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Engineering Characteristics of Lacustrine Deposits Associated with Coal Strip Mining, Southwest Indiana

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Introduction

During the Pleistocene, hundreds of valleys in southwest Indiana were occupied by meltwater lakes. Lake beds were formed in tributary valleys of heavily aggraded glacial sluiceways and today they generally extend beyond the ice-contact boundaries. Most of the lake beds are now veneered with a blanket of loess which makes it more complicated to obtain accurate surface maps depicting these lacustrine deposits.

The lake beds consist of unconslidated, interfingered sediments and are directly associated with outwash, dune sand, loess and sometimes glacial till. The lacustrine sediments themselves consist primarily of silt and clay with thin layers of sands, organics, and marls. They were deposited in quiet waters adjacent to upland areas composed primarily of Pennsylvanian-aged bedrock. The overall stratigraphy of the system is extremely complex.

Many of these lacustrine deposits overly the strippable coal reserves of the state. Owing to their low shear strengths, these deposits create problems for coal strip mining operations such as highwall excavation and cast over spoil piles. The deposits are frequently saturated and because of their very low permeabilities and complicated stratigraphies, they cannot be dewatered prior to excavation.

Previous research performed at Purdue University by Greengold (1981a, 1981b) and Oschman (1984) examined the engineering problems of lacustrine materials associated with coal strip mining areas in Indiana and Illinois, respectively.

Lacustrine deposits were encountered in the construction of Interstate 164 which will be a highway bypass on the east side of Evansville. Exploration and testing data obtained from this highway project (Atlas Soils Inc., 1985) provided additional engineering data on these deposits.

A study involving lacustrine deposits and coal strip mining in southwest Indiana is currently underway at Purdue University to determine in more detail the nature and engineering characteristics of these deposits.

This paper examines the extent and origin of these lacustrine deposits and provides engineering characteristics for these problematic soils.

Origin and Extent of Lake Beds

Major streams that drained southwest Indiana carried such great loads of sediment during glacial times that their valleys became heavily aggraded. This resulted in blockage and ponding of hundreds of tributary streams. Thick deposits of lacustrine silts and clays filled these valleys.

The majority of the lake beds lie in the Wabash Lowland physiographic division. Malott (1922) characterized this landform unit as alluvial in origin and emphasized the prevalence of aggraded valleys. Glacial till partially covers the Wabash Lowland and is underlain by lacustrine, outwash and alluvial sediments. Upland areas are undulating to rolling plains covered by eolian sediments that generally thin to the east from the Wabash River valley train source (Schneider, 1966). The Wabash

Lowland developed from valley-widening caused by pre-glacial erosion of weak Pennsylvanian limestones, sandstones, and shales.

Pennsylvanian strata comprise the Sullivan Lowland bedrock physiographic division. Topography on the bedrock surface is generally much more irregular than is the present topography of the land surface, however, from a regional view point, the relief is smooth and gentle. Bedrock elevations typically occur below 500 feet elevation. Bedrock valleys trend southwest toward the Wabash and Ohio Rivers.

Lacustrine deposits of this study area are only one of the facies of the Atherton Formation which spans the entire Pleistocene epoch in Indiana. Wayne (1963) assigned this name to a group of unconsolidated sediments that resulted from glacial action, but were generally deposited beyond the glacial limits by the action of meltwater or wind. He identified four distinct facies within the Formation. They are: 1) outwash facies, 2) lacustrine facies, 3) dune facies, 4) loess facies. The sediments were primarily derived from outwash, and they interfinger with each other. Figure 1 schematically illustrates the facies of the Atherton Formation.

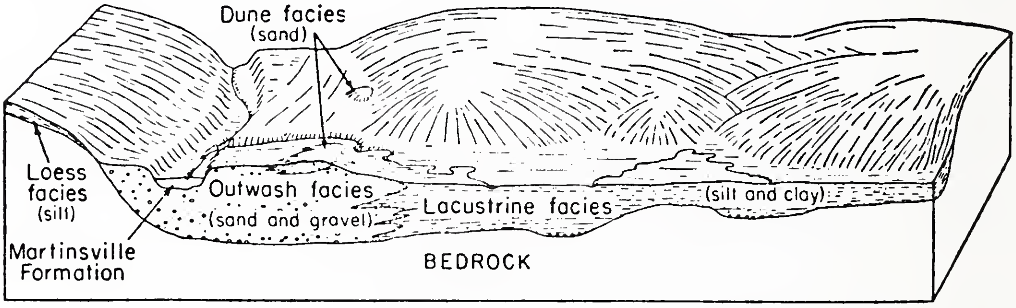

FIGURE 1. Schematic diagram showing the facies relationships of the Atherton Formation (Wayne, 1963).

