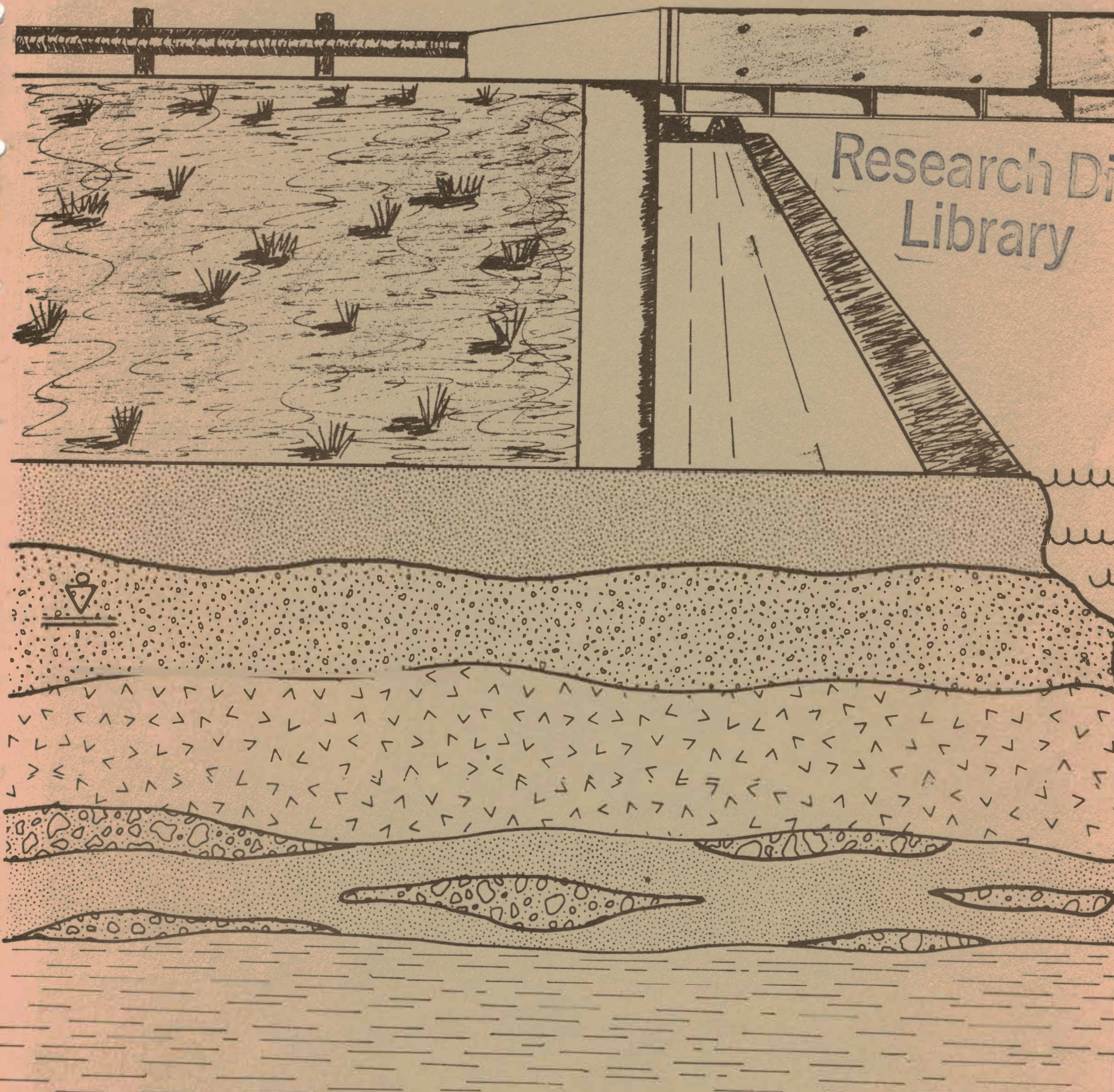
BEARING CAPACITIES



Characterization of Compressible Clayey and Silty Foundation Soils

Research and Development Division
Oklahoma Department of Transportation

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16. Abstract

This study developes a characterization of alluvial soils in two river systems from the surface down to bedrock. Study sites were located in alluvial deposits where fill settlement is a problem.

Continuous undisturbed soil samples were taken. Unconfined compression and consolidation tests were run on the soil layers. The field testing included the standard penetration test. Inclinometers were installed in an attempt to determine if creep existed in the weak soil layers of the alluvium.

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BEARING CAPACITY AND CHARACTERIZATION OF COMPRESSIBLE CLAYEY AND SILTY FOUNDATION SOILS IN OKLAHOMA

BY

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RESEARCH PROJECT 71-08-1

Research and Development Division

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December 1980

PREFACE

This constitutes the final report of Research Project 71-08-1 "Bearing Capacities and Characterization of Compressible Clayey and Silty Foundation Soils in Oklahoma". Included in this report are geotechnical properties of alluvial soils known to allow settlements of fills near bridge abutments. The characterization of the soils include agronomic as well as engineering descriptions. Tables which include several engineering properties are utilized to compare engineering characteristics of the surficial soil to the alluvial deposit below the mapped surface layer.

The author wishes to thank the Oklahoma Department of Transportation Materials Division, the Oklahoma Soil Conservation Service, Jim Nevels, and Jim Schmidt for their assistance in compiling this report.

INTRODUCTION

Purpose

This study is an attempt to characterize the alluvium in two river systems. U.S. Department of Agriculture, Soil Conservation Service soil surveys have the potential to assist highway engineers if they can indicate engineering properties. Variations in engineering properties of alluvial layers were to be determined and then related to the surficial soil description. The known degree of variation in the foundation soil should assist in determining route selection, the intensity of the geotechnical investigation, design criteria, and construction methods.

Scope

Two river systems were to be investigated. Two clayey and two silty pedological soils were sampled from each system. Soil strength parameters relating to consolidation were derived from continuous undisturbed soil samples. Soil classification data were derived from disturbed and undisturbed samples. Inclinometers were installed at the base of fills placed on alluvial soil deposits to determine if soil creep was occurring.

Background

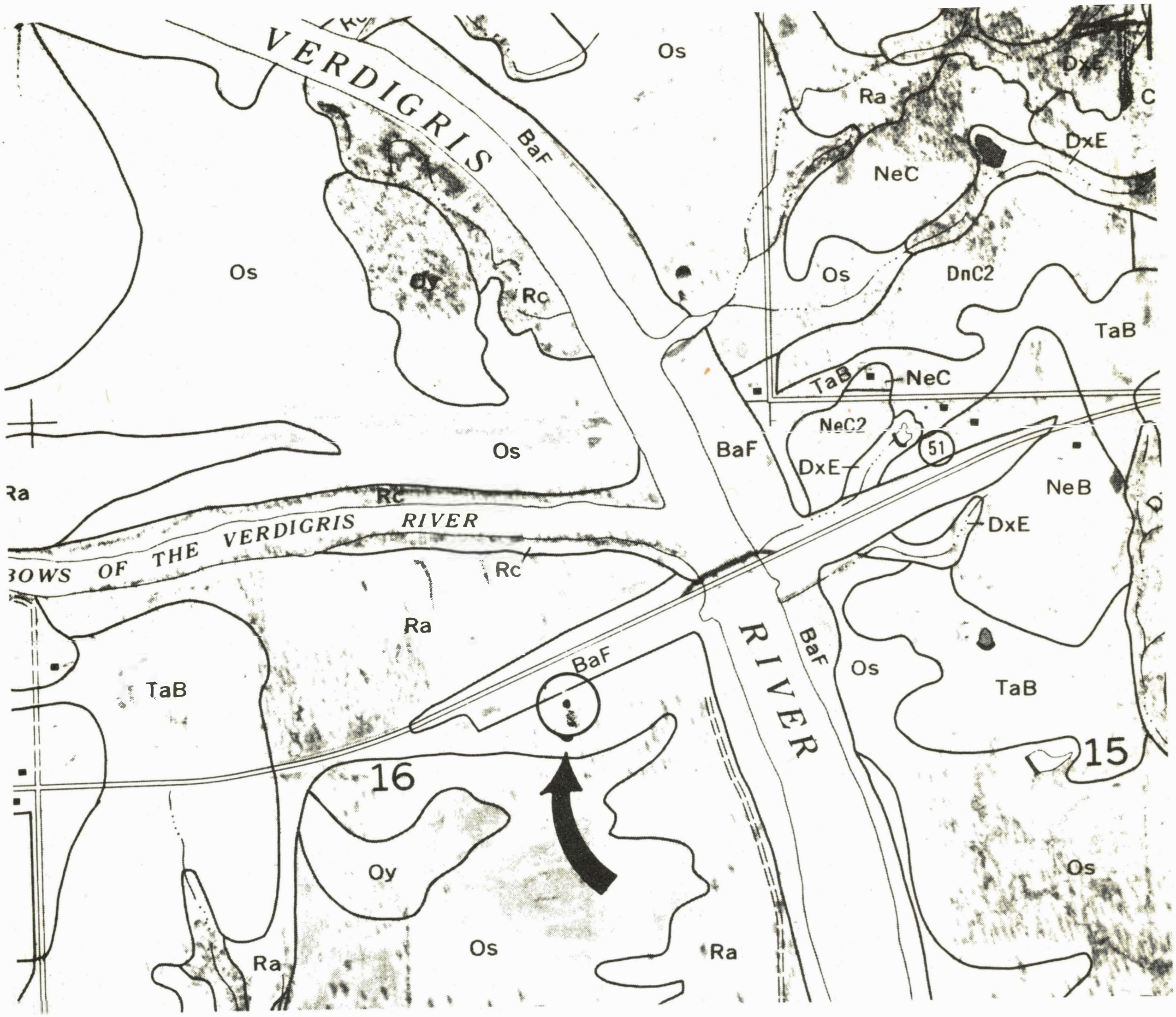
Soft foundation soils allow detrimental settlements and movements to occur in the area of bridge abutments. This settlement often results in rough bridge approaches and abutment rotation. The type of soil allowing unusual settlement is not always recognized. Many times embankment foundation studies are lacking or inadequate.

Embankment construction over soft foundation soils requires extensive investigation to evaluate the on-site conditions. Such investigations can be expensive and time consuming. Even so, effort spent during the foundation investigation phase of a project usually pays for itself many times over. If methods could be developed to assist with the prediction of significant variations in alluvial soil properties, cost effective geotechnical considerations could be planned and performed. This will then provide for optimum embankment performance.

The amount of soil variation expected dictates the subsurface investigation requirements (1, 18). The variations influence such items as; (a) boring spacing (b) amount of undisturbed sampling, and (c) field test type and quantity. Knowledge of the variability allows the engineer to use a cost effective program for planning and implementing embankment investigations and designs.

The Soil Conservation Service, of the U.S. Department of Agriculture, provides county soil (pedological) survey reports (13, 14). These reports show soil map unit outlines on aerial photos. See Figures 1 and 2. In the United States, about 60 to 70 percent of the land area has been mapped. In Oklahoma, 95 percent has been mapped (5). For most purposes the reports work as well for geotechnical planning purposes as for agricultural uses.

The soil units as viewed on a soil map, tend to convey a purity or confidence in the unit that may not be warranted. Variations from unit to unit occur due to inclusions of similar or dissimilar soils within the soil unit (8). Such variations are bothersome to map users unless the concept of inclusions is understood (11).



SOIL LEGEND

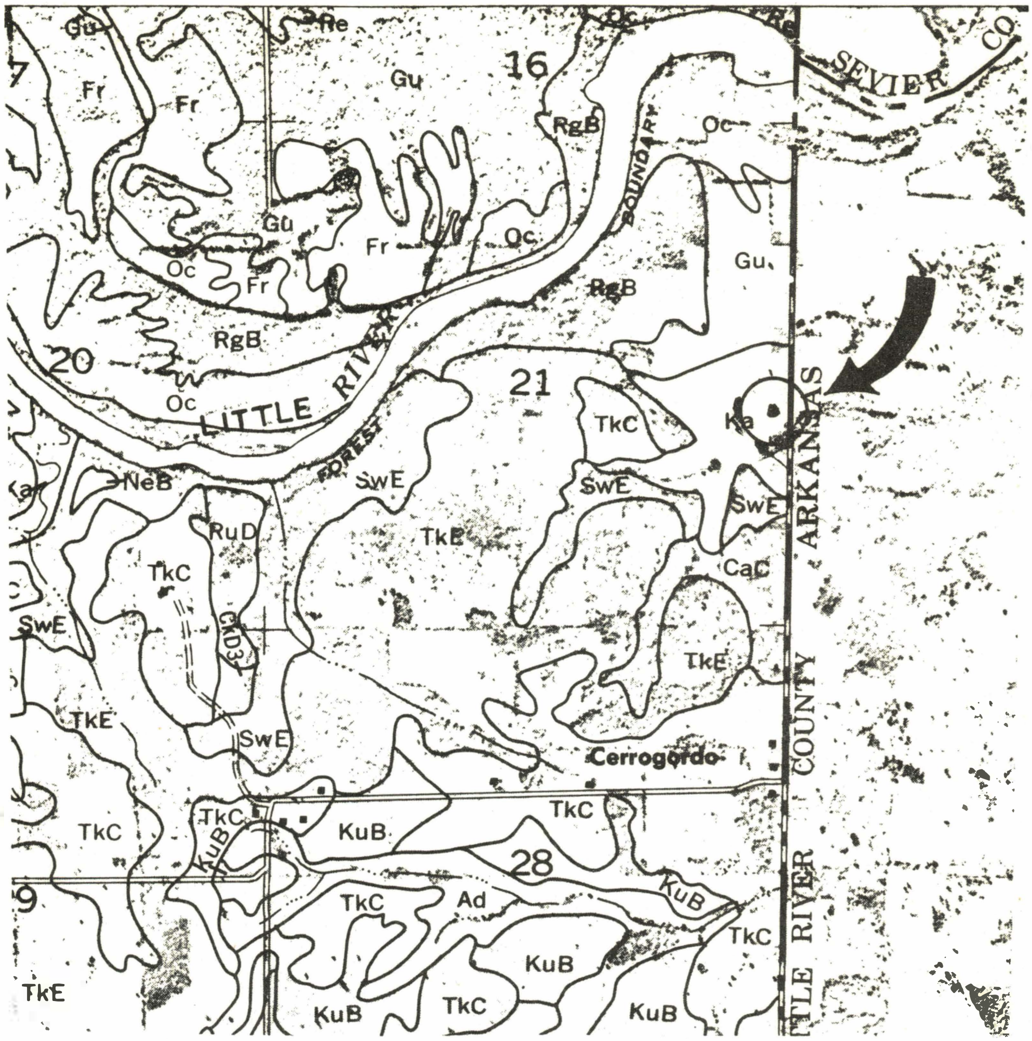
Symbol	Soil Name	Symbol	Soil Name
BaF	Barge Soils	Oy	Osage clay
DnC2	Dennis silt loam	PaA	Parsons silt loam
DxE	Dennis-Radley complex	Ra(Verdigris)	Verdigris silt loam
NeC	Newtonia silt loam	Rc(Verdigris)	Verdigris soils
NeC2	Newtonia silt loam, eroded	TaB	Taloka silt loam
Os	Osage silty clay loam		

⊙ Location of Verdigris soil sampling site, Boring No. 5
Note: The soil name was changed from Verdigris to Radley prior to publication.

Scale — 1:20,000

Location — 1100 ft. east, 300 ft. north of the center of sec. 16, Township 17 north, Range 17 east.

Figure 1. A portion of sheet 23, Soil Survey of Wagoner Co., Ok., courtesy of the Soil Conservation Service.



SOIL LEGEND

Symbol	Soil Name	Symbol	Soil Name
Ad	Adaton loam	Oc	Oclockonee fine sandy loam
CaC	Cadeville loam	Re	Rexor loam
CkD3	Cahaba and Tiak soil	RgB	Rexon-Guyton Complex
Fr	Frizzell loam	RuD	Ruston fine sandy loam
Gu	Guyton Silt loam	SwE	Swink-Hollywood complex
Ka	Kaufman clay	TfC	Tiak fine sandy loam
KuB	Kullit fine sandy loam	TkC	Tiak-Ruston complex, 1-5% slopes
NeB	Newtonia Silt loam	TkE	Tiak-Ruston complex 5-15% slopes

Scale — 1:31,680

Location — 2200 ft. north of the SE corner sec. 21, Township 7 south, Range 27 east.

⊙ Kaufman soil sampling site, Boring No. 7

Figure 2. A portion of sheet 47, Soil Survey of McCurtain Co., Oklahoma. Courtesy of the Soil Conservation Service.

Very often engineers lose faith in a soil survey because they find soils other than the one mapped when they make observations within the map unit. The variations, called inclusions, which occur must be visualized as occurring in a three dimensional body. A brief explanation of inclusions may help in understanding map unit purity.

Most map units or delineations include small scattered areas of soils other than those for which the map unit is named. Investigations have shown that most map units contain five to fifteen percent of a soil other than the one designated on the map. A thorough reading of the county soils report will tell the reader specifically which soils are included.

The included soils may not be significantly different for engineering purposes. For instance, the Osage soil is typically very dark gray or black. It is possible that a small area, included in the map delineation, is a reddish soil. This soil is not Osage. However, the change in color probably does not affect agricultural or engineering properties. For practical purposes they are the same.

Sometimes the included soil may affect engineering uses. The problem comes when the area(s) is so small that a map delineation cannot be made at the map scale being used. In this case, care must be exercised by the engineer to determine if the inclusion demands a different interpretation. For instance, areas mapped as Osage could possibly contain up to 25 percent of a soil called Cleora. Cleora is a more granular soil and as such could act significantly different in terms of engineering performance. Figure 3 shows an example of a shallow to limestone bedrock soil, Scullin, as an inclusion in a Claremore map delineation. The soil scientists are aware of such inconsistencies and describe them in the text of county soil reports.

Soil scientists commonly make observations about 2 meters deep unless bedrock is encountered at a lesser depth. In alluvial deposits, the soil may extend from depths of 2 meters to 50 meters or sometimes much more.

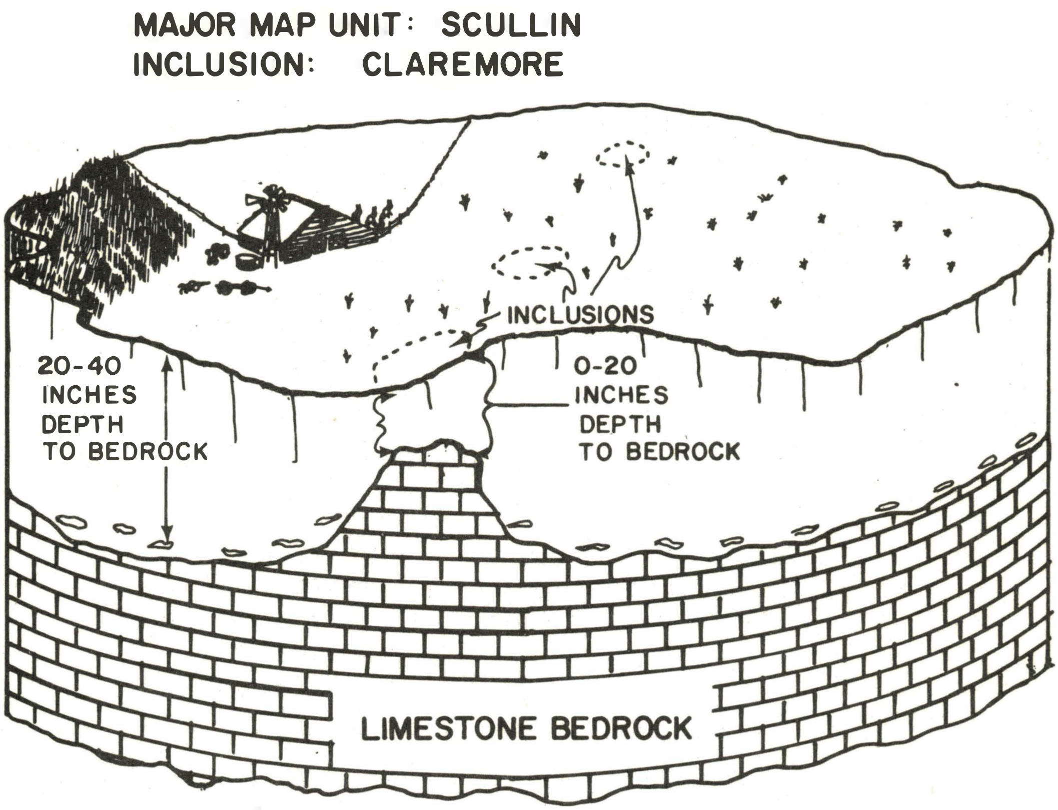


Figure 3. An example of a soil map unit of the Scullin Soil Series with inclusions of the Claremore Soils Series.

