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Stratigraphy of the Glacial Deposits at the National Accelerator Laboratory Site, Batavia, Illinois

Ronald A. Landon
John P. Kempton

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ILLINOIS STATE GEOLOGICAL SURVEY
URBANA, ILLINOIS 61801
John C. Frye, *Chief*

STRATIGRAPHY OF THE GLACIAL DEPOSITS AT THE NATIONAL ACCELERATOR LABORATORY SITE, BATAVIA, ILLINOIS

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ABSTRACT

The identification and correlation of five informal rock-stratigraphic units within the glacial deposits at the National Accelerator Laboratory site near Batavia, Illinois, provided a stratigraphic framework for the preliminary engineering evaluation of the foundation conditions at the site. This stratigraphic study was based on the description and analysis of representative samples taken from initial test borings made throughout the site.

Visual lithologic and textural characteristics served to differentiate the major units while quantitative laboratory analyses of the grain size and the clay mineral composition provided supplementary data for differentiation as well as an effective basis for the correlation of units. Engineering properties, such as unconfined strength, moisture content, dry density and Atterburg limits, showed a strong correlation with the physical properties of the tills and therefore could be related to the various stratigraphic units differentiated within the site.

The five stratigraphic units at the site, from top to bottom, are: Unit A, surficial loess and local alluvial and lacustrine silt and sand; Unit B, silty and clayey tills; Unit C, mostly silty and sandy tills, but including water-laid silt and sand and gravel; Unit D, till containing more than 50 percent clay; and Unit E, silty and sandy till with considerable amounts of outwash sand and gravel.

All of the glacial deposits at the NAL site are Wisconsinan in age.

INTRODUCTION

Following selection of a site at Weston, Illinois, as the location of the U. S. Atomic Energy Commission's 200 billion electron volt accelerator, the Illinois State Geological Survey was requested by the U. S. Army Corps of Engineers to undertake a stratigraphic study of the unconsolidated glacial deposits of the site for the purpose of defining the sequence, character and extent of the various units within the drift. It was anticipated that this information would provide a geologic framework within which the engineering properties determined on individual samples could be organized and systematically evaluated.

The preliminary drilling program at the Weston site of the accelerator facility, now called the National Accelerator Laboratory (NAL), consisted of 67 borings, many of which were drilled to or into bedrock. This drilling program was undertaken by the Foundation Materials Branch of the U. S. Army Corps of Engineers, Chicago, to determine the nature of the subsurface deposits and to provide data for placement of the large accelerator ring within the site. The Geological Survey was provided with samples taken at regular intervals from 28 of the borings distributed throughout the site; these samples were utilized in defining the stratigraphic framework. Reports by the authors (Landon and Kempton, 1967, and Landon, 1967) for the Corps of Engineers form the basis for this report.

It is our purpose in this report to describe the stratigraphy of the NAL site, to describe the methods utilized to define the stratigraphy, and to show how the stratigraphic study was used as a framework for relating engineering properties to the glacial materials encountered. It was not the intent of this study to evaluate foundation conditions.

Site Description

The National Accelerator Laboratory is located approximately 30 miles west of Chicago (fig. 1) and two miles east of Batavia in the southeastern part of T. 39 N., R. 8 E., Kane County, and in the southwestern quarter of T. 39 N., R. 9 E., Du Page County (fig. 2). Along the western edge of the site, a north-trending upland, the Minooka Moraine, rises about 40 feet above the relatively flat central portion. Along the eastern edge, the land surface is gently rolling and it slopes toward the southward flowing West Branch Du Page River. Kress Creek, which flows across the northeastern corner of the site, and two unnamed drainages along the eastern edge are tributaries to the West Branch. Small marshes are found near some of the smaller drainages. Ground-water saturation was common at depths within 10 feet of land surface in the exploratory borings.

Acknowledgments

James E. Hackett was instrumental in initiating this study and in developing many of the subsurface stratigraphic methods employed in it. The cooperation and interest of the U. S. Atomic Energy Commission, the U. S. Army Corps of Engineers, and their engineering consultants were major factors in the success of this study. Special thanks are expressed to Professor Ralph B. Peck, University of Illinois, who reviewed this manuscript. Paul C. Heigold undertook the preliminary statistical treatment of data. Paul B. DuMontelle assisted Heigold and aided in interpreting the engineering data. Grain-size analyses were made under the supervision of W. A. White. H. D. Glass provided the interpretation of the X-ray diffraction data.

