ERDC/GSL TR-16-7

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The Influences of Geologic Depositional Environments on Sand Boil Development, Tara Wildlife Lodge Area in Mississippi

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Final report

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Abstract

A comprehensive study of the subsurface geology in the Tara Wildlife Lodge area in Mississippi was undertaken to identify seepage pathways that lead to sand boils. After the completion of soil borings, geophysical surveys, and cone penetrometer tests and the analysis of the boring logs and test results, the subsurface in the Tara Wildlife area was better characterized with the creation of cross sections and imagery. The cross sections and imagery based on the data helped researchers to better understand the geologic phenomena that were occurring and causing sand boils. Results suggest that the Tara Wildlife Lodge area in the Talla Bena Quadrangle is located on pervious point bar deposits consisting of cohesionless sands with little to no overburden resistance.

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Preface

This study was conducted for the U.S. Army Corps of Engineers (USACE) under the Flood and Coastal Storm Reduction USACE Civil Works Program. The technical monitors were Dr. Cary A. Talbot, Coastal and Hydraulics Laboratory (CHL), and Dr. Maureen K. Corcoran, Geotechnical and Structures Laboratory (GSL).

The work was performed by the Geotechnical Engineering and Geosciences Branch (GEGB) of the Geosciences and Structures Division (GSD), U.S. Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL). At the time of publication, Chad A. Gartrell was Chief, GEGB; Dr. Amy Bednar was Acting Chief, GSD; and Dr. Michael K. Sharp was the Technical Director for Water Resources Infrastructure. The Deputy Director of ERDC-GSL was Dr. William P. Grogan and the Director was Bartley P. Durst.

COL Brian S. Green was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
miles (nautical)	1,852	meters
miles (US statute)	1,609.347	meters
square miles	2.589998 E+06	square meters
yards	0.9144	meters

1 Introduction

Erosion from concentrated through-seepage in a levee or from under-seepage through its foundation may result in a seepage exit velocity sufficient to carry soil particles. If left unchecked, the erosion can proceed backward along the seepage path, forming a “pipe” which can ultimately lead to catastrophic failure of the levee. Underseepage through pervious foundation strata beneath levees may result in (a) excessive hydrostatic pressures beneath an impervious top stratum on the landside, (b) development of sand boils, and (c) if left unchecked, “piping” beneath the levee itself (U.S. Army Corps of Engineers (USACE) 2000). As previously stated, piping is initiated when soil begins to move at a sand boil, or a seepage exit point. According to Kolb (1975), a common problem during floods along the Lower Mississippi River is the formation of sand boils on the landside of levees. The formation of sand boils at or beyond the levee toe is a visible sign of underseepage. Soil depressions in the vicinity of sand boils or the presence of sand cones or alluvial fan-like deposits of soil around the seepage exit point are signs of active internal erosion that require immediate action. Sand bags placed in a ring around the flowing water of a boil during flood fighting allow the water to rise inside the ring, thus reducing the hydraulic head and the resulting exit velocity, which can stop the movement of material; however, identifying locations and conditions that are vulnerable to sand boils is critical to maintaining the integrity of the levee during flood conditions.

1.1 Purpose

The purpose of this research was to evaluate the conditions that produce sand boils along the Mississippi River levee at a site referred to as Tara Wildlife Lodge by examining the occurrence of sand boils in relation to the geology, geomorphology, environments of deposition, and historic levee development.

1.2 Hypothesis

The development of sand boils during high-water events is attributed to specific depositional environments, soil properties of the environments, geologic history, and levee construction.

1.3 Objectives

In order to thoroughly evaluate the conditions that produce sand boils at the Tara Wildlife Lodge, researchers

- Conducted a literature search on the topic of seepage, sand boils, and internal erosion;
- Described the evolution of the present levee system and any corresponding performance incidents in the study area;
- Collected soil data from boring logs and constructed geologic cross sections that identify the types of soils present and the horizontal and vertical extent of the stratigraphy throughout the reach;
- Developed a Geographic Information System (GIS) for organization of the data that were collected;
- Interpreted impervious top stratum from boring logs and geophysical surveys;
- Collected and interpreted resistivity data of selected lines to image the subsurface and the lateral extent of the stratigraphy;
- Evaluated the occurrence and distribution of sand boils during the 2011 flood in light of these data; and
- Identified geologic features, geomorphic landforms, and their relationship to sand boil occurrence.

The approach to evaluating the causes and locations of sand boils in the study area involved collecting sand boil data from the 2011 Mississippi River Flood, collecting and interpreting existing boring logs and cone penetrometer tests (CPTs), and developing geologic cross sections from these data. Surface landforms were identified in the study area to better understand the relationship between sand boil locations and the depositional environments that contain these features. Subsurface boring data were used to characterize the primary soil types within each environment mapped and the engineering properties of these soils. These data were organized using a GIS to facilitate retrieval and display of location-based information.

2 Literature Review

The geology of the Mississippi River Alluvial Valley is well defined on a scale relevant to understanding the alluvial deposits from the meandering of the Mississippi River (Fisk 1944; Kolb 1975; Saucier 1994), but the correlation of soil properties and geologic deposits with sand boil development is not as well understood. For the purpose of understanding the environment in which sand boils occur, a literature review was conducted for this research on both internal erosion and Mississippi River geologic history.

Kolb (1975) provided details on specific orientation of swales, or abandoned channel deposits, with respect to the levee alignment and their effects on the severity of piping. In the Lower Mississippi River Valley, the Mississippi River deposits sediment in a floodplain that is 3 to 15 miles wide on average (Wilson 2003). This narrow floodplain, bounded to its east and west by erosion-resistant bluffs deposited during the Tertiary period (66 million to 2.58 million years before present (BP)), has a top stratum composed mostly of five main meander belt deposits: chute and bar, point bar, abandoned channel, natural levee, and back swamp deposits (USACE 1956).

At the request of the Mississippi River Commission (MRC), Dr. Harold N. Fisk from Louisiana State University in Baton Rouge, LA, prepared a comprehensive journal of the geology in the Lower Mississippi River Alluvial Valley (Fisk 1944). Fisk described the area as an alluvial valley of the Mississippi River beginning near the confluence of the Mississippi and the Ohio Rivers at Cairo, IL, and extending to the Gulf of Mexico. Fisk thought glaciers from the Pleistocene Epoch (1.8 million years BP) originally formed the valley. As the glaciers melted some 30,000 years ago, the sea level rose to its present position, causing the Lower Mississippi Alluvial Valley to become filled with sandy gravels, sands, silts, and clays that are grouped into two broad categories: (a) a sandy substratum and (b) a fine-grained top stratum (Tyler et al. 1956). Fine-grained top-stratum sediments, predominately silts and silty sands, generally have high permeability. The thin top stratum influences the design of the levee. Most of the investigation borings that were reviewed for this analysis contained a thin top stratum, which contributed to seepage and boils (USACE 2012a). According to Saucier (1994), the valley varies in width from approximately 30 miles wide near Natchez, MS, to approximately 125 miles wide between

Memphis, TN, and Little Rock, AR. The ground surface in the valley has an average slope of about 0.6 ft per mile (Tyler et al. 1956).

Through soil borings and geologic cross sections, Fisk (1944) mapped the local distribution of alluvial sediments. Wilson (2003) used this information to correlate soil borings and geologic cross sections with his work at the locations of these deposits. He found that the configuration of the sediment with respect to the levee alignment heavily influences the location of piping.

Over time, the Mississippi River has meandered and left a series of geomorphic features (e.g., oxbow lakes and natural levees) that are indicators of previous river presence (Tyler et al. 1956). The time it takes for the river to change its course is about 100 years, according to Fisk's careful study.

Kolb (1975) stated that a common problem during floods along the Lower Mississippi River is the formation of sand boils on the landside of the levee, resulting from seepage forces that often deposit their granular materials in the form of conical mounds with water flowing from the top of the mound. If the hydrostatic pressure in the pervious substratum landward of a levee becomes greater than the submerged weight of the top stratum, the uplift pressure may cause heaving and rupture at weak spots with a resulting concentration of seepage flow in the form of sand boils. This, in turn, can lead to piping and instability of levees during critical high-water periods.

Saucier (1994) stated that Fisk's contribution was a giant step forward in advancing the state of knowledge of the area; however, as is almost always the case with such a comprehensive work, new concepts emerged, and new geological tools were developed that would provide even more details on the geologic history of the Lower Mississippi River Valley. When this happens, newer concepts and data emerge that are periodically synthesized, and new summaries are prepared; however, Fisk's work influenced so many with its impression of detail, accuracy, and precision that it actually deterred later similar efforts (Saucier 1994).

Saucier (1994) stated that most of the Lower Mississippi River Valley landforms and deposits are the result of three geomorphic processes: fluvial, eolian, and marine. Of these, the fluvial process is predominant and includes the products of both inorganic and organic sedimentation.

The Yazoo River Basin located in northwest Mississippi is the largest in the Mississippi River Alluvial Valley with an area of about 7,600 square miles (Saucier 1994). According to Saucier (1994), it extends about 200 miles from Memphis to Vicksburg and is approximately 60 miles wide at the latitude of Greenwood, MS. Glacial outwash deposits comprise less than 5 percent of the total basin area; the remainder consists of Holocene Epoch (10,000 BP) meander belt and backswamp environments (Saucier 1994). The lowest points in the basin occur just north of Vicksburg, MS. Saucier (1994) stated that the Yazoo River becomes a tributary to the Mississippi River at Vicksburg. Interior drainage of the basin is by way of a complex system of sluggish streams that eventually join the Big Sunflower River and flow into the Yazoo River. Most of the drainage basin is controlled by old river channels. The Holocene alluvial plain of the Mississippi River Alluvial Valley is dominated by abandoned distributaries and meander belts of the Mississippi, the Arkansas, and the Red Rivers (Tyler et al. 1956). All three geomorphic processes function in both construction and erosion modes; at any given time, landforms are being both created and destroyed. In contrast to Fisk (1944), which was written exclusively for engineers, Saucier (1994) was aimed at a broad, multidisciplinary audience of geotechnical and environmental engineers and earth scientists, including archeologists, ecologists, geologists, and sedimentologists. The scope of Saucier's work entails a description of landforms and the depositional environment of the entire alluvial valley.

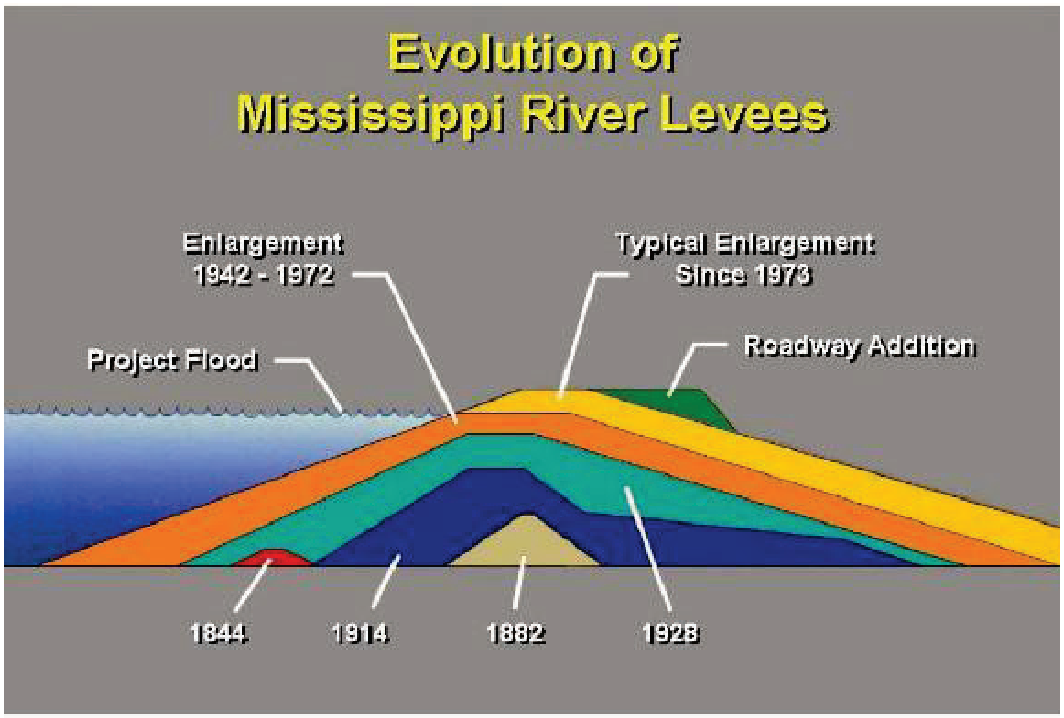
Ridges, swales, and point bars result from variations in the quantity and physical characteristics of the sediment, the energy of the transporting soil, and the environmental setting. For example, silt being transported as a suspended load in floodwaters overtopping a stream bank will build a natural levee in a broad, flat basin, whereas similar material concentrated in a small stream valley will develop an alluvial fan at its mouth.

3 Lower Mississippi River Levee System

3.1 Evolution of the levee system

The present levee system along the Mississippi River has evolved to accommodate land use, improve navigation, and prevent devastation from catastrophic floods. Figure 1 provides the more significant dates of levee development that are directly applicable to the study site used in this research.

Figure 1. Illustration showing progression of levee development (MRC 2007).



Prior to the developments shown in Figure 1, levee construction along the Mississippi River began in 1717 in New Orleans, LA, by the first settlers to occupy the alluvial valley. These early occupants built on terraces formed from fluvial processes of the Mississippi River. Although these "high points" were above the normal stage of the river, levees were then constructed to protect their crops and property. Watermarks left on the trees by floods were used as a basis for a levee project grade (MRC 1945). The project grade of a levee is the elevation to which the levee crest is constructed. Levee construction was originally accomplished by the excavation of parallel drain ditches, known as borrow pits, from which the soil was cast with spades to form an embankment. The levees still required additional heights. Because of this, mules and homemade equipment came into use. In time, even the mule was cast aside for various types of mechanical equipment powered by coal, gasoline, diesel oil, fuel oil, or electricity.

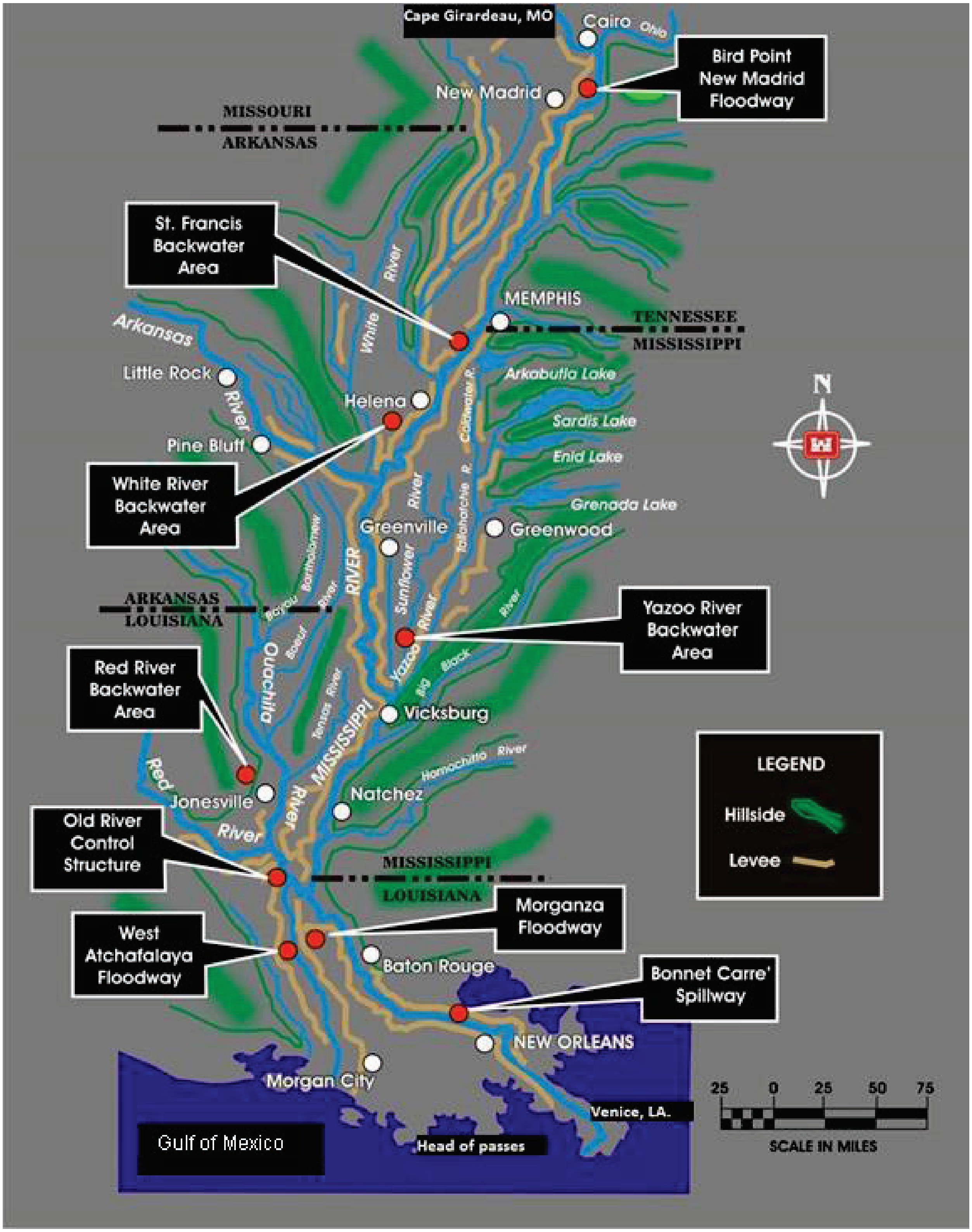
In 1844, levees were still small, and overtopping from flood events occurred often. These levees were constructed by local landowners to protect their homes and farmland. In 1861, the Civil War began, and levee construction and maintenance stopped. Because of the lack of levee maintenance, floods in 1862, 1865, and 1867 severely damaged the levees.

After the Civil War ended in 1865, people realized that flood control was a serious necessity. In 1879, the U.S. Congress passed the Mississippi River Commission Act. The Act required the appointment of seven commissioners to the MRC for the purpose of transforming the Mississippi River into a reliable commercial artery while protecting adjacent towns and fertile agricultural lands from destructive floods (MRC 1945). The seven commissioners include three selected from the U.S. Army Corps of Engineers (USACE); one from the Coast and Geodetic Survey; and three from civil life, two of whom are civil engineers. The duties of the Commission are to direct and complete surveys of the Mississippi River; improve the river channel for navigation, protecting its banks, and preventing destructive floods; report specifically on the practicability, feasibility, and probable cost of plans known as the Jetty System, the Levee System, and the Outlet System; and prepare and submit, prior to the completion of all the surveys and examinations, plans and estimates of the cost of such immediate works as might, in its judgment, constitute part of the general system. A jetty system is a system of structures (dikes) that are used in rivers to prevent bank erosion, a levee system is a series of earthen embankments that parallel both sides of a river to prevent floodwaters from spreading, and an outlet system consists of structures that provide a secondary means of travel for river water. Some outlet systems are used to direct water for construction projects and periods of flooding. No project levee built to MRC standards has ever failed, despite significant floods in 1937, 1945, 1950, 1973, 1975, 1979, 1983, and 1997 (MRC 2007).

However, levees constructed prior to the formation of the MRC did experience failure. In 1882, levees protecting the Mississippi Valley failed at 284 different locations, reflecting the complete inadequacy of the levee system because the levees were only 8 ft high (MRC 2014). In response, the U.S. Congress passed the rivers and harbors legislation that authorized levee construction for the primary purpose of improving navigation, with flood control as an incidental benefit. Shortly thereafter, the MRC Committee on Outlets and Levees issued its report recommending a continuation and refinement of the policy of restraint in the interest of navigation. The MRC report also encouraged a policy of restraint in the interest of navigation dependent on closing gaps and restoring broken levees to their former height. The revised levee plan called for a standard levee grade capable of accommodating a comparable discharge of the 1882 flood with a 3-ft safety margin (MRC2012).

The Great Mississippi Flood of 1927 was the most disastrous flood in the history of the Mississippi River. Herbert Hoover, the then Secretary of Commerce, called it “the greatest peace-time calamity in the history of the country.” The flood prompted an overhaul of flood control plans for the Lower Mississippi River. Both the MRC and the U.S. Army Corps of Engineers (USACE) submitted comprehensive plans that included levees, floodways, and bank protection (MRC 2007). The 1912 and 1913 floods contributed to the reconstruction and enlargement of the levees in 1914. From 1917 until 1928, the federal government participated in levee building on a share basis with the local interests, but the system was faulty because the levees could only be extended in direct proportion to the financial means of the local people (MRC 1945). The U.S. Congress approved “an act for the control of floods on the Mississippi River and its tributaries, and for other purposes” on May 15, 1928 (MRC 1945). Through this historic flood control act, Congress instructed the MRC to implement the engineering plan sponsored by General Edgar Jadwin for controlling floods on the Lower Mississippi River. The plan adopted by Congress under the 1928 Flood Control Act provided for enlarging and strengthening the levees from Cape Girardeau, MO, to the Gulf of Mexico with the objective of safely discharging up to 1,500,000 cu ft/sec of water within the main channel. The plan is referred to as the Mississippi River & Tributaries (MR&T) project (Figure 2). The system protects the vast expanse of the developed alluvial valley from periodic overflows of the Mississippi River. The main stem levee system begins at the head of the alluvial valley at Cape Girardeau, MO, and continues to Venice, LA, approximately 10 miles above the Head-of-Passes near the Gulf of Mexico. The MR&T levee system includes 3,787 miles of authorized embankments and floodwalls (MRC 2007). Of this number, almost 2,216 miles are along the main stem Mississippi River; and the remaining levees are backwater, tributary, and floodway levees (MRC 2007).

Figure 2. Map of the MR&T project (Camillo and Pearcy 2004).



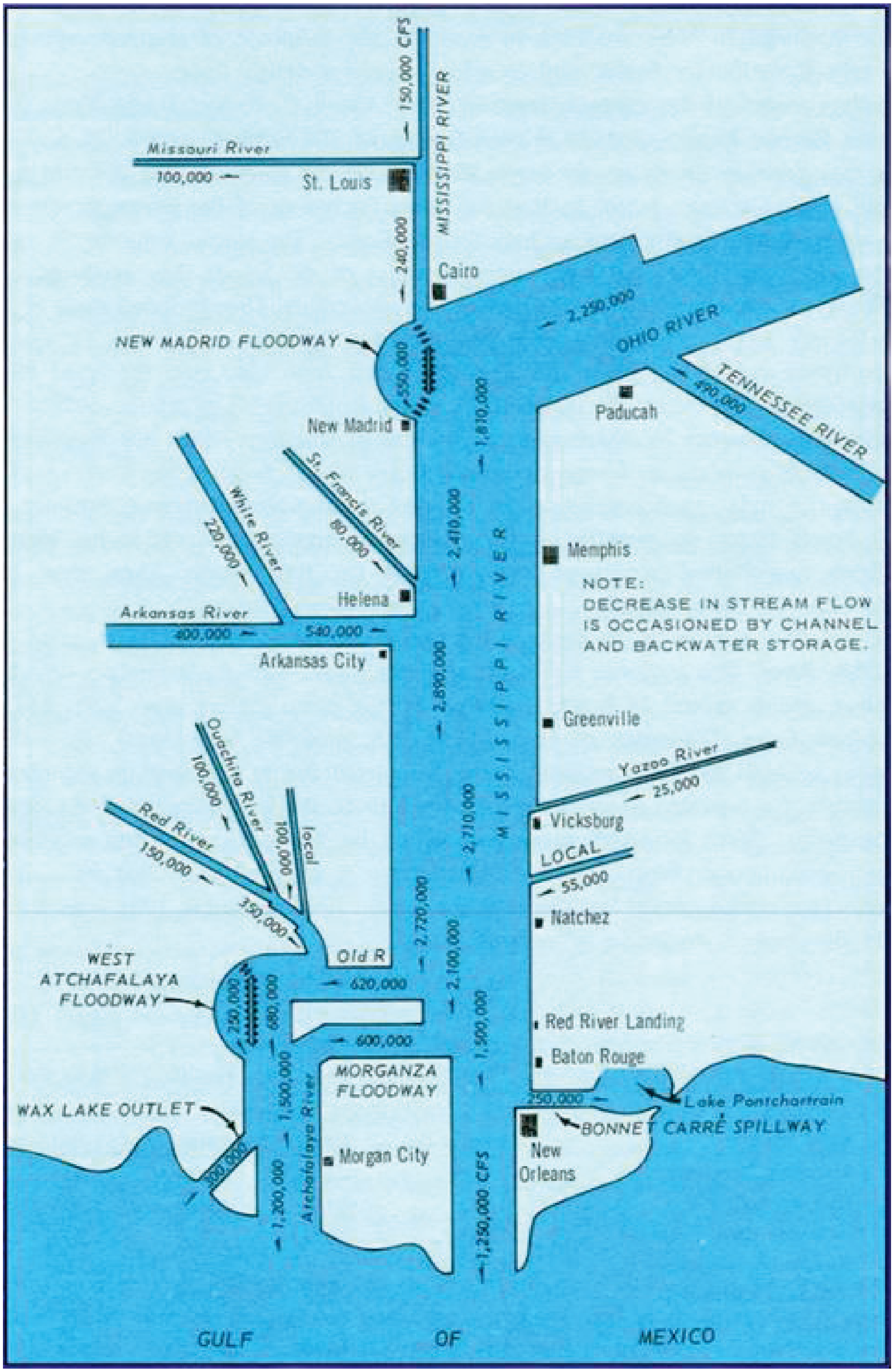
The Flood of 1937, the result of long, continued, heavy rains in the Ohio River Basin, produced a flood of unprecedented magnitude. The Bird Point-New Madrid Floodway was in operation for 38 days. The Bonnet Carré Spillway was also placed in operation and successfully demonstrated its capacity to prevent a dangerous river stage at New Orleans. The Flood of 1937 was the largest flood to which levees on the Mississippi River constructed under the provisions of the Flood Control Act of 1928 had been subjected (MRC 1945).

As the years passed between 1942 and 1972, project flood designs became easier as technology advanced; therefore, gradual levee enlargements occurred (Figure 3).

In 1954, the Senate Committee on Public Works requested a thorough examination of all components of the MR&T project, which led to further revisions of the project design flood. In accordance with that request, the MRC and the Weather Bureau conducted a cooperative study. This study incorporated previously unavailable data regarding the sequence, severity, and distribution of past major storms and investigated 35 different hypothetical combinations of actual storms that produced significant amounts of precipitation and runoff. The Weather Bureau arranged the historical storms sequentially to mimic frontal movements and atmospheric situations that were consistent with those occurring naturally to determine the most feasible pattern capable of producing the greatest amount of runoff on the lower Mississippi River. This included the consideration of storm transpositions, storm intensity adjustments, seasonal variations, and storm mechanics. In simpler terms, the Weather Bureau developed the project design storm series from various combinations of storms and reproduced floods—referred to as hypo-floods—that had a reasonable probability of occurring from a meteorological viewpoint (MRC 2008).

The studies revealed that Hypo-Flood 58A had the best probable chance of producing the greatest discharge on the Lower Mississippi River from Cairo, IL, to the Gulf of Mexico. Three severe storms comprised Hypo-Flood 58A. The first storm was the 1937 storm that struck the Ohio and the lower Mississippi River Basins. The second was the 1950 storm over the same general area. The third storm, which followed three days later, was the 1938 storm with its center transposed 90 miles to the north and the rainfall pattern rotated by 20 deg to maximize its coverage over all the tributary basins on the Lower Mississippi River. To convert Hypo-Flood 58A into the

Figure 3. Map of the Project Design Flood (MRC 2008). Peak discharges are shown in cubic feet per second (cfs).



project design flood, the MRC developed the flood flows that would be produced from the three storms and routed them through the tributary systems under three conditions: unregulated by reservoirs; regulated by reservoirs that existed in 1950; and regulated by existing reservoirs, plus those proposed to be constructed in the near future (1960 time frame). The flood flows were then modeled to determine peak discharges. The Mississippi River Commission selected the 58A flood with near-future reservoirs condition, referred to as 58A-EN (existing or near completion), as the basis for the project flood flow line and adopted it as the project design flood in 1956 (Figure 3). The peak discharges for the revised project design flood were 2,360,000 cfs at Cairo; 2,890,000 cfs at Arkansas City; and 3,030,000 cfs at the latitude of Red River Landing (MRC 2008).

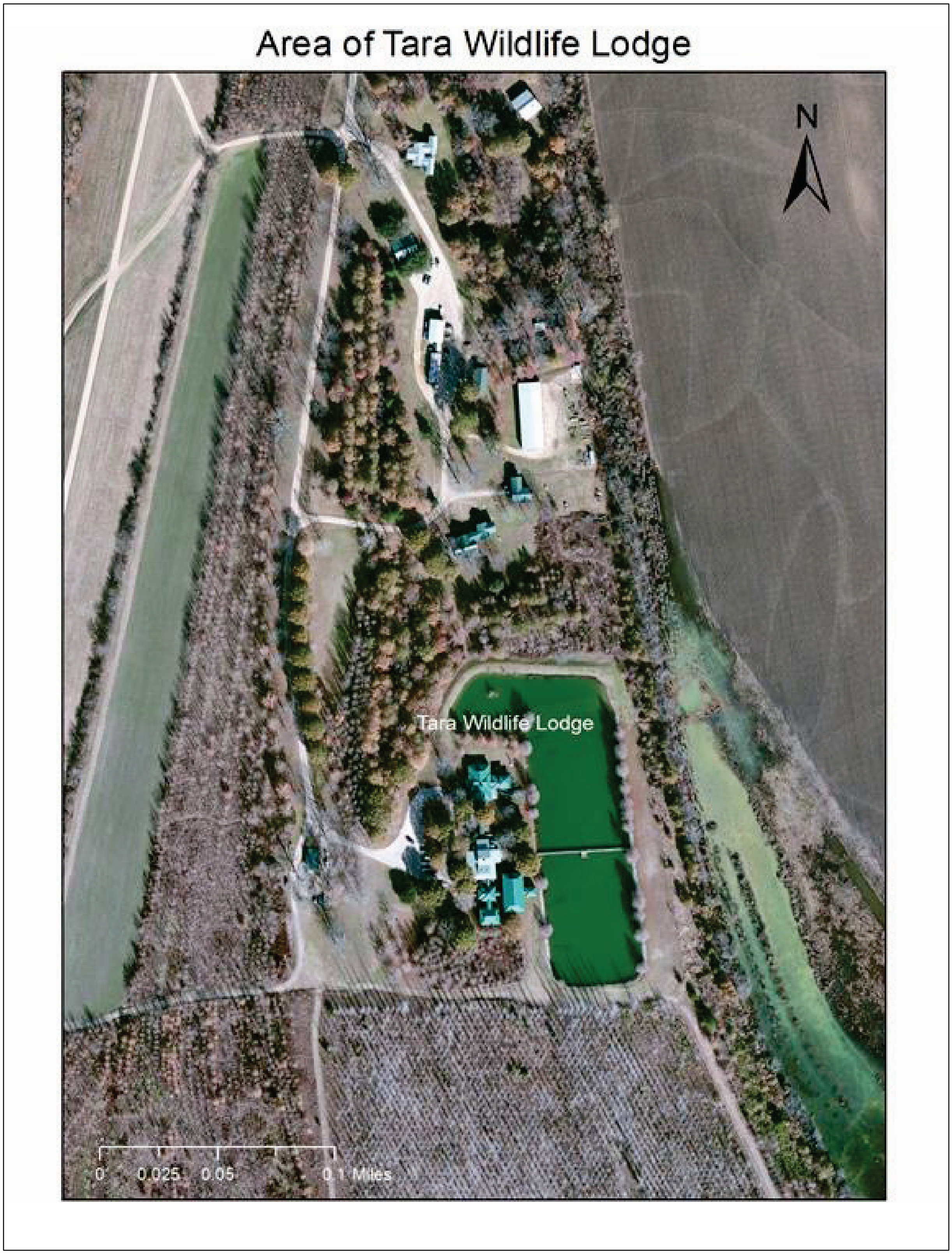
During the Flood of 1973, river gages at Vicksburg, MS, and New Orleans, LA, recorded river elevations higher than ever recorded on the Mississippi River (Camillo 2004). Because of enlargements to the levee systems, there were no catastrophic events. The Camillo (2004) report stated that immediately following the 1973 flood, USACE completed studies and prepared what is now known as the Refined 1973 Project Flood Flow Line. The study provided an evaluation that required an extensive levee enlargement program, some up to 8 ft in height, and a 3-ft freeboard above the newly established project flow line (MRC 2008).

Roadway additions were added to levees for two reasons. The first was to eliminate tire ruts on the levee itself that cause the water to pond and seep into the interior of the levee, causing it to weaken. The second was to provide access for inspection, maintenance, flood fighting, and other emergencies.

3.2 Performance incidents

The Tara Wildlife Lodge area (Figure 4) has been known for having sand boil issues since the placement of the Muddy Bayou Control Structure following the devastation of the 1973 flood. The Muddy Bayou Control Structure regulates the allowance of water into Eagle Lake from the backwaters of the lake (landside). Before the placement of the Muddy Bayou Control Structure, there were no known sand boils occurring in the Tara Wildlife Lodge area. When a flood event occurred, the water surface of Eagle Lake, which is on the landside of the levee, would rise until the piezometric surface reached equilibrium. This meant that the head differential between the riverside and the landside was not enough for sand boils to develop.

Figure 4. Map of Tara Wildlife Lodge (ESRI 2014).



4 Study Location

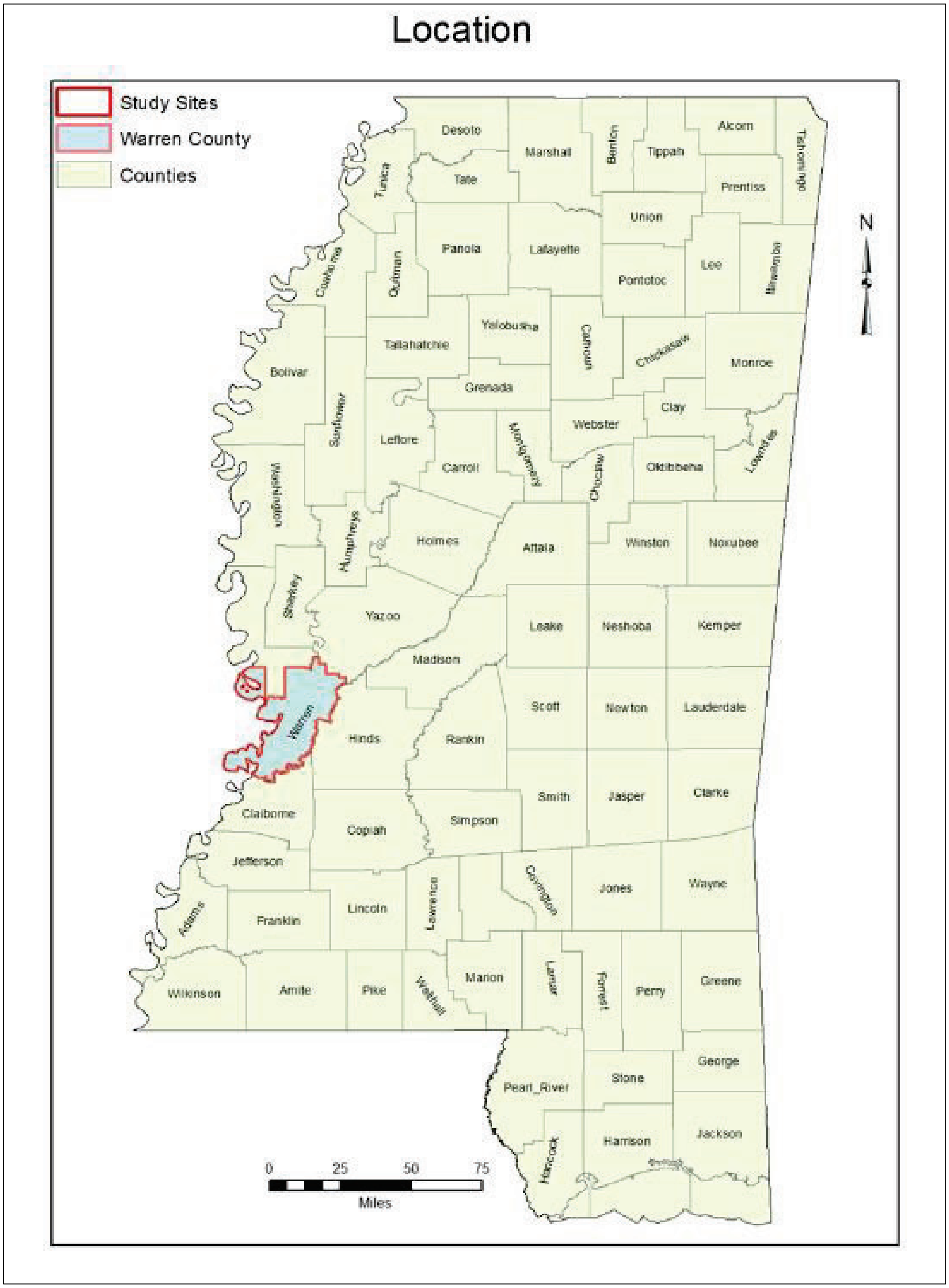
The study site is located on the east bank of the Lower Mississippi River in Warren County, MS (Figure 5), in an area referred to as Tara Wildlife Lodge. The lodge is located in the U.S. Geological Survey (USGS) 1:24000 Talla Bena Quadrangle within the Yazoo River Basin. The area of interest encompasses approximately 2.5 miles of main line Mississippi River levee. The crest of the levee at the study location ranges between 119.0 and 122.0 ft in elevation. This area was designed and constructed to authorized grades, based on the Refined 1973 Project Flood Flowline elevation, ranging from 119.5 ft to 117.5 ft; however, this reach has not been studied to identify the cause of sand boil development (USACE 2012a).