Therefore, the possibility exists that the geotechnical soil properties present in the upper 2 meters might extend to greater depths. Also, it would be of interest to observe if geographically separated soil units still exhibit similar characteristics with depth.

MATERIALS AND METHODS

The pedological soils studied belong to the Osage, Verdigris, Kaufman, and Rexor soil series. These are deep soils developed on alluvial flood plains. See Appendix A. The pedological taxonomic classification of the soils is as follows: Osage is a fine, montmorillonitic, thermic, Vertic Haplaquoll; Verdigris is a fine silty, thermic, Cumulic Haplaquoll; Kaufman is a very fine, montmorillonitic, thermic, Typic Pelludert; Rexor is a fine silty, siliceous thermic, Ultic Hapludalf.

The Osage and Verdigris soils are found in the Verdigris River flood plain of northeastern Oklahoma. The Kaufman and Rexor soils are found in the Little River flood plain of extreme southeastern Oklahoma. See Figures 4, 5 and 6. These soils range in thickness from 60 to 80 inches (1.5 to 2.0 m). The slopes range from 0-2 percent with slopes of less than 1percent being common. Runoff from the surface is slow.

Two sampling sites of each soil were established on the two geographically separated flood plains. Continuous soil samples were taken along the depth of the boring. A 3.5 inch (90mm) thin wall stationary piston sampler was used to facilitate undisturbed sampling (AASHTO T 207-75). The samples were extruded in the field, described, and promptly sealed with wax for transport. A separate boring was made to facilitate standard penetration tests (T 206-74). Laboratory tests included: Atterberg limits (T 89-76 and T 90-70), particle size (T 88-78), moisture-density (T99-74) specific gravity (T 100-75), unconfined

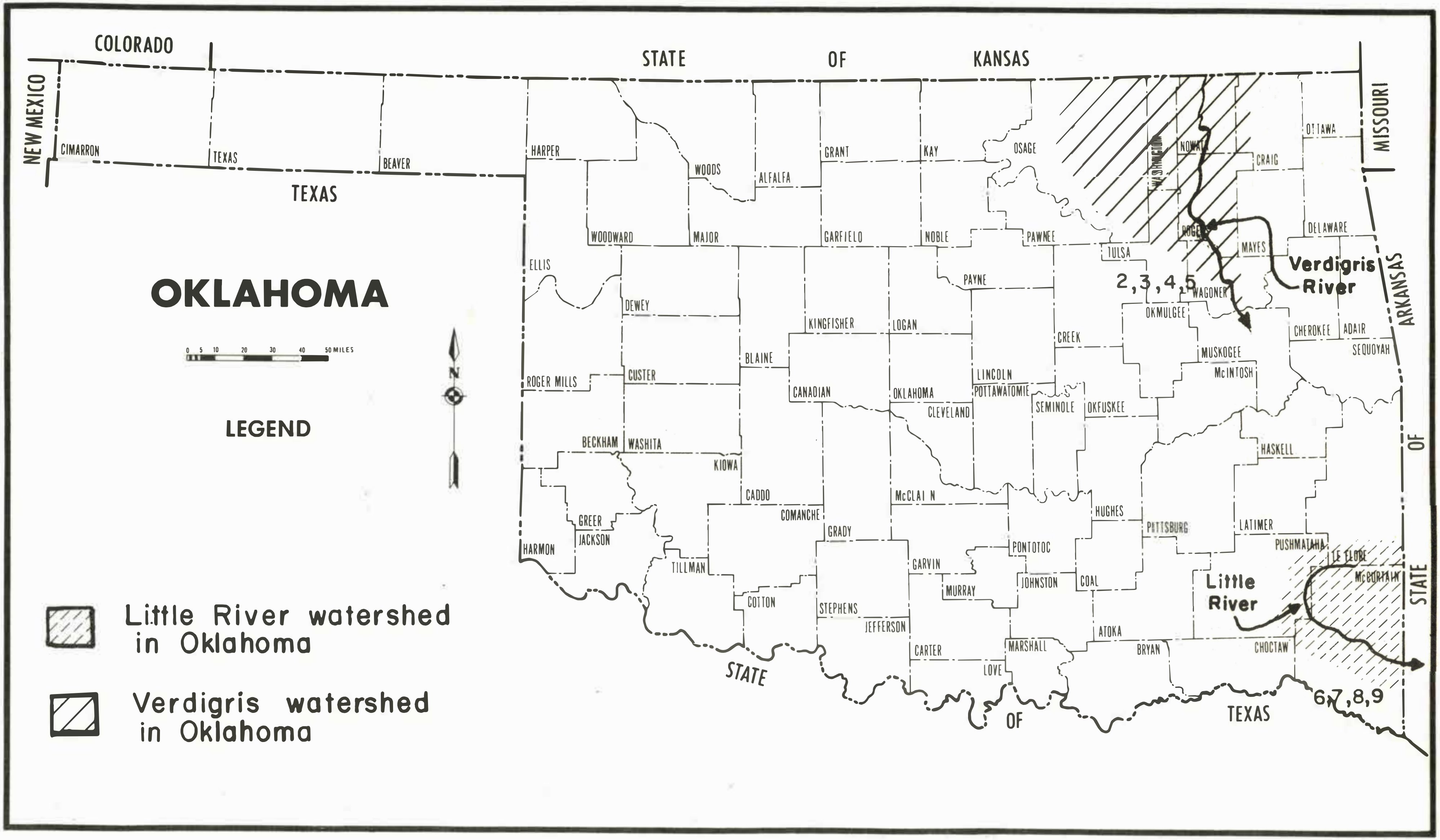


Figure 4. The location of the study areas along the Verdigris River Flood Plain (borings 2, 3, 4, & 5) and the Little River Flood Plain (borings 6, 7, 8, & 9).

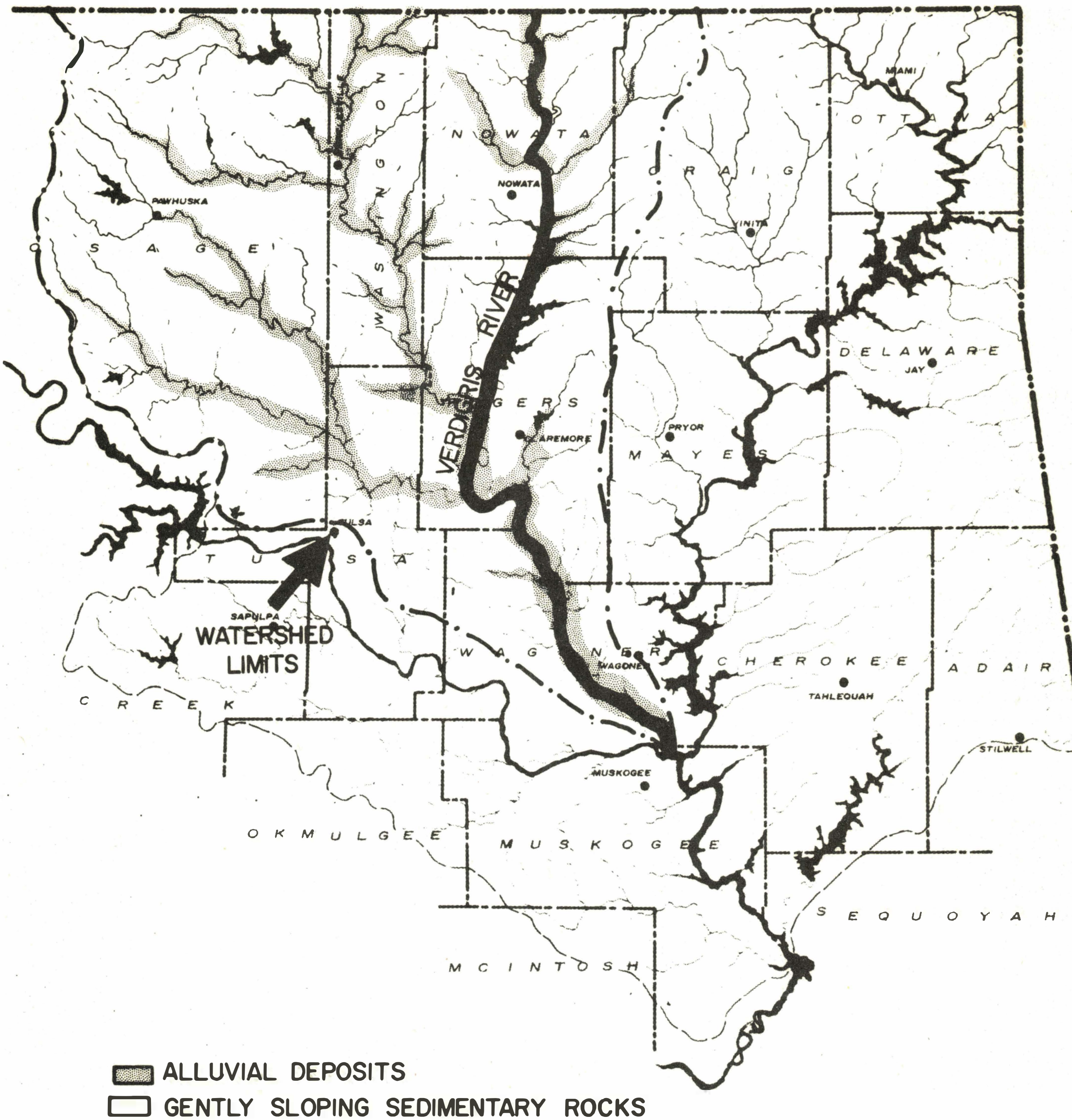


Figure 5. Verdigris River watershed showing general geology.

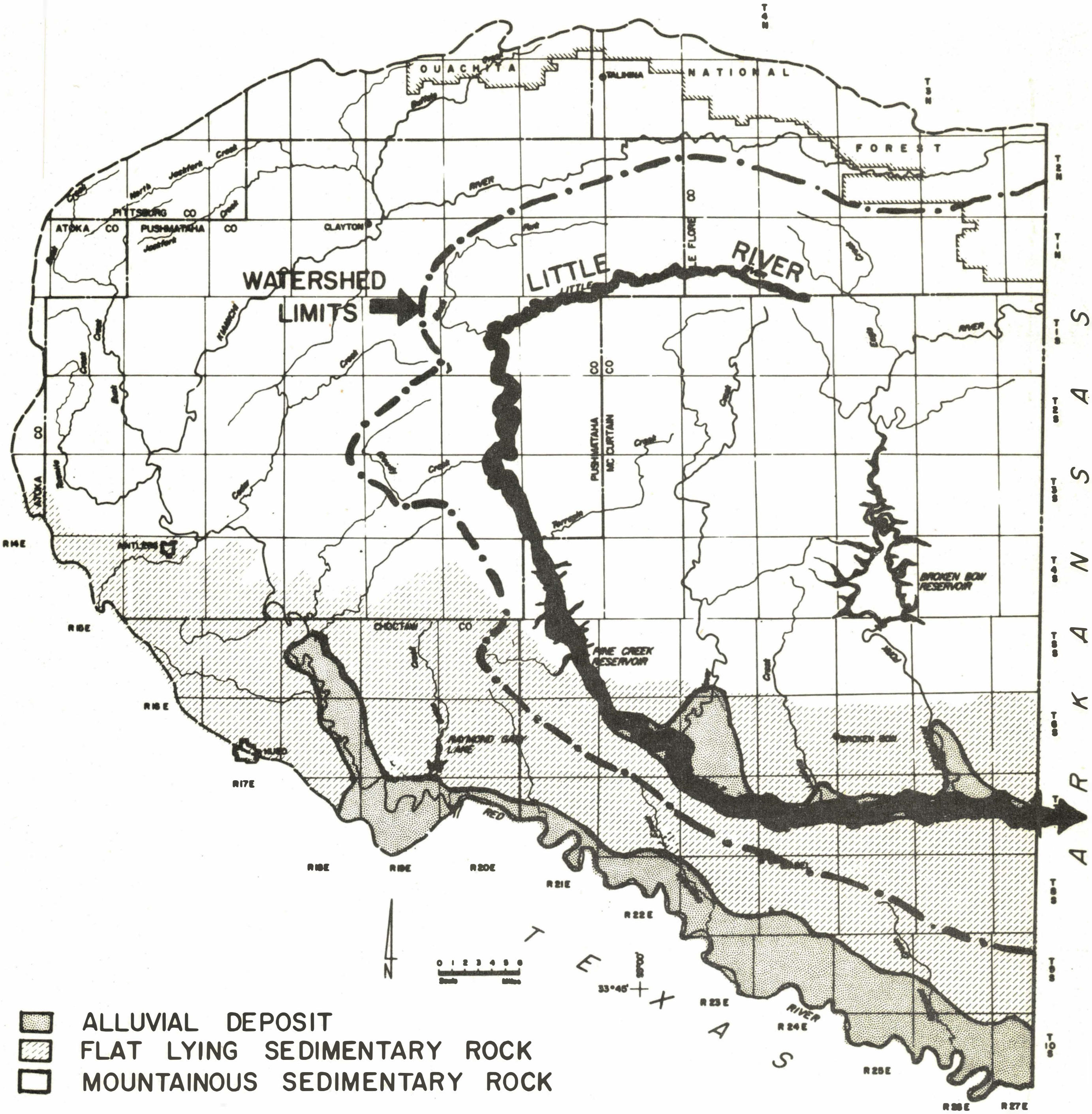


Figure 6. Little River watershed showing general geology.

compression (T 208-70), direct shear (T 236-72), and consolidation (T216-74). The boring was advanced utilizing 7 1/4 in OD, 3 3/4 in ID (184mm OD, 95mm ID) hollow stem augers (T 251-77). Inclinometers were installed using both grout and dry sand procedures (T 254-78).

Retrieving undisturbed samples of the soft silty sediments below the water table presented a considerable challenge. A three inch (76 mm) sharp edged thin wall tube was used for sampling. The tube was attached to a stationary piston sampler. After gaining experience with the sampling procedure, very soft materials could be brought to the surface. Often the materials would liquefy when attempts were made to extract the sample from the tube.

A pocket penetrometer was utilized immediately after withdrawal from the bore hole. The ends of the tubes were trimmed and the penetrometer placed against the soil at the end of the tube. In the softer samples, no movement of the gage was attained. The penetronometer entered the soil with little or no resistance. In many cases, the soils were too soft to utilize the pocket penetrometer.

STREAM CHARACTERISTICS

Verdigris River

The Verdigris River is a 345 mile (555 km) long stream beginning in the gently rolling hills of eastern Kansas and draining southward into the Arkansas River near Muskogee in eastern Oklahoma (17). The geology of the watershed upstream of the study sites consists mostly of gray shales with a considerable amount of limestone. The stream gradient is low, averaging about 2.0 ft/mile (0.37 m/km) in Kansas becoming about 1 ft/mi (0.19m/km) or less as it approaches the study sites.

The flood plain at the study sites is 2-3 miles (3.2-4.8 km) wide. Here, the stream shows characteristics of late maturity and early old age. Much of the flood plain contains oxbow lakes, cutoff meanders, and back swamps. The watershed area above the study sites is about 9,000 mis^2 (23,300 km^2). A peak discharge of 224,000 ft^3/sec (6,340 m^3/sec.) occurred on May 21, 1943. Since 1963 the flow rate at the study sites has been controlled by the Oologah Lake Dam. Peak discharges prior to the construction of Oologah Lake were mostly in the 30,000 - 50,000 ft^3/sec (850 - 1416 m^3/sec) range. The average daily discharge is about 600 ft^3/sec (17 m^3/sec.).

The Verdigris River alluvium averages 41 ft (13 m) in thicknesss and ranges from 34 ft (10 m) to 45 ft (14 m) in five borings. The soil in the upper portions of the alluvium is predominately silty in particle size, mostly CL ranging to CH in the Unified Classification system. The lower meter(s) or so commonly contains gravel and sand mixtures classified as GP. The boundary with the underlying bedrock is usually abrupt with only a thin layer, 4 to 6 inches (100 to 150 mm) thick, of a weathered zone present just above a firm dry shale.

Little River

The Little River is a 217 mile (349 km) long stream beginning in the Ouachita mountains of southeastern Oklahoma and draining south then east into the Red River in southwestern Arkansas near Fulton. The geology of the watershed upstream of the study sites consists mostly of the steeply tilted sandstones and shales of the Ouachita mountains. The stream gradient above site No. 6 is about 8 ft/mi (1.5m/km), the gradient at the remaining sites averages much less as Little River traverses flat lying geological formations. The stream gradients in the flat lying areas approach 1 ft/mi (0.19m/km.). The gradient in the study area ranges from 1/2 to 2 ft/mi (0.1 m/km to 0.38 m/km). The stream shows youthful characteristics in the upper portion of the watershed but abruptly exhibits mature to late maturity characteristics where the gradients are less. The watershed area above the study sites ranges from 645 $mi.^2$ (1671 km^2) at Site No. 6 to about 2,000 mi^2 (5 180 km^2) at Sites 7 & 9.

A peak discharge of 86,000 ft^3/sec (2,435m^3/sec) was observed in February 1938. Average daily discharge is 400 ft^3/sec (11 m^3/sec) prior to completion of Pine Creek Reservoir in 1969 (16).

The Little River alluvium averages 40 ft (12 m) in thickness, ranging from 32 ft (10 m) to 53 ft (16 m) in four borings. The soil in the upper portions of the alluvium is silty to clayey in particle size, mostly CL and CH ranging to SM and GP. The alluvium of the Little River is generally more variable than that of the Verdigris River. This is probably due to higher gradients of up to 13 ft/mi (2.5 m/km) in the upper reaches of the drainage areas.

GROUND WATER LEVELS

In the bore holes at the clayey Osage and Kaufman soil sites, the water tables remained fairly close to the surface throughout 1978. The Osage soil showed water levels ranging from 4.5 ft (1.4 m) to 5.5 ft (1.7 m). The Kaufman soil showed water levels ranging from 3.0 ft (0.9 m) to 13 ft (4.0 m).

The silty Verdigris and Rexor soils exhibited deeper water tables. The Verdigris soil showed water levels ranging from 11.0 ft (3.4 m) to 19.5 ft (5.9 m). The Rexor soil showed water levels ranging from 24.0 ft (7.3 m) to 25.5 ft (7.8 m).

SOIL CHARACTERISTICS

Variability Reflected by Classification Systems

One of the major objectives of this study concerns the characterization of the variability of inorganic alluvial sediments. Three aspects of variability are considered to be pertinent. One concerns the variability in a vertical direction, the second concerns the variability between geographic locations in the same river valley, and the third concerns the differences between two river valleys. Since particle sizes are fundamental properties of soils, considerable effort will be devoted toward showing the relationships of particle size to bearing capacities and other engineering characteristcs. Appendix B contains particle size comparisons and definitions of soil classes.

Significant Soil Properties

Miller, McCormack, and Talbot (8) have shown that certain soil properties are more variable within soil taxonomic units than others. For instance, soil color is the least variable property while plasticity index is much more variable. The implication here is that if the practicing engineer is contemplating the use of pedological surveys, he should determine which soil property will be pertinent for his use. Then proceed with a sampling/testing program based on the known degree of variability of the desired property. For example, fewer borings would be required for determining soil color than for soil plasticity. Tables C1 through C8 in Appendix C show the relationships between the soil properties.

Liquidity Index

The liquidiity index (LI) is defined as the ratio of the natural water content of the soil, minus the plastic limit to the plasticity index. Many of the soil layers in the Verdigris River borings exhibit LI in excess of 1.0. This places the particular soil layers into a class of material sensitive to disturbances. Such layers possess natural moisture content above the liquid limit. According to Grim (6), rapidly deposited sediments may be in a flocculated state. This would render a condition of high void ratios, especially if sufficient quantities of the sodium ion were present. Flood plain environments would favor conditions of rapid as well as slow deposition. Therefore, this condition should be present at the study sites. It may be that layers of high LI soils could exhibit fairly rapid consolidation or collapse under light to moderate loads in neighborhood of 1,000 psf (48 kPa) or less.

