbed soils should be removed from the excavation with a clean-out bucket. Rebar cages should be installed immediately prior to concrete placement to facilitate bottom cleaning of the excavation.

Drilled shafts in granular soils (sands or non-plastic silt), will be prone to sidewall collapse and temporary casing or drilling fluid will likely be required to facilitate excavation of drilled shaft foundations and maintain stability of the excavation. Drilled shafts excavations in lower strength or saturated clay soils may also require temporary casing or drilling fluid in order to reduce any sloughing or swelling of high plasticity clays. All temporary casing should be removed from the excavation during concrete placement. If temporary casing will remain in-place the foundation designer should be consulted to determine if additional foundation capacity is required.

Concrete placed in drilled shaft excavations in the presence of water should be placed using a tremie pipe to properly displace the water accumulated in the excavation. The tremie pipe should be placed to the bottom of the excavation to minimize mixing of the concrete and water during placement. Concrete placed in deeper drilled shafts also should be placed with a tremie pipe to minimize contact with the rebar cage during placement.

Belled drilled shafts may provide additional resistance to counter frost heave and shrink-swell of foundations, but the foundation designer should determine the additional benefits of using a belled drilled shaft. If belled drilled shafts are utilized, it is recommended that the belled portion of the shaft be placed entirely below the frost depth of 7 feet.

4.14.7 Helical Anchor Pile Construction Recommendations

Due to the shrink-swell potential of the fat clays and frost heave potential, helical piles may be considered for this site. If helical anchors are used, all bearing plates should be installed a minimum of two feet below the deeper of the normal groundwater level or the frost depth, which are both assumed to be 7 feet at this project site. The diameter of the shaft should also be minimized to reduce uplift forces from frost and shrink-swell, while still providing adequate lateral load resistance.

5.0 Limitations of Analysis

The analysis and conclusions provided are based on the results of fieldwork from recent geotechnical investigations at the project site. Using generally accepted engineering methods and practices, the investigation performed has made every reasonable effort to characterize the investigated locations and provide general conclusions of the project area. However, the likelihood that conditions may vary from any specific location tested is possible, and careful attention to soil conditions should be undertaken during the time of construction by qualified personnel.

6.0 References

- American Concrete Institute, Building Code Requirements for Structural Concrete (ACI 318-11), 2011.
- Anderson, Fred J., Depth to Bedrock in the Fargo Area, North Dakota, North Dakota Geological Survey, 2011.
- Canadian Foundation Design Manual, 4th Ed., Canadian Geotechnical Society, 2006.
- Das, B. M., 2007. Principles of Foundation Engineering, 6th Ed., Thompson.
- Das, B. M., 2006. Principles of Geotechnical Engineering, 7th Ed. Cengage Learning.
- Federal Highway Administration (FHWA) Publication No. FHWA-NHI-10-016: Drilled Shafts: Construction Procedures and LRFD Design Methods, 1999.
- Klausing, Robert L., *Geology and Groundwater Resources of Cass County, North Dakota: Part 1 – Geology*, North Dakota Geological Survey, United States Department of the Interior, 1968.
- Naval Facilities Engineering and Command, 1986. Soil Mechanics. Design Manual 7.01, Alexandria, VA.
- Meyer, Barry J., and Reese, Lymon C., Analysis of Single Piles Under Lateral Loading, Center for Highway Research, The University of Texas at Austin, 1979.
- Potyondy, J., 1961. "Skin Friction Between Various Soils and Construction Materials", *Geotechnique*, Volume XI, Number 4.
- United States Army Corps of Engineers (USACE). Engineer Manual 1110-1-1904, Settlement Analysis, 1990.
- USGS (accessed January 2017). <http://geohazards.usgs.gov/designmaps/us/application.php>

Tables

Table 1
Summary of Groundwater Levels From Test Pits

Location ID	Groundwater Depth [feet]	Groundwater Depth [feet]
	During Excavation	After Excavation
TP01	7.0	7.0
TP02	7.0	NE
TP03	7.0	NE
TP04	NE	NE
TP05	NE	NE

*NE - Groundwater Not Encountered

Table 2
Physical Laboratory Testing Summary

Sample Location		Approx Soil Type ⁽¹⁾	Moisture Content [%]	Atterberg Limits		
Location ID	Depth			Liq. Limit	Plast. Limit	Plast. Index
[% moisture content]						
TP01	2-4	CH	27.2			
	6-7	CH	30.1	52.1	19.1	33.0
	8-10	CH	32.6			
TP02	4-6	CL/CH	45.3	114.7	27.3	87.4
	8-10	CL/CH	33.9			
TP03	4-6	CL/CH	25.2			
	8-10	CH	33.8	70.9	24.9	46.0
TP04	2-4	CH	30.4			
	4-6	CH	31.6			
	8-10	CH	37.3			
TP05	4-6	CL	31.3	40.5	19.7	20.8
	8-10	CH	39.2			
Number			12	4	4	4
Minimum			25.2	40.5	19.1	20.8
Maximum			45.3	114.7	27.3	87.4
Average			33.2	69.6	22.8	46.8
Standard Deviation			5.4	32.6	4.0	29.0

¹ Soil types listed are approximate. See boring logs for full lithology.

Table 3
Average Undrained Shear Strength
and Friction Angle from CPT

Location ID	ϕ' [deg]	No. of granular layers	s_u [psf]	No. of cohesive layers
CPT01	31	6	1,431	86
CPT02	33	24	1,370	68
CPT03	32	1	1,422	91
CPT04	35	5	1,313	87
CPT05	33	15	1,604	77
CPT06	--	0	1,407	153
CPT07	34	21	1,493	71
CPT08	33	16	1,464	76
CPT09	--	0	1,409	153
CPT10	--	0	1,331	92
CPT11	34	6	1,601	86
CPT12	--	0	1,389	153
CPT13	33	2	1,387	90
CPT14	--	0	1,546	92
CPT15	32	1	1,355	152
CPT16	--	0	1,161	92
CPT17	35	3	1,492	89
CPT18	--	0	1,237	153
CPT19	32	1	1,539	91
CPT20	--	0	1,245	92
CPT21	--	0	1,487	153

Location ID	ϕ' [deg]	No. of granular layers	s_u [psf]	No. of cohesive layers
CPT22	--	0	1,414	92
CPT23	--	0	1,341	153
CPT24	34	1	1,385	152
CPT25	34	16	1,579	76
CPT26	34	2	1,581	90
CPT27	35	11	1,494	142
CPT28	--	0	1,445	92
CPT29	--	0	1,400	92
CPT30	--	0	1,492	153
CPT31	--	0	1,486	92
CPT32	--	0	1,326	92
CPT33	33	3	1,300	150
CPT34	35	3	1,208	89
CPT35	--	0	1,472	92
CPT36	--	0	1,346	153
CPT37	--	0	1,333	92
CPT38	--	0	1,351	92
CPT39	--	0	1,277	153
CPT40	33	3	1,413	89
CPT41	--	0	1,238	92

Table 4
Summary of Lower Strength Soil Layers

Location ID	Depth of Low Strength Soil Layers [feet]
CPT01	None below 7 ft
CPT02	17-20
CPT03	None below 7 ft
CPT04	None below 7 ft
CPT05	None below 7 ft
CPT06	None below 7 ft
CPT07	None below 7 ft
CPT08	None below 7 ft
CPT09	None below 7 ft
CPT10	None below 7 ft
CPT11	None below 7 ft
CPT12	8-8.5
CPT13	7-8
CPT14	None below 7 ft
CPT15	None below 7 ft
CPT16	7-8.5, 9.5-11.5, 17-18
CPT17	None below 7 ft
CPT18	19-25
CPT19	None below 7 ft
CPT20	7.5-8.5, 17-18
CPT21	None below 7 ft

Location ID	Depth of Low Strength Soil Layers [feet]
CPT22	None below 7 ft
CPT23	None below 7 ft
CPT24	25-26
CPT25	None below 7 ft
CPT26	None below 7 ft
CPT27	8.5-11
CPT28	None below 7 ft
CPT29	7.5-8
CPT30	None below 7 ft
CPT31	None below 7 ft
CPT32	None below 7 ft
CPT33	12.5-16
CPT34	16-20
CPT35	None below 7 ft
CPT36	7-8, 10-12
CPT37	7-8
CPT38	9-9.5
CPT39	9.5-10, 15.5-16
CPT40	None below 7 ft
CPT41	15.5-16

**Table 5
Summary of Standard Proctor Results**

Location ID	Depth [ft]	Standard Proctor Data		95% Compaction	In-situ Moisture	95% Compaction
		Maximum Dry Density	Optimum Moisture	Moist Unit Wt. at Opt. Moisture		Moist Unit Wt. at in-situ Moisture
		[pcf]	[%]	[pcf]		[pcf]
TP01	1-5	99.0	22.5	115.2	27.1	119.5
TP03	1-5	86.4	30.2	106.9	26.6	103.9
TP05	1-5	85.6	31.1	106.6	36.0	110.6
Minimum		85.6	22.5	106.6	26.6	103.9
Maximum		99.0	31.1	115.2	36.0	119.5
Average		90.3	27.9	109.6	29.9	111.3
Standard Deviation		6.1	3.9	4.0	4.3	6.4

Table 6
Chemical Test Results on Soil Samples

Location ID	Depth [feet]	pH	Chloride	Sulfate
			[mg/kg]	[mg/kg]
TP01	1-5	7.9	10	120
TP02	1-5	8.1	10	32.2
TP04	1-5	7.9	10	102
TP05	1-5	7.6	10	23700
TP05**	1-5	--	42	16100
Mean		7.9	16.4	8010.8
St. Dev.		0.21	14.22	11180.99
Min.		7.6	10	32
Max		8.1	41.8	23700

*Test results for chlorides were below the detection limit for some tests. A value of 10 mg/kg was used for analysis at those tests.

** Sample was retested for confirmation of high sulfate content

Table 7
Summary of Geotechnical Parameters
for Foundation Design

Parameter	Value	Units
Undrained Soil Shear Strength (cohesive soil - 0 to 7 feet)	500	lb/ft ²
Undrained Soil Shear Strength (cohesive soil - Deeper than 7 feet)	1,100	lb/ft ²
Min. Net Allowable Bearing Capacity, Shallow Foundations (Embedment Depth of 7 feet)	1,850	lb/ft ²
Min. Foundation/Soil Friction Factor	0.4	
Extreme Frost Depth Penetration	84	inches

**Table 8
Deep Foundation Design Parameters**

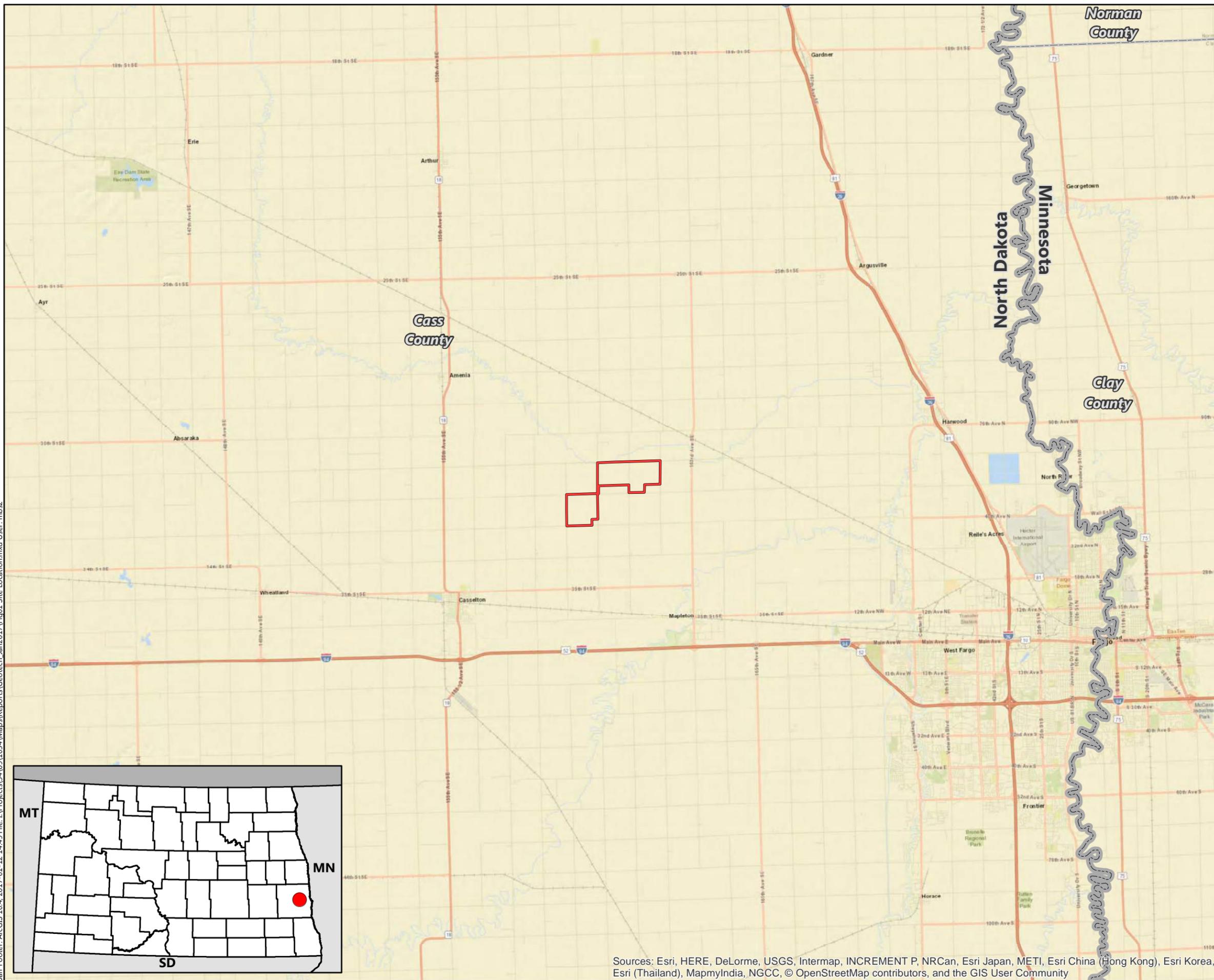
Foundation Type	Depth to Top of Layer [ft]	Depth to Bottom of Layer [ft]	Material Type	Total In-Situ Unit Weight [pcf]	Effective In-Situ Unit Weight [pcf]	Approx. Depth to Groundwater [ft]	Friction Angle [°]	Cohesion [psf]	Horizontal Design Parameters				Active Earth Pressure Coefficient, K_a	Passive Earth Pressure Coefficient, K_p	N_q (sand) OR N_c (clay)*	Axial Design Parameters	
									p-y Modulus, k (Static Loading) [lb/in ³]	p-y Modulus, k (Cyclic Loading) [lb/in ³]	50% Soil Strain	Dilatometer Modulus, E_d [ksf]				Incremental Ultimate Skin Friction Per Soil Layer [kips/ft ²]	Ultimate End Bearing [kips/ft ²]
Driven Pile or Drilled Shaft	0	7	Clay (Frost zone)	95	95	7	0	500	100	--	0.01	183	1.00	1.00	9.00	0.35	--
	7	10	Clay	95	32.6	7	0	1100	500	200	0.007	153	1.00	1.00	9.00	0.77	9.9
	10	15	Clay	95	32.6	7	0	1100	500	200	0.007	153	1.00	1.00	9.00	0.77	9.9
	15	20	Clay	95	32.6	7	0	1100	500	200	0.007	153	1.00	1.00	9.00	0.77	9.9
	20	25	Clay	95	32.6	7	0	1100	500	200	0.007	153	1.00	1.00	9.00	0.77	9.9
	25	30	Clay	95	32.6	7	0	1100	500	200	0.007	153	1.00	1.00	9.00	0.77	9.9

Note - reduced resistance from frost zone (upper 84 inches) is recommended used due to seasonal variations and frost conditions

*Assumes depth/diameter ratio > 3

Figures

Bar Footer: ArcGIS 10.4, 2017-01-12 14:49 File: I:\Projects\34\09\1034\Maps\Reports\Geotech_Jan2017\Fig01_Site Location.mxd User: mbs2



-  Project Area
-  County Boundary

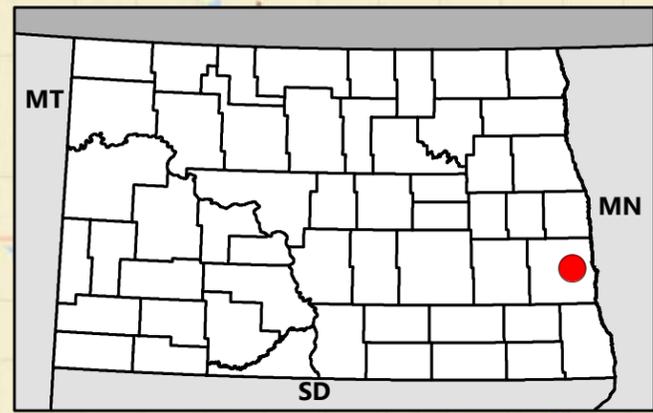
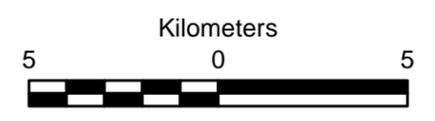
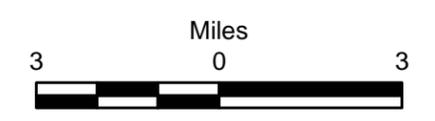
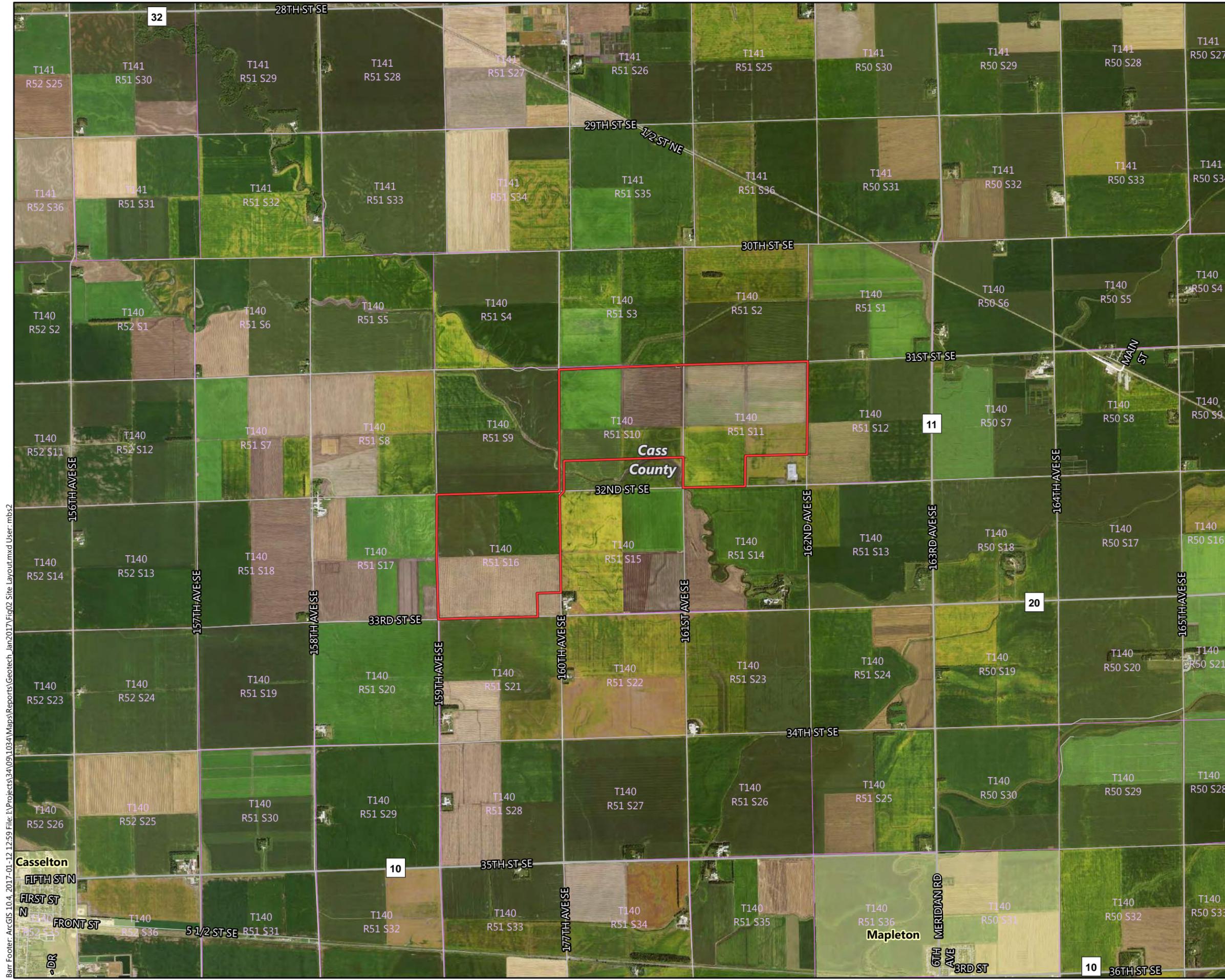


Figure 1

SITE LOCATION
 Harmony Solar Project
 Geronimo Energy
 Cass County, North Dakota

Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community



-  Project Area
-  Municipality
-  Public Land Survey Section
-  County Boundary

Imagery Source: USDA NAIP 2015

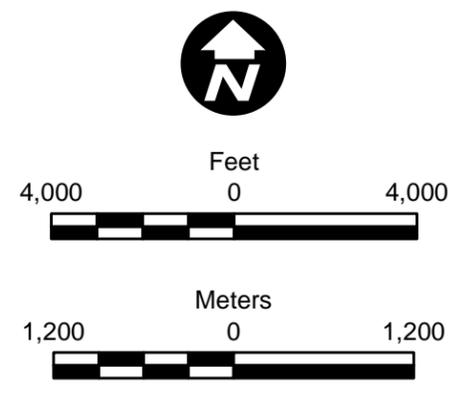
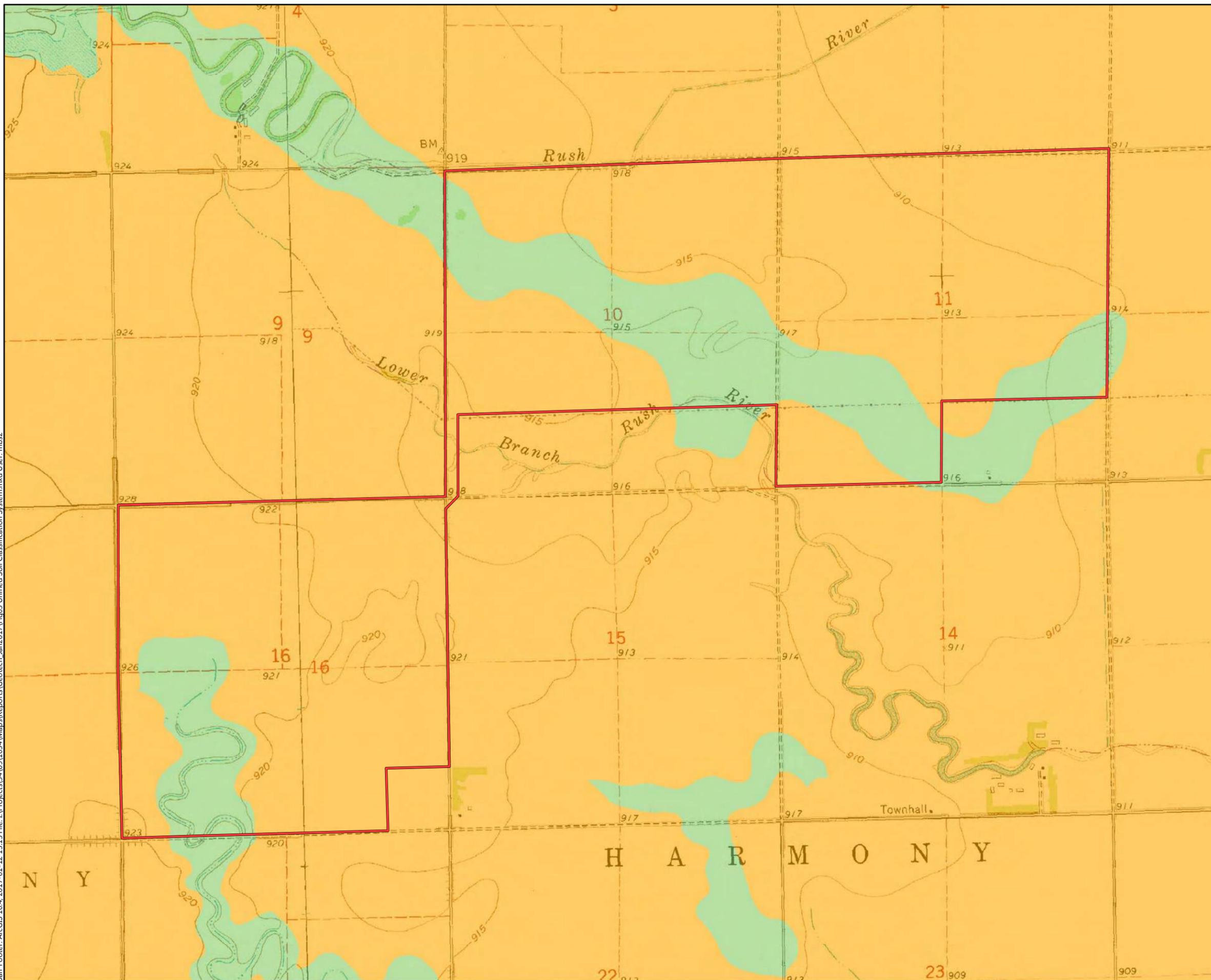


Figure 2
SITE LAYOUT
 Harmony Solar Project
 Geronimo Energy
 Cass County, North Dakota

Barr Footer: ArcGIS 10.4, 2017-01-12 12:59 File: I:\Projects\34\09\1024\Maps\Reports\Geotech Jan2017\Fig2_Site Layout.mxd User: mbs2

Bar Footer: ArcGIS 10.4, 2017-01-12 13:15 File: I:\Projects\34\09\1034\Maps\Reports\Geotech Jan2017\Fig03 Unified Soil Classification System.mxd User: mbs2



Project Area

Unified Soil Classification

MH - Elastic Silt

ML - Silt

Soil Survey Staff, NRCS USDA. Soil Survey Geographic (SSURGO) Database. Available online at: <https://sdmdataaccess.sc.egov.usda.gov>. Accessed 9/26/2016.

Topography Source: USGS 24k DRG

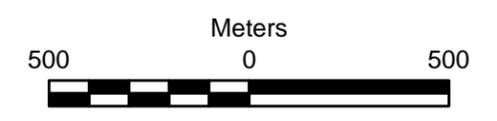
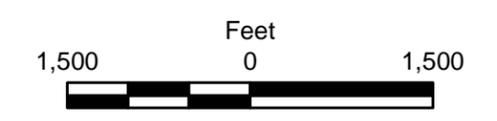
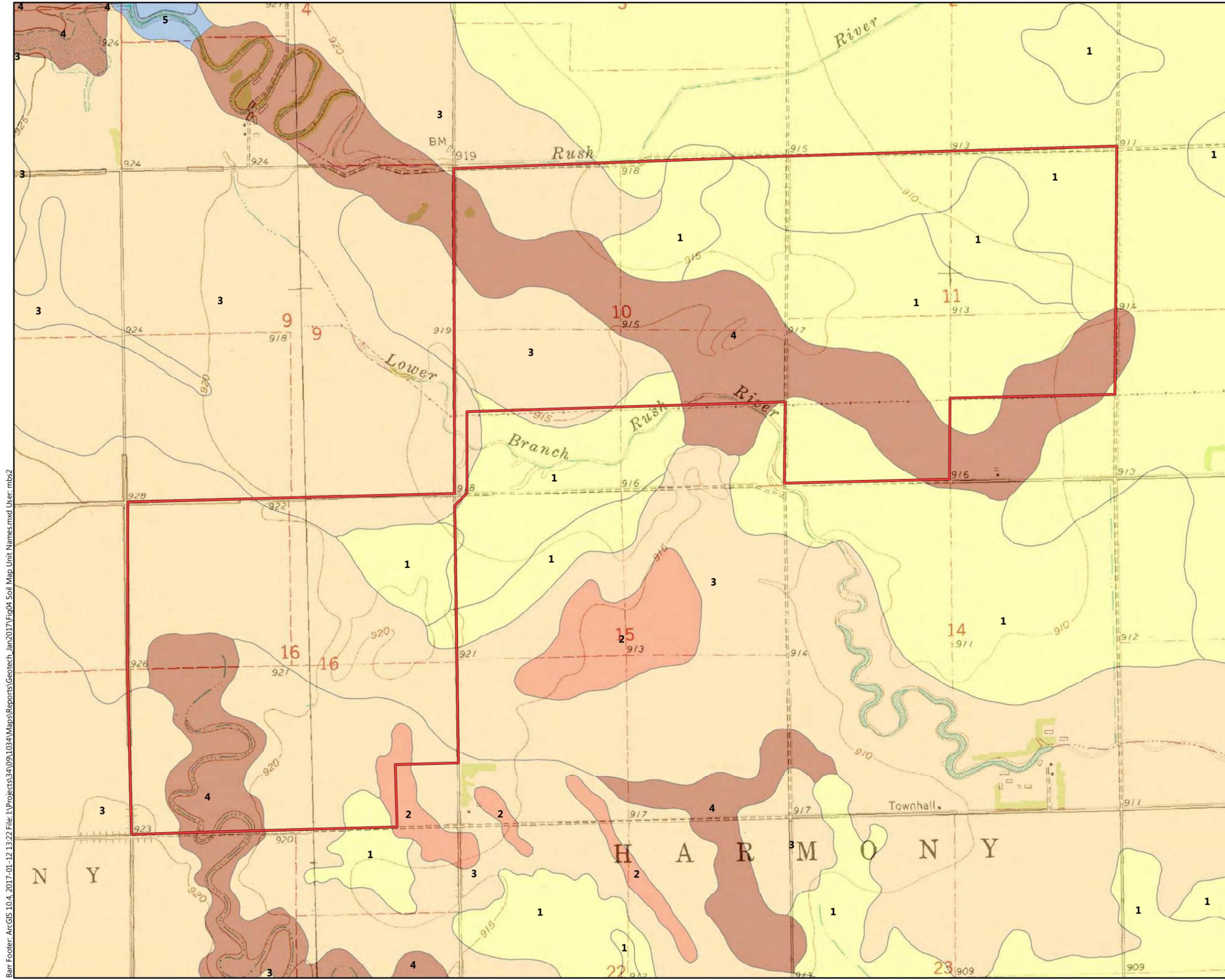


Figure 3

UNIFIED SOIL CLASSIFICATION SYSTEM
 Harmony Solar Project
 Geronimo Energy
 Cass County, North Dakota



-  Project Area
- Soil Map Unit Name
-  1, Fargo (Hegne) silty clays
-  2, Overly silty clay loam
-  3, Bearden (Kindred) silty clay loams
-  4, Misc. silt loams
-  5, Fairdale-Fluvaquents

Soil Survey Staff, NRCS USDA. Soil Survey Geographic (SSURGO) Database. Available online at: <https://sdmdataaccess.sc.egov.usda.gov>. Accessed 9/26/2016.

Topography Source: USGS 24k DRG

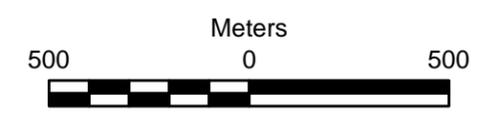
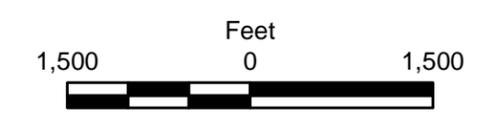
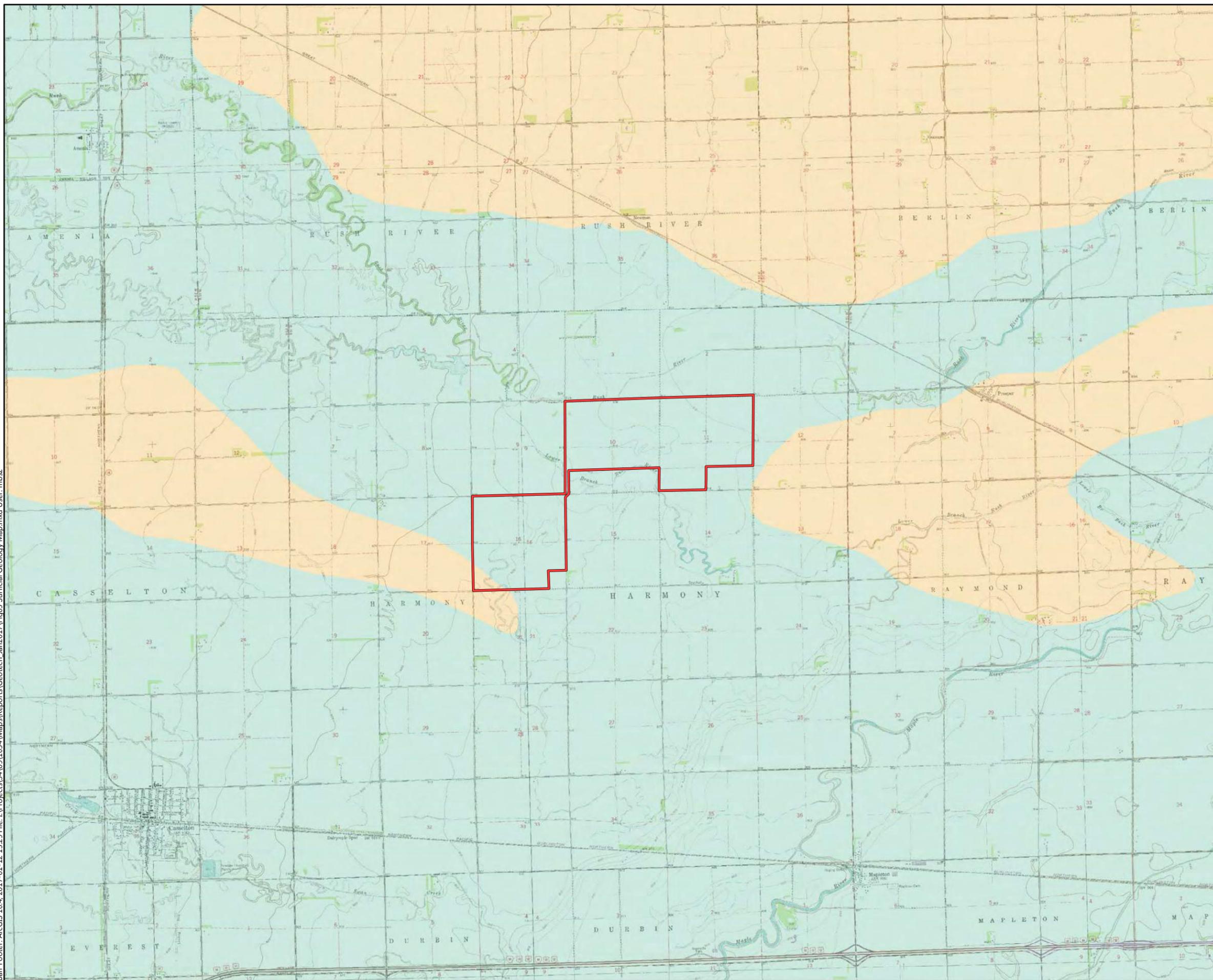


Figure 4

SOIL MAP UNIT NAMES
 Harmony Solar Project
 Geronimo Energy
 Cass County, North Dakota

Bar Footer: ArcGIS 10.4, 2017-01-12 13:29 File: I:\Projects\34\09\1034\Maps\Reports\Geotech_Jan2017\Fig05 Surficial Geology Map.mxd User: mbs2



 Project Area

Surficial Geology

 Qcof - Coleharbor Fm, Silts, 60m thick

 Qor - Oahe Fm, Clays/Sands, 10m thick

Lee Clayton. Surface Geology of North Dakota - 1:500,000 Scale. State of North Dakota. 1980. (Digitized 1997).

Topography Source: USGS 24k DRG



Miles



Kilometers



Figure 5

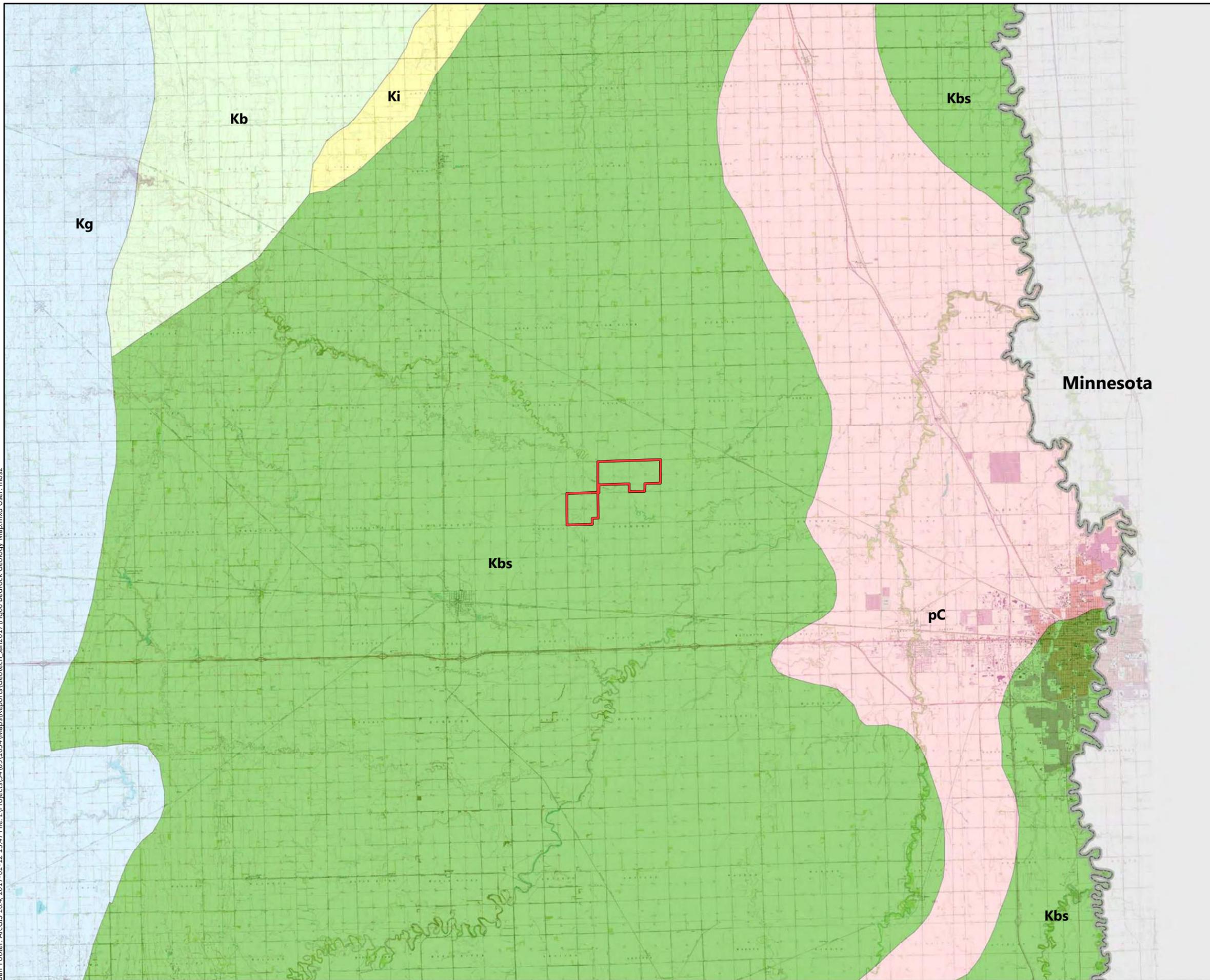
SURFICIAL GEOLOGY MAP

Harmony Solar Project

Geronimo Energy

Cass County, North Dakota

Bar Footer: ArcGIS 10.4, 2017-01-12 13:47 File: I:\Projects\34-09\1034\Maps\Reports\Geotech Jan2017\Fig06 Bedrock Geology Map.mxd User: mbs2



-  Project Area
- Bedrock Geology Units**
-  Kg--Greenhorn Fm
-  Kb--Belle Fourche Fm
-  Kbs--Belle Fourche, Mowry, Newcastle, and Skull Crk. Fms
-  Ki--Inyan Kara Fm
-  pC--Precambrian rocks

Bluemle, John P. Geologic Bedrock Map of North Dakota. NDGS Miscellaneous Map 25, 1:670,000 scale. North Dakota Geological Survey. 1983 (Digitized 2001).