The study site is located in the area of operations of the USACE, Vicksburg District. The length of levee in the USACE, Vicksburg District, is 178.3 miles, of which 144 miles are completed to grade and section, 4.7 miles are under contract to be completed, and 29.6 miles remain to be completed (USACE 2013). According to USACE (2013), the authorized free board is 3 ft above the Project Flood flow line. Most of the remaining sections to be raised are deficient in grade by an average of2 to 3 ft. The average height of the levee is 30 ft (USACE 2013).

The geology of the Mississippi River Alluvial Valley has been well defined on a scale relevant to understanding the alluvial deposits and their chronology in terms of the meandering of the Mississippi River during the Holocene Epoch and the formation of different meander belt deposits (Fisk 1944; Kolb et al. 1968; Saucier 1994). These studies presented a correlation of engineering properties to depositional environments.

Fisk (1944) described the alluvial valley of the Lower Mississippi River as beginning near the confluence of the Mississippi and the Ohio Rivers at Cairo, IL, and extending to the Gulf of Mexico. The valley varies from approximately 30 miles near Natchez, MS, to approximately 125 miles between Memphis, TN, and Little Rock, AR. The ground surface in the valley has an average slope of about 0.6 ft per mile (Tyler et al. 1956).

Figure 5. Map of site location (ESRI 2014).



According to Fisk (1944), deposition of the fluvial sediments within the alluvial valley was in response to continental glaciations during the Pleistocene Epoch (1.8 million to 11,700 years BP). At the end of the Pleistocene, sea level rose to its present position about 3,000 to 5,000 years ago. The rise in sea level affected the base level and caused deposition of coarse sediments within the drainage systems that were flowing into the Gulf of Mexico. The Mississippi River transitioned to the current meandering regime approximately 8,000 to 10,000 years ago (Saucier 1994).

Since that time, the Mississippi River has created a series of meander belts within the alluvial valley. Each meander belt consists of abandoned channels, or oxbow lakes; point bars; and natural levees that are indicators of previous river presence and migration during historic and prehistoric times. It takes the river about 100 years to form an abandoned channel. The Holocene Epoch (11,700 BP) alluvial plain of the Mississippi Alluvial Valley is dominated by abandoned meander belts of the Mississippi, the Arkansas, and the Red Rivers (Tyler et al. 1956).

The subject levee reach is founded on recent alluvial deposits that can be subdivided using the Unified Soil Classification System (USCS) (Figure 6, USACE 1960) into two distinct but unequal parts: a fine-grained top stratum composed of clays (CH-CL), silts (ML), and silty fine-grained sands (SP-SM) underlain by a coarse-grained substratum of fine sands (SP) that generally grade downward into coarse sands (SP) and at the base, sandy gravels (GP) (USACE 2012a). The symbol S represents sands and P means that it is poorly graded with little or no fines. The symbol SM designates that the material is coarse with non-plastic fines. GP represents poorly graded gravels that contain little or no plastic fines.

The levee is located in the southern end of the Yazoo River Basin (Figure 7). The Yazoo River Basin is located in northwestern Mississippi and is the largest drainage basin in the Mississippi River Alluvial Valley, with an area of about 7,600 square miles (Saucier 1994) that extends from Memphis, TN, to Vicksburg, MS. The Yazoo River becomes a tributary to the Mississippi River at Vicksburg. Interior drainage of the basin is by way of a complex system of streams that eventually join the Big Sunflower River and flow into the Yazoo River. The floodplain in the Yazoo River Basin has many oxbow lakes, abandoned channels, and ridges and swales due to migration of the Mississippi River. The lateral migration of the river

Figure 6. The Unified Soil Classification System (USACE 1960).

UNIFIED SOIL CLASSIFICATION SYSTEM

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES
COARSE GRAINED SOILS (More than 50% of material is LARGER than No. 200 sieve size)	GRAVELS (More than 50% of coarse fraction is LARGER than the No. 4 sieve size)	CLEAN GRAVELS (Little or no fines)	GW	Well-graded gravels or gravel-sand mixtures, little or no fines.
			GP	Poorly-graded gravels or gravel-sand mixtures, little or no fines.
		GRAVELS WITH FINES (Appreciable amt. of fines)	GM	Silty gravels, gravel-sand-silt mixtures.
			GC	Clayey gravels, gravel-sand-clay mixtures.
	SANDS (More than 50% of coarse fraction is SMALLER than the No. 4 sieve size)	CLEAN SANDS (Little or no fines)	SW	Well-graded sands or gravelly sands, little or no fines.
			SP	Poorly-graded sands or gravelly sands, little or no fines.
		SANDS WITH FINES (Appreciable amt. of fines)	SM	Silty sands, sand-silt mixtures.
			SC	Clayey sands, sand-clay mixtures.
FINE GRAINED SOILS (More than 50% of material is SMALLER than No. 200 sieve size)	SILTS AND CLAYS (Liquid limit LESS than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
			OL	Organic silts and organic silt-clays of low plasticity.
	SILTS AND CLAYS (Liquid limit GREATER than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
			CH	Inorganic clays of high plasticity, fat clays.
			OH	Organic clays of medium to high plasticity, organic silts.
HIGHLY ORGANIC SOILS			Pt	Peat and other highly organic soils.

BOUNDARY CLASSIFICATIONS: Soils possessing characteristics of two groups are designated by combinations of group symbols.

PARTICLE SIZE LIMITS

SILT OR CLAY	SAND			GRAVEL		COBBLES	BOULDERS
	Fine	Medium	Coarse	Fine	Coarse		

No. 200 No. 40 No. 10 No. 4 ¾ in. 3 in. 12 in.

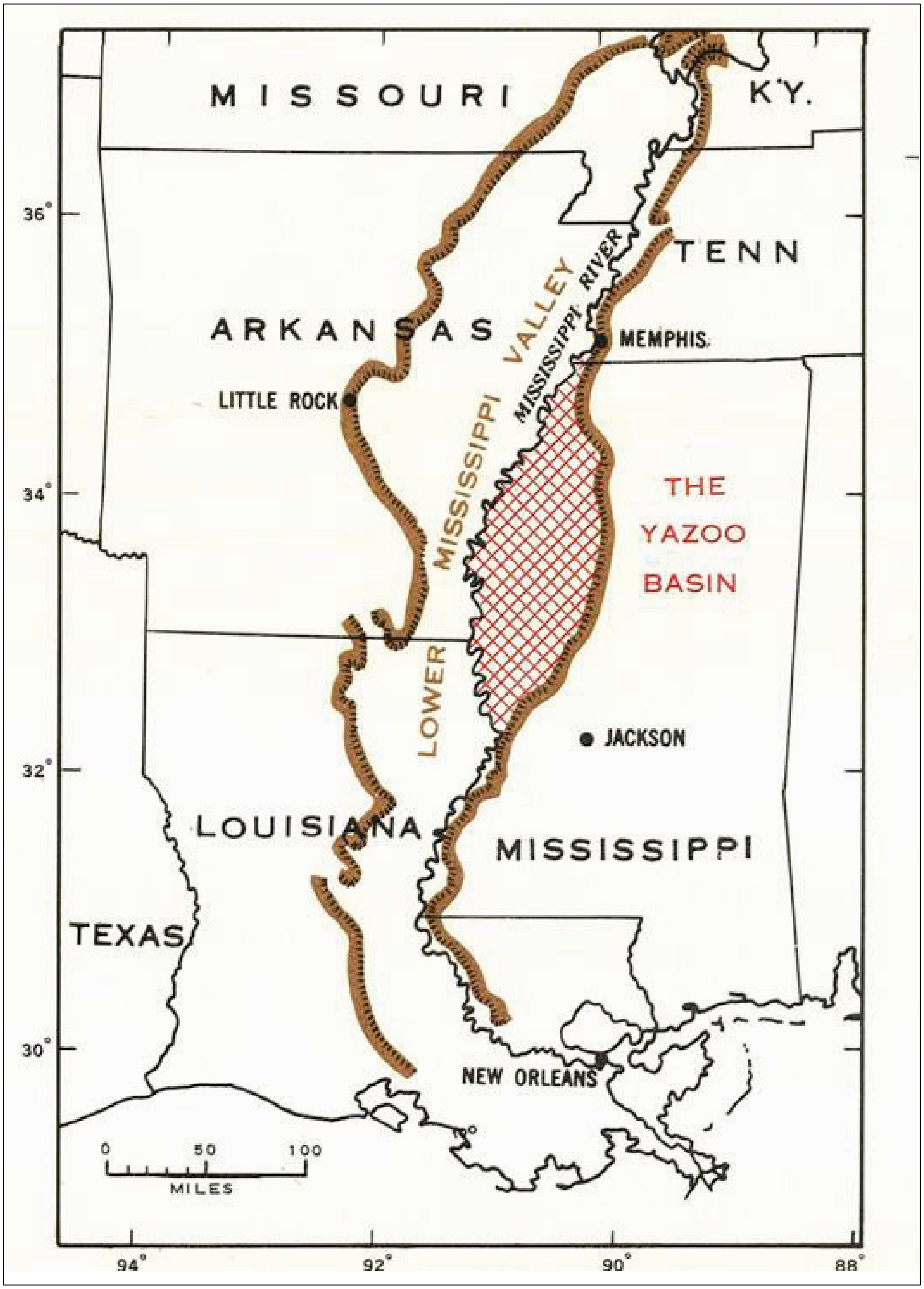
U. S. STANDARD SIEVE SIZE

Reference: The Unified Soil Classification System, Corps of Engineers, U.S. Army Technical Memorandum No. 3-357, Vol. 1, March, 1953 (Revised April, 1960)

1969 R.N.F

Figure G 160

Figure 7. The Yazoo River Basin shown in hatch-mark region (Kolb et al. 1968).



formed ridges and swales that are characteristic of point-bar deposits (Figure 8). Figure 9 is the depiction of the site using Light Detection and Ranging (LiDAR).The floodplain of the Mississippi River flooded frequently until the construction of man-made levees. The physiographic region (Figure 10) of the study location shows the landscape within Warren County, MS (Figure 11), and the study site (Figure 12). The alluvial geology of the Yazoo Basin (Figure 13) depicts the depositional environment specifically characterizing point bars, abandoned courses, abandoned channels, backswamps, and braided streams. A cross section is provided in Figure 14 depicting the subsurface from backswamp to point bar.

The study site has a humid subtropical climate that is mild with no dry season. It remains almost constantly moist from year-round rainfall. The summers are hot and humid with thunderstorms. Winters are mild and have few days each year that remain below freezing.

Figure 8. Map showing depositional formations of ridges, swales, and point bar deposits of sand and thin clay (Mansur et al. 1956).

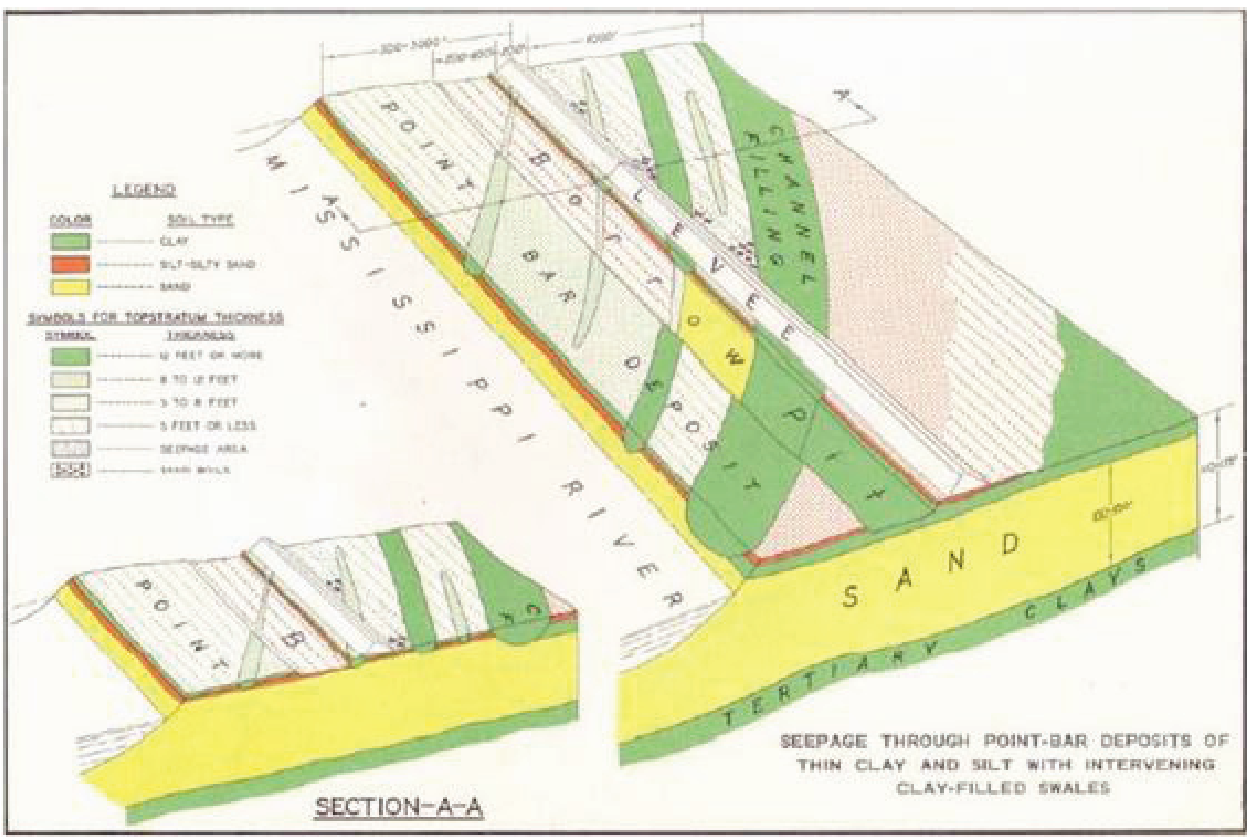


Figure 9. Airborne LiDAR of the study location showing ridge and swale topography (ESRI 2014).

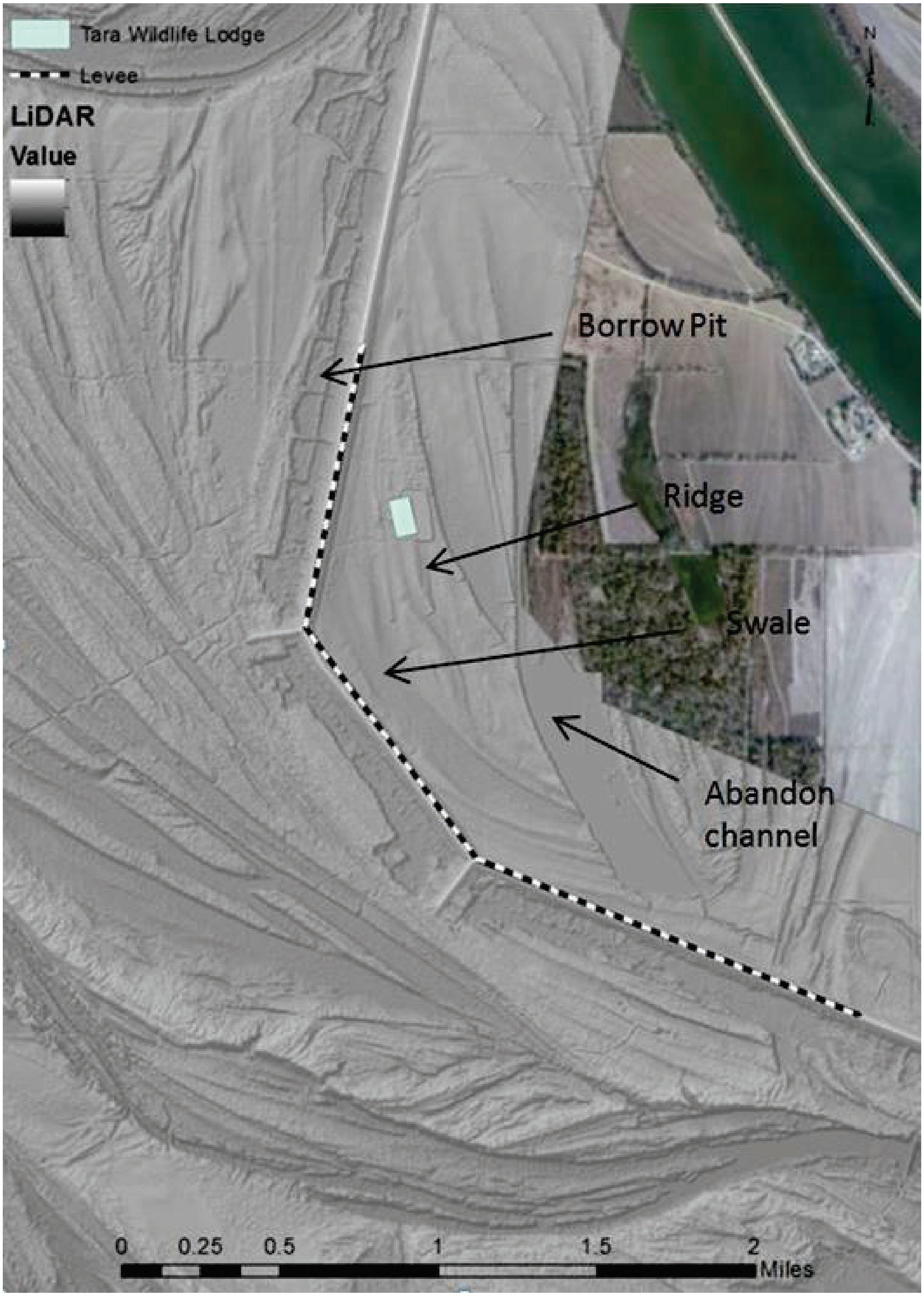


Figure 10. Map of the physiographic region of Mississippi (MARIS 1994).

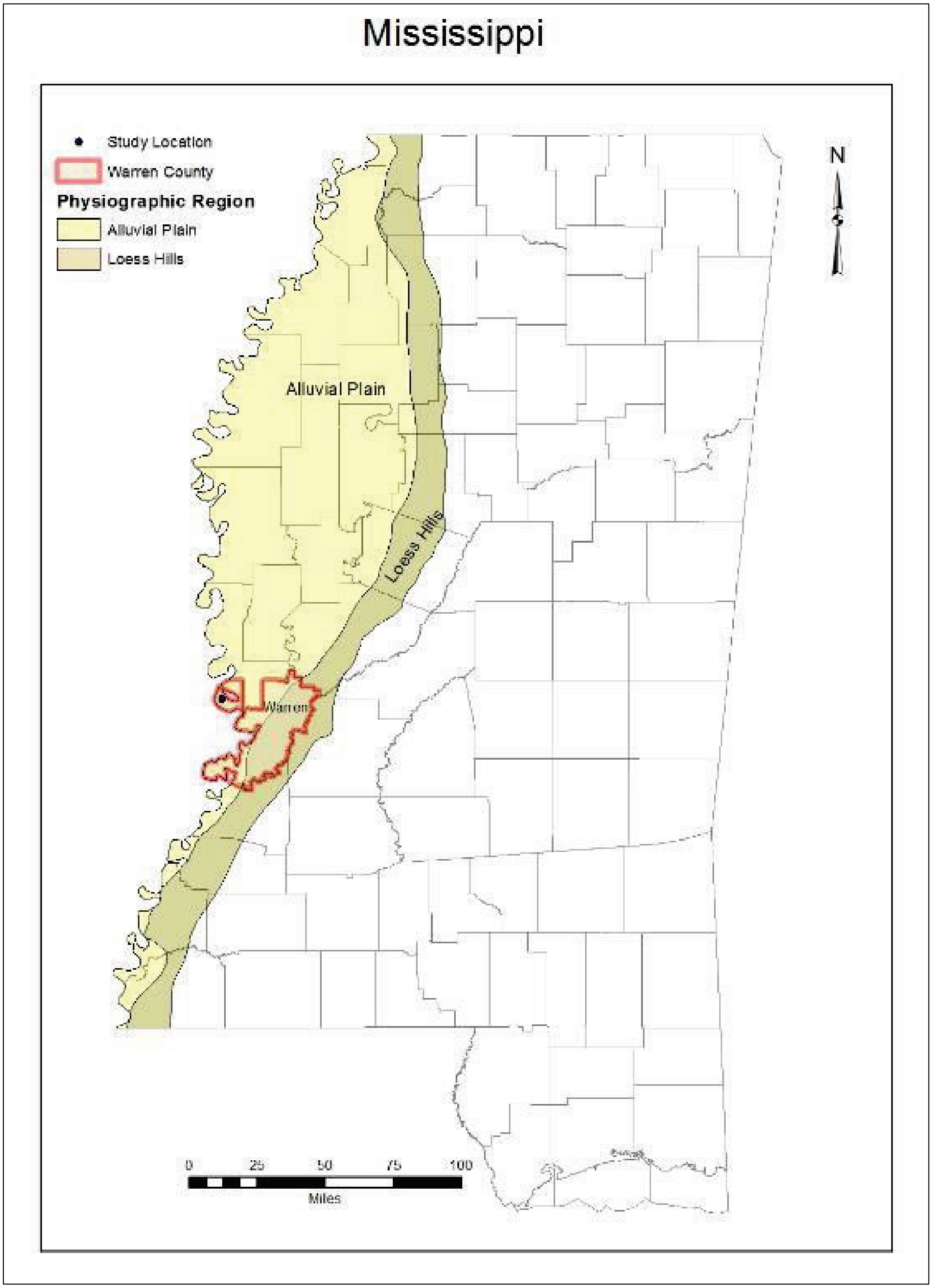


Figure 11. Location of study site (ESRI 2014).

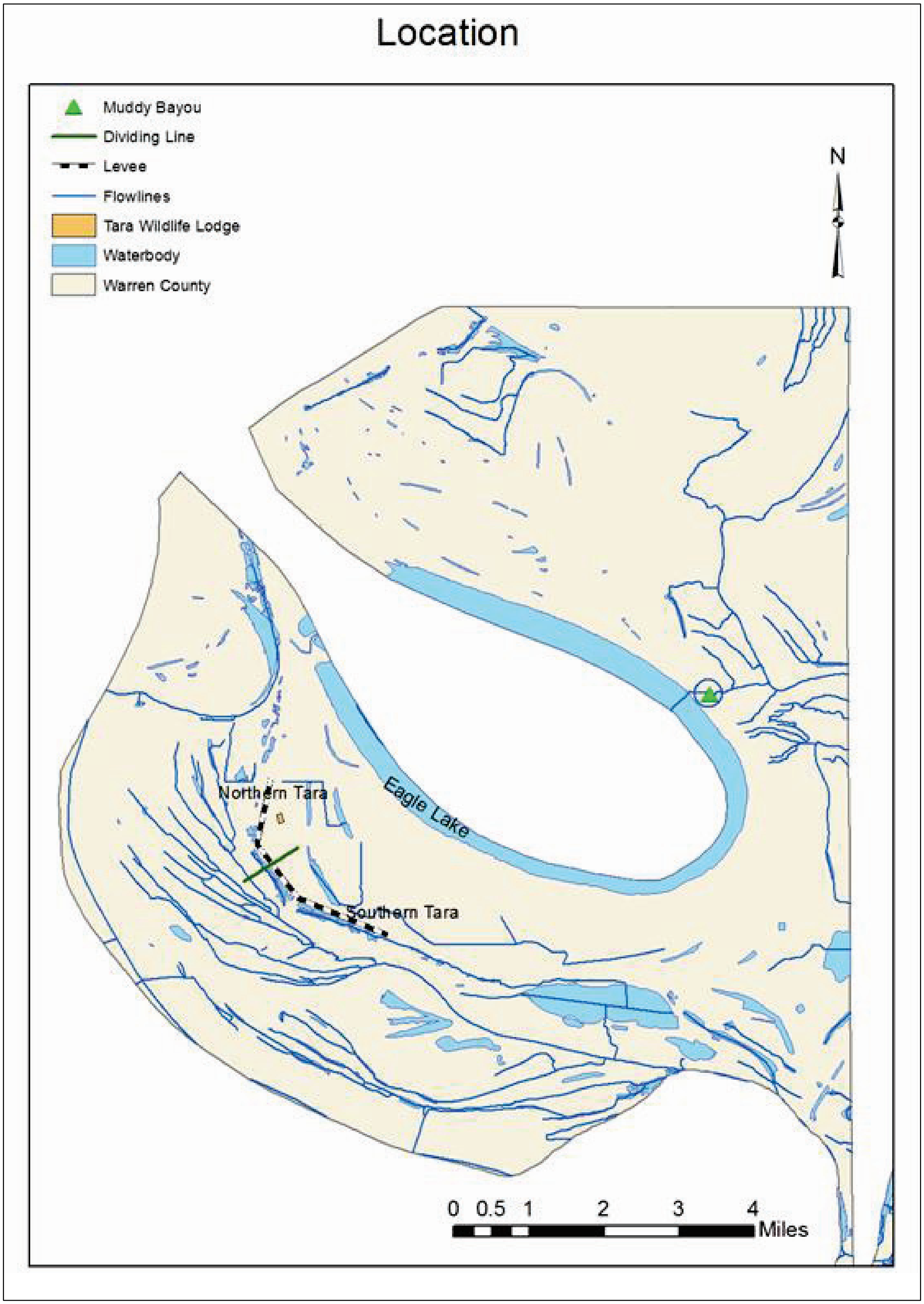
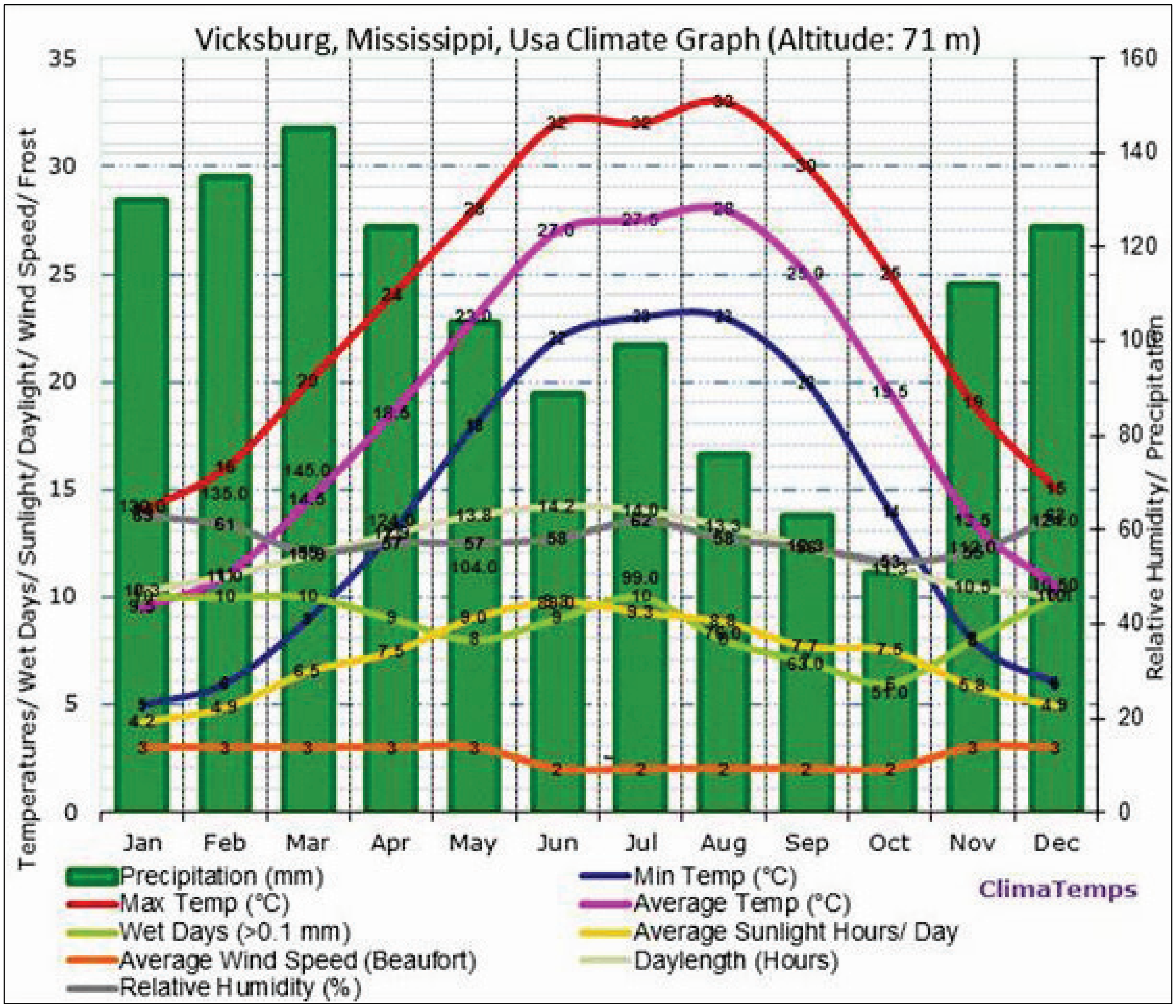


Figure 12. Climatic graph for the Tara Wildlife area (Climatemps 2014).



Data on climate conditions were obtained from Climatemps.com (2014). The average annual temperature is 18.9 deg C (66.1 deg F). Winter temperatures range between 15 deg C (59 deg F) during the day and about 5.5 deg C (42 deg F) at night. Spring temperatures climb during the day to about 23.8 deg C (75 deg F) and usually fall to 13.3 deg C (56 deg F). The average highs in the summer are 32.2 deg C (90 deg F) during the day and 22.7 deg C (73 deg F) at night. In the fall, Vicksburg's temperatures reach a height of 24.4 deg C (76 deg F) during the day and decrease to 13.8 deg C (57 deg F) at night. The total annual precipitation in this area averages about 49 in. (Figure 12).

Figure 13. Alluvial geology of the Yazoo Basin (Modified Kolb et al. 1968).

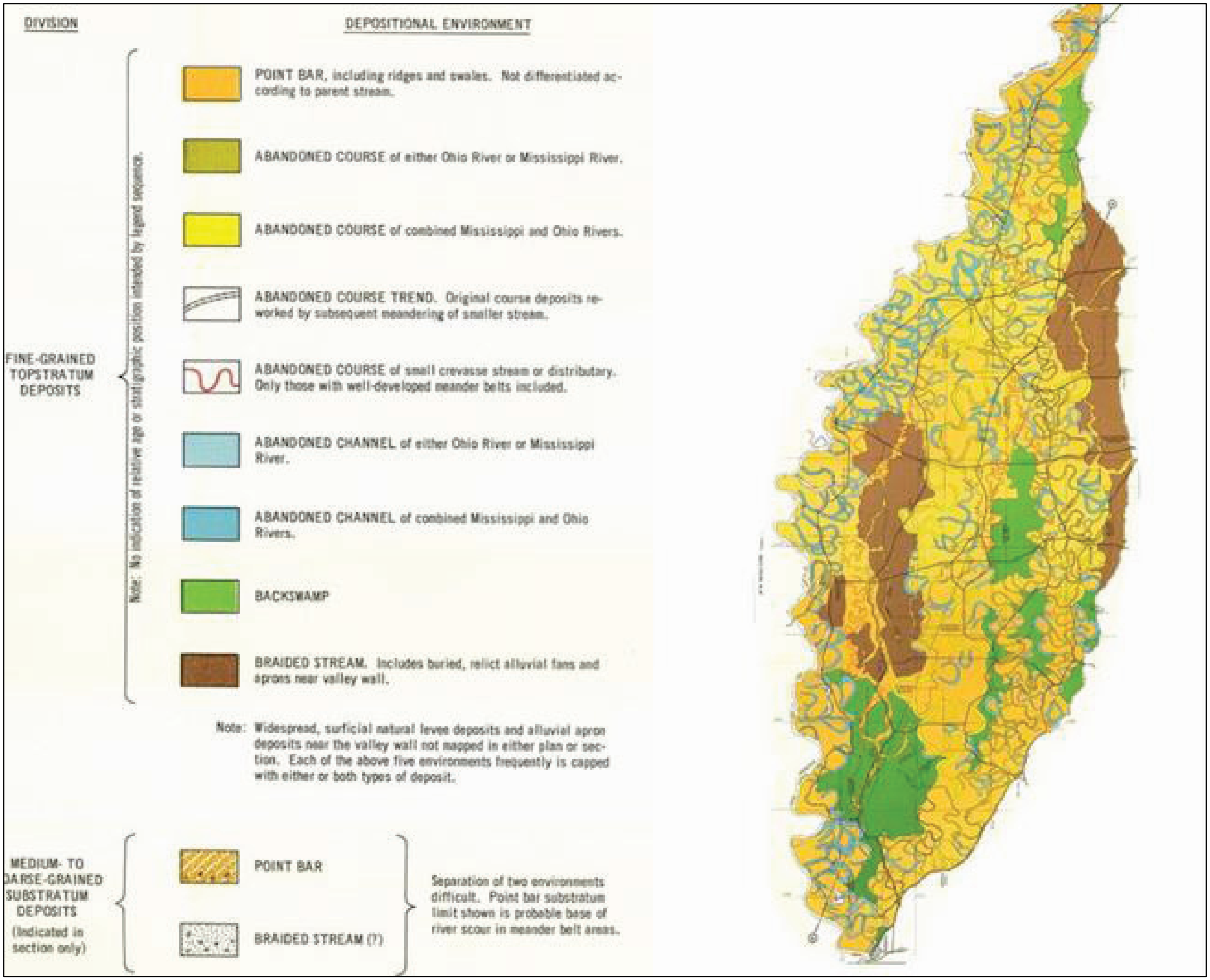
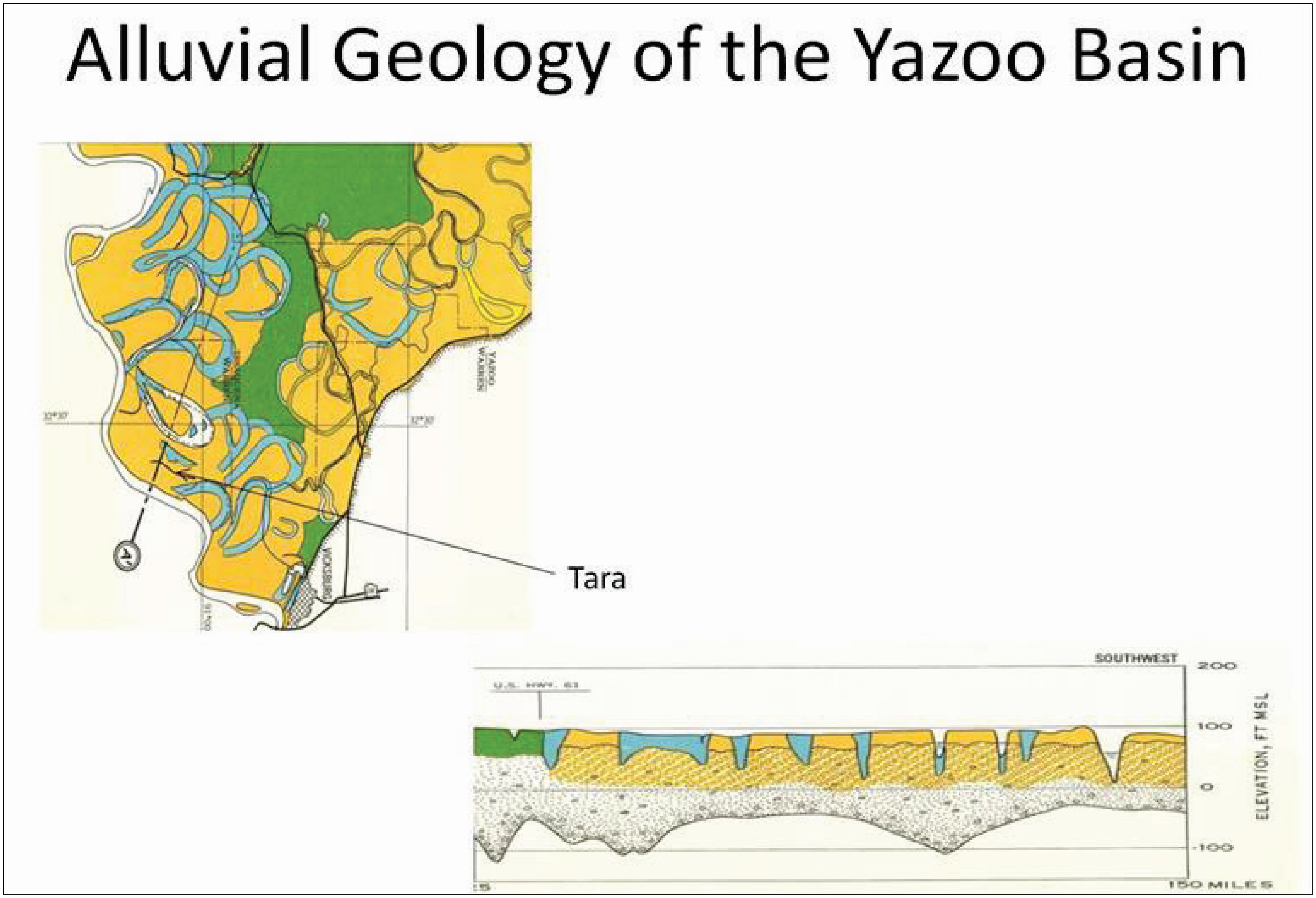


Figure 14. Map of the alluvial geology of the Yazoo River Basin beneath the surface (Modified Kolb et al. 1968).