Classification

When comparing the U.S. Department of Agriculture soil classes and the Unified classes, the differences in classes and their derivation is significant. The USDA classes are derived from particle sizes alone while the Unified classes involve Atterberg limits as well as certain particle sizes. The USDA classes are more sensitive to changes in particle size but the Unified classes may be more convenient for engineering design purposes. Appendices C and D show the relationship of the classification systems to bearing capacities.

The USDA classes in the tables show how deep the surficial soil characteristics extend. When reviewing USDA particle sizes with depth, the more finely grained Osage and Kaufman soils retain their character more deeply than do the coarser Verdigris and Rexor soils. For detailed descriptions of the soil series, see Appendix A. A possible explanation may be that a higher energy depositional environment at the Verdigris and Rexor soil sites produced a higher degree of variation with depth. Note that the weakest bearing capacities are associated with the CL (clay loam) and SICL (silty clay loam) USDA classes.

The Unified classifications show that the weakest soils fall mostly into the CL class. Occasionally, some ML and ML-CL classes also appear to be weak. It is also worth noting that the CL class spans a considerable range in bearing capacites.

It appears that the USDA classes offer the better indication of weak soil layers.

There is a tendency for the CL (Unified) and SICL (USDA) classes of soil to exhibit weak strengths. The clayey (CH) and the sandy (SM, SL) soils possess more strength and stability. It appears that soils with less than 10 percent sand, more than 60 percent silt, and 30 percent or less clay are the weakest. This weakness may be due to the type of microfabric developed during deposition of this particle size class (9).

Fabric

The term fabric refers to the arrangement of particles, particle groups and pore spaces in soils. Many investigators (3, 4, 9) are aware that silty clay alluvial deposits seldom develop single grain fabrics. Silt size particles in slowly sedimented regimes may develop void ratios up to 2.2 (9). The arrangements of the grains and grain assemblages are such that very large pores like Collins and McGowns's (3) transassemblage pores are generated. See Figure 7. Fabrics such as these may be metastable and subject to sudden collapse or liquefaction.

Dudley says most collapsing soils have liquid limits below 45 and plasticity indicies below 25. He also notes that a small amount of clay contributes to the magnitude of total collapse.(4)

In this study it appears as if conditions for soil collapse are present. When clay percentages decrease below 30 percent with sand less than 10 percent, the soils become weak. This is probably due to the specific sizes and shapes of the grains in combination with an alluvial depositional environment producing a metastable fabric.

The layers which were too sensitive to sample probably contain the weakest and most unstable soils. Hence, such layers may be the cause of considerable settlement.

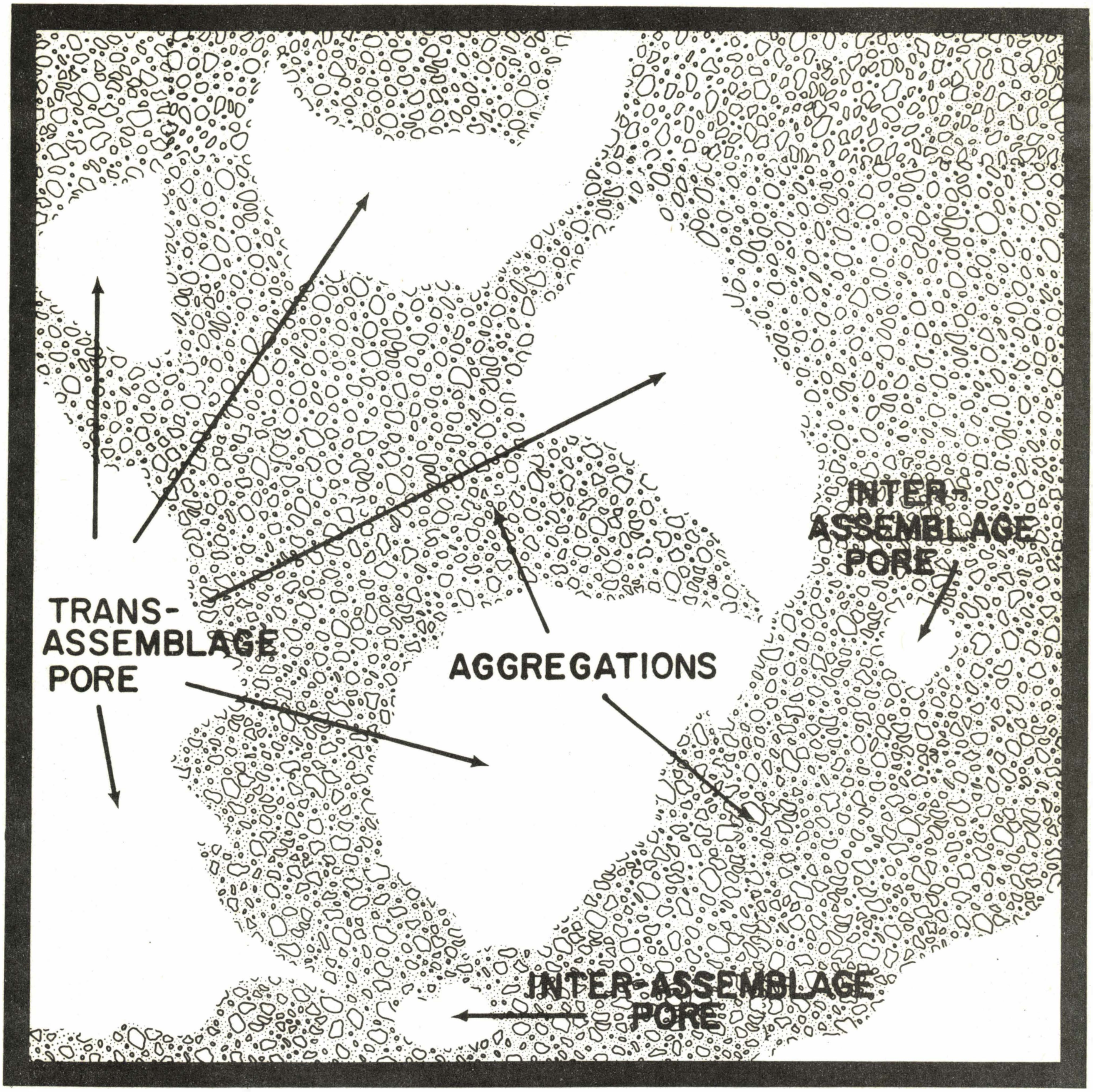


Figure 7. An illustration of microfabric of a fresh water alluvial silty clay. Taken from Collins & McGown, 1974. The assemblages contain mostly silt grains "cemented" with clay.

Creep

Creep is a time-dependent deformation and stress relaxation phenomenon. It is influenced by such items as soil type, structure, stress history, drainage, fabric, and others. Quite often the strain rate is low and can possess periods of primary, secondary, and tertiary phases of movement.(9)

Inclinometers were installed in embankments and adjacent to the embankments at the toe of the fill slope to determine creep rates. They were installed by boring through the entire thickness of the alluvium into the underlying bedrock. They were placed with both grout and sand backfill.

Initially, it was planned to utilize grout for all the holes, but this could not be accomplished with the equipment at hand. Grouting would be the best method due to the slow rates of movement expected from creep conditions. However, grouting was used on only two holes due to a failure of the grout pump. A vibrated fine sand backfill was subsequently used.

Creep movements, if they had existed at the installation sites, could have been as slow as 0.05 ft (4 mm) per year. The settlement of backfill sand seems to have affected inclinometer readings for several weeks. This situation would have masked small motions of the soil. Considerable effort should be expended to obtain a well grouted installation, avoiding the use of sand backfill.

So far, there is no conclusive evidence of creep movement. Four inclinometers were installed at the base of embankments. It is thought that since nine years have passed since construction of the fills, the rate of creep movement if it exists, would be very small. Installations may have to be observed for perhaps three to five years to detect creep type movements.

Bearing Capacities

The silty Verdigris and Osage soil sites exhibit soil layers of weak bearing capacity. The clayey Kaufman and sandy Rexor sites do not contain as many weak layers. See Appendices C and D.

The laboratory strength tests on undisturbed samples included the direct shear and unconfined compression tests. The compression tests yielded the lowest strength values. It is thought that these values are more realistic and indicative of actual conditions than the direct shear values, based on other investigations and experience in Oklahoma.

The bearing capacity was derived from unconfined compression tests as follows:

$$S_{\mu} = \frac{q_{\mu}}{2}$$

Where S_{μ} = bearing capacity

q_{μ} = unconfined compression values

The direct shear tests rendered results which need some explanation. It is thought that even under the tenderest care, the test specimen was probably somewhat disturbed when tested. The applied normal pressure probably caused the metastable fabric to collapse. Thus the test would be run on soil that was disturbed. This condition should develop considerable interlock strength due to the high percentage of durable quartzose silt grains in the weak layers.(9) This composition is similar to the sand sized grains and these durable particles should develop high interlock strength.

The bearing capacity was derived from direct shear tests as follows:

$$S_{\mu} = c + \sigma_n \tan \emptyset$$

where S_{μ} = bearing capacity

c = cohesion

σ_n = depth x unit weight (wet)

$\emptyset$ = friction angle

Some of the layers were so easily disturbed that no sample could be brought to the surface in an undisturbed condition. Interpolations were utilized in the tables where the boring logs indicated similar soil material. Also, bearing capacity values were generated using the standard penetration test when the soils became cohesionless.

Settlement

Four fills placed on the Verdigris and Osage soils in Rogers and Wagoner Counties show some signs of settlement. In all the observed cases, bridge approach slab and/or abutment rotation is occurring. Fills as low as 17 ft (5.1 m) are exhibiting settlement in excess of 0.2 ft (60 mm)

Two fills placed on Kaufman and Rexor are not observed to be settling to any appreciable degree.

Settlement has been calculated for the soil condition at Boring No. 5. This site is Verdigris soil at the surface and contains a considerable thickness of weak silty soil. The settlement problem is described in Appendix E.

Geographic Variation

The variation between the same soil units in the same river flood plain is not great. For example, the silty Verdigris soil in the Verigris flood plain exhibits similar character with depth. Borings No. 4 and No. 5 show 28 ft (8.5 m) and 31 ft (9.4 m) respectively of predominantly silty soil. Also, the clayey Kaufman soil in the Little River flood plain exhibits similar character with depth. Borings No. 7 and No. 8 shows 20 ft (6.1 m) and 26 ft (7.9 m) respectively of predominantly clayey soil.

The variation in soil characteristics between river systems is considerable. The Verdigris River is a sluggish stream draining fine grained sedimentary rocks. The Little River is a faster flowing stream draining more granular sedimentary rocks but spilling out onto an area of flat lying sedimentary rocks. The composition of the source rocks for the alluvial deposit are not the same. Therefore, the quality of the sediment should be different. These differences can be observed in the surficial two meters of soil that soil scientists are able to map. In the eight cases studied for this report, the surficial characteristics extended downward 23 percent to 86 percent of the total thickness of the alluvial soil deposits.

CONCLUSION

Pedological soil surveys can serve as an indicator of engineering characteristics in alluvial soils. Map units indicating weak, silty (CL) soils can serve as a warning of potential problems even at considerable depths.

The hydraulic conditions causing deposition of the surficial soil appear to have been similar to those of lower layers. There is a strong tendency for the soil particle size class to remain the same for some considerable depth.

The differences in conditions from stream to stream are reflected in the difference in soil names. The different soil engineering characteristics are derived mostly from differences in sediment sources and stream gradients.

Pedological surveys can serve as a useful tool in preliminary planning and foundation investigation schemes.

Settlement occurs on many of the fills over silty soils that exceed 30 ft (9 m) in height. Lean clay to silty foundation soils seem to be significant contributors to embankment settlement near bridges. Detailed borings are required to determine the quantity and quality of the alluvial materials at a particular site. Undisturbed sampling and extensive penetration testing should be required in these areas so that accurate settlement calculations may be made. Once this is known, design decisions can be made concerning embankment geometry and construction procedures.

RECOMMENDATIONS

County pedological survey reports should be utilized when determining roadway alignments on flood plains. Mapped surficial soils can serve in developing a foundation investigation. A soil survey indicating the presence of a weak soil should serve as a warning to design and construction engineers; so that proper procedures can be employed to prevent or reduce the effects of weak soil layers.

It is important that soils information be included in the roadway building sequence as early as possible. Pedological information should be available to preliminary project planners so that proper decisions can be made as to alignments, structures, etc., that will be required for a given project.

The interpretations made from pedological surveys must be accurate. People trained in the sciences of agronomy or geology are necessary for accurate and precise interpretations.

Further work should be done on other flood plain soils to confirm the relationship of named map delineations to the soil character at lower depths. This work should emphasize the characterization of extensive problem soils. Also, a data bank should be compiled based on present routine foundation investigations. This data may show the relationship of many mapped soil series with the character of the alluvium with depth.

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APPENDIX A

SOIL DESCRIPTIONS

Established Series
Rev. PK-ELF-LEB
9/5/78

VERDIGRIS SERIES

The Verdigris series consist of deep, well drained or moderately well drained soils that formed in silty alluvium. These soils are on flood plains.

Taxonomic Class: Fine-silty, mixed, thermic Cumulic Hapludolls.

Typical Pedon: Verdigris silt loam - in a cultivated field. (Colors are for moist soil unless otherside stated.)

Ap - 0 to 7 inches; very dark brown (10YR 2/2) silt loam, very dark grayish brown (10YR 3/2) dry; weak medium granular structure; slightly hard, friable; medium acid; abrupt smooth boundary.

A12 - 7 to 28 inches; very dark brown (10YR 2/2) silt loam, very dark grayish brown (10YR 3/2) dry; moderate medium granular structure; slightly hard, friable; scattered worm casts; slightly acid; gradual smooth boundary. (Combined thickness of the A horizon is 11 to 34 inches.)

AC - 28 to 46 inches; dark brown (10YR 3/3) silt loam, brown (10YR 4/3) dry; weak medium granular structure; slightly hard, friable; scattered worm casts; slightly acid; gradual smooth boundary. (9 to 30 inches thick.)

C - 46 to 60 inches; brown (10YR 4/3) silt loam, brown (10YR 5/3) dry; few fine faint yellowish brown (10YR 4/4) mottles; massive; slightly hard, friable; few fine pores; slightly acid.

Type Location: Montgomery County, Kansas; about 1 mile west of Elk City on the flood plain west of the Verdigris River; 2,200 feet south and 2,300 feet east of the NW corner of sec. 5, T. 32 S., R. 14 E.

Range in Characteristics: The thickness of the solum ranges from 24 to 60 inches. Free carbonates are lacking within depths of 50 inches. Reaction of these soils, to depths of 50 inches, ranges from medium acid to neutral. In some pedons faint mottles with colors of higher chroma or lower value or both are below depths of 20 inches.

The A horizon has hue of 7.5YR to 2.5Y, value of 2 or 3 to 5 dry, and chroma of 1 to 3. It is silt loam, loam, or silty clay loam.

The AC horizon has color like the A1 horizon. It is silt loam or silty clay loam.

The C horizon has hue of 7.5YR to 2.5Y, value of 3 to 6 and 4 to 7 dry, and chroma to 2 to 4. It commonly is silt loam or silty clay loam, but in some pedons below depths of 40 inches it is sandy loam, loam, clay loam, or silty clay. In some pedons dark-colored A1b horizons are below the C horizon.

Competing Series: These are the Arrington and Redport in the same family and the Cleora, Frioton, Gowton, Lynnville, Radley, and Staser series. Arrington soils are in a wetter climate. Redport soils have free carbonates below depths of 10 inches and subsoils with hue of 2.5YR and 5YR. Cleora soils are in the coarse loamy family. Frioton soils are in the fine family. Gowton and Staser soils are in the fine-loamy family. Lynnville and Radley soils have mollic epipedons less than 24 inches thick.

Geographic Setting: Verdigris soils are on flood plains. The slope gradient commonly is less than 1 percent, but the range is 0 to 2 percent. The soils formed in silty alluvium. The mean annual temperature varies from 57° to 65° F, and the mean annual precipitation varies from 35 to 47 inches. Thornthwaites annual P-E index ranges from 62 to 82.

Geographically Associated Soils: These are the competing Cleora and Radley soils and the Lightning, Mason, Osage, and Wynona soils. Cleora and Radley soils are on nearby lower areas. Mason soils have an argillic horizon and are on higher areas. Lightning, Osage, and Wynona soils are on slightly lower areas and are more poorly drained.

Established Series
Rev. JHL-HEH
1/25/74

OSAGE SERIES

The Osage series is a member of the fine, montmorillonitic, thermic family of Vertic Hadlaquolls (tentative). These soils typically have very dark brown and black silty clay A horizons, mottled very dark gray silty clay B2g horizons and mottled dark gray silty clayey B3g horizons.

<u>Typifying Pedon</u> Osage silty clay - cultivated

(Colors are for moist soil.)

Ap - 0 to 4 inches; very dark brown (10YR 2/2) silty clay; strong very fine granular structure; firm; sticky, plastic; many roots; strongly acid; abrupt smooth boundary. (4 to 9 inches thick)

A12 - 4 to 9 inches; black (10YR 2/1) silty clay; strong fine angular blocky structure; very firm, very hard, very sticky, plastic; many fine roots; strongly acid; gradual smooth boundary. (4 to 7 inches thick)

A13 - 9 to 15 inches; black (10YR 2/1) silty clay; few fine faint very dark gray (N 3/0) mottles; moderate fine angular blocky structure; extremely firm; extremely hard, very sticky, plastic; common fine roots; medium acid; gradual smooth boundary. (5 to 10 inches thick)

B21g - 15 to 27 inches; very dark gray (5Y 3/1) silty clay; many fine faint very dark grayish brown (2.5Y 3/2) and very dark gray (N 3/0) mottles; weak fine and medium angular blocky structure; extremely firm, extremely hard, very sticky, plastic; few fine roots; very few fine concretions; few slickensides; slightly acid; gradual smooth boundary. (10 to 30 inches thick)

B22g - 27 to 42 inches; very dark gray (5Y 3/1) silty clay; common medium distinct olive brown (2.5Y 4/4) and few fine faint dark gray (5Y 4/1) mottles; dark grayish brown (2.5Y 4/2) rubbed; moderate fine angular blocky structure; extremely firm, extremely hard, very sticky, plastic; common fine soft concretions and dark brown stains; common slickensides; slightly acid; diffuse smooth boundary. (0 to 25 inches thick)

B3g - 42 to 60 inches; dark gray (N 4/0) silty clay; common medium distinct olive brown (2.5Y 4/4) mottles; weak medium angular blocky structure; extremely firm, extremely hard, very sticky, plastic; common concretions as in the B22g horizon; common slickensides; slightly acid.

Type Location: Vernon County, Missouri; 100 feet north and 100 feet east of the center of Sec. 35, T. 38 N., R. 31 W.

Range In Characteristics: The thickness of sola ranges from 40 to 60 or more inches. Mean annual soil temperature is estimated to range from 50 to 65^{o}F. The A horizon has 10YR or 2.5Y hue, value of 2 or 3, and chroma of 1 or 2. The A horizons range from clay to silty clay loam and from strongly acid to neutral.

Color value of rubbed soil is 3.5 or less to depths of 24 to 40 inches. Typically the 10 to 40 inch control section averages 46 to 60 percent clay but some pedons have as little as 35 percent clay and sand is less than 5 percent. The upper part of the B horizon has hue of 10YR through 5 Y or neutral, value of 3 and chroma of less than 2 and faint mottles. The lower part of the B horizon has hue of 2.5Y, or neutral, value of 3 through 5 and chroma of 1.5 or less and mottles of higher chroma. The B horizon ranges from medium acid to neutral in the upper part and from slightly acid to mildy alkaline in the lower part. Some pedons have free calcium carbonates below about 36 inches and many contain gypsum crystals in the lower part of the B horizon.

Competing Series and Their Differentiae: These are the Iberia, Kaman and Roellen soils in the same family and the Alligator, Bernard, Darwin, Lake Charles, Portageville, Sharkey, Summit, Trinity, Tunica, Wabash and Zook. Iberia, Portageville, Roellen, Sharkey, Trinity, and Tunica soils have mollic epipedons less than 24 inches thick, and in addition the Tunica soils have coarser texture below depths of 20 to 36 inches. Kaman soils have a warmer and wetter climate. Alligator soils lack mollic epipedons and have lighter colored more acid B horizons. Bernard and Summit soils have argillic horizons. Darwin, Wabash and Zook soils have mean annual temperature of less than 59^{O}F. Lake Charles soils have intersecting slickensides. Portageville and Trinity soils contain free carbonates at depths of 10 inches or less.