Topography Source: USGS 24k DRG

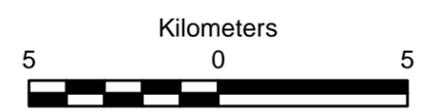


Figure 6

BEDROCK GEOLOGY MAP
 Harmony Solar Project
 Geronimo Energy
 Cass County, North Dakota

Barr Footer: ArcGIS 10.4, 2017-01-12 13:49 File: I:\Projects\34\09\1034\Maps\Reports\Geotech_Jan2017\Fig7\CPT Sounding and DMT Locations.mxd User: mbsz



-  CPT Sounding Location
-  CPT Sounding and DMT Location
-  Project Area

Imagery Source: USDA NAIP 2015

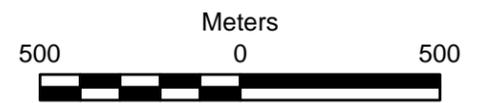


Figure 7

**CPT SOUNDING AND
DMT LOCATIONS**
Harmony Solar Project
Geronimo Energy
Cass County, North Dakota

Bar Footer: ArcGIS 10.4, 2017-01-12 13:51, File: I:\Projects\34\09\1034\Maps\Reports\Geotech_Jan2017\Fig08 Test Pit Locations.mxd User: mbsz



- Test Pit Location
- Project Area

Imagery Source: USDA NAIP 2015

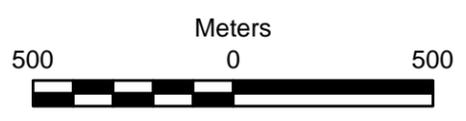
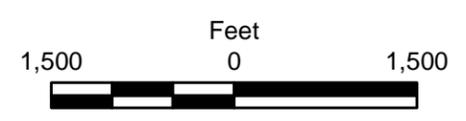


Figure 8

TEST PIT LOCATIONS
Harmony Solar Project
Geronimo Energy
Cass County, North Dakota

Bar Footer: ArcGIS 10.4.1, 2017-05-03 16:40 File: I:\Projects\34109\1034\Maps\Reports\Geotech_Jan2017\Fig09 Electrical and Thermal Resistivity Test Locations.mxd User: mbs2



- Electrical Resistivity Test Location
- Thermal Resistivity Sample Location
- Electrical Resistivity Test and Thermal Resistivity Sample Location
- Project Area

Imagery Source: USDA NAIP 2015

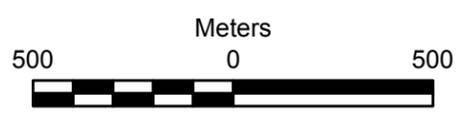
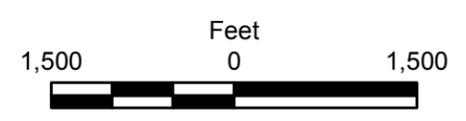


Figure 9

**ELECTRICAL AND THERMAL
RESISTIVITY TEST LOCATIONS**
Harmony Solar Project
Geronimo Energy
Cass County, North Dakota

Undrained Shear Strength, S_u [psf]

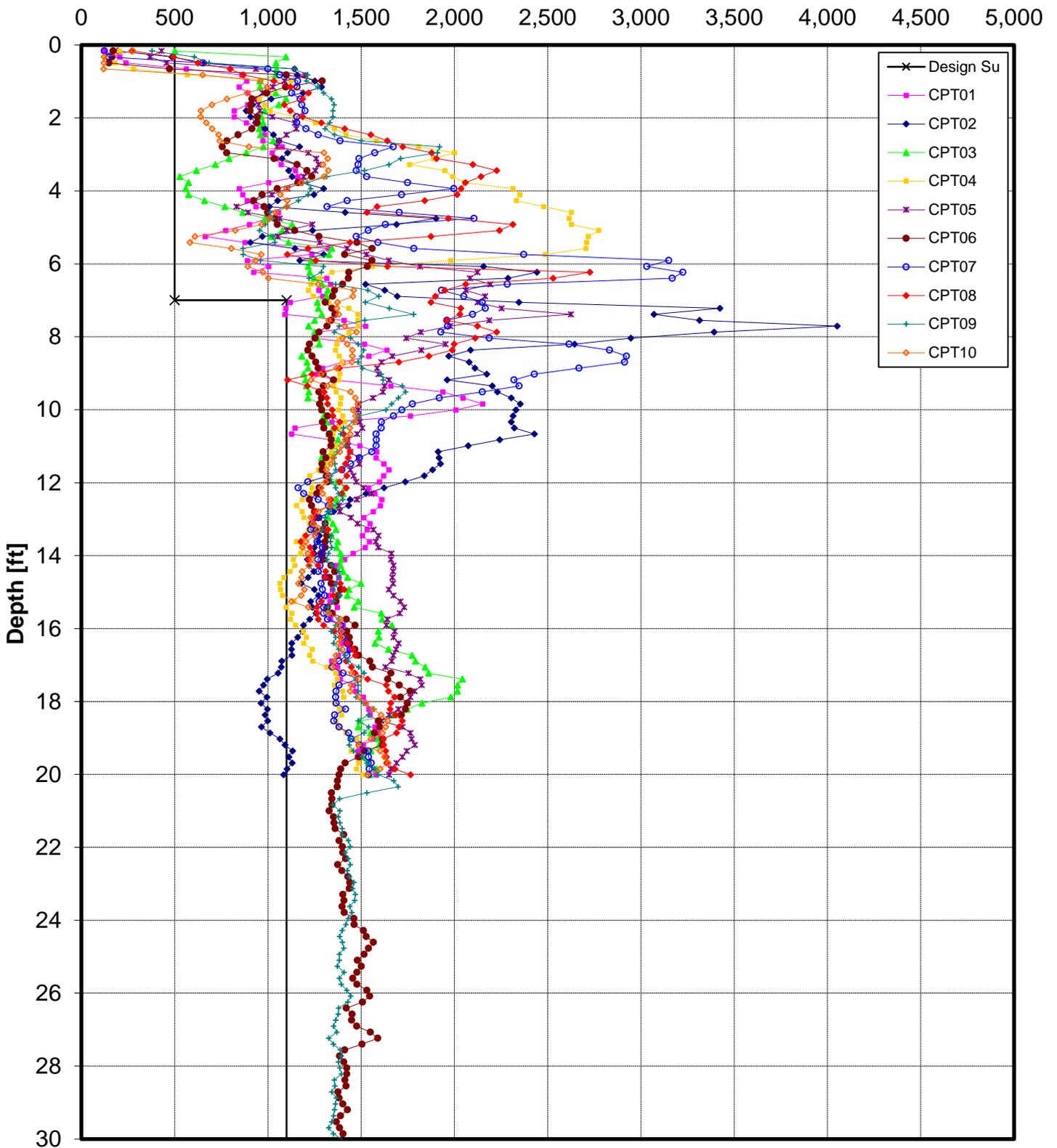


Figure 10. Undrained Shear Strength from CPT vs. Depth Soundings 1 to 10

Undrained Shear Strength, S_u [psf]

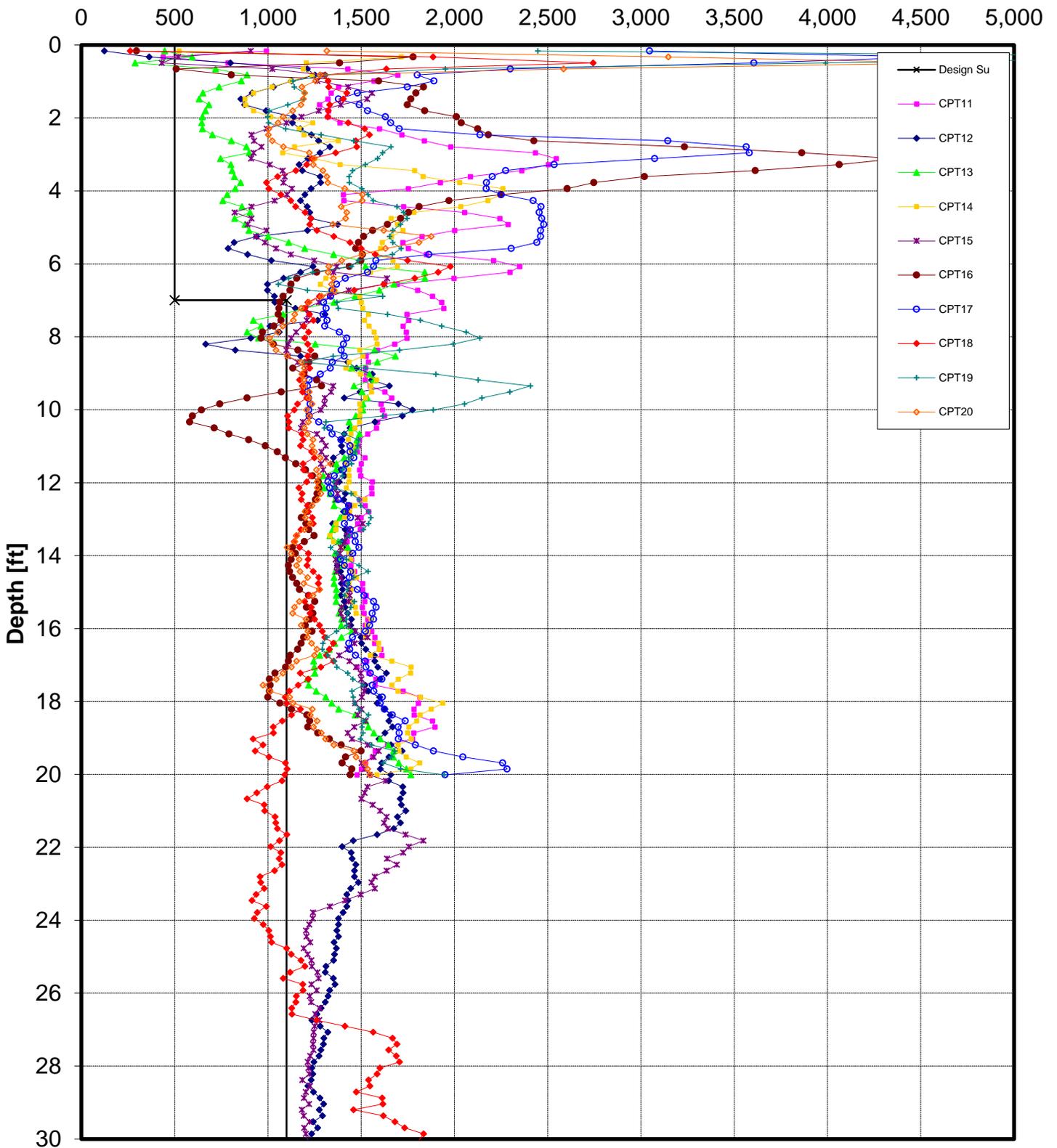


Figure 11. Undrained Shear Strength from CPT vs. Depth Soundings 11 to 20

Undrained Shear Strength, S_u [psf]

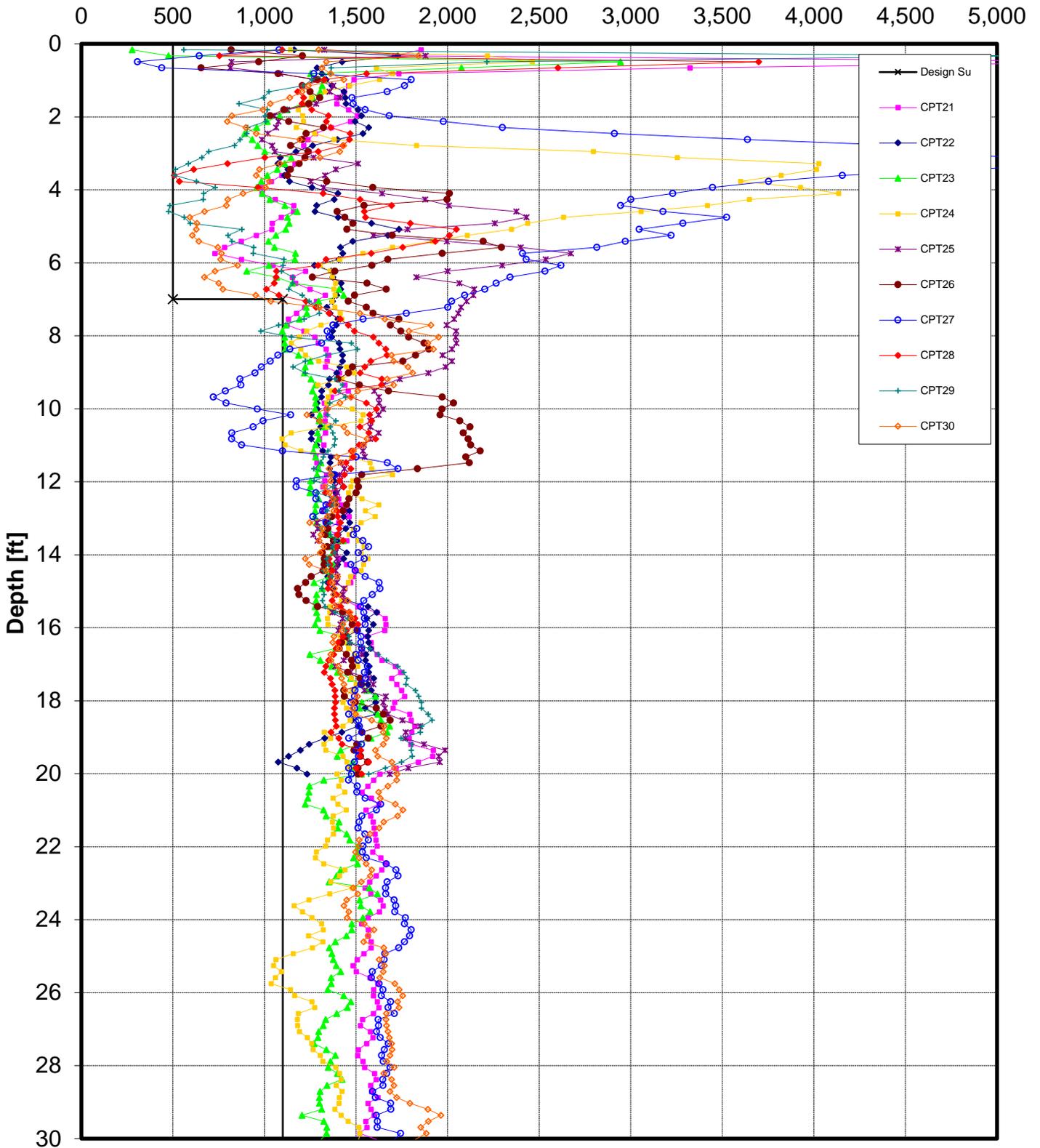


Figure 12. Undrained Shear Strength from CPT vs. Depth Soundings 21 to 30

Undrained Shear Strength, S_u [psf]

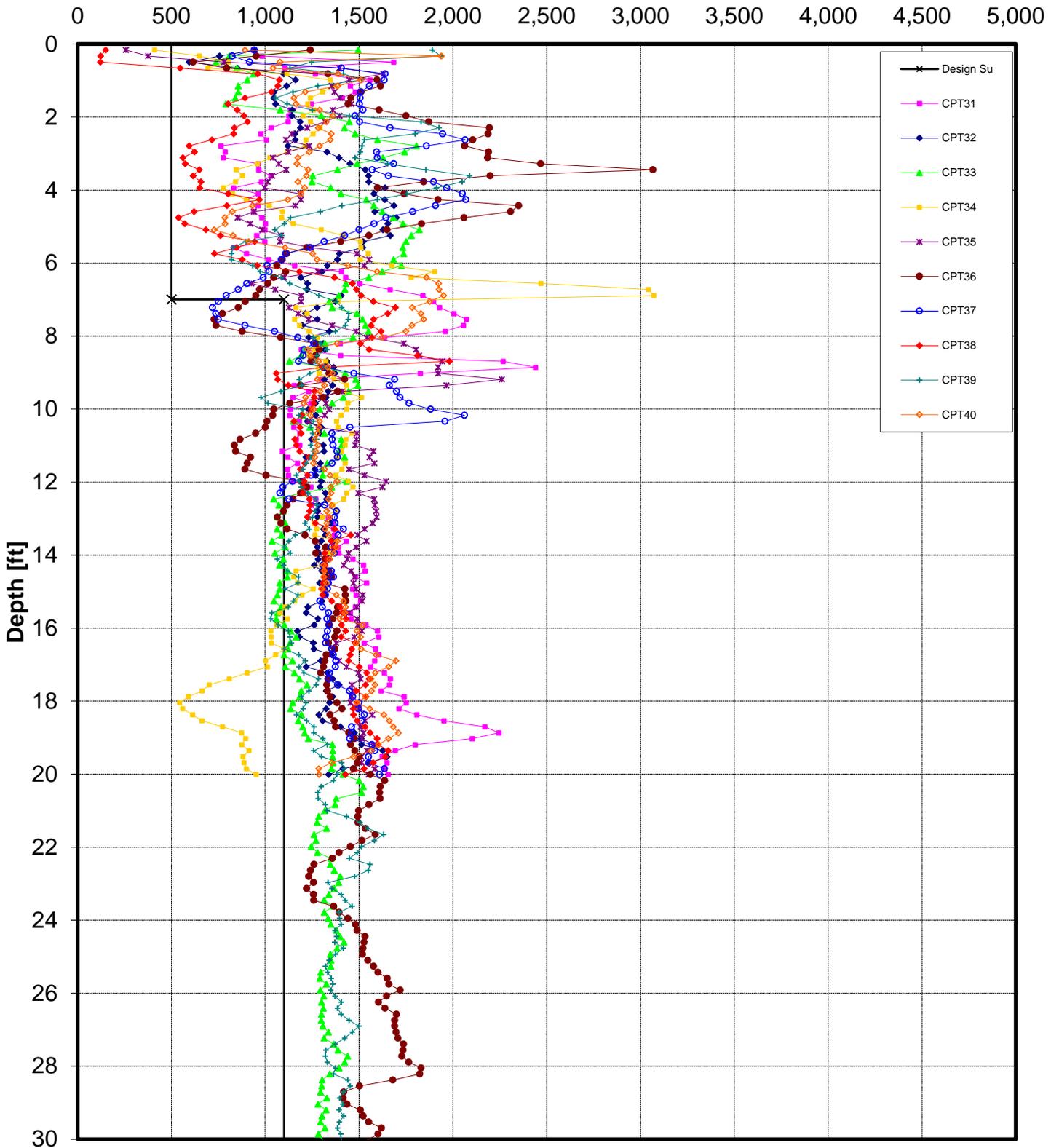


Figure 13. Undrained Shear Strength from CPT vs. Depth Soundings 31 to 40

Undrained Shear Strength, S_u [psf]

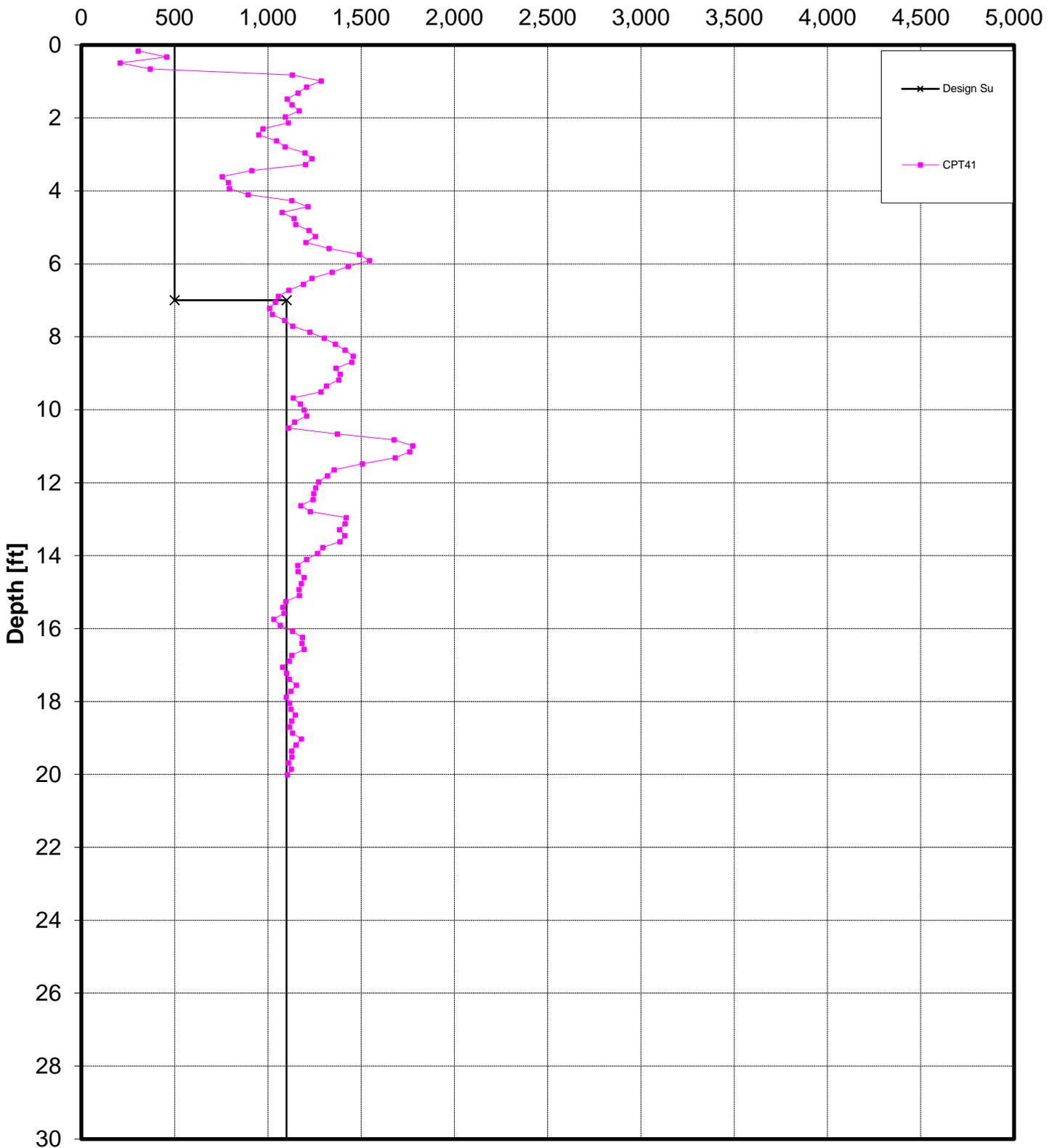
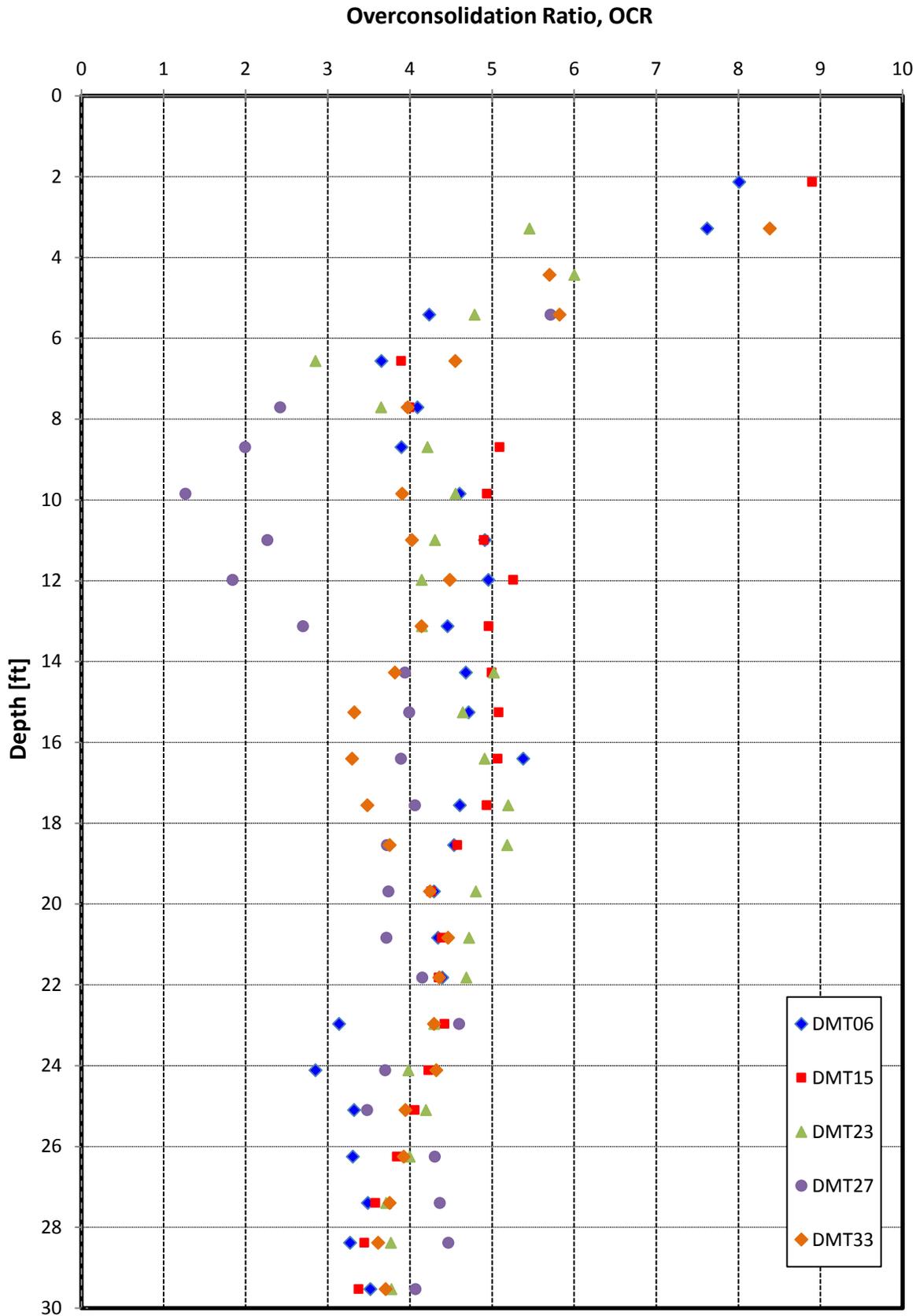
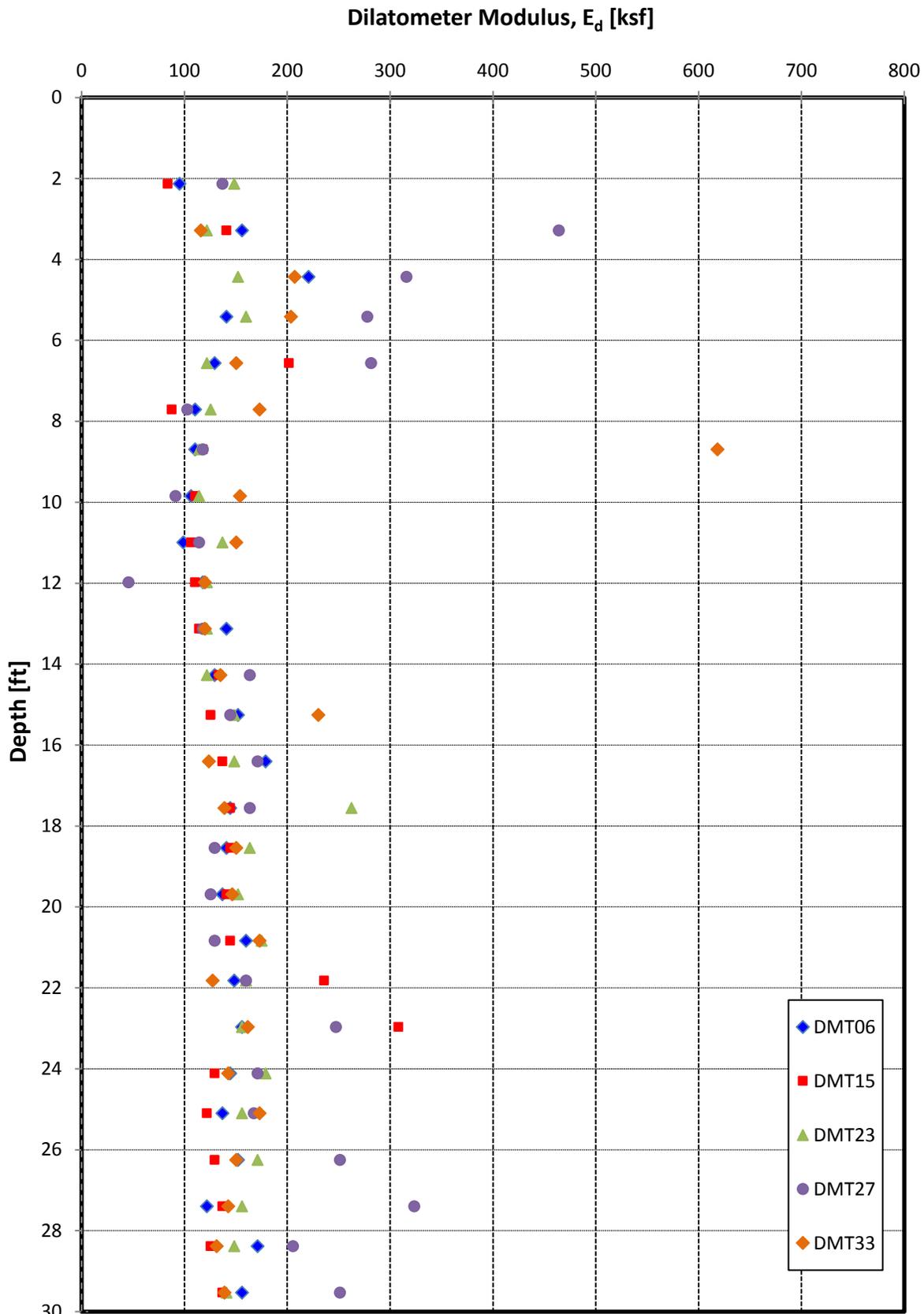


Figure 14. Undrained Shear Strength from CPT vs. Depth Sounding 41



**Figure 15. Overconsolidation Ratio from DMT vs. Depth
(Marchetti et al, 2001)**



**Figure 16. Dilatometer Modulus from DMT vs. Depth
(Marchetti et al, 2001)**

Appendix A

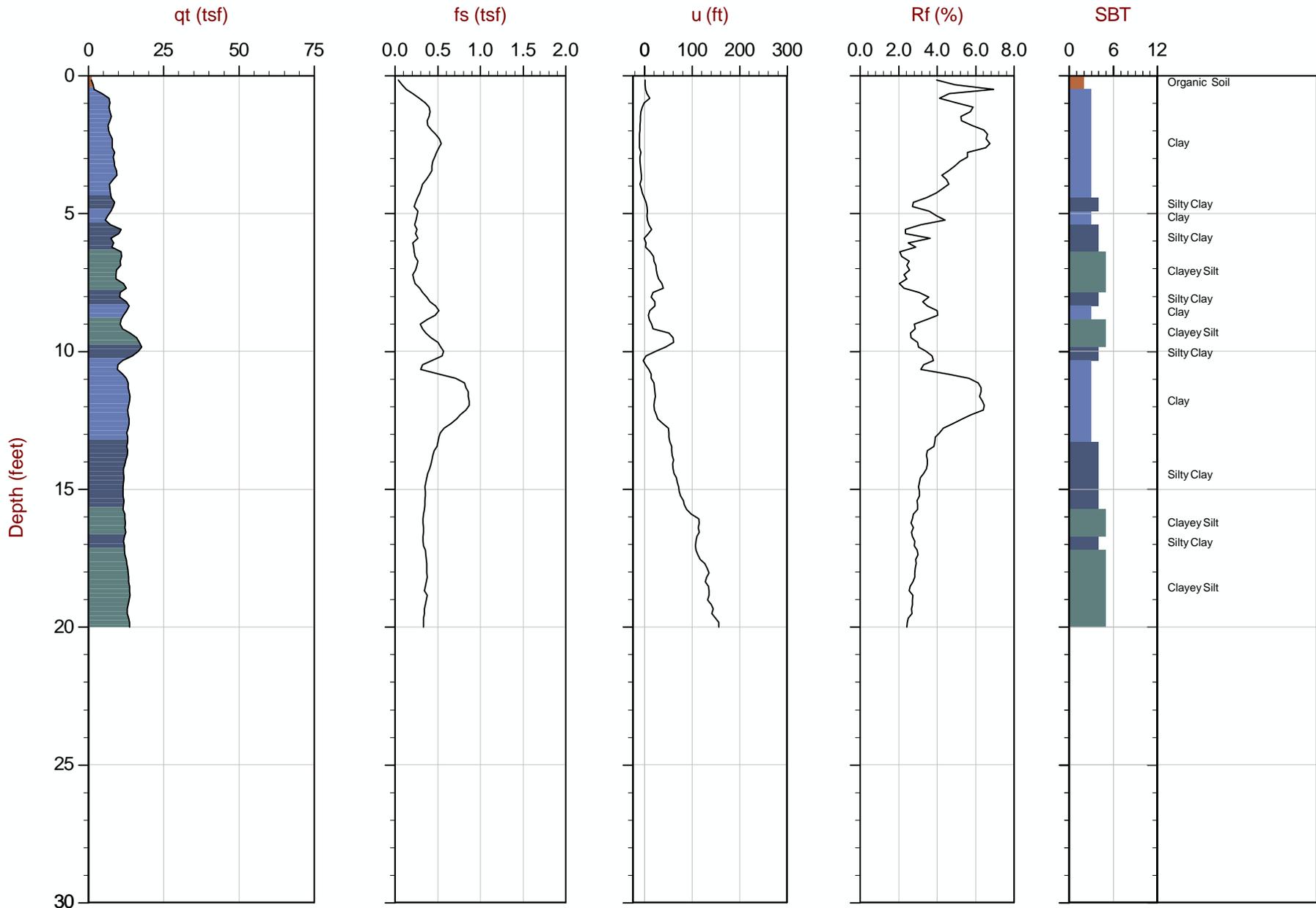
Site Coordinates and Investigation Summary

**Appendix A
Site Coordinates and Investigation Summary**

Location ID	UTM Zone 14N NAD83 [meters]		CPT Testing	DMT	Electrical Resistivity	Thermal Resistivity	Test Pit
	Easting	Northing					
CPT01	641988.9	5201015.8	X				
CPT02	642346.8	5201022.0	X				
CPT03	642764.8	5201022.0	X				
CPT04	643184.5	5201034.4	X				
CPT05	641988.9	5200614.1	X				
CPT06	642346.8	5200620.3	X	X			
CPT07	642764.8	5200620.3	X				
CPT08	643184.5	5200632.6	X				
CPT09	641988.9	5200212.4	X				
CPT10	642346.8	5200218.6	X				
CPT11	642764.8	5200218.6	X				
CPT12	643184.5	5200230.9	X				
CPT13	641983.7	5199790.0	X				
CPT14	642341.7	5199796.1	X				
CPT15	642759.6	5199796.1	X	X			
CPT16	643563.5	5202646.2	X				
CPT17	643964.7	5202658.6	X				
CPT18	644402.9	5202670.9	X				
CPT19	644791.7	5202689.4	X				
CPT20	645211.4	5202695.6	X				
CPT21	645594.1	5202707.9	X				
CPT22	645995.2	5202707.9	X				
CPT23	646433.5	5202732.6	X	X			
CPT24	643563.5	5202249.4	X				
CPT25	643964.7	5202261.7	X				
CPT26	644402.9	5202274.1	X				
CPT27	644791.7	5202292.6	X	X			
CPT28	645211.4	5202314.3	X				
CPT29	645594.1	5202326.6	X				
CPT30	645995.2	5202326.6	X				
CPT31	646433.5	5202351.3	X				
CPT32	643563.5	5201780.0	X				
CPT33	643964.7	5201792.4	X	X			
CPT34	644402.9	5201804.7	X				
CPT35	644791.7	5201823.2	X				
CPT36	645211.4	5201870.8	X				
CPT37	645594.1	5201883.2	X				
CPT38	645995.2	5201857.3	X				
CPT39	646433.5	5201882.0	X		X		
CPT40	645206.2	5201458.5	X				
CPT41	645588.9	5201470.8	X				
TP01	641808.4	5199996.8			X	X	X
TP02	642907.5	5201218.6			X		X
TP03	644653.2	5202863.7			X	X	X
TP04	645420.4	5201296.1					X
TP05	646611.2	5202495.4				X	X

Appendix B

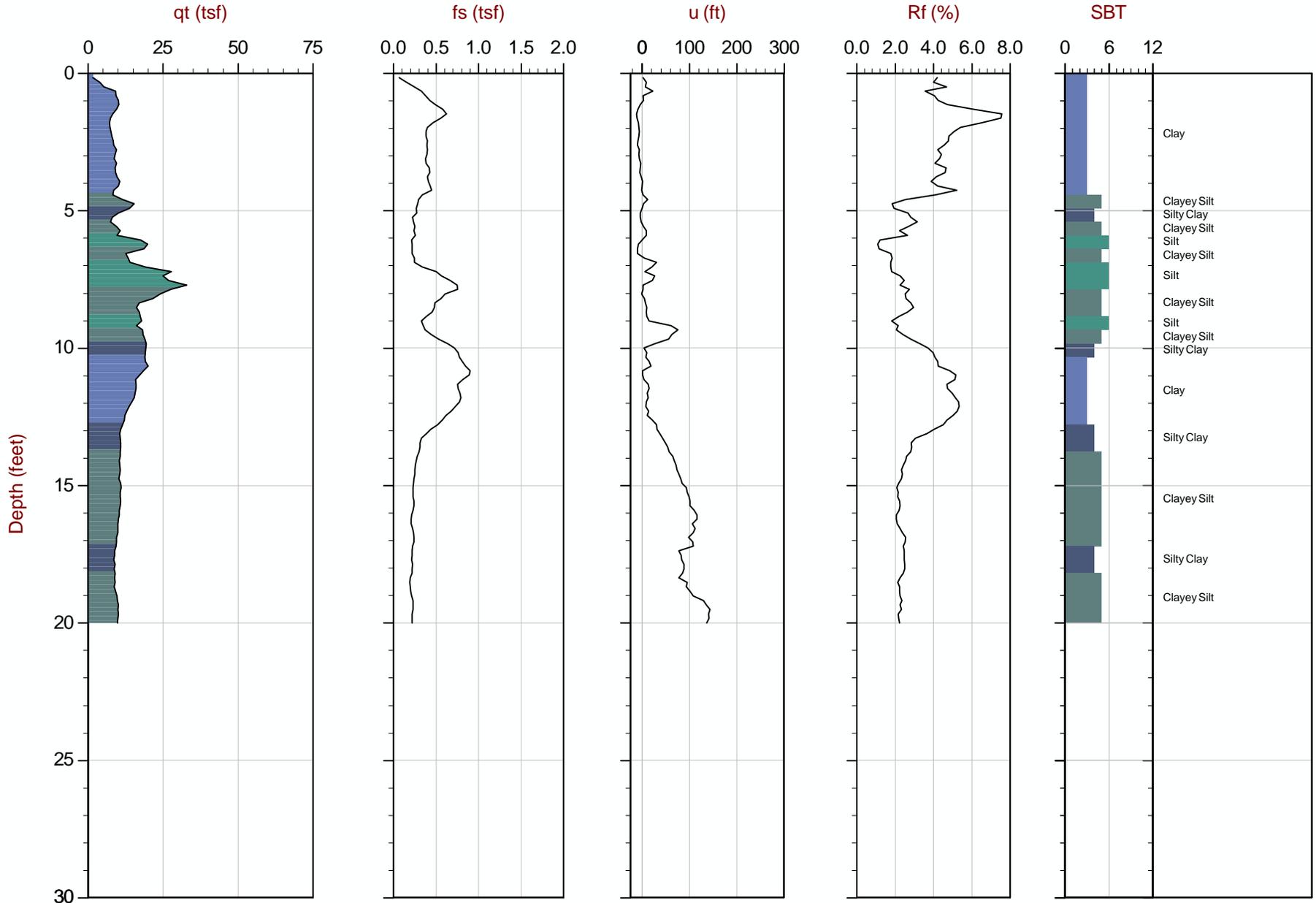
CPT Sounding Logs



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP01.COR
Unit Wt: SBT Zones

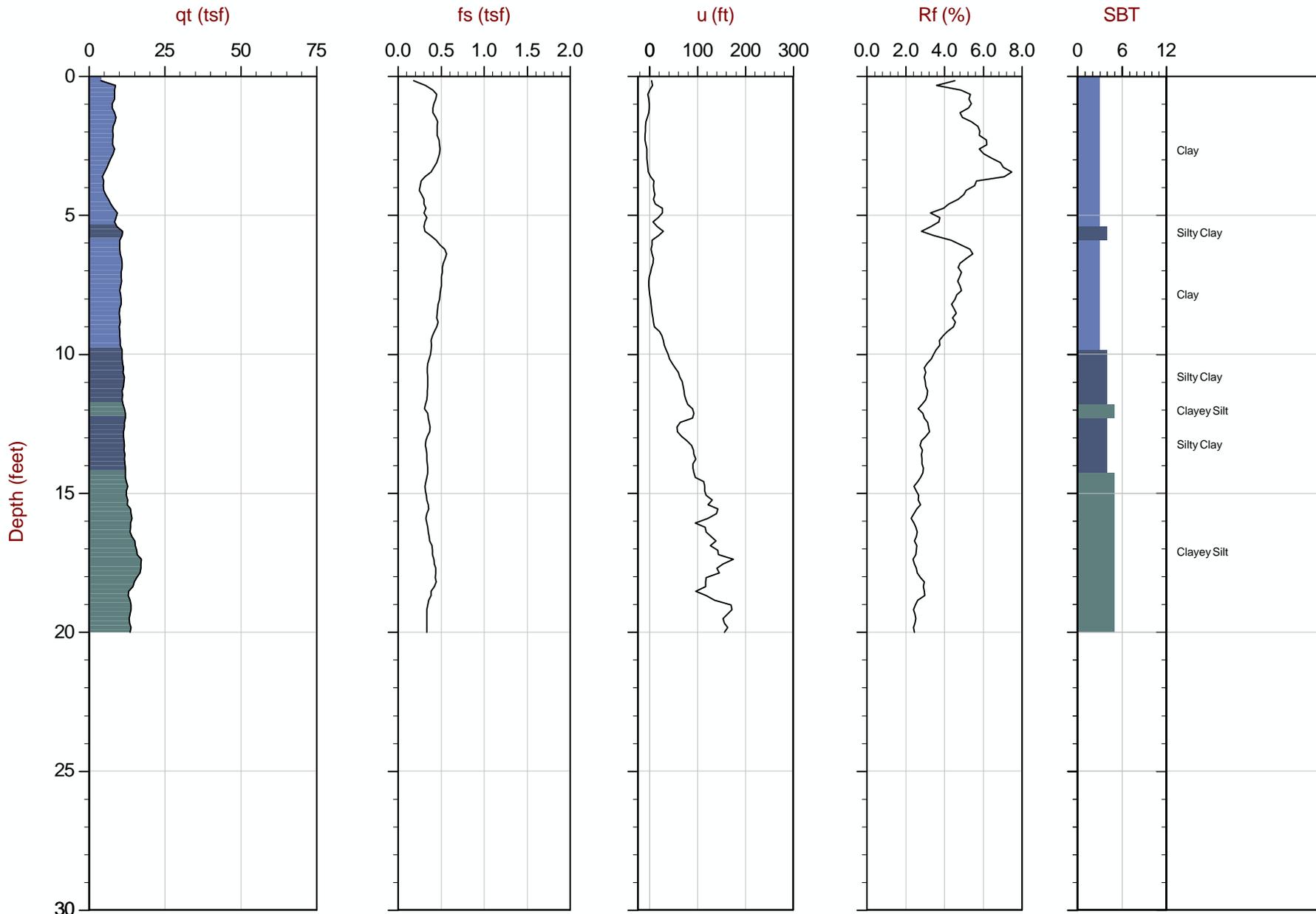
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Coords: Lat: 46.947477 Long: -97.134156
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP02.COR
Unit Wt: SBT Zones

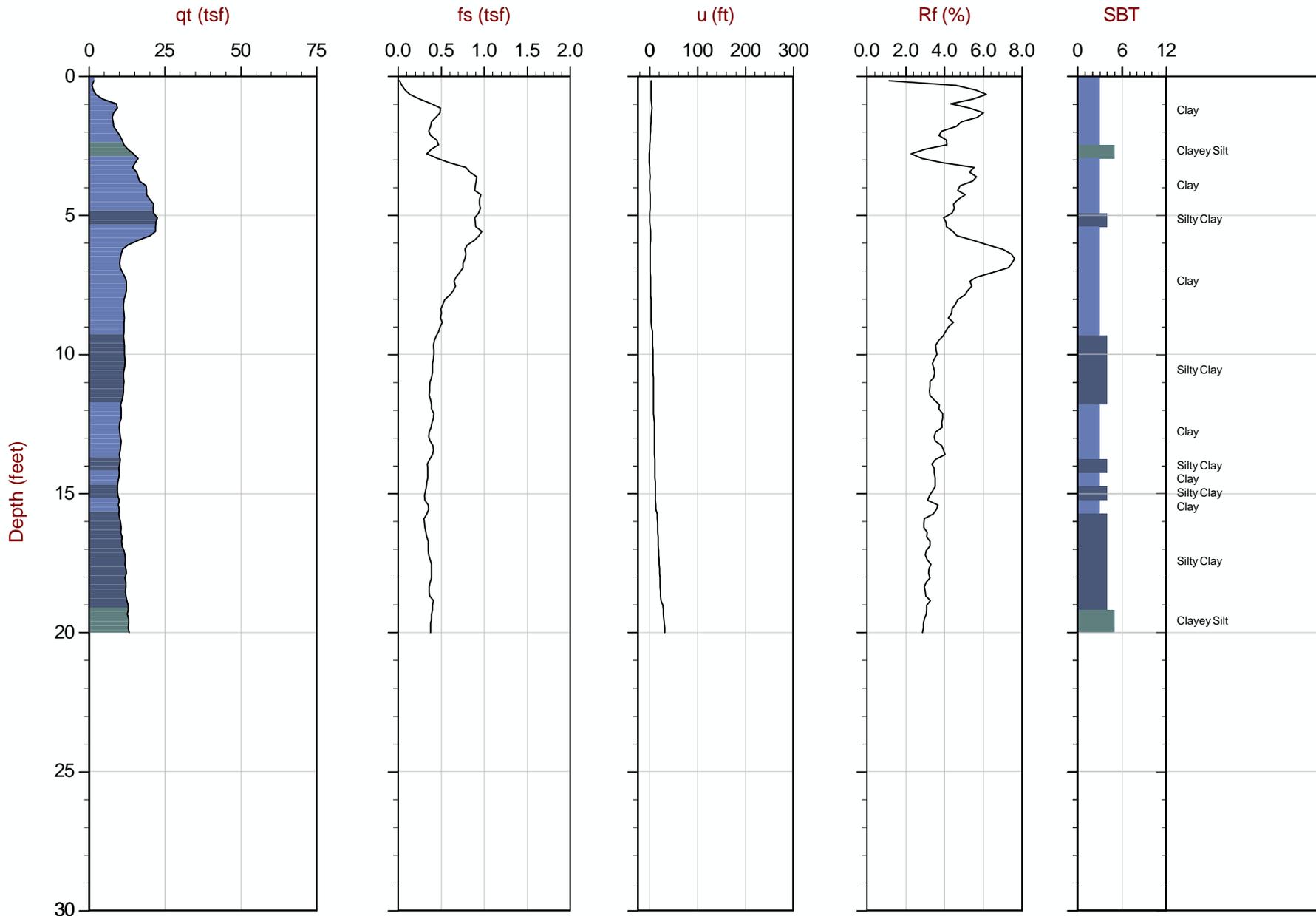
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Coords: Lat: 46.947489 Long: -97.129446
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP03.COR
Unit Wt: SBT Zones

SBT: Robertson and Campanella, 1986
Coords: Lat: 46.947408 Long: -97.123986
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP04.COR
Unit Wt: SBT Zones