Figure 2 represents the distribution of glacial lacustrine deposits in southwest Indiana. Note the dendritic patterns of the deposits indicating that the lakes occupied pre-existing valleys. Because many of these deposits are covered with loess, and a minimum mapping thickness of approximately six feet was used, the unit boundaries should be considered only approximate.

1981 Purdue University Study

In 1981 a study was completed at Purdue University (Greengold, 1981a) involving coal strip mining and lake bed clays. The study area is located near Petersburg, Indiana, (Pike County) approximately 30 miles north of Evansville. Figure 3 gives the site location.

For this coal mine area, subsurface investigations indicated the topography varies in excess of 50 feet in elevation for a site of about 4 square miles. The land surface of the site prior to strip mining also had a relief of nearly 100 feet. Because of this combination the thickness of the unconsolidated materials varied from 0 to 105 feet.

Unconsolidated materials consist of loess, glacial-lacustrine sands, silts and clays; and glacial till which collectively yield an extreme range in soil properties. The lake beds were deposited in glacial Lake Patoka which was in excess of 100 square miles in area.

Stratigraphy is dominated by organic-bearing lacustrine clays and loose, fine to medium, saturated sands. Sands and clays range from small pockets to others greater than 50 feet thick and hundreds of feet across. There are two lake bed deposits