Setting: Osage soils are on nearly level flood plains along major streams. They are formed in thick clayey alluvium. Slope gradients range from 0 to less than 2 percent. Near the type location the average annual precipitation is 39 inches; average July temperature is 80^{O}F ., and average January temperature is 34^{O}F.

Principal Associated Soils: The coarser textured Cleora, Hepler, McCune, and Verdigris soils and the lighter colored soils are on nearby flood plains or low terraces, the Barco, Barden, Bates, Cherokee, Dennis, Lula, Parsons, Summit, and Zaar soils are on nearby uplands.

Drainage and Permeability: Poorly drained. Runoff is slow or very slow. Permeability is estimated to be very slow.

Use and Vegetation: Most areas are cultivated to wheat, soybeans and corn. Native vegetation was mostly deciduous hardwoods and understory of grass.

Distribution and Extent: Southwestern Missouri, Southeastern Kansas and Eastern Oklahoma. The series is moderately extensive.

Series Established: Bates County, Missouri, 1908.

Remarks: The Osage soils were formerly classified as Alluvial soils. Laboratory studies are needed to firm up mineralogy class, the clay mineralogy is questioned for mixed.

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Established Series
Rev. CMT/DDR
9/74

KAUFMAN SERIES

The Kaufman series is a member of the very-fine, montmorillonitic, thermic family of Typic Pelluderts. These soils have black A horizons and very dark gray mottled AC horizons.

Typifying Pedon: Kaufman clay - pasture.
(Colors are for moist soil unless otherwise stated.)

A11 - 0 to 6 inches, black (10YR 2/1) clay; weak and moderate coarse blocky structure parting to moderate medium blocky structure; extremely hard, very firm, sticky and plastic; many fine roots; common very fine pores; few worm casts; peds have shiny faces; slightly acid; diffuse smooth boundary. (2 to 8 inches thick)

A12 - 6 to 19 inches, black (10YR 2/1) clay; moderate fine and medium blocky structure; extremely hard, very firm, sticky, and plastic; common fine roots and very fine pores; few slickensides 1 to 2 inches wide; peds have shiny faces; slightly acid; diffuse wavy boundary. (10 to 30 inches thick)

A13 - 19 to 35 inches, black (10YR 2/1) clay; few fine distinct brown mottles; moderate coarse blocky structure parting to moderate medium blocky structure; extremely hard, very firm, sticky and plastic; few fine roots and very fine pores; few black concretions 2 to

4 mm in diameter; few grooved intersecting slickensides 1 to 3 inches wide; slightly acid; diffuse wavy boundary. (0 to 22 inches thick)

AC1g - 35 to 50 inches, very dark gray (10YR 3/1) clay; common fine distinct olive brown mottles and few fine distinct brown mottles; moderate coarse blocky structure parting to moderate medium blocky structure; extremely hard, very firm, sticky and plastic; few fine roots mostly confined to surfaces of slickensides; few very fine pores; common grooved intersecting slickensides 3 to 6 inches across; few black concretions 2 to 4 mm in diameter; slightly acid; diffuse wavy boundary. (12 to 25 inches thick)

AC2g - 50 to 69 inches, very dark gray (10YR 3/1) clay; few fine distinct dark yellowish brown mottles; moderate coarse blocky structure parting to moderate medium blocky structure; extremely hard, very firm, sticky and plastic; few fine roots mostly on faces of slickensides; few very fine pores; many grooved intersecting slickensides 2 to 10 inches wide tilted at a 45 to 60 degree angle; few black concretions 1 to 4 mm in diameter; slightly acid; diffuse wavy boundary. (15 to 25 inches thick)

AC3g - 69 to 84 inches, very dark gray (10YR 3/1) clay; moderate coarse blocky structure parting to moderate medium blocky structure; extremely hard, very firm, sticky and plastic; many grooved intersecting slickensides 2 to 10 inches wide tilted 25 to 45 degrees; few black concretions 1 to 3 mm in diameter; mildly alkaline.

Type Location: Delta County, Texas; about 4.6 miles east on State Highway 154 from Cooper, Texas, to its intersection with State Highway 19; 3.2 miles east and south on Highways 154 and 19 to the intersection of Farm Road 1536; 3.1 miles east and south on Farm Road 1536; to its intersection with Farm Road 71; 5.0 miles northeast on Farm Road 71 to its intersection with Farm Road 69; 2.6 miles north on Farm Road 69 and continuing on a county road to a bridge on the south Sulphur River; 0.65 mile north on private road and 50 feet west of the road.

Range in Characteristics: The soil is medium acid through mildly alkaline and is calcareous below depths of 24 inches in a few pedons. Undisturbed areas have subdued gilgai, with micro-highs 2 to 6 inches higher than micro-lows.

The A horizon is black (10YR 2/1; N 2/ ; 5Y 2/1) or very dark gray (10YR 3/1; N 3/ ; 5Y 3/1). In some pedons, the A horizon is free of mottles; in others, some part of the A horizon has common fine and medium yellow, brown, and olive mottles. Depth to moist values of 4 or more is greater than 20 inches. The A1 horizon is clay or silty clay. The 10 to 40 inch control section is clay with clay content ranging from 60 to 80 percent. Intersecting slickensides begin about 16 to 32 inches below the surface. The extremes of amplitude or waviness of the boundary between the A and the ACg horizons vary from 6 to 20 inches.

The ACg horizons are very dark gray (10YR 3/1; N 3/ ; 5Y 3/1), dark gray (10YR 4/1; N 4/ ; 5Y 4/1), or gray (10YR 5/1 N 5/ ; 5Y 5/1). In some pedons these horizons have few to common calcium carbonate concretions and are mottled in yellow, brown, and olive.

Competing Series and their Differentiae: These are the Alligator, Eutaw, Fausse, Griffith, Hollywood, Iberia, Lake Charles, Osage, Perry, Roellen, Sharkey, Terouge, and Trinity series. Alligator, Fausse, Perry, Sharkey, and Terouge soils lack intersecting slickensides. Eutaw soils have moist values of more than 3.5 within 12 inches of the soil surface. Griffith, Hollywood, Iberia, Lake Charles, Osage, and Roellen soils have less than 60 percent clay within the control section. Trinity soils are calcareous throughout.

Setting: Kaufman soils are on level to gently sloping flood plains of streams draining Blackland Prairies. Slopes are mainly less than 1 percent; some are as much as 3 percent. The soil is formed in alkaline clayey recent sediments. Climate is warm-humid to moist subhumid. Average annual precipitation ranges from 35 to 50 inches, average annual temperature is about 62° to 70° F., and annual Thornthwaite P-E indices exceed 50.

Principal Associated Soils: These are the competing Trinity and Terouge series, and the Burleson, Catalpa, Crockett, Deport, Graner, Gladewater, Gowen, Heiden, Houston Black, Leson, Tuscumbia, and Wilson series. Burleson, Crockett, Deport, Garner, Heiden, Houston Black, Leson, and Wilson soils have fine textured control sections. Catalpa and Gowen soils have chroma of 2 or more in layers below the A horizon. In addition, Catalpa and Gowen soils have chroma of 2 or more in layers below the A horizon. In addition, Catalpa soils are in a fine family and Gowen soils are in a fine-loamy family. Gladewater and Tuscumbia soils have dark A horizons less than 10 inches thickand are in a fine family.

Drainage and Permeability: Somewhat poorly drained; slow surface runoff; very slow permeability. Water enters the soil rapidly when it is dry and cracked and very slowly when it is wet.

Use and Vegetation: Most cleared areas are in pasture of dallis grass, bermudagrass, and fescues. A few areas are used for cotton, corn sorghums, and soybeans. Native vegetation is hardwoods such as elm, hackberry, oak, ash, and grasses such as species of andropogon, paspalum, panicum, and tripsacum.

Distribution and Extent: Flood plains of streams draining Blackland Prairies from Texas to Alabama. The series is extensive.

Series Established: Hunt County, Texas; 1934.

Remarks: Kaufman soils were formerly classified in the Alluvial great soil group.

Addition Data: Engineering Test Data prepared by the Texas Highway Department from type location.

		Percent passing sieve:				Percent smaller than:			
Report No.		40	60	200	0.05mm	0.005mm	0.002mm	LL	PI
73-108-R	19-35"	99	99	95	92	77	68	80	54
73-109-R	50-69"	--	100	97	94	82	76	94	68
73-110-R	69-84"	--	100	96	93	82	75	89	64

National Cooperative Soil Survey
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Established Series
Rev. JWF
3/79

REXOR SERIES

The Rexor series consists of deep, well drained, moderately permeable soils that formed in loamy alluvium. These soils are on nearly level flood plains of the Ouachita Mountains, Arkansas Valley and Ridges, and the Southern Coastal Plain land resource areas. Slopes are 0 to 1 percent. Mean annual temperature is 63^{O}F, and mean annual precipitation is 50 inches.

Taxonomic Class: Fine-silty, siliceous, thermic Ultic Hapludalfs.

Typical Pedon: Rexor loam, in pasture.
(Colors are for moist soil unless otherwise stated.)

A1 - 0 to 10 inches; brown (10YR 4/3) loam; weak fine granular structure; friable; many fine roots; medium acid; gradual smooth boundary. (7 to 10 inches thick)

B21t - 10 to 36 inches; yellowish brown (10YR 5/4) clay loam; moderate medium and fine subangular blocky structure; friable; patchy thin clay films on faces of peds; dark brown (7.5YR 4/4) coatings on faces of peds; strongly acid; gradual smooth boundary. (8 to 28 inches thick)

B22t - 36 to 48 inches; strong brown (7.5YR 5/6) clay loam; common fine and medium distinct light brownish gray (10YR 6/2) mottles; weak coarse and medium subangular blocky structure; thin patchy clay films on faces of peds; friable; strongly acid.

Type Location: McCurtain County, Oklahoma. About 4 miles north and 1 mile east of Millerton, Oklahoma; 50 feet west and 150 feet north of the southeast corner of Sec. 23, T. 6 S., R. 22 E.

Range in Characteristics: Solum thickness is 35 to 80 inches. Reaction is medium acid to very strongly acid in all horizons.

The A horizon is brown (10YR 4/3), dark brown (7.5YR 3/2, 4/2), very dark grayish brown (10YR 3/2), or dark grayish brown (10YR 4/2). Texture is loam o silt loam. A1 horizons that have moist color value darker than 3.5 are less than 6 inches thick.

The B2t horizon is brown or dark brown (10YR 4/3, 5/3; 7.5YR 4/4, 5/4), strong brown (7.5YR 5/6, 5/8), dark yellowish brown (10YR 4/4) or yellowish brown (10YR 5/4, 5/6, 5/8). It is loam, silt loam, clay loam, or silty clay loam. The average clay content of the upper 20 inches of the B2t horizon ranges from 20 to 35 percent. Some pedons have a few mottles in shades of brown in the upper B2t horizon and the lower B2t horizon have few through many coarse, medium, or fine distinct mottles in shades of gray or brown.

The B3 horizon is brown (7.5YR 5/4), strong brown (7.5YR 5/6, 5/8), yellowish brown (10YR 5/4, 5/6, 5/8), or pale brown (10YR 6/3). Mottles are similar to those in the lower B2t horizon. Texture is loam or silt loam.

Competing Series: This is the Spiro series in the same family and the Armour, Barnsdall, Cowton, Dexter, Dossman, Hicks, Kenn, Neff, Romia, Speer, and Wilburton series in similar families. Armour, Barnsdall, Dexter, Dossman, and Hicks soils have mixed mineralogy and lack a water table within 4 feet of the soils surface. In addition, Dexter and Dossman soils have hue of 5YR or redder in the matrix of the B2t horizon and Hicks soils have phosphatic limestone bedrock within 40 inches of the soils surface. Cowton soils have fine control section. Kenn, Romia, and Speer soils have fine-loamy control section. Neff soils have chroma of 2 in the upper 10 inches of the B2t horizon. Spiro soils have shale bedrock within 20 inches of the soils surface. Wilburton soils have loamy-skeletal control section.

Setting: The Rexor soils are on nearly level floodplains of the Ouachita Mountains, Arkansas Valley and Ridges, and the Southern Coastal Plain land resource areas. They are formed in loamy alluvium. Slopes are 0 to 1 percent. Mean annual precipitation ranges from 40 to 56 inches. Mean annual temperatures range from 60° to 65° F. Thornthwaite annual P-E indices are greater than 64.

Geographically Associated Soils: These are soils of the competing Neff and Speer series and the Cupco, Dela, Frizzel, Guyton, Ochlockonee, and Pushmataha soils. Cupco soils are somewhat poorly drained, have chroma of 1 or 2 as coatings on faces of peds, have water table within 0.5 feet of the surface, and are on slightly lower or concave areas. Dela and Ochlocknee soils have coarse-loamy control section, lack B2t horizons and are adjacent areas. Frizzell soils are somewhat poorly drained, have coarse-silty control section, and are on slightly higher areas. Guyton soils are poorly drained, have chroma of 1 or 2 as coatings on faces of peds, have tongues of A2 horizon extending into the B2t horizon, and are on slightly lower or concave areas. Neff soils are on slightly lower or concave areas. Pushmataha soils are somewhat poorly drained, lack B2t horizons, have coarse-silty control section, and are on slightly lower or concave areas. Speer soils are on higher areas farther from the stream channel.

Drainage and Permeability: Rexor soils are well drianed. Runoff is slow and permeability is moderate. These soils are subject to flooding for very brief periods mainly during November to May. A perched water table ranges from 3 to 5 feet of the soil's surface mainly during November to May.

Use and Vegetation: Most areas have been cleared and are used for tame pasture with small areas used for the production of row crops and small grains. The remaining areas are woodland. Native vegetation is sweetgum, shortleaf pine, white oak, shellbark hickory, loblolly pine, and blackgum with an understory of shrubs.

Distribution and Extent: Ouachita Mountains, Arkansas Valley and Ridges, and Southern Coastal Plain land resource areas of Oklahoma, and possibly Arkansas, Louisiana, and Texas. The series is of limited extent in Oklahoma.

Series Established: McCurtain County, Oklahoma; 1970.

National Cooperative Soil Survey
U.S.A.

APPENDIX B

SOIL CLASSIFICATIONS

U.S. DEPARTMENT OF AGRICULTURE PARTICLE SIZE CLASSES AND DESCRIPTIONS

C--Clay. Soil material that contains 40 percent or more clay, less than 45 percent sand, and less than 40 percent silty. (USDA - smaller than .002 mm).

CL--Clay Loam. Soil material that contains 27 to 40 percent clay and 20 to 45 percent sand.

L--Loam. Soil material that contains 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand.

LS--Loamy Sand. Soil material that contains at the upper limit 85 to 90 percent sand, and the percentage of silt plus 1 1/2 times the percentage of clay is not less than 15; at the lower limit it contains not less than 70 to 85 percent sand, and the percentage of silt plus twice the percentage of clay does not exceed 30.

S--Sand. Soil material that contains 85 percent or more of sand; percentage of silt plus 1 1/2 times the percentage of clay shall not exceed 15. Includes coarse sand, sand, fine sand, and very fine sand. (AASHTO - #200 sieve to #10, USDA - #270 sieve to #10).

SC--Sandy Clay. Soil material that contains 35 percent or more clay and 45 percent or more sand.

SCL--Sandy Clay Loam. Soil material that contains 20 to 35 percent clay, less than 28 percent silt, and 45 percent or more sand.

SL--Sandy Loam. Soil material that contains either 20 percent clay or less, and the percentage of silt plus twice the percentage of clay exceeds 30 to 52 percent or more sand/ or less than 7 percent clay, less than 50 percent silt, and between 43 and 50 percent sand. (This includes fine sandy loam and very fine sandy loam.)

SI--Silt. Soil material that contains 80 percent or more silt and less than 12 percent clay. (USDA - .002 to #270 sieve.)

SIC--Silty Clay. Soil material that contains 40 percent or more clay and 40 percent or more silt.

SICL--Silty Clay Loam. Soil material that contains 27 to 40 percent clay and less than 20 percent sand.

SIL--Silt Loam. Soil material that contains 50 percent or more silt and 12 to 27 percent clay (or) 50 to 80 percent silt and less than 12 percent clay.

Unified Soil Classification System

Primary divisions			Group symbol	Secondary divisions	Laboratory classification criteria		Supplementary criteria for visual identification
Coarse grained soils. (More than half of material is larger than No. 200 sieve size.)	Gravels. (More than half of the coarse fraction is larger than No. 4 sieve size.)	Clean gravels. (Less than 5% of material smaller than No. 200 sieve size.)	GW	Well graded gravels, gravel-sand mixtures, little or no fines.	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3		Wide range in grain size and substantial amounts of all intermediate particle sizes.
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.	Not meeting all gradation requirements for GW.		Predominantly one size or a range of sizes with some intermediate sizes missing.
	...do.......	Gravels with fines. (More than 12% of material smaller than No. 200 sieve size.)[1]	GM	Silty gravels, and gravel-sand-silt mixtures, which may be poorly graded.	Atterberg limits below "A" line, or PI less than 4[2]	Atterberg limits above "A" line with PI between 4 and 7 is borderline case GM-GC	Non-plastic fines or fines of low plasticity.
			GC	Clayey gravels, and gravel-sand-clay mixtures, which may be poorly graded.	Atterberg limits above "A" line, with PI greater than 7		Plastic fines.
Do	Sands. (More than half of the coarse fraction is smaller than No. 4 sieve size.)	Clean sands. (Less than 5% of material smaller than No. 200 sieve size.)	SW	Well graded sands, gravelly sands, little or no fines.	$C_u = \frac{D_{60}}{D_{10}}$ greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3		Wide range in grain sizes and substantial amounts of all intermediate particle sizes.
			SP	Poorly graded sands, gravelly sands, little or no fines.	Not meeting all gradation requirements for SW		Predominately one size or a range of sizes with some intermediate sizes missing.
	...do.......	Sands with fines. (More than 12% of material smaller than No. 200 sieve size.)[1]	SM	Silty sands, and sand-silt mixtures, which may be poorly graded.	Atterberg limits below "A" line, or PI less than 4	Atterberg limits above "A" line with PI between 4 and 7 is borderline case SM-SC	Non-plastic fines or fines of low plasticity.
			SC	Clayey sands, and sand-clay mixtures, which may be poorly graded.	Atterberg limits above "A" line, with PI greater than 7		Plastic fines.

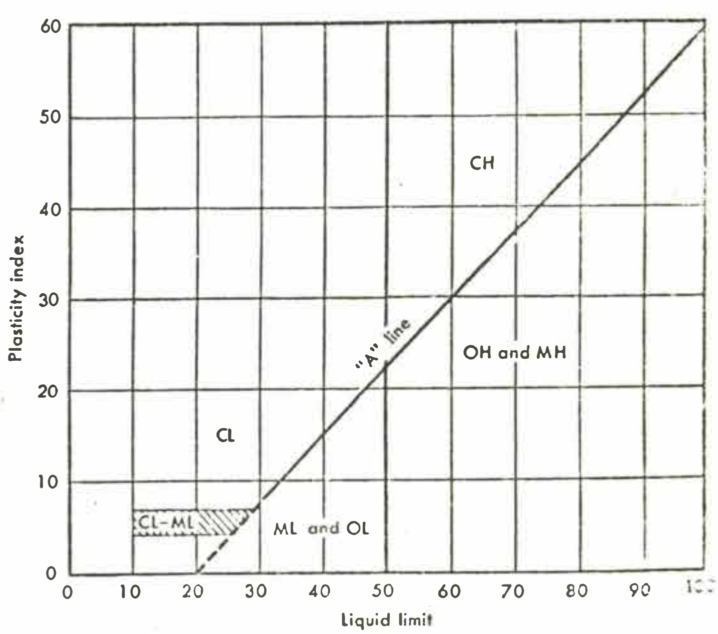
Unified Soil Classification System

Primary divisions		Group symbol	Secondary divisions	Laboratory classification criteria		Supplementary criteria for visual identification: Dry strength	Reaction to shaking	Toughness near plastic limit
Fine grained soils. (More than half of material is smaller than No. 200 sieve size.)	Silts and clays. (Liquid limit less than 50.)	ML	Inorganic silts, clayey silts, rock flour, silty very fine sands.	Atterberg limits below "A" line, or PI less than 4	Atterberg limits above "A" line with PI between 4 and 7 is borderline case ML-CL	None to slight	Quick to slow	None
	... do	CL	Inorganic clays of low to medium plasticity; silty, sandy or gravelly clays.	Atterberg limits above "A" line, with PI greater than 7		Medium, to high	None to very slow	Medium
	... do	OL	Organic silts and organic silt-clays of low plasticity.	Atterberg limits below "A" line		Slight to medium	Slow	Slight
Do	Silts and clays. (Liquid limit greater than 50.)	MH	Inorganic silts, clayey silts, elastic silts, micaceous or diatomaceous silty or fine sandy soils.	Atterberg limits below "A" line		Slight to medium	Slow to none	Slight to medium
	... do	CH	Inorganic clays of high plasticity, fat clays.	Atterberg limits above "A" line		High to very high	None	High
	... do	OH	Organic clays and silty clays of medium to high plasticity.	Atterberg limits below "A" line		Medium to high	None to very slow	Slight to medium
	Highly organic soils	Pt	Peat, meadow mat, highly organic soils.	High ignition loss, LL and PI decrease after drying		Organic color and odor, spongy feel, frequently fibrous texture.		