5 Sand Boil Development

A common problem during floods along the Lower Mississippi River is the formation of sand boils on the landward side of levees (Kolb 1975). Internal erosion begins when water flows through the pervious substratum and seeps upward through the top stratum and produces a sand boil. If the hydrostatic pressure from seepage in the pervious substratum becomes greater than the submerged weight of the top stratum landward of the levee, the uplift pressure may cause heaving and rupture at weak spots with a resulting concentration of seepage flow in the form of sand boils (Kolb 1975).

This, in turn, can lead to instability of the levee during high-water periods. Sand boil development is localized to various factors that are site specific, involving the type of depositional environment, the top stratum characteristics and thickness, lateral extent of the top stratum soils, lateral and vertical extent of the pervious substratum sands, and historic levee construction. The formation of sand boils at or beyond the landside levee toe is one of the first visible signs of excessive underseepage pressure in the substratum. Sand boils typically occur on the landward side and, if nothing is done to reduce the seepage flow's exit velocity, can result in the formation of a conical mound of sand with water flowing from a hole in the center. This formation is caused when the sand is carried by subsurface water to the surface and ejected. There are specific attributes in the subsurface that indicate a fair likelihood of where sand boils may occur. The USACE districts have observed and recorded seepage phenomena during floods along Mississippi River levees in some detail since the early 1930s and 1950s when the first comprehensive study was made of the phenomena of underseepage and sand boils (Mansur et al. 1956).

During the 2011 flood, moderate to heavy underseepage and numerous active sand boils and pin boils were observed within 50 ft of the landside toe in front of Tara Wildlife Lodge. Sand boil and seepage data, obtained in locations shown in Figure 15, were collected using the Mobile Information Collection Application (MICA) that is described in Chapter 6. Three high-energy sand boils with 12- to 16-in. throats were identified (USACE 2012a). These boils cumulatively flowed 100+ gal/min, transported 5+ cu yd of fine sand/silt before and during remedial action, and were located between 10 and 20 ft from the levee toe (USACE 2012b.)

Figure 15. Map showing MICA data collected during the 2011 flood (ESRI 2014).

6 Data Collection

6.1 Electrical resistivity tomography

Electrical resistivity tomography (ERT) is commonly used in geophysical explorations. Geophysical electrical methods involve the measurement of potentials, currents, or electromagnetic fields that are introduced into the earth.

Electrical properties of subsurface materials can be determined by the variation in these measurements due to changes in the electrical conductivity through the materials. The electrical resistivity in the majority of soil minerals is so high that most electrical current flowing through a soil will be through the soil pore water. For this reason, the bulk resistivity of a soil sample will depend mainly on the amount and resistivity of the water contained in the sample, although clay exhibits some surface conduction effects and often displays a different bulk resistivity than other minerals (USACE 1992).

In this regard, the resistivity technique is superior, at least theoretically, to all the other electrical methods, because quantitative results are obtained by using a controlled source of specific dimensions. As in other geophysical methods, the maximum potentialities of resistivity are never realized. The chief drawback is its high sensitivity to minor variations in conductivity near surface; in electronic parlance, the noise level is high. An analogous situation would exist in ground magnetic surveys if one were to employ a magnetometer with sensitivity in the picotesla range (Telford et al. 1990).

The necessary apparatus for resistivity surveys are long, specialized cables, electrode stakes, deep cycle marine battery for a power source, and the computing instrument that interprets the outcome of direct current resistance. Telford et al. (1990) states that, regardless of the specific electrode spread employed, there are really only two basic procedures in a resistivity survey. The particular procedure to be used depends on whether one is interested in resistivity variations with depth or with lateral extent. Lateral mapping was used in this research to investigate seepage parallel to the levee reach.

Surface electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivity and distribution of the surrounding soils and rocks. The usual practice in the field is to apply an electrical direct current (DC) between two electrodes implanted in the ground and then measure the potential between two additional electrodes that do not carry current. Usually, the potential electrodes are in line between the current electrodes, but in principle they can be located anywhere. The farther apart the electrodes, the deeper the subsurface imager will see; but with increased depth, near surface resolution is lost. All analyses are conducted on the basis of direct currents. The distribution of potential can be related theoretically to ground resistivities and their distribution for some simple cases, notably, the case of horizontally stratified ground and the case of homogeneous masses separated by vertical planes (USACE 1995).

6.2 Electrical resistivity tomography at Tara Wildlife Lodge

The purpose for conducting geophysical surveys at the study location was to map and measure pathways of seepage in the subsurface. Two sites in the Talla Bena quadrangle were selected for ERT surveys—one with heavy seepage (Northern Tara Wildlife Lodge) and one without (Southern Tara Wildlife Lodge).

All ERT surveys conducted as part of this investigation were conducted using a SuperSting R8 electrical resistivity system manufactured by Advance Geosciences, Inc., Austin, TX.

The first ERT survey was conducted at the southern end of the Tara Wildlife Lodge where two channels crossed underneath the levee at a 90-deg angle. The southern ERT survey used a 6-m electrode spacing array utilizing 84 electrodes and was conducted on April 16, 2014. The location of the survey line is shown in Figure 16. A new berm with multiple relief wells is being constructed by the USACE, Vicksburg District, at this site.

The northern ERT survey was conducted on May 22, 2014, and consisted of 84 electrodes using a 2-m electrode spacing and a single roll-along (Figure 17). The roll-along method is used to continue the lateral mapping process once the initial survey is complete. Once the initial survey line is complete, in this case utilizing 84 electrodes, a set of electrodes is moved from the start of the survey line to the end. Once the set of electrodes has been moved and reconnected to the ERT system, the survey is continued.

Figure 16. Map of southern ERT survey (ESRI 2014).

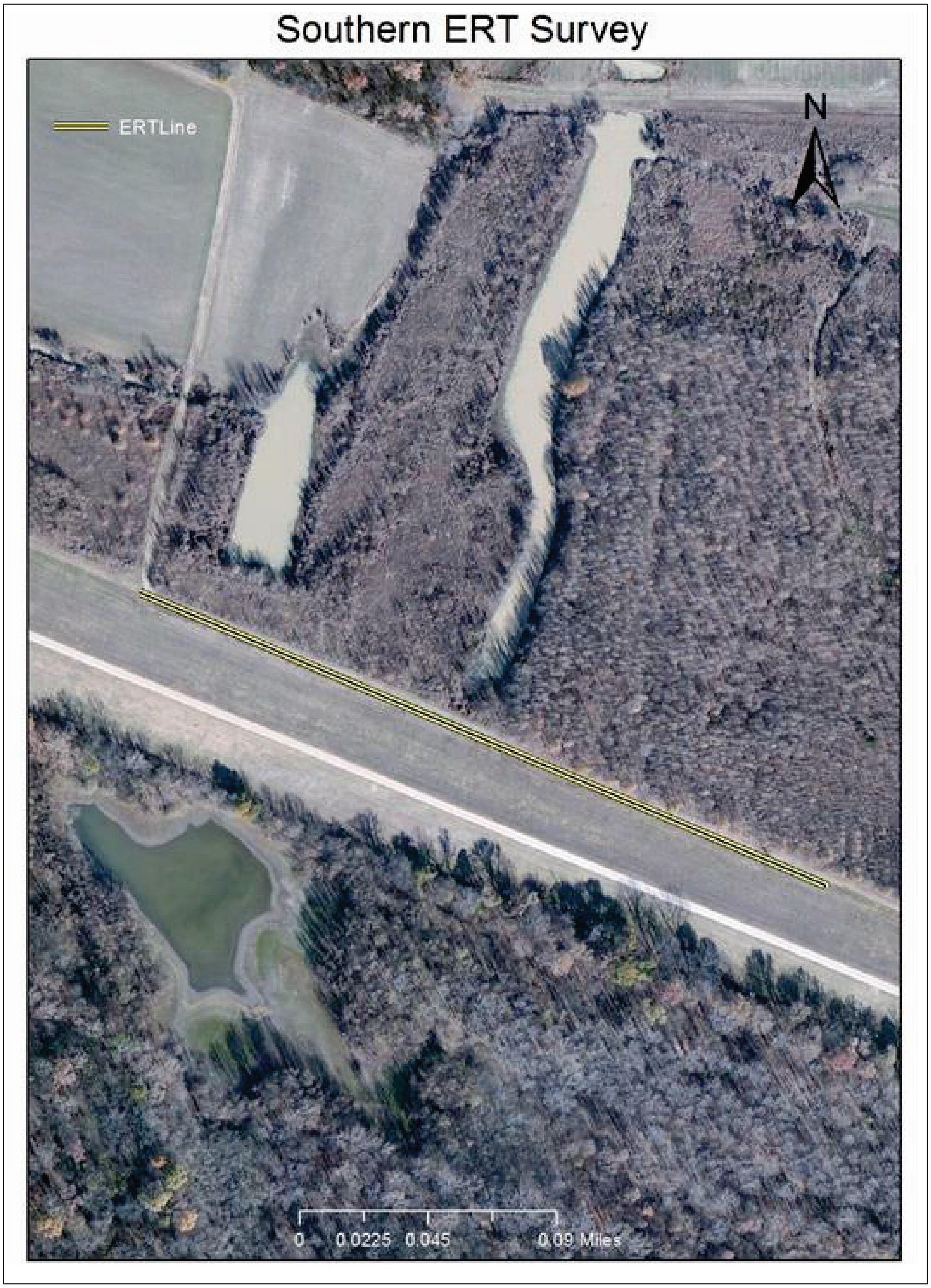
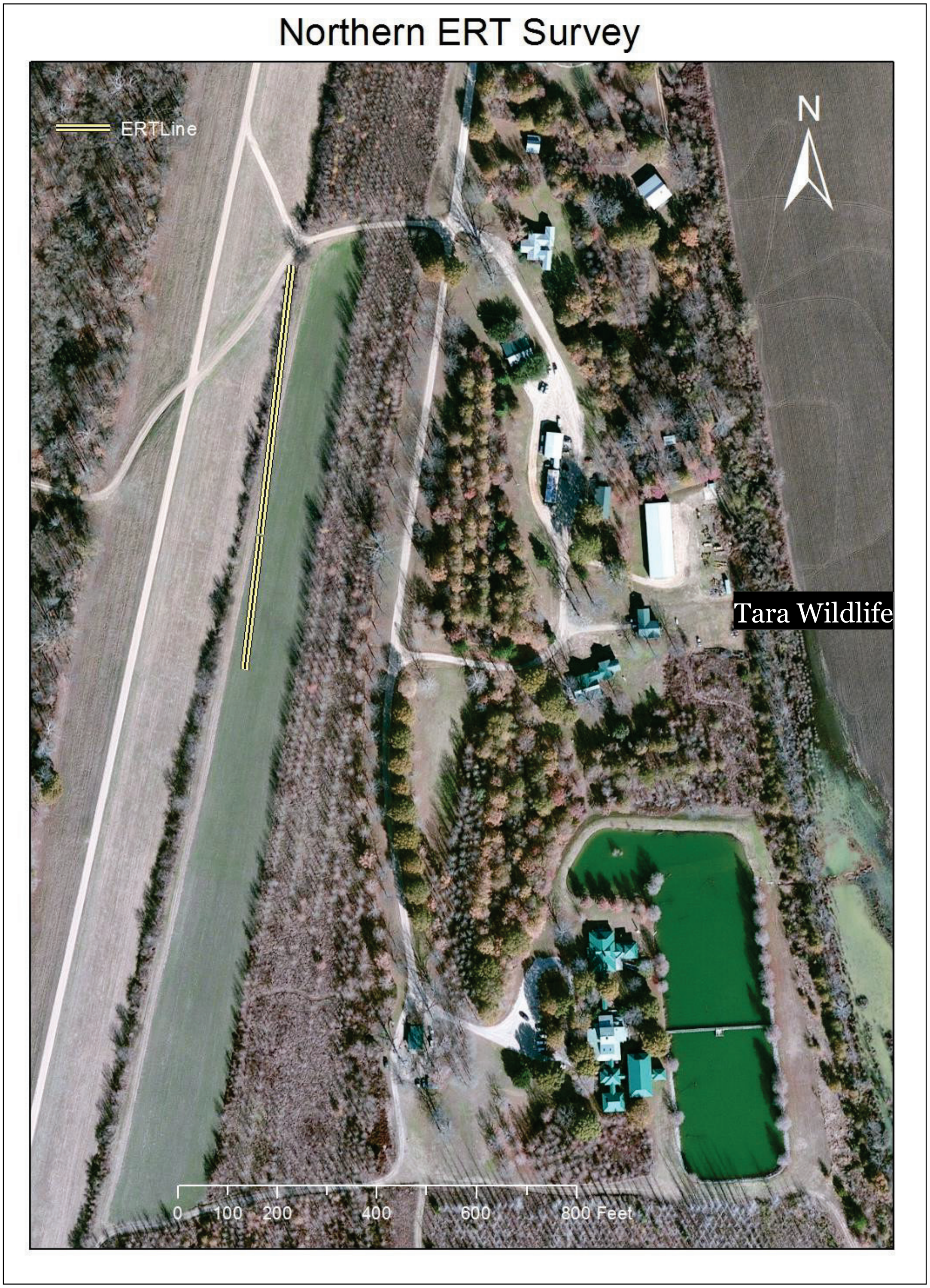


Figure 17. Map of the northern ERT survey at the Tara Wildlife Lodge (ESRI 2014).



For this survey, 14 surveys were “rolled,” resulting in 28 m of additional lateral mapping coverage. The northern ERT survey was strategically placed over places of known seepage (Figures 18 through 20) in order to map and identify anomalies in the subsurface. Imagery downloaded from Google Maps shows the location of both sites during high-water flood events in August of 2009 (Figure 21). Maps from borehole analyses of soil data of the Talla Bena Quadrangle depict the location and a cross-sectional map of the depositional environment located in an area of interest shown in Figures 22 and 23. The second ERT survey was conducted farther north across from the lodge where a new berm is currently being constructed.

The electrical resistivity survey lines at both sites run parallel with the levee on the landward side. The lines are meant to intersect areas where heavy seepage and large sand boils occurred. A Global Positioning System (GPS) was used to locate the start and finish of each electrical resistivity line and the electrodes in order to position the survey line for use in the Geographical Information Systems (GIS).

6.3 LiDAR data

A LiDAR device mounted in an airborne platform emits fast pulses from a focused infrared laser which are beamed toward the ground across the flight path by a scanning mirror. Upon capture by a receiver unit, the reflectance from the ground, tops of vegetation, or structures are relayed to a discriminator and a time interval meter that measures the elapsed time between the transmitted and the received signal. From this information, the distance separating the ground and the airborne platform is determined.

While in flight, the system gathers information on a massive base of scattered ground points and stores them in digital format. An interfaced Inertial Measurement Unit (IMU) records the pitch, roll, and heading of the platform. A kinematic airborne GPS locks onto at least four navigation satellites and registers the spatial position of the aircraft. LiDAR systems can be used to rapidly and accurately map levee systems along rivers and waterways. Profiles and cross sections can be produced and compared to previously collected profiles and cross sections. The resulting LiDAR data sets can also be used to develop a 3-D view of the levee system and identify problems that might have otherwise been missed (USACE 2002). Figures 24 and 25 show how lidar can penetrate vegetation to create bare earth imagery. This allows us to see borrow pits, ridges, and swales.

Figure 18. Study location with both northern and southern ERT survey sites (Google 2009).

Figure 19. Tara Wildlife Lodge showing overflow from sand boils (ESRI 2014).

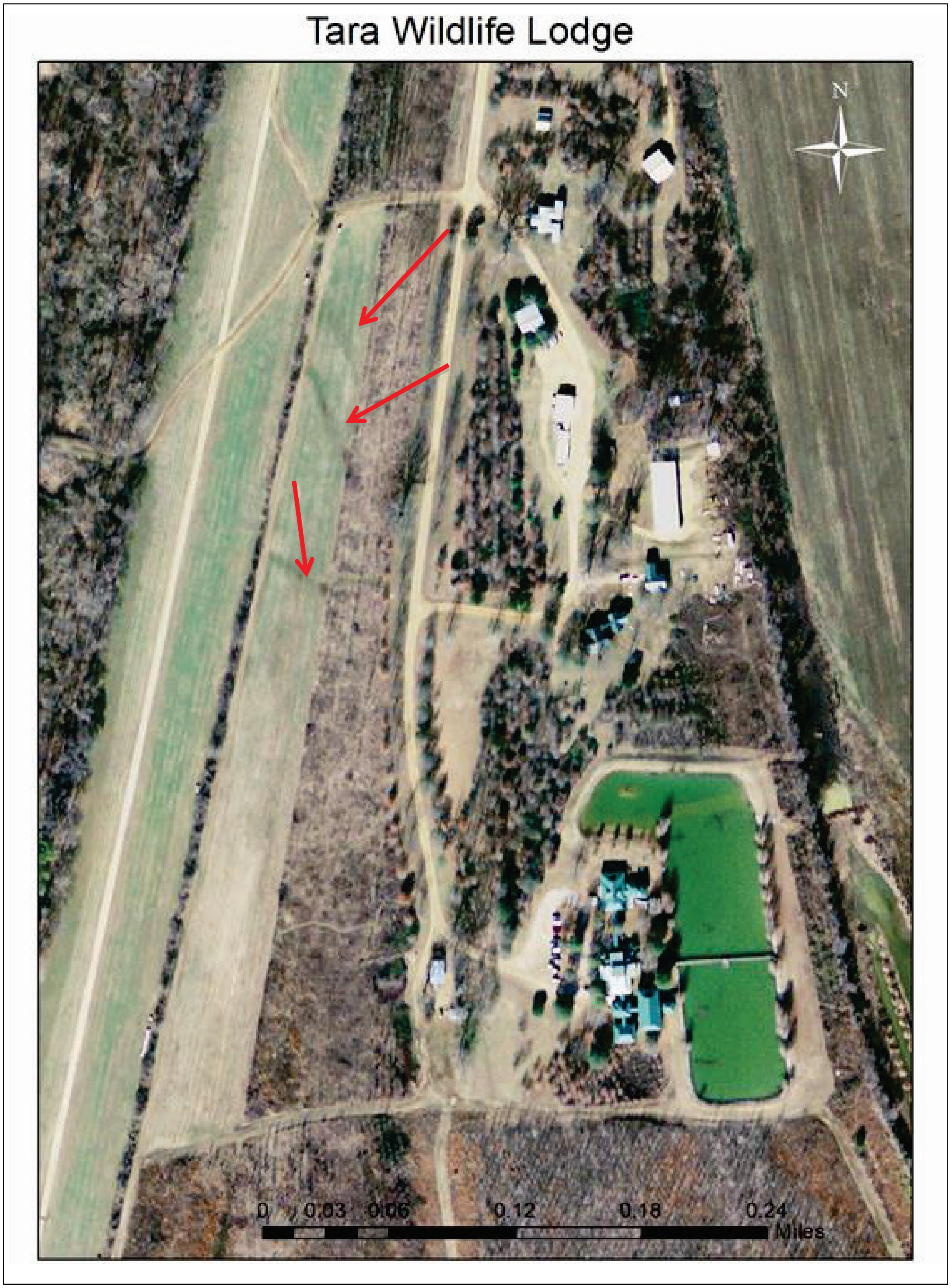
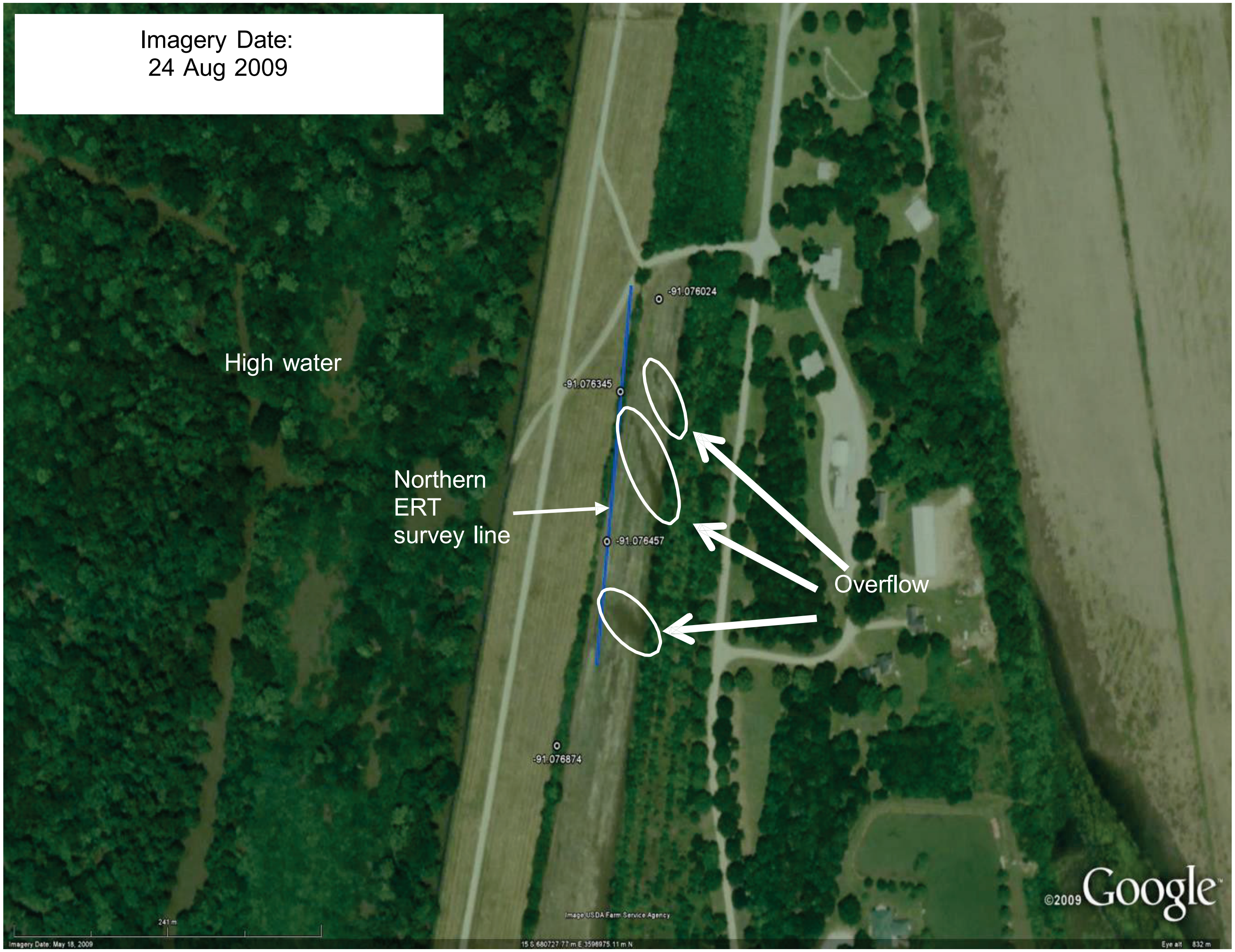


Figure 20. Northern ERT survey transecting areas of seepage. Notice ringed sand boil (Google 2009).

Figure 21. High-water event showing overflow from sand boils and northern ERT survey line (Google 2009).



6.4 Borehole data

Borehole data from April 1944 were collected from the archives of the Vicksburg District. Figures 26 and 27 illustrate the stratified layers of soil depicting clays, sands, and silts.

6.5 Global Positioning System (GPS) data

The positions collected for this research were collected with a Trimble® GeoXH6000 GPS. It is a rugged handheld GPS computer with accuracy within 10 cm (Trimble® 2013). This results in high-accuracy field work and positioning. It also has the ability to take photos. The software system used is Terrasync on the GPS and Pathfinder office for data processing and corrections in the office.

6.6 Mobile Information Collection Application data (MICA)

MICA data were collected from the 2011 flood. These data provided useful information on past sand boil occurrences in the study area. MICA is an application developed by the U.S. Army Research and Development Center (ERDC) used on a smartphone to acquire data, such as photos, latitude and longitude, field notes, and WiFi service. During the destructive floods in the Mississippi River Valley in spring 2011, the MICA system was deployed for rapid flood-related data collection. Instead of the standard field kit, more than 50 Android-based smartphones installed with MICA software were distributed to field personnel in seven flood-affected cities. Emergency Operations Center personnel from the Federal Emergency Management Agency (FEMA) used the MICA system to collect valuable field information and data points during the flood event. More than 12,000 photographs, videos, and notes were captured, automatically geotagged, and transmitted directly from the field to the various command centers, allowing decision-makers to review and analyze critical flood-fighting data within seconds (USACE 2012b).

6.7 Cone penetrometer tests (CPTs)

Thirty-five CPTs, numbered TAR-1-11C through TAR-35-11C, were conducted for the purpose of this study and ranged in depth between 40 and 50 ft (Table 1). TAR is abbreviated for Tara, 1 is the whole number, 11 is the year, and C (for CPT) is the method of collection. These data are in Appendix A. The CPTs provided valuable information on the subsurface layers. Sensors are on the tip and the sleeve of the CPT rod. These sensors measure tip force and friction, indicating what type of soil the cone is passing through.

Table 1. Cone penetrometer locations at Tara Wildlife Lodge, with elevations.

Hole Number	Latitude	Longitude	Elevation
TAR-1.11C	32.49947	-91.07558	95.953
TAR-2.11C	32.4988	-91.07572	94.271
TAR-3.11C	32.4981	-91.07587	94.498
TAR-4.11C	32.49686	-91.07617	93.86
TAR-5.11C	32.49543	-91.07641	92.507
TAR-6.11C	32.49405	-91.07677	95.553
TAR-7.11C	32.49282	-91.07704	92.886
TAR-8.11C	32.49148	-91.07738	93.435
TAR-9.11C	32.49011	-91.07776	92.781
TAR-10.11C	32.48887	-91.07803	93.603
TAR-11.11C	32.48759	-91.07809	97.121
TAR-12.11C	32.48656	-91.07724	94.87
TAR-13.11C	32.48551	-91.07628	94.601
TAR-14.11C	32.48437	-91.07513	94.108
TAR-15.11C	32.48339	-91.07418	96.472
TAR-16.11C	32.4822	-91.07316	95.564
TAR-17.11C	32.48111	91.07216	94.421
TAR-18.11C	32.48019	-91.07135	94.085
TAR-19.11C	32.47925	-91.0703	95.999
TAR-20.11C	32.47874	-91.06884	96.158
TAR-21.11C	32.47824	-91.06734	95.805
TAR-22.11C	32.47775	-91.0658	92.953
TAR-23.11C	32.47727	-91.06434	92.122
TAR-24.11C	32.47677	-91.0628	92.536
TAR-25.11C	32.47621	-91.06124	94.187
TAR-26.11C	32.49953	-91.07638	97.979
TAR-27.11C	32.49889	-91.07658	95.64
TAR-28.11C	32.49822	-91.07667	96.233
TAR-29.11C	32.497	-91.07702	95.109
TAR-30.11C	32.49556	-91.07739	96.094
TAR-31.11C	32.49425	-91.07767	94.192
TAR-32.11C	32.49297	-91.07794	96.26
TAR-33.11C	32.49154	-91.07833	95.348
TAR-34.11C	32.49021	-91.07864	96.026
TAR-35.11C	32.48901	-91.07895	97.378

Figure 22. Map of the Talla Bena Quadrangle with A-A' cross section USGS 1:24000 (Kolb 1975).

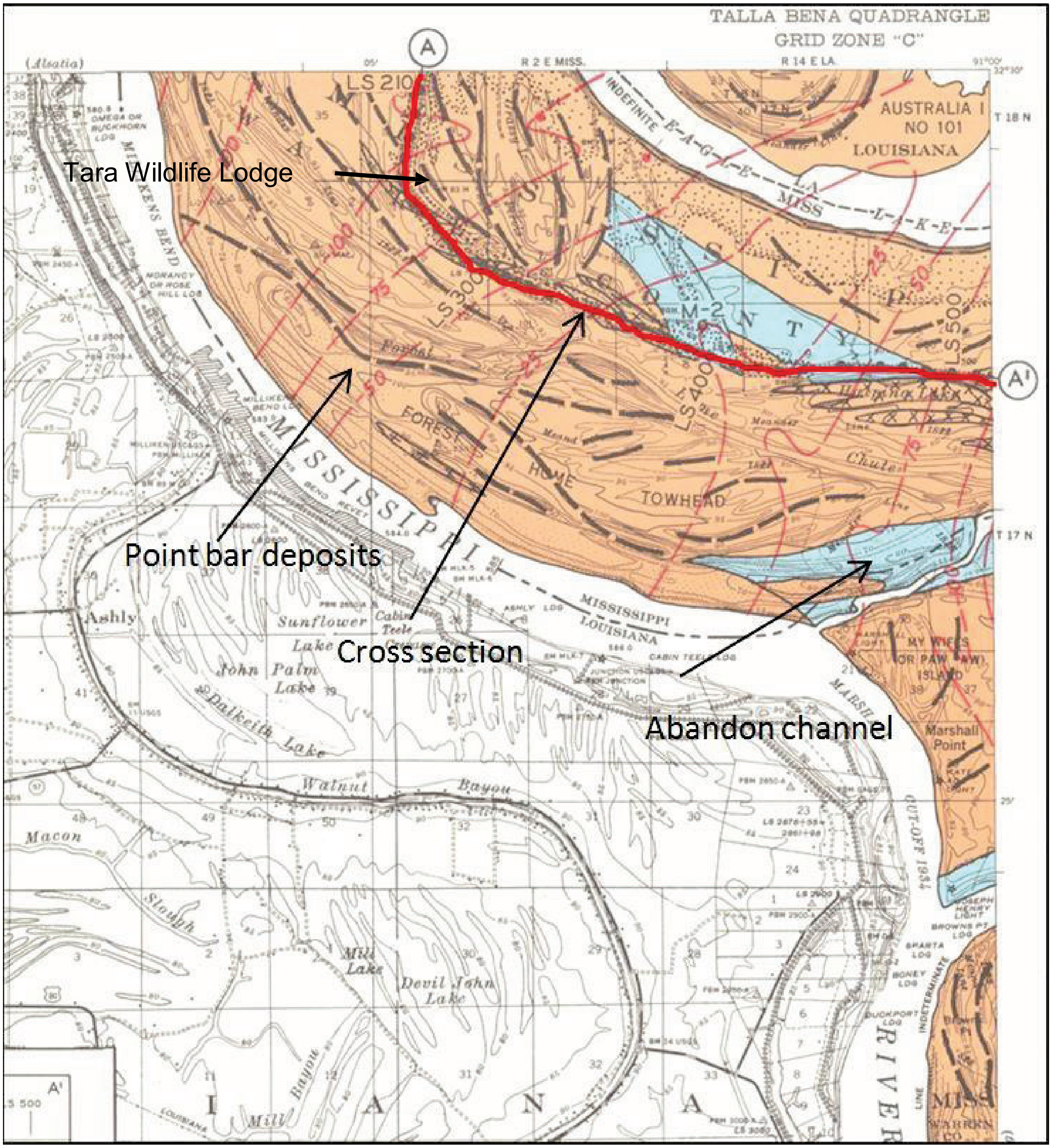


Figure 23. Cross-section map of soils in the Talla Bena Quadrangle A-A' (Kolb 1975).

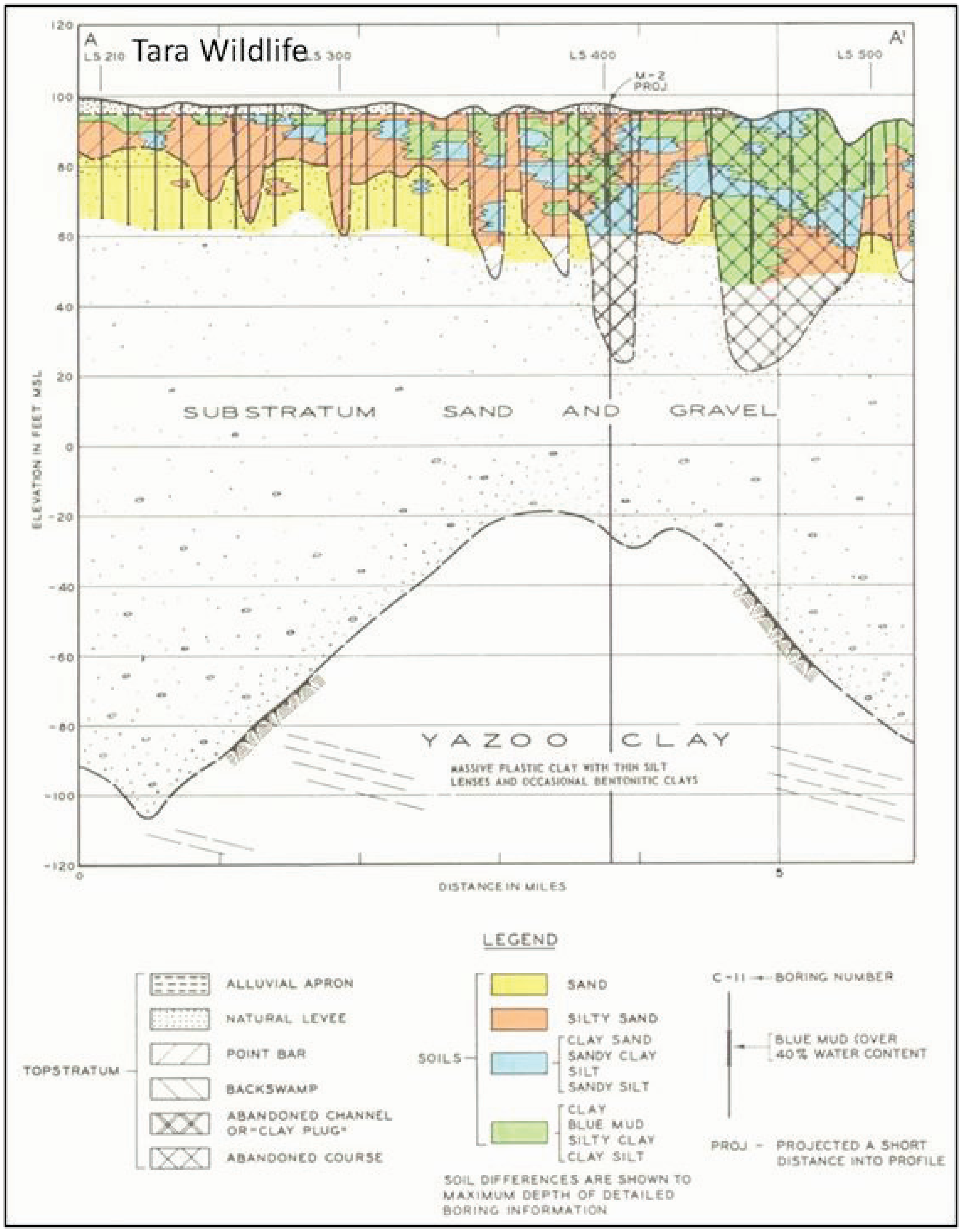


Figure 24. Tara Wildlife area with LiDAR data (ESRI 2014).

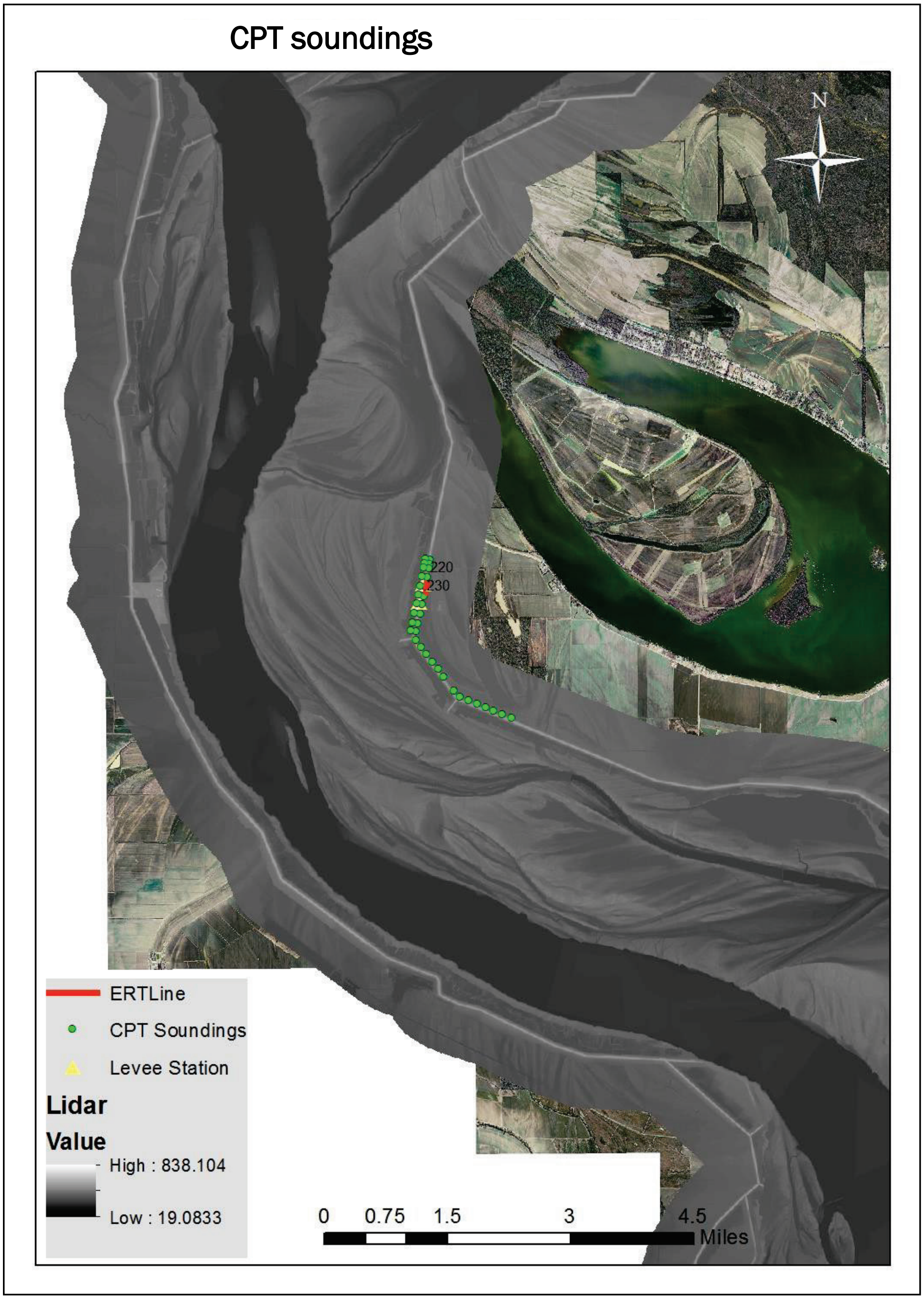


Figure 25. Northern Tara Wildlife area with LiDAR data.