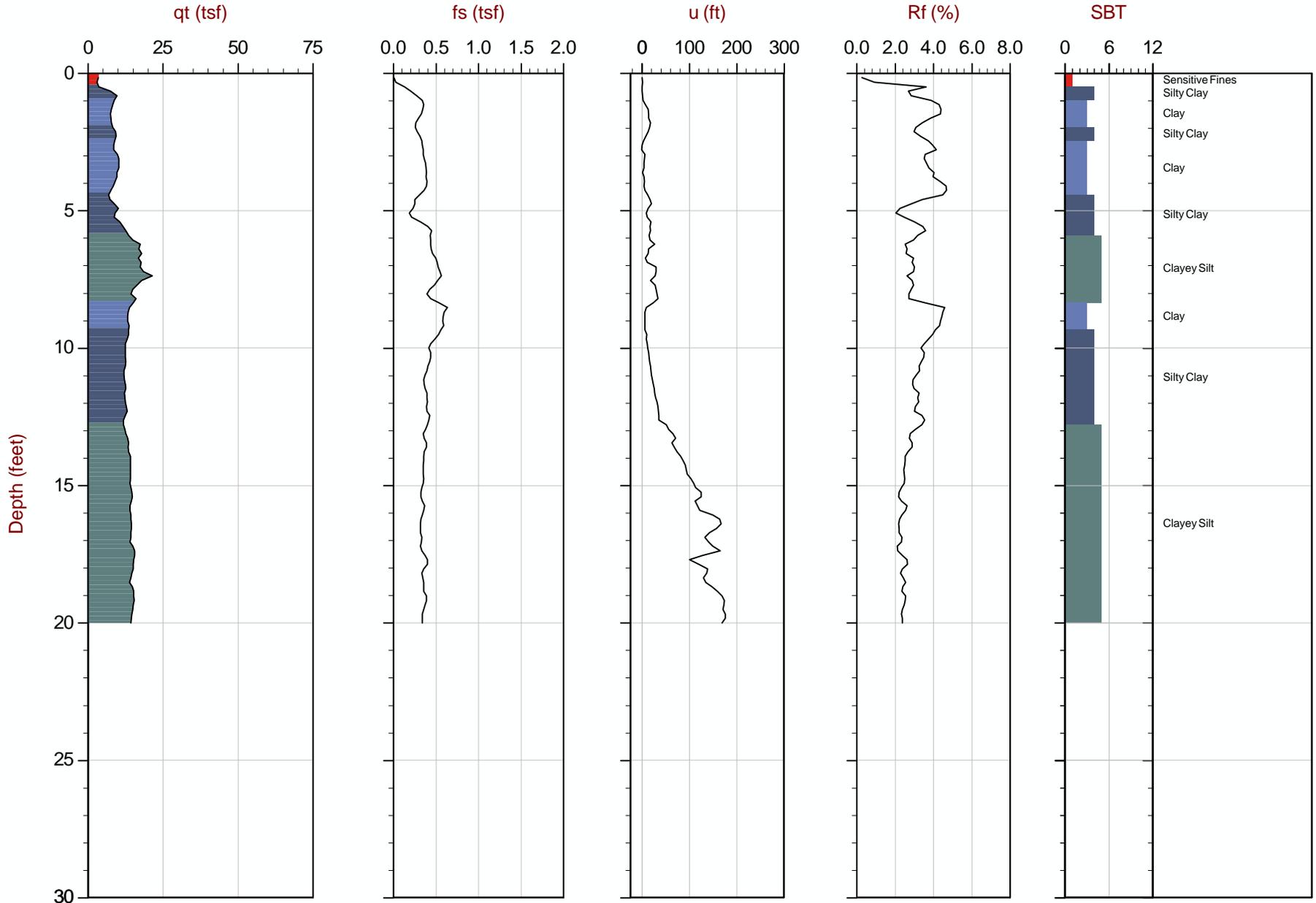
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Coords: Lat: 46.947415 Long: -97.118421
● Equilibrium Pore Pressure from Dissipation



Barr Engineering

Job No: 16-52112
Date: 2016-12-06 11:22
Site: Harmony Solar Project

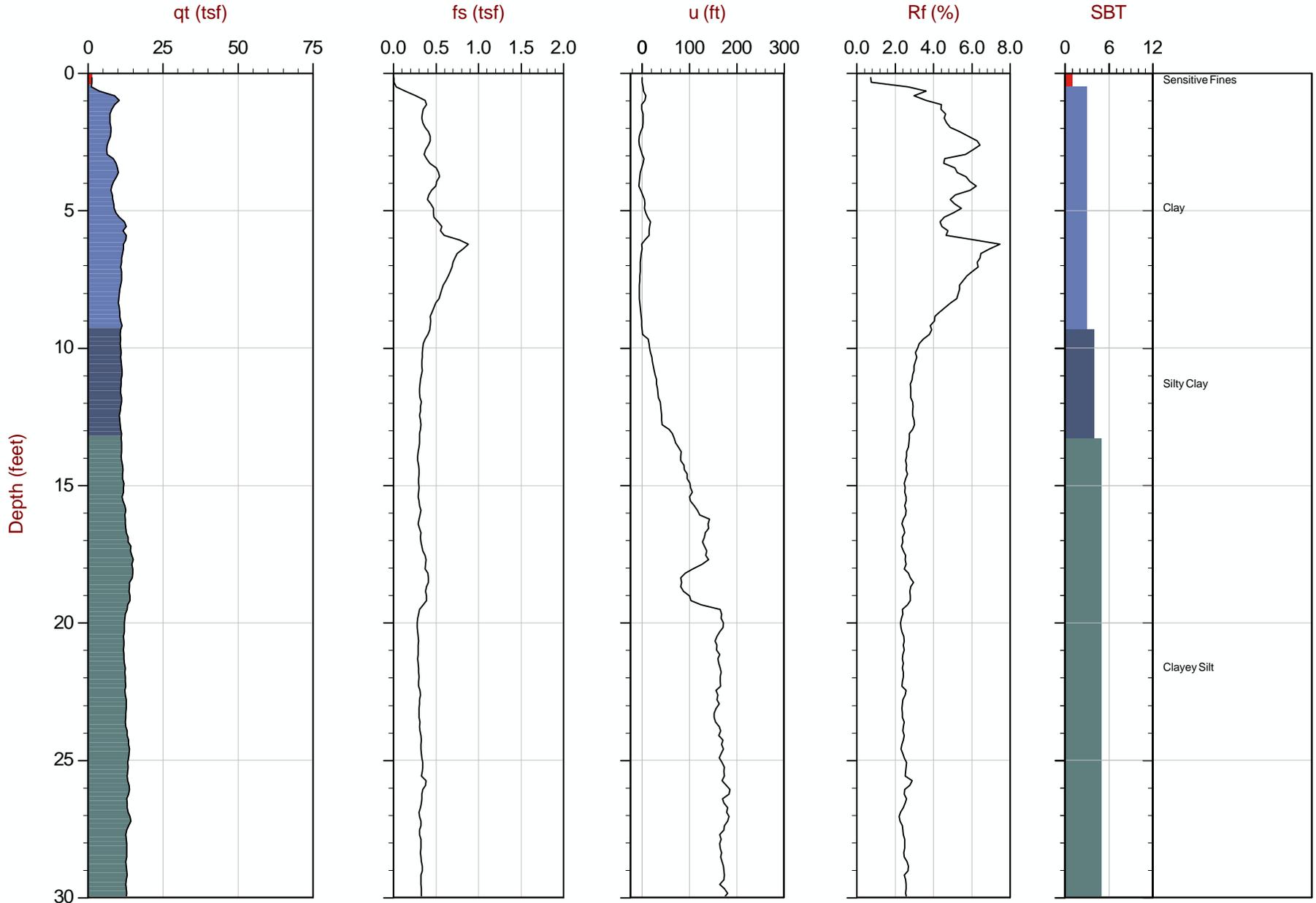
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Cone: 458:T1500F15U500



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

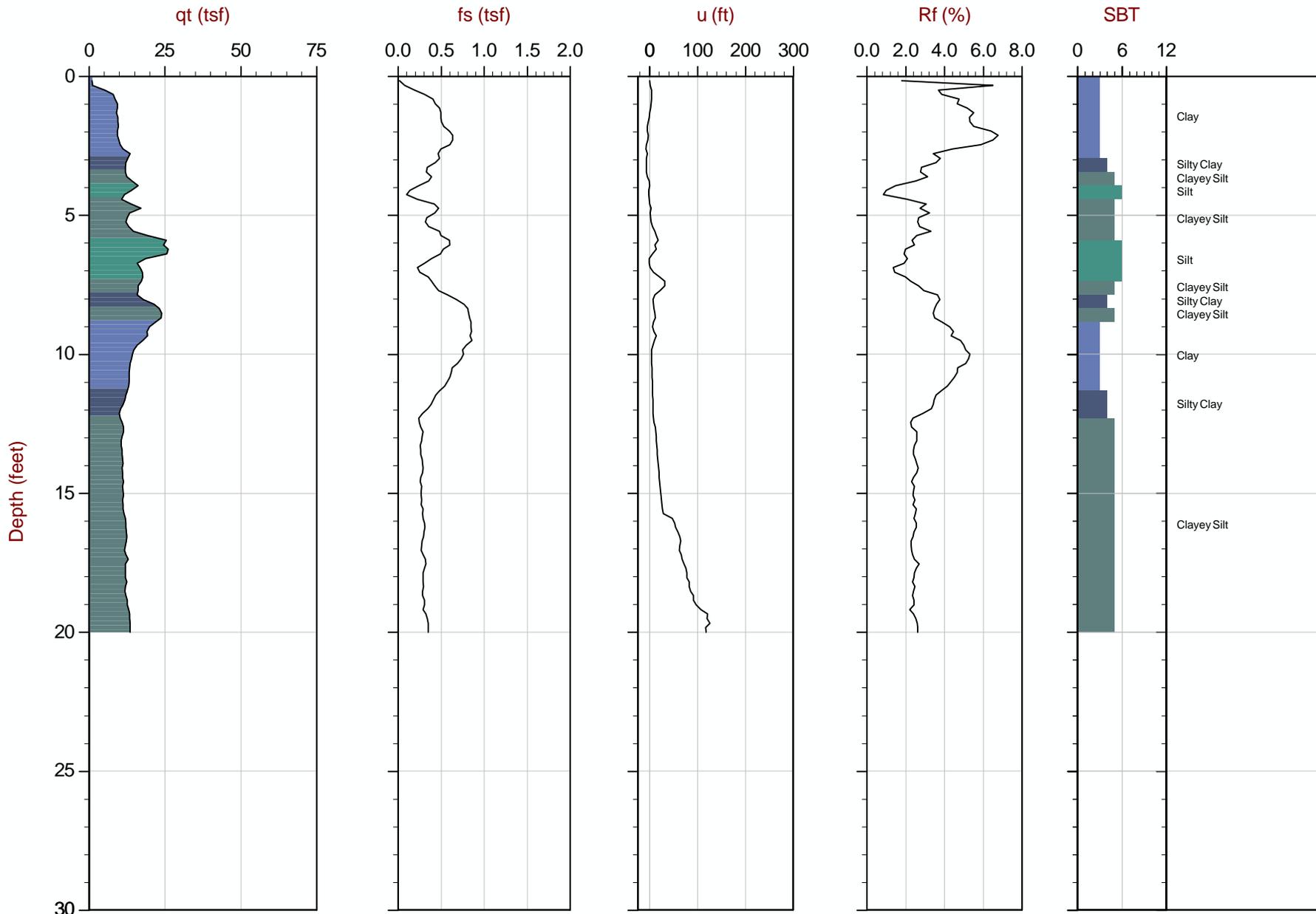
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Coords: Lat: 46.943832 Long: -97.134235
● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP06.COR
Unit Wt: SBT Zones

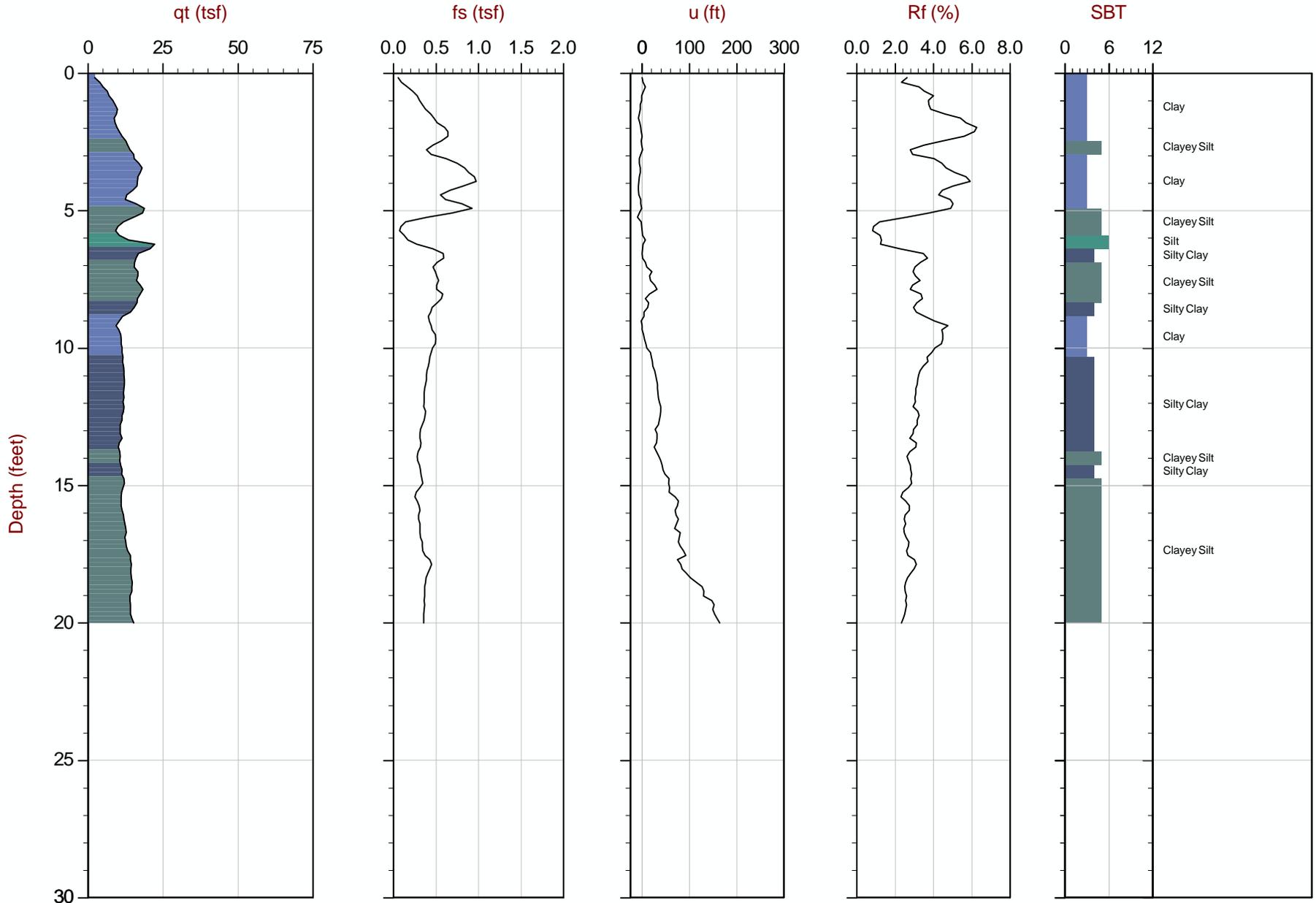
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Coords: Lat: 46.943794 Long: -97.129553
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP07.COR
Unit Wt: SBT Zones

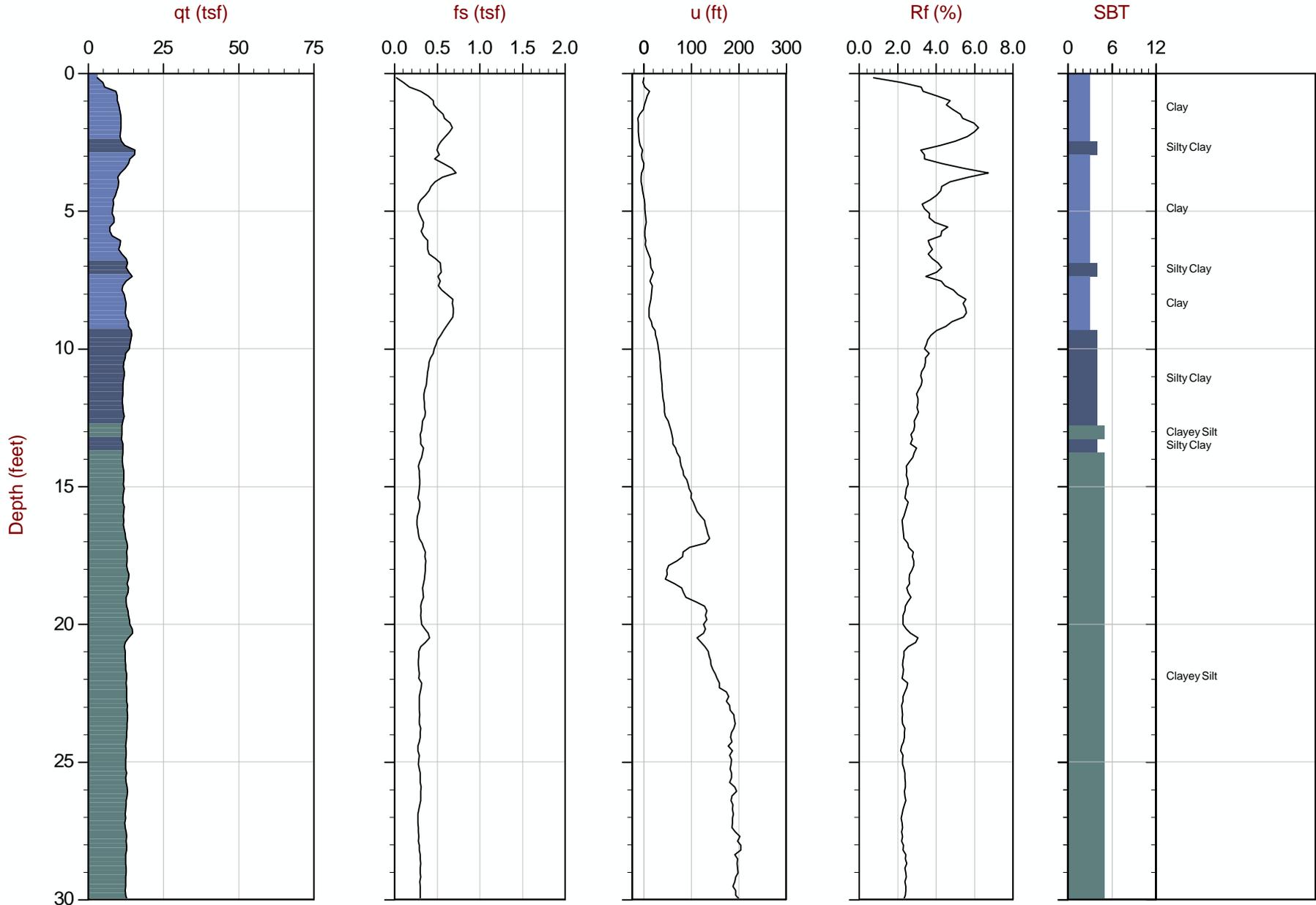
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Coords: Lat: 46.943720 Long: -97.124138
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP08.COR
Unit Wt: SBT Zones

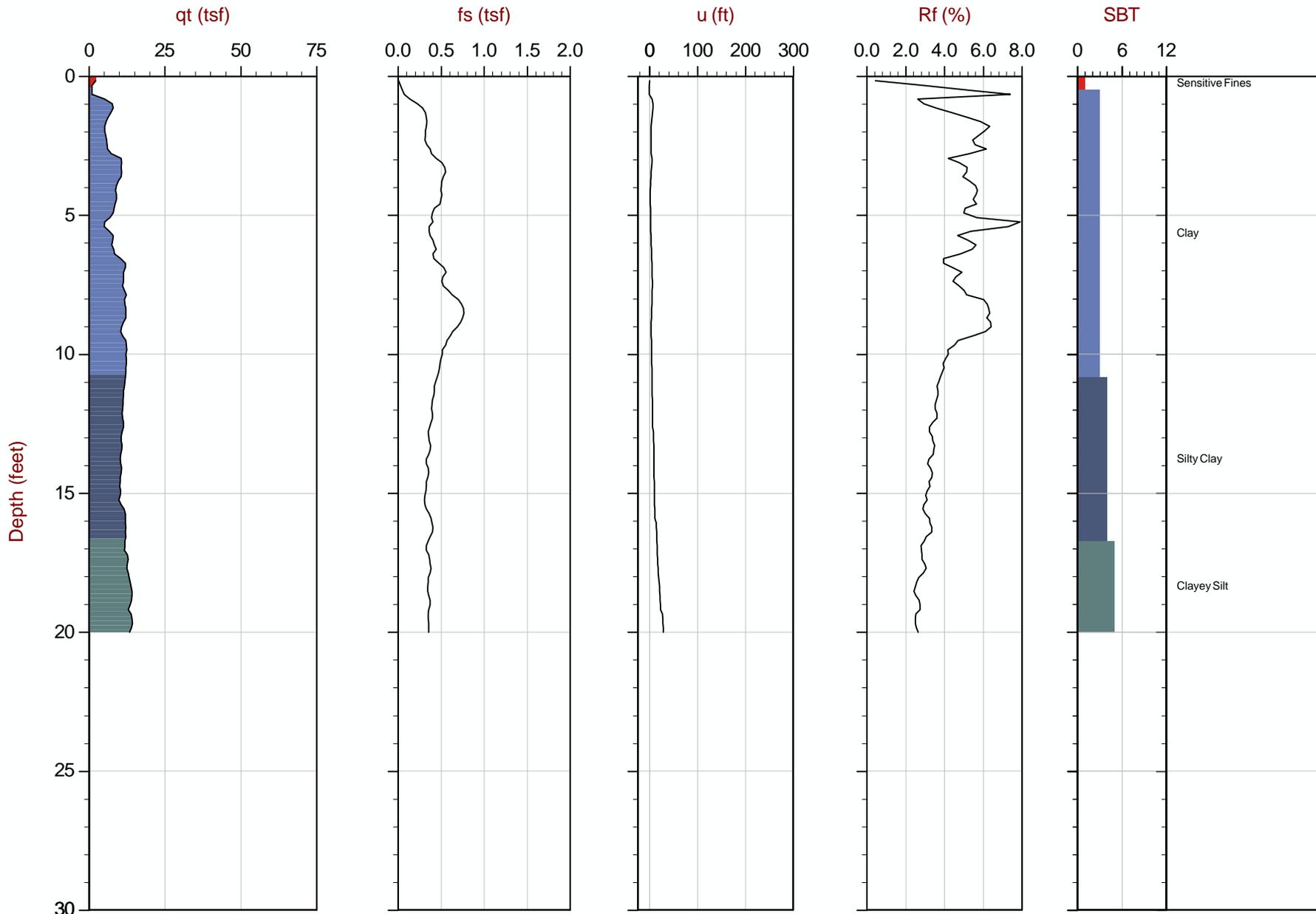
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● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP09.COR
Unit Wt: SBT Zones

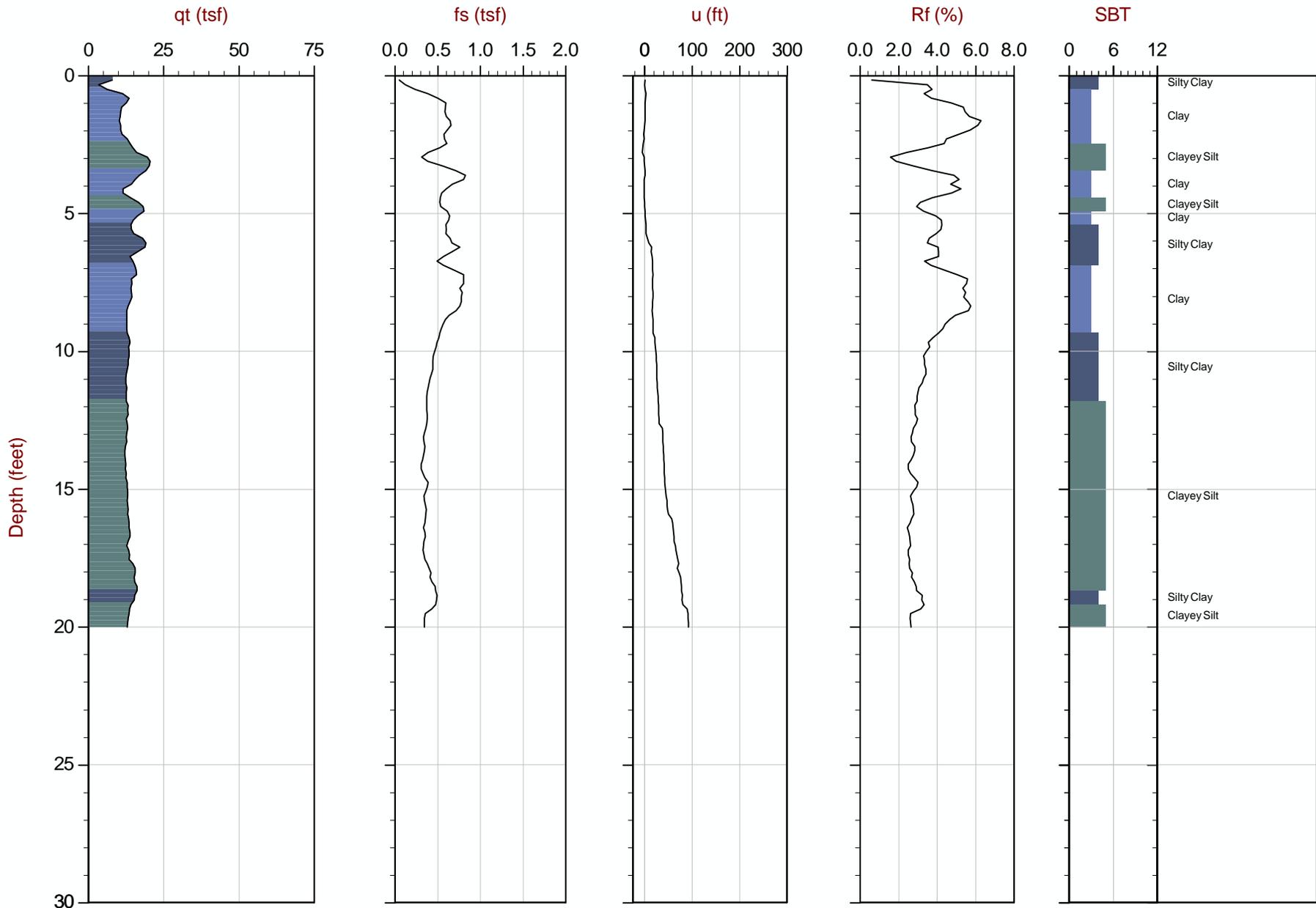
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Coords: Lat: 46.940285 Long: -97.134450
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP10.COR
Unit Wt: SBT Zones

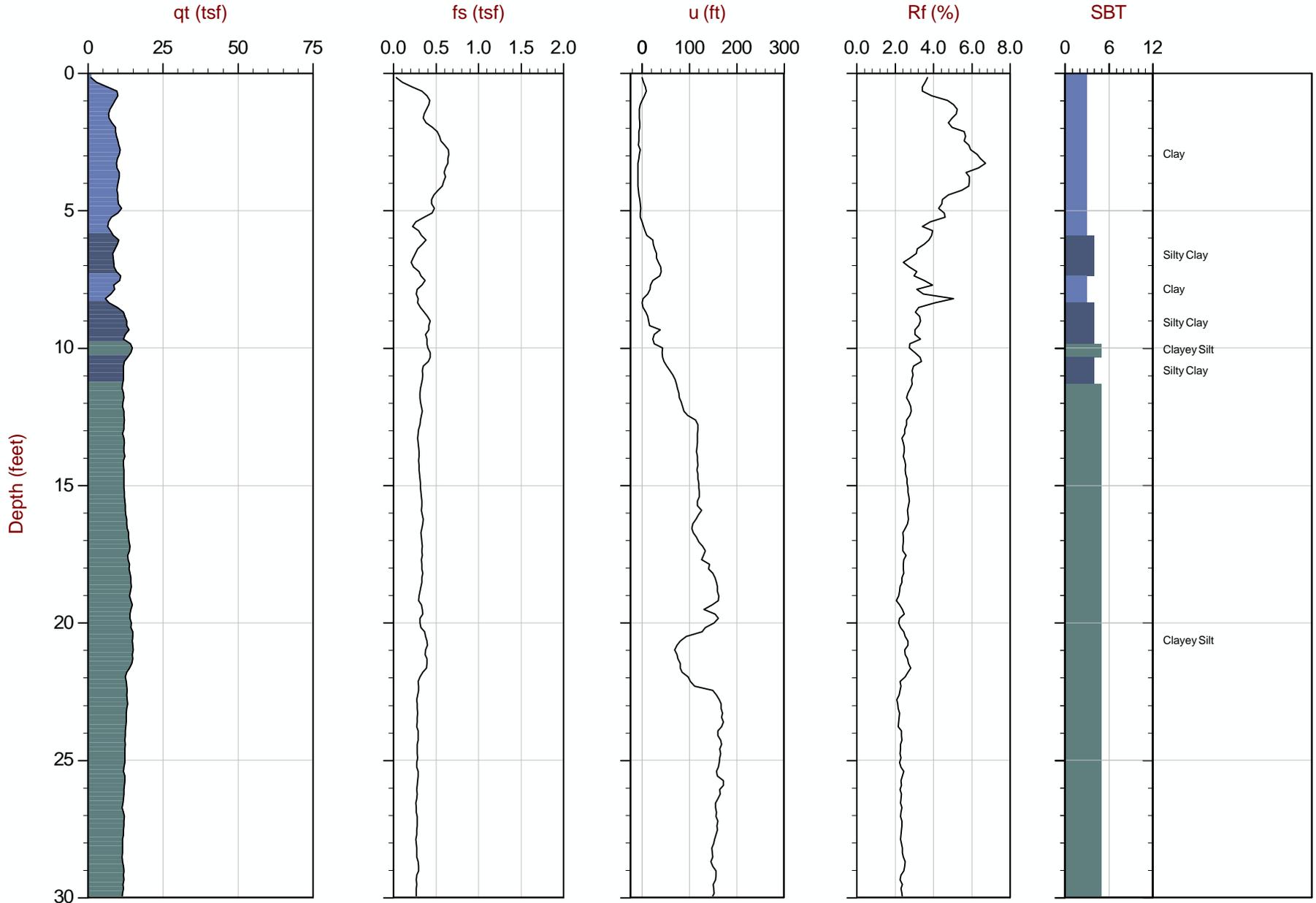
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Coords: Lat: 46.940256 Long: -97.129712
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP11.COR
Unit Wt: SBT Zones

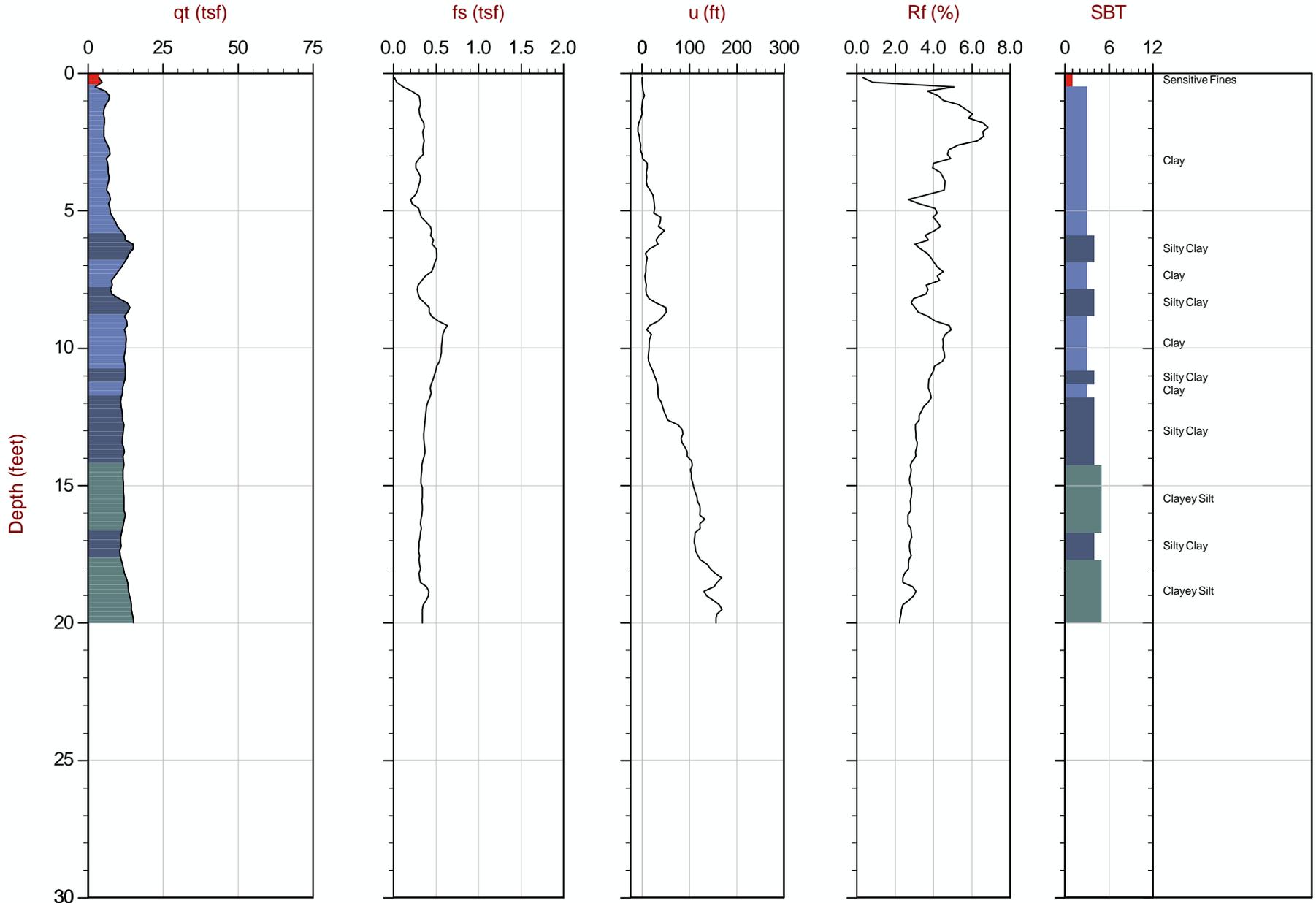
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Coords: Lat: 46.940159 Long: -97.124226
● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP12.COR
Unit Wt: SBT Zones

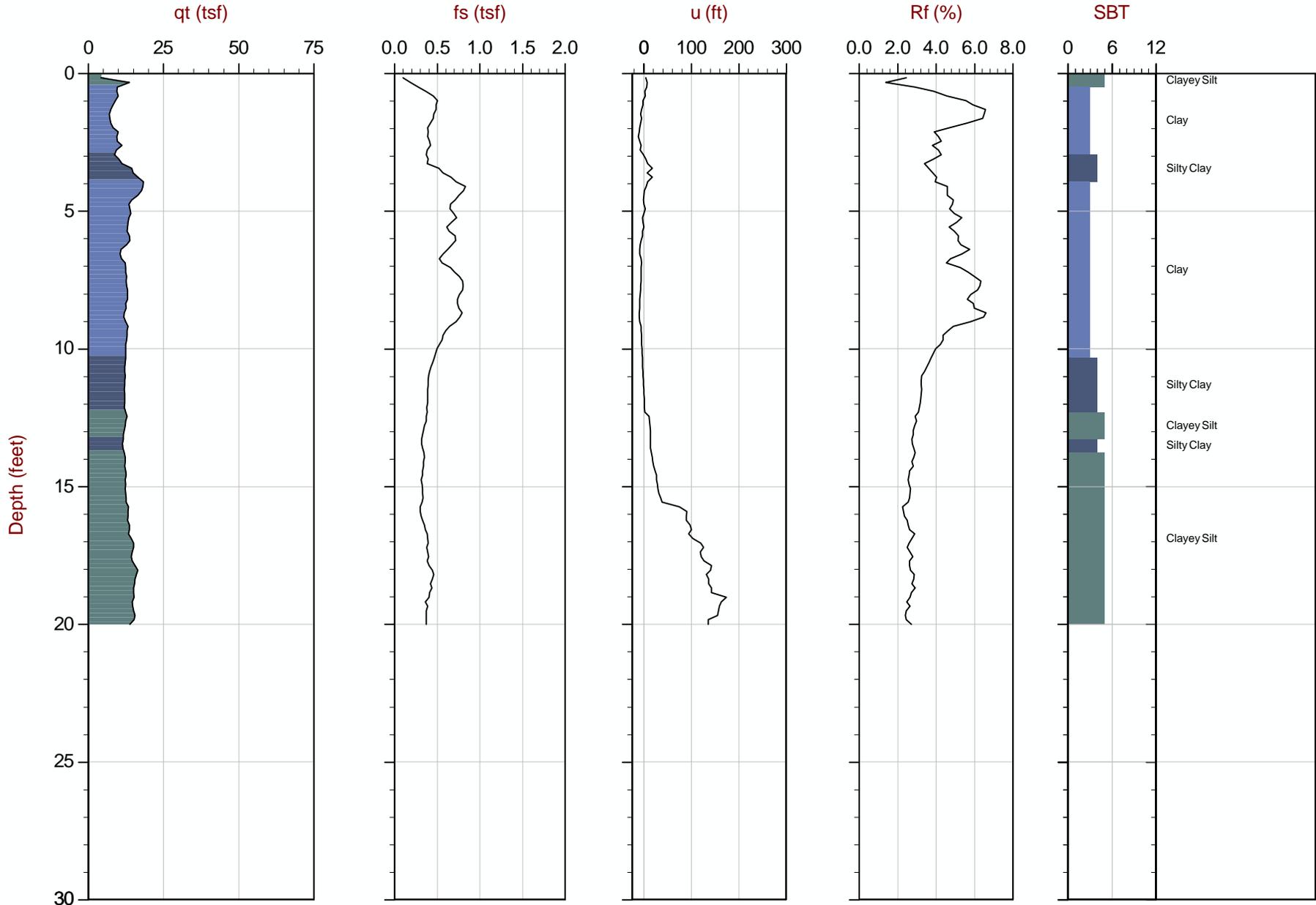
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Coords: Lat: 46.940183 Long: -97.118676
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

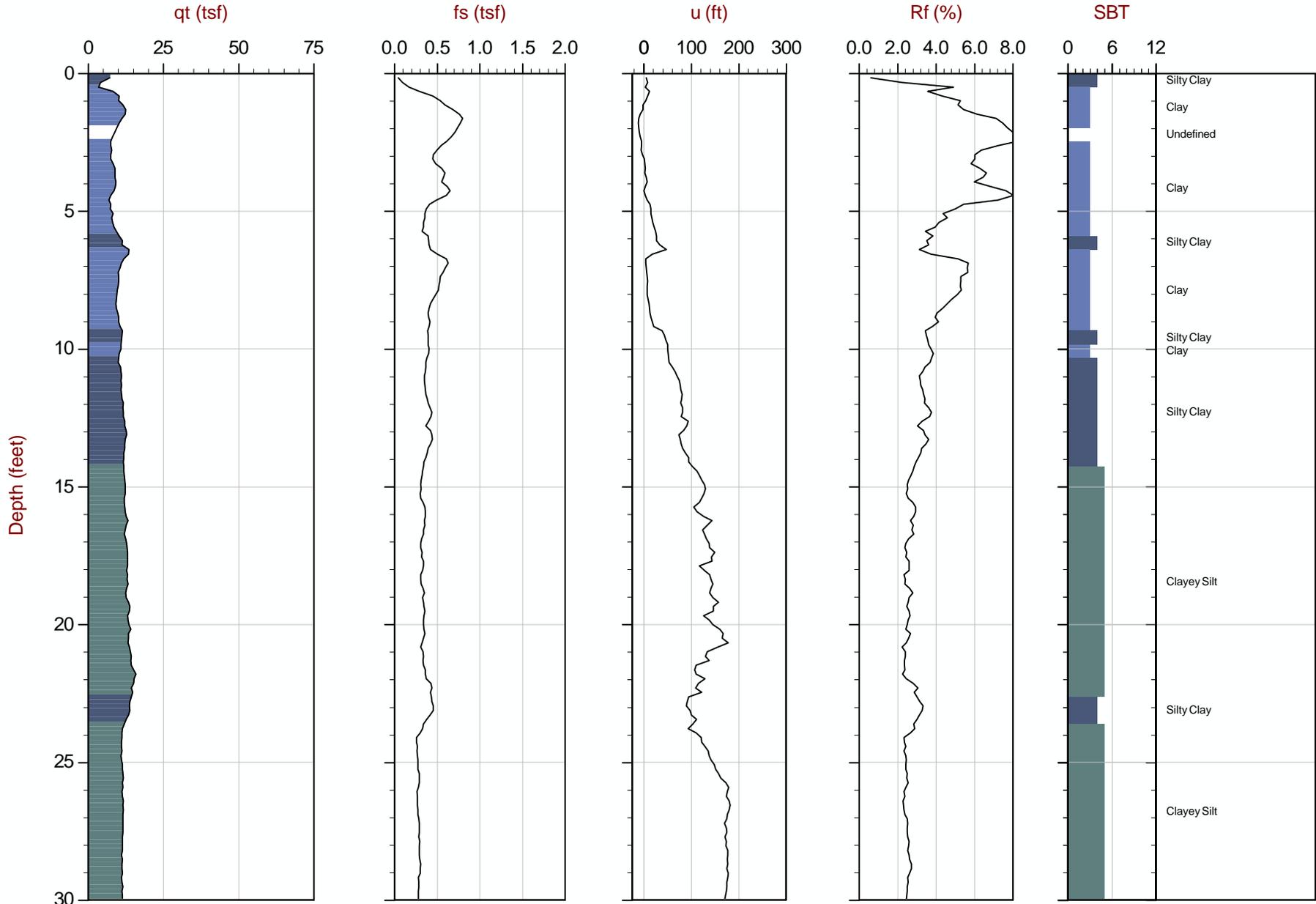
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Coords: Lat: 46.936438 Long: -97.134658
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP14.COR
Unit Wt: SBT Zones

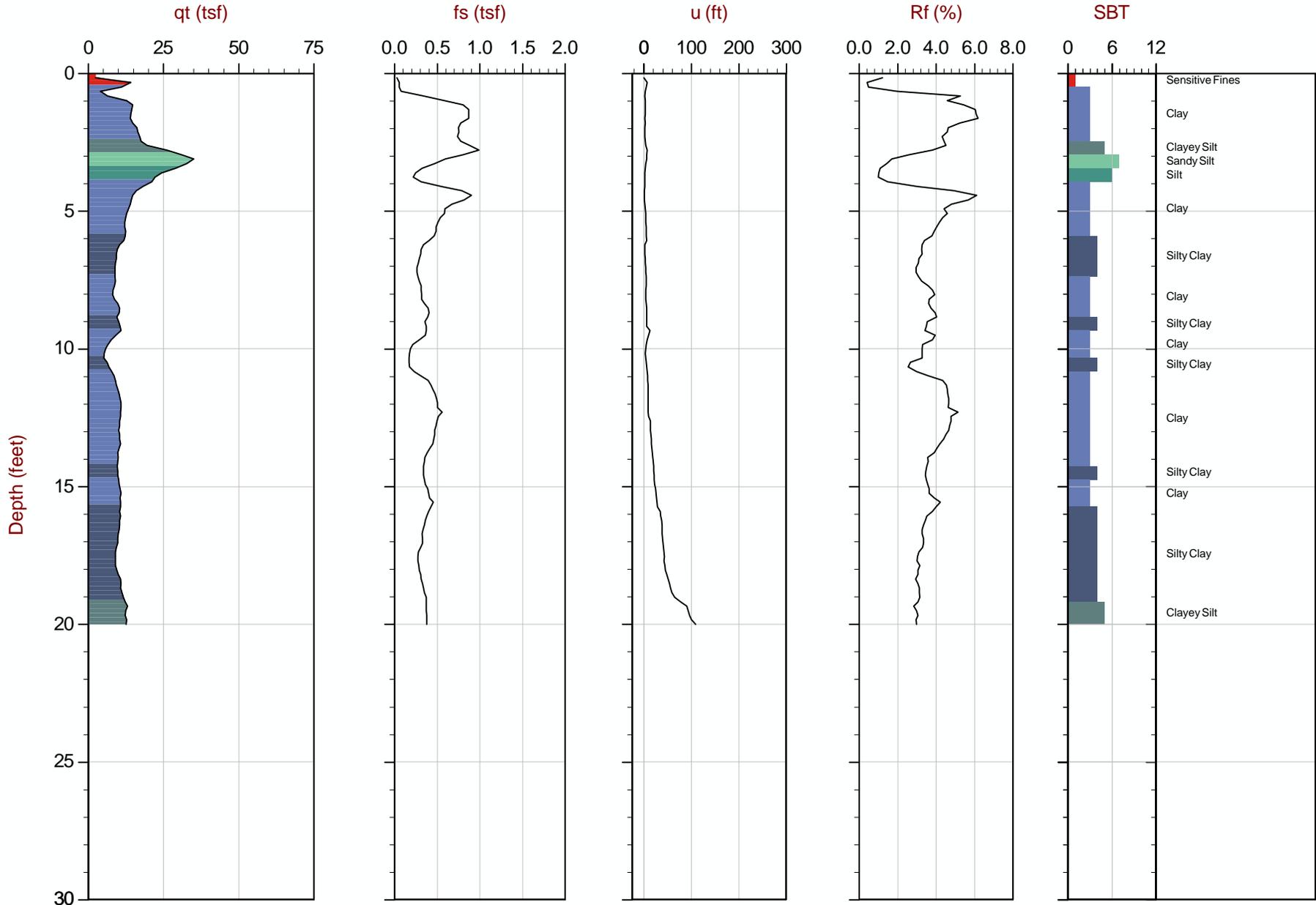
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Coords: Lat: 46.936349 Long: -97.129902
● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