[1]Materials with 5 to 12 percent smaller than No. 200 sieve are borderline cases, designated: GW-GM, SW-SM.
[2]See Ch. 3, Figure 3-1, for position on plasticity chart.

Unified Soil Classification System

Major divisions			Group symbols	Typical names	Laboratory classification criteria		
Coarse-grained soils (More than half of material is *larger* than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows: Less than 5 per cent..........GW, GP, SW, SP; More than 12 per cent..........GM, GC, SM, SC; 5 to 12 per cent..........*Borderline* cases requiring dual symbols**	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM* d / u	Silty gravels, gravel-sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-clay mixtures		Atterberg limits above "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP	Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM* d / u	Silty sands, sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols.
			SC	Clayey sands, sand-clay mixtures		Atterberg limits above "A" line with P.I. less than 7	
Fine-grained soils (More than half of material is *smaller* than No. 200 sieve)	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 silty 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			

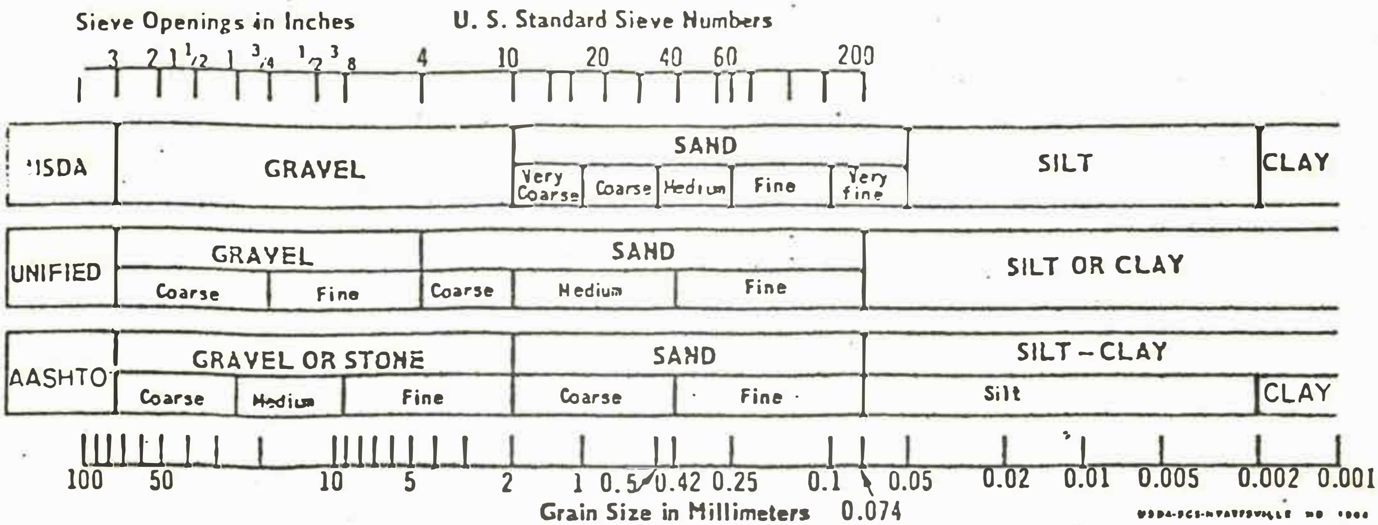


Plasticity Chart

*Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterberg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

**Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

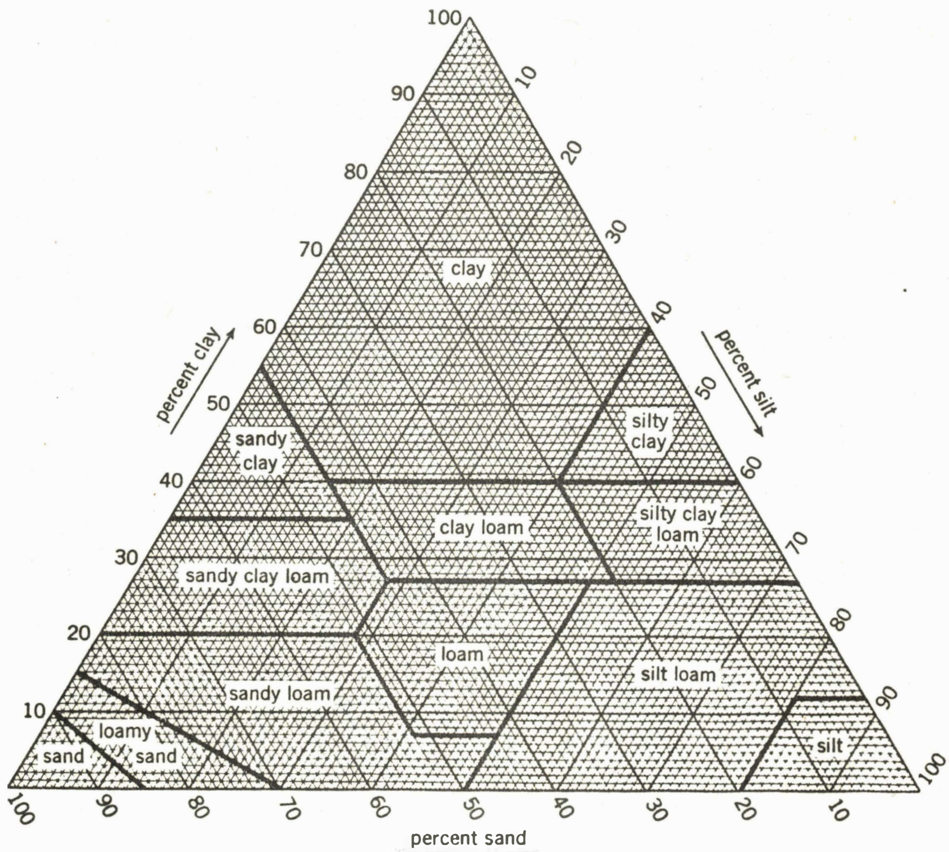
COMPARISON OF PARTICLE SIZE SCALES



U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE

GUIDE FOR TEXTURAL CLASSIFICATION

May 1, 1950



APPENDIX C

SOIL PROPERTIES

Table C-1

BEARING CAPACITY OF CLAYEY AND SILTY FOUNDATION SOILS

CHARACTERISTICS OF BORING NO. 2 IN THE OSAGE SOIL OF THE VERDIGRIS RIVER FLOODPLAIN

NOTE: A LONE PERIOD (.) INDICATES MISSING INFORMATION. A LONE N INDICATES THAT THE SOIL IS NON-PLASTIC.

DEPTH (FT)	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	LIQUID. INDEX	PCT. PASS #10	PCT. PASS #40	PCT. PASS #200	PCT. SAND	PCT. SILT	PCT. CLAY	UNIFIED CLASS	USDA CLASS	BEARING CAPACITY (PSF)	WET DENSITY (LBS/CU FT)	DRY DENSITY (LBS/CU FT)	PERCENT MOISTURE
0.0 TO 5.0	42	21	21	0.24	100	99	91	9	63	28	CL	SICL	983	119	94	26
5.0 TO 8.0	43	19	24	0.00	100	99	83	17	53	30	CL	CL	1,049	126	106	19
8.0 TO 11.5	45	18	27	0.19	100	98	80	20	47	33	CL	CL	1,114	.	.	23
11.5 TO 14.0	26	19	7	0.14	100	100	67	33	48	19	CL-ML	L	1,451	128	106	20
14.0 TO 18.0	34	20	4	0.25	100	100	94	6	80	14	CL-ML	SIL	2,221	124	103	21
18.0 TO 25.0	23	19	4	1.00	100	100	78	22	63	15	CL-ML	L	2,610	127	104	23
25.0 TO 32.5	N	N	0	N	100	95	31	69	26	5	SM	S	3,000	.	.	.
32.5 TO 34.0	N	N	0	N	.	.	.	.	.	.	GP	G	12,000	.	.	.
34.0 TO 35.9	34	23	11	.	100	92	83	17	.	.	CL		.	.	.	.

Table C-2

BEARING CAPACITY OF CLAYEY AND SILTY FOUNDATION SOILS

CHARACTERISTICS OF BORING NO. 3 IN THE OSAGE SOIL OF THE VERDIGRIS RIVER FLOODPLAIN

NOTE: A LONE PERIOD (.) INDICATES MISSING INFORMATION. A LONE N INDICATES THAT THE SOIL IS NON-PLASTIC.

DEPTH (FT)	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	LIQUID. INDEX	PCT. PASS #10	PCT. PASS #40	PCT. PASS #200	PCT. SAND	PCT. SILT	PCT. CLAY	UNIFIED CLASS	USDA CLASS	BEARING CAPACITY (PSF)	WET DENSITY (LBS/CU FT)	DRY DENSITY (LBS/CU FT)	PERCENT MOISTURE
0.0 TO 2.3	35	17	18	0.22	99	97	83	16	50	33	CL	CL	2,021	.	.	21
2.3 TO 5.1	31	18	13	0.38	100	99	87	13	59	28	CL	CL	420	126	102	23
5.1 TO 5.7	36	16	20	0.25	95	94	76	19	42	34	CL	CL	380	.	.	21
5.7 TO 8.0	42	17	25	0.12	100	99	86	14	48	38	CL	CL	340	125	105	20
8.0 TO 8.8	40	22	18	-0.06	100	99	86	14	50	36	CL	SICL	335	.	.	21
8.8 TO 11.0	42	19	23	0.04	100	99	87	13	53	34	CL	SICL	332	131	110	20
11.0 TO 11.8	32	16	16	0.25	100	100	79	21	51	28	CL	CL	330	130	108	20
11.8 TO 14.0	30	16	14	0.36	100	99	79	21	49	30	CL	CL	1,280	.	.	21
14.0 TO 14.8	34	16	18	0.28	100	100	81	19	49	32	CL	CL	230	129	107	21
14.8 TO 16.0	33	16	17	0.24	100	100	78	22	46	32	CL	CL	1,664	.	.	20
16.0 TO 16.8	27	15	12	0.33	100	100	53	47	38	15	CL	SL	1,954	.	.	19
16.8 TO 18.5	20	16	14	0.14	100	100	48	52	30	18	SM	SL	2,243	.	.	18
18.5 TO 19.3	21	15	6	0.67	100	100	43	57	33	10	CL-ML	SL	2,425	133	112	19
19.3 TO 21.0	N	N	0	N	100	100	42	58	32	10	SM	SL	2,924	131	111	18
21.0 TO 21.8	N	N	0	N	100	100	47	53	38	9	SM	SL	2,239	125	103	21
21.8 TO 26.0	N	N	0	N	100	100	40	60	29	11	SM	SL	2,240	.	.	21
26.0 TO 26.8	20	15	5	1.20	100	100	64	36	49	15	ML-CL	SL	2,239	130	107	21
26.8 TO 30.0	21	14	7	0.86	100	100	68	32	53	15	CL	SL	2,000	131	109	20
30.0 TO 30.8	32	18	14	0.36	100	100	83	17	57	26	CL	L	320	129	101	23
30.8 TO 35.5	32	17	15	0.53	100	100	85	15	55	30	CL	CL	310	126	100	25
35.5 TO 36.3	24	17	7	0.86	100	100	75	25	57	18	ML-CL	L	300	129	106	23
36.3 TO 38.0	27	17	10	0.60	100	100	83	17	65	18	CL	SIL	350	129	104	23
38.0 TO 38.8	29	18	11	0.82	100	99	94	6	72	22	CL	SIL	400	125	101	27
38.8 TO 40.0	34	19	15	0.47	100	100	96	4	69	27	CL	SICL	680	122	95	26
40.0 TO 40.8	32	15	17	0.71	100	100	95	5	73	22	CL	SIL	200	125	97	27
40.8 TO 41.5	23	20	3	3.00	100	100	68	32	52	16	ML	L	3,352	127	98	29
41.5 TO 45.0	.	.	.	.	.	.	.	.	.	.			.	.	.	.

Table C-3

BEARING CAPACITY OF CLAYEY AND SILTY FOUNDATION SOILS

CHARACTERISTICS OF BORING NO. 4 IN THE VERDIGRIS SOIL OF THE VERDIGRIS RIVER FLOODPLAIN

NOTE: A LONE PERIOD (.) INDICATES MISSING INFORMATION. A LONE N INDICATES THAT THE SOIL IS NON-PLASTIC.

DEPTH (FT)	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	LIQUID. INDEX	PCT. PASS #10	PCT. PASS #40	PCT. PASS #200	PCT. SAND	PCT. SILT	PCT. CLAY	UNIFIED CLASS	USDA CLASS	BEARING CAPACITY (PSF)	WET DENSITY (LBS/CU FT)	DRY DENSITY (LBS/CU FT)	PERCENT MOISTURE
0.0 TO 1.8	30	19	11	-0.18	100	100	96	4	72	24	CL	SIL	1,290	132	112	17
1.8 TO 3.5	26	21	5	-0.40	100	100	89	11	77	12	ML-CL	SIL	1,124	125	105	19
3.5 TO 4.3	N	N	0	N	100	100	37	63	30	7	SM	LS	727	.	.	18
4.3 TO 6.0	N	N	0	N	100	100	45	55	36	9	SM	SL	1,000	.	.	21
6.0 TO 6.8	33	20	13	0.69	100	100	98	2	72	26	CL	SIL	1,000	.	.	29
6.8 TO 8.5	41	23	18	0.33	100	100	99	1	66	33	CL	SICL	180	114	88	29
8.5 TO 9.3	45	22	23	0.30	100	100	97	3	65	32	CL	SICL	280	116	90	29
9.3 TO 11.0	45	23	22	0.27	100	100	97	3	61	36	CL	SICL	200	117	91	29
11.0 TO 11.8	63	24	39	0.15	100	99	95	5	50	45	CH	SIC	350	120	94	30
11.8 TO 13.5	60	26	34	0.06	100	99	96	4	51	45	CH	SICL	390	121	94	28
13.5 TO 14.3	49	19	30	0.07	100	100	93	7	57	36	CL	SIC	400	129	107	21
14.3 TO 15.5	46	18	28	0.18	100	99	93	7	59	34	CL	SICL	440	.	.	23
15.5 TO 16.3	43	18	25	0.16	100	100	94	6	60	34	CL	SICL	480	128	104	22
16.3 TO 18.0	47	20	27	0.07	100	100	98	2	59	39	CL	SICL	670	128	105	22
18.0 TO 18.8	51	22	29	0.00	100	100	97	3	51	46	CH	SIC	1,040	127	103	22
18.8 TO 20.5	45	22	23	0.04	100	100	97	3	54	43	CL	SIC	800	.	.	23
20.5 TO 21.3	37	20	17	0.12	100	99	87	13	54	33	CL	CL	560	128	105	22
21.3 TO 23.0	35	26	9	-0.33	100	99	84	16	59	25	ML	SIL	545	.	.	23
23.0 TO 23.8	33	17	16	0.25	100	100	73	27	52	21	CL	L	530	129	104	21
23.8 TO 25.5	29	17	12	0.17	100	100	73	27	55	18	CL	L	520	.	.	19
25.5 TO 26.3	29	18	11	0.36	100	100	80	20	62	18	CL	L	610	130	108	22
26.3 TO 28.0	30	18	12	0.33	100	100	82	18	62	20	CL	L	600	.	.	22
28.0 TO 28.8	20	18	2	1.00	100	100	55	45	47	8	ML	SL	270	130	108	20
28.8 TO 30.5	38	18	20	0.10	100	100	100	0	93	7	CL	SL	250	.	.	20
30.5 TO 31.3	19	18	1	3.00	100	100	51	49	39	12	ML	SL	230	130	109	21
31.3 TO 33.0	24	16	8	0.50	100	98	80	20	61	19	CL	L	3,794	.	.	20
33.0 TO 33.8	N	N	0	.	100	100	44	56	34	10	SM	SL	4,000	.	.	
33.8 TO 36.0	18	16	2	3.00	100	100	56	44	36	20	ML	L	2,000	.	.	22
36.0 TO 36.8	N	N	0	.	100	100	48	52	38	10	SM	SL	4,000	.	.	21
36.8 TO 38.2	N	N	0	.	100	99	58	42	43	15	ML	SL	2,000	.	.	20
38.2 TO 50.2	.	.	.	.	.	.	.	.	.	.	GP	G	12,000	.	.	.
50.2 TO 55.0	.	.	.	.	.	.	.	.	.	.			40,000	.	.	.

Table C-4

BEARING CAPACITY OF CLAYEY AND SILTY FOUNDATION SOILS

CHARACTERISTICS OF BORING NO. 5 IN THE VERDIGRIS SOIL OF THE VERDIGRIS RIVER FLOODPLAIN

NOTE: A LONE PERIOD (.) INDICATES MISSING INFORMATION. A LONE N INDICATES THAT THE SOIL IS NON-PLASTIC.

DEPTH (FT)	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	LIQUID. INDEX	PCT. PASS #10	PCT. PASS #40	PCT. PASS #200	PCT. SAND	PCT. SILT	PCT. CLAY	UNIFIED CLASS	USDA CLASS	BEARING CAPACITY (PSF)	WET DENSITY (LBS/CU FT)	DRY DENSITY (LBS/CU FT)	PERCENT MOISTURE
0.0 TO 2.8	29	20	9	0.56	100	100	87	13	70	17	CL	SIL	240	.	.	25
2.8 TO 3.6	36	21	15	0.20	100	100	98	2	79	19	CL	SIL	264	115	92	24
3.6 TO 4.4	27	22	5	1.00	100	100	87	13	68	19	ML-CL	SIL	240	115	91	27
4.4 TO 6.0	25	19	6	1.50	100	100	66	34	49	17	ML-CL	L	228	122	97	28
6.0 TO 6.8	34	20	14	0.64	100	100	90	10	63	27	CL	CL	246	113	91	29
6.8 TO 8.8	31	20	11	.	100	100	87	13	62	25	CL	SIL	227	.	.	.
8.8 TO 9.6	46	20	26	0.19	100	100	92	8	56	36	CL	SICL	208	127	102	25
9.6 TO 11.0	47	20	27	0.15	100	99	92	8	53	39	CL	SICL	212	126	101	24
11.0 TO 11.8	45	23	22	0.14	100	100	96	4	59	37	CL	SICL	212	.	.	26
11.8 TO 13.5	39	19	20	0.30	100	100	93	7	59	34	CL	L	212	.	.	25
13.5 TO 14.3	30	18	12	.	100	100	80	20	52	28	CL	CL	212	.	.	.
14.3 TO 15.5	30	17	13	0.54	100	100	90	10	65	25	CL	L	212	.	.	24
15.5 TO 16.3	36	18	18	0.22	100	100	84	16	59	25	CL	SIL	212	125	102	22
16.3 TO 18.0	29	17	12	0.75	100	100	90	10	67	23	CL	L	215	127	101	26
18.0 TO 18.8	29	18	11	0.73	100	100	79	21	58	21	CL	L	297	122	97	26
18.8 TO 20.0	34	18	16	0.50	100	100	93	7	64	29	CL	SICL	188	127	101	26
20.0 TO 20.8	32	17	15	0.53	100	100	83	17	60	23	CL	L	224	121	97	25
20.8 TO 22.0	31	17	14	0.71	100	100	83	17	58	25	CL	L	224	.	.	27
22.0 TO 22.8	32	19	13	0.54	100	99	92	8	67	25	CL	SIL	259	122	97	26
22.8 TO 24.0	41	19	22	0.32	100	100	85	15	50	35	CL	SICL	220	123	97	26
24.0 TO 24.8	32	18	14	0.57	100	100	86	14	65	21	CL	SIL	239	124	98	26
24.8 TO 26.0	40	20	20	0.35	100	99	93	7	61	32	CL	SICL	220	122	96	27
26.0 TO 26.8	23	18	5	.	100	100	64	36	47	17	ML-CL	L	220	.	.	.
26.8 TO 28.0	39	20	19	.	100	99	91	9	59	32	CL	SICL	220	.	.	.
28.0 TO 28.8	37	20	17	.	100	100	90	10	62	28	CL	CL	220	.	.	.
28.8 TO 30.0	30	16	14	0.86	100	100	92	8	71	21	CL	L	220	.	.	28
30.0 TO 30.8	26	18	8	1.13	100	100	66	34	52	14	CL	L	220	.	.	27
30.8 TO 32.0	21	20	1	6.00	100	100	53	47	39	14	ML	SL	4,000	.	.	26
32.0 TO 32.8	N	N	0	.	100	100	47	53	35	12	SM	SL	4,000	.	.	.
32.8 TO 33.1	N	N	0	.	100	100	40	60	28	12	SM	SL	4,000	.	.	26
33.1 TO 34.0	N	N	0	.	100	99	46	54	34	12	SM	SL	4,000	.	.	.
34.0 TO 38.0	N	N	0	.	100	100	25	75	18	7	SM	LS	4,000	.	.	.
38.0 TO 39.5	N	N	0	.	60	52	14	46	12	2	SM	S	4,000	.	.	.
39.5 TO 40.5	.	.	.	.	.	.	.	.	.	.	GW	G	20,000	.	.	.