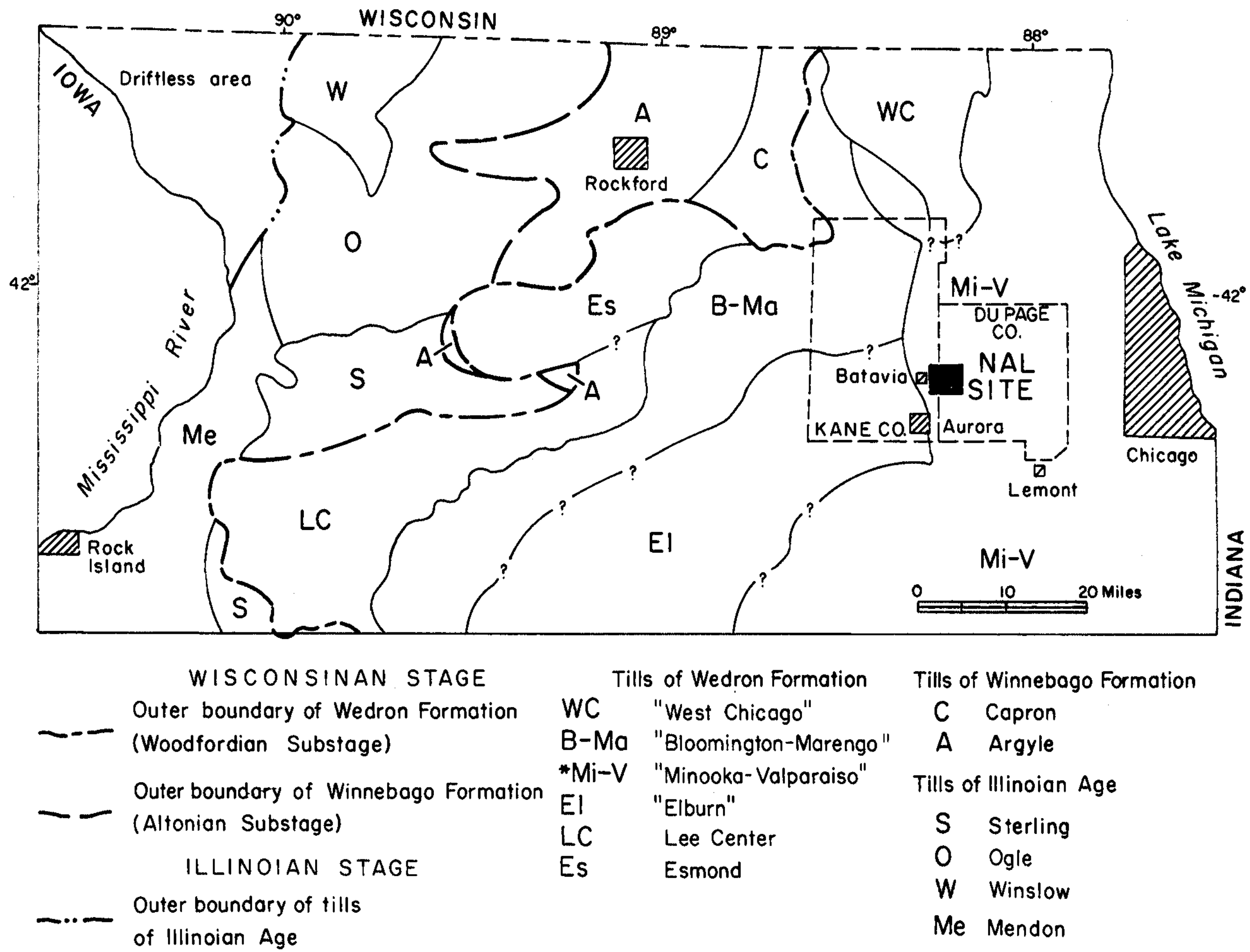


Fig. 1 - Northern Illinois showing location of NAL site and distribution of till units; modified from Kempton and Hackett, 1968b, and Frye, Glass, Kempton and Willman, 1969. Till names in quotes are taken from principal moraine(s) composed of the specific till. *Undifferentiated gray, generally silty, clayey tills east of and including the Marseilles and Minooka Moraines (Ekblaw, 1959).