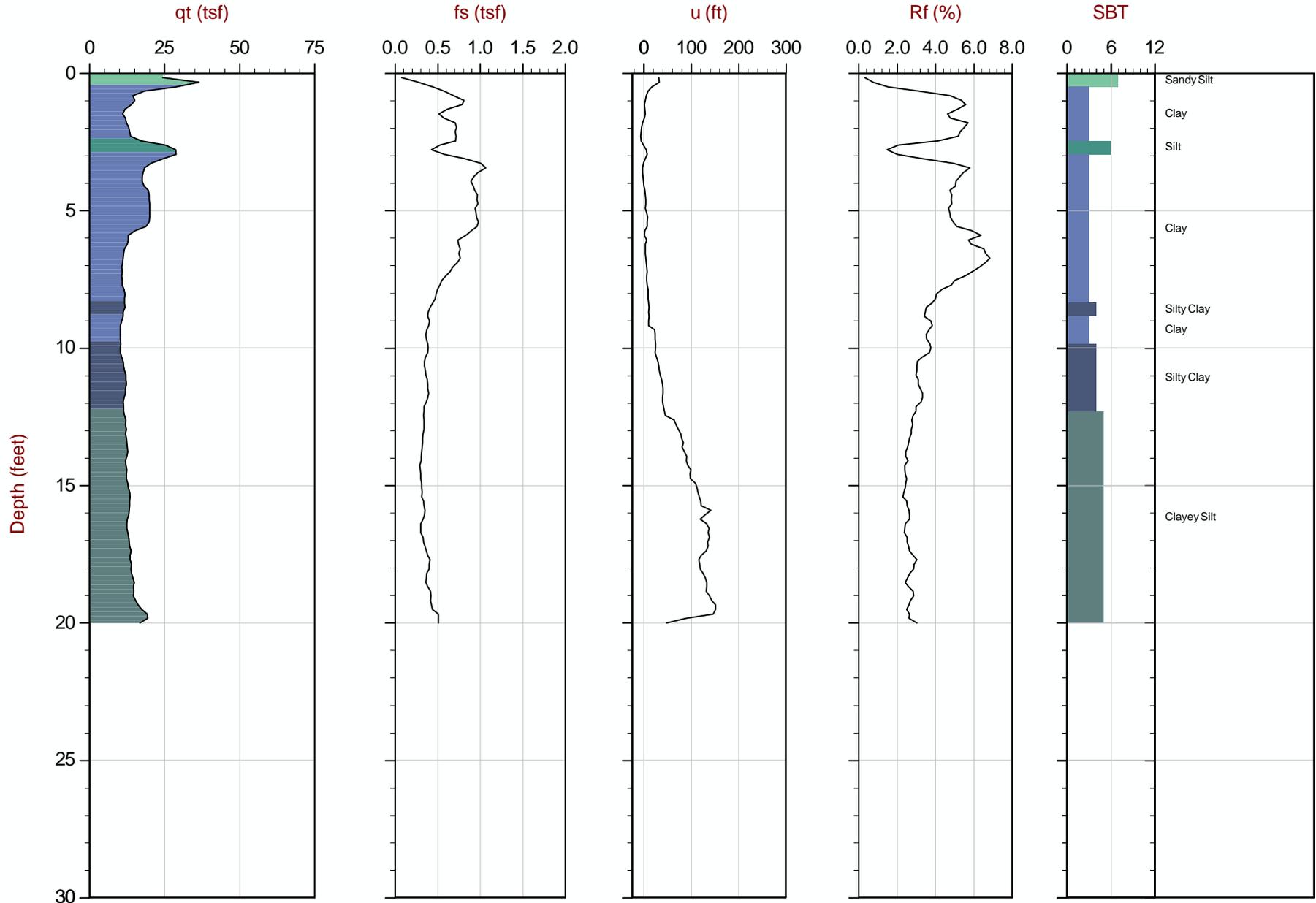
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Coords: Lat: 46.936325 Long: -97.124423
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP16.COR
Unit Wt: SBT Zones

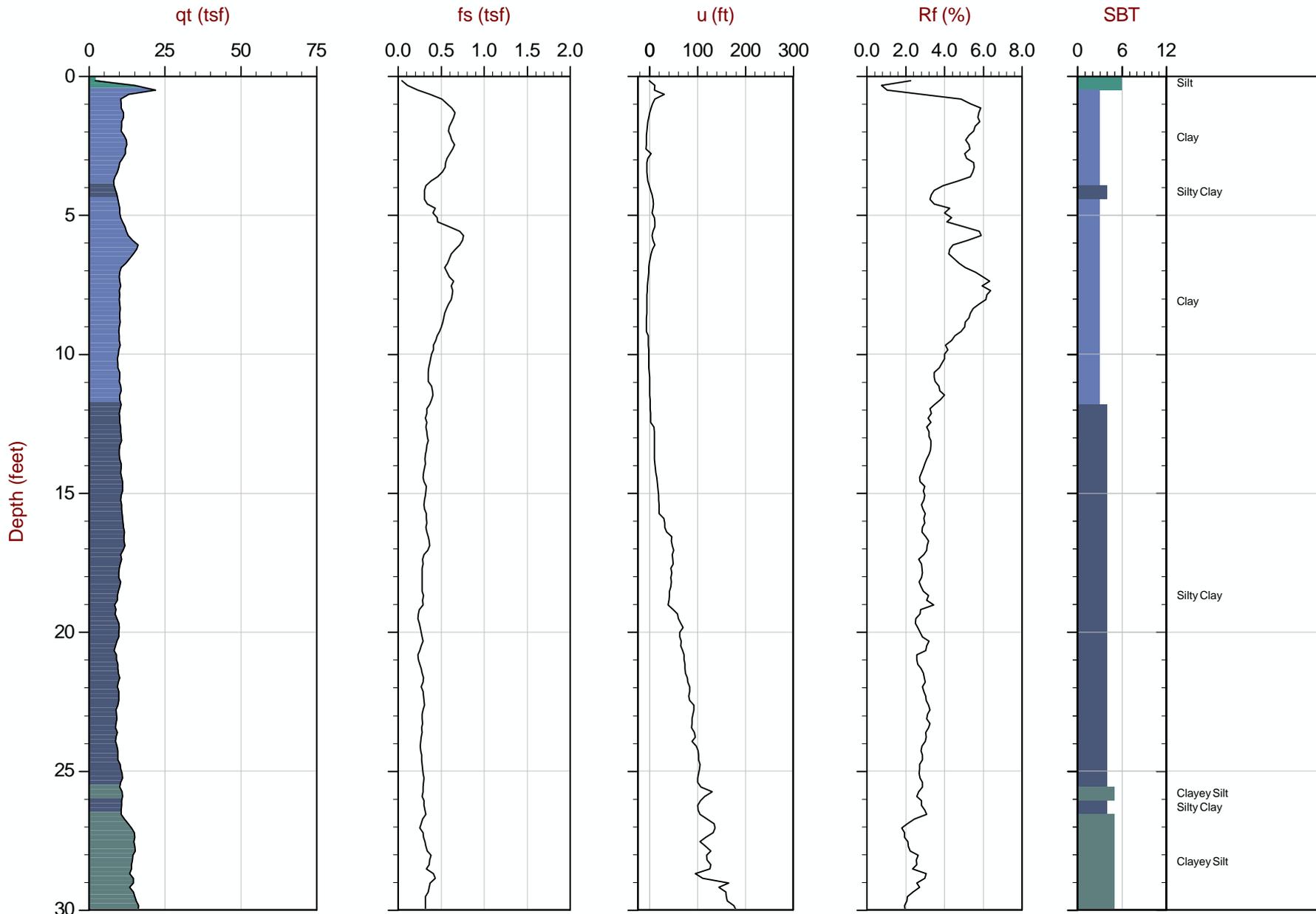
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Coords: Lat: 46.961785 Long: -97.112918
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP17.COR
Unit Wt: SBT Zones

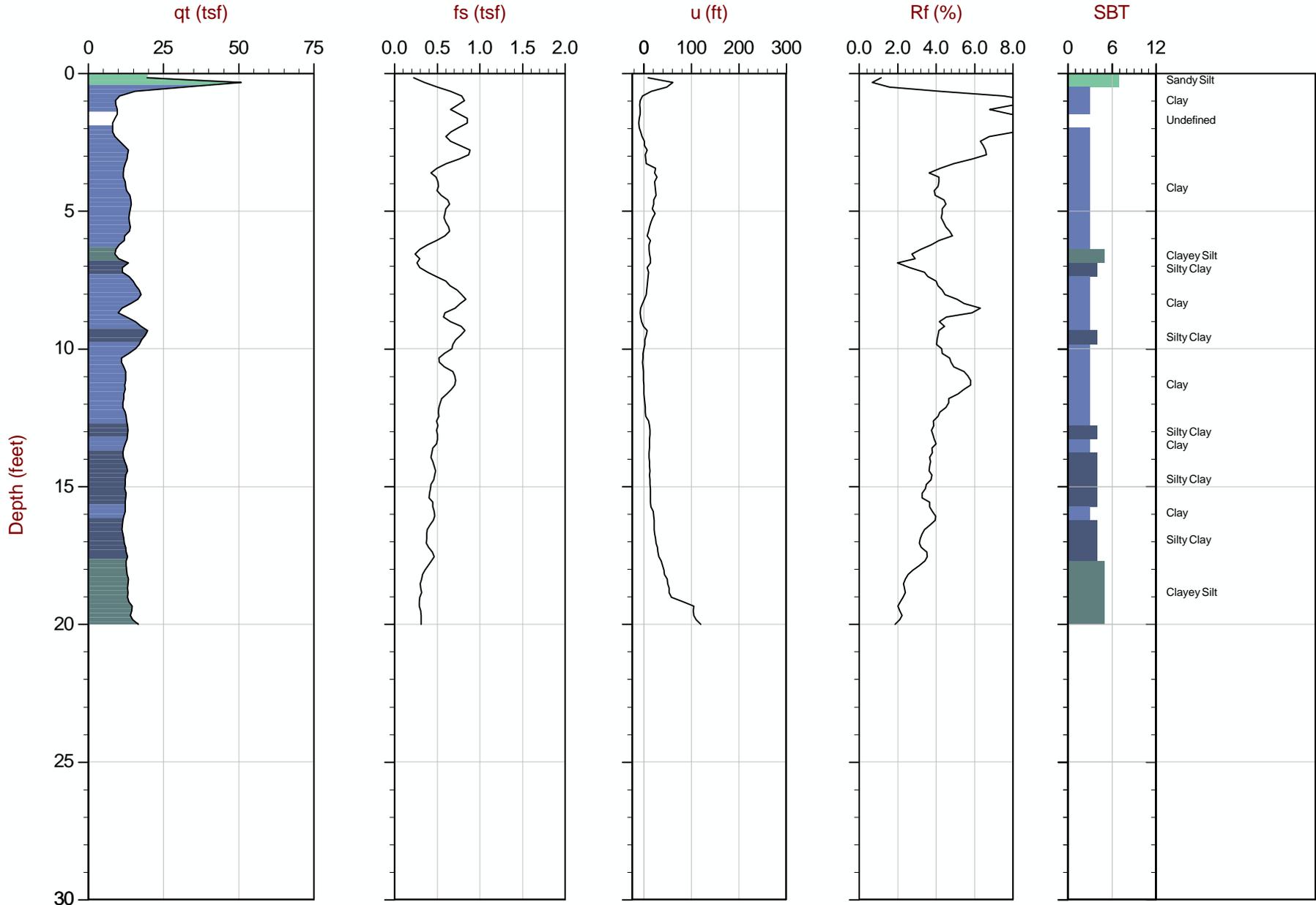
SBT: Robertson and Campanella, 1986
Coords: Lat: 46.961804 Long: -97.107563
● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

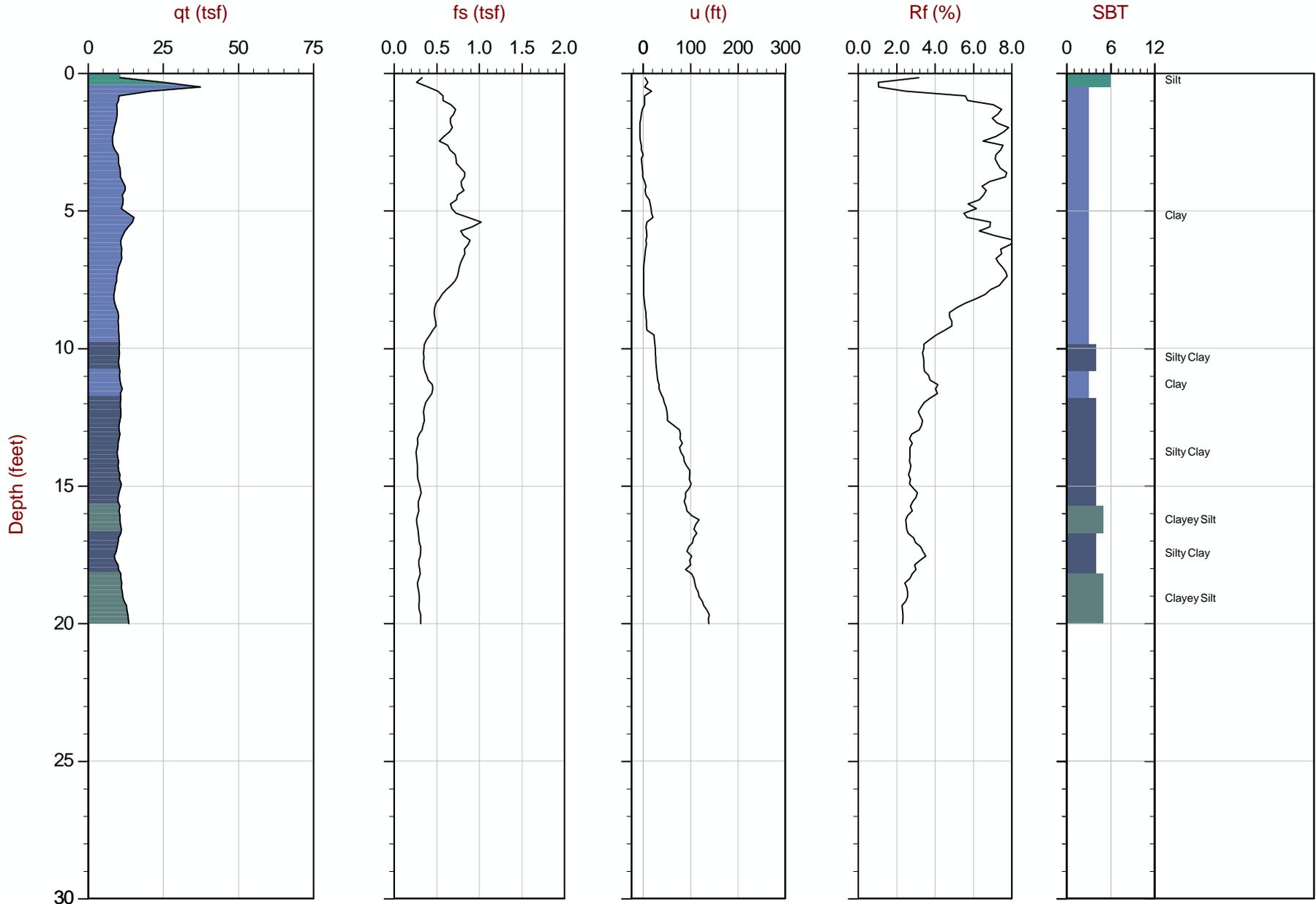
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Coords: Lat: 46.961778 Long: -97.101967
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

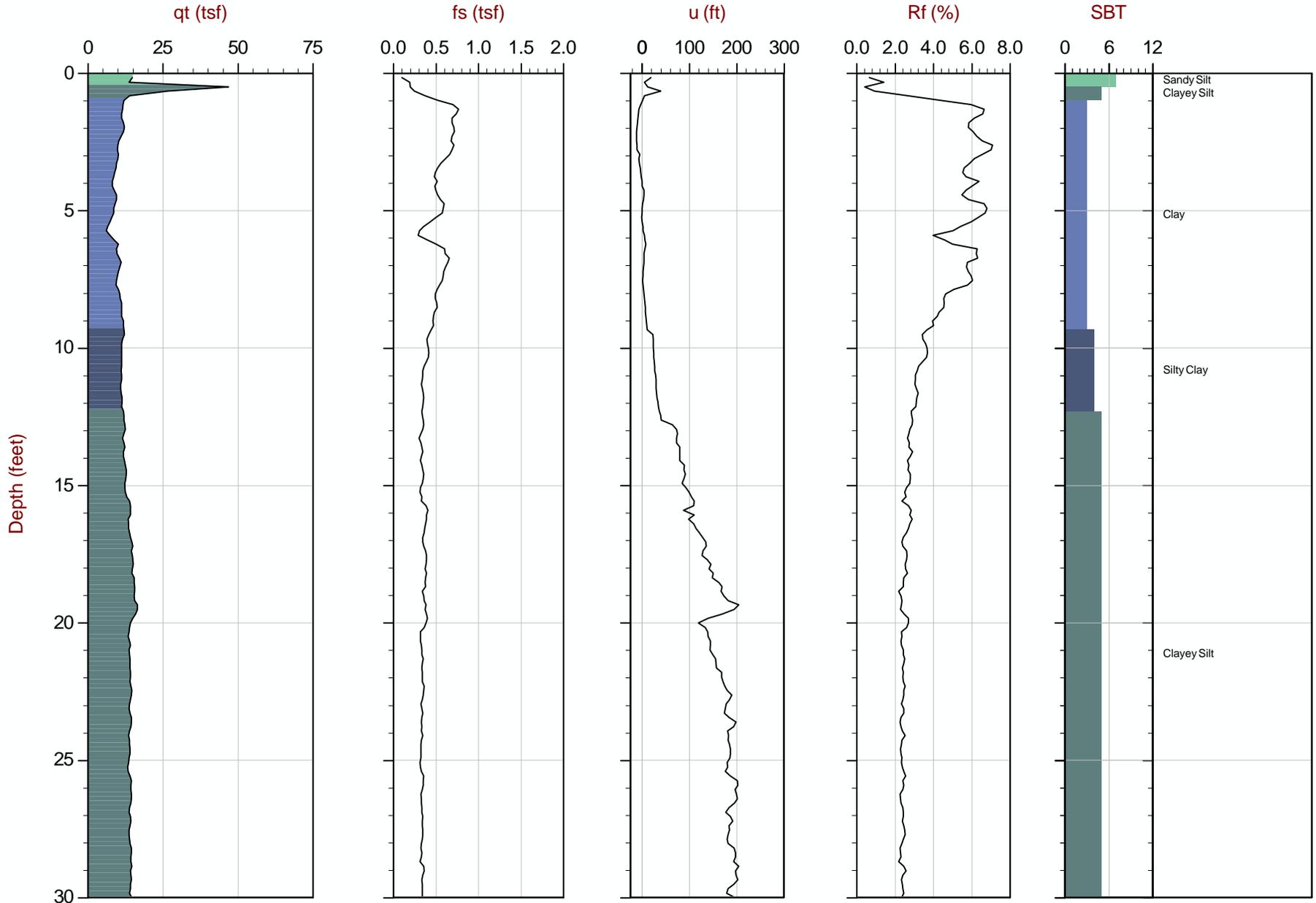
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Coords: Lat: 46.961895 Long: -97.096815
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

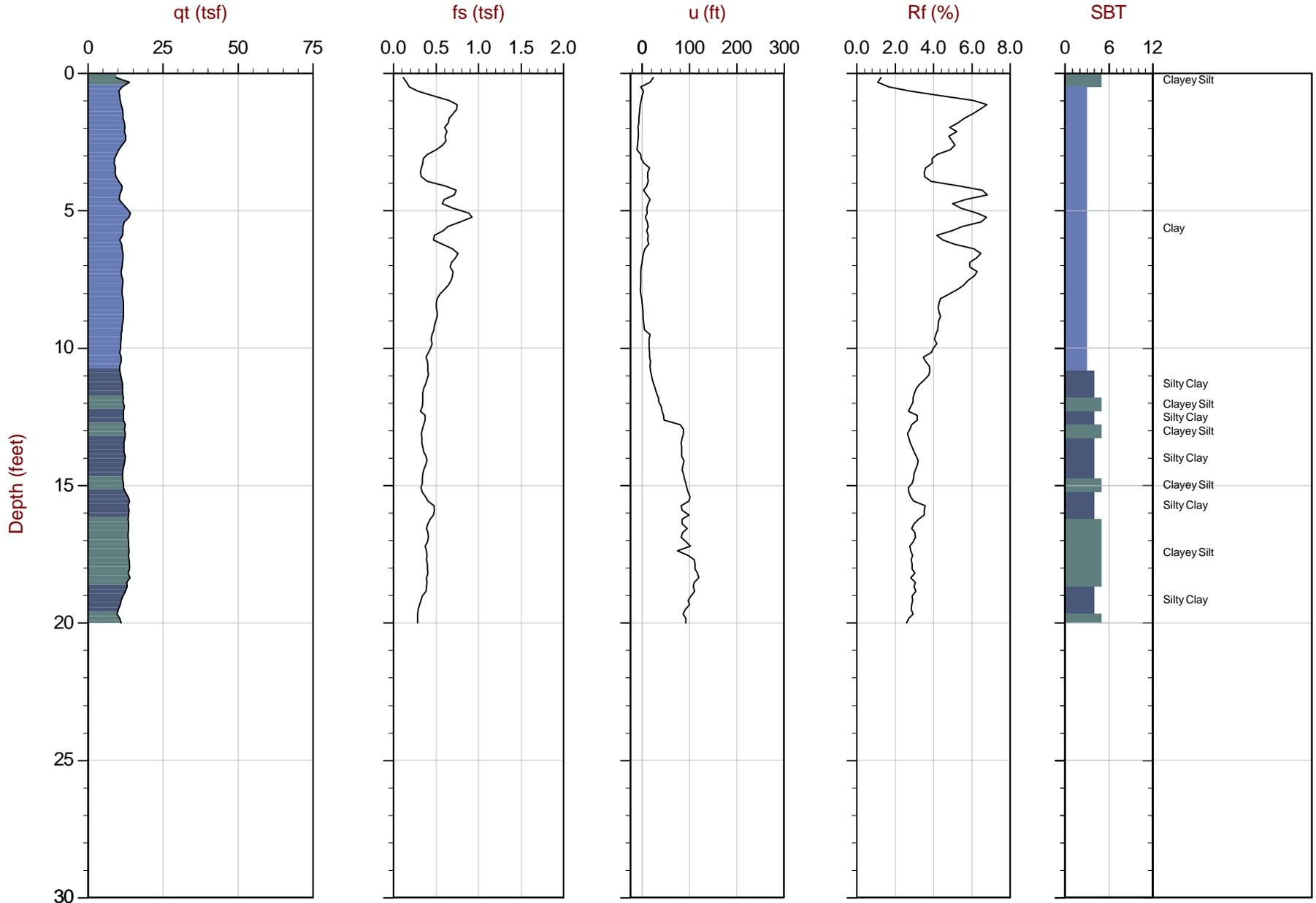
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Coords: Lat: 46.961872 Long: -97.091273
● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

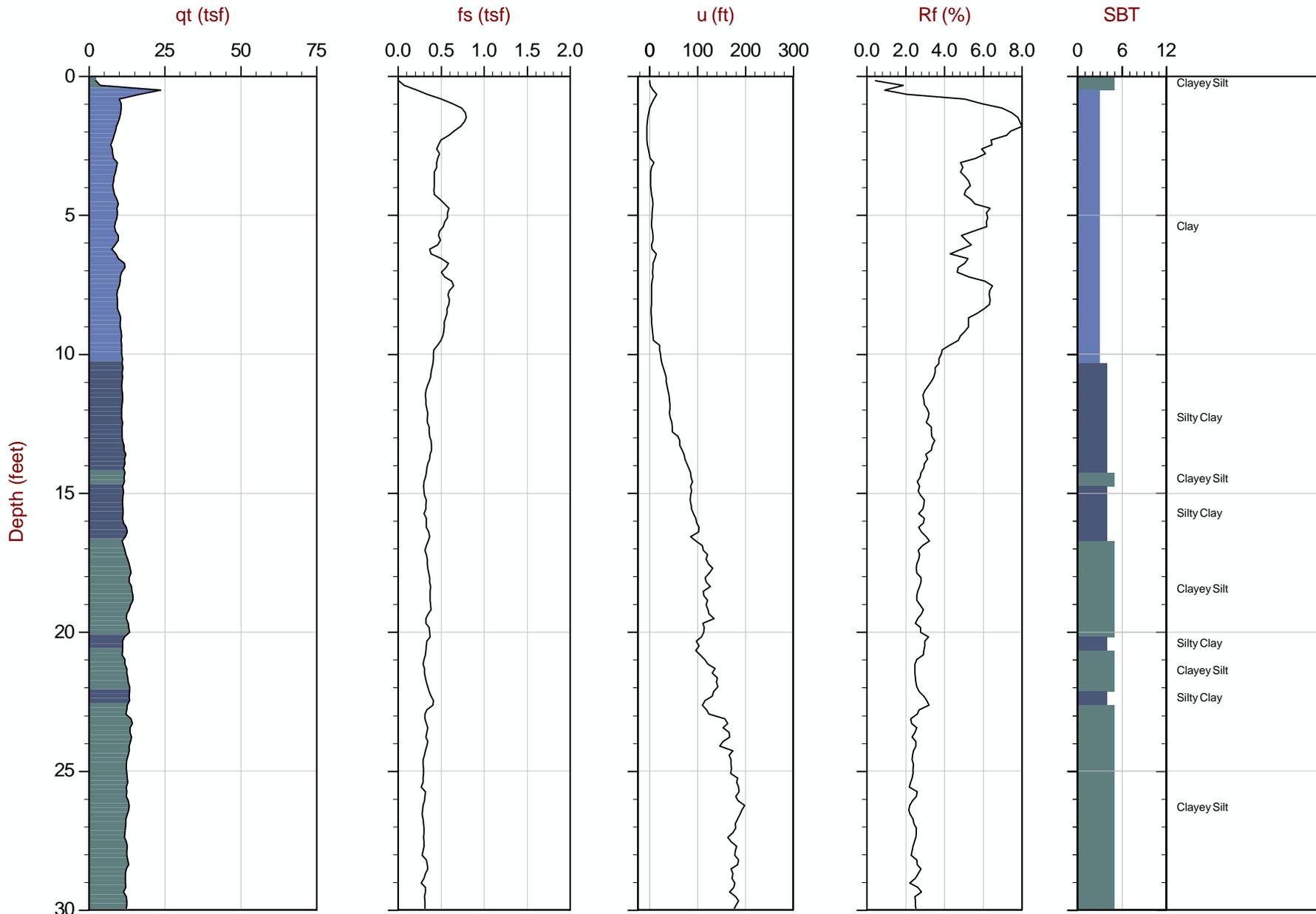
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Coords: Lat: 46.961925 Long: -97.086310
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP22.COR
Unit Wt: SBT Zones

SBT: Robertson and Campanella, 1986
Coords: Lat: 46.961806 Long: -97.081032
● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

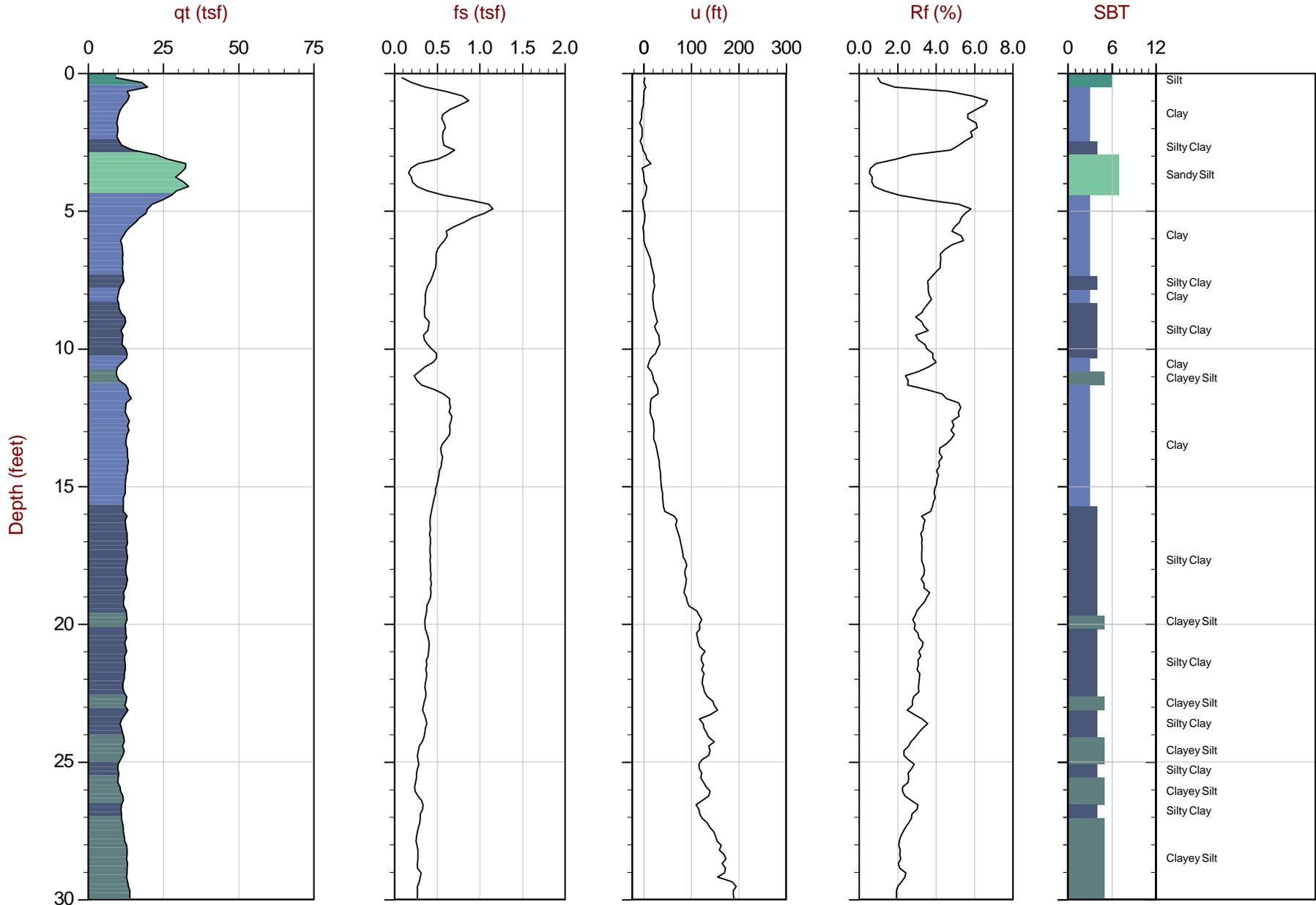
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Coords: Lat: 46.961912 Long: -97.075277
● Equilibrium Pore Pressure from Dissipation



Barr Engineering

Job No: 16-52112
Date: 2016-12-08 08:29
Site: Harmony Solar Project

Sounding: CPT-24
Cone: 458:T1500F15U500



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP24.COR
Unit Wt: SBT Zones

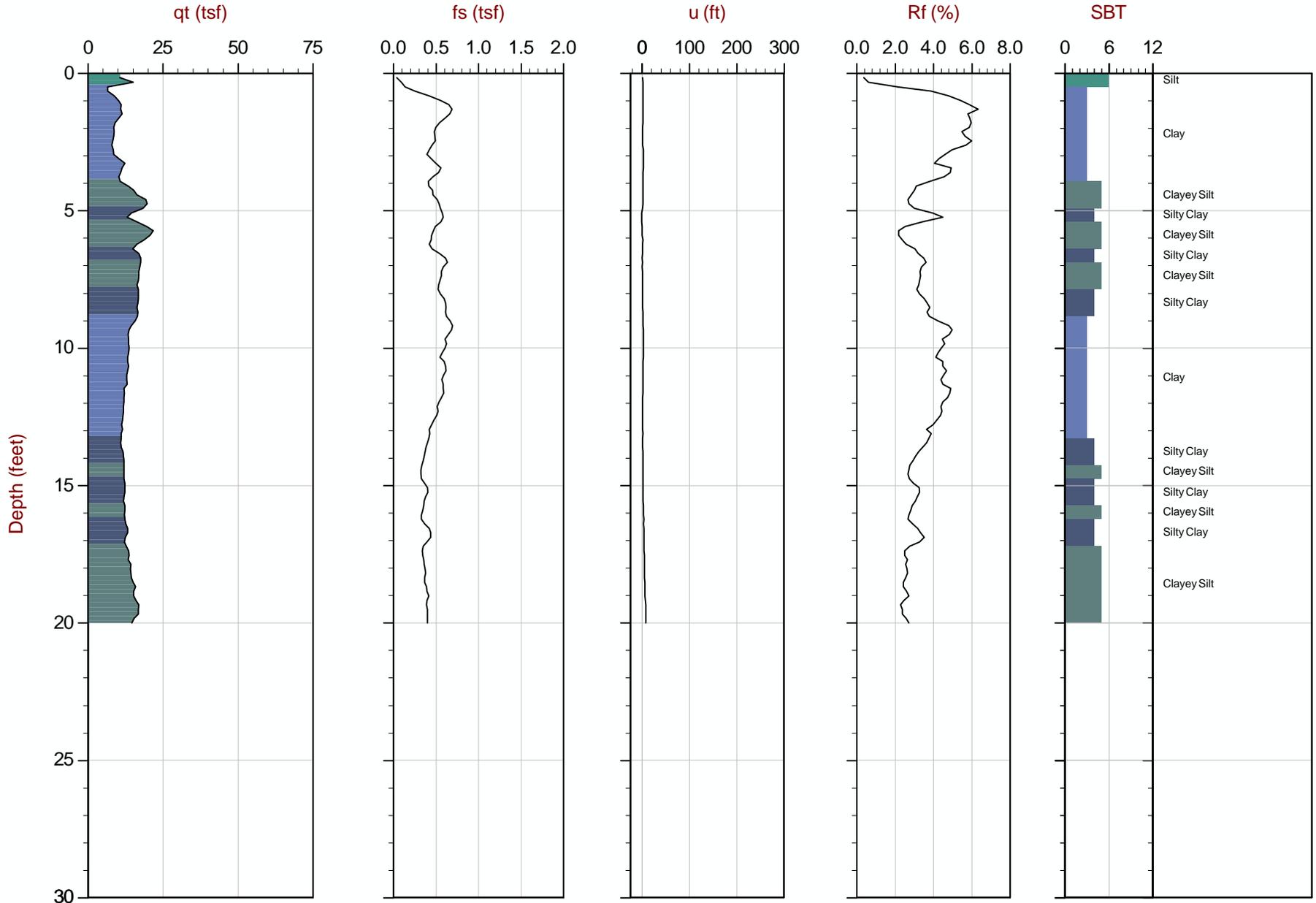
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Coords: Lat: 46.958235 Long: -97.113073
● Equilibrium Pore Pressure from Dissipation



Barr Engineering

Job No: 16-52112
Date: 2016-12-08 09:12
Site: Harmony Solar Project

Sounding: CPT-25
Cone: 458:T1500F15U500



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP25.COR
Unit Wt: SBT Zones

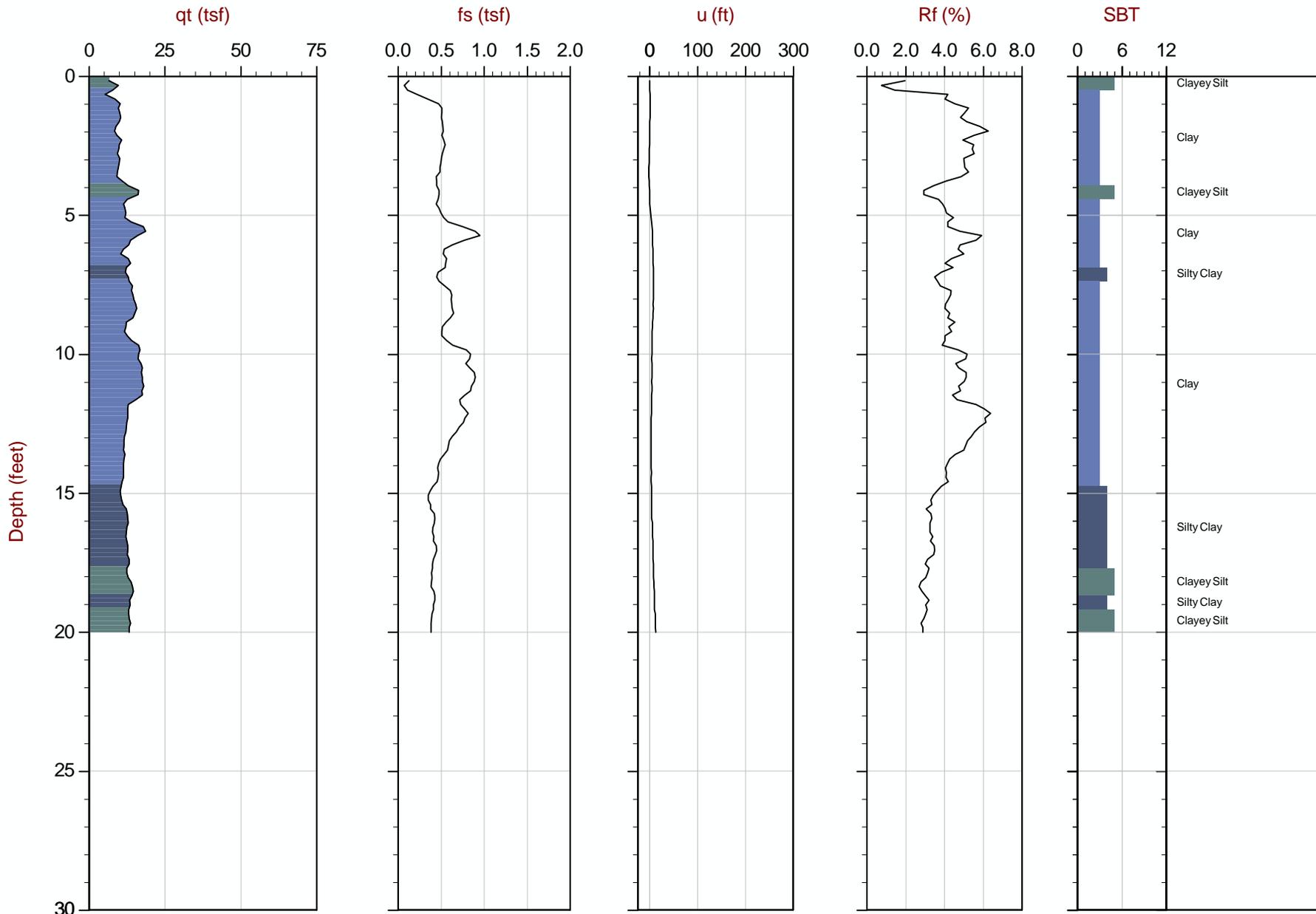
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Coords: Lat: 46.958223 Long: -97.107843
● Equilibrium Pore Pressure from Dissipation



Barr Engineering

Job No: 16-52112
Date: 2016-12-08 09:58
Site: Harmony Solar Project

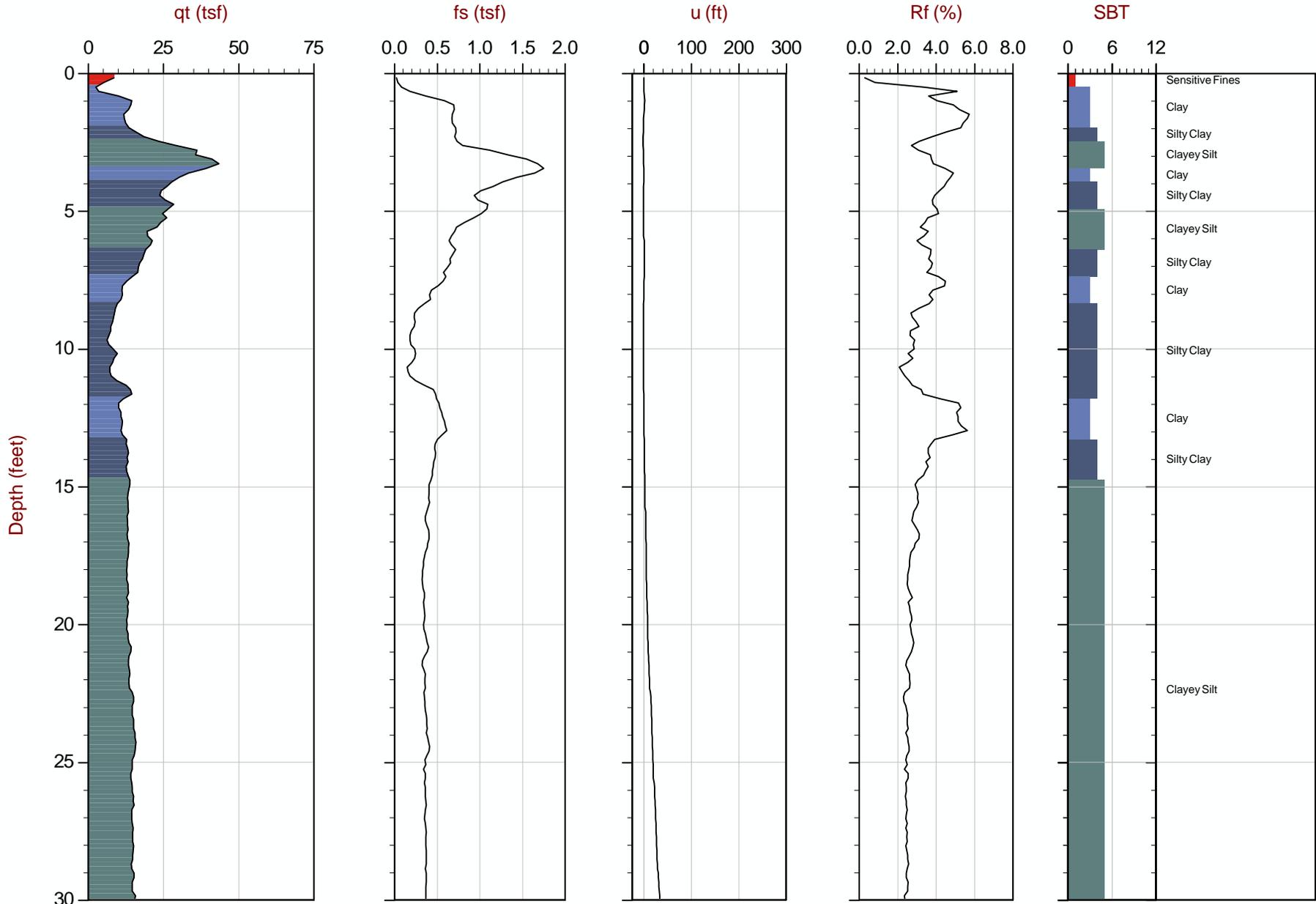
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Cone: 458:T1500F15U500



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

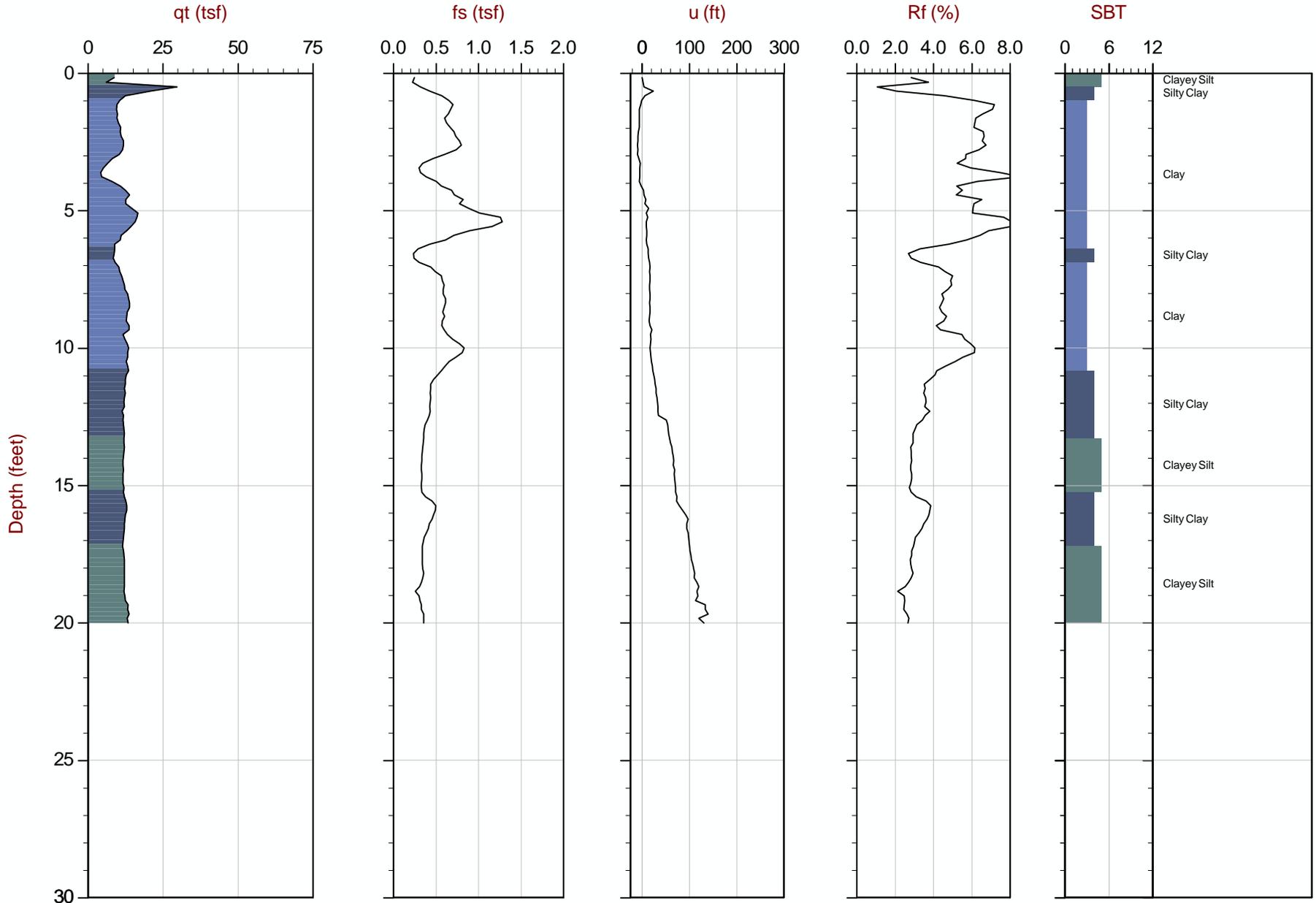
SBT: Robertson and Campanella, 1986
Coords: Lat: 46.958223 Long: -97.102073
● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP27.COR
Unit Wt: SBT Zones