Table C-5

BEARING CAPACITY OF CLAYEY AND SILTY FOUNDATION SOILS

CHARACTERISTICS OF BORING NO. 6 IN THE REXOR SOIL OF THE LITTLE RIVER FLOODPLAIN

NOTE: A LONE PERIOD (.) INDICATES MISSING INFORMATION. A LONE N INDICATES THAT THE SOIL IS NON-PLASTIC.

DEPTH (FT)	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	LIQUID. INDEX	PCT. PASS #10	PCT. PASS #40	PCT. PASS #200	PCT. SAND	PCT. SILT	PCT. CLAY	UNIFIED CLASS	USDA CLASS	BEARING CAPACITY (PSF)	WET DENSITY (LBS/CU FT)	DRY DENSITY (LBS/CU FT)	PERCENT MOISTURE
0.0 TO 2.8	N	N	0	.	100	100	41	59	32	9	SM	SL	1,500	.	.	.
2.8 TO 4.0	N	N	0	.	100	100	64	36	51	13	SM	SL	1,500	.	.	.
4.0 TO 4.8	N	N	0	.	100	100	70	30	54	16	ML	SIL	1,000	.	.	.
4.8 TO 5.6	N	N	0	.	100	100	44	56	34	10	SM	SL	1,500	.	.	.
5.6 TO 6.1	N	N	0	.	100	100	60	40	49	11	SM	SL	1,500	.	.	.
6.1 TO 7.5	N	N	0	.	100	100	63	37	54	9	SM	SL	1,000	.	.	.
7.5 TO 10.0	N	N	0	.	100	100	38	62	29	9	SM	LS	1,500	116	103	.
10.0 TO 12.5	N	N	0	.	100	100	10	90	6	4	SW-SM	S	1,400	.	.	.
12.5 TO 15.0	N	N	0	.	100	100	16	84	10	6	SM	S	1,400	.	.	.
15.0 TO 17.5	N	N	0	.	100	100	14	86	10	4	SM	S	1,500	.	.	.
17.5 TO 18.8	N	N	0	.	100	100	16	84	10	6	ML	LS	1,000	123	105	.
18.8 TO 22.5	N	N	0	N	100	100	53	47	43	10	ML	SL	3,000	.	.	12
22.5 TO 26.2	N	N	0	.	100	100	44	56	43	1	ML	SL	3,000	134	115	.
26.2 TO 27.5	N	N	0	.	100	100	21	79	16	5	SM	LS	3,000	.	.	.
27.5 TO 33.2	N	N	0	.	52	47	11	41	8	3	SW	S	8,000	.	.	.
33.2 TO 34.1	28	17	11	.	95	89	10	85	6	4	SW-SM	S	8,000	.	.	.
34.1 TO 37.0	33	17	16	.	100	100	98	2	69	29	CL	SICL	8,000	.	.	.
37.0 TO 38.5	33	14	19	.	100	100	92	8	59	33	CL	SICL	8,000	.	.	.

Table C-6

BEARING CAPACITY OF CLAYEY AND SILTY FOUNDATION SOILS

CHARACTERISTICS OF BORING NO. 7 IN THE KAUFMAN SOIL OF THE LITTLE RIVER FLOODPLAIN

NOTE: A LONE PERIOD (.) INDICATES MISSING INFORMATION. A LONE N INDICATES THAT THE SOIL IS NON-PLASTIC.

DEPTH (FT)	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	LIQUID. INDEX	PCT. PASS #10	PCT. PASS #40	PCT. PASS #200	PCT. SAND	PCT. SILT	PCT. CLAY	UNIFIED CLASS	USDA CLASS	BEARING CAPACITY (PSF)	WET DENSITY (LBS/CU FT)	DRY DENSITY (LBS/CU FT)	PERCENT MOISTURE
0.0 TO 8.8	60	24	36	0.00	100	99	97	3	42	55	CH	C	260	125	101	24
8.8 TO 10.5	48	22	26	0.04	100	99	97	3	43	54	CL	SIC	285	120	98	23
10.5 TO 11.3	60	25	35	0.03	100	99	96	4	38	58	CH	C	285	123	97	26
11.3 TO 12.1	59	24	35	0.09	100	100	97	3	39	58	CH	C	310	125	99	27
12.1 TO 14.1	64	27	37	.	100	99	95	5	35	60	CH	C	505	125	92	.
14.1 TO 16.5	62	27	35	-0.03	100	99	96	4	41	55	CH	C	700	124	99	26
16.5 TO 17.3	64	24	40	0.05	100	99	92	8	33	59	CH	C	615	119	95	26
17.3 TO 18.1	60	22	38	0.11	100	98	94	6	40	54	CH	C	530	124	98	26
18.1 TO 18.9	65	27	38	0.03	100	99	96	4	40	56	CH	C	715	.	.	28
18.9 TO 19.6	60	23	37	0.11	100	99	96	4	42	54	CH	C	715	.	.	27
19.6 TO 27.4	45	21	24	0.08	100	100	99	1	54	45	CL	SIC	900	124	101	23
27.4 TO 53.5	.	.	.	.	.	.	.	.	.	.	GP	G	8,000	.	.	.

Table C-7

BEARING CAPACITY OF CLAYEY AND SILTY FOUNDATION SOILS

CHARACTERISTICS OF BORING NO. 8 IN THE KAUFMAN SOIL OF THE LITTLE RIVER FLOODPLAIN

NOTE: A LONE PERIOD (.) INDICATES MISSING INFORMATION. A LONE N INDICATES THAT THE SOIL IS NON-PLASTIC.

DEPTH (FT)	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	LIQUID. INDEX	PCT. PASS #10	PCT. PASS #40	PCT. PASS #200	PCT. SAND	PCT. SILT	PCT. CLAY	UNIFIED CLASS	USDA CLASS	BEARING CAPACITY (PSF)	WET DENSITY (LBS/CU FT)	DRY DENSITY (LBS/CU FT)	PERCENT MOISTURE
0.0 TO 6.0	73	27	46	.	100	99	96	4	26	70	CH	C	285	.	.	.
6.0 TO 6.8	66	24	42	0.05	100	99	95	5	41	54	CH	C	489	120	95	26
6.8 TO 7.6	63	28	35	-0.06	100	99	94	6	43	51	CH	SIC	431	119	94	26
7.6 TO 11.3	64	27	37	-0.03	100	99	93	7	36	57	CH	C	431	.	.	26
11.3 TO 12.1	64	26	38	-0.03	100	98	94	6	38	56	CH	C	431	.	.	25
12.1 TO 16.5	63	25	38	-0.05	100	99	93	7	37	56	CH	C	372	120	97	23
16.5 TO 17.3	64	24	40	0.07	100	99	93	7	36	57	CH	C	294	124	97	27
17.3 TO 18.1	74	29	45	-0.09	100	99	93	7	35	58	CH	C	406	124	99	25
18.1 TO 21.5	72	26	46	-0.02	100	100	92	8	33	59	CH	C	870	126	101	25
21.5 TO 22.3	48	20	28	0.04	100	100	88	12	44	44	CL	C	906	129	107	21
22.3 TO 25.5	56	22	34	0.06	100	100	89	11	44	45	CH	C	941	129	104	24
25.5 TO 26.3	21	18	3	0.67	100	100	70	30	54	16	ML	L	1,000	.	.	20
26.3 TO 30.0	20	17	3	1.67	100	100	61	39	45	16	ML	L	1,000	.	.	22
30.0 TO 30.8	28	18	10	0.60	100	100	94	6	68	26	CL	SIL	1,000	125	102	24
30.8 TO 31.6	32	19	13	0.46	100	100	95	5	67	28	CL	SICL	1,000	126	104	25
31.6 TO 32.2	36	20	16	0.25	100	100	98	2	64	34	CL	SICL	1,000	125	101	24

Table C-8

BEARING CAPACITY OF CLAYEY AND SILTY FOUNDATION SOILS

CHARACTERISTICS OF BORING NO. 9 IN THE REXOR SOIL OF THE LITTLE RIVER FLOODPLAIN

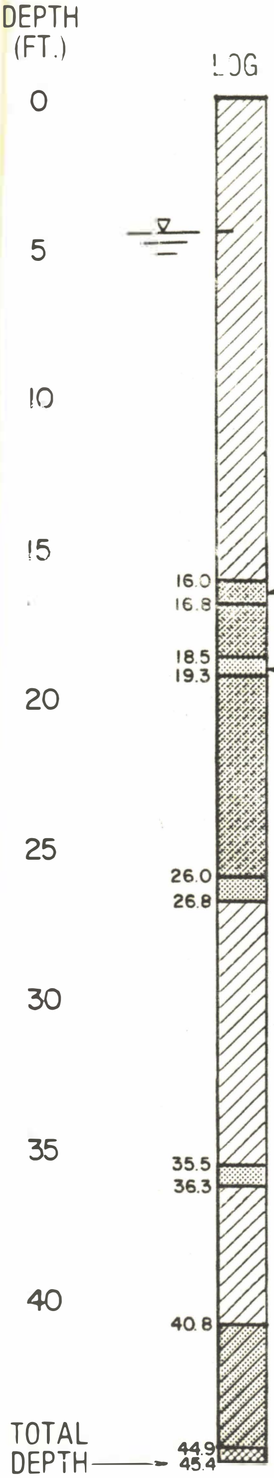
NOTE: A LONE PERIOD (.) INDICATES MISSING INFORMATION. A LONE N INDICATES THAT THE SOIL IS NON-PLASTIC.

DEPTH (FT)	LIQUID LIMIT	PLASTIC LIMIT	PLAST. INDEX	LIQUID. INDEX	PCT. PASS #10	PCT. PASS #40	PCT. PASS #200	PCT. SAND	PCT. SILT	PCT. CLAY	UNIFIED CLASS	USDA CLASS	BEARING CAPACITY (PSF)	WET DENSITY (LBS/CU FT)	DRY DENSITY (LBS/CU FT)	PERCENT MOISTURE
0.0 TO 1.8	16	15	1	-7.00	100	100	49	51	32	17	ML	SL	1,000	111	103	8
1.8 TO 5.5	N	N	0	.	100	100	45	55	29	16	ML	SL	1,000	111	102	9
5.5 TO 6.3	21	14	7	0.14	100	100	69	31	45	24	ML	L	1,000	.	.	15
6.3 TO 7.1	37	16	21	0.05	100	100	73	27	39	34	CL	CL	830	128	109	17
7.1 TO 10.0	26	15	11	0.27	100	100	65	35	34	31	CL	CL	840	129	109	18
10.0 TO 10.8	N	N	0	.	100	96	18	82	9	9	SM	LS	3,000	.	.	12
10.8 TO 11.6	N	N	0	.	100	81	16	84	3	13	SM	LS	3,000	.	.	17

APPENDIX D

COMPARISON OF SOIL PROPERTIES

TABLE D - 1 OSAGE SOIL,



SOIL DESCRIPTION

WATER LEVEL AT 24 HRS.

SILTY CLAY, DARK OLIVE AND BLACK TO OLIVE MOTTLED YELLOWISH BROWN

SANDY CLAY, TAN MOTTLED YELLOW AND BROWN

SILTY SAND, FINE, MOTTLED TAN AND YELLOWISH BROWN

FINE SAND AND LEAN SILTY CLAY MIXTURE, MOTTLED TAN AND YELLOWISH BROWN

SILTY SAND, FINE, MOTTLED TAN AND YELLOWISH BROWN

FINE SAND AND LEAN SILTY CLAY MIXTURE, GRAY MOTTLED YELLOWISH BROWN

SILTY CLAY, GRAY MOTTLED YELLOWISH BROWN

FINE SAND AND LEAN SILTY CLAY MIXTURE, DARK GRAY

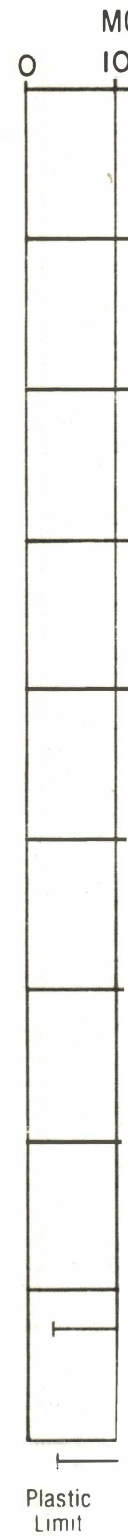
SILTY CLAY, DARK GRAY

CLAYEY FINE SAND, DARK GRAY

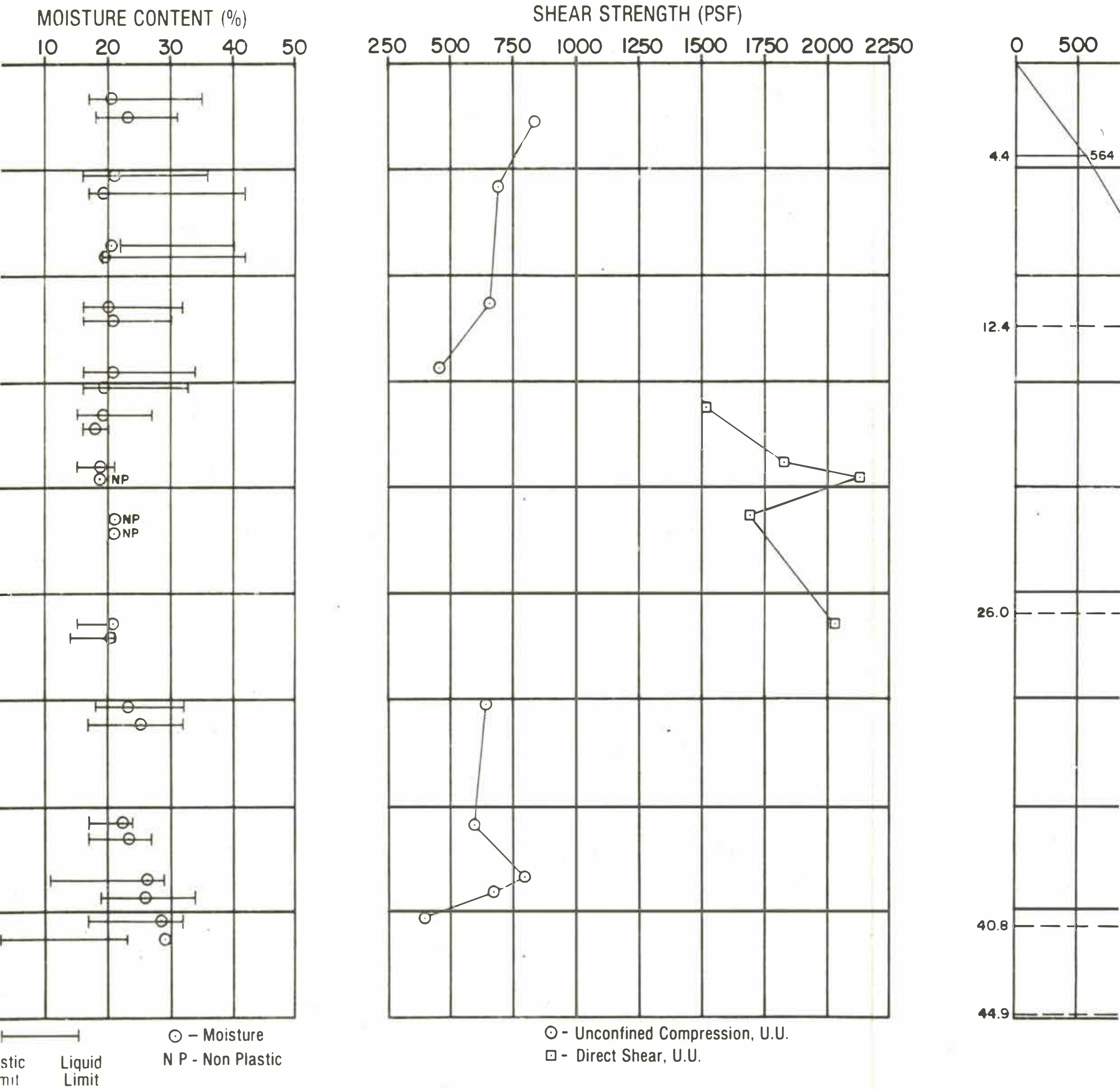
SHALE, GRAY

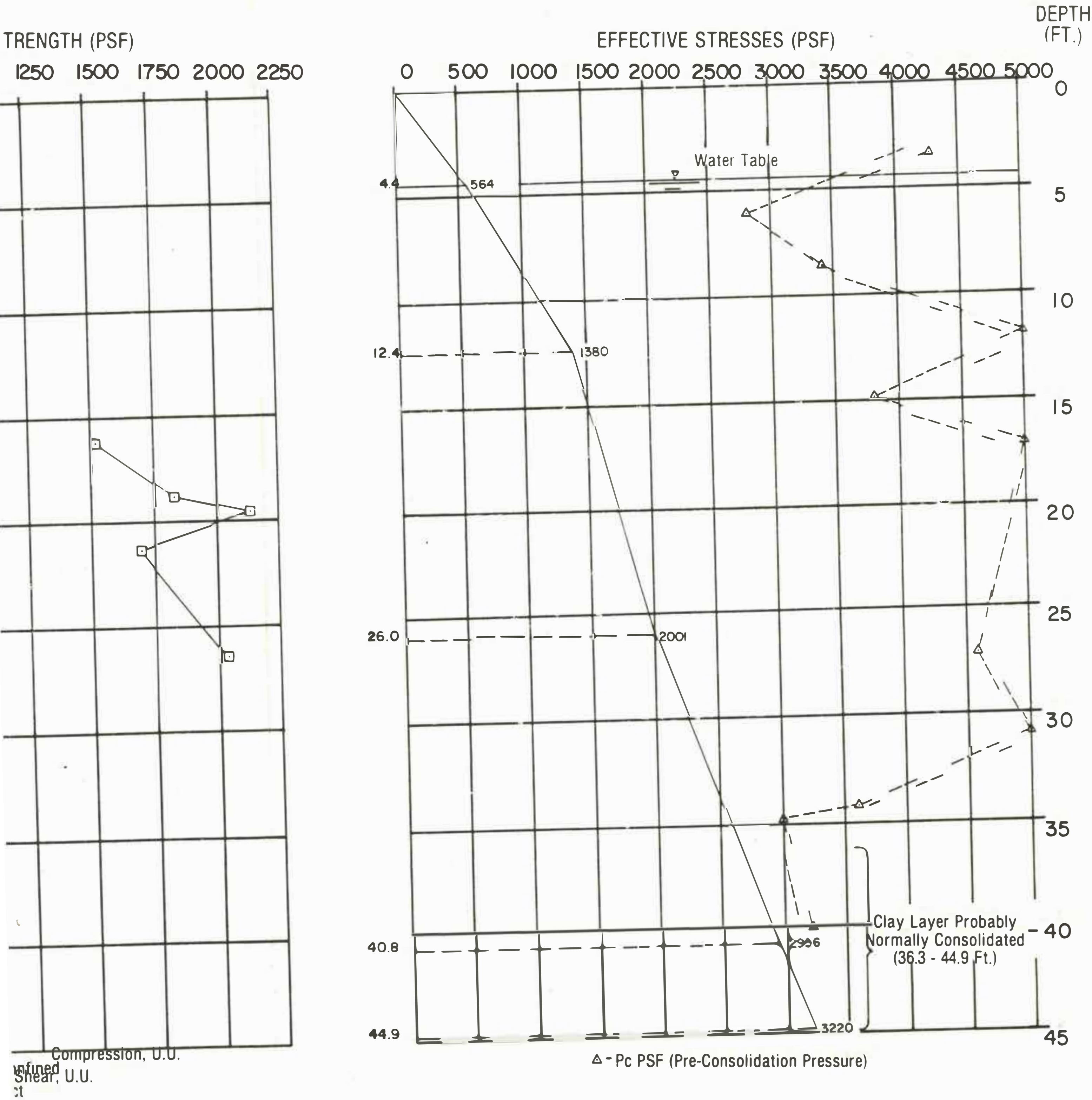
PARTICLE SIZES (%)