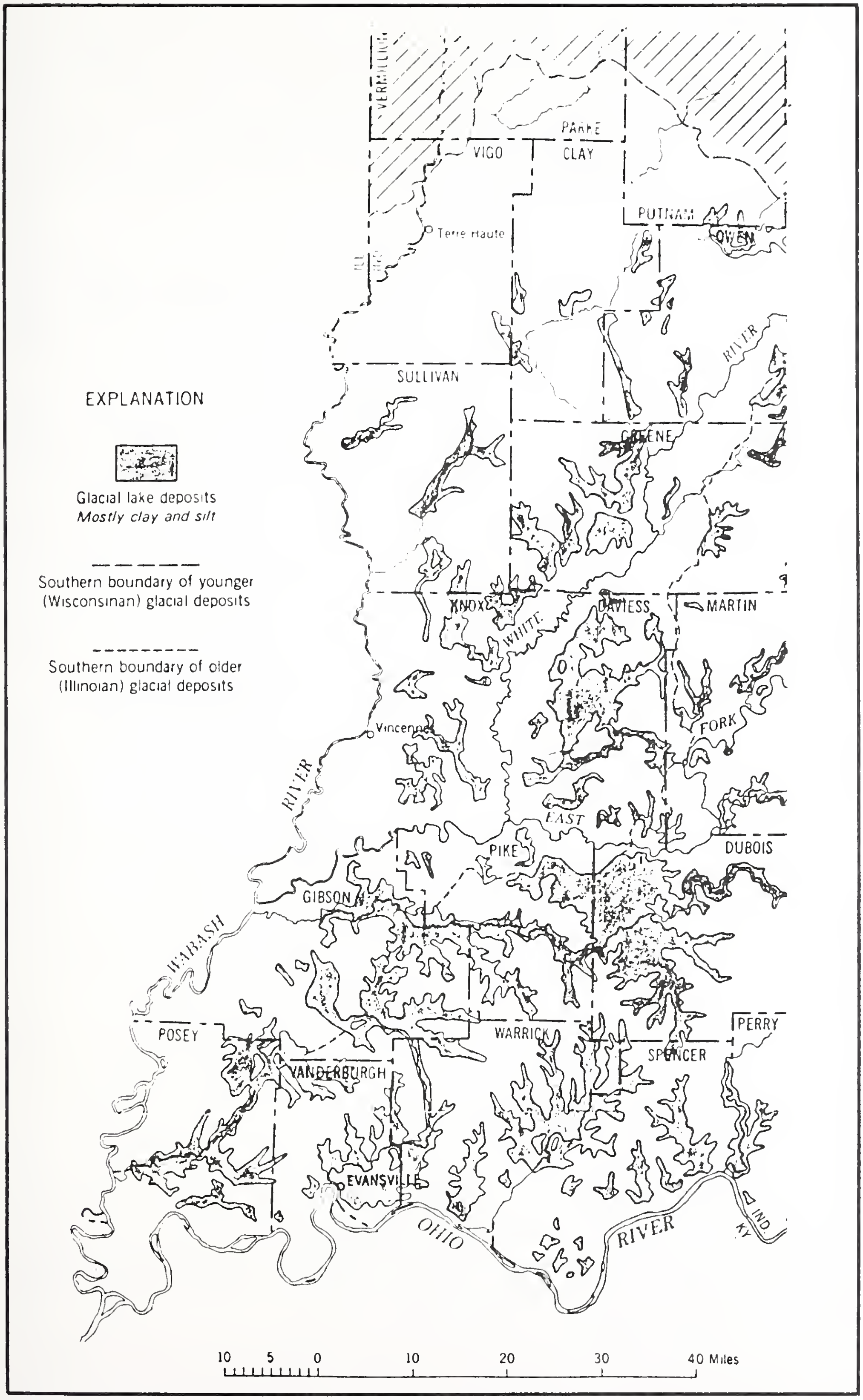

FIGURE 2. Map showing the distribution of glacial lacustrine deposits in southwestern Indiana (from Gray, 1971).