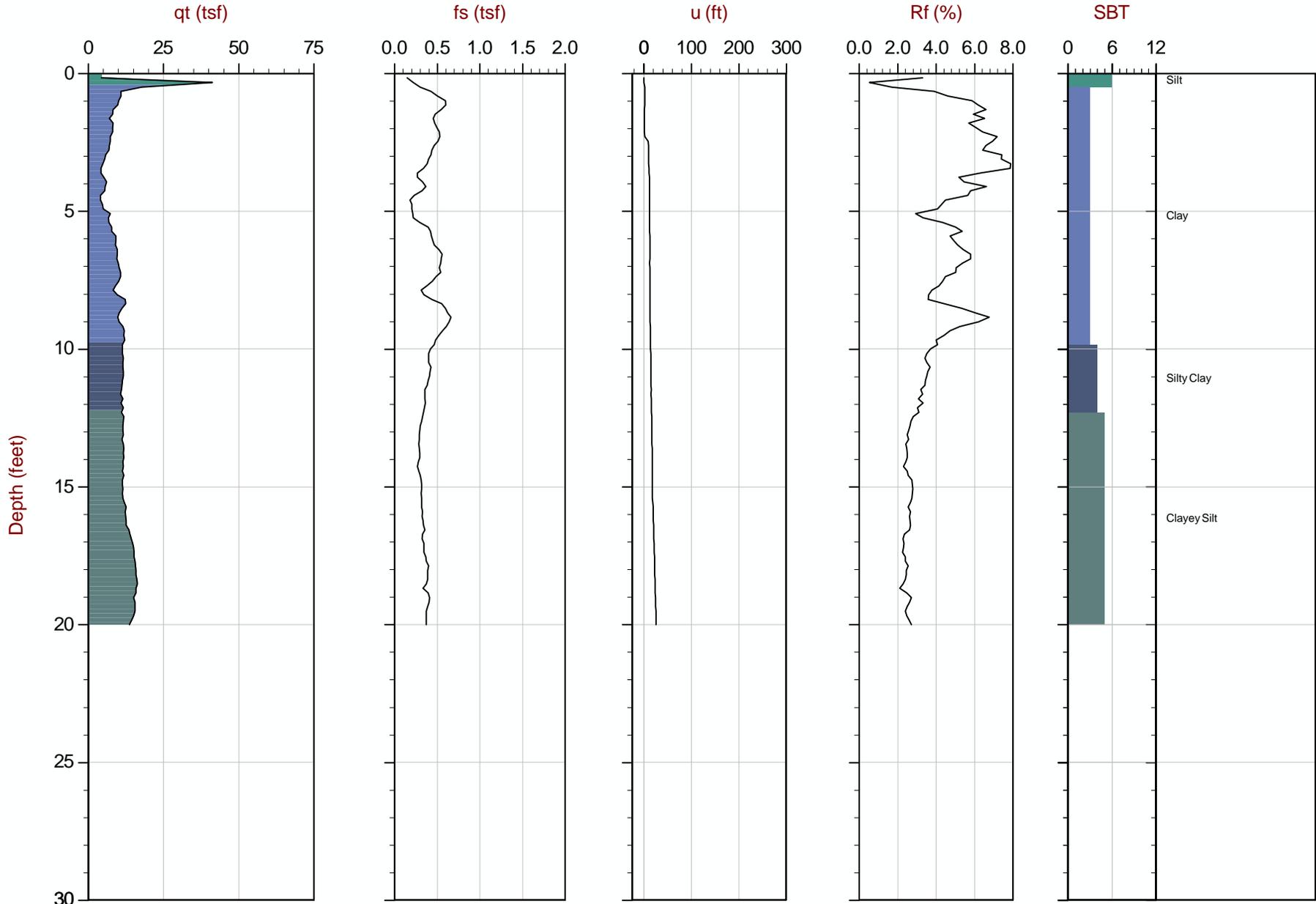
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Coords: Lat: 46.958340 Long: -97.096938
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP28.COR
Unit Wt: SBT Zones

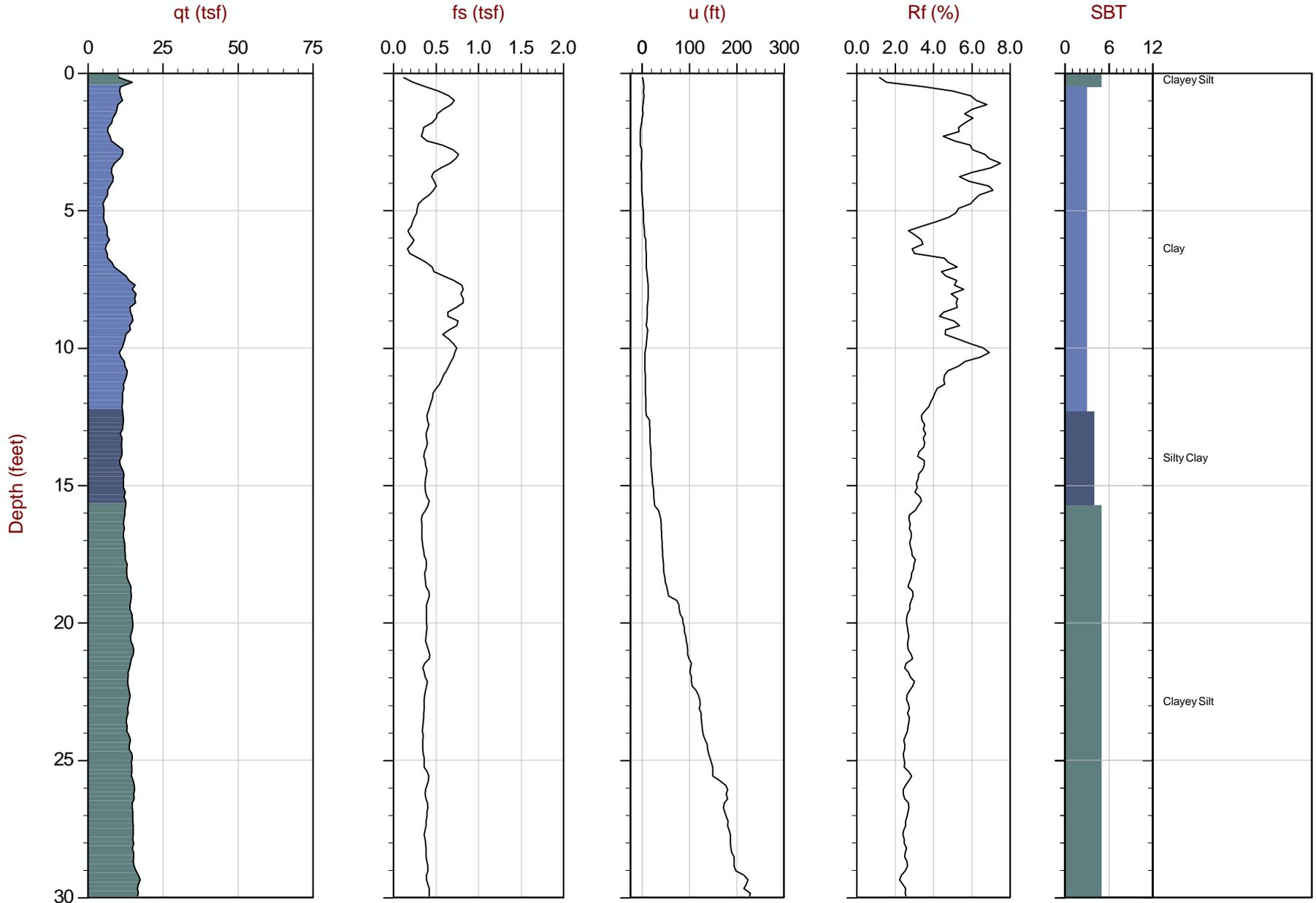
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Coords: Lat: 46.958386 Long: -97.091422
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP29.COR
Unit Wt: SBT Zones

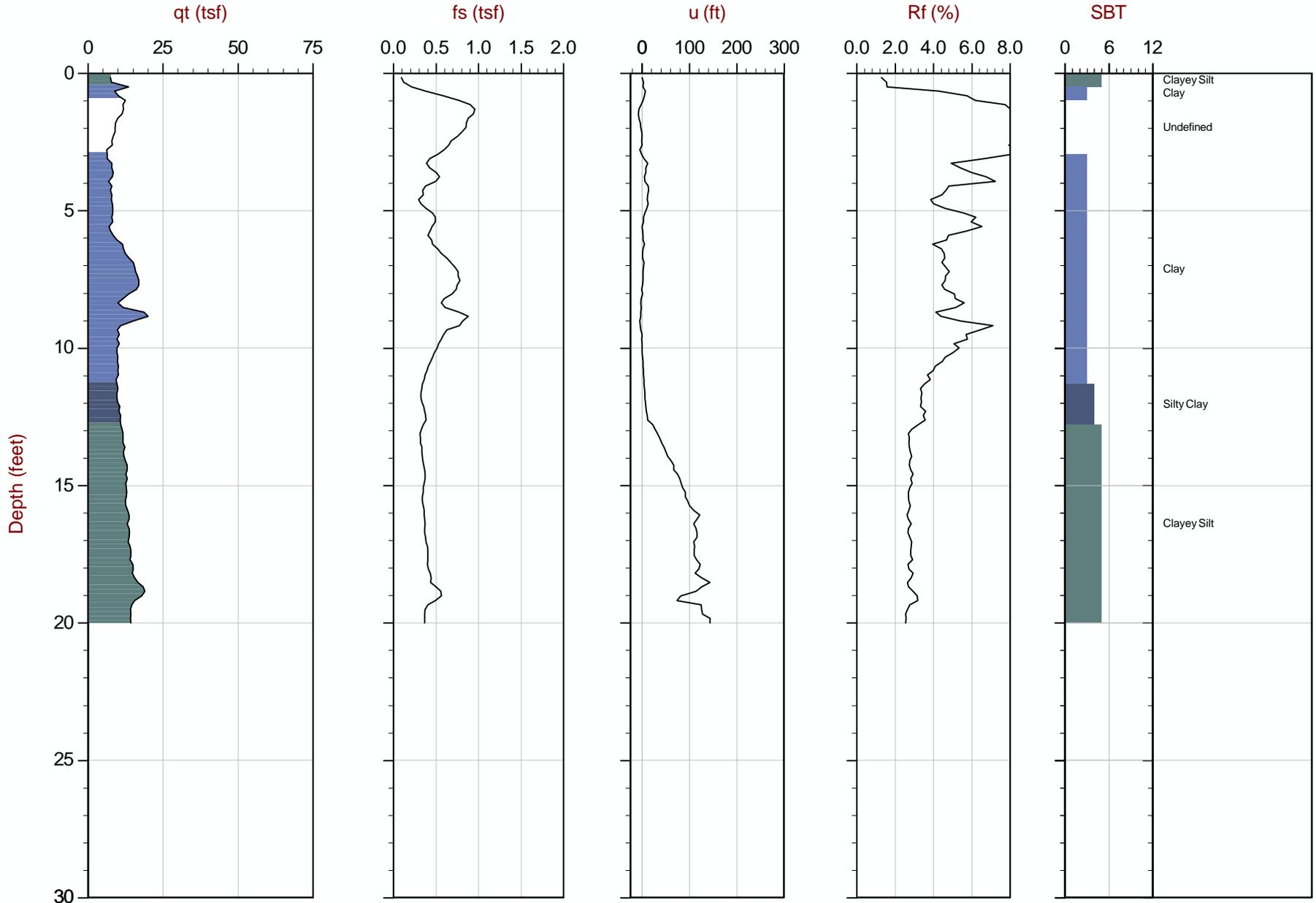
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Coords: Lat: 46.958447 Long: -97.086425
● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

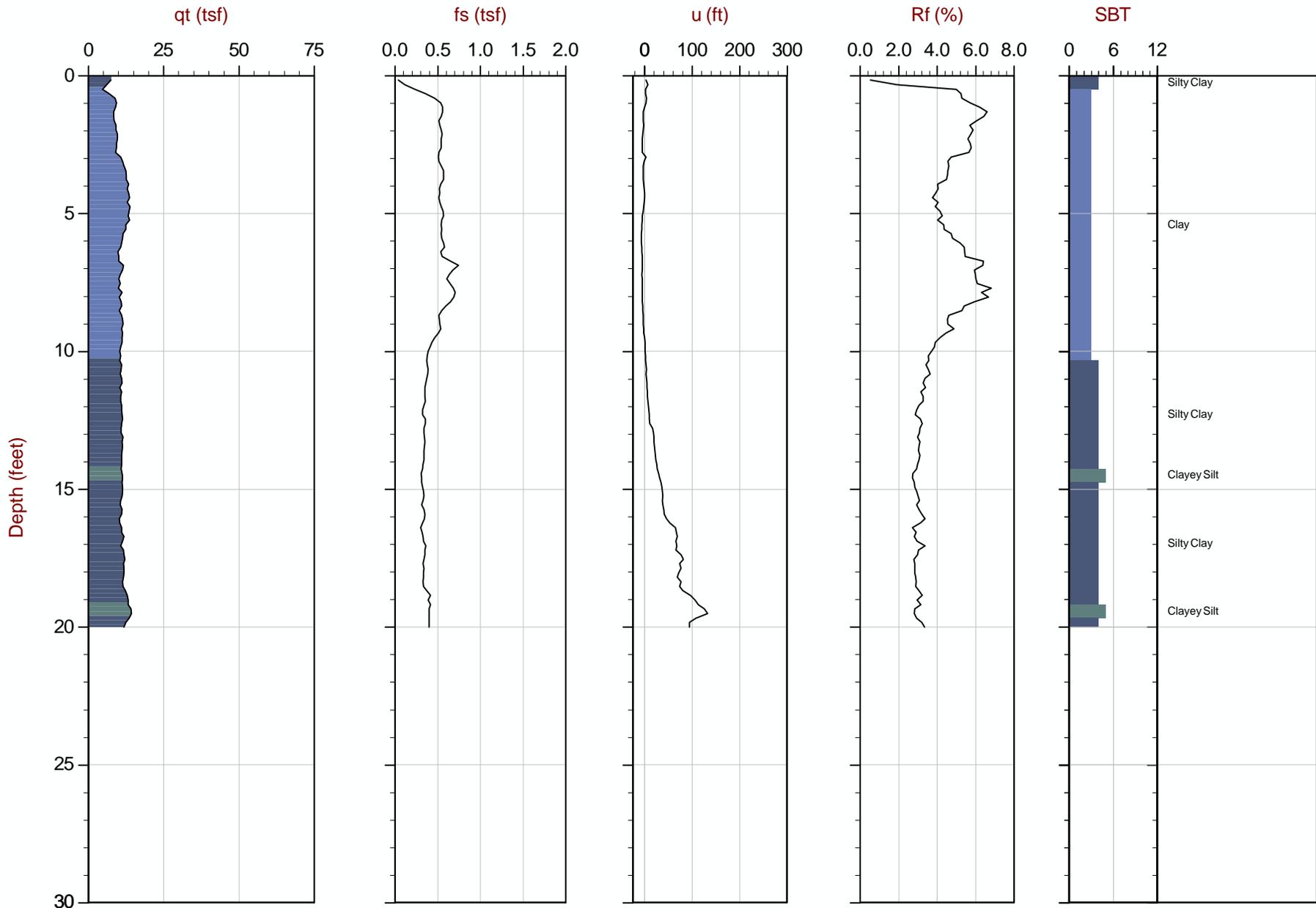
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Coords: Lat: 46.958344 Long: -97.081156
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP31.COR
Unit Wt: SBT Zones

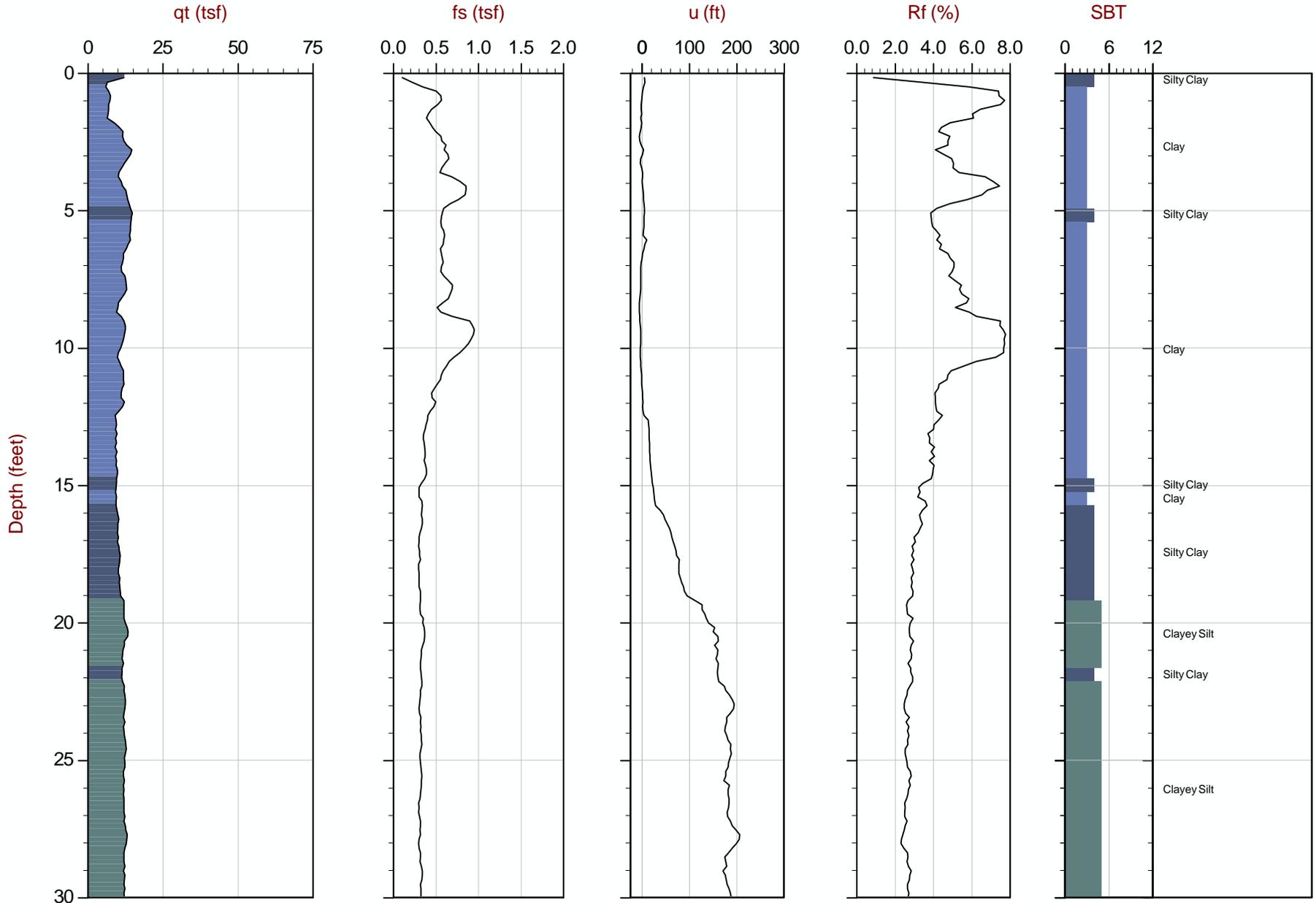
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Coords: Lat: 46.958459 Long: -97.075342
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP32.COR
Unit Wt: SBT Zones

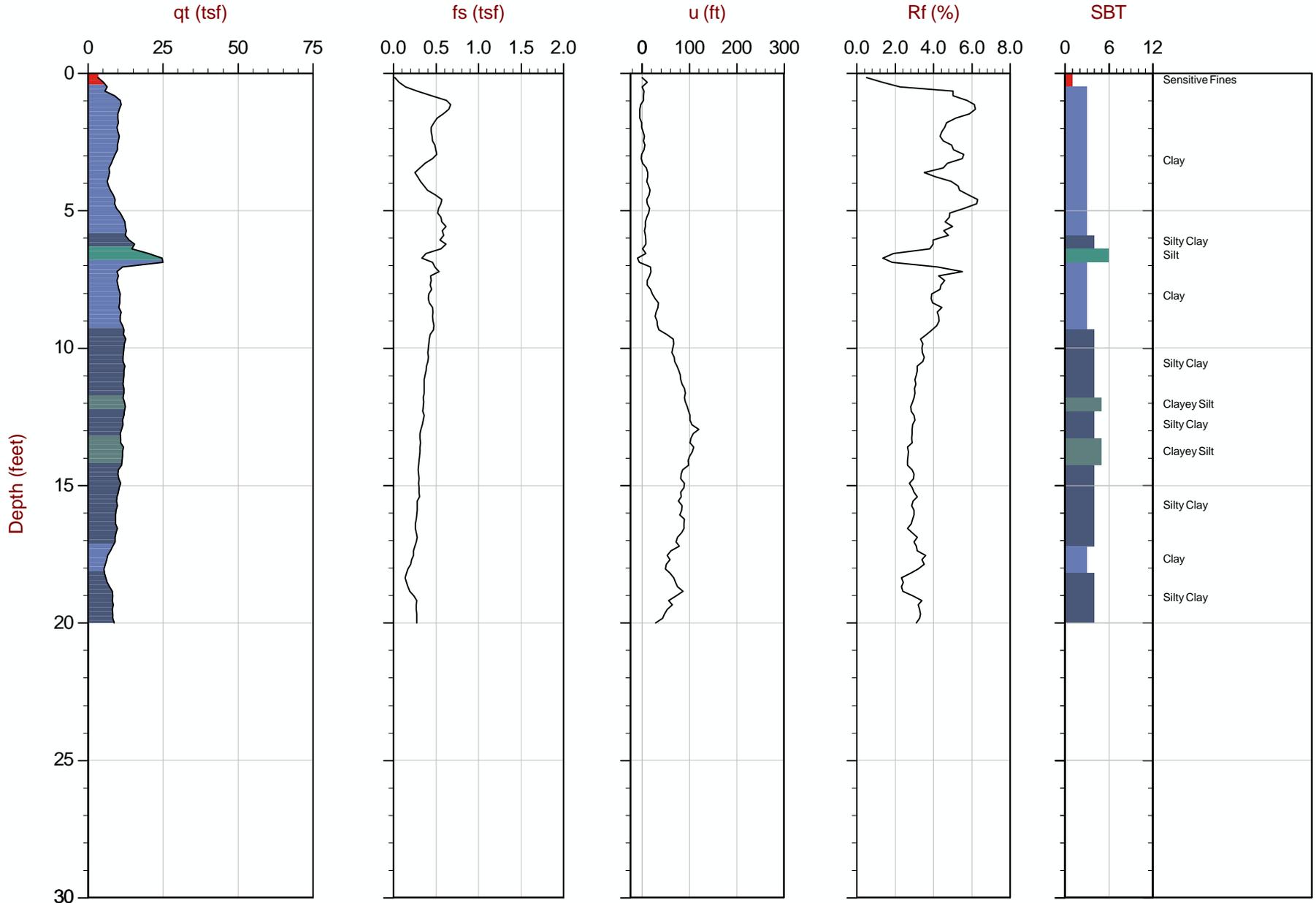
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Coords: Lat: 46.953993 Long: -97.113233
● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP33.COR
Unit Wt: SBT Zones

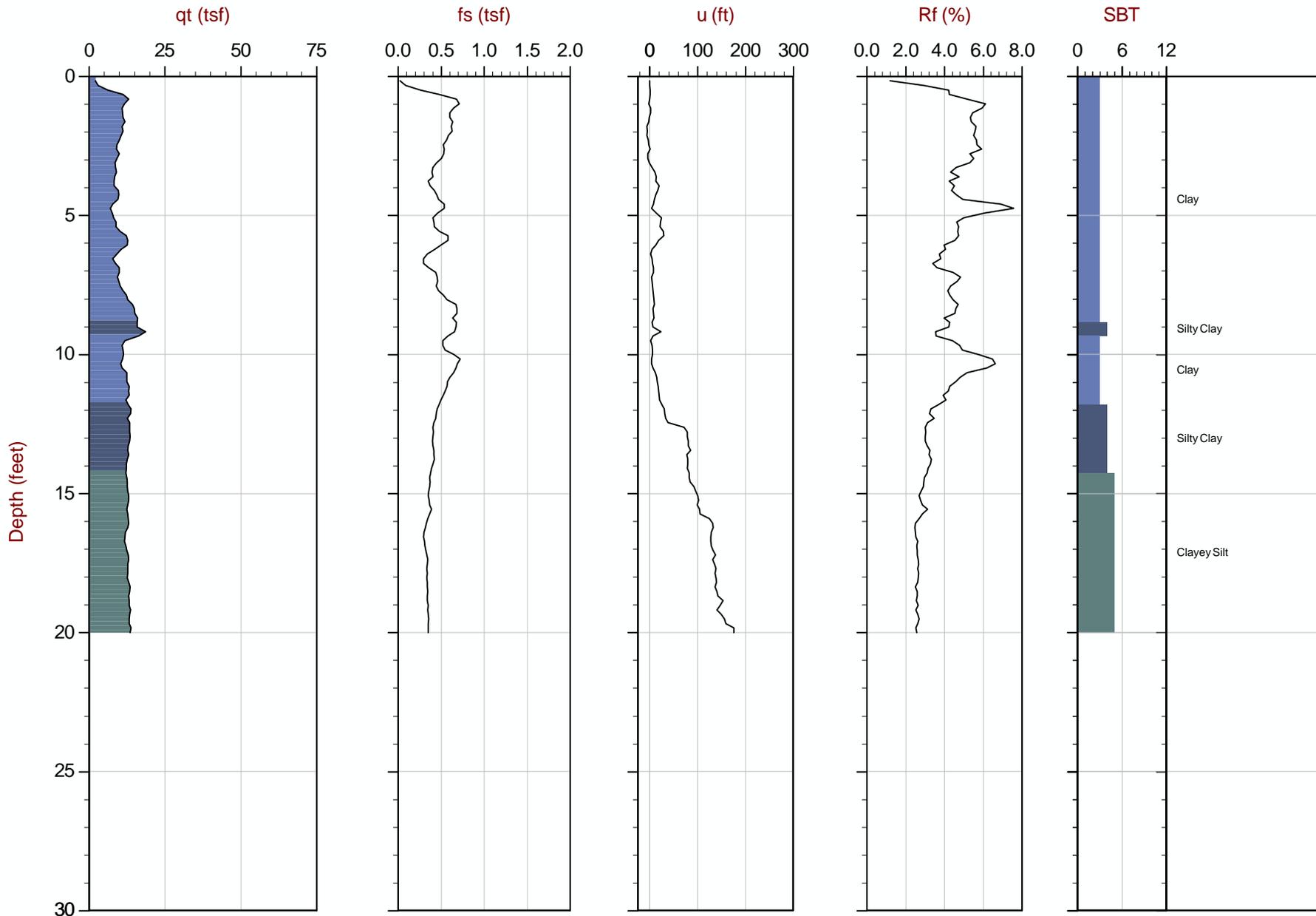
SBT: Robertson and Campanella, 1986
Coords: Lat: 46.953977 Long: -97.107962
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP34.COR
Unit Wt: SBT Zones

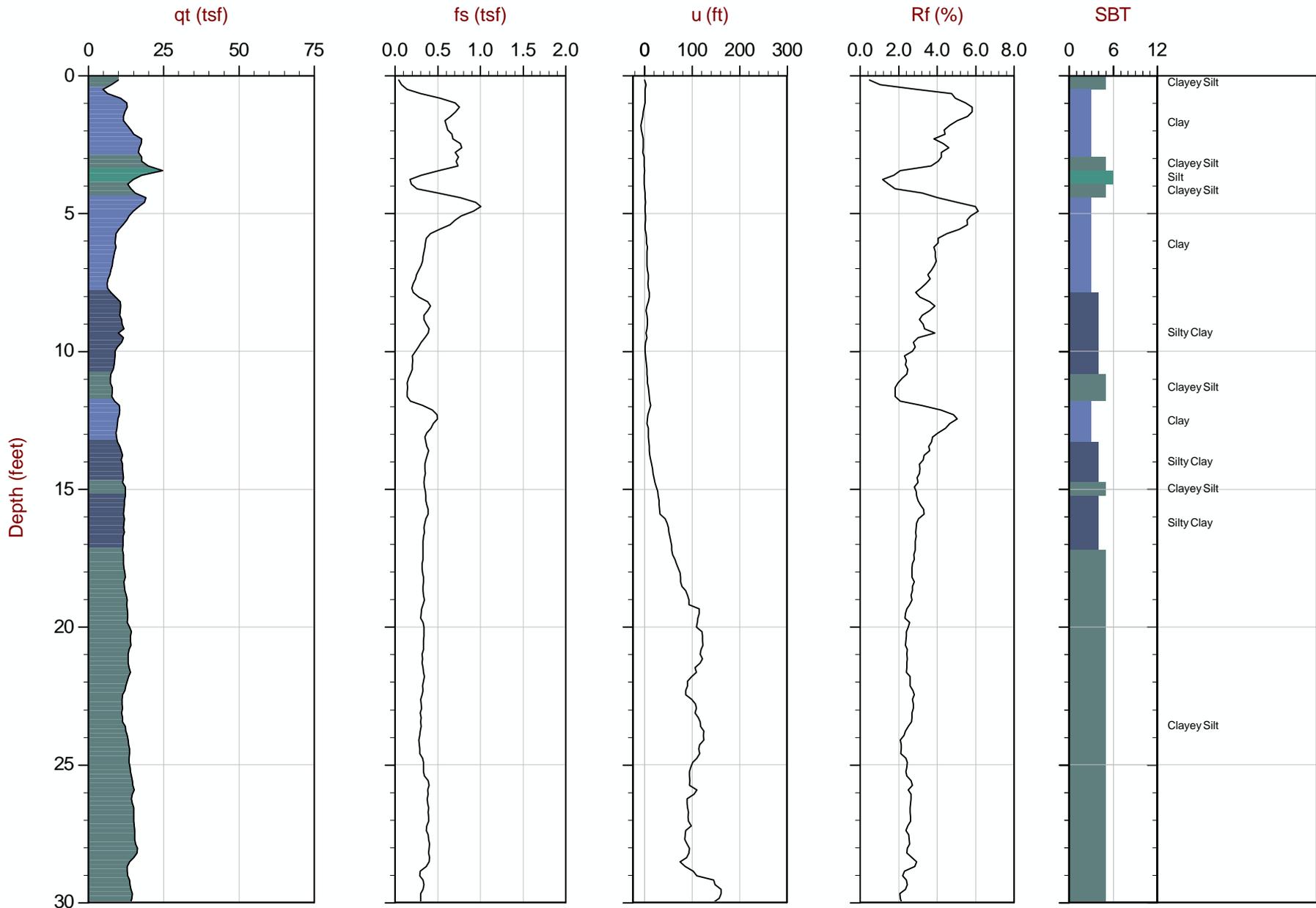
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Coords: Lat: 46.953981 Long: -97.102203
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP35.COR
Unit Wt: SBT Zones

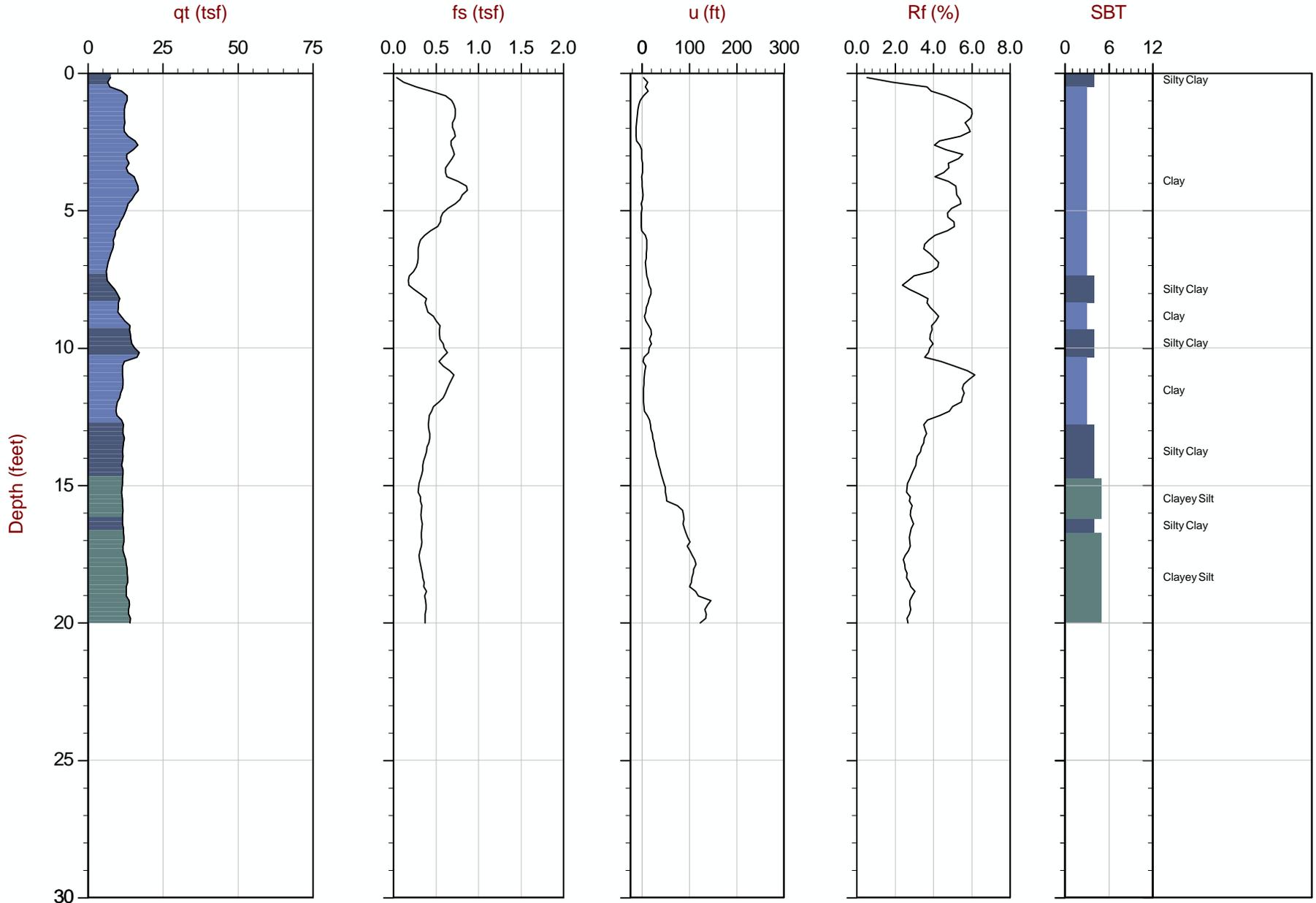
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Coords: Lat: 46.954100 Long: -97.097091
● Equilibrium Pore Pressure from Dissipation



Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

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Unit Wt: SBT Zones

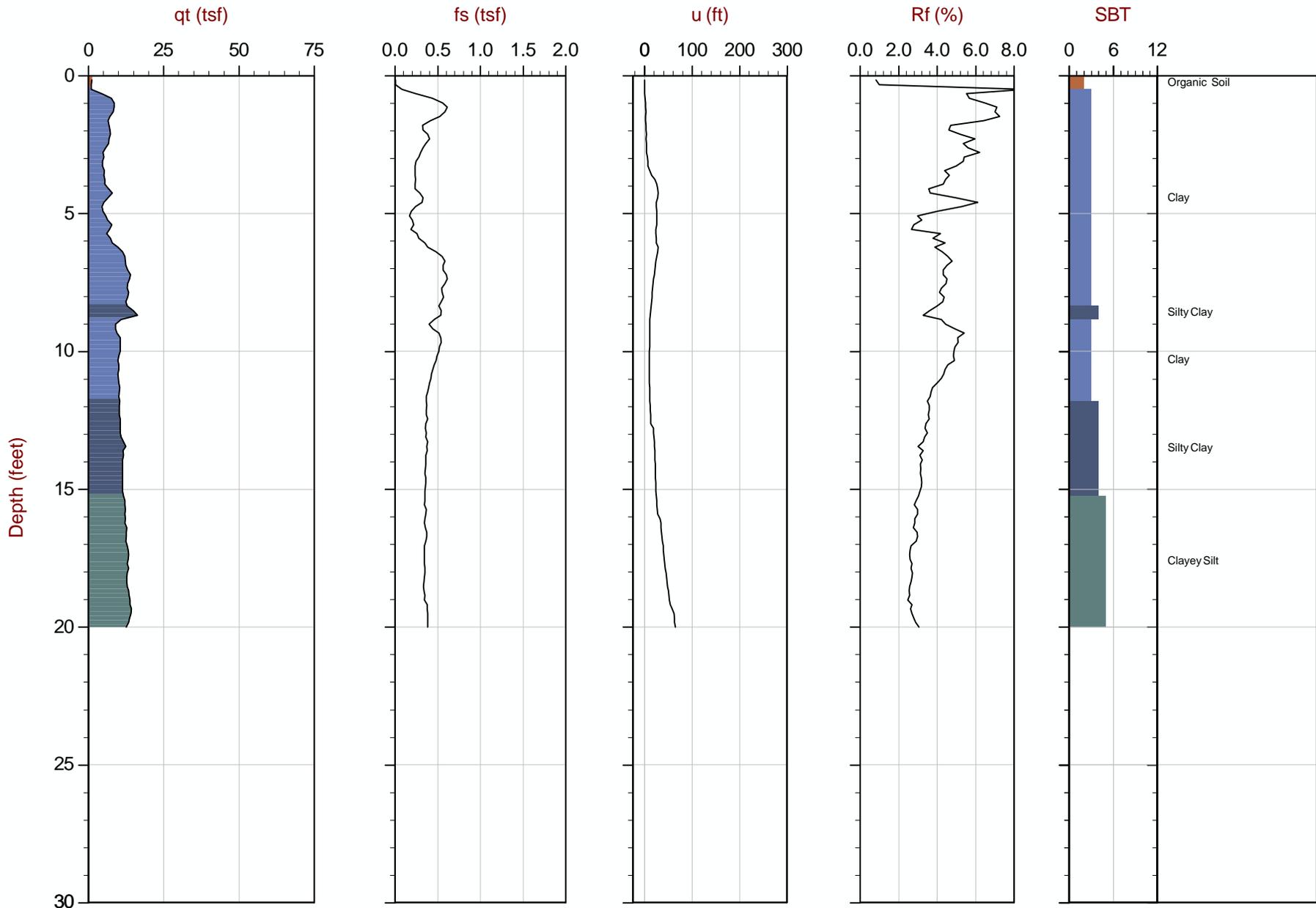
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Coords: Lat: 46.954421 Long: -97.091538
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP37.COR
Unit Wt: SBT Zones

SBT: Robertson and Campanella, 1986
Coords: Lat: 46.954548 Long: -97.086505
● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP38.COR
Unit Wt: SBT Zones

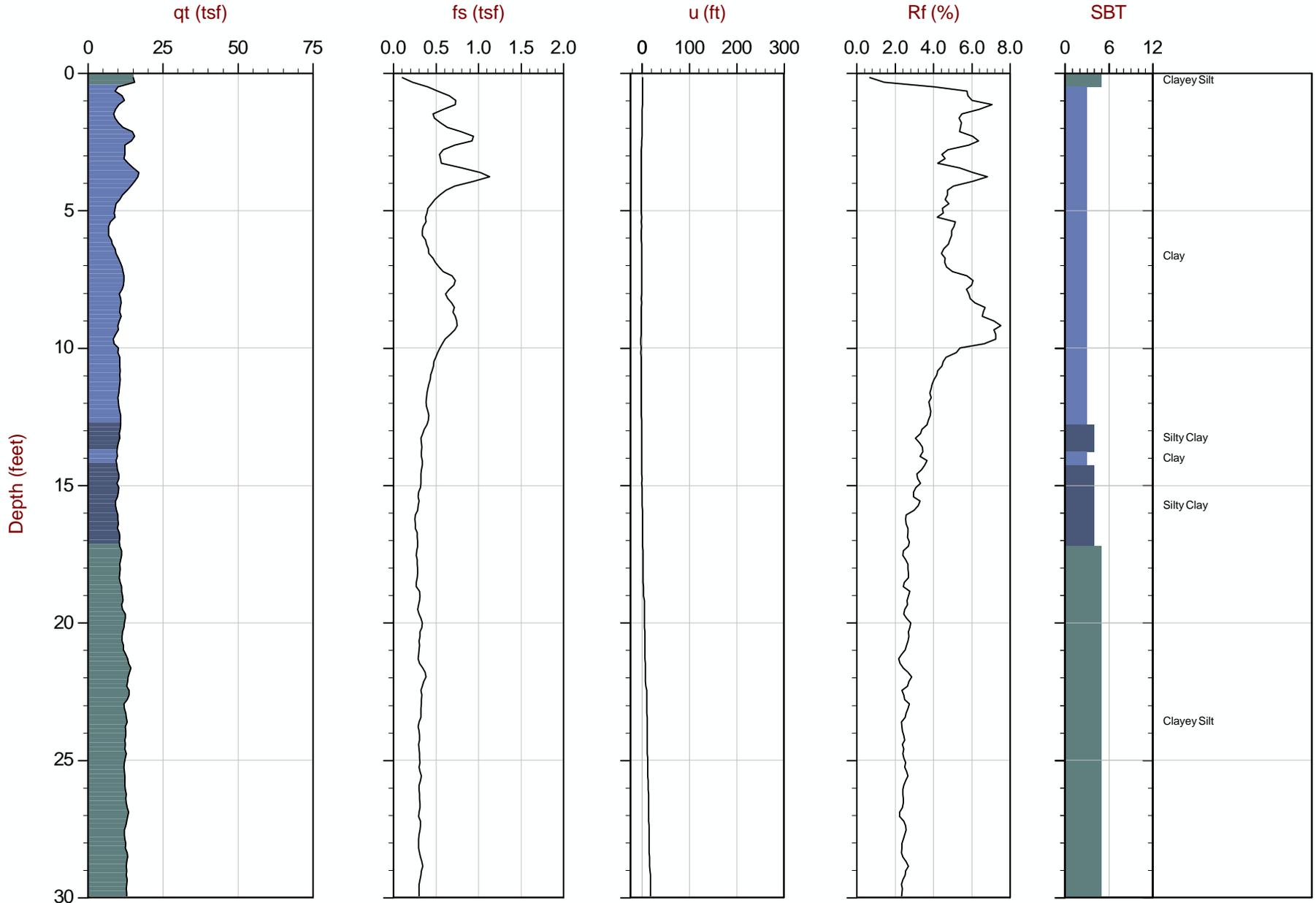
SBT: Robertson and Campanella, 1986
Coords: Lat: 46.954230 Long: -97.081236
● Equilibrium Pore Pressure from Dissipation