DENSITY WET (P.C.F.)	SAND (2.0mm)	SILT (0.074 mm)	CLAY (0.002mm)	UNIFIED CLASS	USDA CLASS
-----	17	50	33	CL	CL
102.0	13	55	28	CL	SiCL
-----	24	42	34	CL	CL
104.8	15	47	38	CL	CL
-----	13	51	36	CL	SICL
109.5	14	52	34	CL	SICL
108.2	21	51	28	CL	CL
-----	12	49	30	CL	CL
106.7	22	45	32	CL	CL
-----	19	49	32	CL	CL
-----	53	33	15	SL ?	SL
-----	46	36	18	SM	SL
111.5	57	33	15	CL-ML	SL
111.0	58	32	10	SM	SL
103.2	53	38	9	SM	SL
-----	60	29	11	SM	SL
108.3	37	48	15	ML-CL	SL
109.0	32	53	15	CL	SL
101.0	17	57	26	CL	L
100.4	15	55	30	CL	CL
105.6	25	57	18	ML-CL	L
104.3	17	65	18	CL	SiL
-----	7	71	22	CL	SiL
100.7	4	69	27	CL	SiCL
95.4	5	73	22	CL	SiL
97.5	32	52	16	ML	L



ƆIL, BORING NO. 3, ROGERS COUNTY, VERDIGRIS RIVER





TRENGTH (PSF)
1250 1500 1750 2000 2250
EFFECTIVE STRESSES (PSF)
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
DEPTH (FT.)
0 5 10 15 20 25 30 35 40 45
Water Table
4.4
564
12.4
1380
26.0
2001
40.8
2956
44.9
3220
Clay Layer Probably Normally Consolidated (36.3 - 44.9 Ft.)
Δ - Pc PSF (Pre-Consolidation Pressure)
Compression, U.U.
nfined
Shear, U.U.
ct

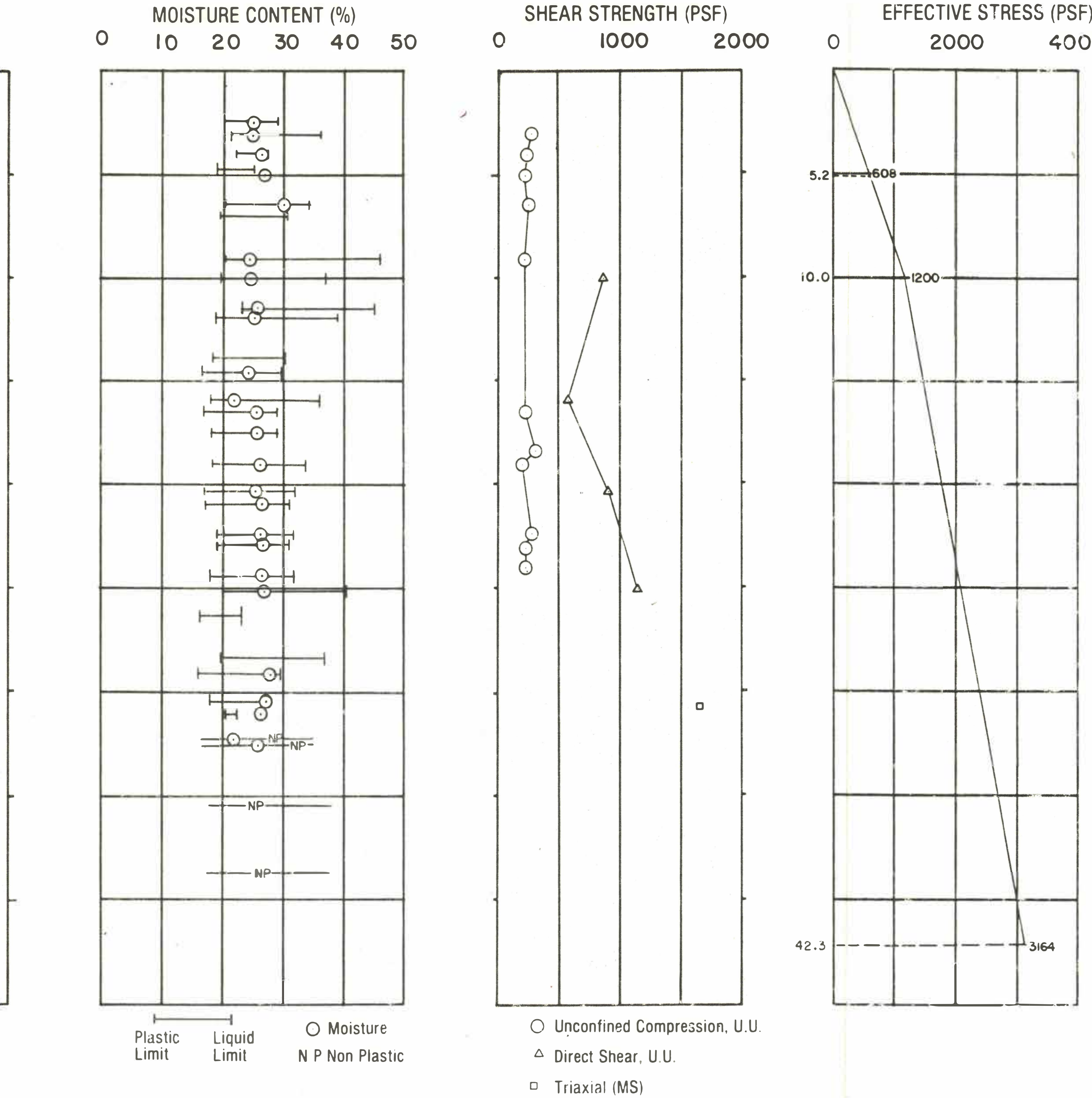
TABLE D - 2

DEPTH (FT)	LOG	SOIL DESCRIPTION
0		SILTY CLAY, GRAY TO BROWN
	3.6	CLAYEY SAND, GRAY TO BROWN MOTTLED REDDISH BROWN
5	5.2	
10		WATER LEVEL 9-16-76
15		SILTY CLAY, MOTTLED GRAY AND BROWN, FINE BLOCKY STRUCTURE
20		
25	25.6	FINE SAND, MOTTLED GRAY AND BROWN
	26.8	SILTY CLAY, MOTTLED GRAY AND BROWN PALE
30	29.4	SILTY CLAY, MOTTLED GRAY
	30.8	
35		SILTY SAND, GRAY
40	39.5	MIXED SILTY SAND AND SHALEY GRAVELS, GRAY
	42.3	
	43.4	
45	EOB	

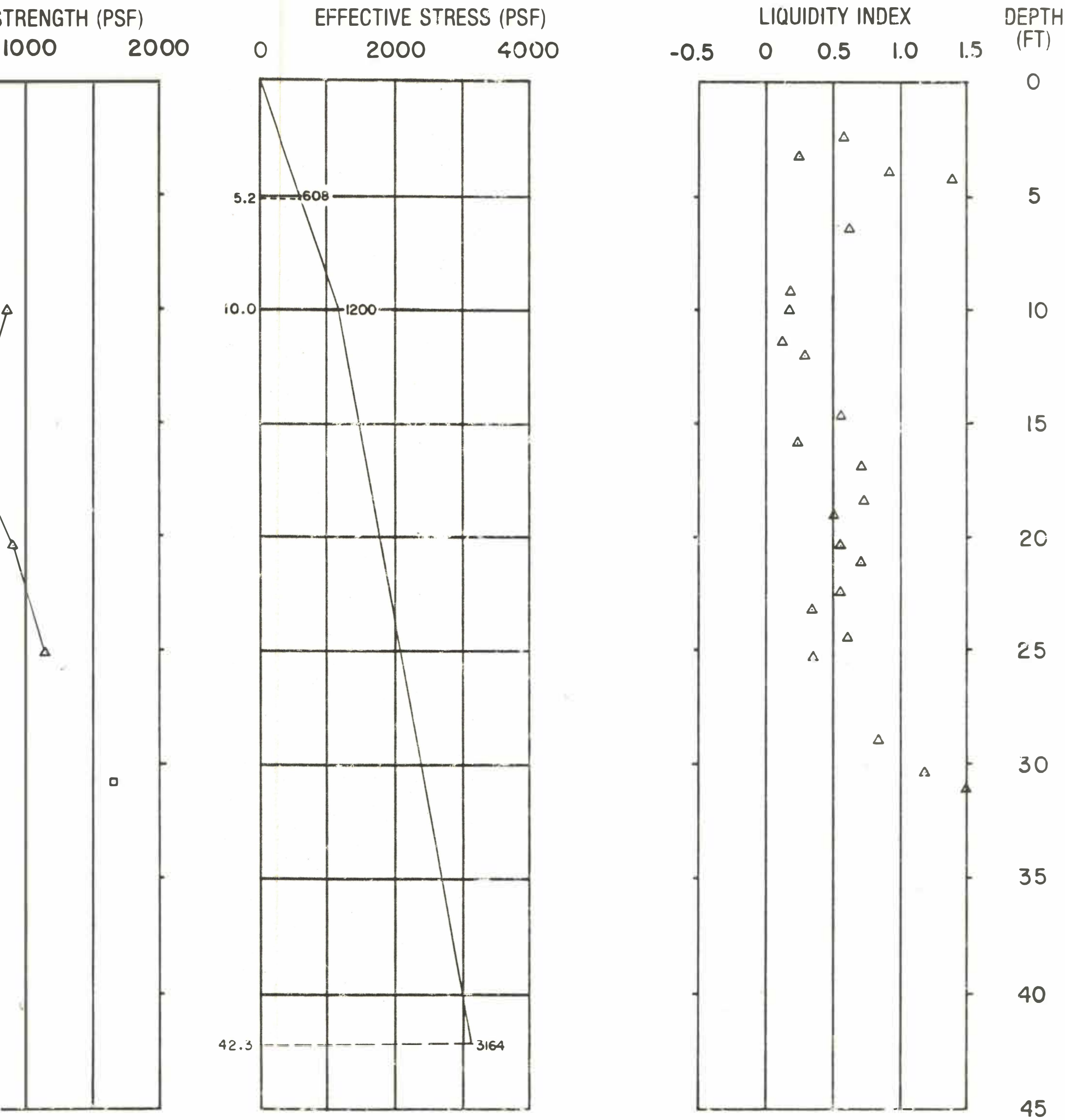
PARTICLE SIZES (%)

DENSITY WET (P.C.F.)	SAND (2.0 mm)	SILT (0.074 mm)	CLAY (0.002 mm)	UNIFIED CLASS	U C
114.7	13	69	18	ML–CL	Si
122.1	34	49	17	ML–CL	
112.8	9	64	27	CL	Si
—	8	6	36	CL	Si
126.6	13	62	25	CL	Si
126.1	8	54	38	CL	Si
—	3	60	37	CL	Si
—	7	60	33	CL	Si
—	20	53	27	CL	Si
—	9	66	25	CL	Si
125.4	17	59	24	CL	Si
126.5	11	67	22	CL	Si
121.8	22	57	21	CL	Si
127.0	7	64	29	CL	Si
121.4	18	59	23	CL	Si
—	17	58	25	CL	Si
122.1	8	67	25	CL	Si
123.2	11	54	35	CL	Si
124.0	13	61	26	CL	Si
122.0	8	60	32	CL	Si
—	36	47	17	ML–CL	L
—	9	54	37	CL	L
—	9	63	28	CL	Si
—	8	71	21	CL	S
—	34	52	14	CL	Si
—	47	39	14	ML	L
—	53	35	12	SM	S
—	61	28	11	SM	S
—	54	34	12	SM	S
—	75	19	6	SM	S
—	87	11	2	SM	

VERDIGRIS SOIL BORING NO. 5 WAGONER COUNTY SH 51 AND VERDIGRIS RIVER



SH 51 AND VERDIGRIS RIVER

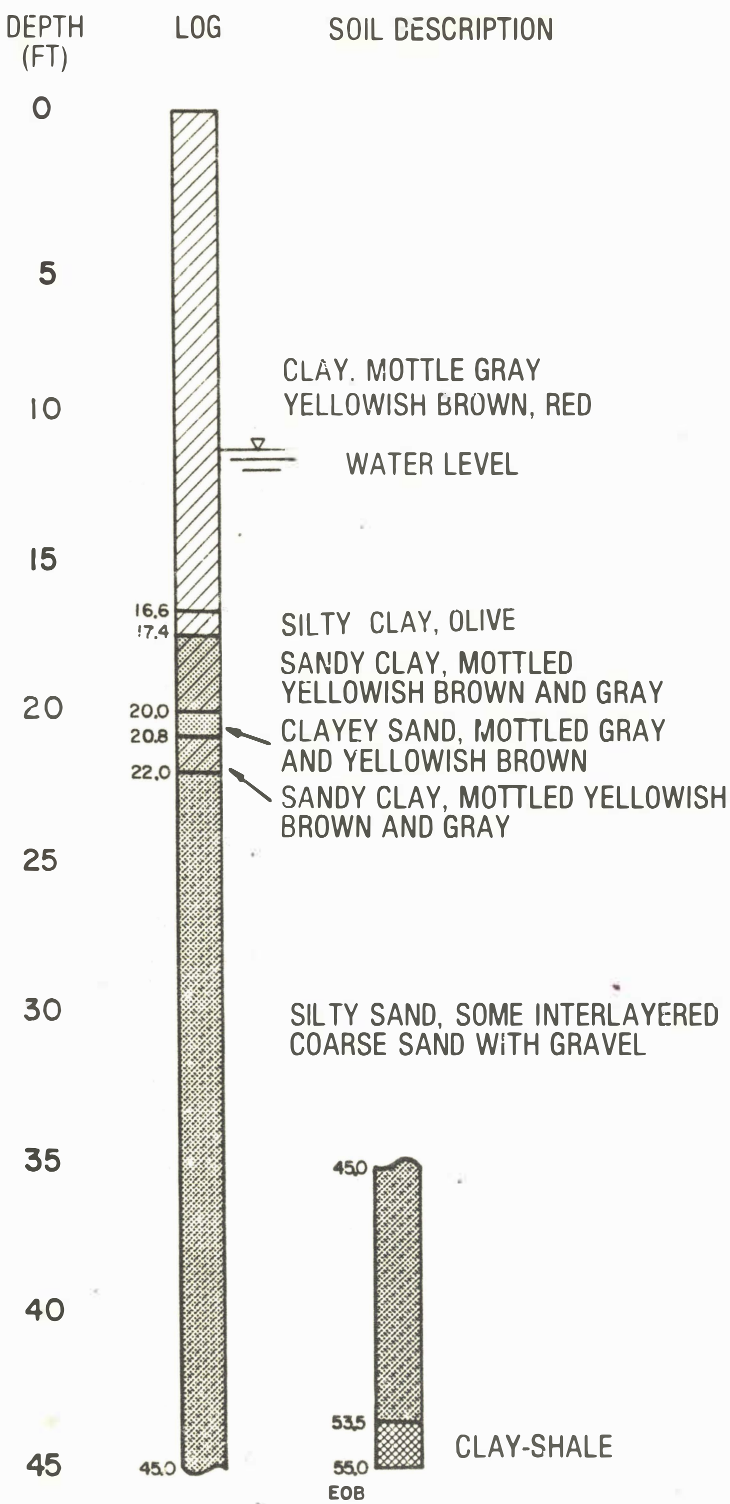


fined Compression, U.U.

Shear, U.U.

al (MS)