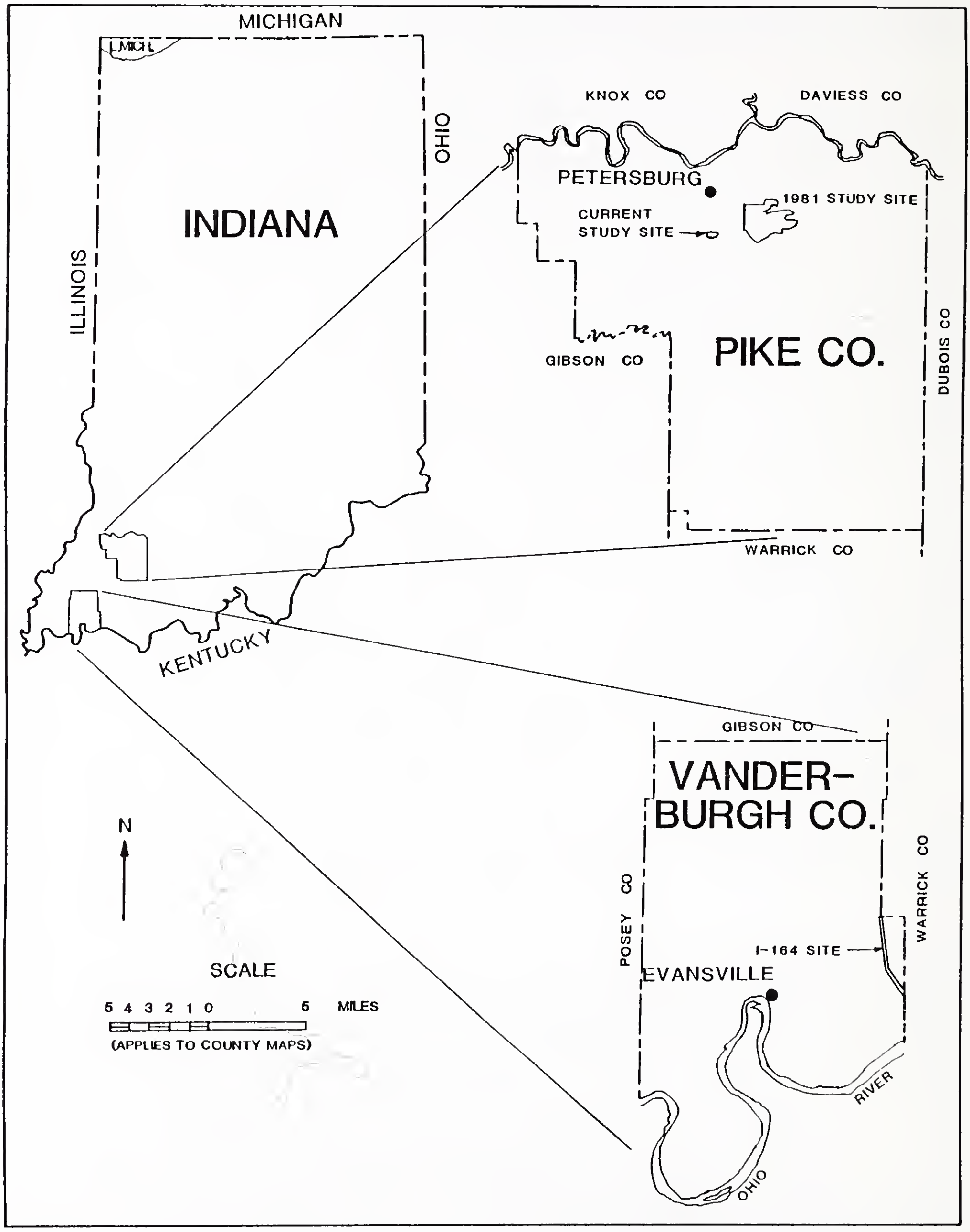

FIGURE 3. Site locations map.

on the four-square mile site. The northern unit with an areal extent of about 1/4 of a square mile is Wisconsin in age. The southern unit is of Illinoian age and is about one square mile in extent. Bedrock is the Pennsylvanian-aged Dugger Formation, here a gray sandy shale interbedded with yellow and gray sandstone and some limestone. The coal seam being mined is the Indiana Number V seam or Springfield Coal which is about 6 feet thick at this location.

Samples were obtained in borings by standard penetration tests and by Shelby tube sampling. Split spoon samples were taken at 5 foot intervals. Twelve borings were accomplished. Two layers of unconsolidated materials were indicated; the upper layer 18 to 23 feet thick showed N values ranging from 8 and 22 blows per foot.

This layer presumably included loess, lake silts, alluvium and glacial till. The lower layer includes glacial till, plus gray lacustrine clays and sands. Blow counts in the lower unit ranged from zero in the loose saturated sands to 91 blows per foot in the very stiff glacial till.

Shear strengths for the gray lacustrine clay ranged from 0.08 to 1.37 $tons/ft^2$ with an average of 0.6, based on 15 unconfined compression tests and 16 shear vane tests. The loess had a range of shear strength from 0.08 to 1.44 $tons/ft^2$ and an average of 0.7, based on four unconfined tests and four vane tests. The yellow clays or "lake silts" averaged 0.08 $tons/ft^2$ for two shear vane tests of 0.04 and 0.11 $tons/ft^2$. In a previous study of the coal mine area, values ranging from 0.42 to 2.03 were obtained for the silty yellow clays. In that earlier study shear strengths of the glacial till ranged from 2.51 to 5.25 $tons/ft^2$ with dry unit weights between 94 and 101 lbs/ft^3.

In the study by Greengold (1981a) the sensitivity of the gray clay averaged 1.7 based on 15 shear vane tests. Values ranged from 1.2 to 2.5. Clays with sensitivities < 2 are considered to be insensitive (Bowles, 1979, p. 377). The loess has an average sensitivity of 1.5 (2 tests) whereas the lake silts averaged 1.6 (2 tests).

Units weights for the loess (in situ or wet density) ranged from 106 to 133 psf, averaging 124 pcf for four samples. The lake silts (calcareous, pebbly yellow clays) ranged from 120 to 135 pcf, averaging 125 pcf for two samples. The gray lake clays varied from 113 to 144 pcf with an average of 139 pcf for 13 samples.

Water content of the gray clay ranged from 17 to 46% with an average of about 26% for 29 samples. In a general way shear strength decreased with increasing water content but there was not a strong correlation between them.

Again with respect to the gray lacustrine clay the shear strength did not increase with depth (or with increasing overburden pressure). Instead the lowest values of shear strength were found near the base of the gray lacustrine clay. This indicates a potential slope stability problem when these materials are excavated during strip mining.

For this strip mine in Pike County, Indiana slope stability in the spoil piles formed by the large drag line is also a concern. The unconsolidated material ranges from 0 to 105 feet thick as stated previously and the rock overburden above the coal seam ranges upward to 160 feet thick. Where soils comprise more than 40% of the total overburden section, spoil pile instabilities arise as rock volume is insufficient to retain the soil. The rock spoil is piled into two parallel rows with the soil placed in the V-notch between them. When the soil comprises more than 40% of the total overburden it overflows the V-notch volume. In such cases, the extra soil must be stripped away prior to the dragline operation and moved to the high wall side of the cut using large trucks.