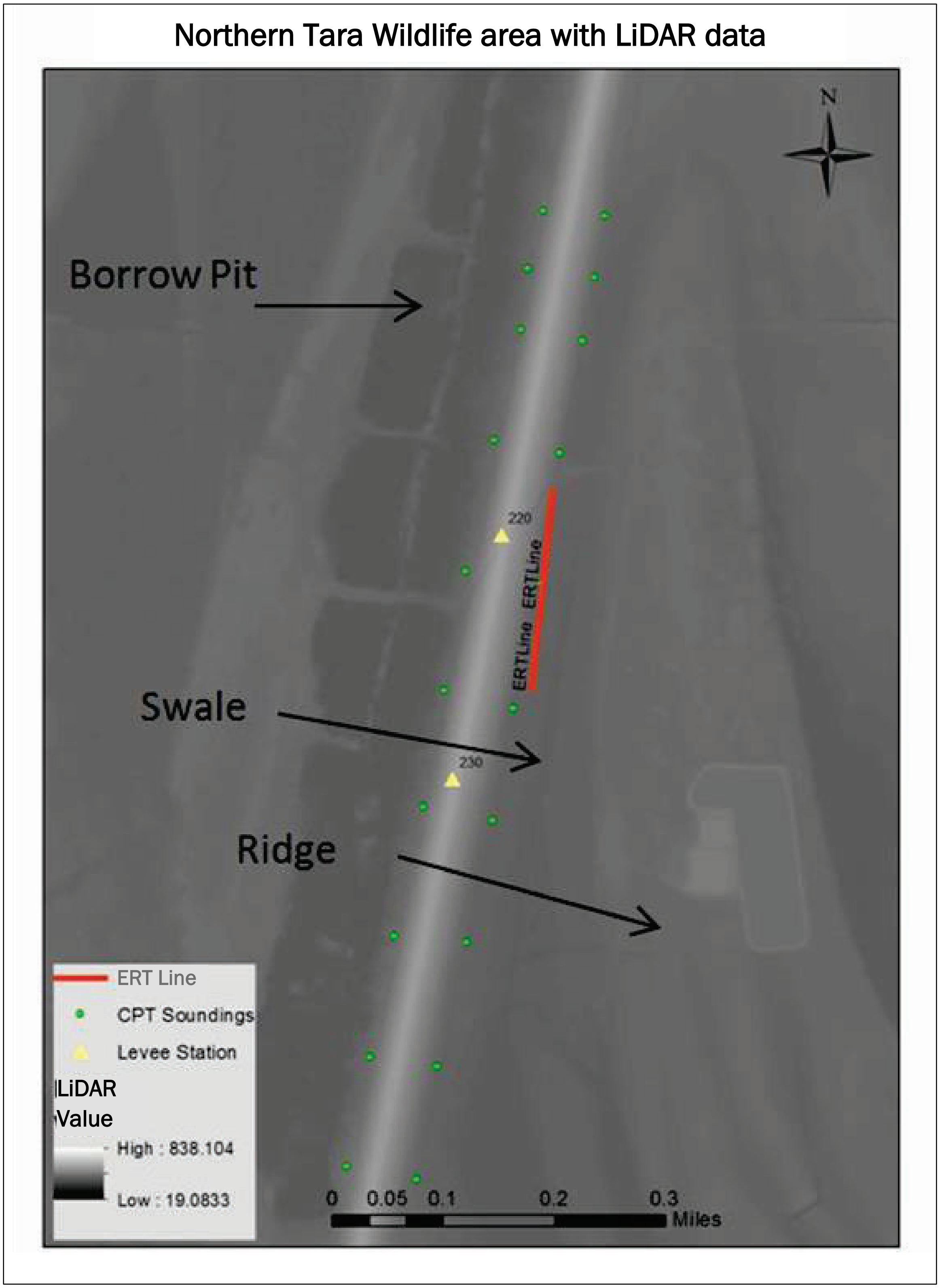


Figure 26. Borehole investigations in northern area of Tara Wildlife Lodge modified from USACE 1944

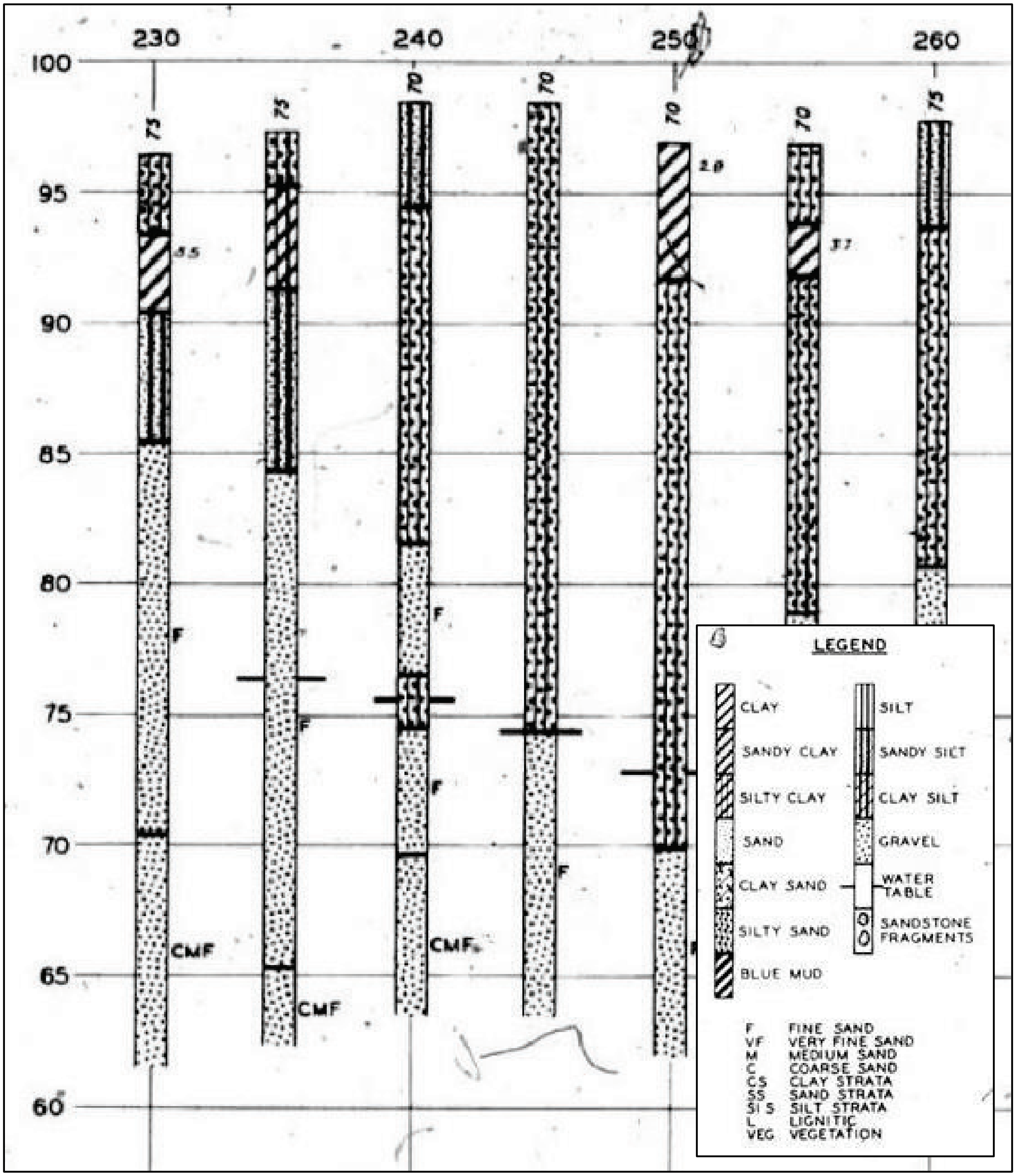
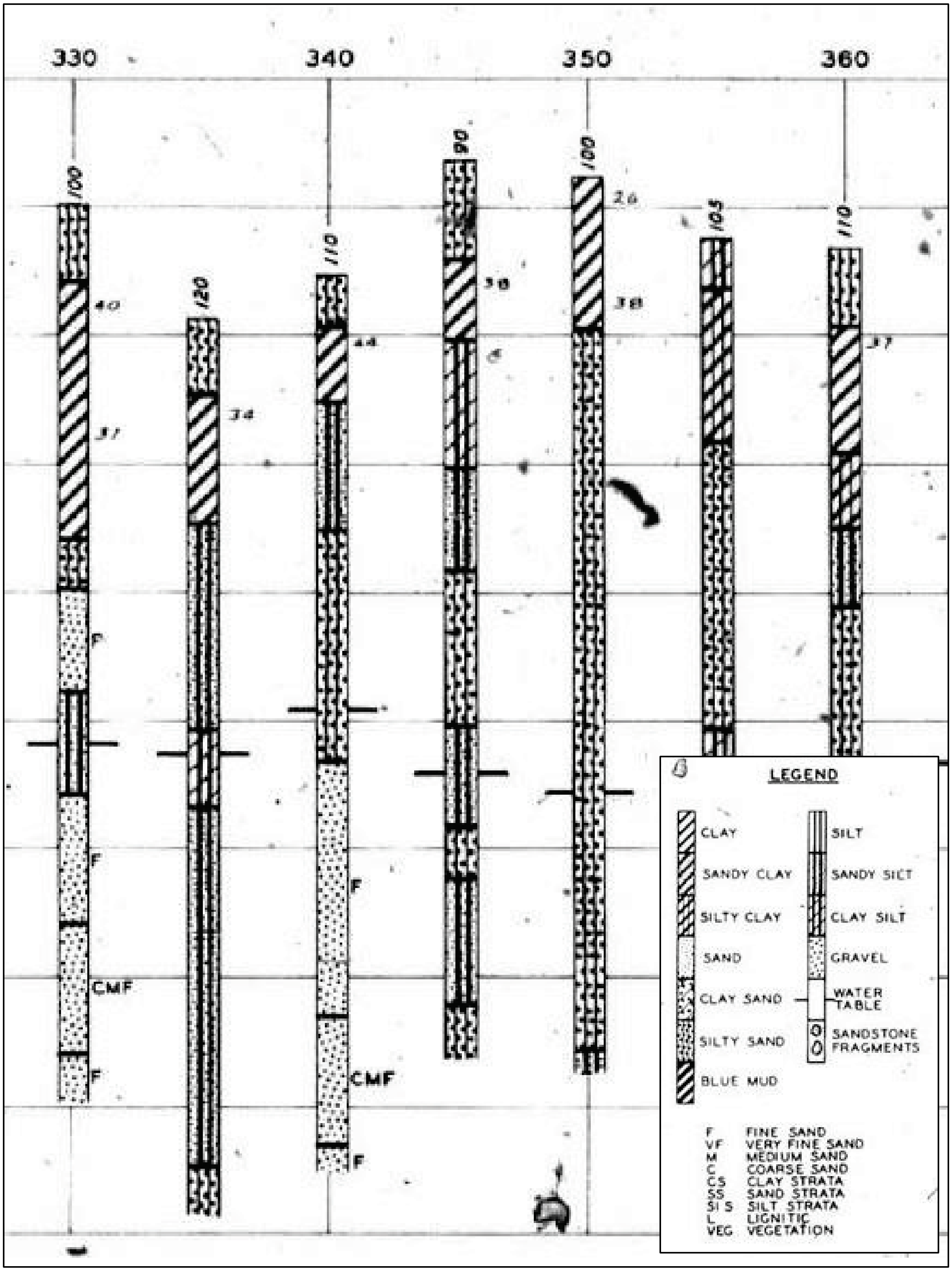


Figure 27. Borehole investigations in southern area boreholes from Tara Wildlife Lodge (modified from USACE 1944).



7 Results

The ERT data show that the overlying clay layer is very thin and in some places nonexistent. Figure 28 shows levels of electrical resistivity. The blue color in the image at the location of the sand boils is interpreted as low resistivity deposits, which may indicate an area of high seepage or low density (e.g., fully-saturated gravel or sand).

In the southern part of Tara Wildlife Lodge, an ERT survey was conducted to map the two suspected seepage pathways (Figures 29 and 30). An area of low resistant material was identified at the northern point of the survey. Two channels were identified by using aerial photography. The channel that lies at the northern point of the survey coincides with the low resistivity deposits interpreted from the ERT. Two channels of water traveled under the levee and were identified as shown in Figure 31.

The northern channel has a very low resistivity, indicating that this area may have high hydraulic conductivity if this represents a fully-saturated gravel or sand; however, the ERT did not reveal low-resistivity soils in the path of the second channel. This channel was possibly filled in with a sandy material during construction of the levee. The clay top stratum is nonexistent in some areas, as evident by the boring data. This is a problem when downward forces are needed to prevent the upward forces of excessive seepage pressure in the pervious substratum. Without an impervious top stratum, boils are likely to occur. Because the subsurface consists mostly of noncohesive soil, this area is prone to underseepage and potential piping through the subsurface stratum.

The CPT soundings show that the dominant soil types are silt, silty sand, and sand. These soils were laid down from the course of the meandering Mississippi River and are common with point bar deposition. Point bar deposits consist of sandy sediments deposited on the inside of river bends as a result of meandering. As confirmed by the CPTs, the top stratum is not always impervious clay; and at this location it seems to be a silty sand. For example, a comparison of TAR-09-11C (Figure 32) and TAR-34-11C (Figure 33), which are 83 m from one another, shows a difference in deposits. On the landward side at approximately 9 ft in depth, there is a layer of fine silt. This is usually an indicator of a seepage pathway. On the

Figure 28. Results of the northern Tara Wildlife Lodge ERT data.

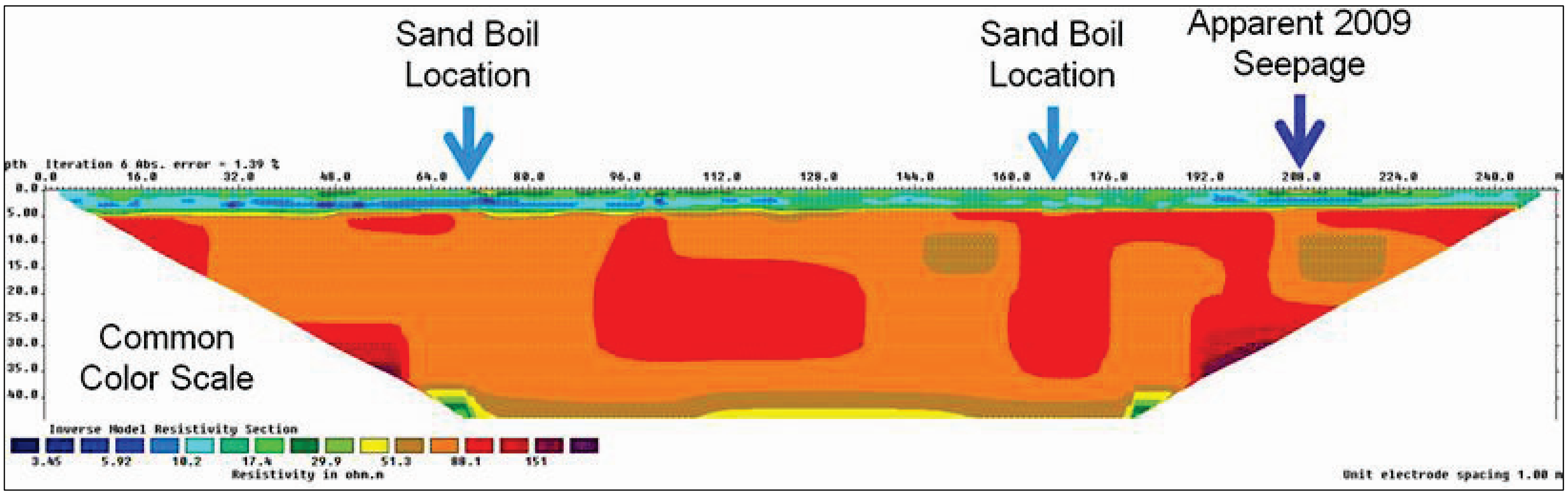
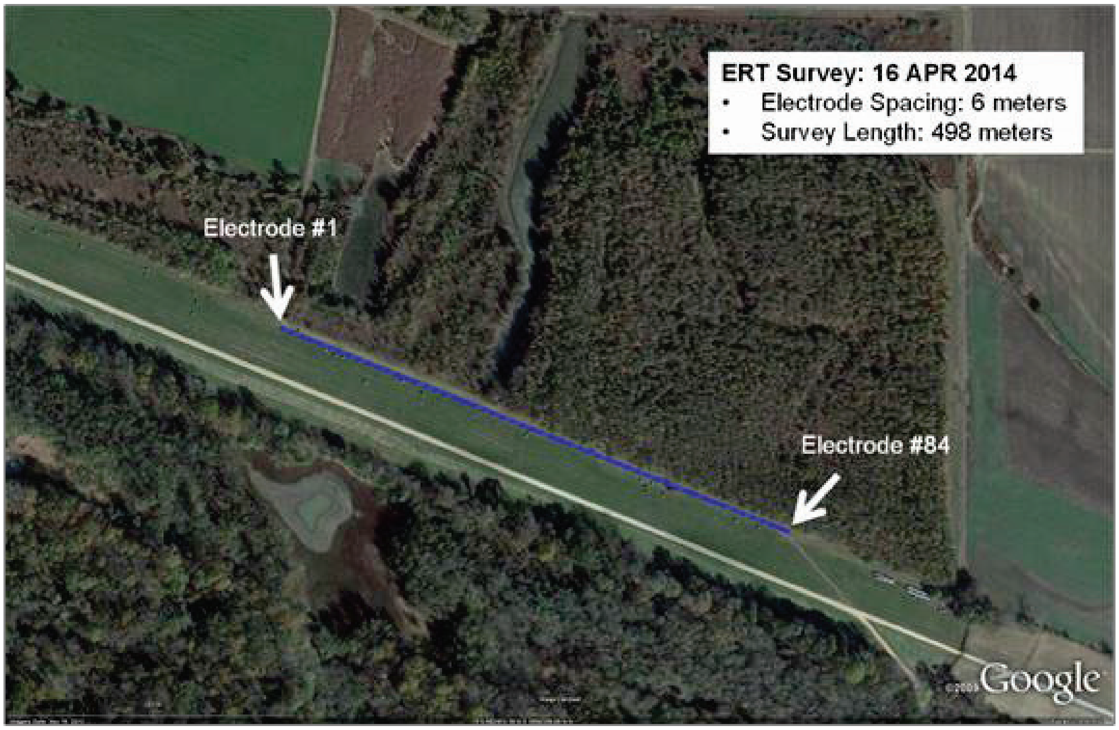


Figure 29. Southern Tara Wildlife Lodge electrical resistivity array (Google 2009).



riverside, there is no indication of a low-density layer, although there is a layer of silty sand from 4 ft to 10 ft, which could be an entry point for water. Most of the CPT data indicated a thin top stratum, which contributes to seepage and sand boils. Within the point bar top stratum, two types of formations occur. The first is a ridge. Ridges are deposited during high stages of the river and are composed of sands; the second, a swale, is silty and clayey deposits that occur during the falling stages and settle in low-lying areas below the ridges. They are composed of silty and clayey soils that are not as permeable as the ridges and may extend to depths of 40 ft in some areas. Cross sections were developed to measure the top stratum thickness of the study area. Ridges and swales can be seen in the CPT cross sections. Indications of a thin-to-nonexistent impervious top stratum can also be seen. This is an area where sand boils are likely to occur.

The software programs used to produce the cross sections of the CPT data are called gINT and Canvas 11. These are subsurface data management and reporting software that allow users to enter their raw data and have it interpreted for reporting subsurface details of soil. The cross sections are developed manually, and Canvas® is the illustration software (Figures 35 to 37).

Figure 30. Subsurface image of the southern Tara Wildlife Lodge ERT.

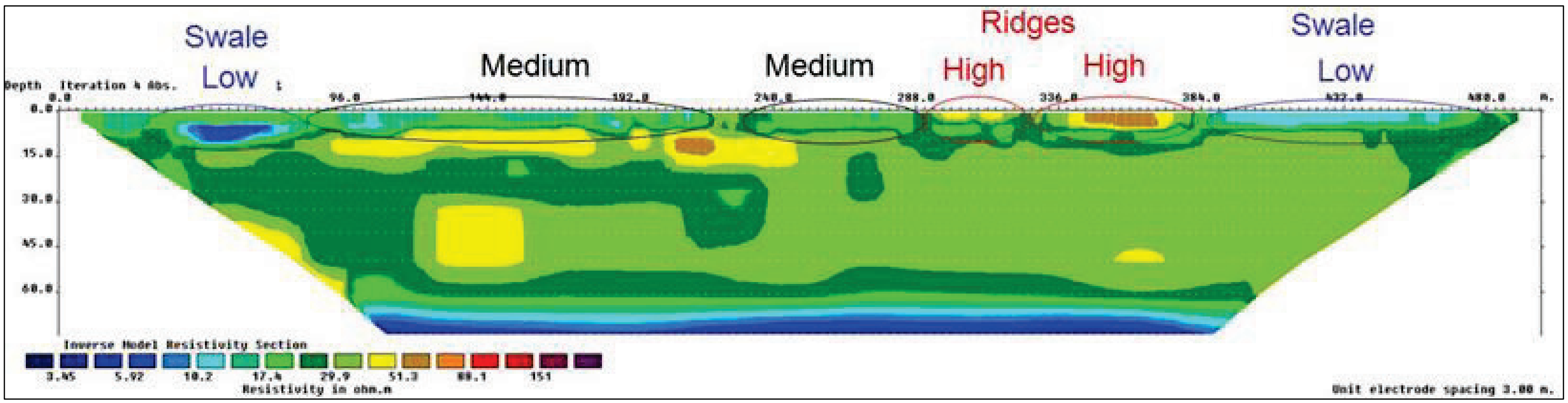
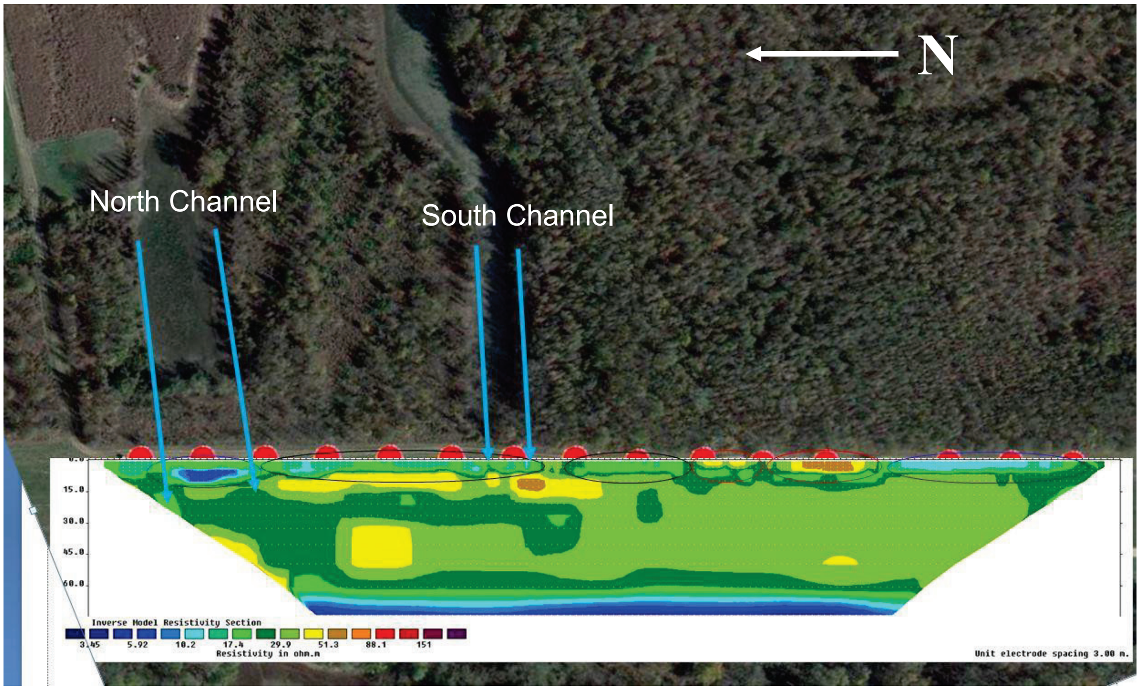


Figure 31. Map showing two channels that possibly act as conduits for water to flow into the subsurface (modified from Google 2009).



Based on the borehole data, the impervious top stratum thickness is nonexistent in some areas. This is definitely a problem when downward forces are needed to prevent the upward forces of sand boils. Without an impervious top stratum, boils are likely to occur. Because the depositional environment consists of mostly noncohesive soil, this area is prone to the formation of sand boils and potential for piping through the subsurface stratum.

ERT surveys were conducted using the metric system. A 2-m spacing and a 6-m spacing were used for the northern and southern surveys, respectively. The northern survey extended over three known sand boils. Currently, construction is underway in this area for placement of a seepage berm and installation of relief wells. The northern area had sand boils in areas where the levee and swale meet and create an acute angle. The southern array had 6-m electrode spacing, which is used for imaging depth. The imagery reached a depth of 131.7 m. The suballuvium starts around 66 m deep. This layer is the Tertiary Age Yazoo Clay Formation of the Jackson Group. The Yazoo Clay is composed of massive, dark colored, carbonaceous clay with thin silt and sandy silt lenses in some areas. At the southern array, there were minimal sand boils recorded. The flow is possibly controlled in this area by two natural draining channels. This allows the water to flow under the levee and into a drainage channel for relief.

Figure 32. Cone penetrometer readings and soil behavior type for TAR-9.11C (USACE 2012a).

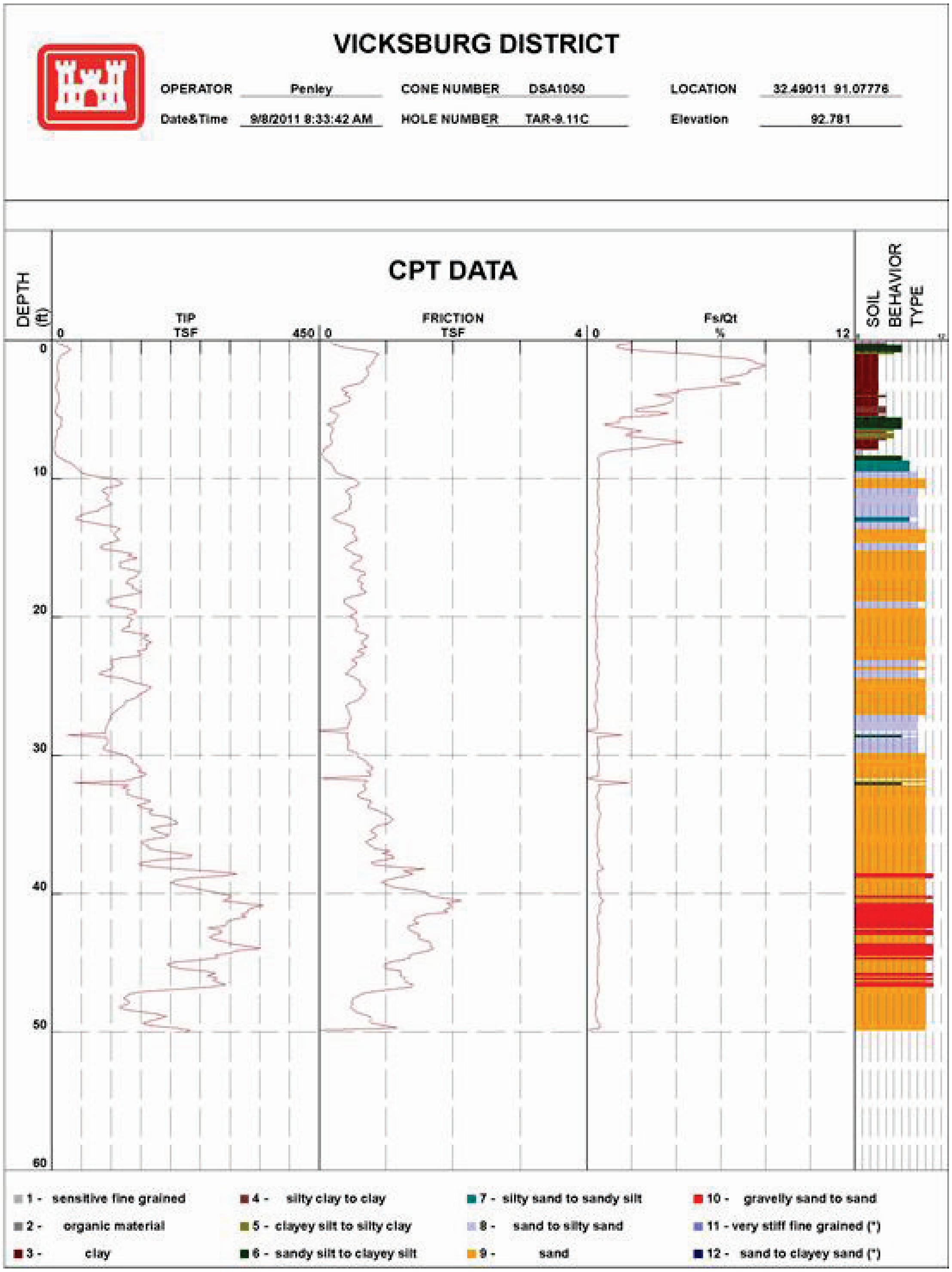


Figure 33. Cone penetrometer readings and soil behavior type for TAR-34.11C (USACE 2012a).

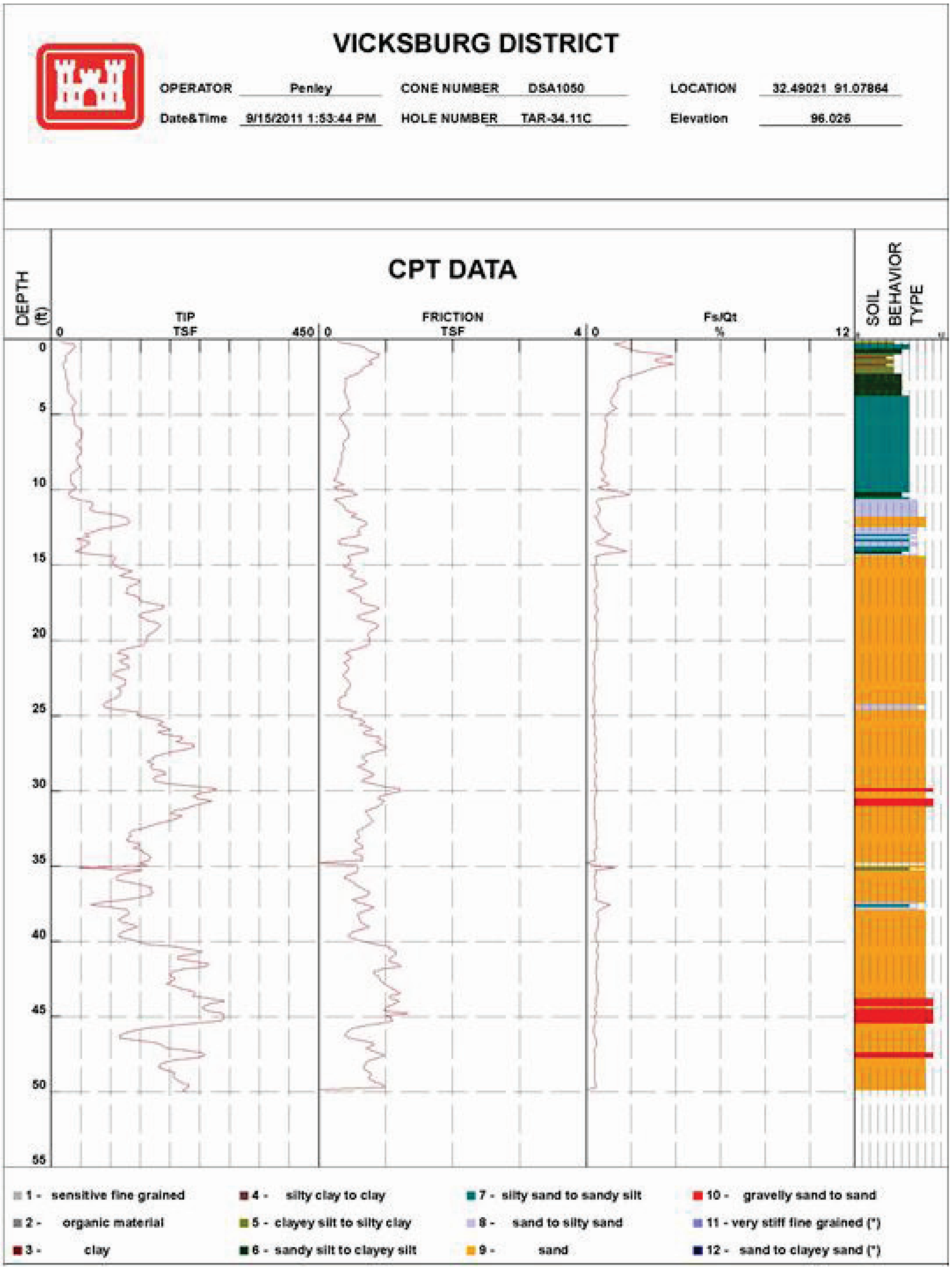


Figure 34. Map of cone penetrometer tests and location of sand boils from MICA data from the 2011 flood (ESRI 2014).

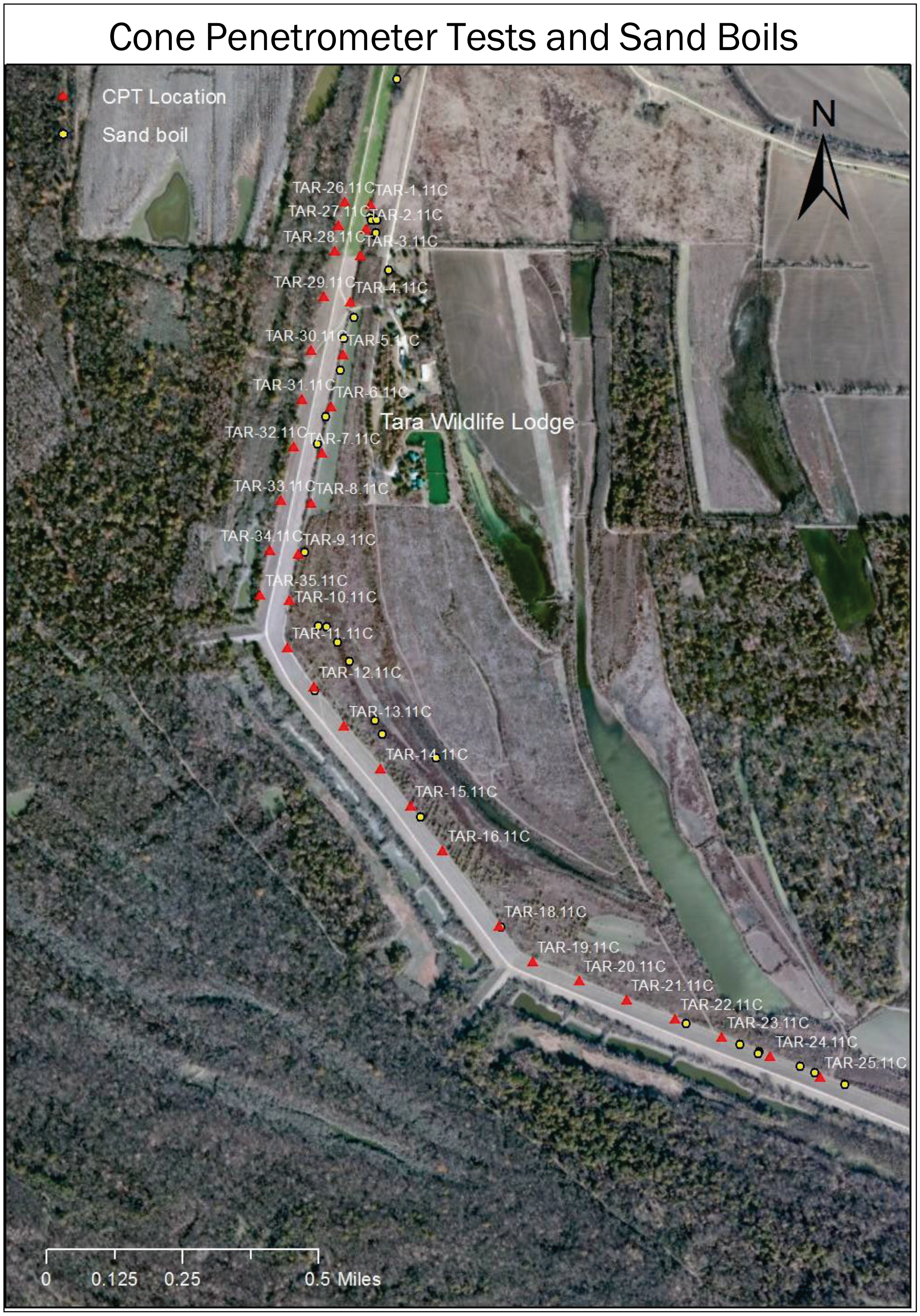


Figure 35. Cross section of CPTs 1-10, indicating a thin blanket and ridge and swale topography (modified from Bentley 2014).