TABLE D - 3 KAUF

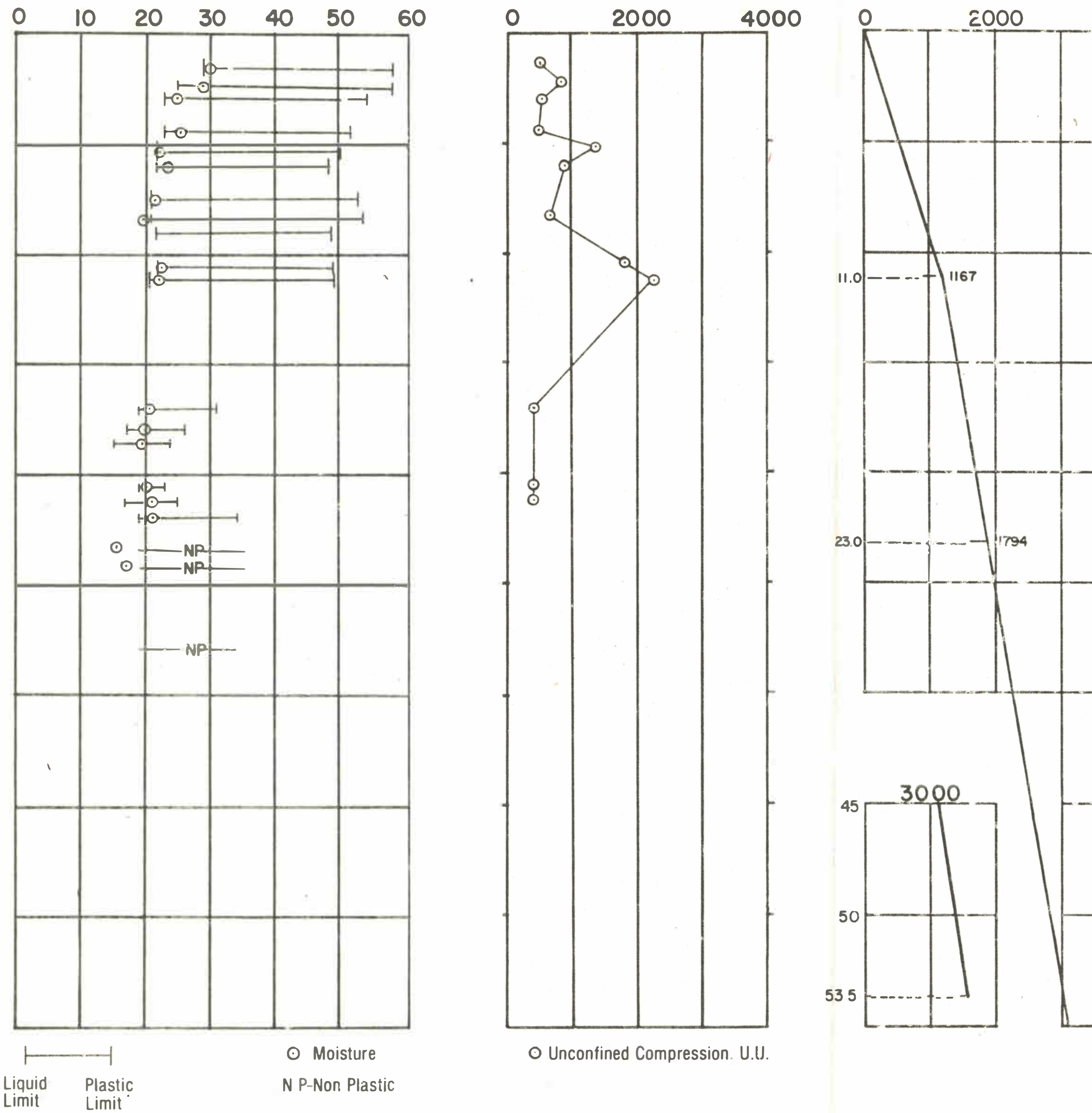


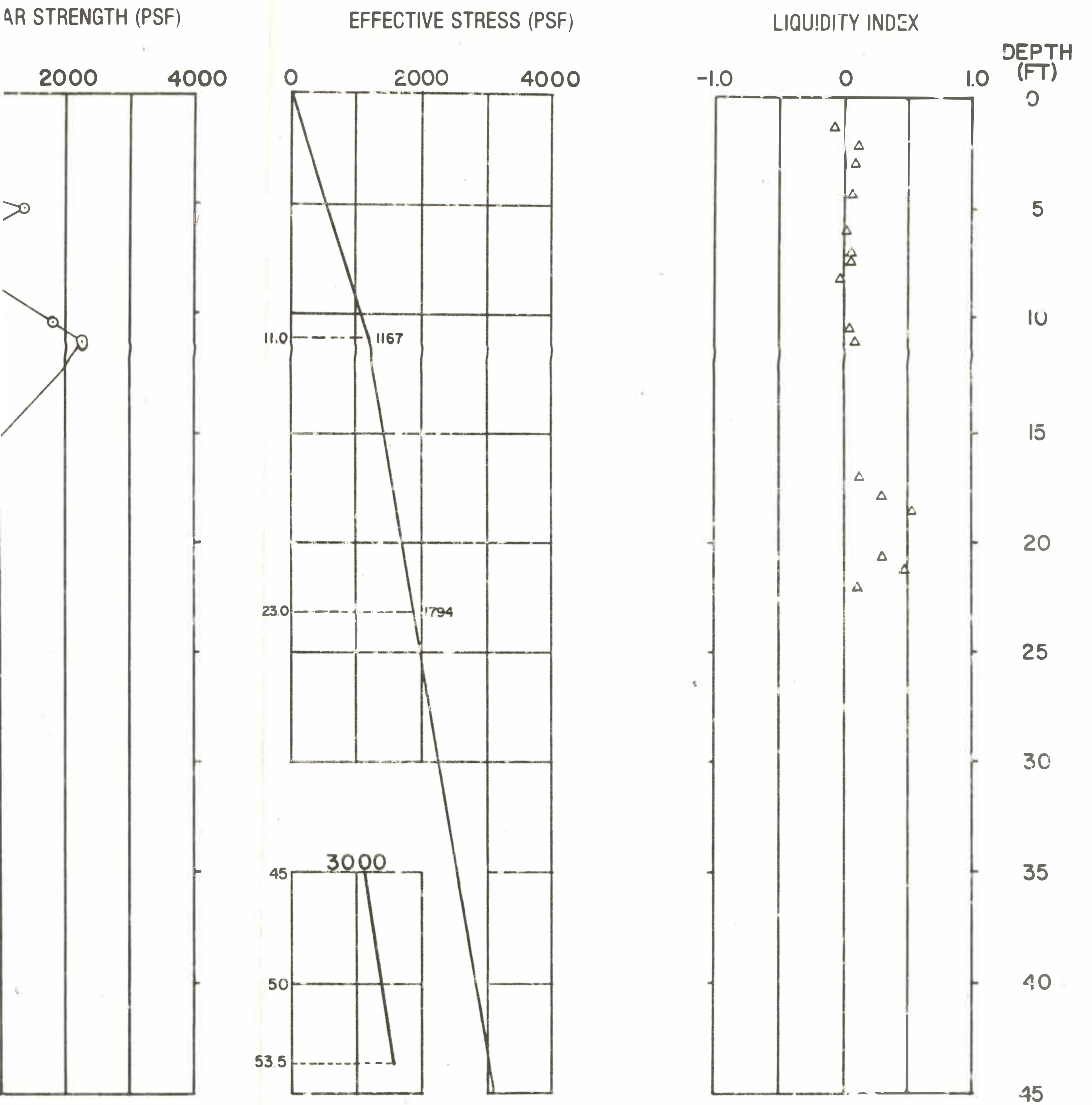
PARTICLE SIZES (%)

DENSITY WET (P.C.F.)	SAND (2.0 mm)	SILT (0.074 mm)	CLAY (0.002 mm)	UNIFIED CLASS	USDA CLASS
115.9	10	47	43	CH	SiC
113.8	7	45	48	CH	SiC
118.5	8	45	47	CH	SiC
122.1	6	48	46	CH	SiC
121.3	11	45	44	CH	SiC
124.0	9	46	45	CL	SiC
124.9	4	41	55	CH	SiC
119.9	4	42	54	CL	SiC
123.0	4	33	58	CH	C
125.4	3	38	59	CH	C
124.6	4	36	60	CH	C
124.2	4	41	55	CH	SiC
118.7	8	33	59	CH	C
124.1	6	40	54	CH	SiC
—	4	40	56	CH	SiC
----	4	42	54	CH	SiC
124.1	1	54	45	CL	SiC

AN SOIL BORING NO. 7 McCURTAIN COUNTY LITTLE RIVER

MOISTURE CONTENT (%) SHEAR STRENGTH (PSF) EFFECTIVE STRESS





confined Compression, U.U.

APPENDIX E

SETTLEMENT PROBLEMS

SETTLEMENT PROBLEM

In order to demonstrate the potential magnitude of settlement, test data from Boring No. 5 were used to develop an estimate of total primary settlement The actual settlement of the fill was at least 9 inches (229 mm), for a fill height of 45 feet (13.7 m). See Figure E1. The fill was constructed in 1971. Calculated settlement was 12 inches (305 mm) for a hypothetical 30 foot (9.1 m) fill and 22 inches (560 mm) for a hypothetical 60 foot (18.3 m) fill placed on the same foundation soil.

The calculations for the determination of the settlement are presented below. Each defineable layer was assigned values from consolidation tests. The method used can be found in the Department of the Navy "Design Manual", Soil Mechanics, Foundations and Earth Structures NAVDOCKS DM-7 or many other soil mechanics texts.

Seven layers were recognized in this boring. Layers 1, 2, 3, 4, and 5 were considered to be compressible. Other layers were granular and not considered to be compressible.

Layer 1 is described as a silty clay (CL), layer 2 is a clayey sand (ML-CL), layer 3, a silty clay (CL), layer 4 a silty clay (CL) and layer 5 a silty clay (CL). See Figure E2. The soils were considered to be overconsolidated but the normally consolidated condition seemed to be approached with depth.

Two fill heights were assumed to determine settlement. Case One assumes a 30 ft. (9.1 m) fill while Case Two assumes a 60 ft. (18.3 m) fill.

The theoretical settlement, as measured near the end of the bridge, does not agree with the actual settlement. Some major sources of error are possibly probably due to the following: the fill lying unsurfaced for about a year allowing consolidation to take place, the grade not constructed to design specifications, some settlement taking in layers assumed to be incompressible, and consolidation due to the driving of piles nearby.

Case One

Thirty Feet of Fill Height

Layer 1 CL

P_1 = 114.5 (1.8) = 206.1 psf (0.103 tsf)

e_I from e-log P curve = 0.785

P' = 120(30) = 3600 psf = 1.8 tsf; avg. density of embankment in lbs/ft^3 x embankment height in ft.

P = P_1 + P' = 0.103 + 1.8 or 1.903 tsf at mid point of Layer No. 1

e from e-log P curve = 0.736

Then:

$$S = d \frac{e_I - e}{1 + e_I} = 3.6 \; \frac{0.785 - 0.736}{1.785} = 0.0988 \text{ ft. or } 1.19 \text{ inches of settlement}$$

where:

S = settlement

d = thickness of layer being compressed in feet

e_I = initial void ratio

e = final void ratio

P_1 = wet density x mid-point of layer

P' = stress due to column of soil from embankment; average density of embankment soil x embankment height = 3,600 lbs.

P = P_1 + P'

Layer 2 ML-CL

P_1 = 114.6(4.4) = 504.24 psf = (0.252 tsf)

e_I from e-log P curve = 0.836

P = P_1 + P'

P = 0.252 + 1.8

P = 2.05 tsf

e from e-log P curve = 0.739

$$S = d \frac{e_I - e}{1 + e_I}$$

$$S = 1.6 \; \frac{0.836 - 0.739}{1.836} = 0.084 \text{ ft.} = 1.01 \text{ inches of settlement}$$

Layer 3 CL

P_1 = 119.5(9) + (15.6-9)(119.5 - 62.4) = 1452.36 psf = (0.726 tsf)*

e_I from e-log P curve = 0.772

$P = P_1 + P'$

P = 0.726 + 1.8 tsf

P = 2.526 tsf

e from e-log P curve = 0.724

$$S = d \frac{e_I + e}{1 + e_I}$$

$$S = 20.4 \frac{0.772 - 714}{1.772} = 0.667 \text{ ft.} = 8.01 \text{ inches of settlement}$$

*Encounter water table at 9.0 ft.

Layer 4 CL

P_1 = 114.4(9) + (28.1 - 9)(114.4 - 62.4) = 2022.8 psf = (1.01 tsf)

e_I from e-log P curve 0.765

$P = P_1 + P'$

P = 1.01 + 1.8

P = 2.81 tsf

e from e-log P curve = 0.705

$$S = d \frac{e_I - e}{1 + e_I} = \frac{0.765 - 0.705}{1.765} = 0.088 \text{ ft.} = 1.06 \text{ inches of settlement}$$

Layer 5 CL

P_1 = 114.4(30.1) 114.4(9) + (114.4 - 62.4(30.1 - 9) = 2168.4 psf (1.084 tsf)

e_I from e-log P curve 0.787

$P = P_1 + P'$

P = 1.084 + 1.8

P = 2.88 tsf

e from e-log P curve = 0.712

$$S = d \frac{e_I - e}{1 + e_I}$$

$$S = 1.4 \frac{0.787 - 0.712}{1.787} = .0587$$

Total theoretical settlement = 11.97 inches for a 30 ft. embankment overburden.

Case Two

Sixty Feet of Fill Height

Layer 1, CL

P_1 = 114.5(1.8) = 206.1 psf = 0.103 tsf

e_I from e-log P curve = 0.785

P' = 120 (60) = 7200 psf = 3.6 tsf; avg. density of embankment x embankment height.

$P = P_1 + P'$

$P = 0.103 + 3.6$

$P = 3.703$ tsf

e from e-log P curve = 0.682

$$S = d \frac{e_I - e}{1 + e_I}$$

$$S = 3.6 \frac{0.785 - 0.682}{1.785} = 0.2077 \text{ ft.}$$

S = 2.49 inches of settlement

Layer 2 ML-CL

P_1 = 114.6(4.4) = 504.24 psf = 0.252 tsf

e_I from e-log P curve = 0.836

$P = P_1 + P'$

$P = 0.252 + 3.6$

$P = 3.85$ tsf

e from e-log P curve = 0.686

$$S = d \frac{e_I - e}{1 + e_I}$$

$$S = 1.6 \frac{.0836 - 0.686}{1.836} = 0.1307 \text{ ft.}$$

S = 1.57 inches of settlement

Layer 3 CL

$P_1 = 119.5(9) + (15.6 - 9)(119.5 - 62.4) = 1452.36$ psf = 0.726 tsf

e_I from e-log P curve = 0.772

$P = P_1 + P'$

$P = 0.726 + 3.6$

$P = 4.326$ tsf

e from e-log P curve = 0.665

$$S = d \frac{e_I - e}{1 + e_I}$$

$$S = 20.4 \frac{0.772 - 0.665}{1.772} = 1.2318 \text{ ft.}$$

S = 14.78 inches of settlement

Layer 4 CL

$P_1 = 114.4(9) + (28.1 - 9)(114.4 - 62.4) = 2022.8$ psf = 1.01 tsf

e_I from e-log P curve = 0.765

$P = P_1 + P'$

$P = 1.01 + 3.6$

$P = 4.61$ tsf

e from e-log P curve = 0.660

$$S = d \frac{e_I - e}{1 + e_I} = 2.6 \frac{0.765 - 0.660}{1.765} = 0.1547 \text{ ft.}$$

S = 1.85 inches of settlement.

Layer 5 CL

$P_1 = 114.4(9) + (114.4 - 62.4)(30.1 - 9) + 114.4(30.1) = 5570.2$ psf = 2.785 tsf

e_I from e-log P curve = 0.787

$P = P_1 + P'$

$P = 2.785 + 3.6$

$P = 6.385$ tsf

e from e-log P curve = 0.672

$$S = d \frac{e_I - e}{1 + e_I}$$

$$S = 1.4 \frac{0.787 - 0.672}{1.787} = 0.0900 \text{ ft.}$$

S = 1.08 inches of settlement.

Total theoretical settlement = 21.77 inch for a 60 ft. embankment overburden.

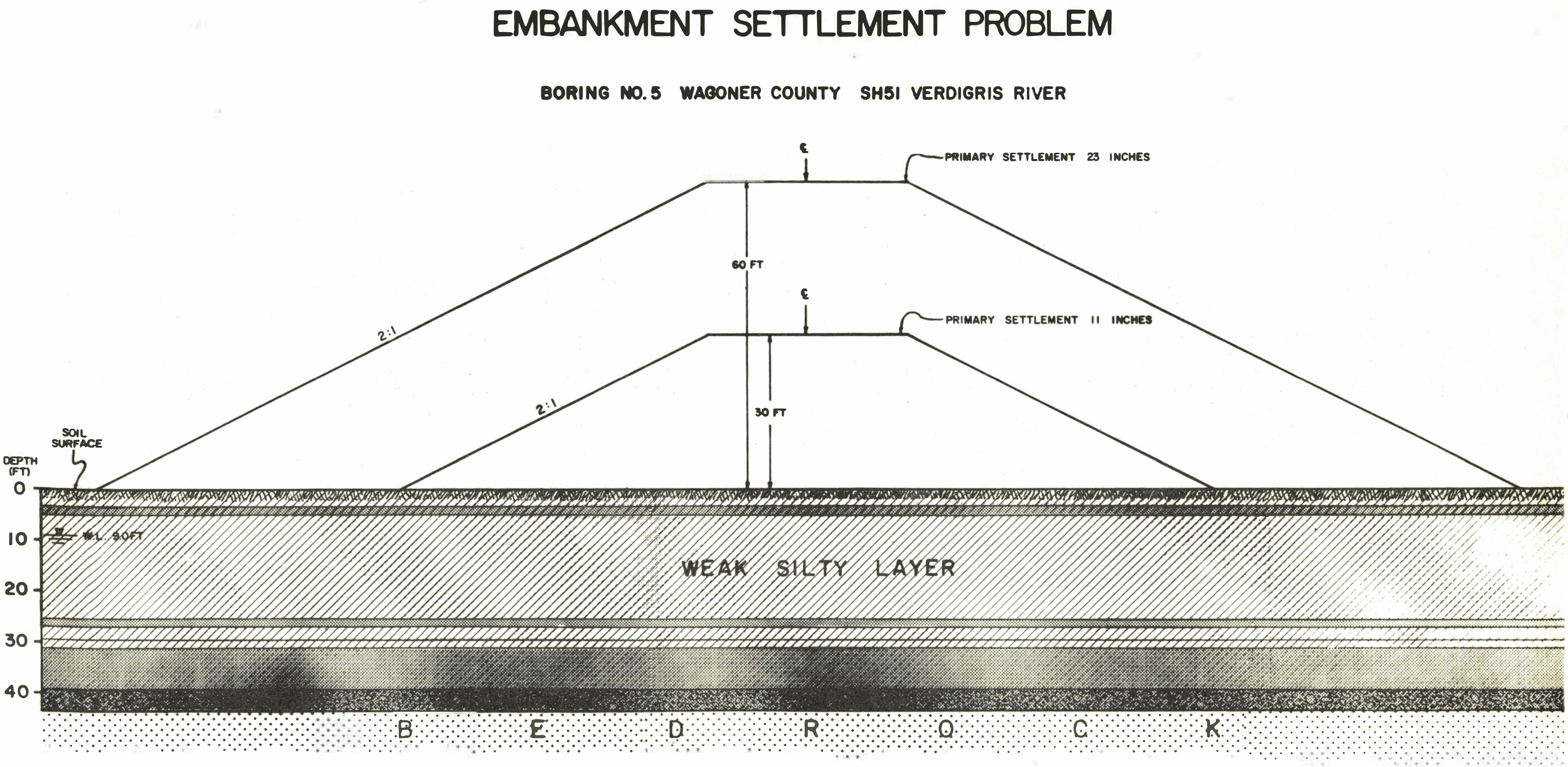


Figure E-1. Hypothetical embankments placed on the weak silty soils at Boring No. 5.

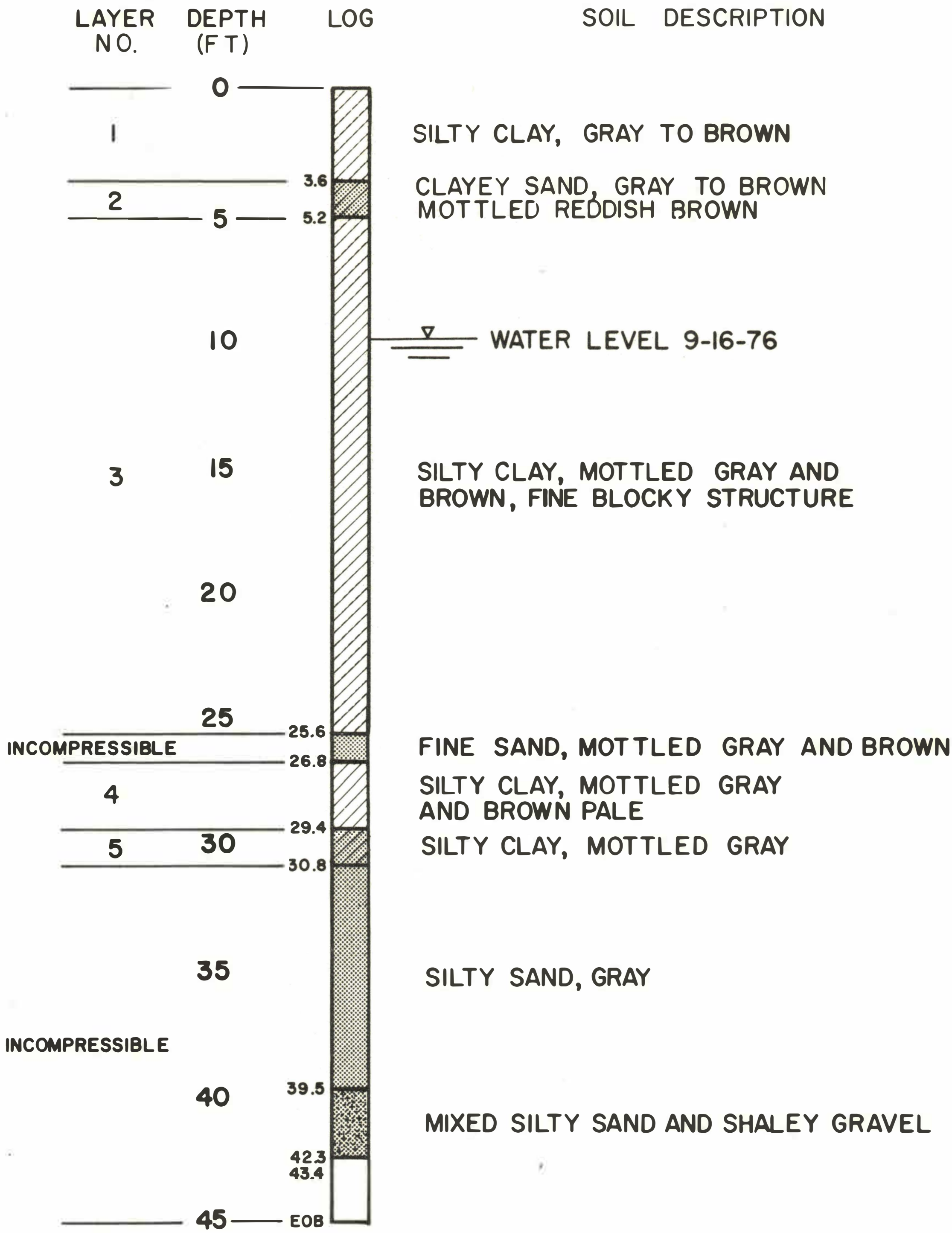


Figure E-2. Log of Boring No. 5, Verdigris Soil.