In the study by Greengold (1981a) several recommendations were made to reduce slope stability problems in the highwall. These included: dewatering sands where applicable, benching in thick soils to reduce slope failures and reorienting the pit to prevent the concentration of soft material in certain sections of the excavation.

Interstate Highway I-164 Study

Interstate Highway 164 is currently under construction east of Evansville, Indiana. When completed it will extend for about 13 miles connecting Indiana State Road 66 to Interstate 64. With almost a north-south alignment, it will serve as a bypass around the east side of Evansville (Atlas Soils Report, 1985).

I-164 is located close to the north-south boundary between Warrick County on the east and Vanderburgh County on the west. These two counties are immediately north of the Ohio River in southwestern Indiana (Figure 3).

The site lies south of the maximum extent of Illinoian glacial ice in the unglaciated portion of Indiana. Glacial fluvial deposits in the form of lake bed clays and sandy outwash occur in southern Vanderburgh and Warrick Counties. In the extreme southern part of the counties near the Ohio River, alluvial sand prevails as stream deposits and adjacent terraces. Lacustrine deposits are found northward for several miles until residual soils formed by the weathering of Pennsylvanian shales and siltstones prevail. The lacustrine deposits of gray clay and sand are found up to 50 feet thick in eastern Vanderburgh County.

To obtain additional details on the engineering properties of lacustrine clays, a 4.7 mile section of the design plans for I-164 were evaluated. For this section of road, 37 road centerline borings were taken and 36 structure borings were completed. The road borings ranged in depth from 6 to 36 feet deep whereas the structure borings, located at bridge overpass structures, were typically 30 to 80 feet deep. Many of these extended to bedrock (West, 1987).

In this area the upper 10 feet or so was typically a brown silty loam, i.e. loess. This wind deposited silty material is prevalent on the eastern side of the Wabash River in Indiana. The gray silty clay, lacustrine materials occurred below the loess. The gray clays had standard penetration values (N values) ranging from 7 to 30 blows per foot with typical values about 15 to 20. Moisture contents ranged from 16 to 50% with most values around 26%. The plasticity index for the gray clays was about 12, with liquid limits and plastic limits about 32 and 20, respectively. Wet unit weights ranged from 117 to 132 lb/ft^3 with natural moisture contents for these samples about 25%.

Unconfined compression tests had been run on 17 soil samples. Shear strengths ranged from .066 to 1.50 $tons/ft^2$ with an average of 0.56 $tons/ft^2$. Rimac values had been made on the split spoon samples following drilling. For 374 samples tests an average of 0.935 T/ft^2 was obatined for these tests. Comparing the two answers, 0.935 is 1.67 times greater than the 0.56 value obtained from unconfined compression tests. The Rimac values tend to be high for such comparisons.

Eleven triaxial compression tests had been run on the samples. The cohesion values ranged from .25 to 1.3 $tons/ft^2$ and the ϕ angles from 0 to 3.8 degrees.

Current Research

A study is presently underway at Purdue University involving lacustrine clays and coal strip mining in southwest Indiana. The Prides Creek-East Pit owned by Solar Sources, Inc. is located in Pike County, two miles south of Petersburg, Indiana (Figure 3). A thick lacustrine deposit was encountered by the coal company during strip mining operations at the western boundary of their property. This is an on going research project supported by the U.S. Bureau of Mines, through the Indiana Mining and Minerals Resources Research Institute.

Elevation of the bedrock surface at the site varies more than 70 feet over a distance of approximately one half mile from east to west. The original landsurface across the same location varied approximately 30 feet. Thickness of the unconsolidated materials at the site ranged from approximately 3 to 60 feet. These isolated lake bed deposits had an areal extent of about seven square miles.

Unconsolidated deposits consist of loess, organic bearing to rich, highly calcareous silts, clays, and some sands. Glacial till was not encountered at the site. Bedrock consists of the Pennsylvanian Dugger Formation. Coals mined at the site are the Bucktown (Coal Vb) and Springfield (Coal V) coal members of the Dugger and Petersburg Formations, respectively.