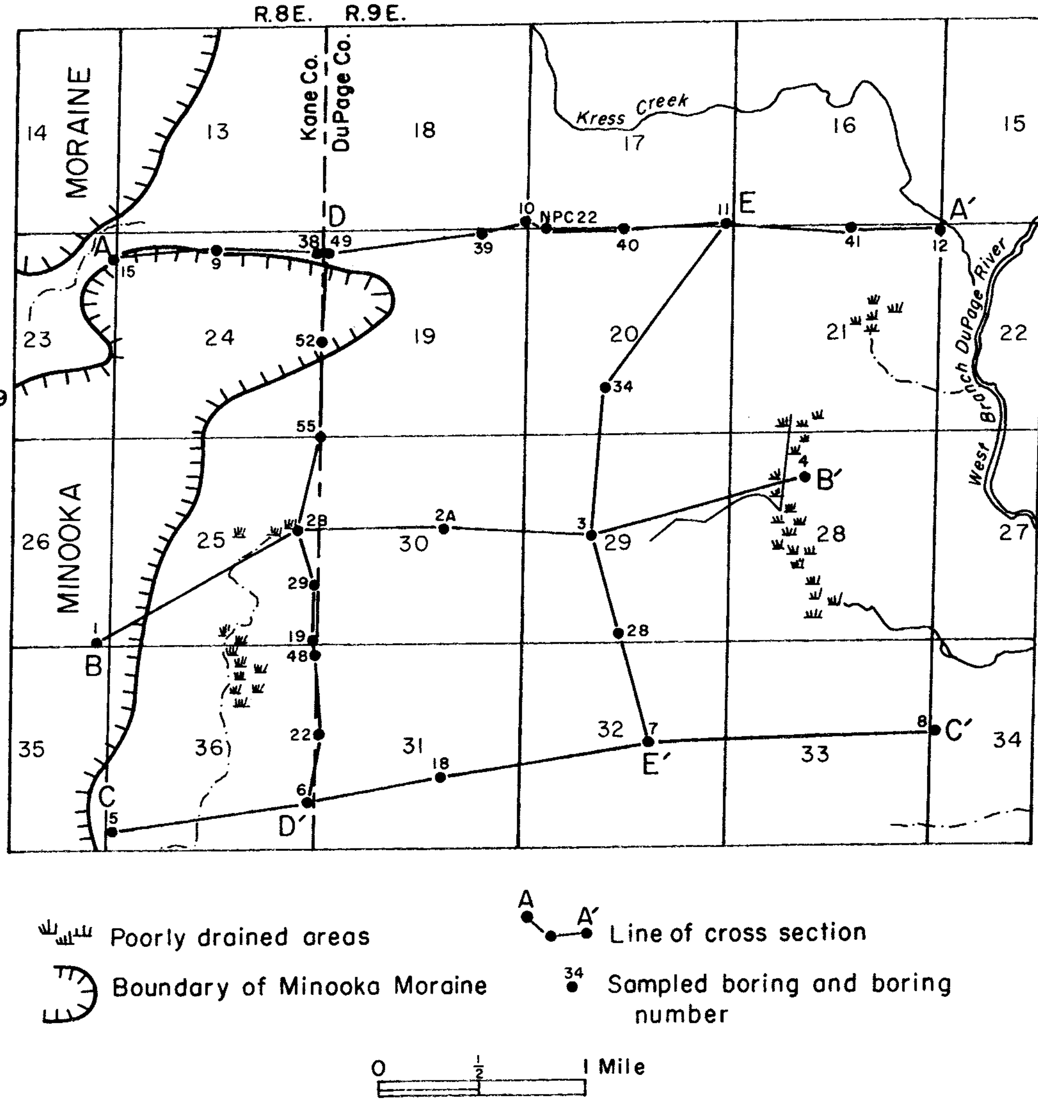


Fig. 2 - NAL site showing main physical features, location of borings used for stratigraphic control in this study, and lines of cross sections.

METHOD OF STUDY

The need for detailed quantitative descriptions of the glacial materials within a well-defined stratigraphic framework at the NAL site dictated the methods of geologic evaluation used in this study. Previous studies in Illinois (Otto, 1942; Kempton and Hackett, 1962; Chryssafopoulos, 1963; Willman, Glass and Frye, 1963; Kempton, 1963; and Johnson, 1964) have suggested that quantitative data on clay mineralogy, texture, and other physical properties could be used to differentiate and correlate glacial materials, particularly tills. More recent studies (Kempton and Hackett, 1968a, 1968b; Frye, Glass, Kempton and Willman, 1969; and Jacobs and Lineback, 1969) have substantiated the value of such quantitative data and have established that many glacial tills are relatively homogeneous over rather large areas and thereby allow for local and regional extrapolation of properties. Thus the use of a large quantity of such data from the boring samples at the NAL site along with other, routine geologic descriptions was considered an essential basis for defining the sequence and character of the glacial deposits at the site.

Grain-Size Analysis

Grain-size determinations, based on the Wentworth classification, were made by the use of Tyler sieves and by hydrometer procedure. The data presented as the grain-size distribution are classified as follows: gravel - greater than 2.0 mm; sand - 0.062 mm to 2.0 mm; silt - 0.0039 mm to 0.062 mm; and clay - less than 0.0039 mm. The sand, silt and clay percentages were calculated from the less than 2 mm fraction only.

Approximately 340 grain-size analyses were made on the tills at the NAL site.

Mineralogical Analysis

The clay mineral and carbonate data used in this study were obtained by the methods described by Willman, Glass and Frye (1963, p. 11). Montmorillonite includes all clay materials that expand to about 17° A with ethylene glycol. Chlorite includes all 14° A material that does not expand with ethylene glycol; it also includes any non-expandable vermiculite. Illite and kaolinite are used as generally accepted. The values for kaolinite and chlorite are combined while the values for montmorillonite and illite are given separately. (Since little or no kaolinite has been identified from the X-ray data of the till samples analyzed for this study, the values of kaolinite plus chlorite are essentially a measure of the chlorite present.) Determination of the presence of carbonate minerals was made by X-ray analysis and indicates semiquantitatively the amounts of calcite and dolomite.

Clay mineral data are useful in differentiating glacial deposits, particularly tills, when the various deposits have different sources and thus contain noticeably different clay mineral suites. These data are also useful in recognizing buried weathering profiles. Since chlorite is very sensitive to oxidation, its progressive loss upward in the weathering profile is frequently the basis for recognition of a significant interval of ice-free conditions (Willman, Glass, and Frye, 1963, 1966).

The presence of certain clay minerals, particularly the expandable clay minerals such as montmorillonite, is also quite significant in engineering projects. Large amounts of these expandable clay minerals may frequently cause settlement and other problems.