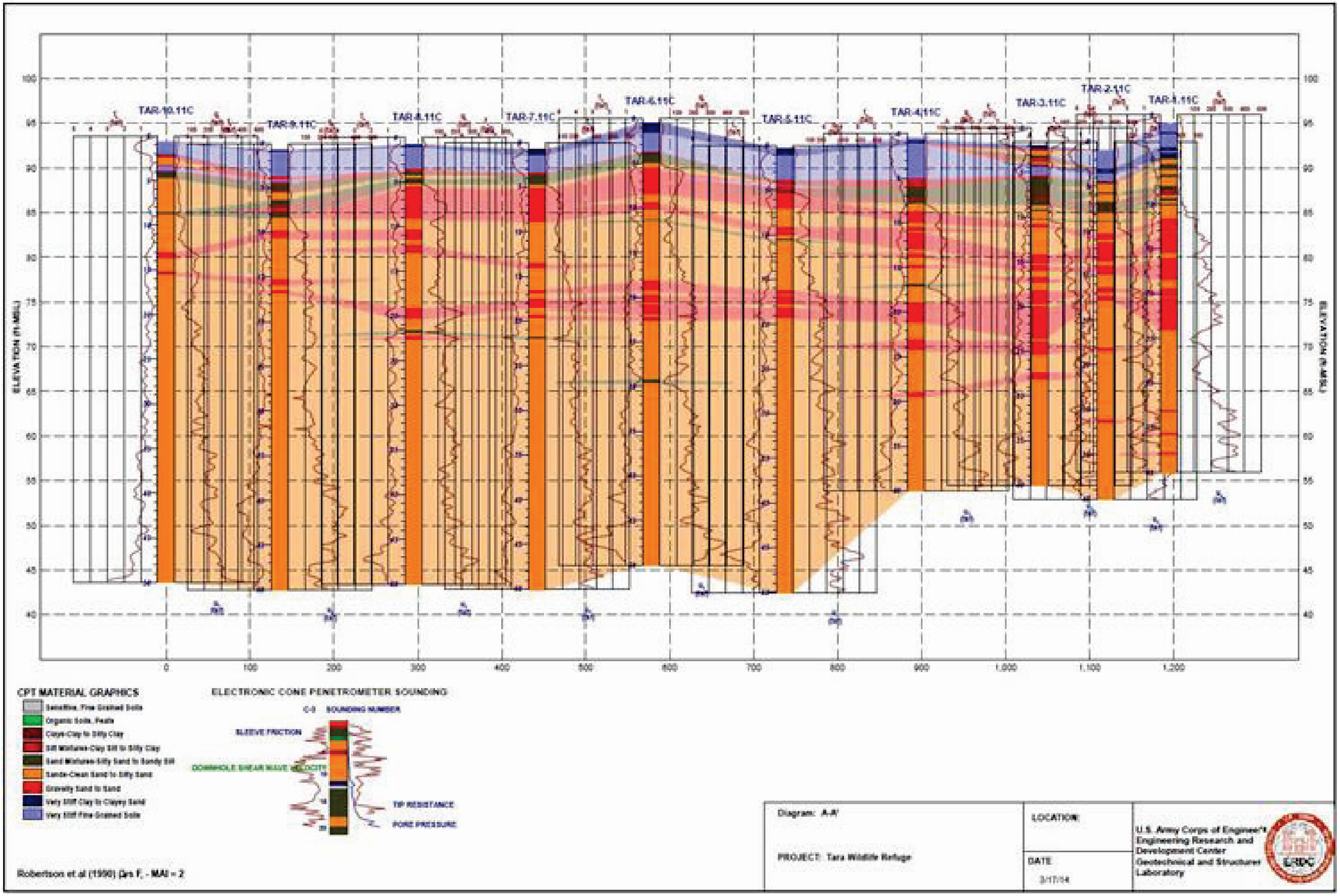


Figure 36. Cross section of CPTs 10-18, indicating a thin blanket and ridge and swale topography (modified from Bentley 2014).

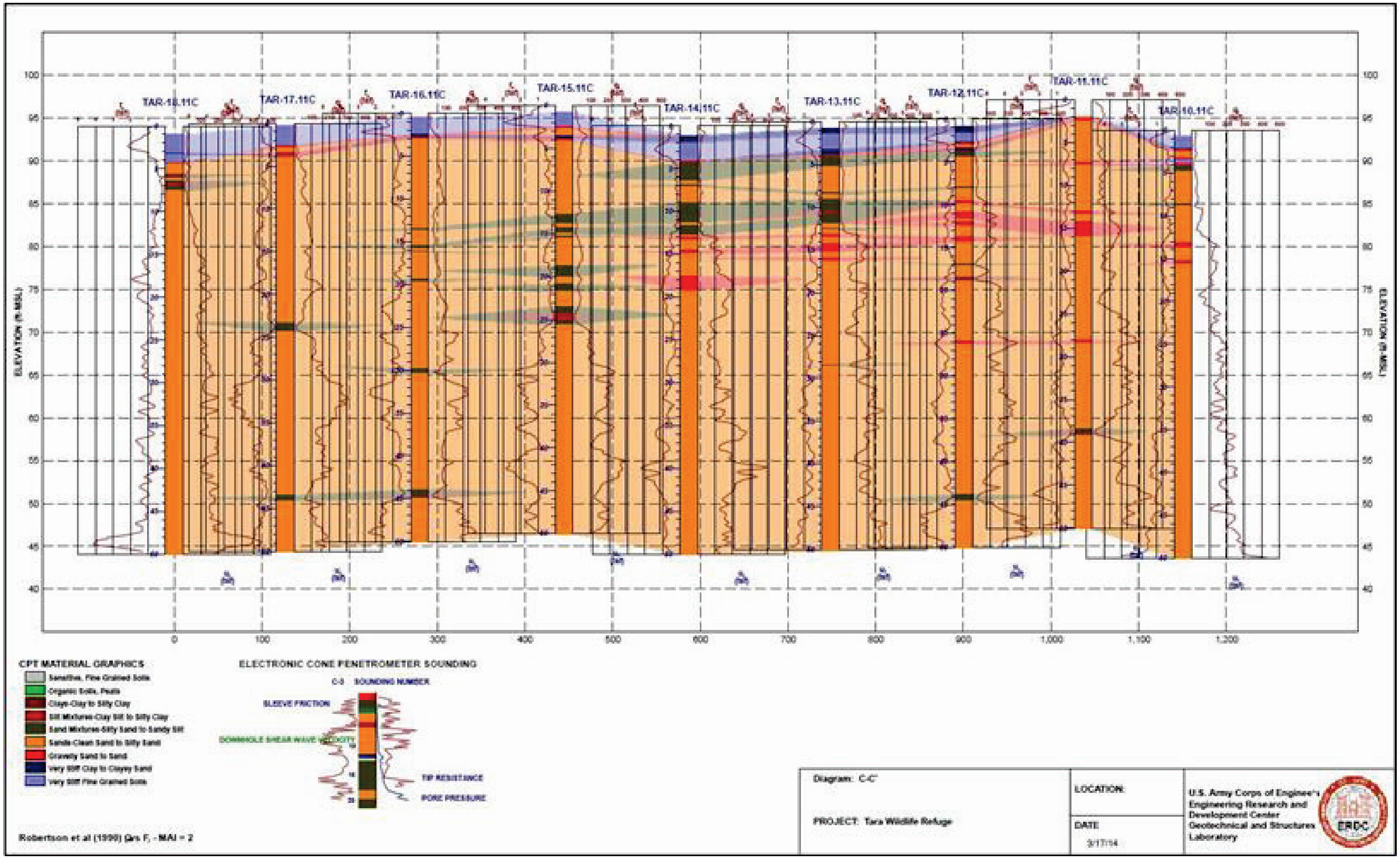
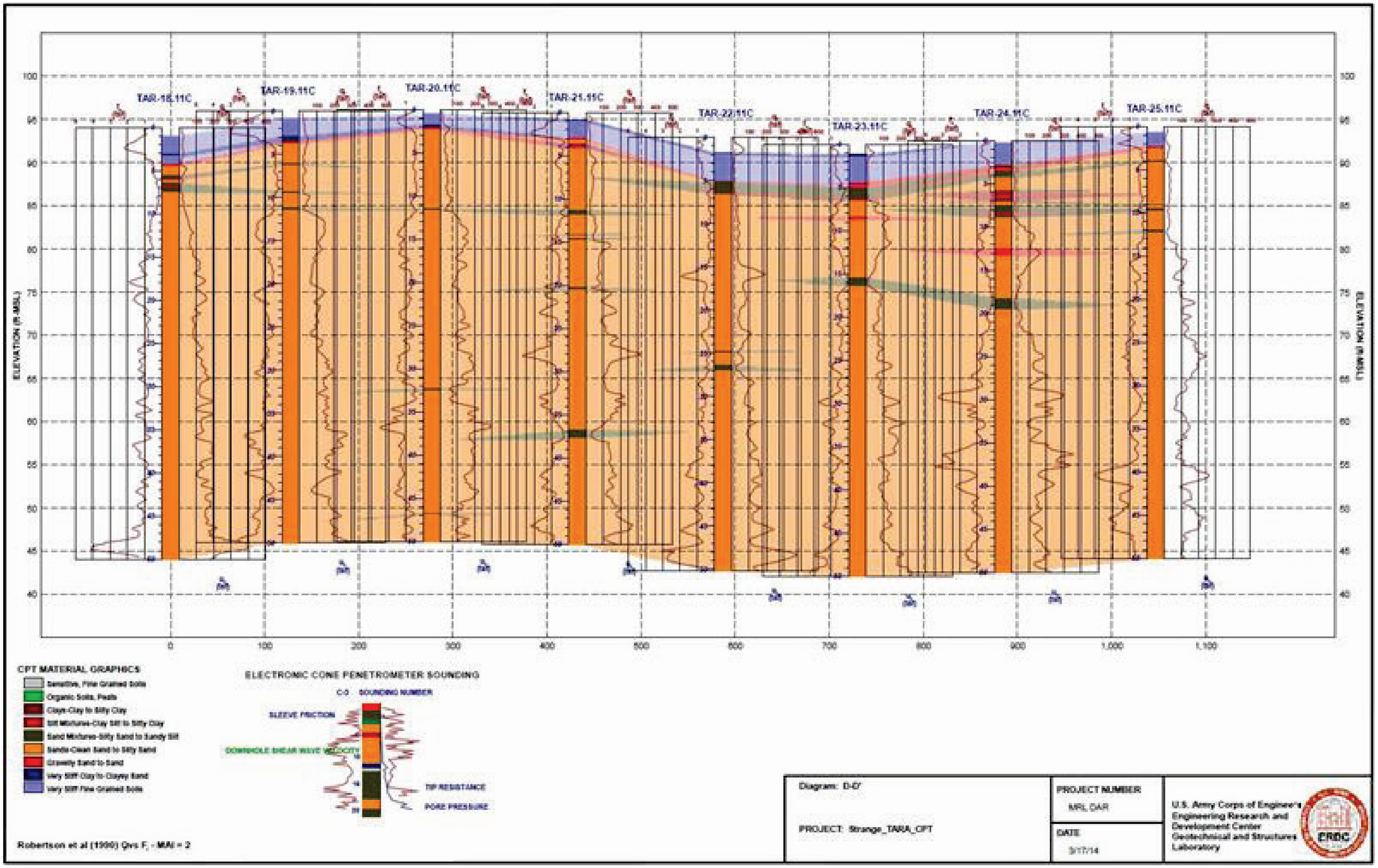


Figure 37. Cross section of CPTs 18-25, indicating a thin blanket and ridge and swale topography (modified from Bentley 2014).



8 Conclusions

During subsurface geophysical investigations, the Tara Wildlife Lodge area in Warren County was found to have a thin layer of impervious top stratum. This causes the area to have multiple underseepage and sand boil issues. After conducting geophysical tests and developing multiple cross sections, data indicate the Tara Wildlife Lodge area could be at risk of multiple sand boils developing from excessive uplift pressures in the substratum.

The CPT soundings showed the complexity of the subsurface, and the ERT revealed potential seepage paths.

Specific landforms (i.e., ridges, swales, and point bars) and their placement indicate where sand boils are likely to occur, based on topography. Fine-grained top stratum sediments, predominately silts and silty sands, generally have high permeability, which lends to increased flow through these deposits. The thin top stratum influences the design of the levee. Most of the investigative borings that were reviewed for this analysis contained a thin top stratum that contributed to seepage and boils during the 2011 flood of record as well as previous flood events (USACE 2012a). Other contributing factors are borrow pits, ridges, and swales.

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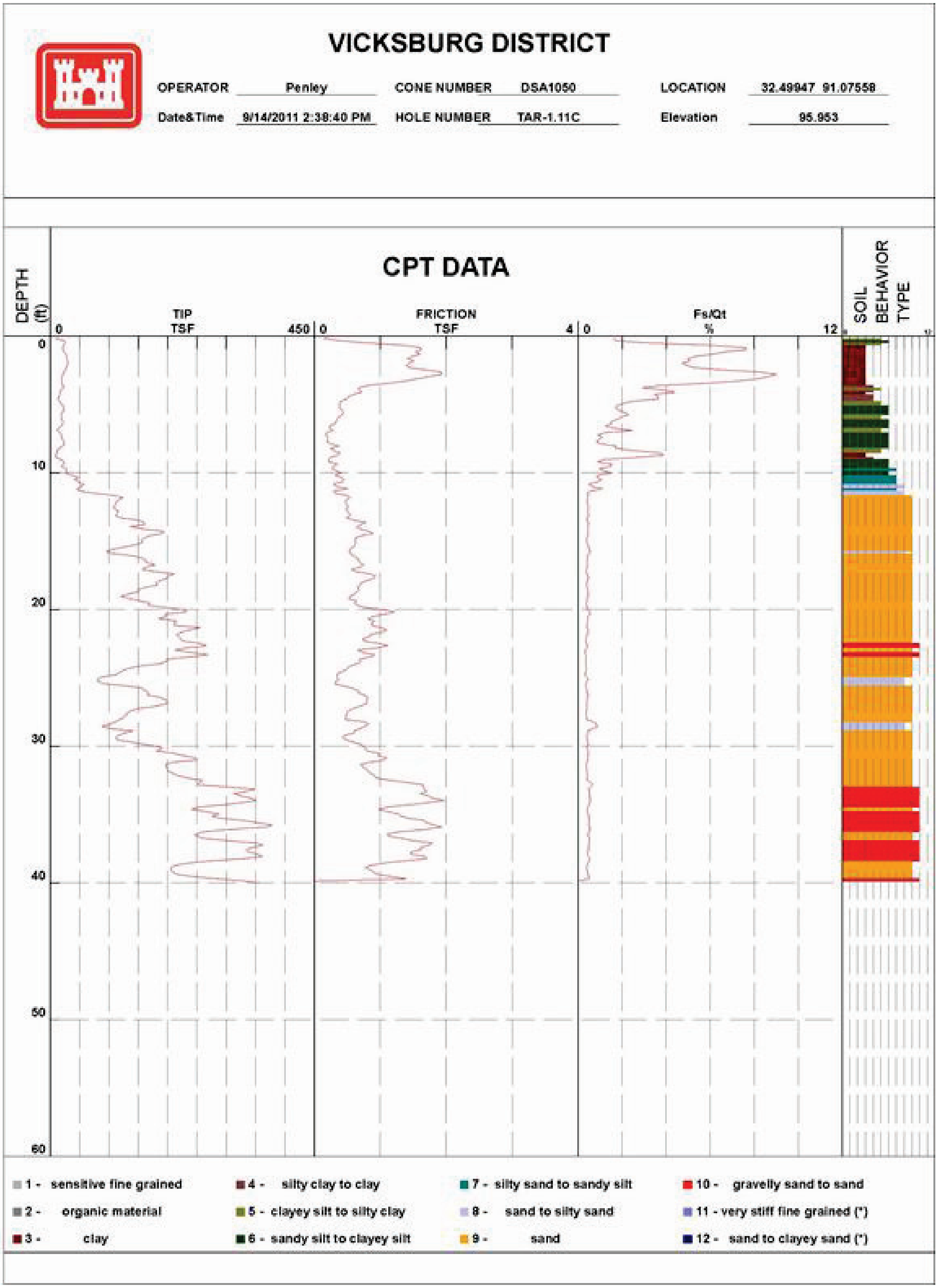
Appendix A: Cone Penetrometer Tests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DEPTH (ft)
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FRICTION TSF
Fs/Qt %
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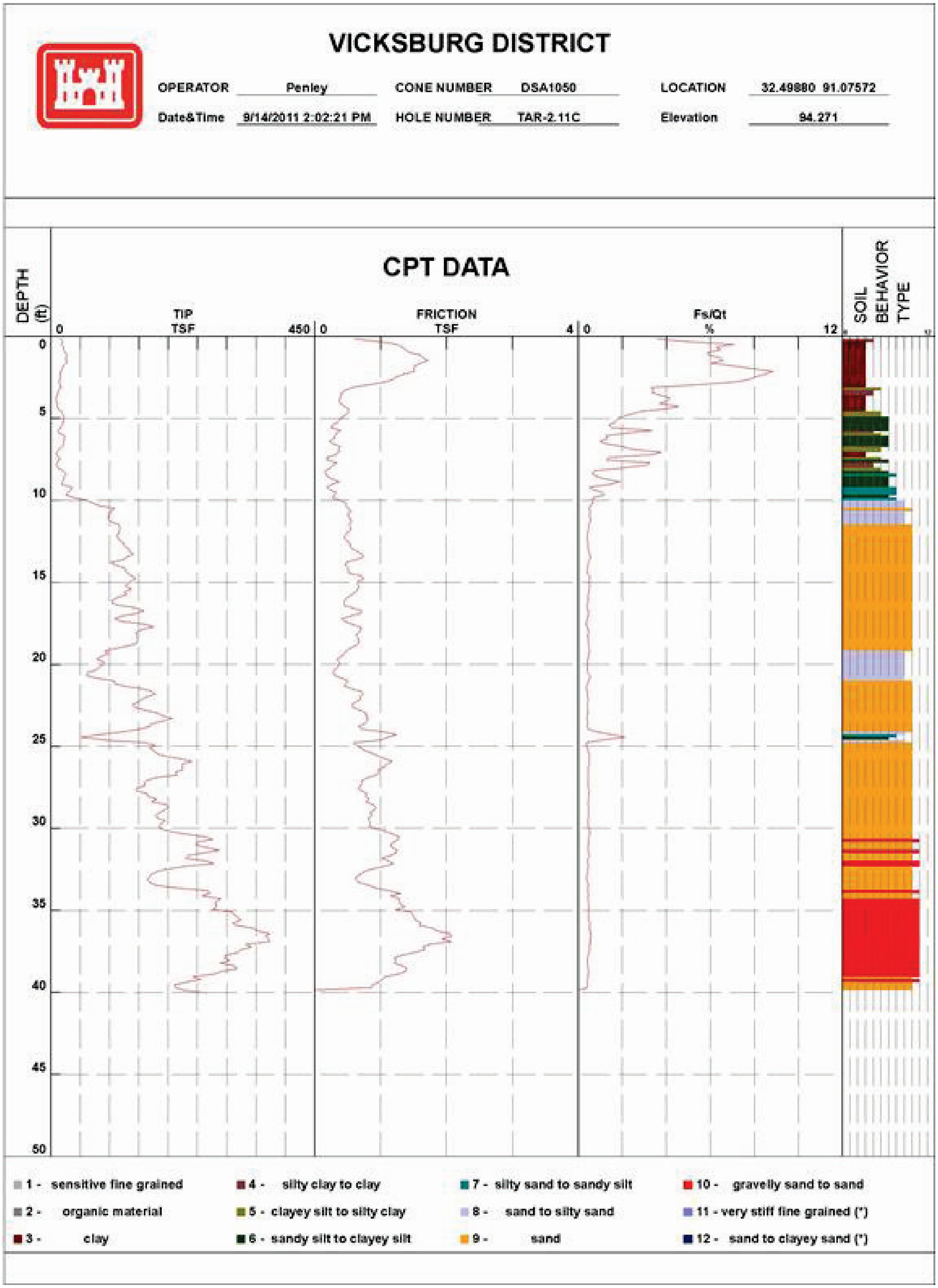
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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FRICTION TSF
Fs/Qt %
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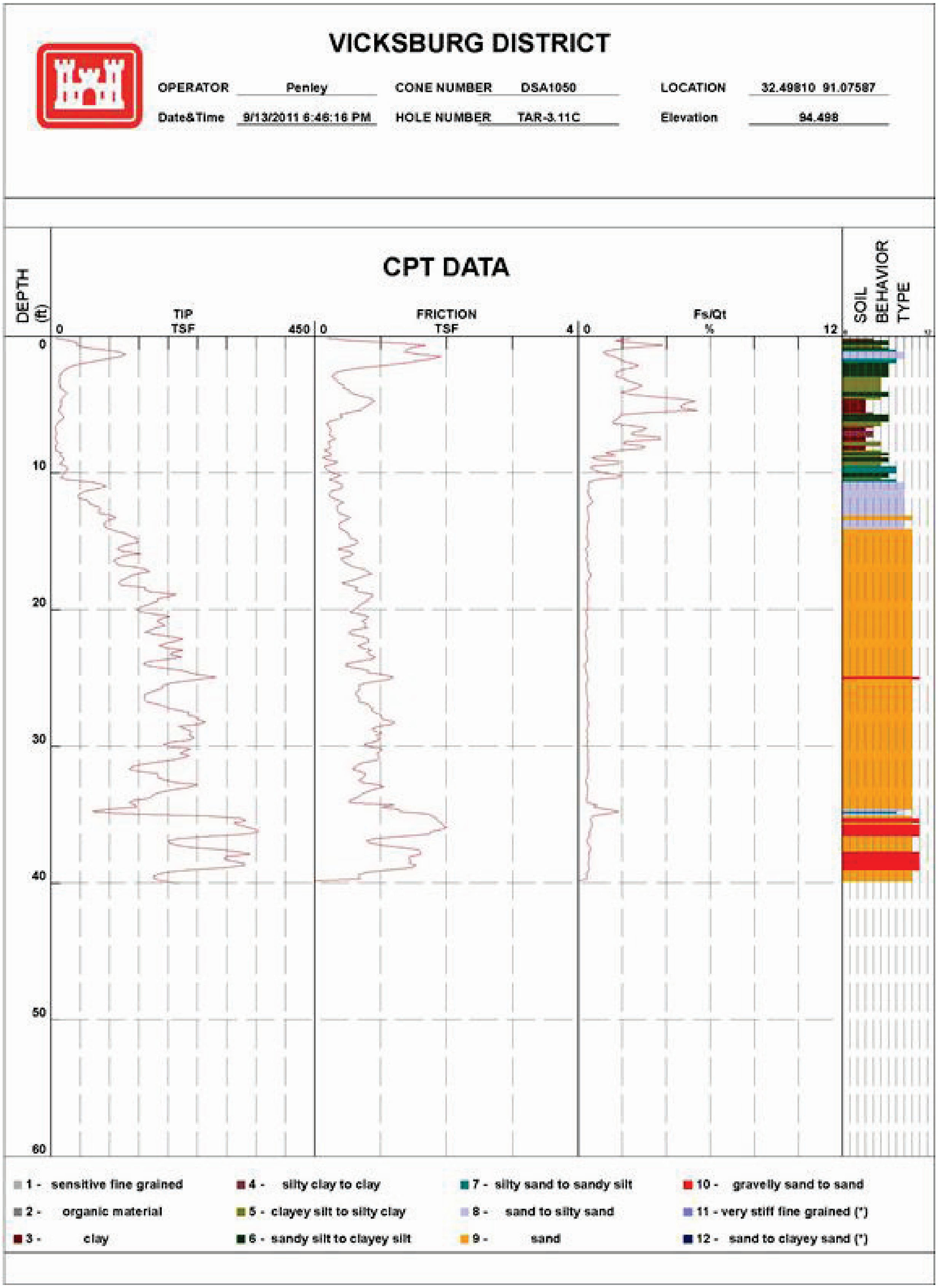
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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FRICTION TSF
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4
Fs/Qt %
0
12
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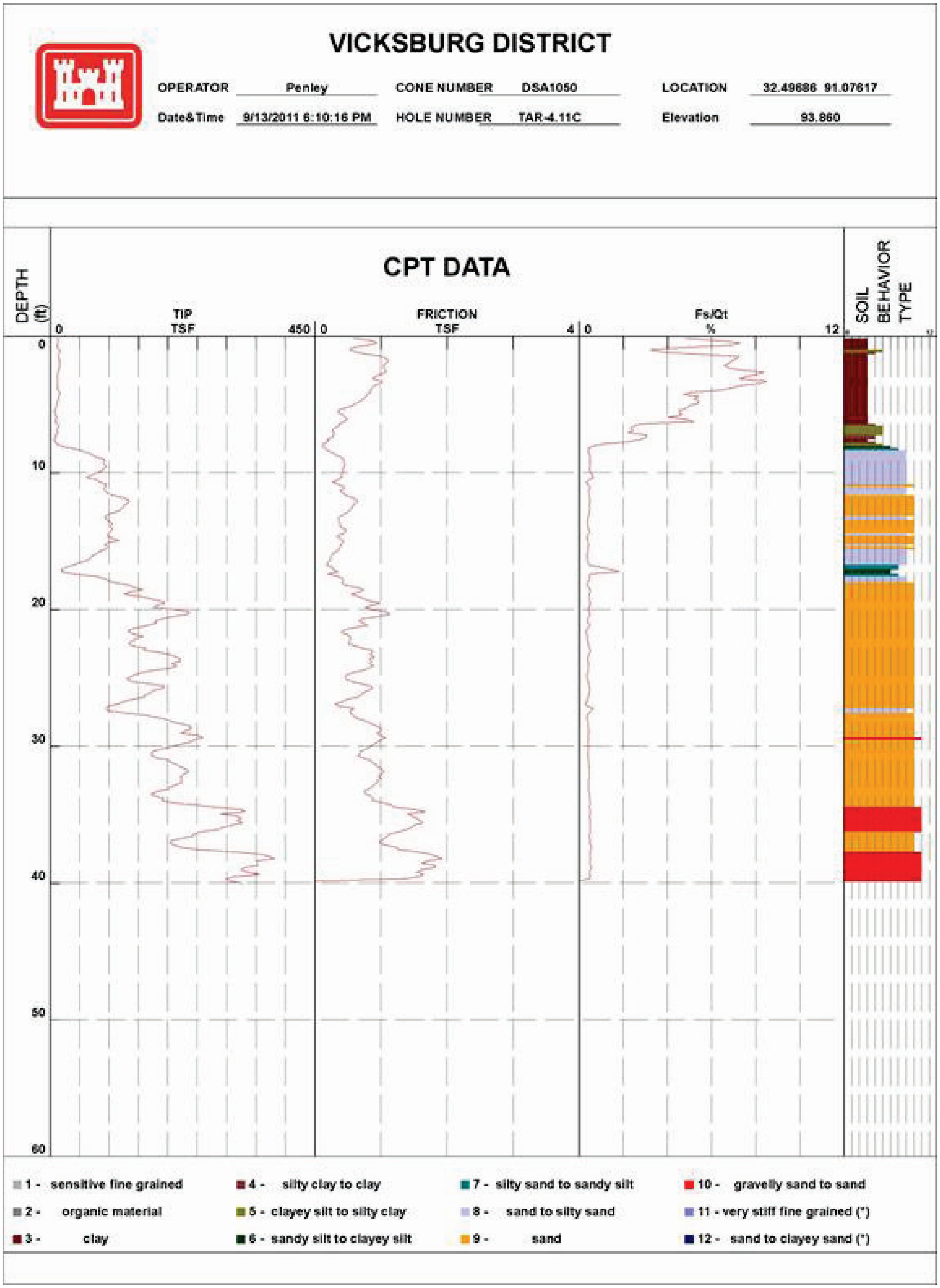
10
20
30
40
50
60
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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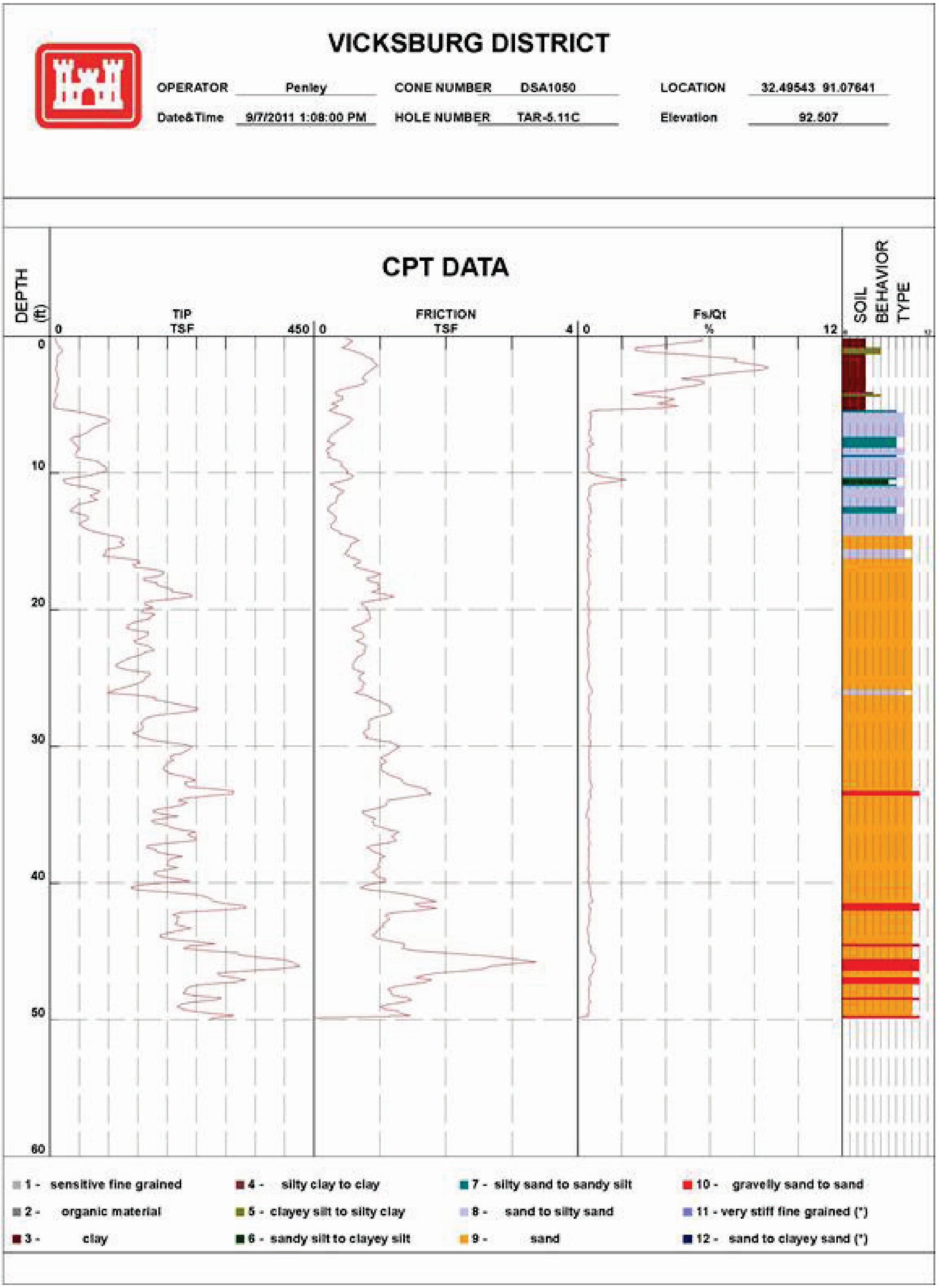
0
4
Fs/Qt %
0
12
SOIL BEHAVIOR TYPE
0
10
20
30
40
50
60
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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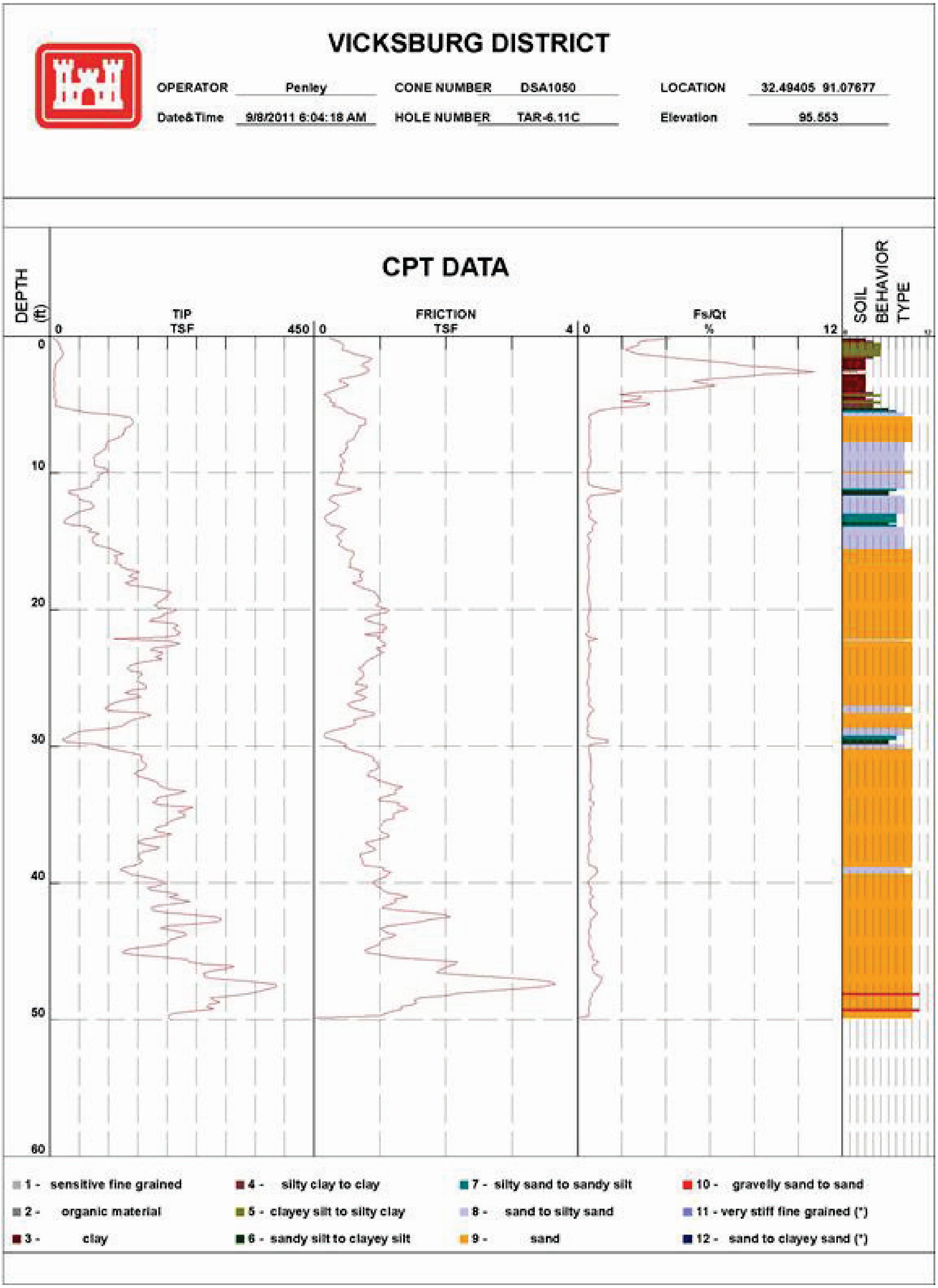
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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40
50
60
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3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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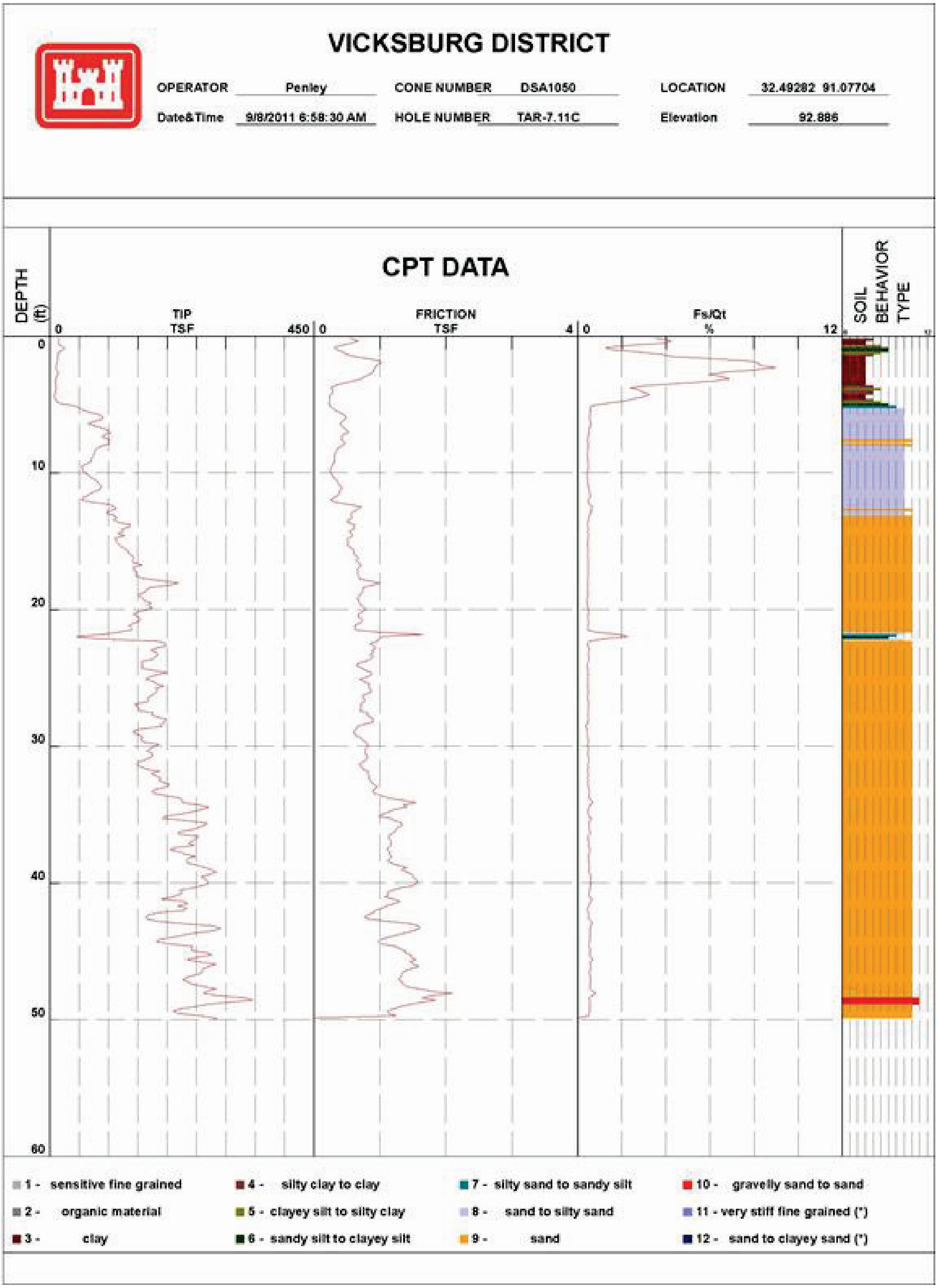
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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Fs/Qt %
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12
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20
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40
50
60
1 - sensitive fine grained
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4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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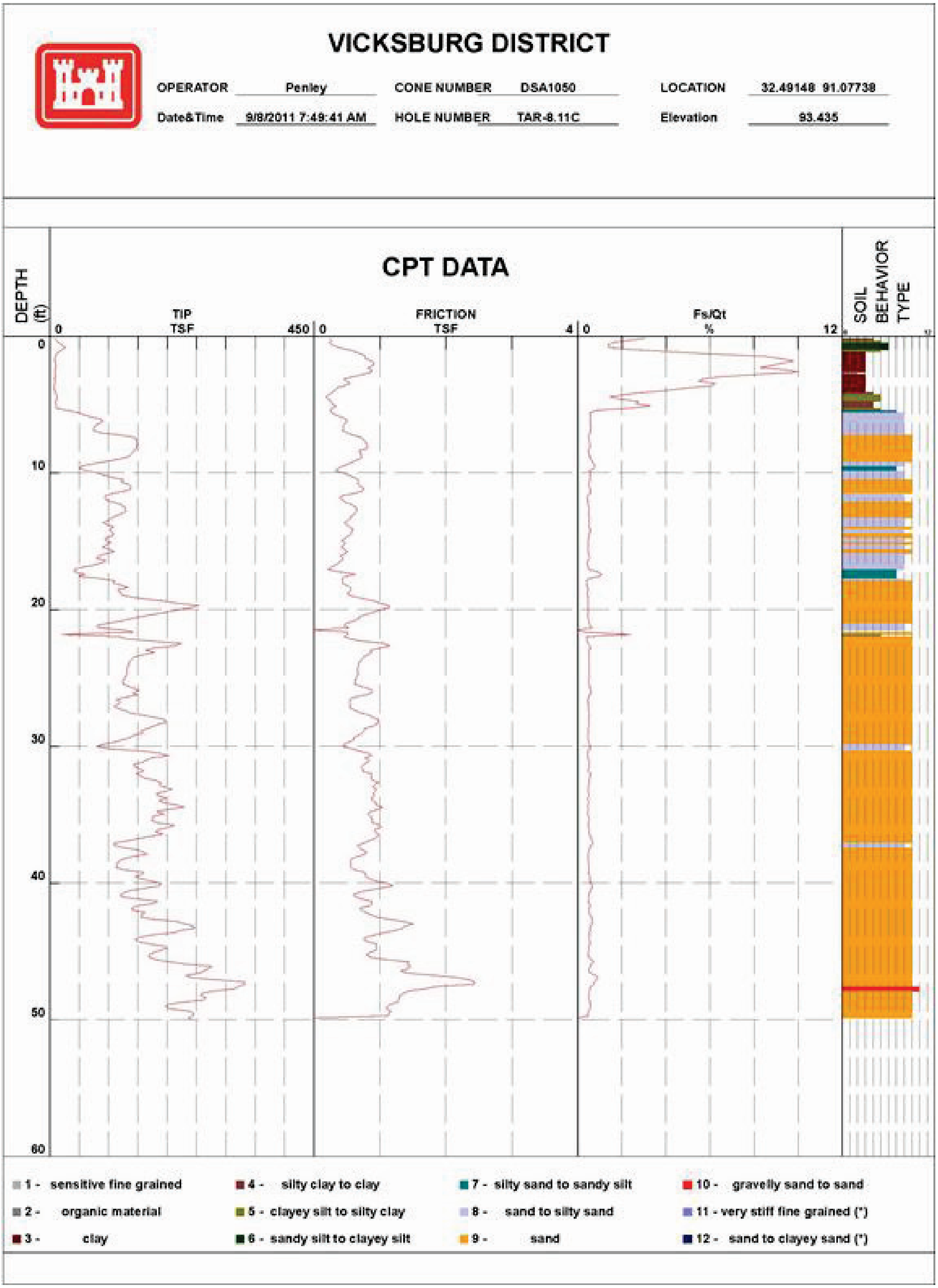
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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FRICTION TSF
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4
Fs/Qt %
0
12
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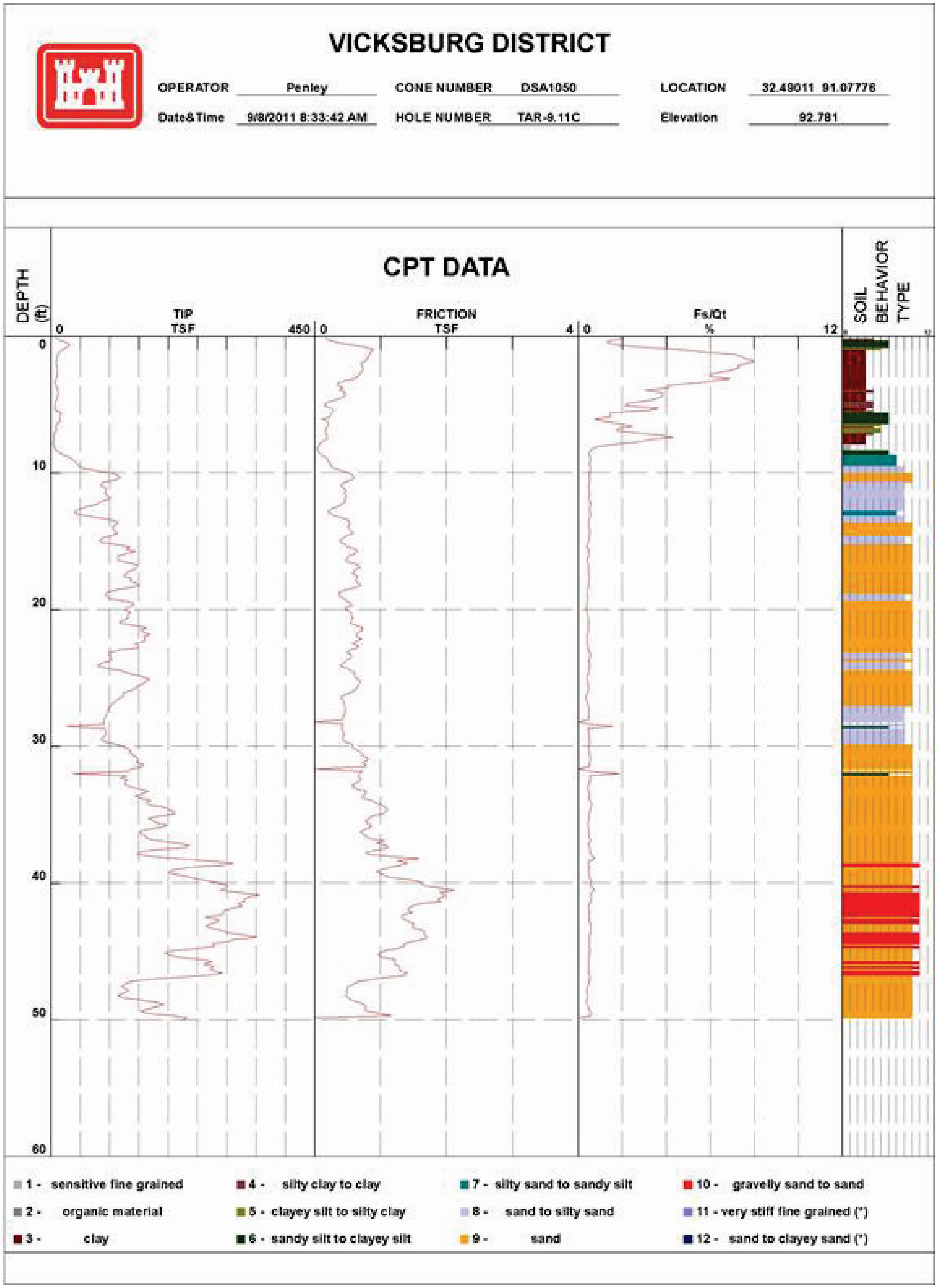
30
40
50
60
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)