Barr Engineering

Job No: 16-52112
Date: 2016-12-08 13:53
Site: Harmony Solar Project

Sounding: CPT-39
Cone: 458:T1500F15U500

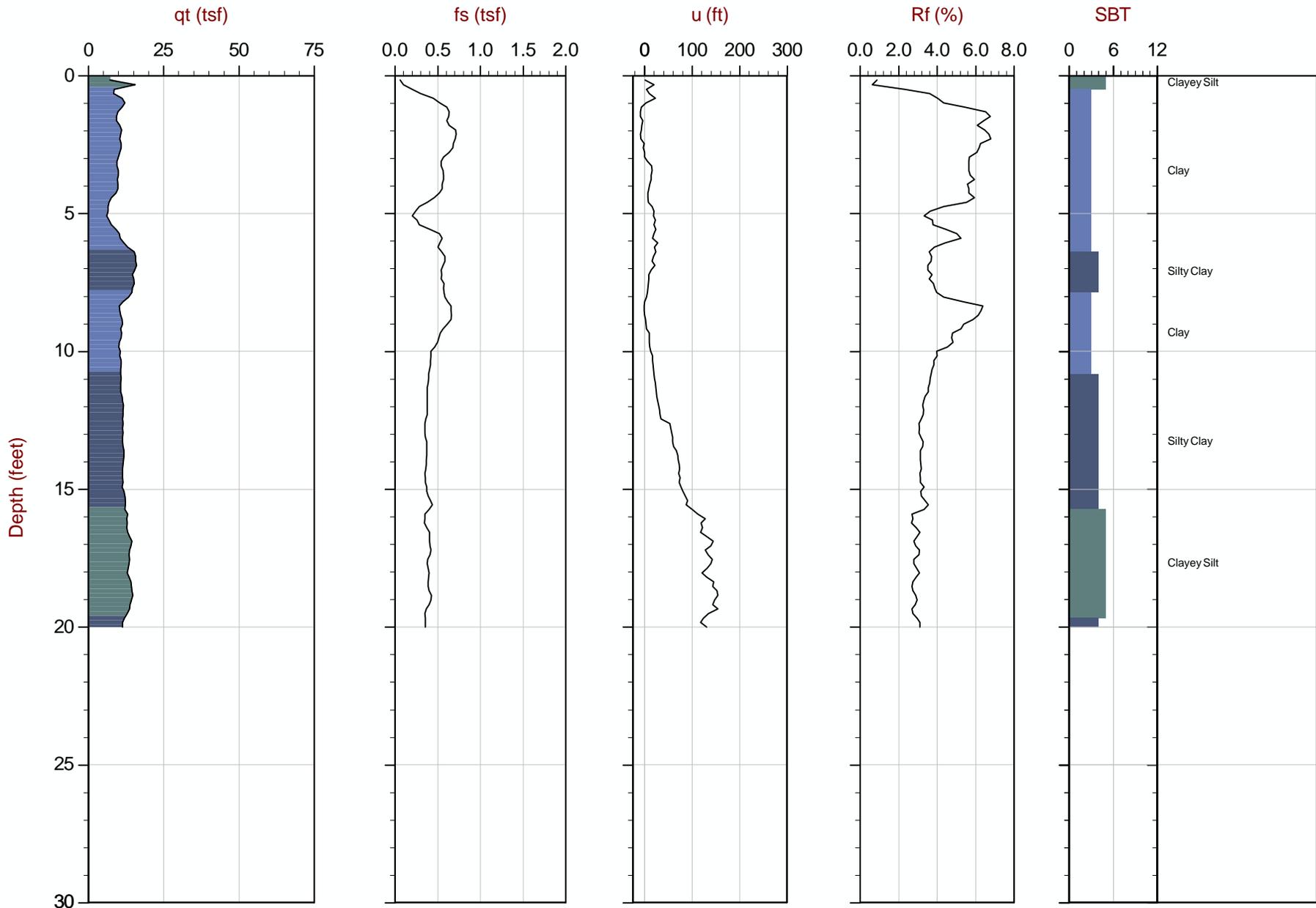


Max Depth: 9.150 m / 30.02 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP39.COR
Unit Wt: SBT Zones

SBT: Robertson and Campanella, 1986
Coords: Lat: 46.954282 Long: -97.075548

● Equilibrium Pore Pressure from Dissipation



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP40.COR
Unit Wt: SBT Zones

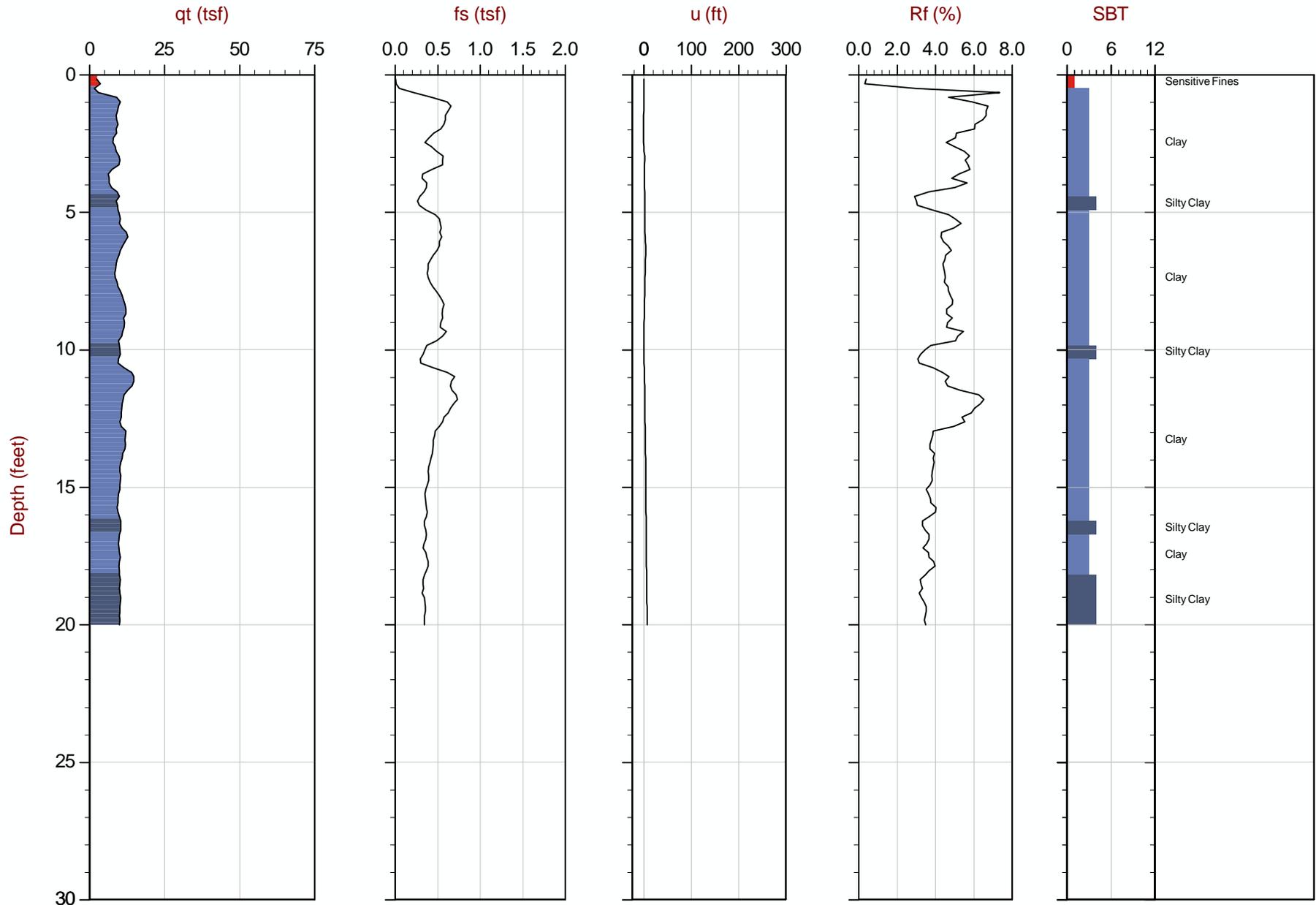
SBT: Robertson and Campanella, 1986
Coords: Lat: 46.950697 Long: -97.091737
● Equilibrium Pore Pressure from Dissipation



Barr Engineering

Job No: 16-52112
Date: 2016-12-07 15:56
Site: Harmony Solar Project

Sounding: CPT-41
Cone: 458:T1500F15U500



Max Depth: 6.100 m / 20.01 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.150 m

File: 16-52112_CP41.COR
Unit Wt: SBT Zones

SBT: Robertson and Campanella, 1986
Coords: Lat: 46.950767 Long: -97.086748
● Equilibrium Pore Pressure from Dissipation

Appendix C

DMT Test Results



Job No.: 16-52112
 Client: Harmony Solar Project
 Project: Near Mapleton, ND
 Sounding ID: DMT-06
 Date: 10-Dec-16
 Ground Water Depth (ft): 8.0
 Zm (bar): 0.0

Datum: WGS 84 Lat/Long
 Latitude: 46.943805
 Longitude: -97.129594

DILATOMETER TEST RESULTS

Depth ¹ (ft)	A (bar)	B (bar)	C (bar)	Average ΔA (bar)	Average ΔB (bar)	p ₀ (bar)	p ₁ (bar)	p ₂ (bar)	u ₀ (psf)	v _T ² (pcf)	σ _{vo} (psf)	σ _{vo} ¹ (psf)	I _b	K _D	E _D (bar)	K _e	OCR ³	OCR ⁴	φ ⁴ (deg)	R _M	E _D (ksf)	s _u ⁴ (psf)	s _u ⁵ (psf)	M (ksf)
2.1	1.55	3.45		0.18	0.48	1.7	3.0		0	103	221	221	0.79	15.7	46	2.4	8.0	25.0		2.9	95	640	347	279
3.3	2.40	5.10		0.18	0.48	2.5	4.6		0	108	345	345	0.87	15.0	75	2.3	7.6	23.1		2.9	156	940	516	450
4.4	1.25	4.80		0.18	0.48	1.3	4.3		0	107	467	467	2.38	5.7	106				37.9	2.0	221			440
5.4	2.20	4.70		0.18	0.48	2.3	4.2		0	107	573	573	0.85	8.3	67	1.6	4.2	9.2		2.3	141	749	477	326
6.6	2.30	4.65	0.2	0.18	0.48	2.4	4.2	0.4	0	107	696	696	0.75	7.2	62	1.5	3.7	7.3		2.2	129	756	499	280
7.7	3.05	5.15	0.9	0.18	0.48	3.2	4.7	1.1	0	108	819	819	0.48	8.0	53	1.6	4.1	8.8		2.3	110	1025	658	251
8.7	3.15	5.25	1.3	0.18	0.48	3.3	4.8	1.5	43	108	925	882	0.47	7.7	53	1.6	3.9	8.1		2.2	110	1038	675	246
9.8	4.00	6.05	1.9	0.18	0.48	4.1	5.6	2.0	115	109	1050	935	0.36	9.0	51	1.7	4.6	10.5		2.4	107	1357	846	255
11.0	4.55	6.50	2.6	0.18	0.48	4.7	6.0	2.7	187	109	1175	989	0.30	9.7	47	1.8	4.9	11.7		2.5	99	1556	955	244
12.0	4.85	7.05	2.6	0.18	0.48	4.9	6.6	2.8	248	110	1284	1036	0.34	9.7	56	1.8	5.0	11.8		2.5	118	1648	1008	292
13.1	4.65	7.15	2.7	0.18	0.48	4.7	6.7	2.8	320	111	1412	1092	0.42	8.8	67	1.7	4.5	10.0		2.4	141	1522	956	333
14.3	5.15	7.50	3.0	0.18	0.48	5.2	7.0	3.2	391	111	1539	1148	0.35	9.2	62	1.7	4.7	10.8		2.4	129	1700	1055	312
15.3	5.45	8.10	3.4	0.18	0.48	5.5	7.6	3.5	453	112	1650	1197	0.40	9.3	73	1.8	4.7	10.9		2.4	152	1789	1109	369
16.4	6.55	9.55	3.7	0.18	0.48	6.6	9.1	3.9	524	114	1781	1256	0.39	10.6	86	1.9	5.4	13.4		2.6	179	2214	1328	456
17.6	5.90	8.45	3.5	0.18	0.48	6.0	8.0	3.7	596	112	1910	1314	0.35	9.1	69	1.7	4.6	10.5		2.4	145	1908	1189	347
18.5	6.05	8.55	4.2	0.18	0.48	6.1	8.1	4.3	658	112	2020	1363	0.33	8.9	67	1.7	4.5	10.3		2.4	141	1942	1215	335
19.7	6.00	8.45	3.7	0.18	0.48	6.1	8.0	3.8	729	112	2149	1420	0.33	8.4	66	1.7	4.3	9.4		2.3	137	1889	1198	319
20.8	6.35	9.10	4.2	0.18	0.48	6.4	8.6	4.3	801	113	2279	1478	0.37	8.5	77	1.7	4.3	9.6		2.3	160	1993	1261	373
21.8	6.65	9.25	4.2	0.18	0.48	6.7	8.8	4.4	862	113	2390	1528	0.32	8.6	71	1.7	4.4	9.8		2.3	148	2091	1319	349
23.0	5.05	7.75	2.9	0.18	0.48	5.1	7.3	3.0	934	112	2519	1585	0.46	6.2	75	1.3	3.1	5.8		2.0	156	1423	976	313
24.1	4.80	7.35	3.0	0.18	0.48	4.9	6.9	3.1	1006	111	2646	1640	0.45	5.6	69	1.3	2.9	5.0		1.9	145	1307	919	276
25.1	5.70	8.15	3.1	0.18	0.48	5.8	7.7	3.3	1067	112	2756	1689	0.36	6.5	66	1.4	3.3	6.3		2.1	137	1628	1102	282
26.2	5.90	8.55	2.9	0.18	0.48	6.0	8.1	3.0	1139	112	2885	1746	0.39	6.5	73	1.4	3.3	6.3		2.1	152	1675	1134	313
27.4	6.40	8.65	4.1	0.18	0.48	6.5	8.2	4.3	1210	112	3013	1803	0.28	6.9	58	1.4	3.5	6.8		2.1	122	1849	1235	257
28.4	6.25	9.15	3.3	0.18	0.48	6.3	8.7	3.4	1272	113	3125	1853	0.41	6.4	82	1.4	3.3	6.2		2.0	171	1755	1191	351
29.5	6.90	9.60	3.7	0.18	0.48	7.0	9.1	3.8	1343	113	3255	1912	0.34	6.9	75	1.5	3.5	6.9		2.1	156	1983	1322	331

1. Depth is referenced below the existing ground surface at the time of testing.
2. Mayne et al., 2002
3. Mayne, 1995
4. Marchetti et al., 2001
5. Schmertman, 1991



Job No.: 16-52112
 Client: Harmony Solar Project
 Project: Near Mapleton, ND
 Sounding ID: DMT-15
 Date: 10-Dec-16
 Ground Water Depth (ft): 8.0
 Zm (bar): 0.0

Datum: WGS 84 Lat/Long
 Latitude: 46.936303
 Longitude: -97.124418

DILATOMETER TEST RESULTS

Depth ¹ (ft)	A (bar)	B (bar)	C (bar)	Average ΔA (bar)	Average ΔB (bar)	p _o (bar)	p ₁ (bar)	p ₂ (bar)	u _o (psf)	v _T ² (pcf)	σ _{vo} (psf)	σ _{vo} ¹ (psf)	I _b	K _D	E _D (bar)	K _o	OCR ³	OCR ⁴	φ ⁴ (deg)	R _M	E _D (ksf)	s _u ⁴ (psf)	s _u ⁵ (psf)	M (ksf)
2.1	1.70	3.45		0.20	0.45	1.8	3.0		0	103	220	220	0.63	17.5	40	2.6	8.9	29.4		3.0	84	729	385	254
3.3	1.35	3.85	0.20	0.20	0.45	1.5	3.4	0.4	0	105	341	341	1.33	8.9	67					2.4	141			336
6.6	2.50	5.80		0.20	0.45	2.6	5.4		0	110	701	701	1.08	7.6	97	1.6	3.9	8.1		2.2	202	825	536	450
7.7	2.95	4.75	1.00	0.20	0.45	3.1	4.3	1.2	0	106	823	823	0.39	7.8	42	1.6	4.0	8.4		2.3	88	1000	646	197
8.7	4.15	6.35	2.2	0.20	0.45	4.3	5.9	2.4	43	110	931	888	0.38	10.0	56	1.8	5.1	12.3		2.5	118	1461	888	295
9.8	4.30	6.40	2.1	0.20	0.45	4.4	6.0	2.3	115	109	1057	942	0.35	9.7	53	1.8	4.9	11.7		2.5	110	1491	913	272
11.0	4.55	6.60	2.5	0.20	0.45	4.7	6.2	2.7	187	109	1182	996	0.32	9.6	51	1.8	4.9	11.6		2.5	107	1562	959	262
12.0	5.15	7.25	3.1	0.20	0.45	5.3	6.8	3.3	248	110	1291	1043	0.30	10.3	53	1.9	5.3	13.0		2.5	110	1787	1077	279
13.1	5.15	7.30	3.0	0.20	0.45	5.3	6.9	3.2	320	110	1418	1098	0.31	9.7	55	1.8	5.0	11.8		2.5	114	1748	1070	282
14.3	5.50	7.90	3.2	0.20	0.45	5.6	7.5	3.4	391	112	1546	1155	0.34	9.8	64	1.8	5.0	12.0		2.5	133	1855	1133	330
15.3	5.85	8.15	3.4	0.20	0.45	6.0	7.7	3.6	453	112	1656	1203	0.30	10.0	60	1.8	5.1	12.3		2.5	126	1975	1201	314
16.4	6.15	8.60	3.7	0.20	0.45	6.3	8.2	3.9	524	112	1785	1260	0.31	10.0	66	1.8	5.1	12.2		2.5	137	2062	1255	342
17.6	6.30	8.85	3.4	0.20	0.45	6.4	8.4	3.6	596	113	1914	1318	0.33	9.7	69	1.8	4.9	11.7		2.5	145	2086	1278	357
18.5	6.10	8.65	3.4	0.20	0.45	6.2	8.2	3.6	658	113	2025	1368	0.34	9.0	69	1.7	4.6	10.4		2.4	145	1971	1230	346
19.7	5.95	8.45	3.5	0.20	0.45	6.1	8.0	3.7	729	112	2154	1425	0.34	8.4	67	1.6	4.3	9.3		2.3	141	1876	1192	326
20.8	6.40	8.95	3.9	0.20	0.45	6.5	8.5	4.1	801	113	2284	1483	0.33	8.6	69	1.7	4.4	9.8		2.3	145	2027	1279	340
21.8	6.65	10.40	3.8	0.20	0.45	6.7	10.0	4.0	862	116	2397	1535	0.52	8.5	113	1.7	4.4	9.6		2.3	236	2075	1312	552
23.0	7.10	11.80	2.7	0.20	0.45	7.1	11.4	2.9	934	118	2533	1599	0.64	8.7	148	1.7	4.4	9.9		2.4	308	2206	1389	726
24.1	6.95	9.30	4.7	0.20	0.45	7.1	8.9	4.9	1006	113	2662	1656	0.27	8.3	62	1.6	4.2	9.2		2.3	129	2159	1375	299
25.1	6.90	9.15	4.9	0.20	0.45	7.0	8.7	5.1	1067	112	2772	1705	0.26	8.0	58	1.6	4.1	8.6		2.3	122	2113	1359	276
26.2	6.80	9.15	5.0	0.20	0.45	6.9	8.7	5.2	1139	112	2901	1763	0.28	7.5	62	1.5	3.8	7.9		2.2	129	2040	1330	286
27.4	6.60	9.05	4.4	0.20	0.45	6.7	8.6	4.6	1210	112	3030	1820	0.31	7.0	66	1.5	3.6	7.1		2.1	137	1929	1280	293
28.4	6.55	8.85	4.5	0.20	0.45	6.7	8.4	4.7	1272	112	3141	1869	0.29	6.8	60	1.4	3.4	6.7		2.1	126	1888	1265	264
29.5	6.65	9.10	4.5	0.20	0.45	6.8	8.7	4.7	1343	112	3270	1926	0.31	6.6	66	1.4	3.4	6.5		2.1	137	1896	1278	285
0.0	0.00	0.00		0.00	0.00	0.0	0.0	0.0	0	0	0	0	0.00	0.0	0	0.0	0.0	0.0	0.0	0.0	0	0	0	0
0.0	0.00	0.00		0.00	0.00	0.0	0.0	0.0	0	0	0	0	0.00	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0

1. Depth is referenced below the existing ground surface at the time of testing.
2. Mayne et al., 2002
3. Mayne, 1995
4. Marchetti et al., 2001
5. Schmertman, 1991



Job No.: 16-52112
 Client: Harmony Solar Project
 Project: Near Mapleton, ND
 Sounding ID: DMT-23
 Date: 10-Dec-16
 Ground Water Depth (ft): 8.0
 Zm (bar): 0.0

Datum: WGS 84 Lat/Long
 Latitude: 46.961885
 Longitude: -97.075265

DILATOMETER TEST RESULTS

Depth ¹ (ft)	A (bar)	B (bar)	C (bar)	Average ΔA (bar)	Average ΔB (bar)	p _o (bar)	p ₁ (bar)	p ₂ (bar)	u _o (psf)	v _T ² (pcf)	σ _{vo} (psf)	σ _{vo} ¹ (psf)	I _b	K _D	E _D (bar)	K _e	OCR ³	OCR ⁴	φ ⁴ (deg)	R _M	E _D (ksf)	s _u ⁴ (psf)	s _u ⁵ (psf)	M (ksf)
2.1	1.40	3.95		0.15	0.45	1.5	3.5		0	105	224	224	1.41	13.5	71					2.8	148			414
3.3	1.70	3.90	0.15	0.15	0.45	1.8	3.5	0.3	0	105	345	345	0.95	10.7	58	1.9	5.5	13.7		2.6	122	619	370	312
4.4	2.60	5.20	0.50	0.15	0.45	2.7	4.8	0.7	0	108	469	469	0.79	11.8	73	2.0	6.0	15.9		2.7	152	949	553	404
5.4	2.55	5.25	0.50	0.15	0.45	2.6	4.8	0.7	0	109	576	576	0.85	9.4	77	1.8	4.8	11.2		2.4	160	878	542	390
6.6	1.80	4.00	0.5	0.15	0.45	1.9	3.6	0.6	0	105	697	697	0.90	5.6	58	1.3	2.9	5.0		1.9	122	556	391	233
7.7	2.75	5.00	0.9	0.15	0.45	2.8	4.6	1.1	0	108	821	821	0.61	7.2	60	1.5	3.6	7.3		2.2	126	891	588	271
8.7	3.45	5.55	1.6	0.15	0.45	3.5	5.1	1.8	43	108	928	884	0.45	8.3	55	1.6	4.2	9.2		2.3	114	1148	732	263
9.8	4.00	6.10	2.0	0.15	0.45	4.1	5.7	2.2	115	109	1053	938	0.39	9.0	55	1.7	4.6	10.4		2.4	114	1343	840	272
11.0	4.05	6.45	2.2	0.15	0.45	4.1	6.0	2.3	187	110	1179	993	0.47	8.5	66	1.7	4.3	9.5		2.3	137	1325	840	319
12.0	4.10	6.30	2.1	0.15	0.45	4.2	5.9	2.3	248	110	1287	1039	0.41	8.1	58	1.6	4.1	8.9		2.3	122	1322	846	279
13.1	4.35	6.55	2.4	0.15	0.45	4.4	6.1	2.5	320	110	1413	1094	0.39	8.1	58	1.6	4.1	8.9		2.3	122	1393	891	279
14.3	5.55	7.75	3.5	0.15	0.45	5.6	7.3	3.7	391	111	1541	1150	0.31	9.9	58	1.8	5.0	12.1		2.5	122	1860	1135	303
15.3	5.40	7.95	3.2	0.15	0.45	5.5	7.5	3.3	453	112	1651	1198	0.39	9.1	71	1.7	4.6	10.7		2.4	148	1758	1093	357
16.4	6.00	8.55	3.8	0.15	0.45	6.1	8.1	3.9	524	113	1781	1256	0.35	9.6	71	1.8	4.9	11.6		2.5	148	1975	1212	365
17.6	6.75	10.80	3.5	0.15	0.45	6.7	10.4	3.6	596	116	1914	1318	0.56	10.2	126	1.9	5.2	12.7		2.5	263	2224	1345	661
18.5	6.95	9.70	4.6	0.15	0.45	7.0	9.3	4.7	658	114	2026	1369	0.34	10.2	78	1.9	5.2	12.7		2.5	164	2305	1395	412
19.7	6.75	9.35	4.6	0.15	0.45	6.8	8.9	4.8	729	113	2157	1427	0.33	9.4	73	1.8	4.8	11.3		2.4	152	2184	1347	371
20.8	6.95	9.85	4.8	0.15	0.45	7.0	9.4	4.9	801	114	2288	1487	0.37	9.3	84	1.8	4.7	10.9		2.4	175	2225	1379	424
21.8	7.15	9.85	5.0	0.15	0.45	7.2	9.4	5.1	862	114	2400	1538	0.33	9.2	77	1.7	4.7	10.8		2.4	160	2283	1416	386
23.0	6.85	9.50	4.6	0.15	0.45	6.9	9.1	4.8	934	114	2530	1596	0.33	8.4	75	1.7	4.3	9.4		2.3	156	2124	1347	363
24.1	6.65	9.60	4.7	0.15	0.45	6.7	9.2	4.9	1006	114	2661	1656	0.40	7.8	86	1.6	4.0	8.4		2.2	179	2003	1295	402
25.1	7.20	9.85	5.2	0.15	0.45	7.2	9.4	5.3	1067	114	2773	1706	0.32	8.2	75	1.6	4.2	9.1		2.3	156	2205	1407	359
26.2	7.15	10.00	5.3	0.15	0.45	7.2	9.6	5.4	1139	114	2904	1766	0.36	7.9	82	1.6	4.0	8.5		2.3	171	2148	1387	386
27.4	6.90	9.55	5.0	0.15	0.45	6.9	9.1	5.1	1210	113	3035	1824	0.34	7.3	75	1.5	3.7	7.5		2.2	156	2021	1330	339
28.4	7.20	9.75	5.1	0.15	0.45	7.3	9.3	5.3	1272	113	3146	1875	0.31	7.4	71	1.5	3.8	7.7		2.2	148	2117	1388	325
29.5	7.45	9.90	4.9	0.15	0.45	7.5	9.5	5.0	1343	113	3276	1933	0.28	7.4	67	1.5	3.8	7.7		2.2	141	2188	1434	309

1. Depth is referenced below the existing ground surface at the time of testing.
2. Mayne et al., 2002
3. Mayne, 1995
4. Marchetti et al., 2001
5. Schmertman, 1991



Job No.: 16-52112
 Client: Harmony Solar Project
 Project: Near Mapleton, ND
 Sounding ID: DMT-27
 Date: 10-Dec-16
 Ground Water Depth (ft): 8.0
 Zm (bar): 0.0

Datum: WGS 84 Lat/Long
 Latitude: 46.958399
 Longitude: -97.096918

DILATOMETER TEST RESULTS

Depth ¹ (ft)	A (bar)	B (bar)	C (bar)	Average ΔA (bar)	Average ΔB (bar)	p _o (bar)	p ₁ (bar)	p ₂ (bar)	u _o (psf)	v _T ² (pcf)	σ _{vo} (psf)	σ _{vo} ¹ (psf)	I _b	K _D	E _D (bar)	K _e	OCR ³	OCR ⁴	φ ⁴ (deg)	R _M	E _D (ksf)	s _u ⁴ (psf)	s _u ⁵ (psf)	M (ksf)
2.1	1.30	3.75		0.15	0.50	1.4	3.3		0	104	222	222	1.39	12.8	66					2.7	137			374
3.3	4.05	10.80		0.15	0.50	3.9	10.3		0	117	357	357	1.64	22.8	222					3.3	464			1523
4.4	3.65	8.45		0.15	0.50	3.6	8.0		0	114	488	488	1.21	15.4	151					2.9	316			918
5.4	3.25	7.55		0.15	0.50	3.2	7.1		0	113	599	599	1.19	11.2	133	2.0	5.7	14.7		2.6	278	1138	672	725
6.6	3.20	7.55		0.15	0.50	3.2	7.1		0	113	728	728	1.23	9.1	135					2.4	282			677
7.7	1.85	3.85	0.5	0.15	0.50	1.9	3.4	0.6	0	105	849	849	0.73	4.8	49	1.1	2.4	3.9		1.7	103	551	404	179
8.7	1.65	3.85		0.15	0.50	1.7	3.4		43	105	952	908	0.96	3.9	56	1.0	2.0	2.8		1.6	118	462	355	184
9.8	1.10	2.95		0.15	0.50	1.2	2.5		115	101	1068	953	1.11	2.5	44	0.7	1.3	1.4		1.1	91	275	237	102
11.0	2.15	4.30		0.15	0.50	2.2	3.8		187	106	1189	1003	0.74	4.4	55	1.1	2.3	3.5		1.7	114	599	446	191
12.0	1.80	3.05	0.7	0.15	0.50	1.9	2.6	0.9	248	100	1288	1040	0.35	3.6	22	0.9	1.8	2.5		1.5	46	480	376	67
13.1	2.85	5.05	1.0	0.15	0.50	2.9	4.6	1.1	320	107	1411	1091	0.59	5.3	56	1.2	2.7	4.6		1.8	118	812	578	218
14.3	4.40	7.20	1.8	0.15	0.50	4.4	6.7	2.0	391	111	1539	1148	0.53	7.7	78	1.6	3.9	8.3		2.2	164	1371	889	366
15.3	4.65	7.20	2.3	0.15	0.50	4.7	6.7	2.5	453	111	1648	1196	0.44	7.8	69	1.6	4.0	8.4		2.3	145	1451	937	325
16.4	4.80	7.70	2.2	0.15	0.50	4.8	7.2	2.4	524	112	1777	1253	0.52	7.6	82	1.6	3.9	8.1		2.2	171	1473	958	381
17.6	5.25	8.05	2.5	0.15	0.50	5.3	7.6	2.7	596	112	1906	1310	0.45	8.0	78	1.6	4.1	8.7		2.3	164	1626	1046	371
18.5	5.00	7.35	2.5	0.15	0.50	5.1	6.9	2.7	658	111	2015	1358	0.38	7.3	62	1.5	3.7	7.5		2.2	129	1509	992	282
19.7	5.25	7.55	2.9	0.15	0.50	5.3	7.1	3.1	729	111	2142	1413	0.35	7.3	60	1.5	3.7	7.6		2.2	126	1580	1038	274
20.8	5.45	7.80	3.1	0.15	0.50	5.5	7.3	3.3	801	111	2270	1469	0.35	7.3	62	1.5	3.7	7.5		2.2	129	1629	1072	282
21.8	6.30	9.05	4.0	0.15	0.50	6.3	8.6	4.1	862	113	2382	1519	0.37	8.2	77	1.6	4.2	9.0		2.3	160	1937	1239	366
23.0	7.30	11.20	4.1	0.15	0.50	7.3	10.7	4.3	934	116	2515	1581	0.50	9.0	118	1.7	4.6	10.5		2.4	247	2291	1429	593
24.1	6.15	9.05	3.5	0.15	0.50	6.2	8.6	3.7	1006	113	2645	1640	0.41	7.3	82	1.5	3.7	7.5		2.2	171	1810	1192	372
25.1	6.00	8.85	3.6	0.15	0.50	6.0	8.4	3.7	1067	113	2757	1690	0.42	6.8	80	1.4	3.5	6.8		2.1	167	1727	1155	353
26.2	7.65	11.60	4.0	0.15	0.50	7.6	11.1	4.1	1139	117	2891	1752	0.49	8.5	120	1.7	4.3	9.5		2.3	251	2335	1481	584
27.4	8.10	13.00	2.9	0.15	0.50	8.0	12.5	3.0	1210	119	3027	1817	0.60	8.6	155	1.7	4.4	9.7		2.3	323	2465	1558	758
28.4	8.45	11.80	5.6	0.15	0.50	8.5	11.3	5.8	1272	116	3141	1870	0.36	8.8	98	1.7	4.5	10.0		2.4	205	2612	1641	486
29.5	8.05	12.00	5.3	0.15	0.50	8.0	11.5	5.4	1343	117	3276	1932	0.47	8.0	120	1.6	4.1	8.7		2.3	251	2401	1544	570

1. Depth is referenced below the existing ground surface at the time of testing.
2. Mayne et al., 2002
3. Mayne, 1995
4. Marchetti et al., 2001
5. Schmertman, 1991



Job No.: 16-52112
 Client: Harmony Solar Project
 Project: Near Mapleton, ND
 Sounding ID: DMT-33
 Date: 10-Dec-16
 Ground Water Depth (ft): 8.0
 Zm (bar): 0.0

Datum: WGS 84 Lat/Long
 Latitude: 46.954009
 Longitude: -97.107966

DILATOMETER TEST RESULTS

Depth ¹ (ft)	A (bar)	B (bar)	C (bar)	Average ΔA (bar)	Average ΔB (bar)	p _o (bar)	p ₁ (bar)	p ₂ (bar)	u _o (psf)	v _T ² (pcf)	σ _{vo} (psf)	σ _{vo} ¹ (psf)	I _b	K _D	E _D (bar)	K _o	OCR ³	OCR ⁴	φ ⁴ (deg)	R _M	E _D (ksf)	s _u ⁴ (psf)	s _u ⁵ (psf)	M (ksf)
3.3	2.70	4.90	0.20	0.15	0.53	2.8	4.4	0.4	0	107	352	352	0.58	16.5	56	2.5	8.4	26.8		3.0	116	1079	579	345
4.4	2.55	5.95		0.15	0.53	2.6	5.4		0	110	478	478	1.12	11.2	99	2.0	5.7	14.7		2.6	207	906	535	541
5.4	3.20	6.55	1.00	0.15	0.53	3.2	6.0	1.2	0	111	587	587	0.87	11.4	97	2.0	5.8	15.2		2.6	204	1143	672	535
6.6	3.00	5.65	0.65	0.15	0.53	3.1	5.1	0.8	0	109	713	713	0.68	8.9	72	1.7	4.6	10.3		2.4	150	1019	637	359
7.7	3.10	6.05	1.0	0.15	0.53	3.1	5.5	1.2	0	110	839	839	0.76	7.8	83	1.6	4.0	8.4		2.2	173	1013	655	389
8.7	2.80	11.60	0.5	0.15	0.53	2.5	11.1	0.6	43	116	953	910	3.38	5.8	296				37.9	2.0	618			1252
9.8	3.55	6.25	0.9	0.15	0.53	3.6	5.7	1.1	115	110	1080	965	0.60	7.7	74	1.6	3.9	8.1		2.2	154	1139	740	343
11.0	3.90	6.55	1.6	0.15	0.53	4.0	6.0	1.7	187	110	1206	1020	0.54	7.9	72	1.6	4.0	8.5		2.3	150	1251	807	340
12.0	4.55	6.80	2.4	0.15	0.53	4.6	6.3	2.6	248	110	1315	1067	0.37	8.8	57	1.7	4.5	10.1		2.4	120	1499	940	284
13.1	4.45	6.70	2.5	0.15	0.53	4.5	6.2	2.7	320	110	1441	1121	0.38	8.1	57	1.6	4.1	8.9		2.3	120	1425	912	274
14.3	4.35	6.80	2.0	0.15	0.53	4.4	6.3	2.2	391	110	1568	1176	0.44	7.5	65	1.5	3.8	7.9		2.2	135	1350	882	298
15.3	4.05	7.75	1.9	0.15	0.53	4.0	7.2	2.0	453	113	1679	1226	0.83	6.5	110	1.4	3.3	6.3		2.1	230	1183	800	476
16.4	4.15	6.45	2.1	0.15	0.53	4.2	5.9	2.3	524	109	1804	1280	0.43	6.5	59	1.4	3.3	6.3		2.1	124	1223	829	254
17.6	4.60	7.10	2.6	0.15	0.53	4.7	6.6	2.7	596	111	1931	1335	0.44	6.8	66	1.4	3.5	6.8		2.1	139	1366	913	293
18.5	5.15	7.80	2.8	0.15	0.53	5.2	7.3	3.0	658	112	2041	1384	0.42	7.4	72	1.5	3.8	7.7		2.2	150	1556	1021	329
19.7	6.05	8.65	3.7	0.15	0.53	6.1	8.1	3.9	729	113	2171	1441	0.35	8.3	70	1.6	4.2	9.3		2.3	146	1889	1202	339
20.8	6.65	9.60	3.5	0.15	0.53	6.7	9.1	3.7	801	114	2301	1501	0.38	8.8	83	1.7	4.5	10.0		2.4	173	2096	1316	410
21.8	6.70	9.05	4.5	0.15	0.53	6.8	8.5	4.6	862	112	2412	1550	0.28	8.6	61	1.7	4.4	9.7		2.3	127	2100	1327	298
23.0	6.90	9.70	4.5	0.15	0.53	6.9	9.2	4.7	934	114	2543	1609	0.34	8.4	77	1.7	4.3	9.4		2.3	162	2139	1357	376
24.1	7.20	9.75	4.8	0.15	0.53	7.3	9.2	5.0	1006	113	2673	1667	0.29	8.5	68	1.7	4.3	9.5		2.3	143	2234	1415	333
25.1	6.85	9.80	4.8	0.15	0.53	6.9	9.3	4.9	1067	114	2785	1718	0.37	7.8	83	1.6	3.9	8.3		2.2	173	2055	1332	388
26.2	7.05	9.70	4.7	0.15	0.53	7.1	9.2	4.9	1139	113	2915	1776	0.32	7.7	72	1.6	3.9	8.2		2.2	150	2110	1369	336
27.4	7.00	9.55	4.4	0.15	0.53	7.1	9.0	4.5	1210	113	3045	1835	0.30	7.4	68	1.5	3.8	7.7		2.2	143	2062	1353	312
28.4	6.95	9.35	4.5	0.15	0.53	7.0	8.8	4.7	1272	112	3156	1884	0.28	7.1	63	1.5	3.6	7.2		2.1	131	2020	1338	282
29.5	7.35	9.85	4.8	0.15	0.53	7.4	9.3	4.9	1343	113	3286	1942	0.28	7.3	66	1.5	3.7	7.5		2.2	139	2147	1413	302
0.0	0.00	0.00		0.00	0.00	0.0	0.0	0.0	0	0	0	0	0.00	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0

1. Depth is referenced below the existing ground surface at the time of testing.
2. Mayne et al., 2002
3. Mayne, 1995
4. Marchetti et al., 2001
5. Schmertman, 1991

Appendix D

Test Pit Logs



Barr Engineering Company
 4300 MarketPointe Drive Suite 200
 Minneapolis, MN 55435
 Telephone: 952-832-2600

LOG OF BORING TP01

Sheet 1 of 1

Project: Harmony Solar Project

Location: Cass County, North Dakota

Client: Geronimo Energy

Elevation, feet	Depth, feet	Barr Project Number: 34091034	MATERIAL DESCRIPTION (ASTM D2488)	Graphic Log	Sample Type & Rec.	STANDARD PENETRATION TEST DATA N in blows/ft	WATER CONTENT % PL ——— X ——— LL	SIEVE ANALYSIS GRAVEL SAND SILT CLAY FINES	Physical Properties										
									WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %				
0.0	0.0	Surface Elev.:	TOPSOIL (CL): black to dark brown; frozen.																
	0.7		FAT CLAY (CH): brown to dark brown; moist; with silt; some fine sand.																
	2.5																		
	5.0		4.5 ft: trace coarse sand pebbles.																
	7.5		7.0 ft: observed water seeping into test pit.						19.1		52.1								
	10.0		Bottom of Boring at 10.0 feet																

Completion Depth: 10.0
 Date Boring Started: 12/14/16
 Date Boring Completed: 12/14/16
 Logged By: DJZ
 Drilling Contractor: Earthwork Services, Inc.
 Drilling Method: Backhoe
 Ground Surface Elevation:
 Coordinates: UTM 14N N:5199996.8m, E:641808.4m
 Datum: NAD83

Remarks: Trench backfilled and compacted with spoils material.

SAMPLE TYPES	WATER LEVELS (ft)	LEGEND
<input checked="" type="checkbox"/> GRAB SAMPLE	∇ At Time of Drilling 7.0	MC Moisture Content γ Dry Unit Weight ϕ Friction Angle
		Q_u Unconfined Compression Q_p Hand Penetrometer UC Gs Specific Gravity RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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 Minneapolis, MN 55435
 Telephone: 952-832-2600

LOG OF BORING TP02

Sheet 1 of 1

Project: Harmony Solar Project Location: Cass County, North Dakota Client: Geronimo Energy

Elevation, feet	Depth, feet	Barr Project Number: 34091034	MATERIAL DESCRIPTION (ASTM D2488)	Graphic Log Sample Type & Rec.	STANDARD PENETRATION TEST DATA N in blows/ft	WATER CONTENT %	SIEVE ANALYSIS	Physical Properties										
								WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %				
0.0	0.0	Surface Elev.:	TOPSOIL (CL): black to dark brown; frozen.															
1.0	1.0		INTERBEDDED LEAN AND FAT CLAY (CL/CH): brown; moist.															
5.0	5.0					27.3												
7.5	7.5		7.0 ft: wet soil; no water seeping in to test pit.															
10.0	10.0		Bottom of Boring at 10.0 feet															

Completion Depth: 10.0	Remarks: Trench backfilled and compacted with spoils material.
Date Boring Started: 12/14/16	
Date Boring Completed: 12/14/16	
Logged By: DJZ	
Drilling Contractor: Earthwork Services, Inc.	
Drilling Method: Backhoe	
Ground Surface Elevation:	
Coordinates: UTM 14N N:5201218.6m, E:642907.5m	
Datum: NAD83	

SAMPLE TYPES	WATER LEVELS (ft)	LEGEND
GRAB SAMPLE	At Time of Drilling 7.0	MC Moisture Content Q_u Unconfined Compression
		γ Dry Unit Weight Q_p Hand Penetrometer UC
		ϕ Friction Angle Gs Specific Gravity
		RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF BORING TP03

Sheet 1 of 1

Project: Harmony Solar Project

Location: Cass County, North Dakota

Client: Geronimo Energy

Elevation, feet	Depth, feet	Barr Project Number: 34091034	MATERIAL DESCRIPTION (ASTM D2488)	Graphic Log Sample Type & Rec.	STANDARD PENETRATION TEST DATA N in blows/ft	WATER CONTENT % PL ———— X ———— LL	SIEVE ANALYSIS GRAVEL SAND SILT CLAY FINES	Physical Properties										
								WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %				
0.0	Surface Elev.:		TOPSOIL (CL): black to dark brown; frozen.															
1.5			FAT CLAY (CH): brown and black; moist.															
5.0			INTERBEDDED LEAN AND FAT CLAY (CL/CH): brown and black to dark brown; moist.															
7.0			7.0 ft: wet soil; no water seeping in to test pit.															
8.0			FAT CLAY (CH): brown; moist; trace coarse sand pebbles.							24.9								
10.0			Bottom of Boring at 10.0 feet															

Completion Depth: 10.0
 Date Boring Started: 12/14/16
 Date Boring Completed: 12/14/16
 Logged By: DJZ
 Drilling Contractor: Earthwork Services, Inc.
 Drilling Method: Backhoe
 Ground Surface Elevation:
 Coordinates: UTM 14N N:5202863.7m, E:644653.2m
 Datum: NAD83

Remarks: Trench backfilled and compacted with spoils material.