For this study, X-ray diffraction data were obtained on 66 samples from four borings within the NAL site.

Use of Engineering Properties

Those engineering properties that are in part a function of both lithology and mineralogy, namely Atterberg limits and moisture content and to a lesser extent, dry density, were found to be useful supplementary information in defining stratigraphic units. These properties were utilized mainly when a question arose as to which unit an individual sample belonged. However, it should be emphasized that in this study, the units present were defined and correlated principally on the basis of genetic type and lithologic and mineralogic properties. Since many of the engineering properties are the function of both lithology and mineralogy, they can be directly related to the units, and the range of properties can, in general, be extrapolated for the same unit elsewhere once the geologic identification of the unit has been made.

For this study, approximately 1500 engineering property determinations, including moisture content (360), dry density (120) and Atterberg limits (720), were made available by the U. S. Army Corps of Engineers. An additional 21 moisture content determinations and 20 values for unconfined compressive strength were available (Larsen and Lund, 1965, p. 8-10) from a previous boring from within the area. (The unconfined compressive strength is a measure of the consistency of the undisturbed cohesive glacial materials, expressed as the load per unit of cross-sectional area in tons per square foot.)

Data Processing and Evaluation

With the large amount of quantitative data and stratigraphic information obtained from even a relatively small number of borings, summarizing and evaluating the data were a major undertaking. Initially the quantitative data from each unit in each boring were summarized and the average values for each property determined. This procedure greatly facilitated correlating units between borings and allowed for a generalized determination of the properties of each unit throughout the NAL site.

In order to obtain a more rapid and precise summary of the property data for each stratigraphic unit, the IBM 640 digital computer at the University of Illinois was employed. The purpose of the summary was twofold: (1) to establish the ranges and mean values for the numerous properties of the various tills and (2) to test for similarities or differences among the individual tills.

For each boring, computer input included general information about the hole; the elevations of the top and bottom of each sampling interval; the corresponding genetic interpretation, grain size, and mineralogical and engineering properties of the material for each sampling interval; and the preliminary stratigraphic interpretation. The stratigraphic data input included elevations of the top and bottom of each stratigraphic unit, a numerical designation for each distinct till lithology, and a letter designation for each group of similar tills and related deposits. The ranges, means, and standard deviations of pertinent textural, mineralogical, and engineering properties were calculated by the computer for each stratigraphic unit in each boring.

These properties were also tabulated for each stratigraphic unit by summarizing information from all borings from which samples were available. The initial step was thus to summarize all data available for each unit, including the number of samples and the mean for each property or measurement. This information is listed in table 1.

TABLE 1 - SUMMARY OF DATA FOR TILLS AT NAL SITE

Unit	Subunit	Till no.		Sand	Silt	Clay	Qu	W	DD	LL	PI
A		Loess, Silt, Sand	No. spls.	15	15	15	No data	43	10	40	40
			Mean	8	67	25		24.9	94	41.4	21.6
B		1	No. spls.	107	107	107	7	97	36	90	90
			Mean	9	53	38	3.2	16.5	115.3	27.9	12.4
		2	No. spls.	30	30	30	No data	29	7	30	30
			Mean	8	44	48		18.5	114.0	30.6	14.5
C	C1	3	No. spls.	21	21	21	1	16	No data	15	15
			Mean	33	45	22	5.2	12.8		21.5	8.1
		Sand and gravel, Silt									
	C2	4	No. spls.	37	37	37	2	31	11	29	29
			Mean	26	47	27	3.0	11.8	130.2	22.6	9.6
		5	No. spls.	37	37	37	8	37	10	29	29
			Mean	20	43	37	2.6	15.0	122.1	28.0	13.5
D		6	No. spls.	81	81	81	No data	101	53	106	106
			Mean	8	36	56		20.8	107.0	39.3	18.9
E		7	No. spls.	29	29	29	No data	25	2	25	25
			Mean	40	45	15		10.1	127.5	16.6	4.7
		Sand and gravel									

EXPLANATION

Qu - unconfined compressive strength in tons/ft^2 (undisturbed)
W - natural moisture content in percent
DD - dry density in pounds/ft^3
LL - liquid limit in percent
PI - plasticity index
Sand, silt and clay in percent of less than 2 mm fraction
Sand 2-0.062 mm
Silt 0.062-0.0039 mm
Clay < 0.0039 mm

BEDROCK GEOLOGY AND TOPOGRAPHY

Dolomite of Silurian age is the bedrock beneath the NAL site. It lies beneath approximately 60 to 100 feet of glacial drift. The exploratory borings indicate a total relief of 53 feet on the bedrock surface, from an elevation of 688 feet above sea level in the northwest corner to an elevation of 635 feet in the northeast corner (fig. 3). The bedrock surface beneath the western three-fourths of the site generally slopes to the southeast in conformance with the regional formational dip of 10 to 15 feet per mile. A bedrock high in sec. 20, T. 39 N., R. 9 E., approximately 10 feet above the surrounding surface, and a bedrock low in sec. 36, T. 39 N., R. 8 E., approximately 15 feet below the surrounding surface,