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60
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3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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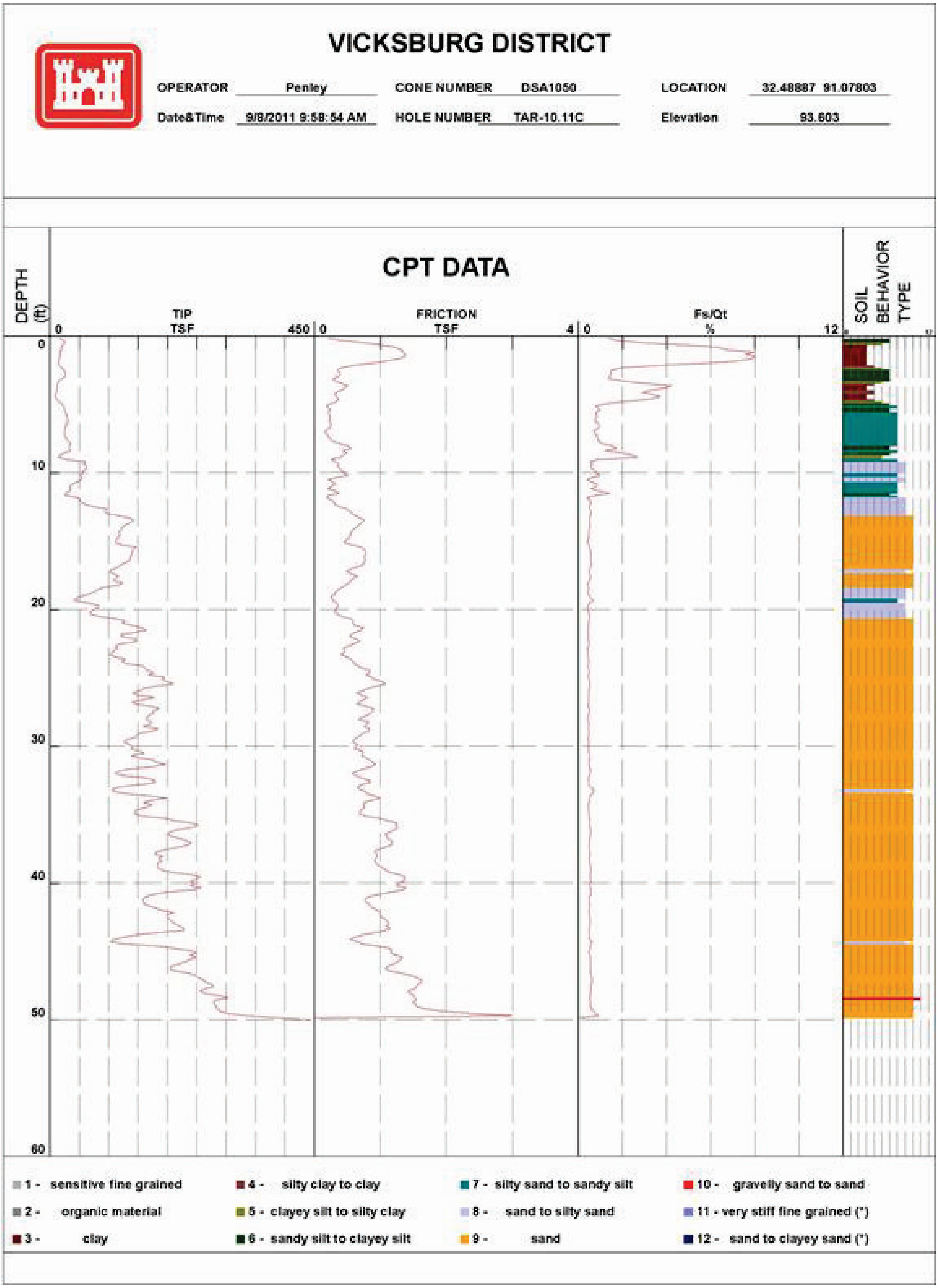
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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Fs/Qt %
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30
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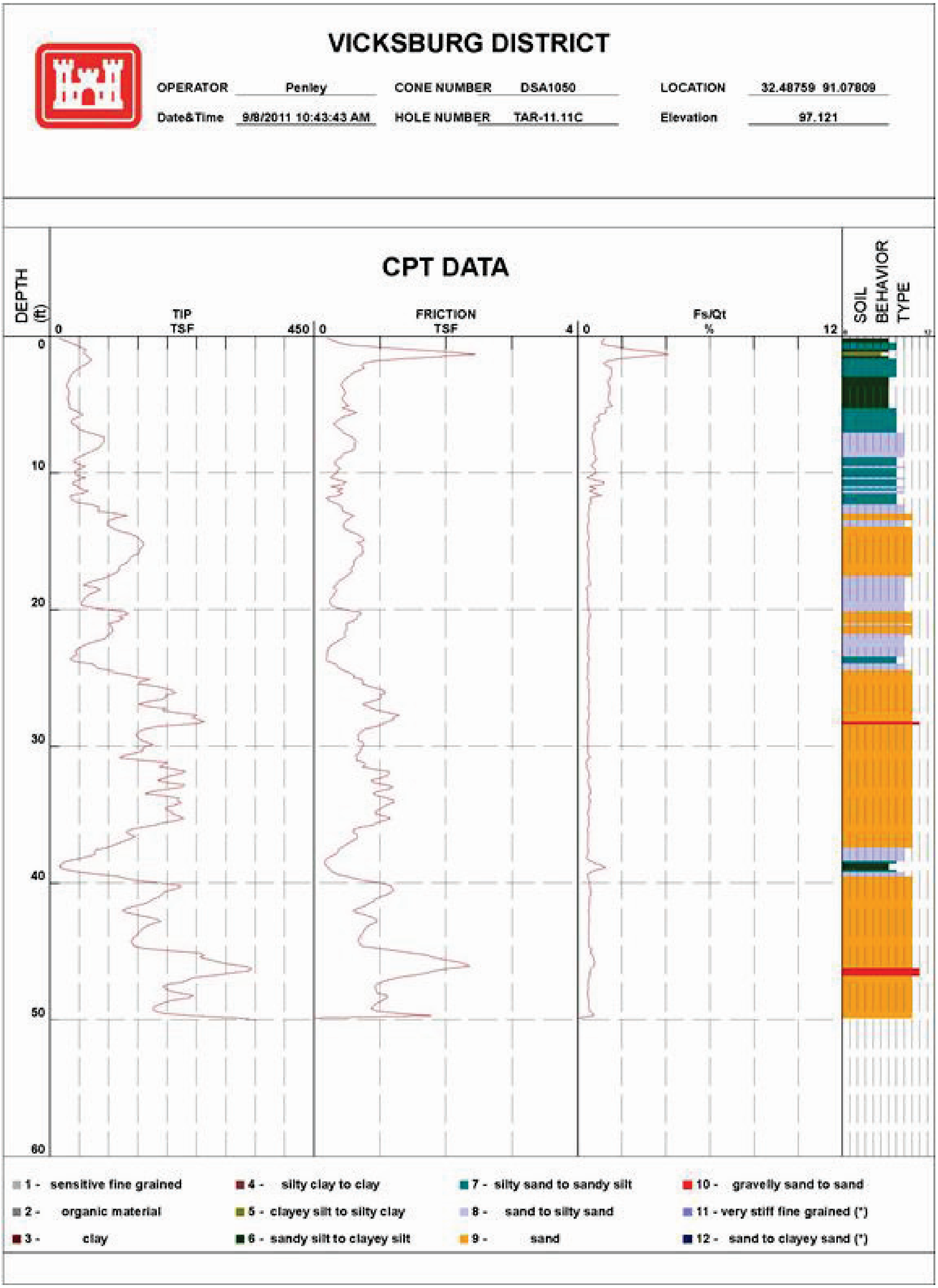
50
60
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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SOIL BEHAVIOR TYPE
0
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40
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60
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2 - organic material
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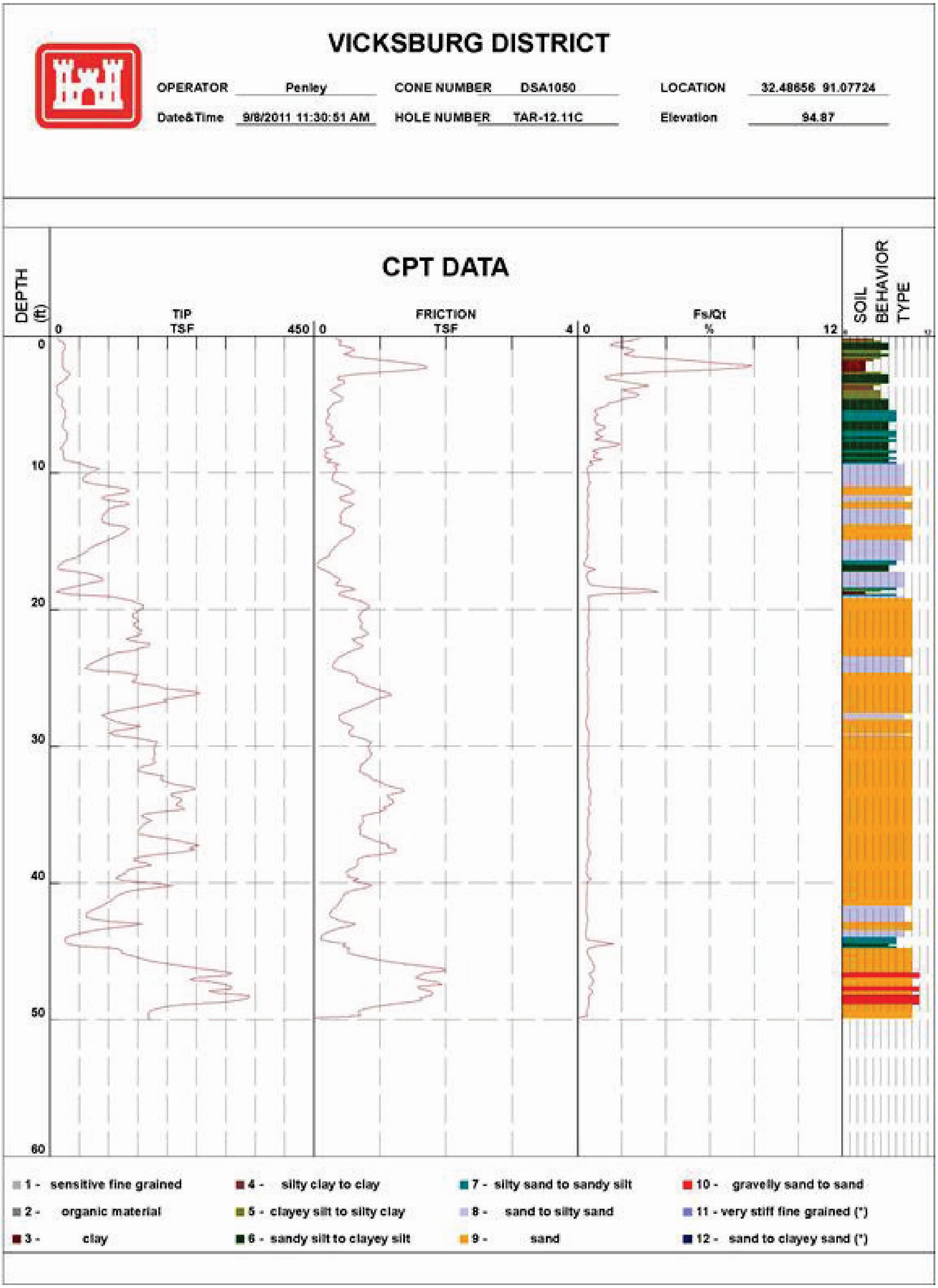
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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60
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2 - organic material
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4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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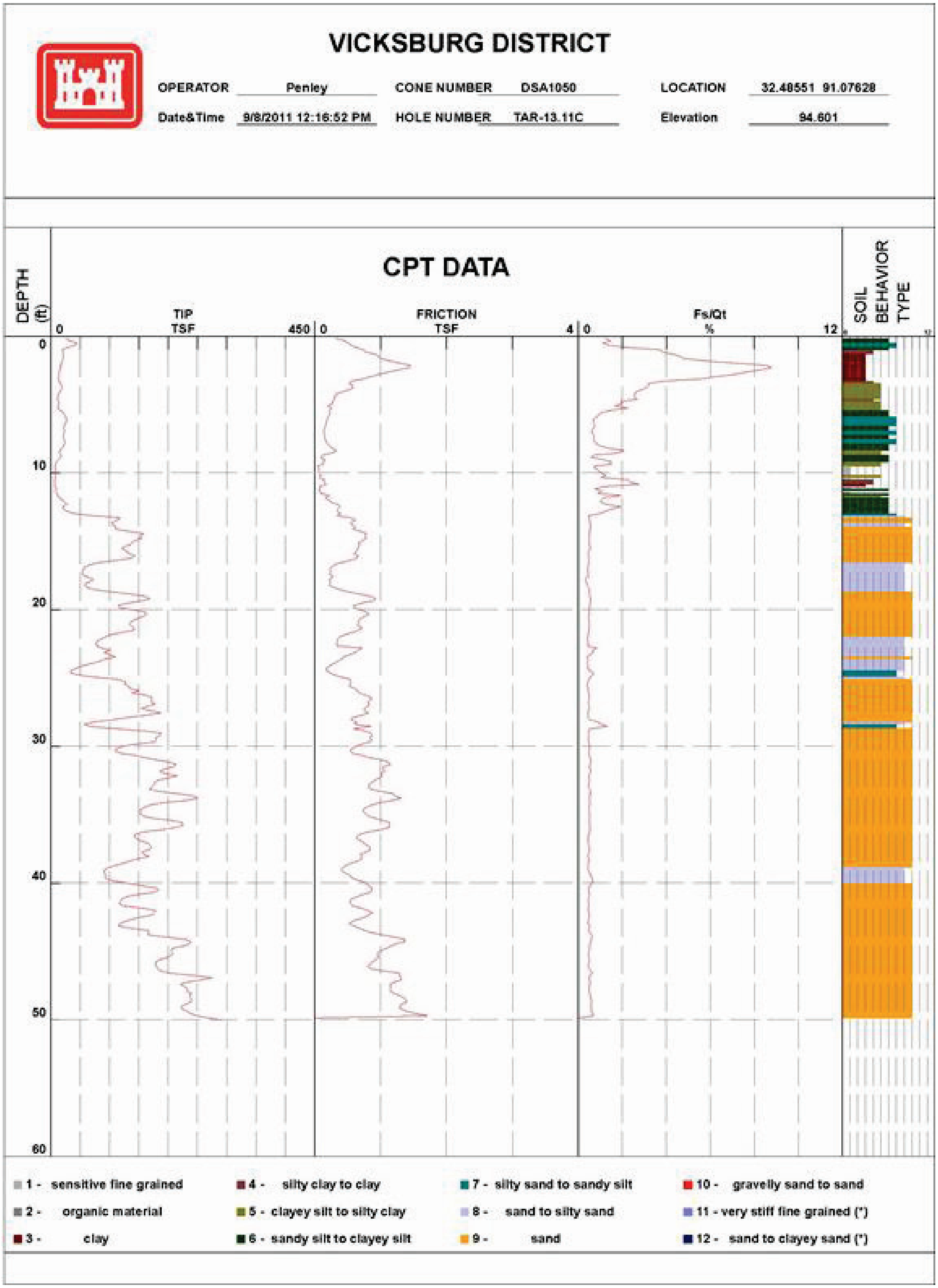
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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Fs/Qt %
0 12
SOIL BEHAVIOR TYPE
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60
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3 - clay
4 - silty clay to clay
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6 - sandy silt to clayey silt
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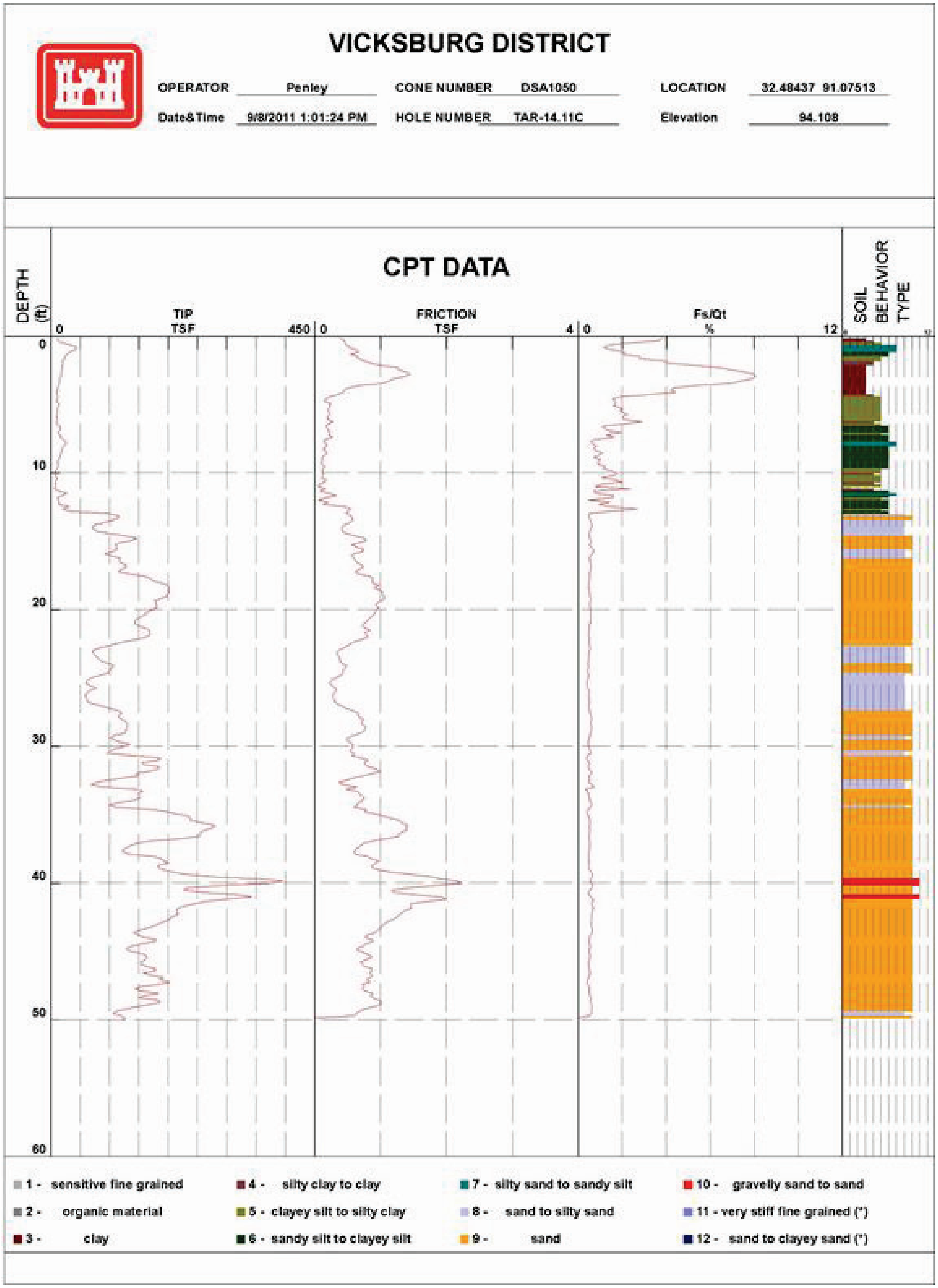
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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60
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3 - clay
4 - silty clay to clay
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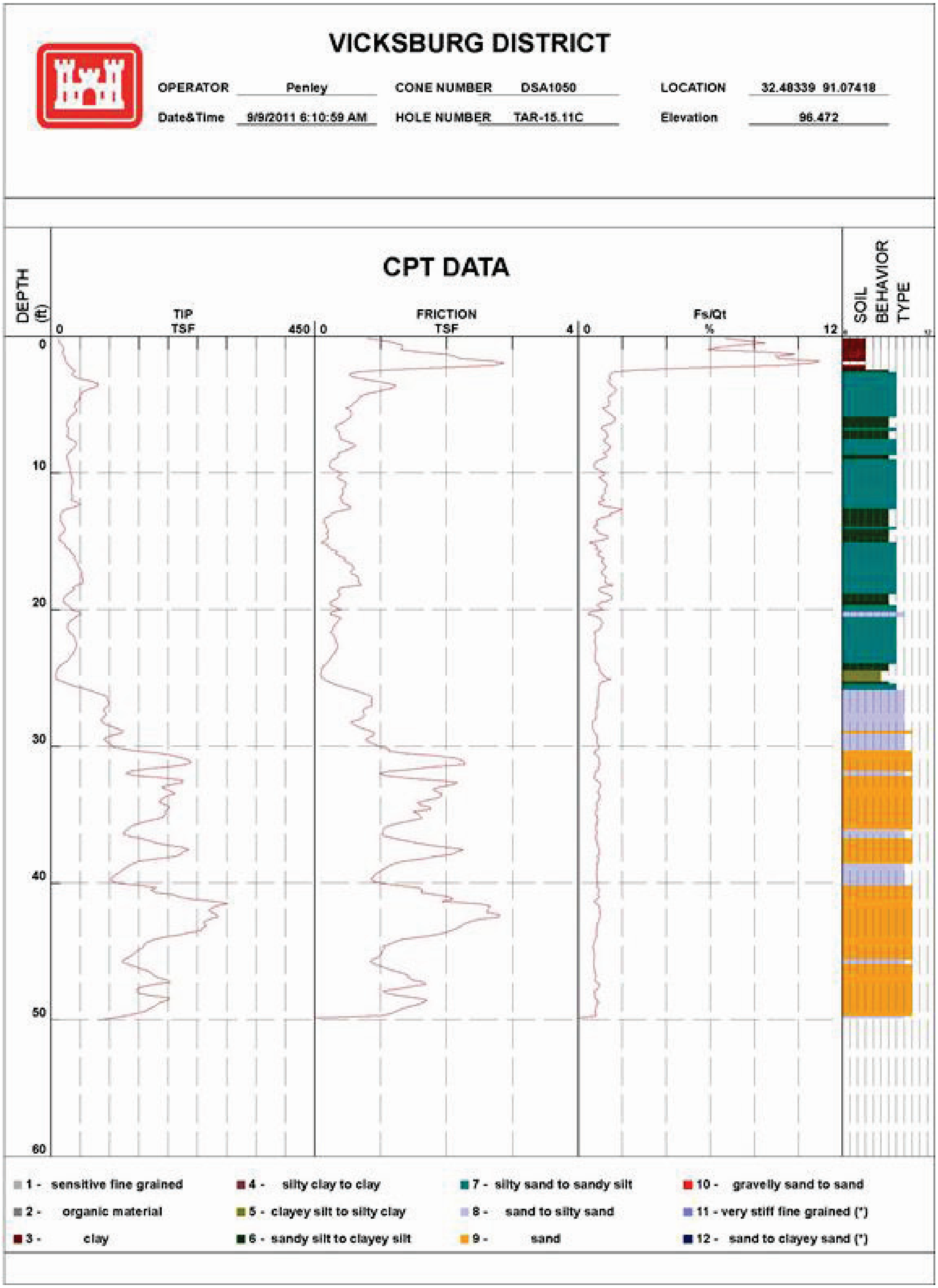
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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Elevation 96.472
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Fs/Qt %
0 12
SOIL BEHAVIOR TYPE
0 10 20 30 40 50 60
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2 - organic material
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5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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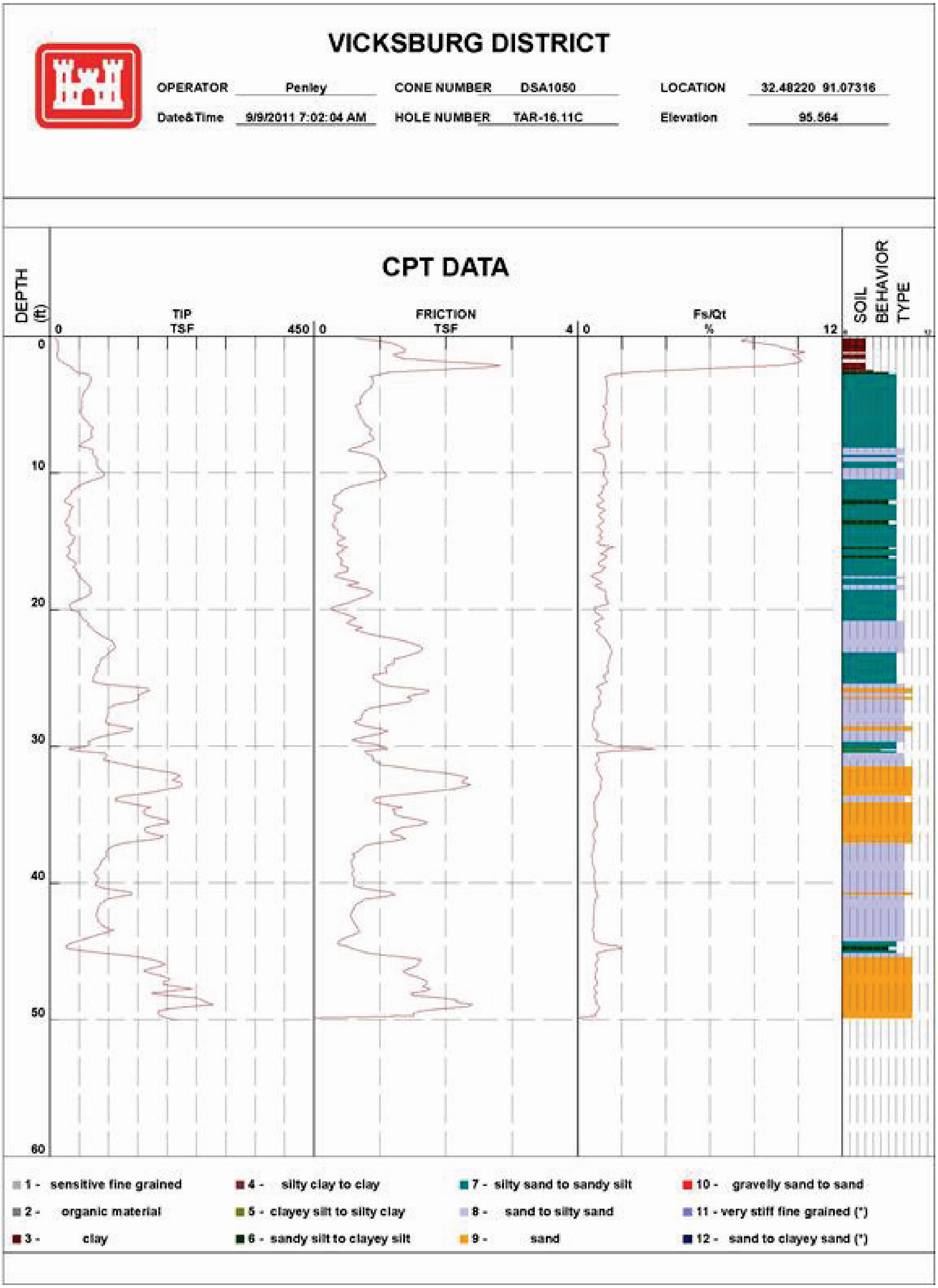
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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Fs/Qt %
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60
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6 - sandy silt to clayey silt
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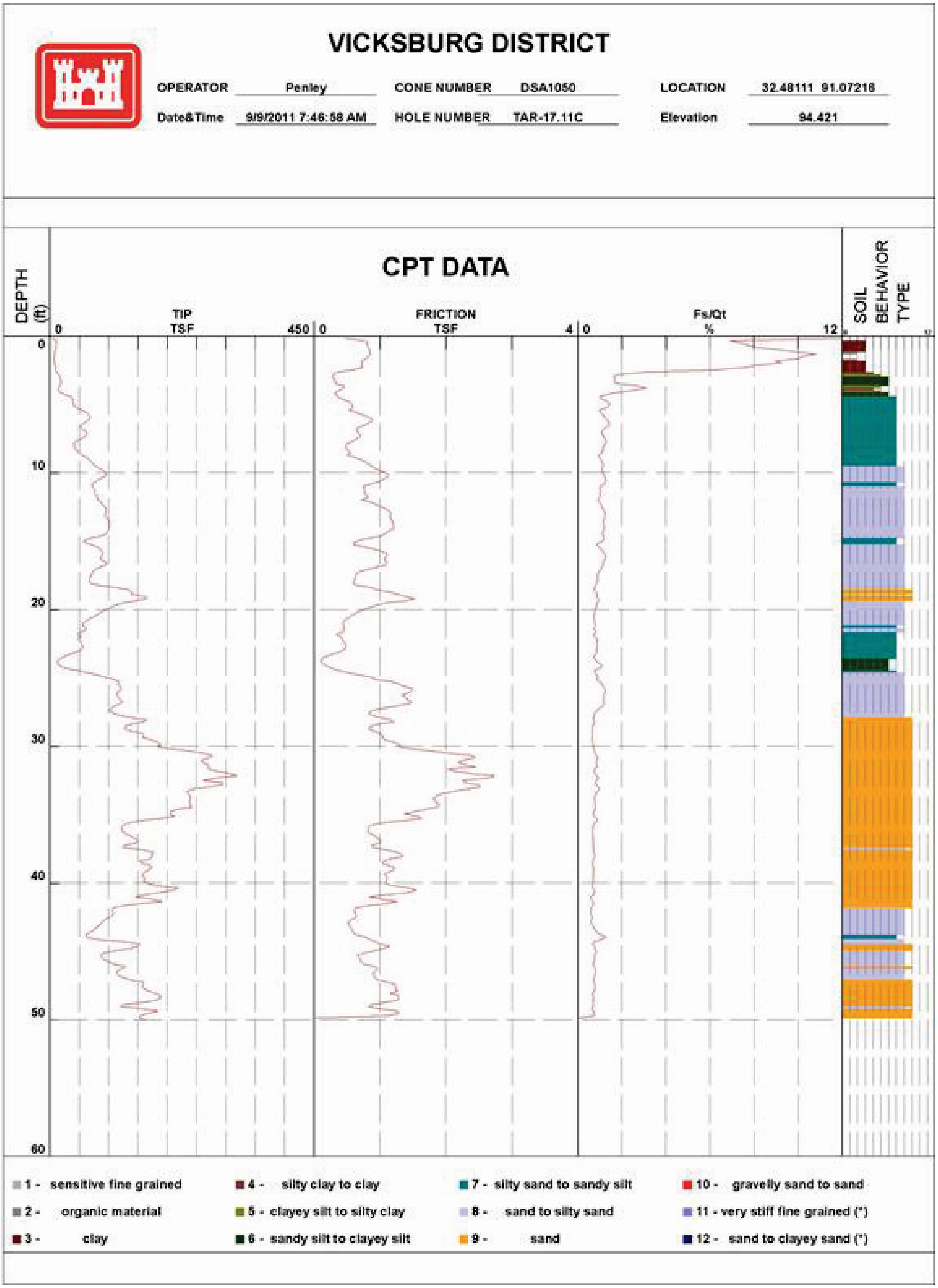
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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Elevation 94.421
CPT DATA
DEPTH (ft)
TIP TSF
FRICTION TSF
Fs/Qt %
SOIL BEHAVIOR TYPE
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2 - organic material
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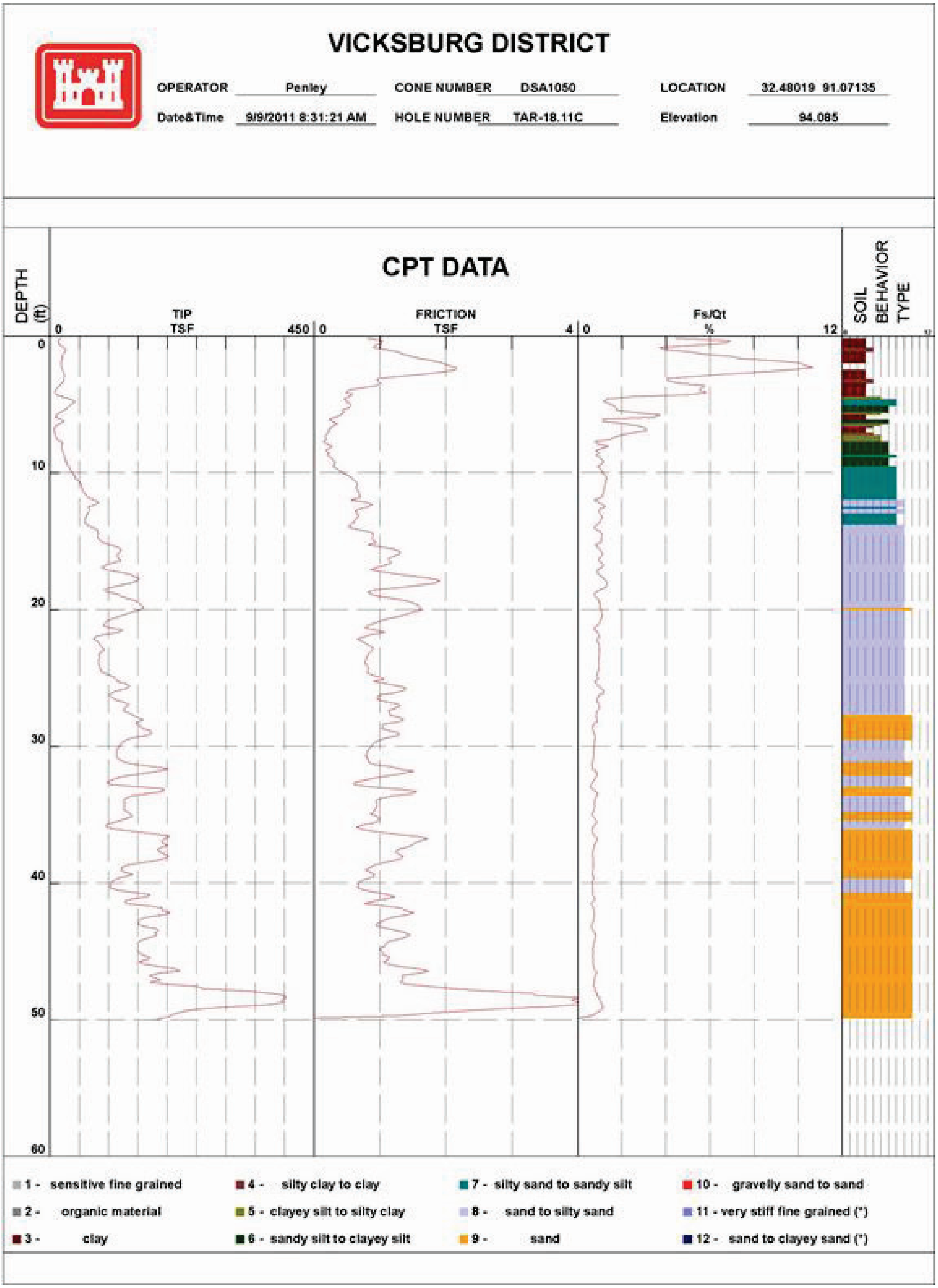
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