A boring involving continuous split spoon sampling was made through the lacustrine section to bedrock in the summer, 1986. Upper and lower portions of each split spoon sample were collected. A stratigraphic section for the boring was developed

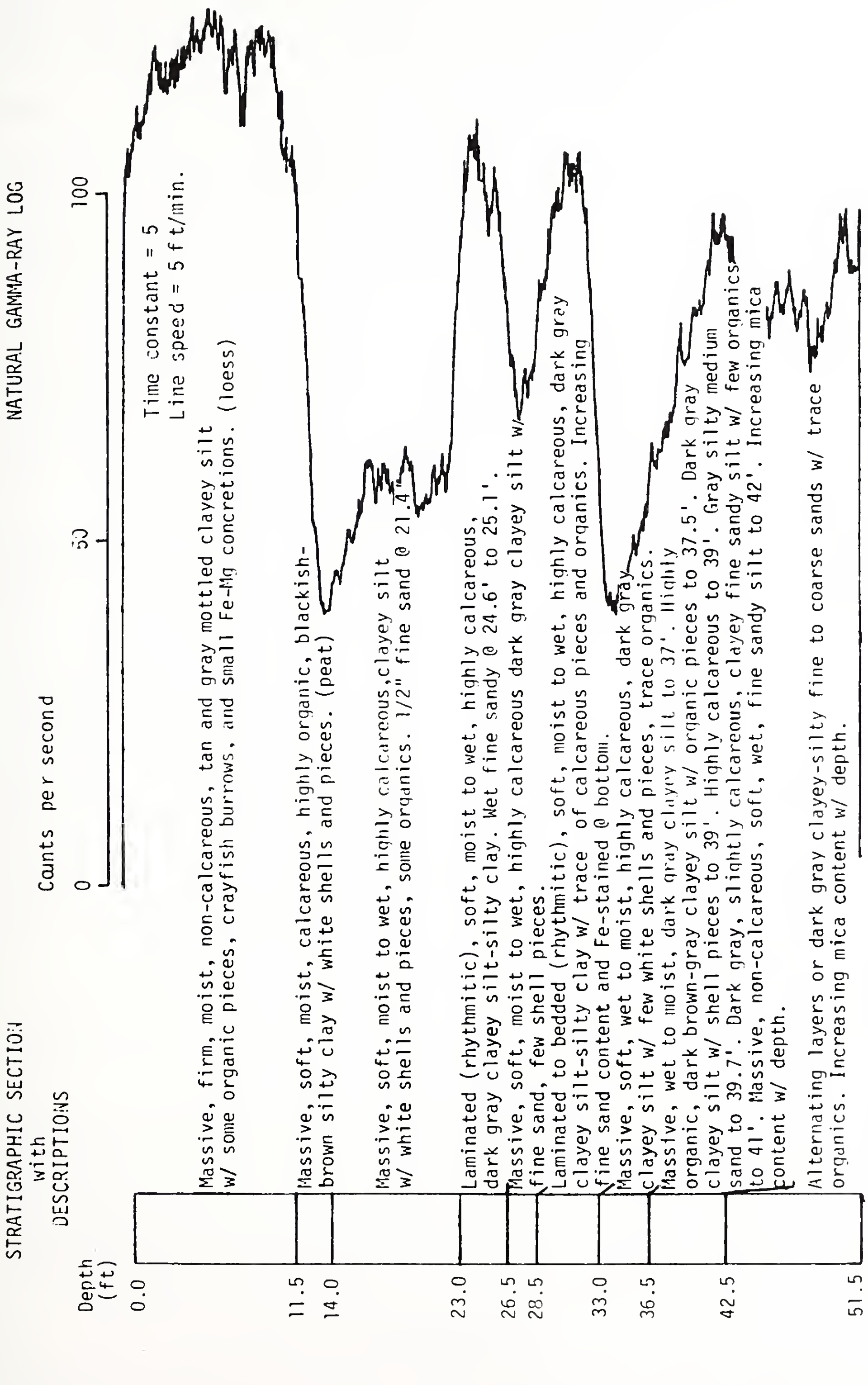

FIGURE 4. Stratigraphic section and natural gamma-ray log of boring at the Prides Creek site.

from the drilling logs and samples which was subsequently compared to the natural gamma-ray log of the boring. The gamma-log provides a signature for the deposit. Figure 4 presents the gamma-log signature and a descriptive stratigraphic section of the deposit. The boundaries shown in the section are somewhat penetration values (N) of the deposit ranged from 5 to 9 for the loess and from 2 to 5 for the lacustrine silts and clays.

In table 1, results are presented for laboratory analysis completed on bag samples collected from the exposed face at the Prides Creek site.