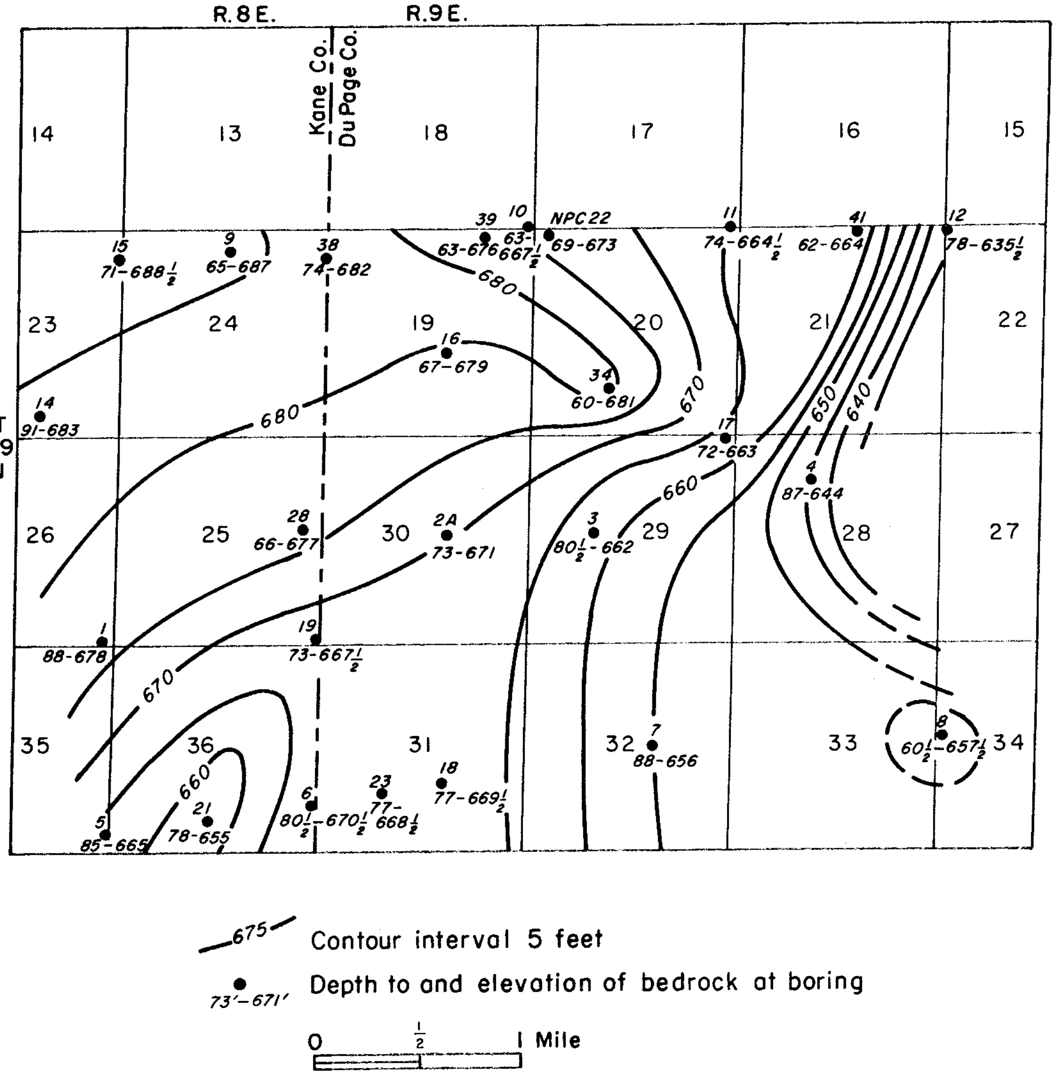


Fig. 3 - Bedrock topography of NAL site.

are the only known major disruptions on this surface. Beneath the eastern fourth of the site, the bedrock surface drops off approximately 25 feet in one-half mile into what is probably the west flank of a bedrock valley which trends north-south and which has been mapped regionally. Descriptions of the bedrock cores have been made by Elwood Atherton of the staff of the Illinois State Geological Survey and are in the Survey files; they are also reproduced in the report of the Corps of Engineers (Dept. of the Army, 1967).

STRATIGRAPHY OF GLACIAL DEPOSITS

Previous Investigations

Regional geologic studies most pertinent to the NAL site have been published by Bretz (1939, 1955), Horberg and Potter (1955), and Zeizel, Walton, Sasman and Prickett (1962). Field investigations in the summer of 1965 (Landon, Hackett and Hughes, 1965) and visual inspection of split-spoon samples from nine borings to bedrock scattered throughout Du Page County (Larsen and Lund, 1965) were of great assistance in the present study. These borings, part of a regional drilling program (Hackett and Hughes, 1965), included one (NPC-22) that was drilled and sampled within the area of the NAL site. Stratigraphic studies to the west (Kempton and Hackett, 1968a, 1968b; Frye, Glass, Kempton and Willman, 1969) provided evidence which suggests possible correlations with the tills encountered at the site.