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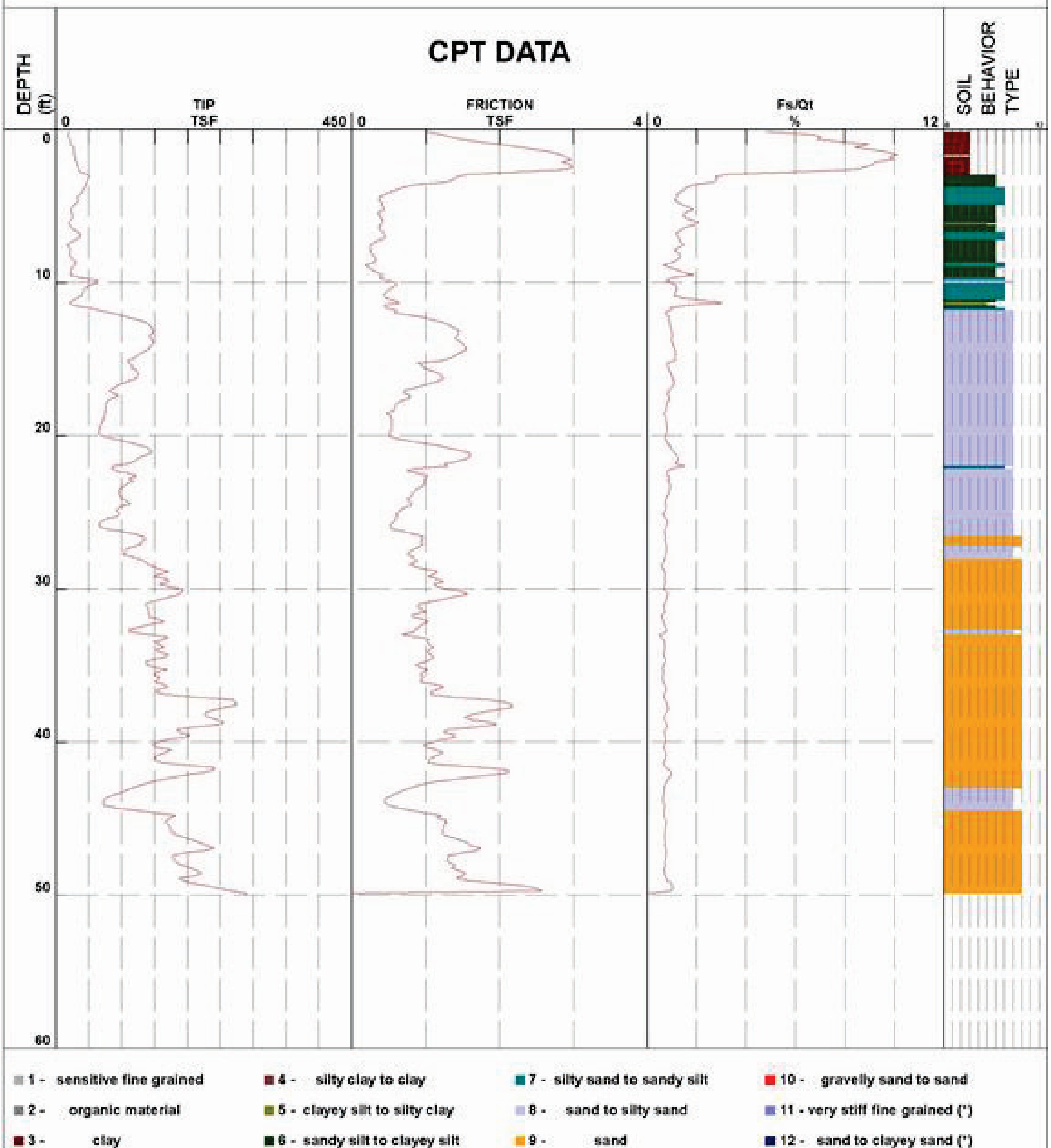