SAMPLE TYPES	WATER LEVELS (ft)	LEGEND	
<input checked="" type="checkbox"/> GRAB <input type="checkbox"/> SAMPLE	∇ At Time of Drilling 7.0	MC Moisture Content	Q_u Unconfined Compression
		γ Dry Unit Weight	Q_p Hand Penetrometer UC
		ϕ Friction Angle	Gs Specific Gravity
			RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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 Minneapolis, MN 55435
 Telephone: 952-832-2600

LOG OF BORING TP04

Sheet 1 of 1

Project: Harmony Solar Project Location: Cass County, North Dakota Client: Geronimo Energy

Elevation, feet	Depth, feet	Barr Project Number: 34091034	MATERIAL DESCRIPTION (ASTM D2488)	Graphic Log Sample Type & Rec.	STANDARD PENETRATION TEST DATA N in blows/ft	WATER CONTENT %	SIEVE ANALYSIS	Physical Properties							
								WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %	
0.0	0.0	Surface Elev.:	TOPSOIL (CL): black to dark brown; frozen.		10 20 30 40	20 40 60	GRAVEL SAND SILT CLAY FINES								
2.5	1.0		FAT CLAY WITH LEAN CLAY AND SILTY CLAY LENSES (CH): brown and black to dark brown; moist.			×									
5.0	5.0					×									
7.5	6.0		FAT CLAY WITH FEW SILTY CLAY LAYERS (CH): brown; moist.												
10.0	10.0		Bottom of Boring at 10.0 feet			×									

Completion Depth: 10.0	Remarks: Trench backfilled and compacted with spoils material.		
Date Boring Started: 12/14/16			
Date Boring Completed: 12/14/16			
Logged By: DJZ			
Drilling Contractor: Earthwork Services, Inc.			
Drilling Method: Backhoe			
Ground Surface Elevation:			
Coordinates: UTM 14N N:5201296.1m, E:645420.4m			
Datum: NAD83			

SAMPLE TYPES	WATER LEVELS (ft)	LEGEND
GRAB SAMPLE	At Time of Drilling Dry	MC Moisture Content Q_u Unconfined Compression
		γ Dry Unit Weight Q_p Hand Penetrometer UC
		ϕ Friction Angle Gs Specific Gravity
		RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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 4300 MarketPointe Drive Suite 200
 Minneapolis, MN 55435
 Telephone: 952-832-2600

LOG OF BORING TP05

Sheet 1 of 1

Project: Harmony Solar Project

Location: Cass County, North Dakota

Client: Geronimo Energy

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Elevation, feet	Depth, feet	Barr Project Number: 34091034	MATERIAL DESCRIPTION (ASTM D2488)	Graphic Log	Sample Type & Rec.	STANDARD PENETRATION TEST DATA N in blows/ft	WATER CONTENT % PL ——— X ——— LL	SIEVE ANALYSIS GRAVEL SAND SILT CLAY FINES	Physical Properties									
									WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %			
0.0	Surface Elev.:		TOPSOIL (CL): black to dark brown; frozen.															
1.5			FAT CLAY (CH): black and dark brown; moist.															
4.0			SILTY LEAN CLAY (CL): dark brown; moist; softer than above and below; increased moisture content.				19.7	40.5					31.3					
6.0			FAT CLAY WITH INTERBEDDED SILTY CLAY LENSES (CH): dark brown; moist.															
10.0			Bottom of Boring at 10.0 feet										39.2					

Completion Depth: 10.0	Remarks: Trench backfilled and compacted with spoils material.		
Date Boring Started: 12/14/16			
Date Boring Completed: 12/14/16			
Logged By: DJZ			
Drilling Contractor: Earthwork Services, Inc.			
Drilling Method: Backhoe			
Ground Surface Elevation:			
Coordinates: UTM 14N N:5202495.4m, E:646611.2m			
Datum: NAD83			

SAMPLE TYPES	WATER LEVELS (ft)	LEGEND
<input checked="" type="checkbox"/> GRAB SAMPLE	<input type="checkbox"/> At Time of Drilling <input type="checkbox"/> Dry	MC Moisture Content γ Dry Unit Weight ϕ Friction Angle
		Q_u Unconfined Compression Q_p Hand Penetrometer UC Gs Specific Gravity RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

Appendix E

Photographs of Test Pits

TP-01



TP-02



TP-03



TP-04



TP-05



Appendix F

Physical Laboratory Test Results

Water Content Test Summary (ASTM:D2216)

Project: Harmony Solar Job: 10689
 Client: Barr Engineering Company Date: 12/29/2016

Sample Information & Classification

Boring #	TP-01	TP-01	TP-01	TP-02	TP-02	TP-03	TP-03	TP-04
Sample #								
Depth (ft)	2-4	6-7	8-10	4-6	8-10	4-6	8-10	2-4
Type	Bag							
Material Classification	Fat Clay (CH)							
Water Content (%)	27.2	30.1	32.6	45.3	33.9	25.2	33.8	30.4

Sample Information & Classification

Boring #	TP-04	TP-04	TP-05	TP-05				
Sample #								
Depth (ft)	4-6	8-10	4-6	8-10				
Type	Bag	Bag	Bag	Bag				
Material Classification	Fat Clay (CH)	Fat Clay (CH)	Lean Clay (CL)	Fat Clay (CH)				
Water Content (%)	31.6	37.3	31.3	39.2				

Sample Information & Classification

Boring #								
Sample #								
Depth (ft)								
Type								
Material Classification								
Water Content (%)								

Sample Information & Classification

Boring #								
Sample #								
Depth (ft)								
Type								
Material Classification								
Water Content (%)								

Laboratory Test Summary

Project: Harmony Solar

Job: 10689

Client: Barr Engineering Company

Date: 12/29/2016

Sample Information & Classification

Boring #	TP-01	TP-02	TP-03	TP-05				
Sample #								
Depth (ft)	6-7	4-6	8-10	4-6				
Sample Type	Bag	Bag	Bag	Bag				
Material Classification	Fat Clay (CH)	Fat Clay (CH)	Fat Clay (CH)	Lean Clay (CL)				

Atterberg Limits (ASTM:D4318)

Liquid Limit	52.1	114.7	70.9	40.5				
Plastic Limit	19.1	27.3	24.9	19.7				
Plasticity Index	33.0	87.4	46.0	20.8				

Sample Information & Classification

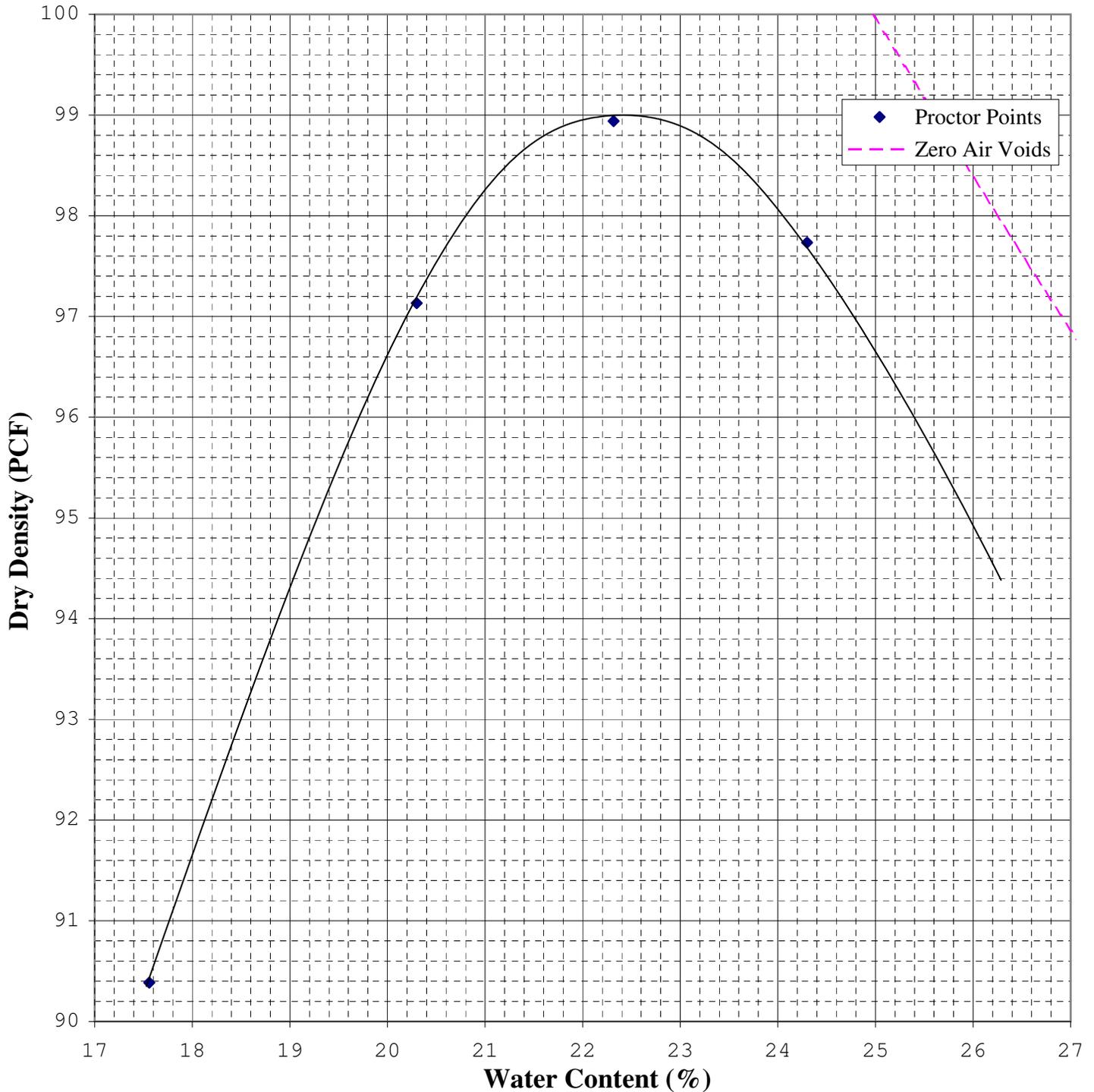
Boring #								
Sample #								
Depth (ft)								
Sample Type								
Material Classification								

Atterberg Limits (ASTM:D4318)

Liquid Limit								
Plastic Limit								
Plasticity Index								

Moisture Density Curve ASTM: D698, Method B

Project: **Harmony Solar** Date: **12/27/16**
 Client: **Barr Engineering Company** Job No. **10689**
 Boring No. **TP-01** Sample: Depth(ft): **1-5** Location:
 Soil Type: **Lean Clay with a trace of organic material (CL)**
 As Received W.C. (%): **27.1** LL: PL: PI: Specific Gravity: **2.67** *Assumed
 Maximum Dry Density (pcf): **99.0** Opt. Water Content (%): **22.5**



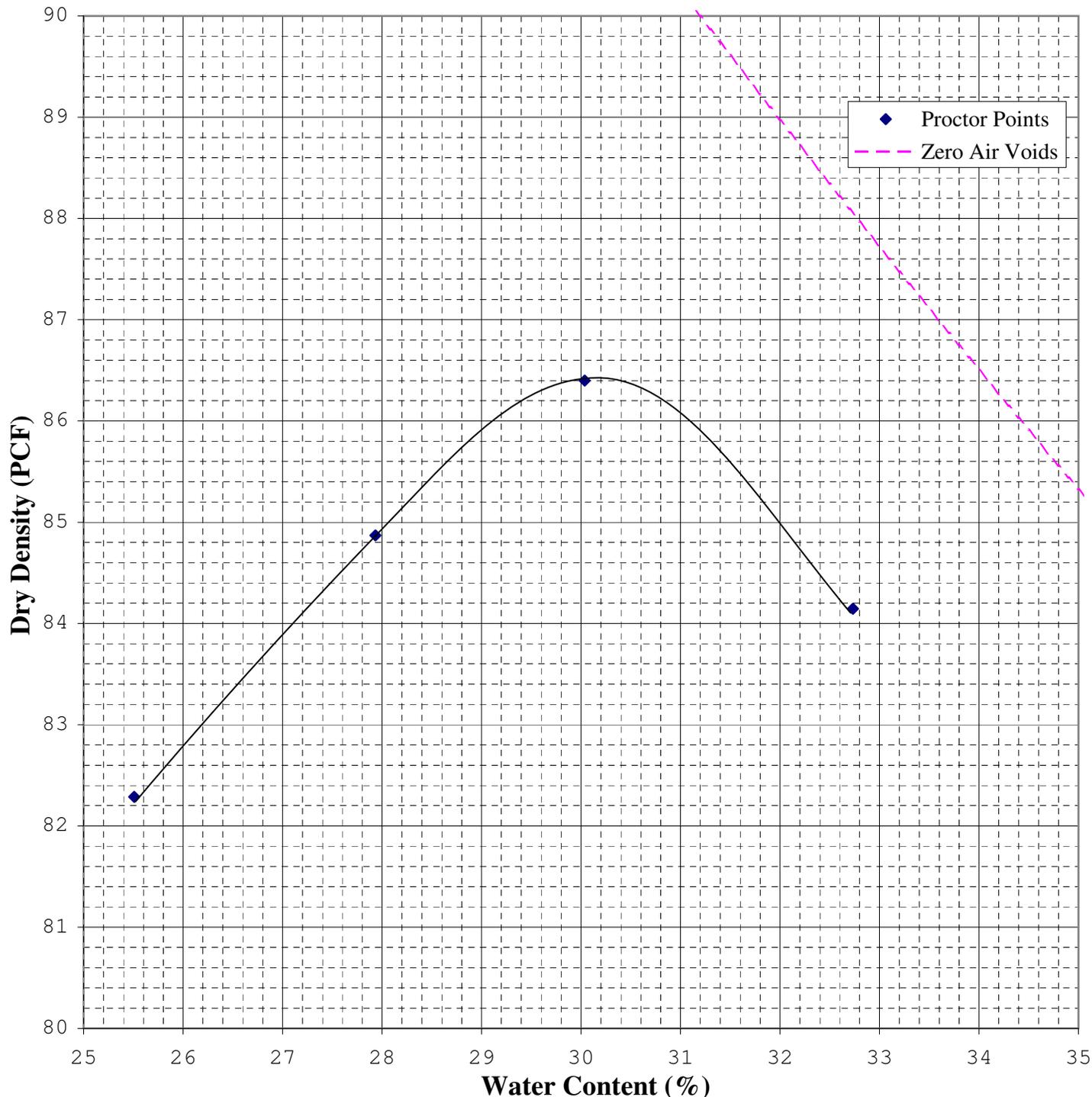
9530 James Ave South



Bloomington, MN 55431

Moisture Density Curve ASTM: D698, Method B

Project: Harmony Solar		Date: 12/27/16
Client: Barr Engineering Company		Job No. 10689
Boring No. TP-03	Sample:	Depth(ft): 1-5
Location:		
Soil Type: Organic Clay with sand (OL)		
As Received W.C. (%): 26.6	LL: ◆	PL: ▲
		PI: ◆
		Specific Gravity: 2.62 ◆ *Assumed ▲
Maximum Dry Density (pcf): 86.4		Opt. Water Content (%): 30.2



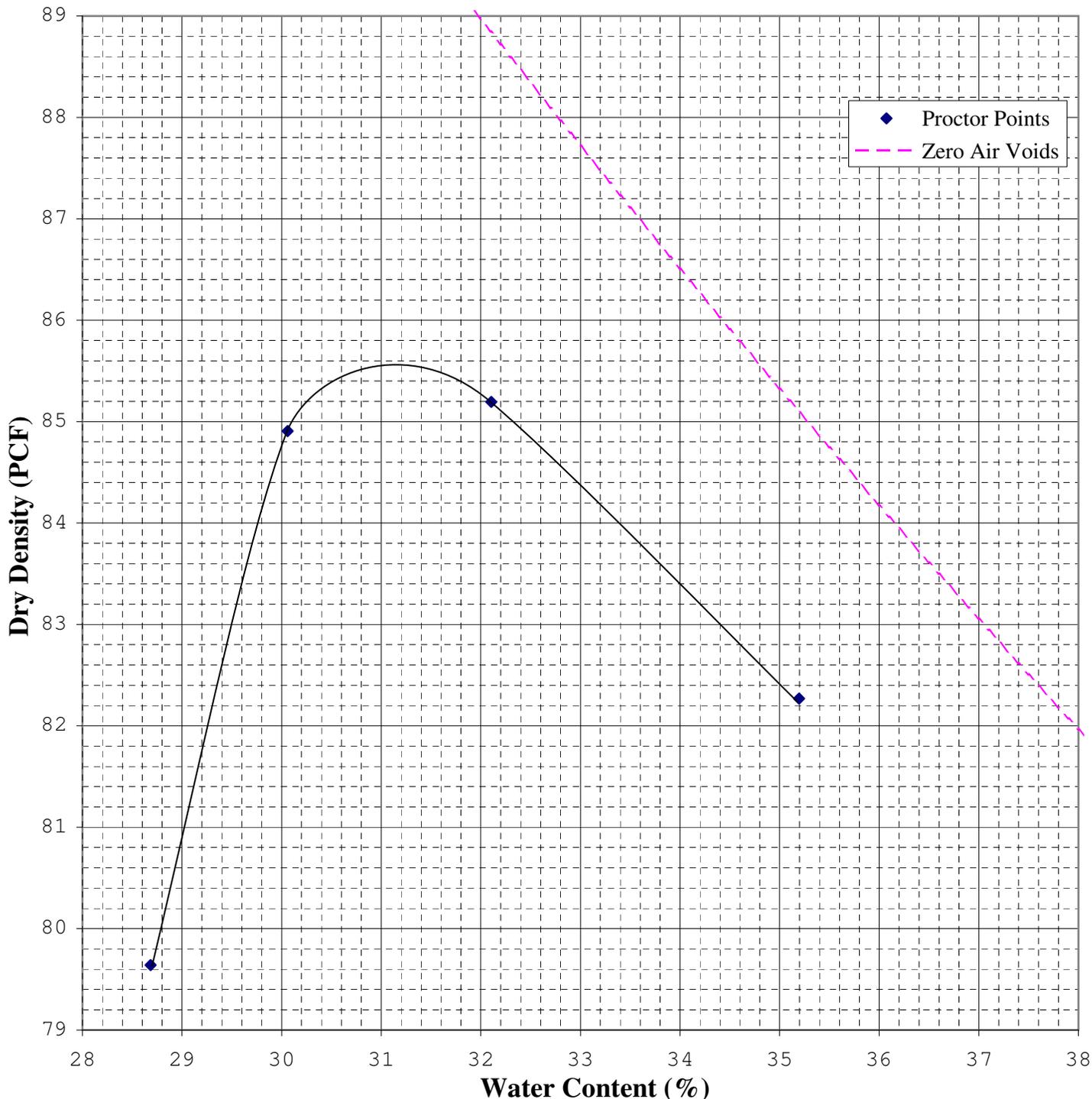
9530 James Ave South



Bloomington, MN 55431

Moisture Density Curve ASTM: D698, Method B

Project:	Harmony Solar	Date:	12/27/16
Client:	Barr Engineering Company	Job No.:	10689
Boring No.:	TP-05	Sample:	
		Depth(ft):	1-5
		Location:	
Soil Type:	Organic Clay with sand (OH)		
As Received W.C. (%):	36.0	LL:	
		PL:	
		PI:	
		Specific Gravity:	2.62 *Assumed
Maximum Dry Density (pcf):	85.6	Opt. Water Content (%):	31.1



Appendix G

Chemical Test Results

pH Testing Summary Sheet (ASTM:D4972)

Project: Harmony Solar
 Client: Barr Engineering Company

Job: 10689
 Date: 12/27/2016

Boring / Location	Sample	Sample Type	Depth (ft)	pH	Visual Classification
TP-01		Bulk	1-5	7.9	Lean Clay w/a trace of organic material (CL/CH)
TP-02		Bulk	1-5	8.1	Fat Clay (CH)
TP-04		Bulk	1-5	7.9	Fat Clay w/a trace of organic material (CH)
TP-05		Bulk	1-5	7.6	Organic Clay with sand (OH)

January 06, 2017

John Whelan
Soil Engineering Testing
9530 James Ave S
Minneapolis, MN 55431

RE: Project: 10689 Harmony Solar
Pace Project No.: 1280933

Dear John Whelan:

Enclosed are the analytical results for sample(s) received by the laboratory on December 23, 2016. The results relate only to the samples included in this report. Results reported herein conform to the most current, applicable TNI/NELAC standards and the laboratory's Quality Assurance Manual, where applicable, unless otherwise noted in the body of the report.

If you have any questions concerning this report, please feel free to contact me.

Sincerely,



Kristin A Hanson
kristin.hanson@pacelabs.com
Project Manager

Enclosures

cc: Slade Olson, Soil Engineering Testing
Tyler Sandoz, SET



REPORT OF LABORATORY ANALYSIS

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CERTIFICATIONS

Project: 10689 Harmony Solar

Pace Project No.: 1280933

Virginia Minnesota Certification ID's

315 Chestnut Street, Virginia, MN 55792

Alaska Certification UST-107

Alaska Certification UST-107

Alaska Certification #MN01084

Arizona Department of Health Certification #AZ0785

Minnesota Dept of Health Certification #: 027-137-445

North Dakota Certification: # R-203

Wisconsin DNR Certification # : 998027470

WA Department of Ecology Lab ID# C1007

Nevada DNR #MN010842015-1

Oklahoma Department of Environmental Quality

REPORT OF LABORATORY ANALYSIS

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SAMPLE SUMMARY

Project: 10689 Harmony Solar

Pace Project No.: 1280933

Lab ID	Sample ID	Matrix	Date Collected	Date Received
1280933001	TP-01 @1-5'	Solid	12/22/16 00:00	12/23/16 20:40
1280933002	TP-02 @1-5'	Solid	12/22/16 00:00	12/23/16 20:40
1280933003	TP-04 @1-5'	Solid	12/22/16 00:00	12/23/16 20:40
1280933004	TP-05 @1-5'	Solid	12/22/16 00:00	12/23/16 20:40

REPORT OF LABORATORY ANALYSIS

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SAMPLE ANALYTE COUNT

Project: 10689 Harmony Solar

Pace Project No.: 1280933

Lab ID	Sample ID	Method	Analysts	Analytes Reported	Laboratory
1280933001	TP-01 @1-5'	ASTM D 2974-13 (2013)	KRV	1	PASI-V
		EPA 9056A	DMB	2	PASI-V
1280933002	TP-02 @1-5'	ASTM D 2974-13 (2013)	KRV	1	PASI-V
		EPA 9056A	DMB	2	PASI-V
1280933003	TP-04 @1-5'	ASTM D 2974-13 (2013)	KRV	1	PASI-V
		EPA 9056A	DMB	2	PASI-V
1280933004	TP-05 @1-5'	ASTM D 2974-13 (2013)	KRV	1	PASI-V
		EPA 9056A	DMB	2	PASI-V

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ANALYTICAL RESULTS

Project: 10689 Harmony Solar

Pace Project No.: 1280933

Sample: TP-01 @1-5' **Lab ID: 1280933001** Collected: 12/22/16 00:00 Received: 12/23/16 20:40 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
Dry Weight Analytical Method: ASTM D 2974-13 (2013)								
Percent Moisture	20.7	%	0.10	1		01/03/17 12:09		
9056 IC Anions Analytical Method: EPA 9056A Preparation Method: EPA 300.0								
Chloride	ND	mg/kg	9.7	1	01/05/17 11:00	01/05/17 22:15	16887-00-6	
Sulfate	120	mg/kg	19.5	1	01/05/17 11:00	01/05/17 22:15	14808-79-8	

Sample: TP-02 @1-5' **Lab ID: 1280933002** Collected: 12/22/16 00:00 Received: 12/23/16 20:40 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
Dry Weight Analytical Method: ASTM D 2974-13 (2013)								
Percent Moisture	22.7	%	0.10	1		01/03/17 12:09		
9056 IC Anions Analytical Method: EPA 9056A Preparation Method: EPA 300.0								
Chloride	ND	mg/kg	10.0	1	01/05/17 11:00	01/06/17 01:07	16887-00-6	
Sulfate	32.2	mg/kg	20.0	1	01/05/17 11:00	01/06/17 01:07	14808-79-8	

Sample: TP-04 @1-5' **Lab ID: 1280933003** Collected: 12/22/16 00:00 Received: 12/23/16 20:40 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
Dry Weight Analytical Method: ASTM D 2974-13 (2013)								
Percent Moisture	24.0	%	0.10	1		01/03/17 12:09		
9056 IC Anions Analytical Method: EPA 9056A Preparation Method: EPA 300.0								
Chloride	ND	mg/kg	9.7	1	01/05/17 11:00	01/06/17 01:29	16887-00-6	
Sulfate	102	mg/kg	19.4	1	01/05/17 11:00	01/06/17 01:29	14808-79-8	

Sample: TP-05 @1-5' **Lab ID: 1280933004** Collected: 12/22/16 00:00 Received: 12/23/16 20:40 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
Dry Weight Analytical Method: ASTM D 2974-13 (2013)								
Percent Moisture	22.6	%	0.10	1		01/03/17 12:09		
9056 IC Anions Analytical Method: EPA 9056A Preparation Method: EPA 300.0								
Chloride	ND	mg/kg	10.0	1	01/05/17 11:00	01/05/17 15:05	16887-00-6	
Sulfate	23700	mg/kg	4010	200	01/05/17 11:00	01/05/17 18:40	14808-79-8	

REPORT OF LABORATORY ANALYSIS

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QUALITY CONTROL DATA

Project: 10689 Harmony Solar

Pace Project No.: 1280933

QC Batch:	103159	Analysis Method:	ASTM D 2974-13 (2013)
QC Batch Method:	ASTM D 2974-13 (2013)	Analysis Description:	Dry Weight/Percent Moisture
Associated Lab Samples:	1280933001, 1280933002, 1280933003, 1280933004		

SAMPLE DUPLICATE: 409943

Parameter	Units	1280933002 Result	Dup Result	RPD	Max RPD	Qualifiers
Percent Moisture	%	22.7	22.5	1	10	

Results presented on this page are in the units indicated by the "Units" column except where an alternate unit is presented to the right of the result.

REPORT OF LABORATORY ANALYSIS

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QUALITY CONTROL DATA

Project: 10689 Harmony Solar

Pace Project No.: 1280933

QC Batch: 103369 Analysis Method: EPA 9056A
 QC Batch Method: EPA 300.0 Analysis Description: 9056 IC Anions, Soil
 Associated Lab Samples: 1280933001, 1280933002, 1280933003, 1280933004

METHOD BLANK: 410833 Matrix: Solid
 Associated Lab Samples: 1280933001, 1280933002, 1280933003, 1280933004

Parameter	Units	Blank Result	Reporting Limit	Analyzed	Qualifiers
Chloride	mg/kg	ND	10.0	01/05/17 12:38	
Sulfate	mg/kg	ND	20.0	01/05/17 12:38	

LABORATORY CONTROL SAMPLE: 410832

Parameter	Units	Spike Conc.	LCS Result	LCS % Rec	% Rec Limits	Qualifiers
Chloride	mg/kg	500	528	106	80-120	
Sulfate	mg/kg	500	519	104	80-120	

MATRIX SPIKE & MATRIX SPIKE DUPLICATE: 410834 410835

Parameter	Units	1280936015 Result	MS Spike Conc.	MSD Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limits	RPD	Max RPD	Qual
Chloride	mg/kg	ND	493	495	528	531	106	107	80-120	1	20	
Sulfate	mg/kg	ND	493	495	527	526	104	104	80-120	0	20	

MATRIX SPIKE & MATRIX SPIKE DUPLICATE: 410836 410837

Parameter	Units	1280934001 Result	MS Spike Conc.	MSD Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limits	RPD	Max RPD	Qual
Chloride	mg/kg	ND	490	497	537	544	108	108	80-120	1	20	
Sulfate	mg/kg	40.1	490	497	549	561	104	105	80-120	2	20	

Results presented on this page are in the units indicated by the "Units" column except where an alternate unit is presented to the right of the result.

REPORT OF LABORATORY ANALYSIS

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QUALIFIERS

Project: 10689 Harmony Solar

Pace Project No.: 1280933

DEFINITIONS

DF - Dilution Factor, if reported, represents the factor applied to the reported data due to dilution of the sample aliquot.

ND - Not Detected at or above adjusted reporting limit.

J - Estimated concentration above the adjusted method detection limit and below the adjusted reporting limit.

MDL - Adjusted Method Detection Limit.

PQL - Practical Quantitation Limit.

RL - Reporting Limit.

S - Surrogate

1,2-Diphenylhydrazine decomposes to and cannot be separated from Azobenzene using Method 8270. The result for each analyte is a combined concentration.

Consistent with EPA guidelines, unrounded data are displayed and have been used to calculate % recovery and RPD values.

LCS(D) - Laboratory Control Sample (Duplicate)

MS(D) - Matrix Spike (Duplicate)

DUP - Sample Duplicate

RPD - Relative Percent Difference

NC - Not Calculable.

SG - Silica Gel - Clean-Up

U - Indicates the compound was analyzed for, but not detected.

N-Nitrosodiphenylamine decomposes and cannot be separated from Diphenylamine using Method 8270. The result reported for each analyte is a combined concentration.

Pace Analytical is TNI accredited. Contact your Pace PM for the current list of accredited analytes.

TNI - The NELAC Institute.

LABORATORIES

PASI-V Pace Analytical Services - Virginia

REPORT OF LABORATORY ANALYSIS

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QUALITY CONTROL DATA CROSS REFERENCE TABLE

Project: 10689 Harmony Solar

Pace Project No.: 1280933

Lab ID	Sample ID	QC Batch Method	QC Batch	Analytical Method	Analytical Batch
1280933001	TP-01 @1-5'	ASTM D 2974-13 (2013)	103159		
1280933002	TP-02 @1-5'	ASTM D 2974-13 (2013)	103159		
1280933003	TP-04 @1-5'	ASTM D 2974-13 (2013)	103159		
1280933004	TP-05 @1-5'	ASTM D 2974-13 (2013)	103159		
1280933001	TP-01 @1-5'	EPA 300.0	103369	EPA 9056A	103432
1280933002	TP-02 @1-5'	EPA 300.0	103369	EPA 9056A	103432
1280933003	TP-04 @1-5'	EPA 300.0	103369	EPA 9056A	103432
1280933004	TP-05 @1-5'	EPA 300.0	103369	EPA 9056A	103432

REPORT OF LABORATORY ANALYSIS

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Sample Condition Upon Receipt **Client Name:** SET **Project #:**

Courier: Fed Ex UPS USPS Client
 Commercial Pace SpeeDee Other: Quicksilver

Tracking Number: _____

Custody Seal on Cooler/Box Present? Yes No **Seals Intact?** Yes No **Optional:** Proj. Due Date: _____ Proj. Name: _____

Packing Material: Bubble Wrap Bubble Bags None Other: _____ **Temp Blank?** Yes No

Thermometer 151401163 **Type of Ice:** Wet Blue None Samples on ice, cooling process has begun
Used: 151401164

Cooler Temp Read (°C): 10.4 **Cooler Temp Corrected (°C):** 10.4 **Biological Tissue Frozen?** Yes No N/A
 Temp should be above freezing to 6°C **Correction Factor:** True **Date and Initials of Person Examining Contents:** BC 12-22-16

USDA Regulated Soil (N/A, water sample)
 Did samples originate in a quarantine zone within the United States: AL, AR, CA, FL, GA, ID, LA, MS, NC, NM, NY, OK, OR, SC, TN, TX or VA (check maps)? Yes No Did samples originate from a foreign source (internationally, including Hawaii and Puerto Rico)? Yes No
 If Yes to either question, fill out a Regulated Soil Checklist (F-MN-Q-338) and include with SCUR/COC paperwork.

	COMMENTS:
Chain of Custody Present? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	1.
Chain of Custody Filled Out? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	2.
Chain of Custody Relinquished? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	3.
Sampler Name and/or Signature on COC? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No <input type="checkbox"/> N/A	4.
Samples Arrived within Hold Time? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	5.
Short Hold Time Analysis (<72 hr)? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	6.
Rush Turn Around Time Requested? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	7.
Sufficient Volume? <input type="checkbox"/> Yes <input type="checkbox"/> No	8.
Correct Containers Used? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	9.
-Pace Containers Used? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	
Containers Intact? <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	10.
Filtered Volume Received for Dissolved Tests? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	11. Note if sediment is visible in the dissolved container
Sample Labels Match COC? <input checked="" type="checkbox"/> Yes <input checked="" type="checkbox"/> No <input type="checkbox"/> N/A -Includes Date/Time/ID/Analysis Matrix: <u>SL</u> <u>BC 12-22-16</u>	12. <u>No date and time on COC and Label</u>
All containers needing acid/base preservation have been checked? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	13. <input type="checkbox"/> HNO ₃ <input type="checkbox"/> H ₂ SO ₄ <input type="checkbox"/> NaOH Positive for Res. Chlorine? Y N
All containers needing preservation are found to be in compliance with EPA recommendation? (HNO ₃ , H ₂ SO ₄ , <2pH, NaOH >9 Sulfide, NaOH >12 Cyanide) <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	Sample #
Exceptions: VOA, Coliform, TOC/DOC Oil and Grease, DRO/8015 (water) and Dioxin. <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	Initial when completed: Lot # of added preservative:
Headspace in VOA Vials (>6mm)? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	14.
Trip Blank Present? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	15.
Trip Blank Custody Seals Present? <input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	
Pace Trip Blank Lot # (if purchased):	

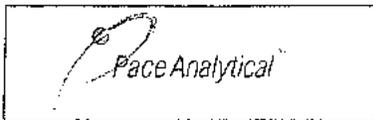
CLIENT NOTIFICATION/RESOLUTION **Field Data Required?** Yes No

Person Contacted: _____ Date/Time: _____

Comments/Resolution: _____

Project Manager Review: [Signature] **Date:** 12-28-16

Note: Whenever there is a discrepancy affecting North Carolina compliance samples, a copy of this form will be sent to the North Carolina DEHNR Certification Office (i.e. out of hold, incorrect preservative, out of temp, incorrect containers).



Document Name:
Sample Condition Upon Receipt Form
Document No.:
F-VM-C-001-Rev.09

Document Revised: 23Feb2015
Page 1 of 1
Issuing Authority:
Pace Virginia, Minnesota Quality Office

Sample Condition
Upon Receipt

Client Name: Get Project: WO#: 1280933

WO#: 1280933



Courier: Fed Ex UPS USPS Client
 Commercial Pace Other

Tracking Number: _____

Custody Seal on Cooler/Box Present? Yes No Seals Intact? Yes No

Packing Material: Bubble Wrap Bubble Bags None Other: Hard Case Temp Blank? Yes No

Thermometer Used: 140792808 Type of Ice: Wet Blue None Samples on ice, cooling process has begun

Cooler Temp Read °C: 0.8 Cooler Temp Corrected °C: 1.2 Biological Tissue Frozen? Yes No N/A
Temp should be above freezing to 6°C Correction Factor: +0.3 Date and Initials of Person Examining Contents: JMC 12/27/16

Comments: CA 12-27-16

Chain of Custody Present?	<input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A	1.
Chain of Custody Filled Out?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A	2.
Chain of Custody Relinquished?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A	3.
Sampler Name and Signature on COC?	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No <input type="checkbox"/> N/A	4.
Samples Arrived within Hold Time?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A	5.
Short Hold Time Analysis (<72 hr)?	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No <input type="checkbox"/> N/A	6.
Rush Turn Around Time Requested?	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No <input type="checkbox"/> N/A	7.
Sufficient Volume?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A	8.
Correct Containers Used?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A	9.
-Pace Containers Used?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A	
Containers Intact?	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/> N/A	10.
Filtered Volume Received for Dissolved Tests?	<input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	11. Note if sediment is visible in the dissolved containers.
Sample Labels Match COC?	<input checked="" type="checkbox"/> Yes <input checked="" type="checkbox"/> No <input type="checkbox"/> N/A	12. <u>NO DATE/TIMES ON COC OR BAGS</u>
-Includes Date/Time/ID/Analysis Matrix: <u>SL</u>		
All containers needing acid/base preservation will be checked and documented in the pH logbook.	<input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	See pH log for results and additional preservation documentation
Headspace in Methyl Mercury Container	<input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	13.
Headspace in VOA Vials (>6mm)?	<input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	14.
Trip Blank Present?	<input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	15.
Trip Blank Custody Seals Present?	<input type="checkbox"/> Yes <input type="checkbox"/> No <input checked="" type="checkbox"/> N/A	
Pace Trip-Blank Lot # (if purchased):		

CLIENT NOTIFICATION/RESOLUTION

Field Data Required? Yes No

Person Contacted: John

Date/Time: 12-27-16 KAT

Comments/Resolution: was relinquish date

FECAL WAIVER ON FILE Y N

TEMPERATURE WAIVER ON FILE Y N

Project Manager Review: [Signature]

Date: 12-28-16

Note: Whenever there is a discrepancy affecting North Carolina compliance samples, a copy of this form will be sent to the North Carolina DEHNR Certification Office (i.e. out of hold, incorrect preservative, out of temp, incorrect containers)

Soil Engineering Testing, Inc.

Sample Delivery Group: L882704
Samples Received: 01/07/2017
Project Number: 10689
Description: Harmony Solar

Report To: John Whelan
9530 James Ave. South
Bloomington, MN 55431

Entire Report Reviewed By:



John Hawkins
Technical Service Representative

Results relate only to the items tested or calibrated and are reported as rounded values. This test report shall not be reproduced, except in full, without written approval of the laboratory. Where applicable, sampling conducted by ESC is performed per guidance provided in laboratory standard operating procedures: 060302, 060303, and 060304.



¹ Cp: Cover Page	1	
² Tc: Table of Contents	2	
³ Ss: Sample Summary	3	
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⁵ Sr: Sample Results	5	
TP-05 L882704-01	5	
⁶ Qc: Quality Control Summary	6	
Wet Chemistry by Method 9056A	6	
⁷ Gl: Glossary of Terms	7	
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⁹ Sc: Chain of Custody	9	

SAMPLE SUMMARY



TP-05 L882704-01 Solid

Collected by

Collected date/time
01/06/17 12:00

Received date/time
01/07/17 10:00

Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst
Wet Chemistry by Method 9056A	WG942326	1	01/12/17 13:30	01/12/17 17:57	KCF
Wet Chemistry by Method 9056A	WG942326	20	01/12/17 13:30	01/13/17 08:19	KCF

¹Cp

²Tc

³Ss

⁴Cn

⁵Sr

⁶Qc

⁷Gl

⁸Al

⁹Sc



All sample aliquots were received at the correct temperature, in the proper containers, with the appropriate preservatives, and within method specified holding times. All MDL (LOD) and RDL (LOQ) values reported for environmental samples have been corrected for the dilution factor used in the analysis. All Method and Batch Quality Control are within established criteria except where addressed in this case narrative, a non-conformance form or properly qualified within the sample results. By my digital signature below, I affirm to the best of my knowledge, all problems/anomalies observed by the laboratory as having the potential to affect the quality of the data have been identified by the laboratory, and no information or data have been knowingly withheld that would affect the quality of the data.

John Hawkins
Technical Service Representative

- ¹ Cp
- ² Tc
- ³ Ss
- ⁴ Cn
- ⁵ Sr
- ⁶ Qc
- ⁷ Gl
- ⁸ Al
- ⁹ Sc



Wet Chemistry by Method 9056A

Analyte	Result mg/kg	Qualifier	RDL mg/kg	Dilution	Analysis date / time	Batch
Chloride	41.8		10.0	1	01/12/2017 17:57	WG942326
Sulfate	16100		1000	20	01/13/2017 08:19	WG942326

¹ Cp

² Tc

³ Ss

⁴ Cn

⁵ Sr

⁶ Qc

⁷ Gl

⁸ Al

⁹ Sc



Method Blank (MB)

(MB) R3190395-1 01/12/17 15:10

Analyte	MB Result	MB Qualifier	MB MDL	MB RDL
	mg/kg		mg/kg	mg/kg
Chloride	U		0.795	10.0
Sulfate	U		0.57	50.0

1 Cp

2 Tc

3 Ss

4 Cn

Laboratory Control Sample (LCS) • Laboratory Control Sample Duplicate (LCSD)

(LCS) R3190395-2 01/12/17 15:30 • (LCSD) R3190395-3 01/12/17 15:51

Analyte	Spike Amount	LCS Result	LCSD Result	LCS Rec.	LCSD Rec.	Rec. Limits	LCS Qualifier	LCSD Qualifier	RPD	RPD Limits
	mg/kg	mg/kg	mg/kg	%	%	%			%	%
Chloride	200	200	196	100	98	80-120			2	15
Sulfate	200	197	194	98	97	80-120			1	15

5 Sr

6 Qc

L882704-01 Original Sample (OS) • Matrix Spike (MS) • Matrix Spike Duplicate (MSD)

(OS) L882704-01 01/12/17 17:57 • (MS) R3190395-5 01/12/17 18:18 • (MSD) R3190395-6 01/12/17 19:21

Analyte	Spike Amount	Original Result	MS Result	MSD Result	MS Rec.	MSD Rec.	Dilution	Rec. Limits	MS Qualifier	MSD Qualifier	RPD	RPD Limits
	mg/kg	mg/kg	mg/kg	mg/kg	%	%		%			%	%
Chloride	500	41.8	501	507	92	93	1	80-120			1	15

7 Gl

8 Al

9 Sc



Abbreviations and Definitions

SDG	Sample Delivery Group.
MDL	Method Detection Limit.
RDL	Reported Detection Limit.
U	Not detected at the Reporting Limit (or MDL where applicable).
RPD	Relative Percent Difference.
Original Sample	The non-spiked sample in the prep batch used to determine the Relative Percent Difference (RPD) from a quality control sample. The Original Sample may not be included within the reported SDG.
Rec.	Recovery.

Qualifier Description

The remainder of this page intentionally left blank, there are no qualifiers applied to this SDG.

¹ Cp

² Tc

³ Ss

⁴ Cn

⁵ Sr

⁶ Qc

⁷ Gl

⁸ Al

⁹ Sc



ESC Lab Sciences is the only environmental laboratory accredited/certified to support your work nationwide from one location. One phone call, one point of contact, one laboratory. No other lab is as accessible or prepared to handle your needs throughout the country. Our capacity and capability from our single location laboratory is comparable to the collective totals of the network laboratories in our industry. The most significant benefit to our "one location" design is the design of our laboratory campus. The model is conducive to accelerated productivity, decreasing turn-around time, and preventing cross contamination, thus protecting sample integrity. Our focus on premium quality and prompt service allows us to be **YOUR LAB OF CHOICE**.
 * Not all certifications held by the laboratory are applicable to the results reported in the attached report.



State Accreditations

Alabama	40660	Nevada	TN-03-2002-34
Alaska	UST-080	New Hampshire	2975
Arizona	AZ0612	New Jersey–NELAP	TN002
Arkansas	88-0469	New Mexico	TN00003
California	01157CA	New York	11742
Colorado	TN00003	North Carolina	Env375
Connecticut	PH-0197	North Carolina ¹	DW21704
Florida	E87487	North Carolina ²	41
Georgia	NELAP	North Dakota	R-140
Georgia ¹	923	Ohio–VAP	CL0069
Idaho	TN00003	Oklahoma	9915
Illinois	200008	Oregon	TN200002
Indiana	C-TN-01	Pennsylvania	68-02979
Iowa	364	Rhode Island	221
Kansas	E-10277	South Carolina	84004
Kentucky ¹	90010	South Dakota	n/a
Kentucky ²	16	Tennessee ¹⁴	2006
Louisiana	AI30792	Texas	T 104704245-07-TX
Maine	TN0002	Texas ⁵	LAB0152
Maryland	324	Utah	6157585858
Massachusetts	M-TN003	Vermont	VT2006
Michigan	9958	Virginia	109
Minnesota	047-999-395	Washington	C1915
Mississippi	TN00003	West Virginia	233
Missouri	340	Wisconsin	9980939910
Montana	CERT0086	Wyoming	A2LA
Nebraska	NE-OS-15-05		

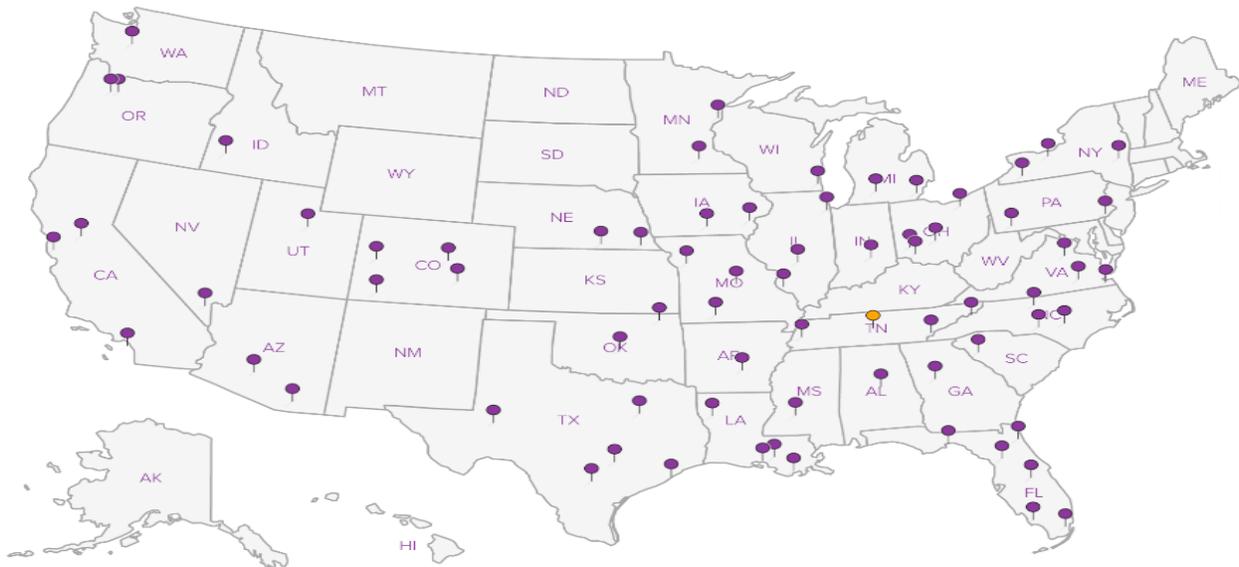
Third Party & Federal Accreditations

A2LA – ISO 17025	1461.01	AIHA	100789
A2LA – ISO 17025 ⁵	1461.02	DOD	1461.01
Canada	1461.01	USDA	S-67674
EPA–Crypto	TN00003		

¹ Drinking Water ² Underground Storage Tanks ³ Aquatic Toxicity ⁴ Chemical/Microbiological ⁵ Mold ^{n/a} Accreditation not applicable

Our Locations

ESC Lab Sciences has sixty-four client support centers that provide sample pickup and/or the delivery of sampling supplies. If you would like assistance from one of our support offices, please contact our main office. **ESC Lab Sciences performs all testing at our central laboratory.**

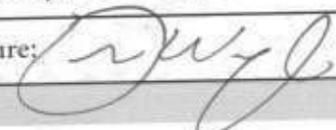




Cooler Receipt Form

Client: SOIENGBMN SDG# LB 82704
 Cooler Received/Opened On: 1/7/17 Temperature Upon Receipt: AMB °C

Received By: Don Wright

Signature: 

Receipt Check List	Yes	No	N/A
Were custody seals on outside of cooler and intact?			<input checked="" type="checkbox"/>
Were custody papers properly filled out?	<input checked="" type="checkbox"/>		
Did all bottles arrive in good condition?	<input checked="" type="checkbox"/>		
Were correct bottles used for the analyses requested?	<input checked="" type="checkbox"/>		
Was sufficient amount of sample sent in each bottle?	<input checked="" type="checkbox"/>		
Were all applicable sample containers correctly preserved and checked for preservation? (Any not in accepted range noted on COC)			<input checked="" type="checkbox"/>
If applicable, was an observable VOA headspace present?			<input checked="" type="checkbox"/>
Non Conformance Generated. (If yes see attached NCF)			<input checked="" type="checkbox"/>

Appendix H

Electrical Resistivity Test Results

May 5, 2017

Mr. Joe Ibrahim
Director of Construction
Geronimo Energy
7650 Edinborough Way, Suite 725
Edina, Minnesota 55435

**Re: Soil Electrical Resistivity Testing
Harmony Solar Project
Cass County, North Dakota**

Dear Mr. Ibrahim:

Barr Engineering Co. (Barr) collected soil resistivity measurements at the Harmony Solar Project site on May 2, 2017. This letter presents the methods and results. [Table 1](#) summarizes the coordinates of each test location and other pertinent information.