Other studies (Otto, 1942; Peck and Reed, 1954; and Chryssafopoulos, 1964) have provided additional information, including considerable quantities of engineering data, on the character of the drift and have suggested approaches for differentiating tills on the basis of subsurface data.

Sequence and Character of Deposits

From the study and the analyses of the samples from the test borings, the unconsolidated deposits at the NAL site were found to consist of a sequence of tills with interbedded silts, clayey silts, and sand and gravel, frequently overlain by surficial silts and sands. The deposits were grouped into five major informal units on the basis of lithologic similarities and stratigraphic position (table 1). In descending order these units are as follows: Unit A, the surficial silts and sands; Unit B, clayey silt till and silty clay till with minor interbedded silt; Unit C, sandy and silty tills with major silt and sand and gravel deposits; Unit D, silty clay till; and Unit E, sandy and silty till and sand and gravel deposits. All but one of these major units contain lithologically consistent tills that are in a given sequence and that are generally continuous throughout the site. However, they may have local abrupt changes in thickness and elevation and may be locally absent. A composite stratigraphic section of the deposits listing the unit designation, genesis, grain-size distribution, and engineering properties - including moisture content, Atterberg limits and dry densities - is shown on table 1.

Unit A - Unit A consists of surficial deposits of loessal silt, lacustrine silts and sands, and alluvial silts and sands (figs. 4, 5). The loessal silt is characterized by a high montmorillonite content (77 to 80 percent) in contrast to the underlying till deposits, which are high in illite and very low in montmorillonite. The lacustrine and alluvial silt and sand deposits, previously delineated in a geologic mapping program in Du Page County (Landon, Hackett and Hughes, 1965), are mineralogically similar to the underlying till.

The deposits comprising Unit A are present throughout much of the area east of the Minooka Moraine where they are generally 10 feet thick and reach a maximum thickness of about 20 feet (fig. 4). Loess, probably the most extensive of these surficial materials, attains a maximum thickness of about 5 feet; although it has not been sampled or noted in several of the borings, it may cover nearly the entire area with a thickness of at least 1 to 3 feet.

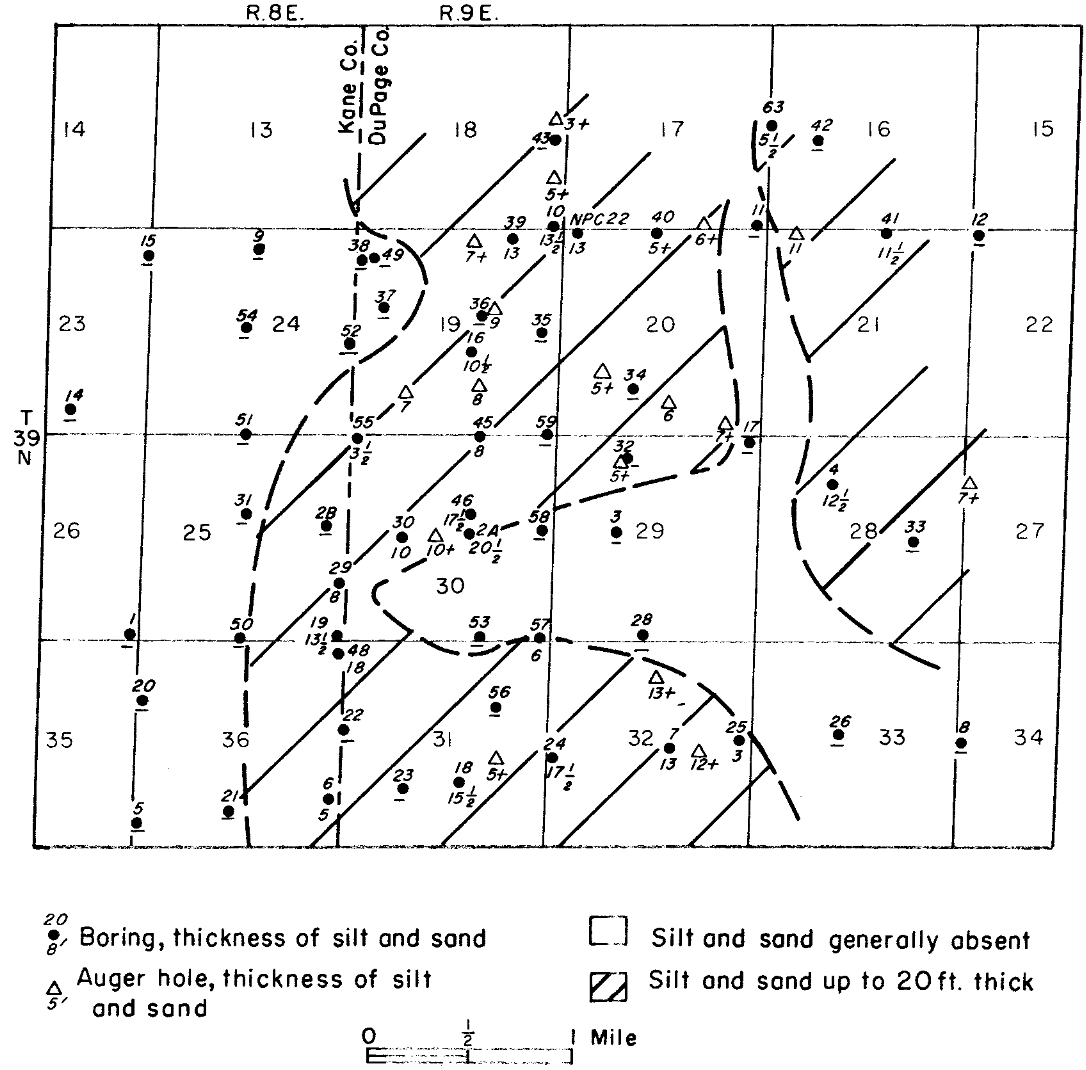


Fig. 4 - Distribution and thickness of surficial silt and sand (Unit A).