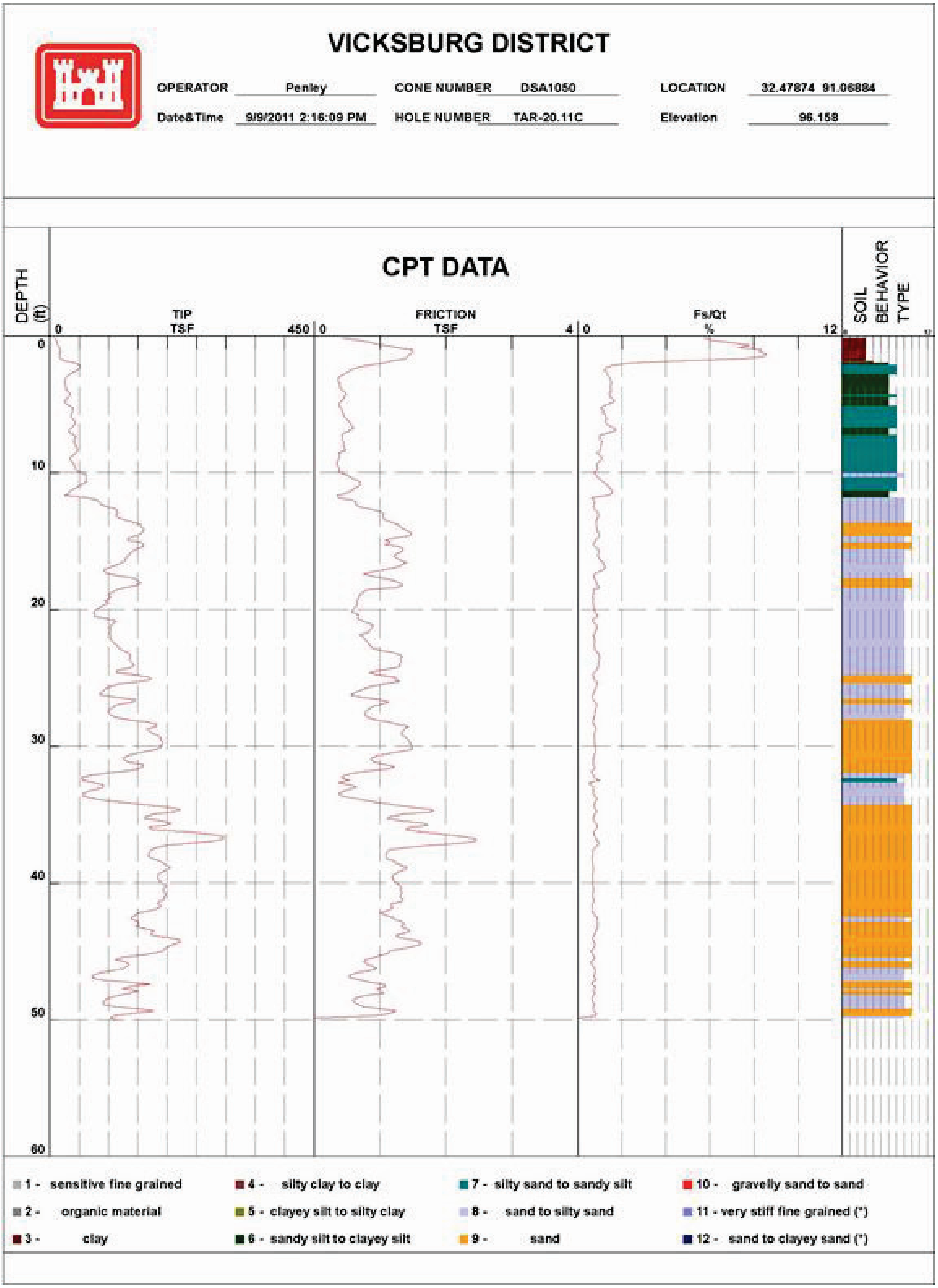
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5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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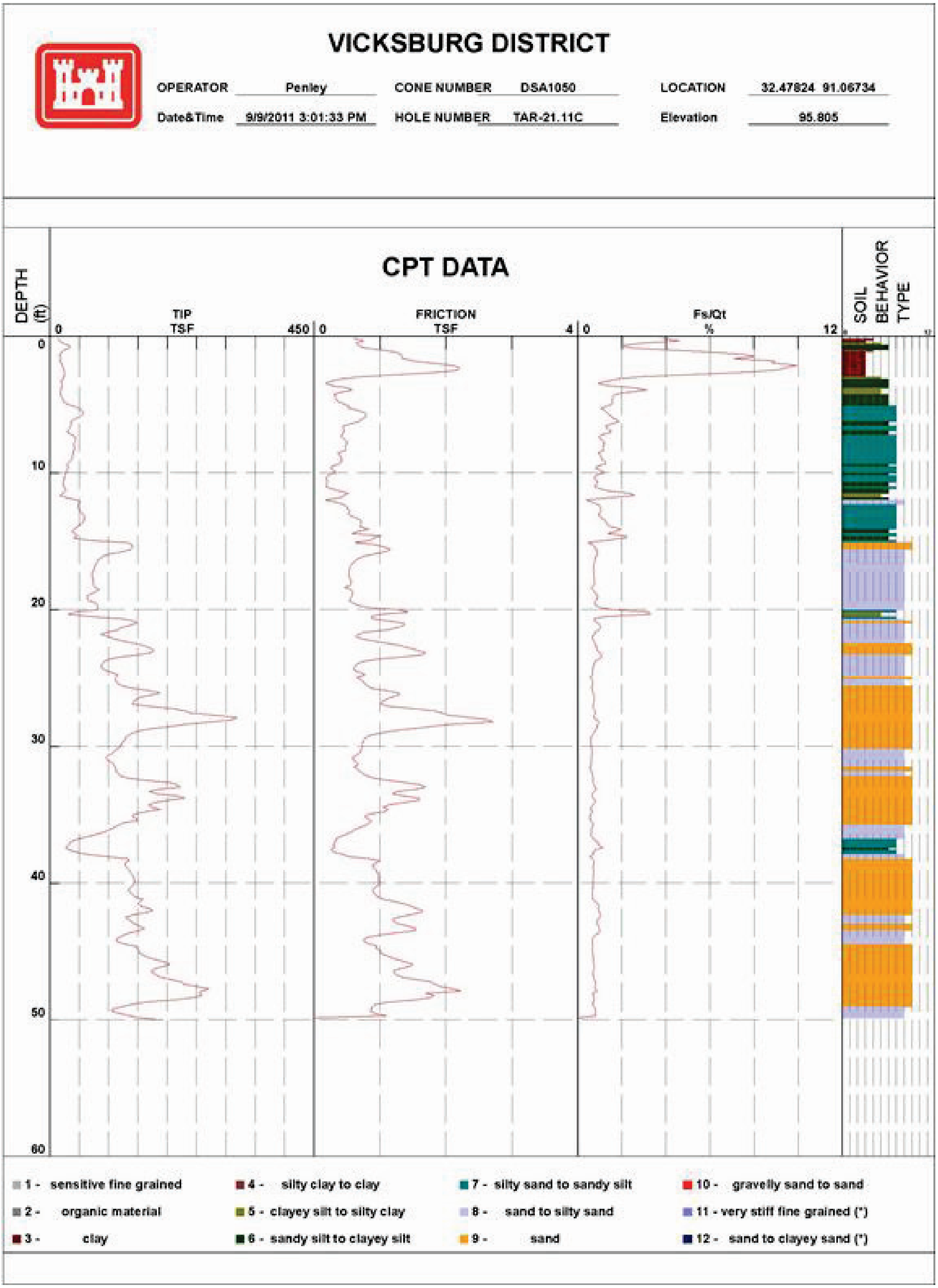
12 - sand to clayey sand (*)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6 - sandy silt to clayey silt
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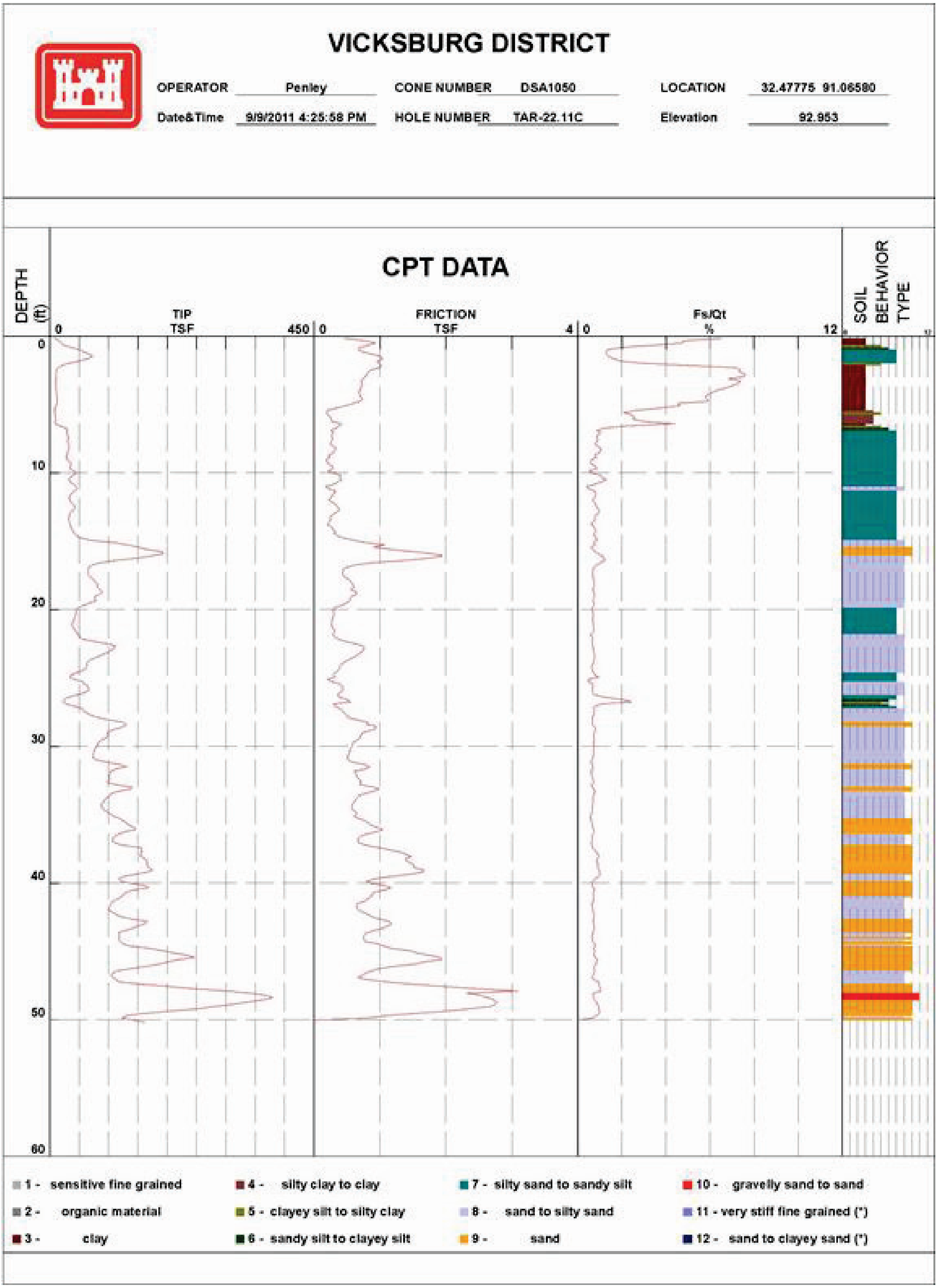
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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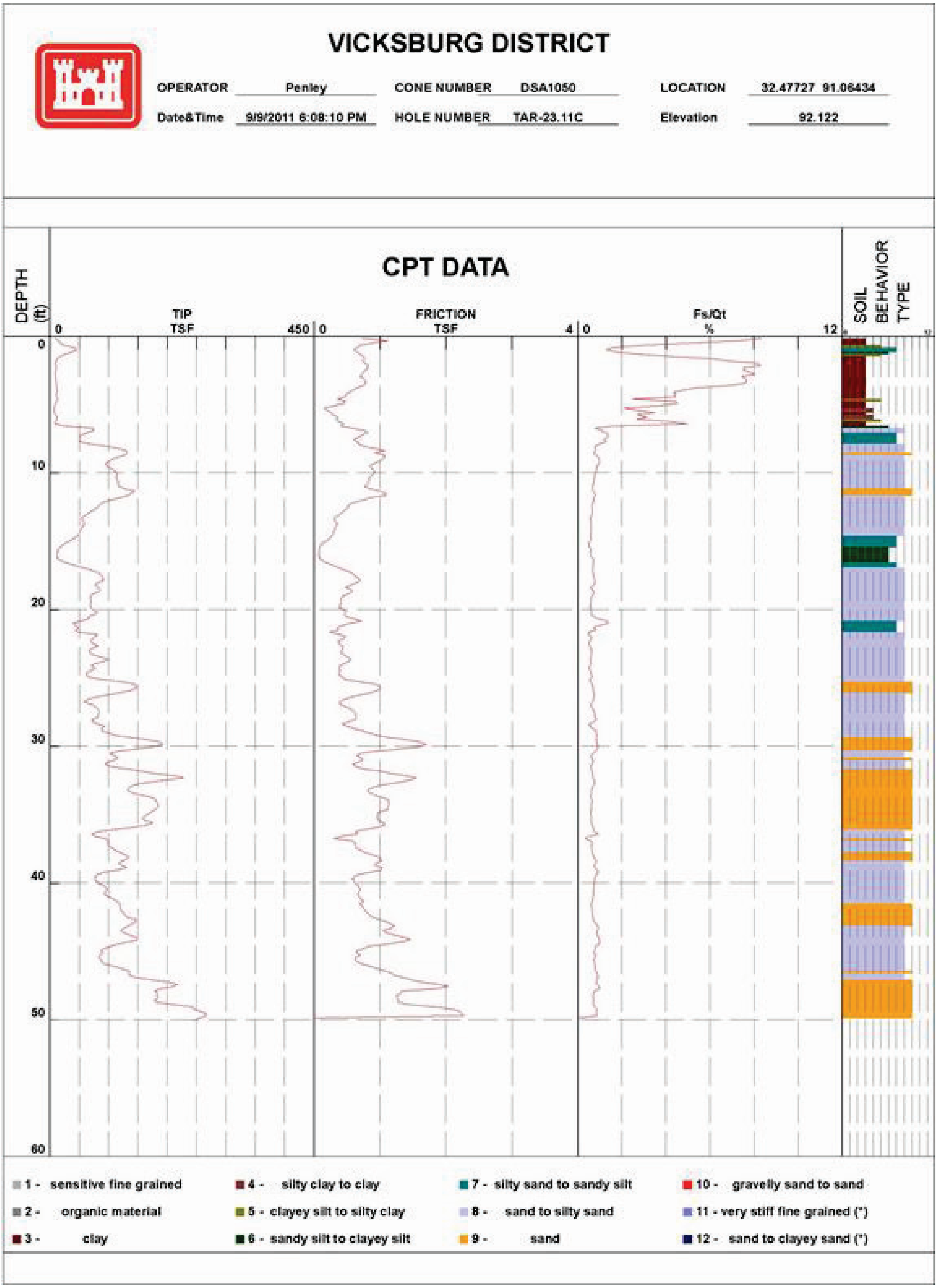
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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3 - clay
4 - silty clay to clay
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6 - sandy silt to clayey silt
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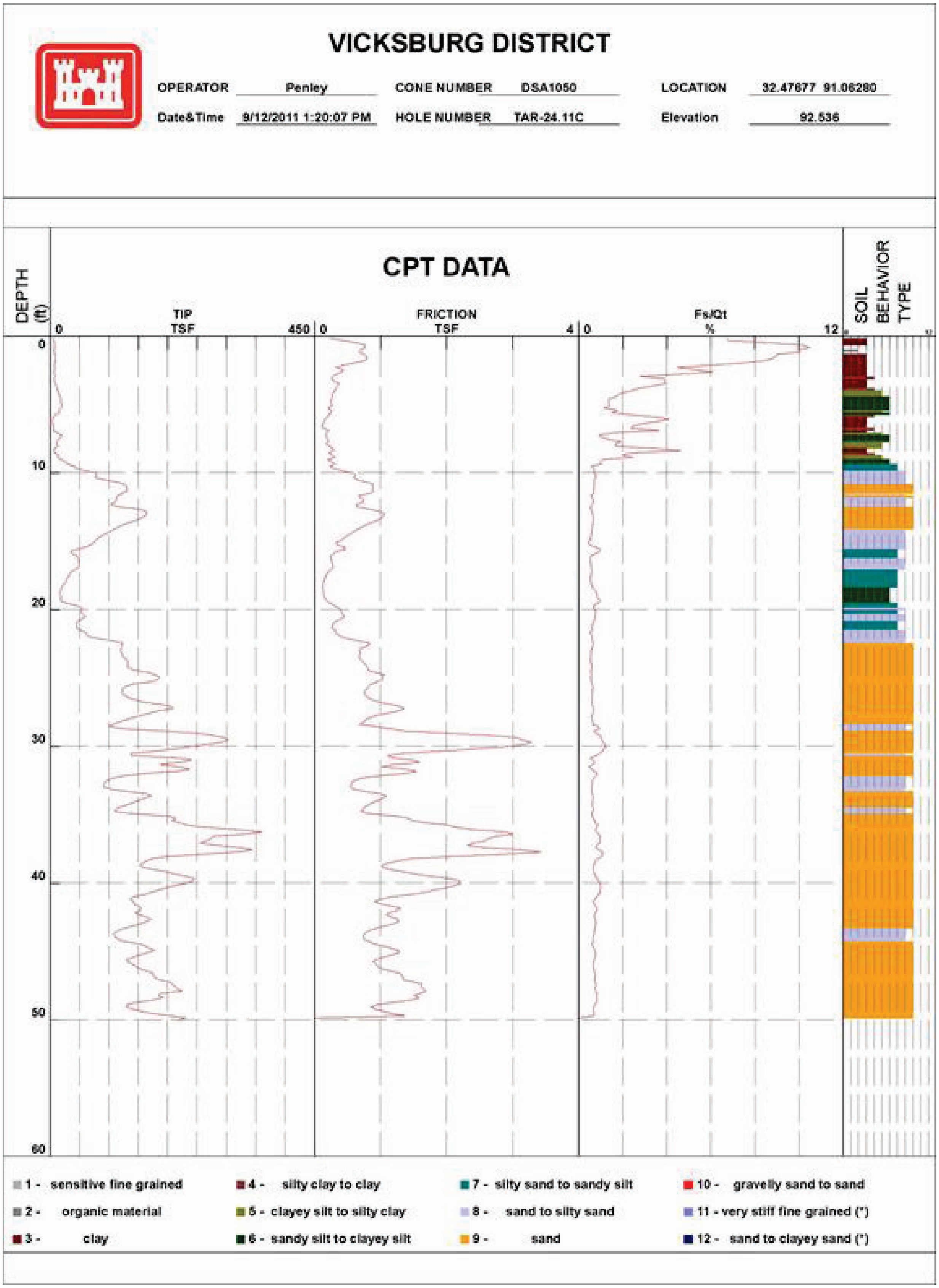
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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6 - sandy silt to clayey silt
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9 - sand
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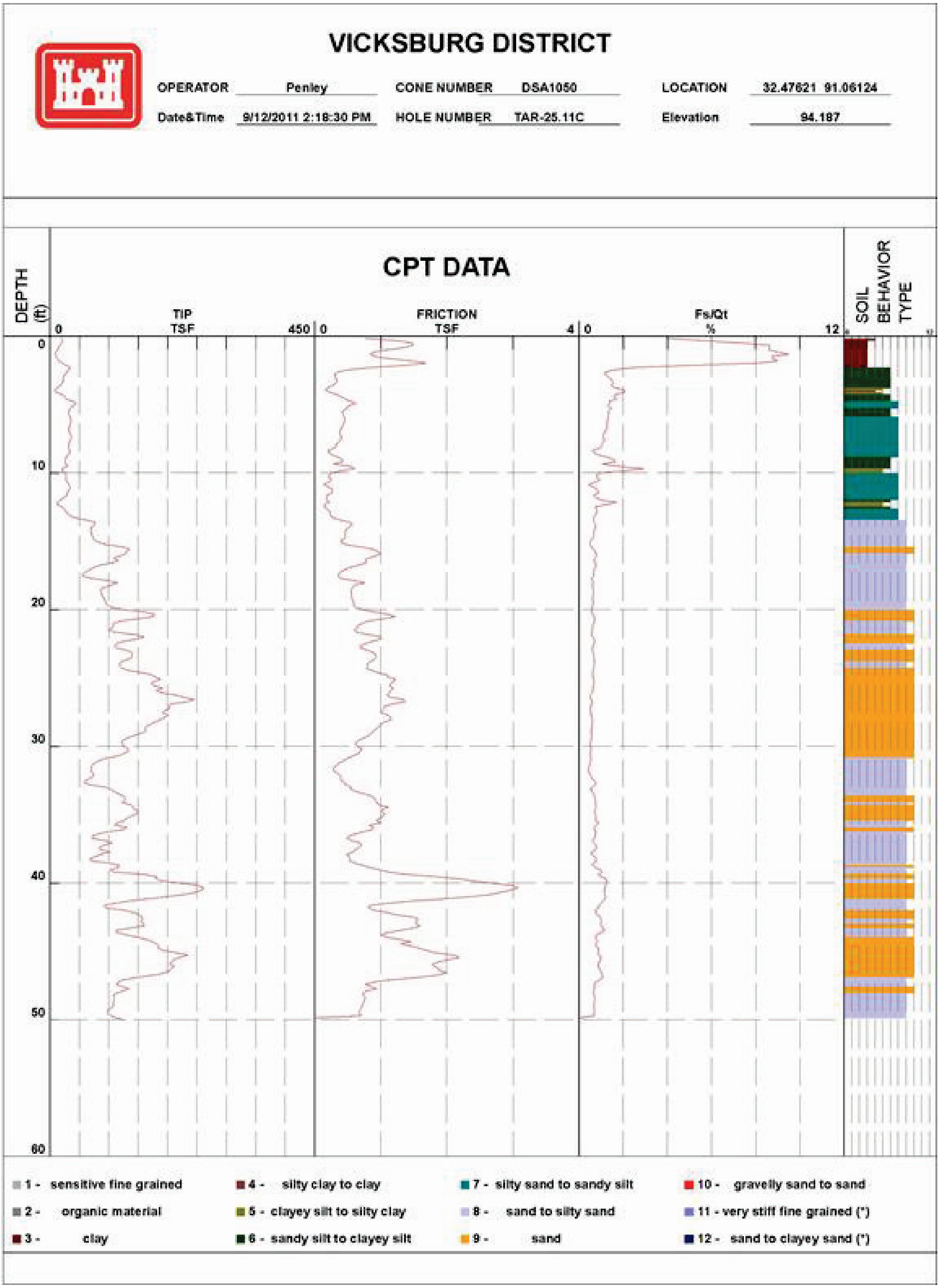
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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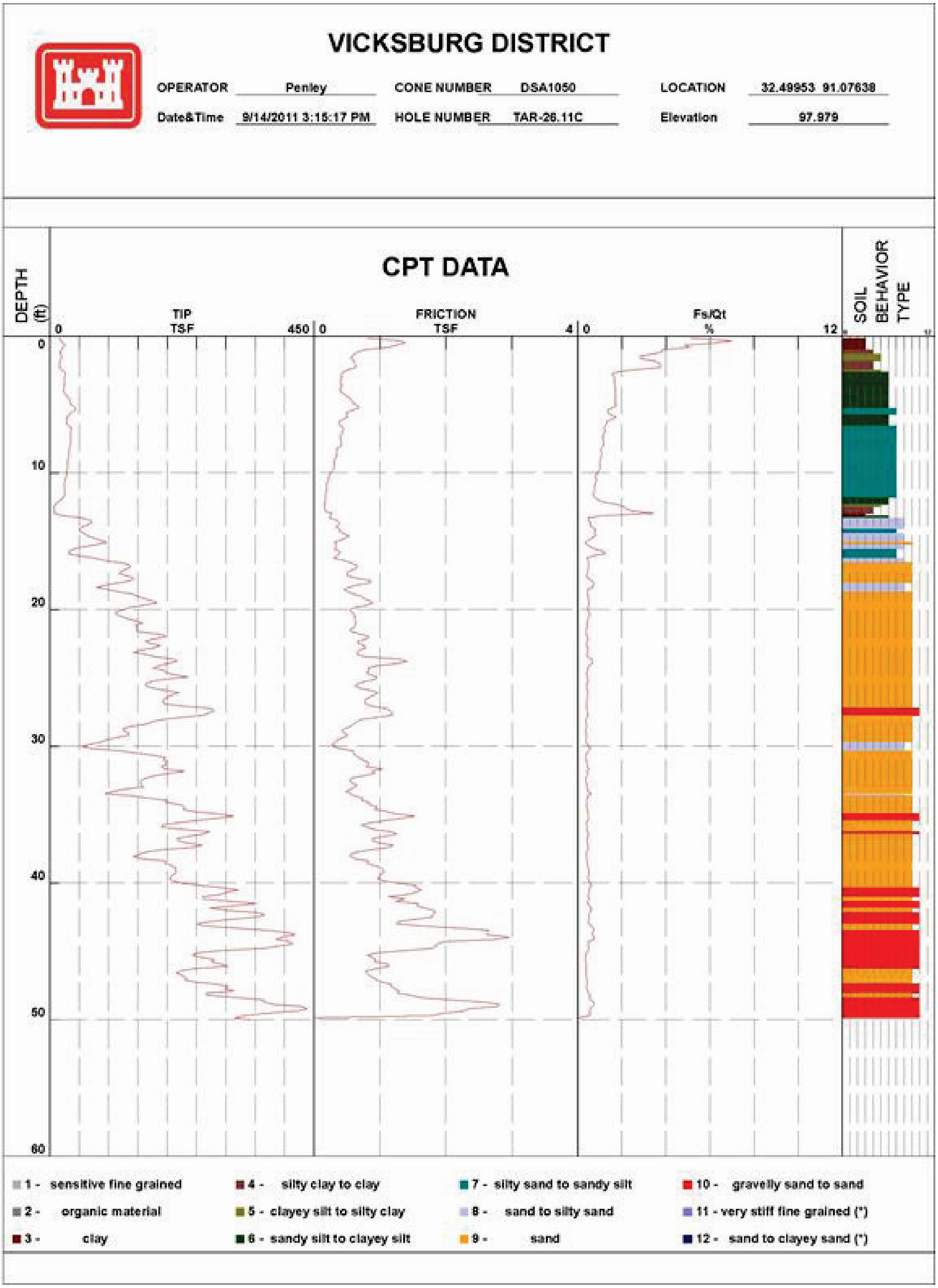
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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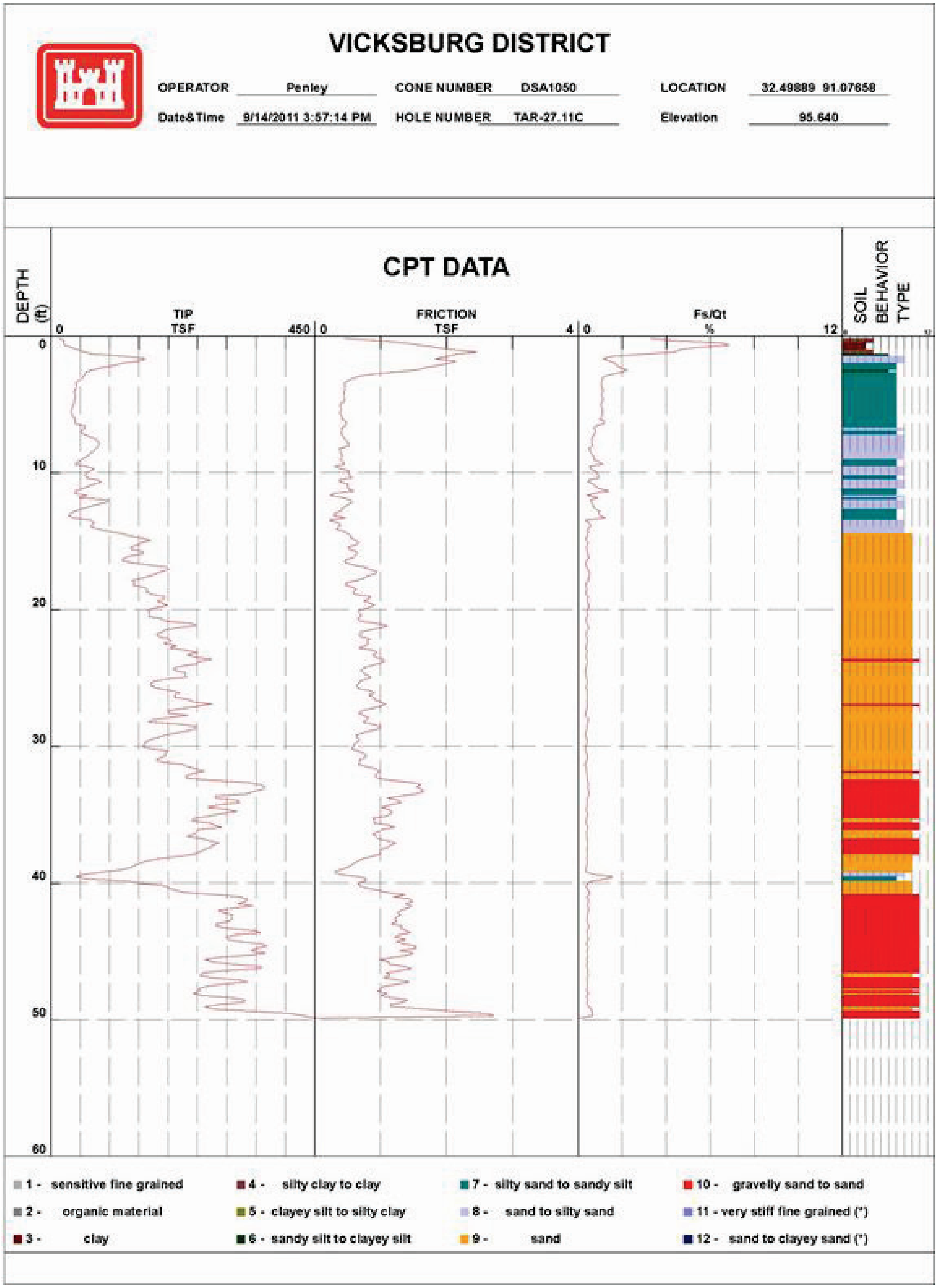
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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60
1 - sensitive fine grained
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3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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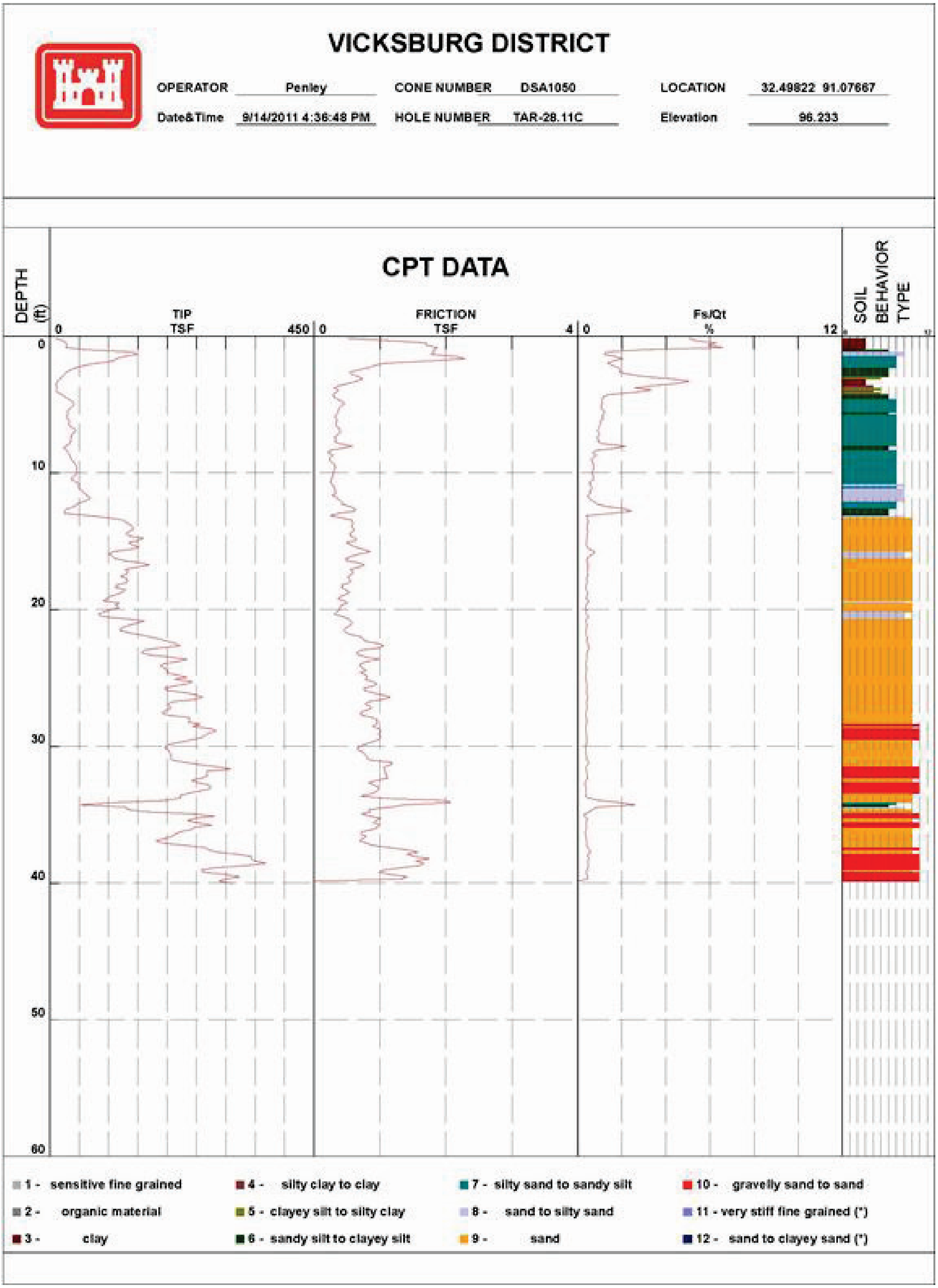
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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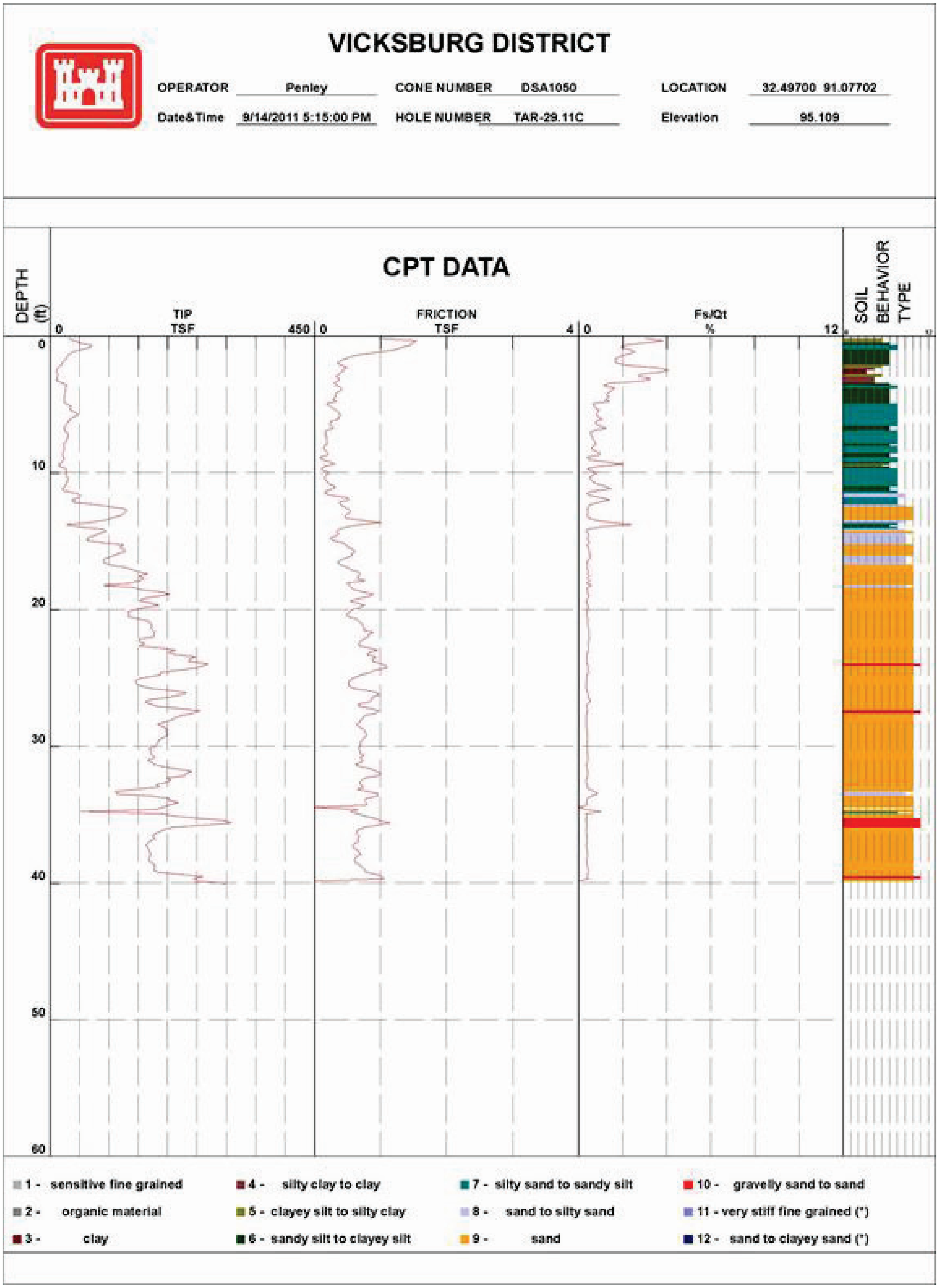
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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2 - organic material
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4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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9 - sand
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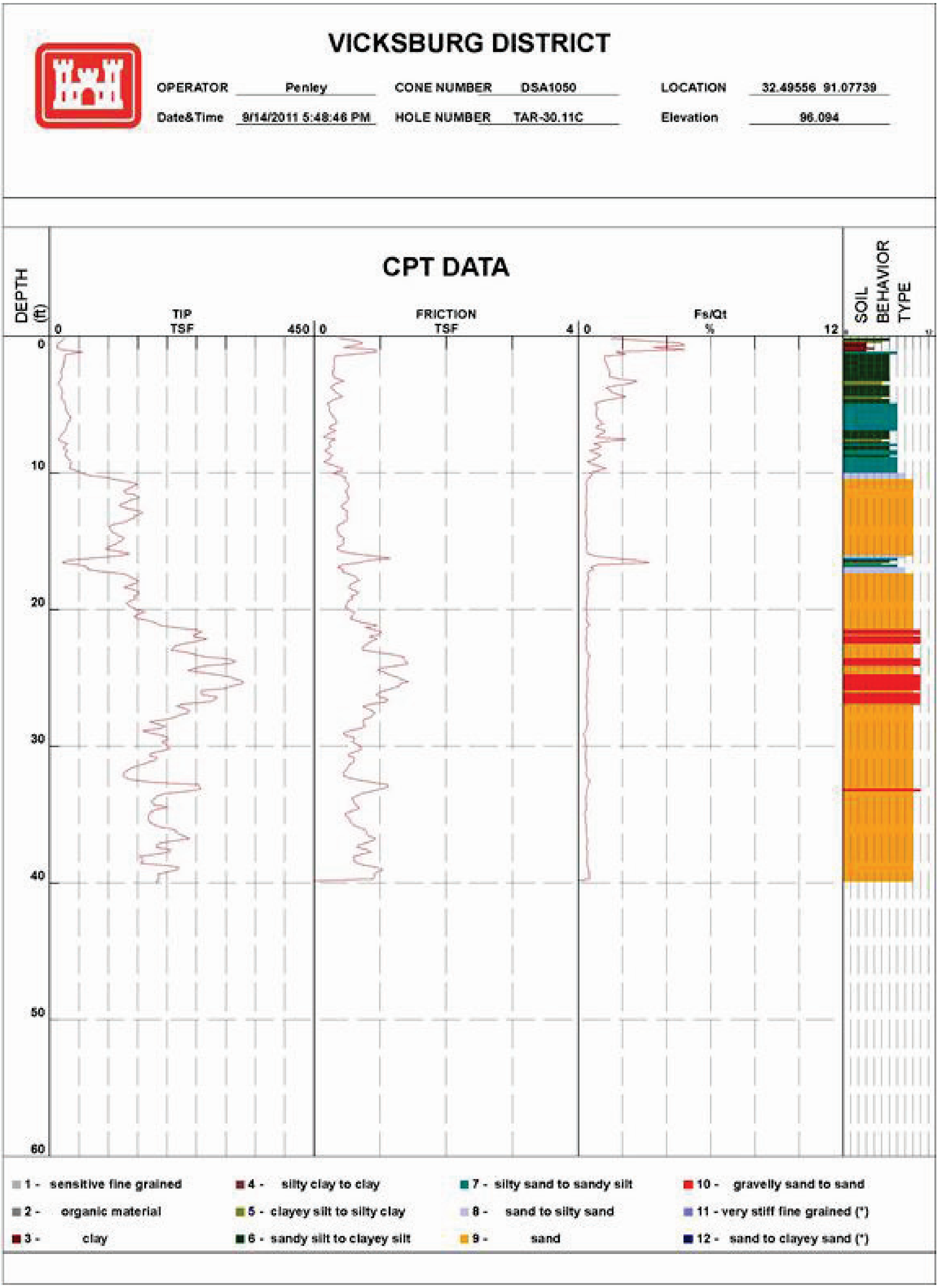
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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10 - gravelly sand to sand
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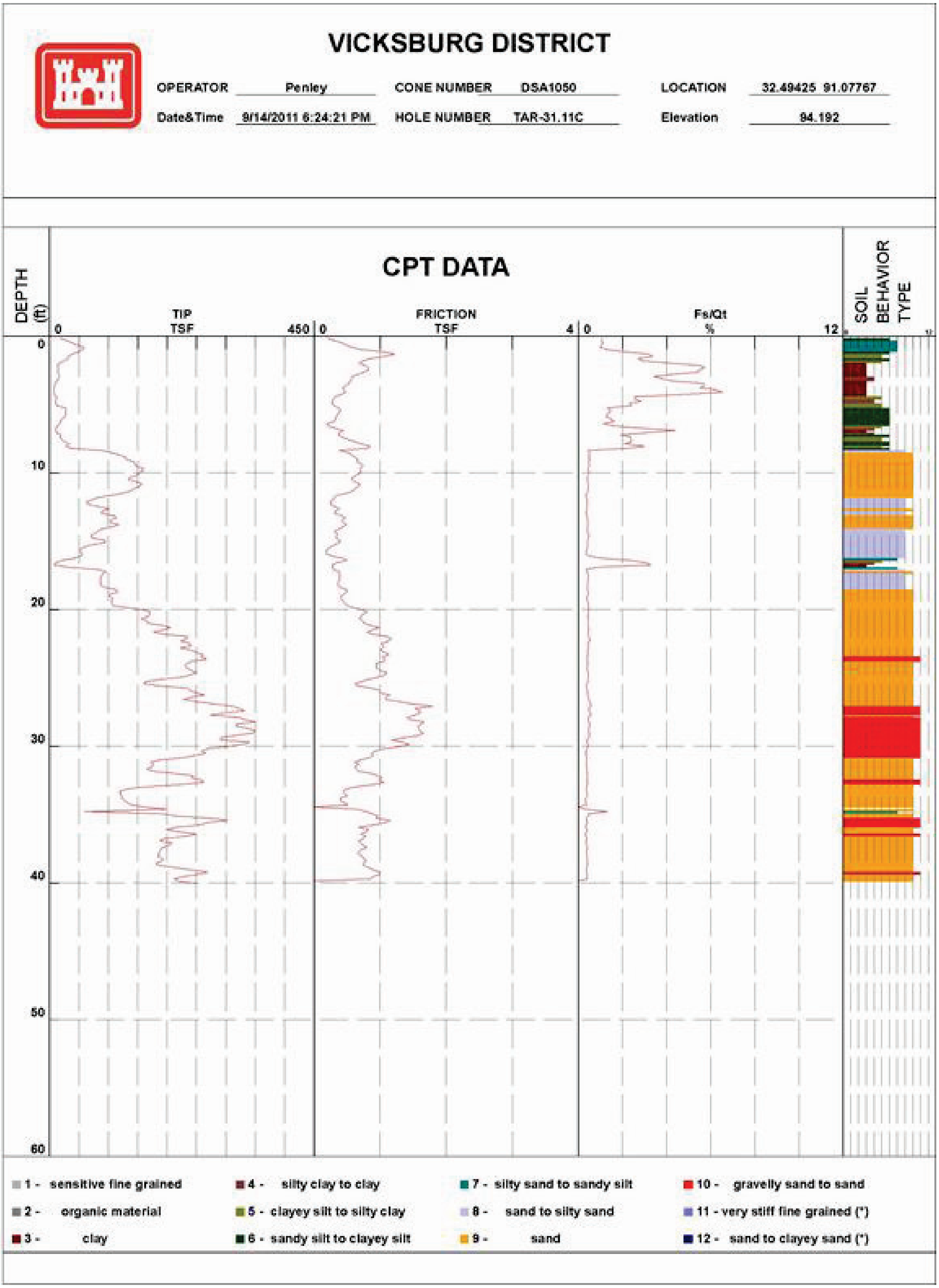
12 - sand to clayey sand (*)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4 - silty clay to clay
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6 - sandy silt to clayey silt
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11 - very stiff fine grained (*)
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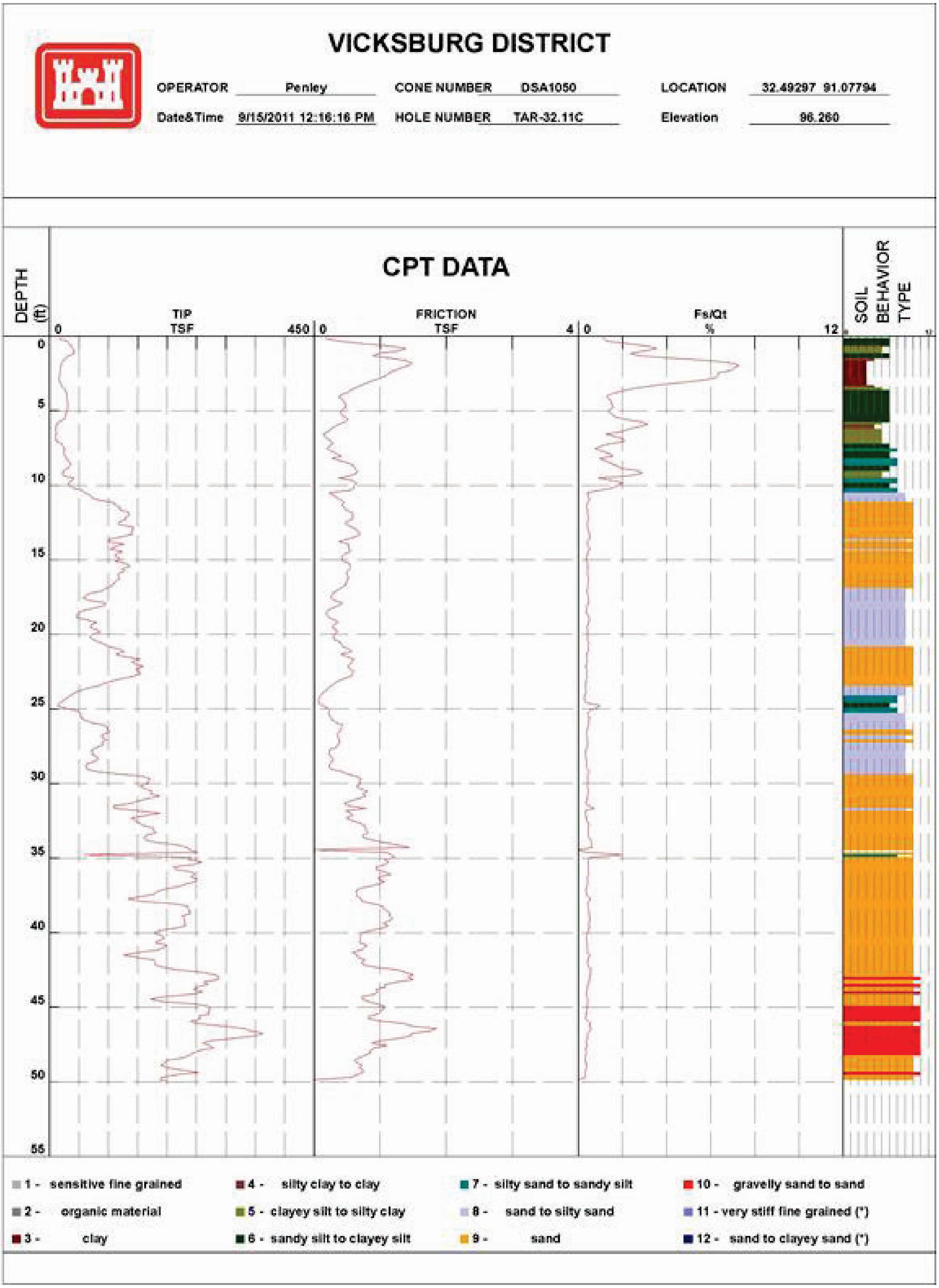
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Fs/Qt %
0 12
SOIL BEHAVIOR TYPE
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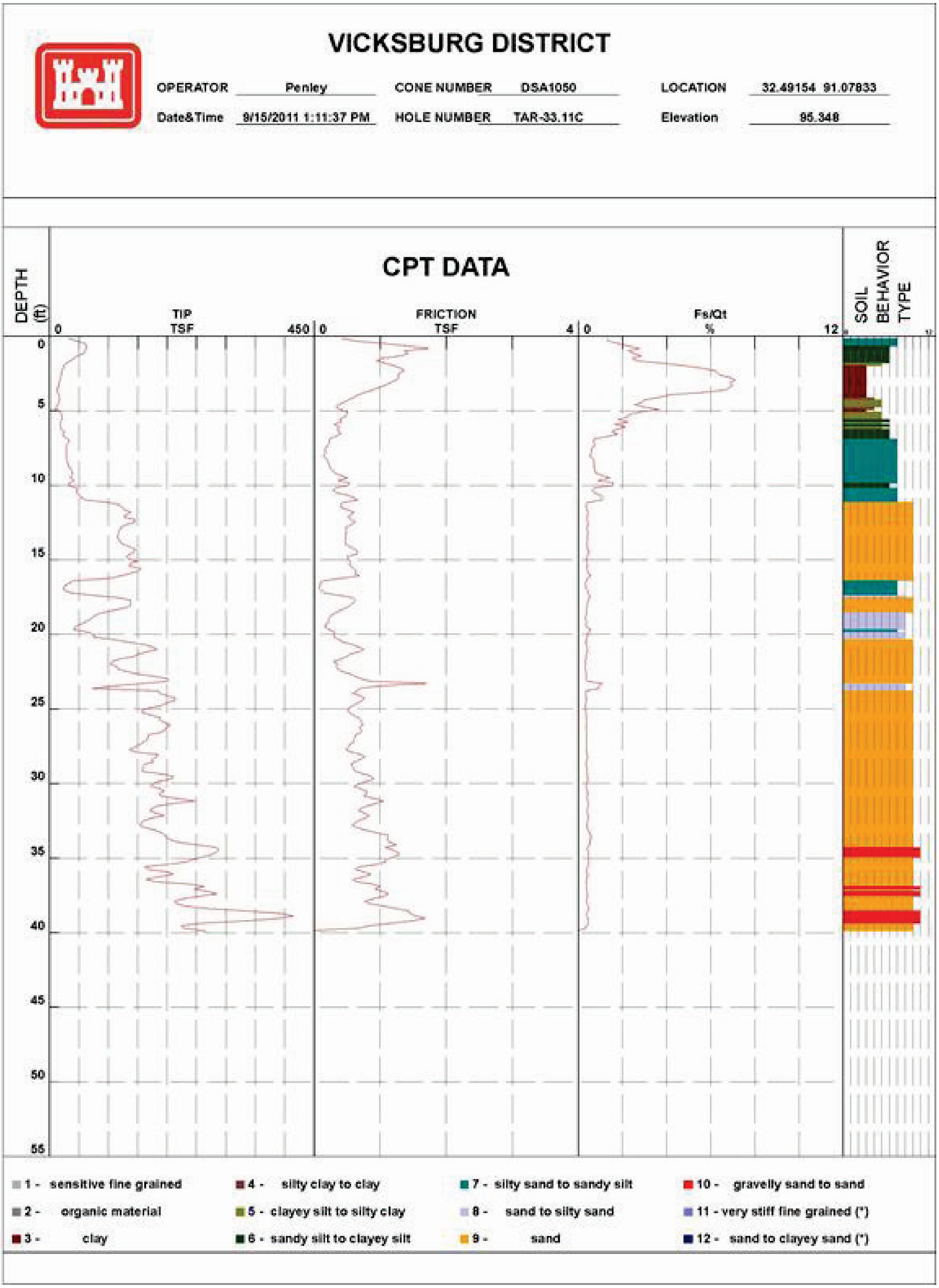
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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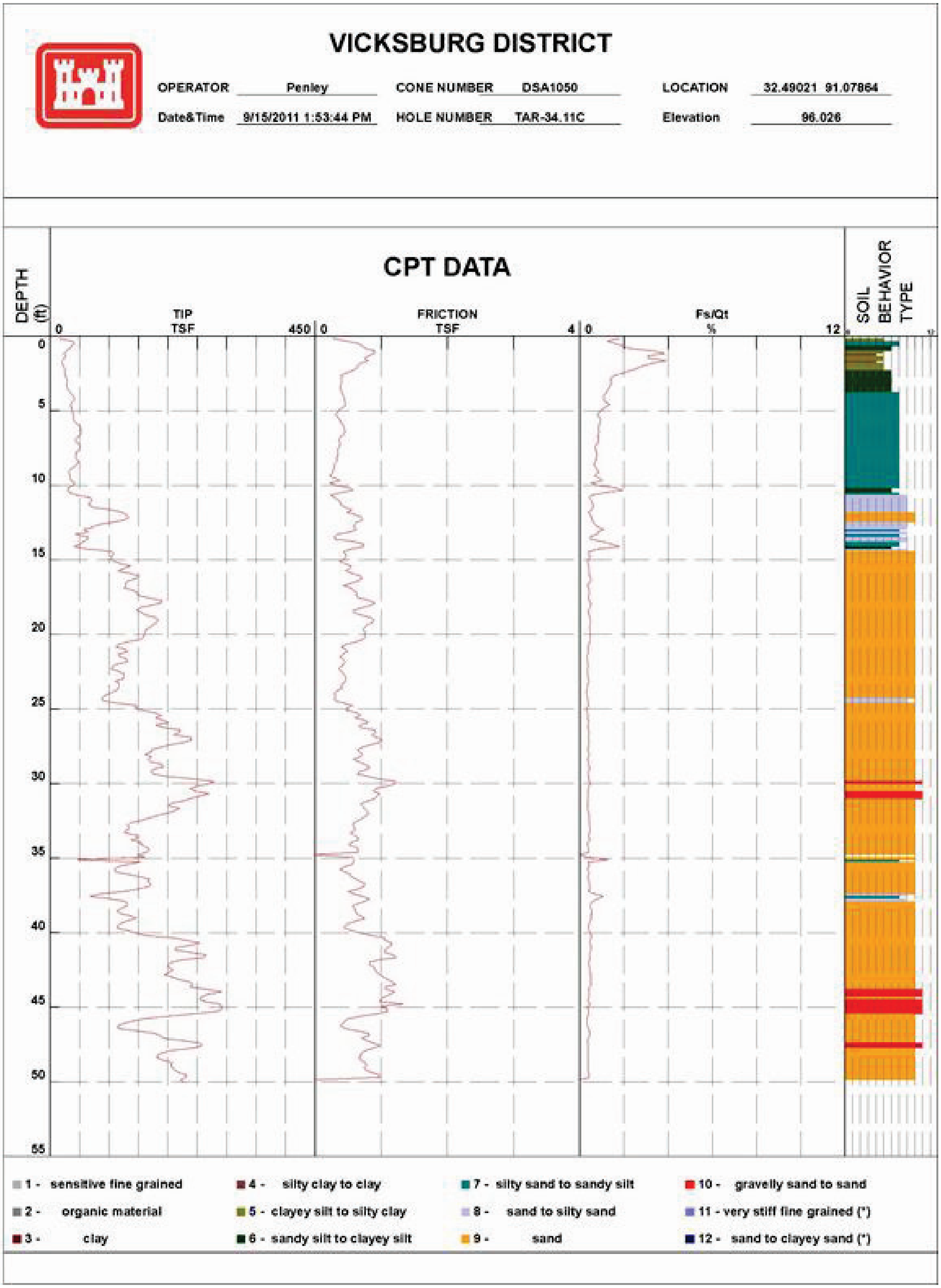
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40
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4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
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11 - very stiff fine grained (*)
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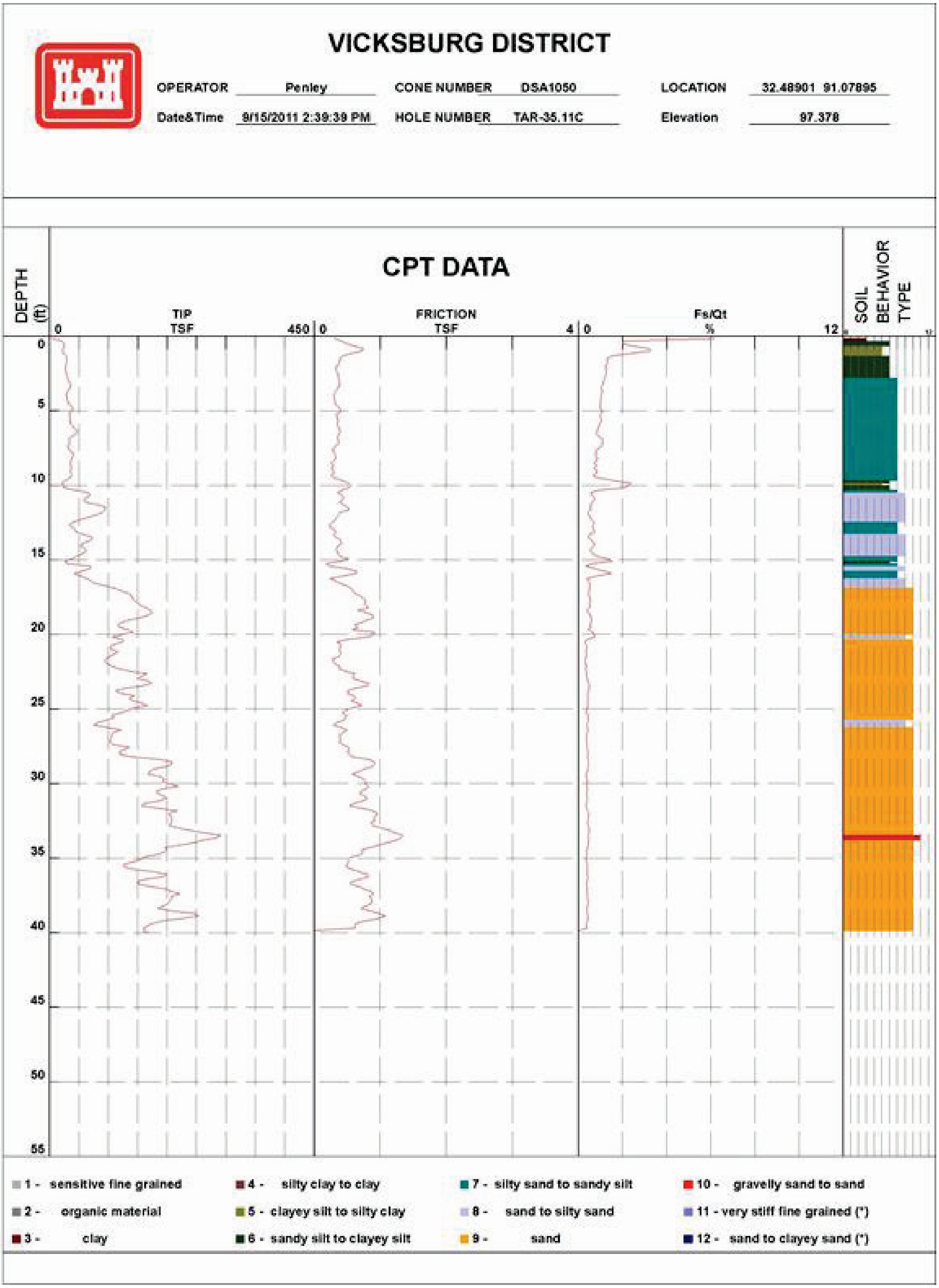
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10 - gravelly sand to sand
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March 2016	Final report	

4. TITLE AND SUBTITLE
The Influences of Geologic Depositional Environments on Sand Boil Development, Tara Wildlife Lodge Area in Mississippi

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Ryan C. Strange, Maureen K. Corcoran, Joseph B. Dunbar, and Darrel Schmitz

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Research and Development Center
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13. SUPPLEMENTARY NOTES

14. ABSTRACT
A comprehensive study of the subsurface geology in the Tara Wildlife Lodge area in Mississippi was undertaken to identify seepage pathways that lead to sand boils. After the completion of soil borings, geophysical surveys, and cone penetrometer tests and the analysis of the boring logs and test results, the subsurface in the Tara Wildlife area was better characterized with the creation of cross sections and imagery. The cross sections and imagery based on the data helped researchers to better understand the geologic phenomena that were occurring and causing sand boils. Results suggest that the Tara Wildlife Lodge area in the Talla Bena Quadrangle is located on pervious point bar deposits consisting of cohesionless sands with little to no overburden resistance.

15. Subject Terms

Internal erosion	Resistivity	Deposition
Piping	Sand boil	Mississippi River
Seepage	Geology	Alluvial plains
	Levees	Geological cross sections
	Geophysical surveys	Penetrometers - Testing

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
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