Methods

A total of four electrical resistivity tests were completed by Barr for the project. Tests were performed at three proposed test pit locations and one location near an existing substation, assumed to be representative of the interconnect point for the project. Test locations were selected by Barr to be representative of the soils present across the site (included in [Table 1](#)). All tests were centered as close to the proposed test location as possible while trying to avoid ground disturbed by the test pits. The test pit locations were offset approximately 100 feet from the section line or roadway to avoid any affects from potential utilities. The test locations are indicated on [Figure 1](#). Coordinates of each test location and other pertinent information can be found in [Table 1](#).

Table 1 Electrical Resistivity Testing Conditions and Coordinates

Resistivity Testing Conditions			Coordinates [NAD83]	
Location ID	Sounding Number	Ambient Air Temperature [°F]	Latitude	Longitude
TP-01	1	66	46.93831	-97.13644
TP-02	2	64	46.94882	-97.12203
TP-03	3	64	46.96322	-97.09856
CPT-39	4	62	46.95429	-97.07553

Barr conducted the work in accordance with ASTM method G57 "Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method" (equivalent to IEEE Std. 81).

At all tests locations, a single resistivity array orientation was utilized and five resistivity measurements in the array orientation were obtained. Each measurement corresponded to one of the following electrode ("a") spacings: 2, 5, 10, 20, and 40 feet. The array orientation was then rotated 90 degrees with measurements taken at the same "a" spacings.

The equipment used to collect the data consisted of a resistivity meter, four metal electrodes and connecting wire. A Mini-Res Ultra resistivity meter manufactured by L & R Instruments, Inc. was used to collect the data. The resistivity meter read in resistance (Ω) directly, and did not require the conversion of electrical potential (V) and inductance (I) to calculate resistance (V/I in Ω). Before and after each array was completed, the resistivity meter was connected to a resistor of known resistance, and the resulting values were compared to the known resistance value for quality assurance and quality control purposes. The meter was properly calibrated for all test locations and no instrument adjustments had to be made.

Co-linear arrays of four electrodes were placed in the ground for each measurement. Electrical current was input to the ground through the two outer electrodes of the array. The voltage drop produced by the resulting electrical field was measured across the two inner electrodes. The "a" spacing was increased with each measurement, expanding the array about a common center. Increasing the electrode separation increases the depth of investigation, and indicates vertical variation in resistivity.

In order to check the accuracy of the single resistivity array, a perpendicular array was set up at each test location for all electrode spacings.

Apparent resistivity (ρ_a) was calculated for each measurement and corresponding electrode spacing (a) using the resistance measurement (Ω) and the geometric factor (K) as follows:

$$\rho_a = K(V/I)$$

where:

$$K = 2\pi a$$

All field results and calculated values are presented in the attachments.

Results and Discussion

Apparent resistivity measurements for the tests ranged from 540 to 1,431 ohm-centimeters (Ω -cm), with an average apparent resistivity of 859 Ω -cm.

Soil resistivity variations are likely associated with differences in soil type, layer thicknesses, and degree of water saturation in the near surface soils. Higher moisture contents and higher clay contents generally reduce the electrical resistivity of a soil.

The results were generally consistent for locations tested. In general, there was a relationship between electrode spacing and apparent resistivity at tested locations where apparent resistivity generally decreased slightly or remained relatively constant as electrode spacing increased. [Table 2](#) provides a summary of the range found in apparent resistivity with electrode spacing at the tested locations.

Table 2 Apparent Resistivity versus Electrode Spacing for Test Locations

Electrode Spacing [feet]	Apparent Resistivity [Ω -cm]		
	Range	Mean	Standard Deviation
2	930-1,431	1,205	180
5	647-1,320	985	297
10	548-1,075	784	222
20	540-847	657	126
40	590-774	664	66

Thank you for the opportunity to provide this service. Please call me at 952-832-2797 with questions or requests for additional information.

Sincerely,



Bill W. Kussmann

Attachments

- Figure 1: Electrical Resistivity Test locations
- Electrical Resistivity Test Results

Bar Footer: ArcGIS 10.4.1, 2017-05-03 16:39 File: I:\Projects\34\09\1034\Maps\Reports\Resistivity\Fig01 Electrical Resistivity Test Locations.mxd User: mbs2



-  Electrical Resistivity Test Location
-  Project Area

Imagery Source: USDA NAIP 2015

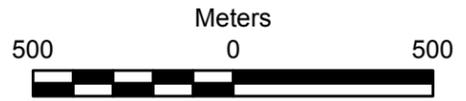


Figure 1

**ELECTRICAL RESISTIVITY
TEST LOCATIONS**
Harmony Solar Project
Geronimo Energy
Cass County, North Dakota

WENNER SOUNDING

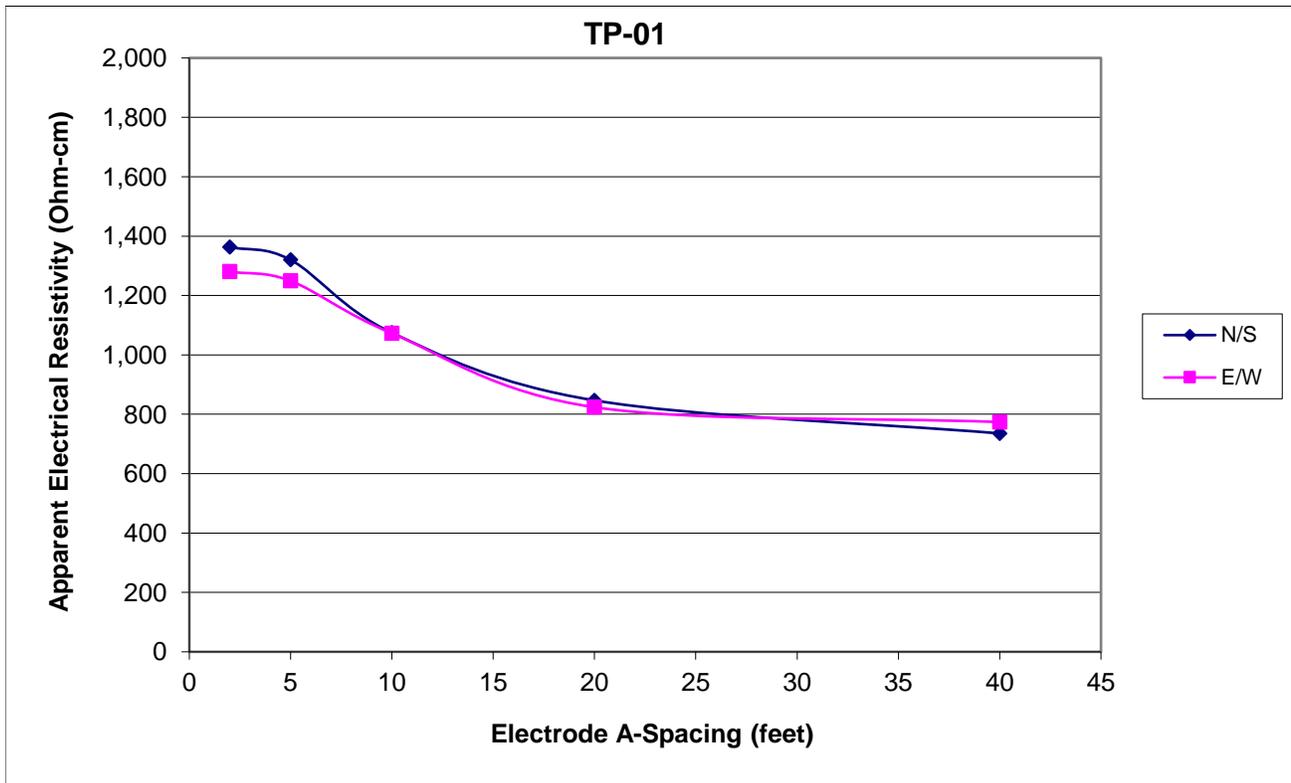
PROJECT: Harmony Solar Project

Sounding Number 1
 Observer AJL
 Location TP-01

Date 5/2/2017

Electrode Spacing "a" feet	Resistance V/I Ohms	Geometric Factor $K=2\pi a$ feet	Apparent Resistivity $\rho_a=K(V/I)$ Ohm-feet	Apparent Resistivity $\rho_a=K(V/I)$ Ohm-cm
N/S Orientation				
2	3.558	12.57	44.71	1363.1
5	1.378	31.42	43.29	1319.9
10	0.561	62.83	35.25	1074.7
20	0.221	125.66	27.77	846.7
40	0.096	251.33	24.13	735.6
E/W Orientation				
2	3.342	12.57	42.00	1280.4
5	1.304	31.42	40.97	1249.0
10	0.560	62.83	35.19	1072.7
20	0.215	125.66	27.02	823.7
40	0.101	251.33	25.38	773.9

Cultural Features none
 Ground Cover planted field
 Weather 66°F
 Line Location and Bearing NS/EW



WENNER SOUNDING

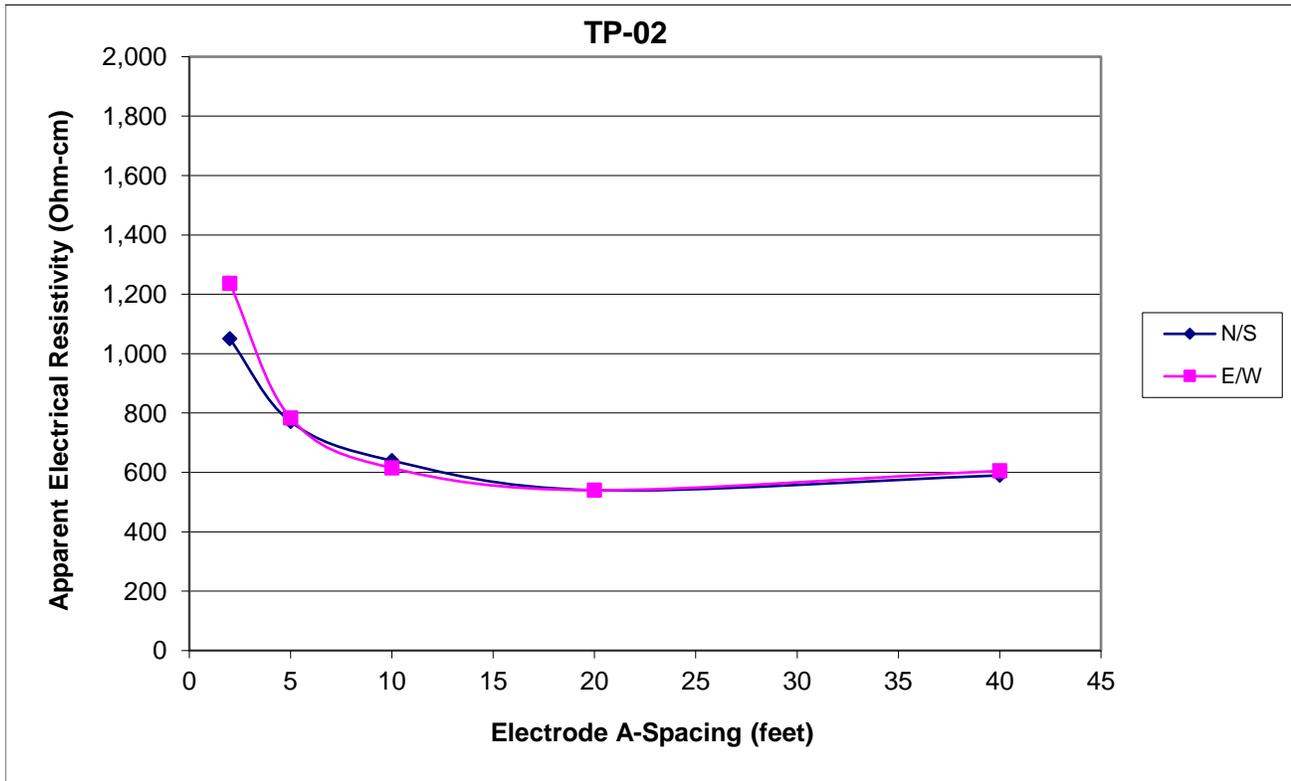
PROJECT: Harmony Solar Project

Sounding Number 2
 Observer AJL
 Location TP-02 Offset

Date 5/2/2017

Electrode Spacing "a" feet	Resistance V/I Ohms	Geometric Factor $K=2\pi a$ feet	Apparent Resistivity $\rho_a=K(V/I)$ Ohm-feet	Apparent Resistivity $\rho_a=K(V/I)$ Ohm-cm
N/S Orientation				
2	2.740	12.57	34.43	1049.8
5	0.805	31.42	25.29	771.0
10	0.334	62.83	20.99	639.8
20	0.141	125.66	17.72	540.2
40	0.077	251.33	19.35	590.0
E/W Orientation				
2	3.228	12.57	40.56	1236.7
5	0.818	31.42	25.70	783.5
10	0.321	62.83	20.17	614.9
20	0.141	125.66	17.72	540.2
40	0.079	251.33	19.85	605.3

Cultural Features none
 Ground Cover wheat stubble
 Weather 64°F
 Line Location and Bearing NS/EW



WENNER SOUNDING

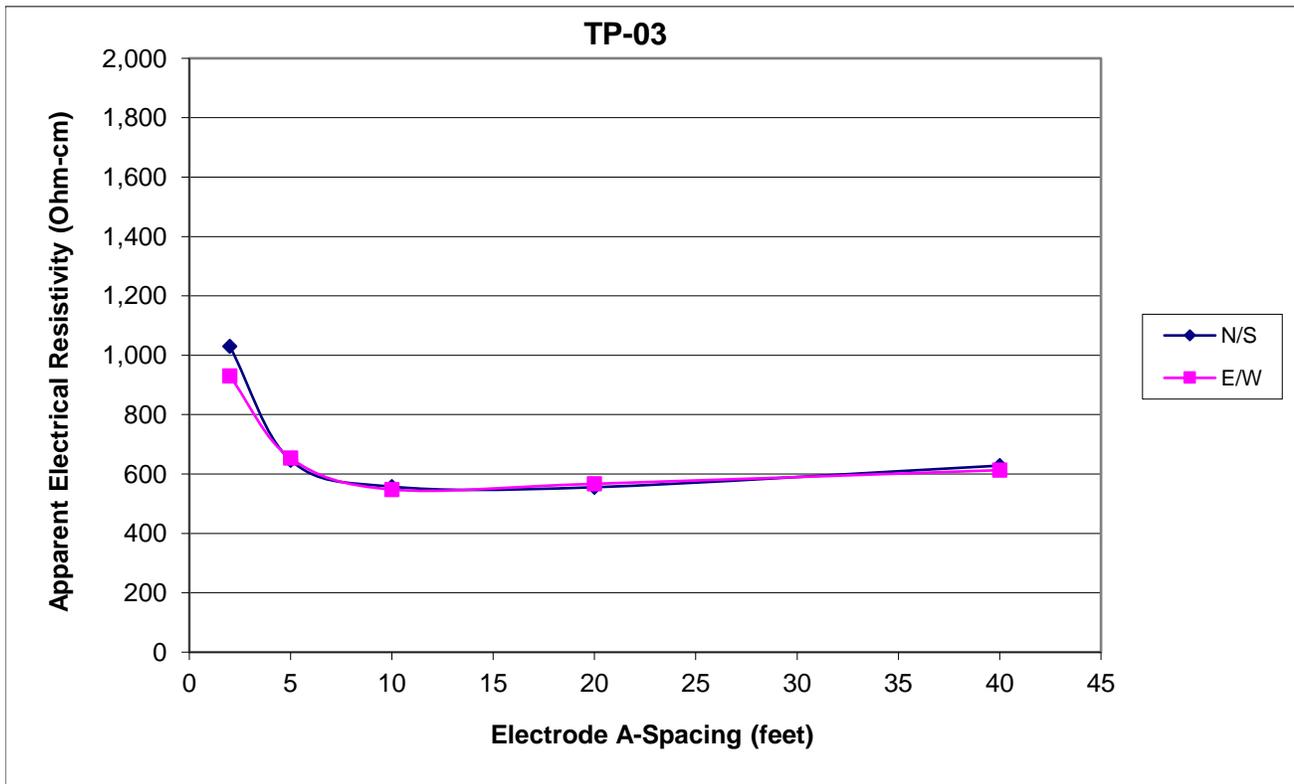
PROJECT: Harmony Solar Project

Sounding Number 3
 Observer AJL
 Location TP-03 Offset

Date 5/2/2017

Electrode Spacing "a" feet	Resistance V/I Ohms	Geometric Factor $K=2\pi a$ feet	Apparent Resistivity $\rho_a=K(V/I)$ Ohm-feet	Apparent Resistivity $\rho_a=K(V/I)$ Ohm-cm
N/S Orientation				
2	2.688	12.57	33.78	1029.8
5	0.675	31.42	21.21	646.5
10	0.291	62.83	18.28	557.4
20	0.145	125.66	18.22	555.5
40	0.082	251.33	20.61	628.3
E/W Orientation				
2	2.427	12.57	30.50	929.8
5	0.682	31.42	21.43	653.2
10	0.286	62.83	17.97	547.9
20	0.148	125.66	18.60	567.0
40	0.080	251.33	20.11	613.0

Cultural Features none
 Ground Cover planted wheat
 Weather 64° F
 Line Location and Bearing NS/EW



WENNER SOUNDING

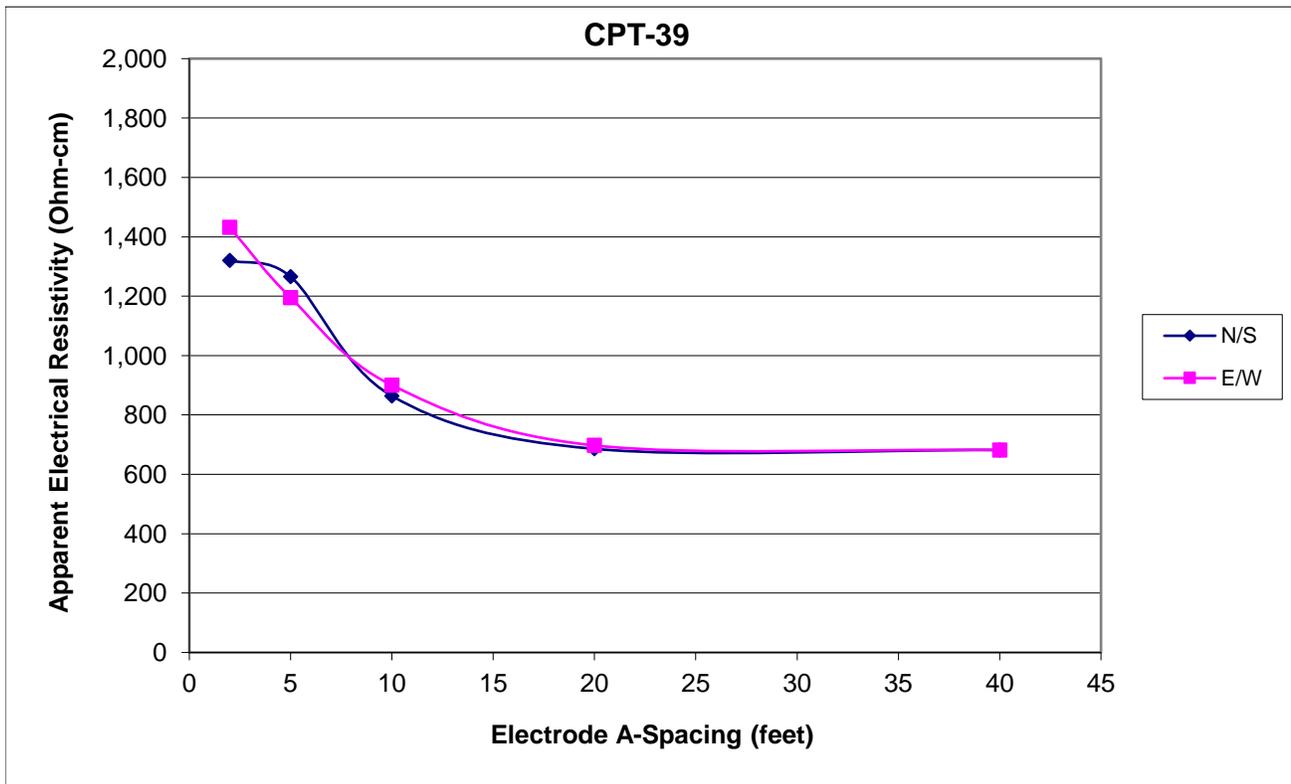
PROJECT: Harmony Solar Project

Sounding Number 4
 Observer AJL
 Location CPT-39

Date 5/2/2017

Electrode Spacing "a" feet	Resistance V/I Ohms	Geometric Factor $K=2\pi a$ feet	Apparent Resistivity $\rho_a=K(V/I)$ Ohm-feet	Apparent Resistivity $\rho_a=K(V/I)$ Ohm-cm
N/S Orientation				
2	3.447	12.57	43.32	1320.6
5	1.321	31.42	41.50	1265.3
10	0.451	62.83	28.34	863.9
20	0.179	125.66	22.49	685.8
40	0.089	251.33	22.37	682.0
E/W Orientation				
2	3.736	12.57	46.95	1431.3
5	1.248	31.42	39.21	1195.3
10	0.470	62.83	29.53	900.3
20	0.182	125.66	22.87	697.3
40	0.089	251.33	22.37	682.0

Cultural Features powerlines on section roads to N-S and E-W, transmission station to S
 Ground Cover wheat stubble
 Weather 62°F
 Line Location and Bearing NS/EW



Electrical Resistivity Test Results
 Harmony Solar Project
 May 2017
 Cass County, North Dakota
 34091031

Summary of Electrical Resistivity Test Results:

	Electrode "a" Spacing [feet]	TP-01 Resistivity $\rho_a = K(V/I)$ Ohm-cm	TP-02 Resistivity $\rho_a = K(V/I)$ Ohm-cm	TP-03 Resistivity $\rho_a = K(V/I)$ Ohm-cm	CPT-39 Resistivity $\rho_a = K(V/I)$ Ohm-cm
N/S Orientation	2	1,363	1,050	1,030	1,321
	5	1,320	771	647	1,265
	10	1,075	640	557	864
	20	847	540	556	686
	40	736	590	628	682
E/W Orientation	2	1,280	1,237	930	1,431
	5	1,249	783	653	1,195
	10	1,073	615	548	900
	20	824	540	567	697
	40	774	605	613	682
	Average:	1,054	737	673	972

Statistical Summary - Apparent Resistivity Averages (Ohm-cm)						
	Electrode "a" Spacing [feet]	Max	Min	Range (NS & EW)	Mean (NS & EW)	St Dev (NS & EW)
N/S Orientation	2	1,363	1,030	930 - 1431	1,205	180
	5	1,320	647	647 - 1320	985	297
	10	1,075	557	548 - 1075	784	222
	20	847	540	540 - 847	657	126
	40	736	590	590 - 774	664	66
E/W Orientation	2	1,431	930			
	5	1,249	653			
	10	1,073	548			
	20	824	540			
	40	774	605			

Apparent Resistivity Average-Ohm-cm:	859
---	------------

Appendix I

Thermal Resistivity Test Results



February 27, 2017

Mr. Joe Ibrahim
Director of Construction
Geronimo Energy
7650 Edinborough Way
Suite 725
Edina, Minnesota 55435

**Re: Soil Thermal Resistivity Testing
Harmony Solar Project
Cass County, North Dakota**

Dear Mr. Ibrahim:

Barr Engineering Co. (Barr) collected soil samples in support of thermal resistivity testing at the Harmony Solar Project in December 2016. Laboratory thermal resistivity testing was completed on the samples in January 2017. This letter presents the methods and results.

Methods

A total of three bulk soil samples were collected by Barr personnel at select locations. Samples were collected using auger techniques to drill down to a depth of 5 feet. Samples were collected from the cuttings between a depth of 1 and 5 feet below the existing grade (excluding the highly organic topsoil). The samples were placed in five-gallon buckets and sealed in the field to preserve the in situ moisture content. All samples were delivered to Soil Engineering Testing, Inc. (SET) of Bloomington, Minnesota, for laboratory testing.

Barr personnel located the thermal resistivity sample locations based on the selected coordinates for the corresponding test pit locations.

Locations where samples were collected for testing are shown on [Figure 1](#). Coordinates of each sample location and other pertinent information can be found in [Table 1](#).

Table 1: Thermal Resistivity Sample Information

Location ID	Sample Depth [ft]	Coordinates UTM Zone 14N [m], NAD83	
		Easting	Northing
TP-01	1-5	641808.4	5199996.8
TP-03	1-5	644653.2	5202863.7
TP-05	1-5	646611.2	5202495.4

SET completed the testing in accordance with ASTM method D5334-08 "Standard Test Method for Determination of Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure." Laboratory tests included measurement of the soil's in situ moisture content, Standard Proctor

density and optimum moisture content, and thermal dryout characteristics, which is a function of moisture content. The bulk samples were re-compacted near the optimum moisture content as determined through standard proctor testing. The test samples were recompacted to approximately 85 percent of standard Proctor density. Soil was compacted in four layers in test molds (75 mm diameter by 150 mm high) to minimize contact resistance at the soil/probe interface and to ensure a uniform density.

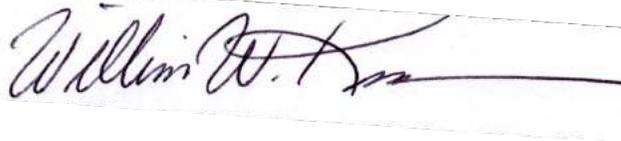
Thermal dryout characteristics were measured using a laboratory type thermal needle held central and vertical in the base plate. Thermal resistivity measurements were conducted starting at the existing moisture content of the soil sample to the totally dry condition. At the end of each drying stage, samples were sealed and brought to thermal equilibrium with the ambient air to ensure uniform moisture re-distribution through the sample. Tests were conducted using a KD2 Thermal Property Analyzer. The instrument was calibrated prior to testing.

Results

The resulting laboratory soil thermal resistivity measurements presented in tabular form with full dryout curves are included in the attached Thermal Resistivity Report by SET.

Thank you for the opportunity to provide this service. Please call me at 952-832-2797 with questions or requests for additional information.

Sincerely,

A handwritten signature in black ink, appearing to read "William W. Kussmann", is written over a faint, dashed rectangular line. The signature is fluid and cursive.

William W. Kussmann

Attachments

Figure 1: Thermal Resistivity Test Locations
Thermal Resistivity Test Results

Bar Footer: ArcGIS 10.4, 2017-01-12 13:53 File: I:\Projects\34\09\1034\Maps\Reports\Geotech_Jan2017\Fig09 Thermal Resistivity Sample Locations.mxd User: mbs2



- Thermal Resistivity Sample Location
- Project Area

Imagery Source: USDA NAIP 2015

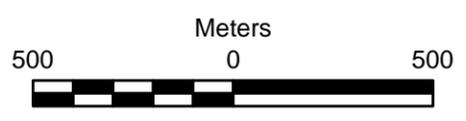
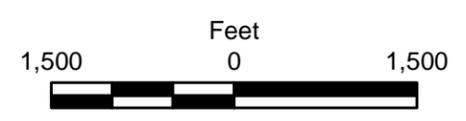


Figure 1

**THERMAL RESISTIVITY
SAMPLE LOCATIONS**
Harmony Solar Project
Geronimo Energy
Cass County, North Dakota

Thermal Resistivity Report ASTM D:5334

Project: **Harmony Solar**

Job #: **10689**

Client: **Barr Engineering Company**

Date: **1/24/17**

Boring	Specimen Type	Depth (ft)	Type	Classification	Initial Conditions			Dry
					Dry Density (PCF)	WC (%)	Thermal Resistivity (°C-cm/W)	Thermal Resistivity (°C-cm/W)
TP-01	Reconstituted	1-5	Bulk	Lean Clay with a trace of organic material (CL)	84.3	22.2%	95	242
TP-03	Reconstituted	1-5	Bulk	Organic Clay with sand (OH)	73.8	29.6%	102	261
TP-05	Reconstituted	1-5	Bulk	Organic Clay with sand (OH)	73.4	30.1%	113	289
Specimens reconstituted to approximately 85% of maximum standard proctor density near the optimum moisture content.								

9530 James Ave South



Bloomington, MN 55431

<http://www.soilengineeringtesting.com>

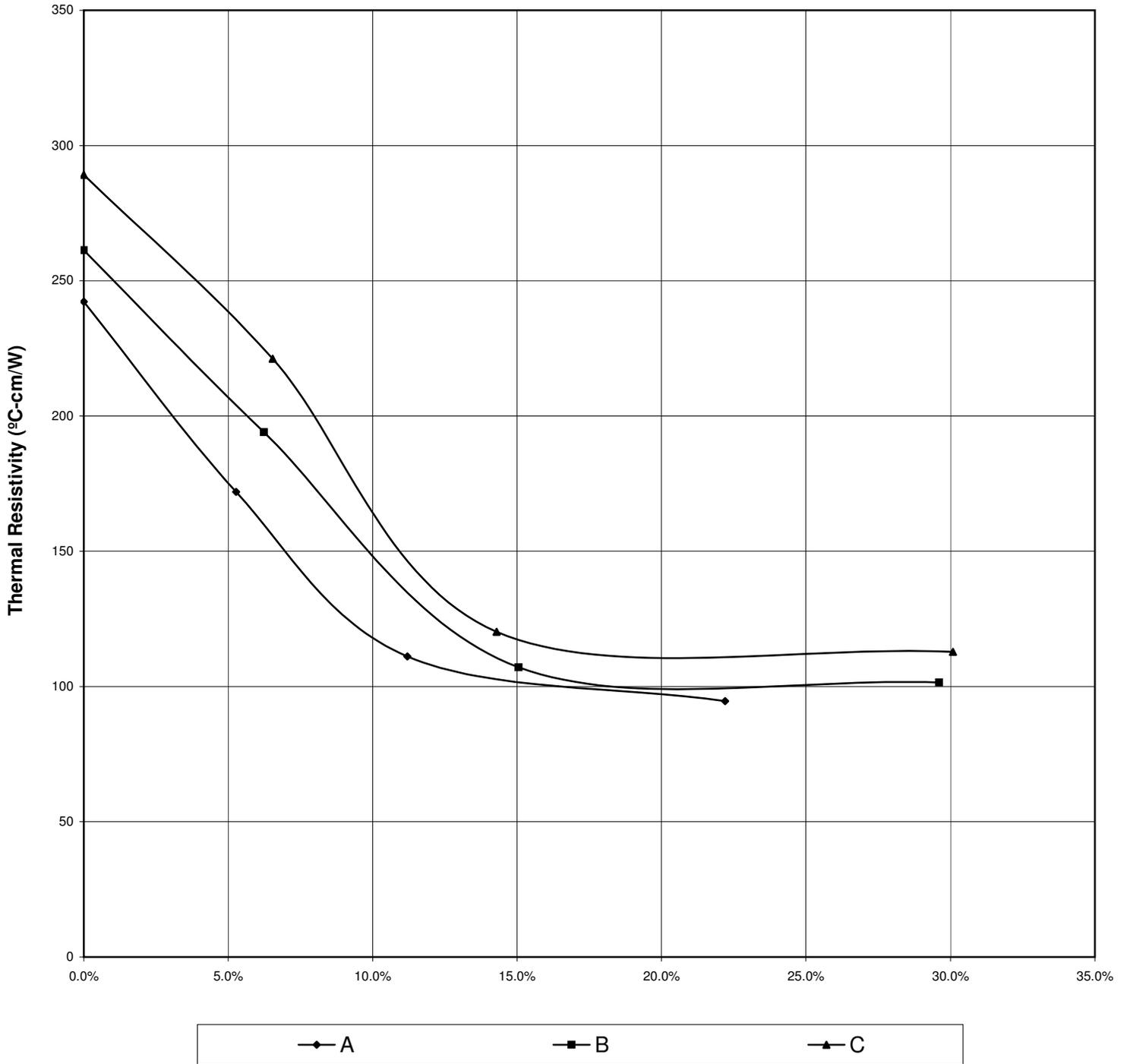
Thermal Resistivity Report ASTM D:5334

Project: Harmony Solar
 Client: Barr Engineering Company

Job: 10689
 Date: 1/24/17

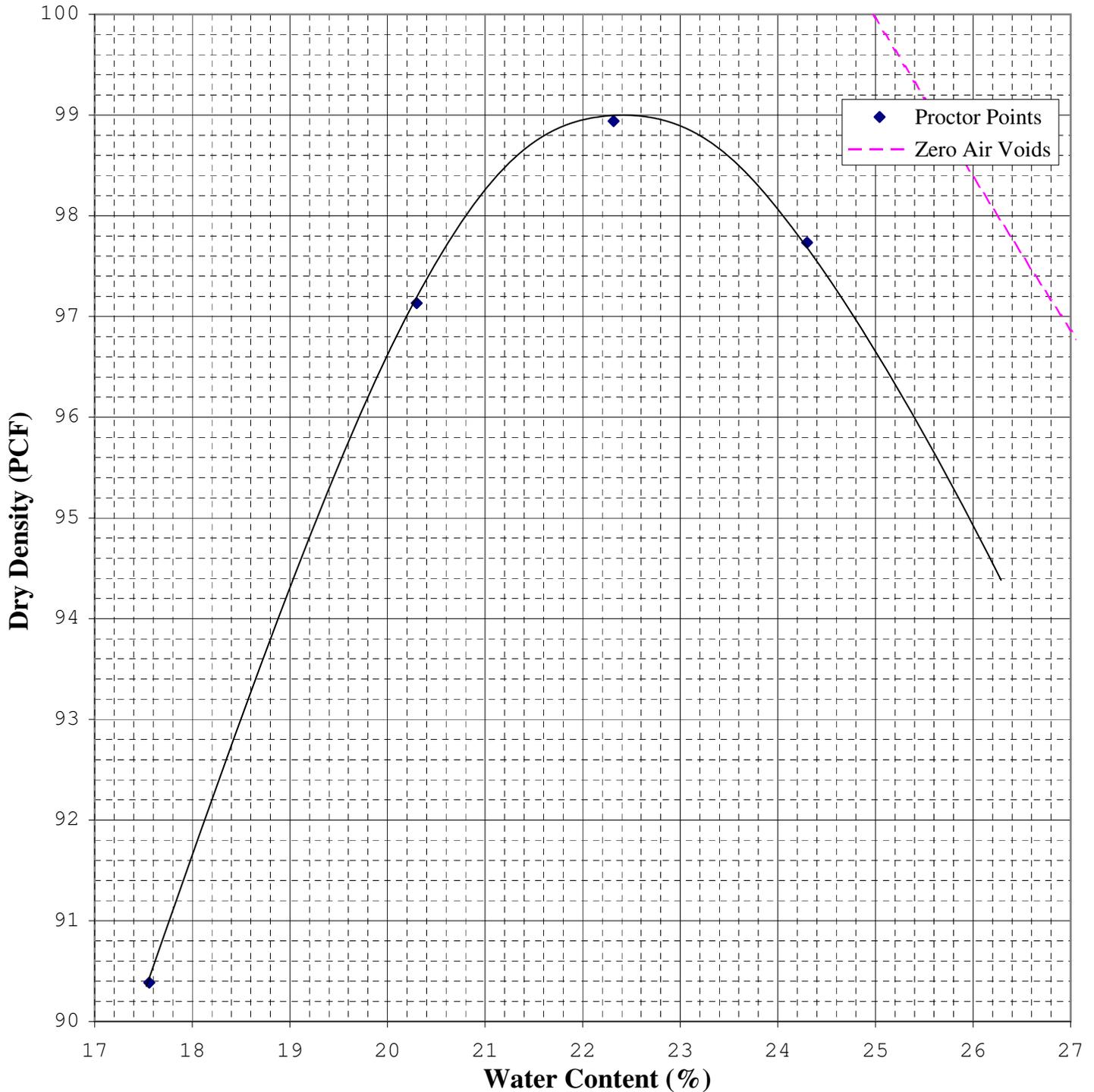
	Boring	Depth (ft)
Specimen A:	TP-01	1-5
Specimen B:	TP-03	1-5
Specimen C:	TP-05	1-5

Thermal Dryout Curves (Resistivity vs. Water Content)



Moisture Density Curve ASTM: D698, Method B

Project: **Harmony Solar** Date: **12/27/16**
 Client: **Barr Engineering Company** Job No. **10689**
 Boring No. **TP-01** Sample: Depth(ft): **1-5** Location:
 Soil Type: **Lean Clay with a trace of organic material (CL)**
 As Received W.C. (%): **27.1** LL: PL: PI: Specific Gravity: **2.67** *Assumed
 Maximum Dry Density (pcf): **99.0** Opt. Water Content (%): **22.5**



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Moisture Density Curve ASTM: D698, Method B

Project: **Harmony Solar**
Client: **Barr Engineering Company**

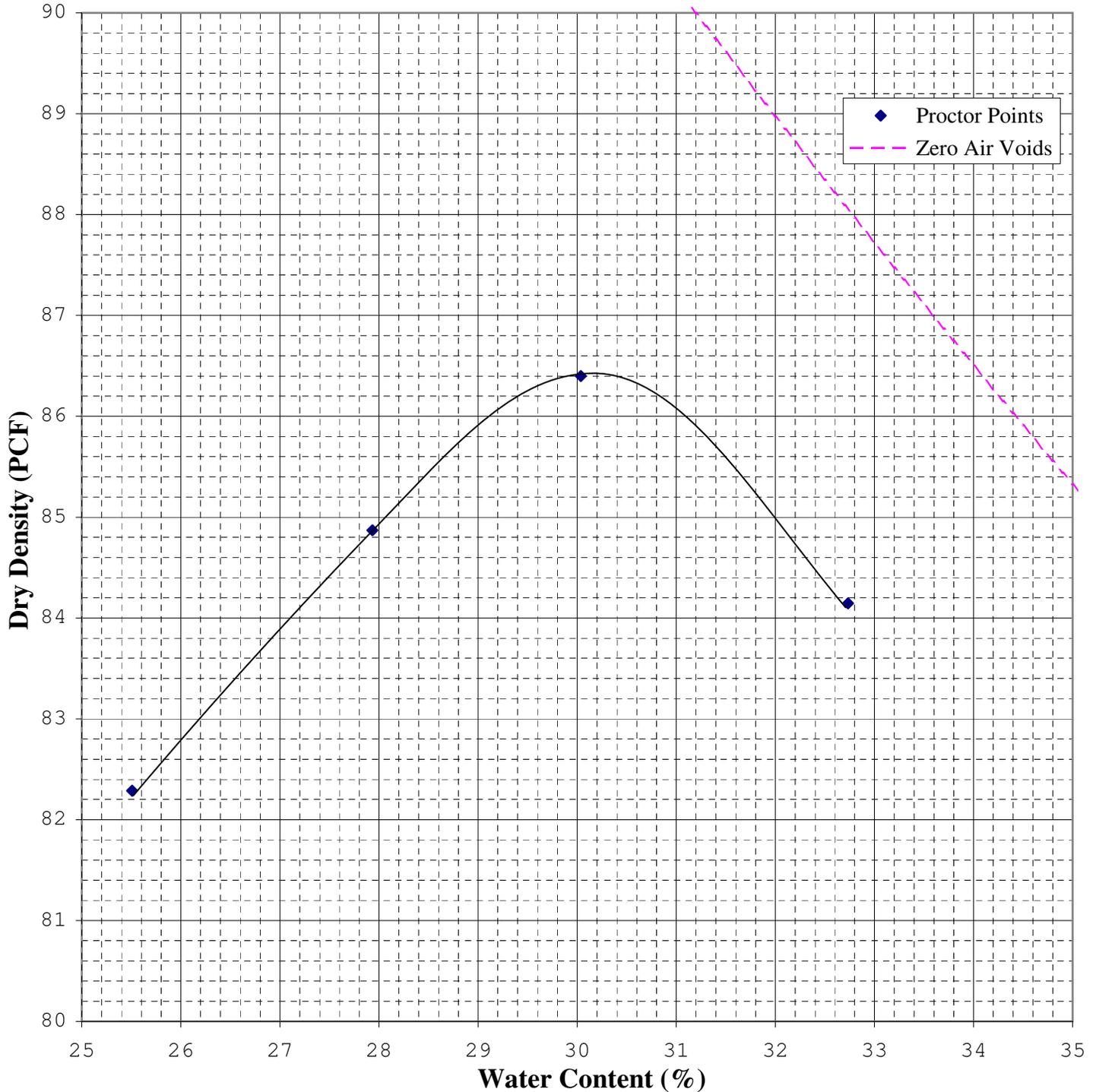
Date: **12/27/16**
Job No. **10689**

Boring No. **TP-03** Sample: _____ Depth(ft): **1-5** Location: _____

Soil Type: **Organic Clay with sand (OL)**

As Received W.C. (%): **26.6** LL: _____ PL: _____ PI: _____ Specific Gravity: **2.62** *Assumed

Maximum Dry Density (pcf): **86.4** Opt. Water Content (%): **30.2**



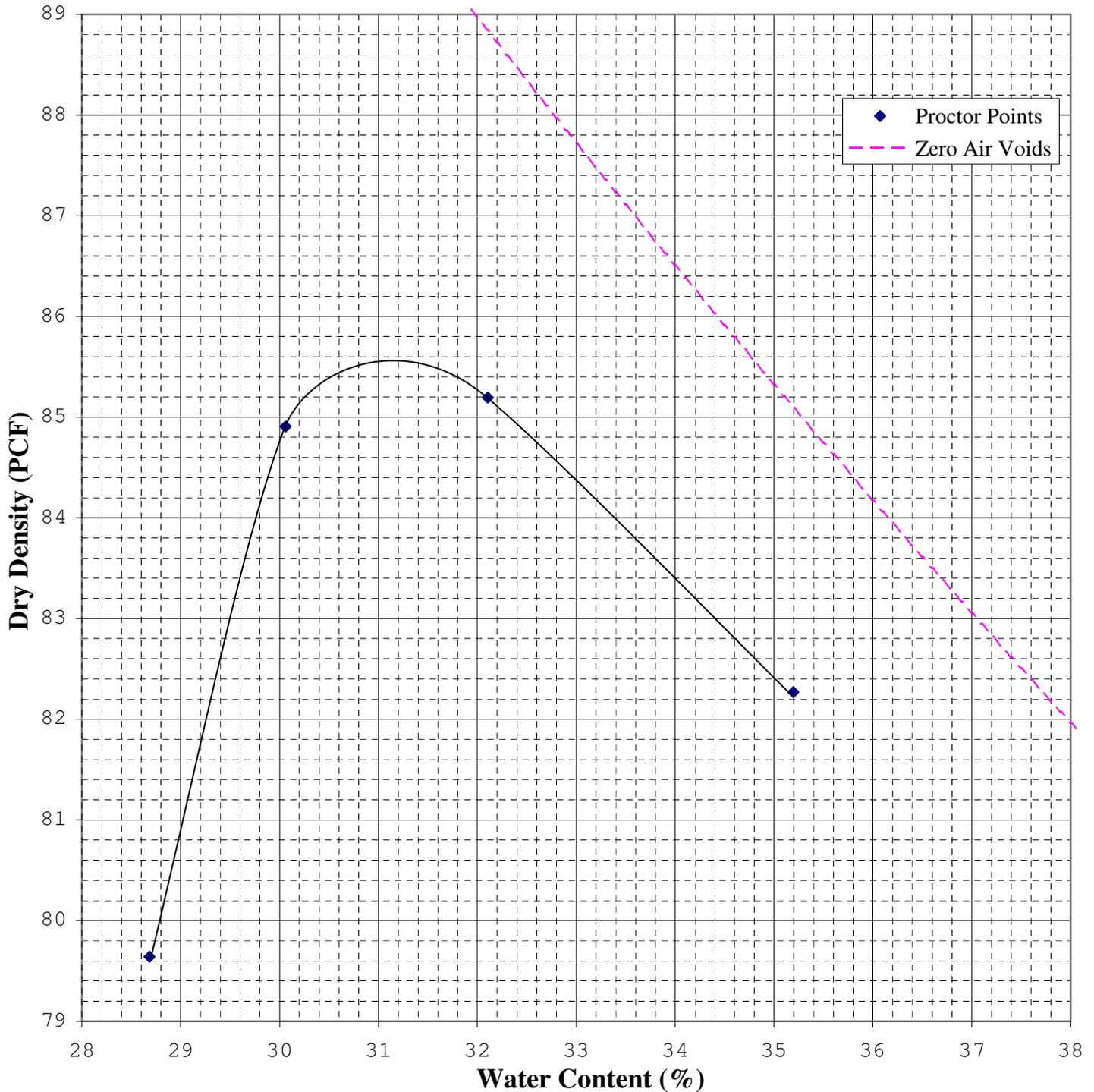
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Bloomington, MN 55431

Moisture Density Curve ASTM: D698, Method B

Project:	Harmony Solar	Date:	12/27/16
Client:	Barr Engineering Company	Job No.:	10689
Boring No.:	TP-05	Sample:	
		Depth(ft):	1-5
		Location:	
Soil Type:	Organic Clay with sand (OH)		
As Received W.C. (%):	36.0	LL:	
		PL:	
		PI:	
		Specific Gravity:	2.62 *Assumed
Maximum Dry Density (pcf):	85.6	Opt. Water Content (%):	31.1



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