Unit B - Unit B, beneath Unit A, consists of clayey silt and silty clay tills (tills 1 and 2, table 1). These tills generally change from brown or grayish brown in the upper, oxidized portion to a dark gray at depth, usually at or near the level of ground-water saturation. A characteristic blocky structure is present in these tills where they are exposed in cuts. Mineralogically, the tills in Unit B are similar to the majority of the other till units within the drift. They are characterized by a very low montmorillonite content (less than 10 percent), a low chlorite content (15 to 20 percent), and a high illite content (75 to 85 percent) in the clay fraction, and also by a high dolomite content in both the clay and gravel fractions; they also contain numerous black shale pebbles. This mineralogy is typical of tills deposited by glaciers that moved out of the Lake Michigan Basin (Willman, Glass and Frye, 1963). The tills in Unit B are the surficial tills throughout the area and compose the tills of the Minooka and Marseilles Moraines to the west.

Of the two principal till lithologies recognized within Unit B, the lower (till 2) contains a mean of 10 percent more clay than the upper (till 1). Till 1, having a mean of 9 percent sand, 53 percent silt and 38 percent clay (table 1), averages 15 percent higher in silt than in clay. Till 2 nearly always contains more clay than silt with clay always higher than 40 percent in the samples analyzed. It has a mean of 8 percent sand, 44 percent silt and 48 percent clay. However, in every boring in which these two tills occur within Unit B, the silty till (till 1) is always on top (fig. 6, table 1).

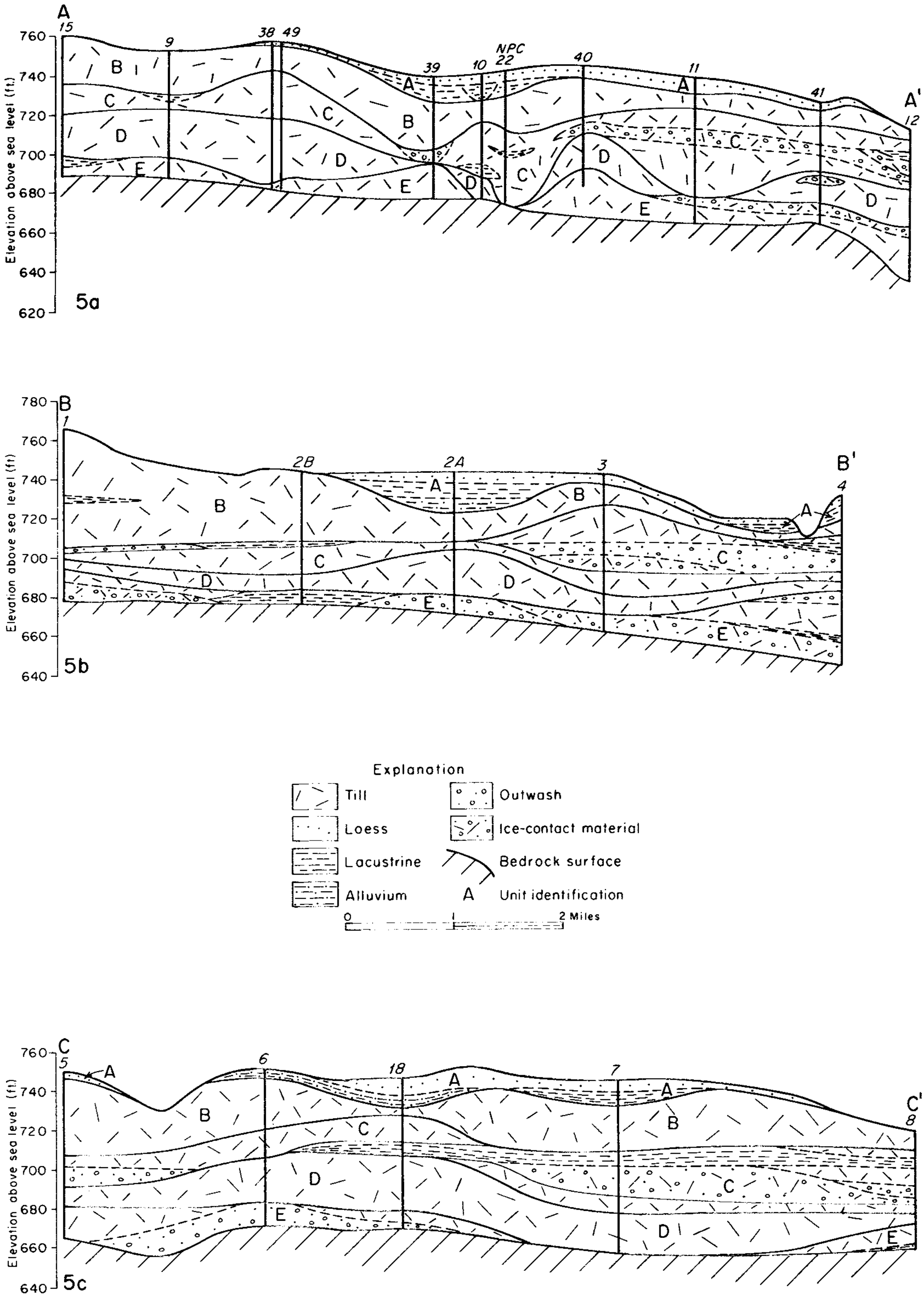
In two of the borings studied (fig. 2: 1, 48), these two tills were in repetitive sequence. In one boring (5), a possible repetitive sequence of these two tills occurs three times. All borings within which a repetitive sequence is found occur on the Minooka Moraine or within about one mile of the inside edge of it. This repetition of tills may have been formed by the shearing of active glacier ice over dead ice near the outer margin of the glacier during the building of the Minooka Moraine.