Adjacent to the split spoon boring, a second boring was made to collect undisturbed samples using pushed Shelby tubes. Unit weights, natural moisture contents, and unconfined compressive strength tests were performed on these samples.

The average natural unit weight for the loess was 121.5 pcf with an average natural moisture content of 24%. The shear strength ranged from 0.32 to 0.56 ton/ft^2 and averaged 0.42 ton/ft^2.

The lacustrine silts and clays occur below the 11.5 foot thick surficial loess layer. Their natural unit weights ranged from 99 to 122 pcf. The average of eleven determinations was 114 pcf. Unconfined compression tests were run on 20 samples. Shear strengths ranged from 0.16 to 0.60 ton/ft^2. The average was 0.40 ton/ft^2. Natural moisture content ranged from 21 to 67% with an average of 41.1%, based on 31 determinations. The results of these tests are summarized in Table 2.

It is clear that the strength of this deposit is quite low. The lacustrine silts and clays are reasonably plastic with plasticity indices ranging from 4 to 51. The clay content ranged as high as 52%. The lacustrine soils are designated as ML, CL, CH, and OH according to the Unified Soil Classification. As in the Greengold (1981a) study, there was no strong correlation between water content and shear strength.

X-ray diffraction analyses were run on the clay size fraction of the lacustrine deposit. The analyses showed that the lacustrine deposit contains the following clay minerals; montmorillinite and possibly vermiculite, illite, chlorite, and kaolinite. The mean approximate percentages of the clay minerals are: Expandables—53.8%, Illite—25.8%, Kaolinite + chlorite—20.4%. The high percentage of the expandable clay minerals underscores the stability problems encountered at the site. As the lacustrine materials are excavated, the highwall face is open and exposed to repeated wetting and drying cycles. Studies have shown that the shear strength of expansive clays containing montmorillinite decreases as a result of wetting and rewetting (Gibbs et al., 1960).

Comparison to Test Results

A comparison can be made for the gray lacustrine clays for the three sites discussed above. This is summarized in Table 2.

From this comparison it is evident that the lacustrine deposits of the current study area are weaker than those of the other two sites. In the current study area the soils are more plastic and have higher natural moisture contents. Also, they contain a large percentage of clay minerals. X-ray analyses indicate that greater than 50% of the clay minerals are of the expandable types. The characteristics of the other two sites are perhaps more typical of lake bed deposits for larger depositional areas.

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TABLE 1. Soil Samples Results, Prides Creek-East Pit

Description	Approx. Depth (ft)	N value blows/ft	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	% Silt (<.004mm)	% Clay (>.004mm)	Unified Soil Classification
Gray w/tan mottling slightly clayey silt with organics	6	6	28	18	10	71	25	CL
Dark gray soft moist silty clay w/some small calcareous pieces	13	3	88	37	51	43	43	OH
Dark gray soft moist silty clay w/small white calcareous pieces	17	2	50	36	14	72	17	MH
Dark gray moist to wet silty clay w/ a few small calcareous pieces	22	2	51	26	25	76	7	CH
Dark gray wet soft clay to silty clay w/ a few small calcareous pieces	26	4	32	28	4	83	9	ML
Dark gray clayey silt w/ a few small calcareous pieces	30	5	24	17	7	72	23	CL
Dark gray moist to wet clayey silt w/ trace of small calcareous pieces and trace organics	30.5	2	33	16	17	48	52	CL
Dark gray moist clay w/ a few small calcareous pieces	33	3	39	30	9	78	11	ML
Dark gray soft silty clay	37	2	35	27	8	77	11	ML

TABLE 2. Comparison of results, three locations of lacustrine clay deposits.

Study Designation	N value Blows/ft	Shear Strength Range T/ft²	Average Shear Strength T/ft²	w% Range	w% Average	PI Range	PI Average	Sensitivity		Natural Unit Wt.		Dry Unit Wt.	
								Range	Avg.	Range pcf	Avg. pcf	Range pcf	Avg. pcf
1981 Study	8-22	0.08-1.37	0.6	16-53	26.4	—	—	1.2-2.6	1.7	106-144	129	76-122	103
Current Study	3-5	0.16-0.60	0.4	21-67	41.1	4-51	17	—	—	99-122	114	59-100	82
I-164 Study	7-30	0.07-1.50	0.56	16-50	25.8	7-21	12	—	—	117-132	125	88-109	99

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