Unit C - Unit C is generally present in the middle portion of the drift sequence at the site. It is composed of sandy and silty tills with major deposits of sand and gravel and silt. Three main tills, 3, 4, and 5 (table 1) are differentiated for this report. The sand and gravel and the lacustrine silt which separate the upper till of this unit from the lower two tills occur extensively throughout the site. Along with the sandy character of the upper till (till 3), they provide a rather distinctive stratigraphic marker and have been included in subunit C1 along with till 3. Till 5 contains the most clay of the tills in the unit.

Subunit C1, which includes till 3, occurs in 20 borings and is found directly below Unit B. Till 3 is typically gray to brownish gray, sandy and silty, and frequently contains less than 20 percent clay although the mean for 21 samples is 33 percent sand, 45 percent silt and 22 percent clay. This till has a high illite content, accounting for an average of more than 75 percent of the clay minerals. It commonly occurs above the silt and sand and gravel (fig. 6). The maximum thickness of the subunit is 33 feet in boring 3 while the maximum thickness of the water-laid materials is 22 feet.

Subunit C2 (tills 4 and 5) consists of gray to light gray, silty to clayey silt tills with somewhat less sand than till 3 of subunit C1. Till 4 contains an average of 26 percent sand, 47 percent silt and 27 percent clay. Till 5, the lowermost till, averages 20 percent sand, 43 percent silt and 37 percent clay. Both tills have a high illite content.

Unit D - In the lower portion of the drift sequence is the silty clay till that comprises Unit D (till 6). Although the till is somewhat similar to those tills


A
A'
Elevation above sea level (ft)
5a
B
B'
5b
Explanation
Till
Outwash
Loess
Ice-contact material
Lacustrine
Bedrock surface
Alluvium
Unit identification
0
1
2 Miles
C
C'
5c

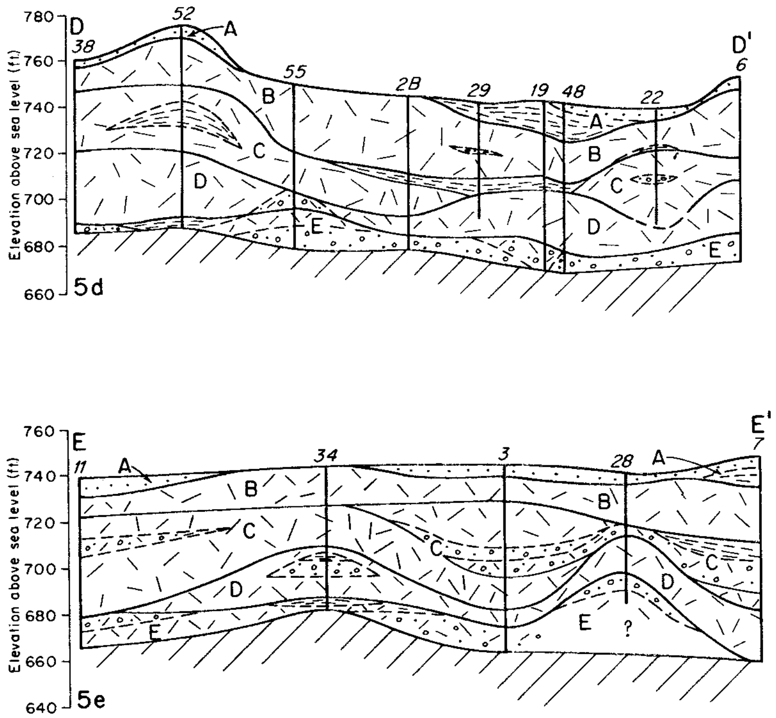


Fig. 5 (a-e) - Cross sections showing drift lithology and correlation of units. (See figure 2 for location of borings and cross-section lines).

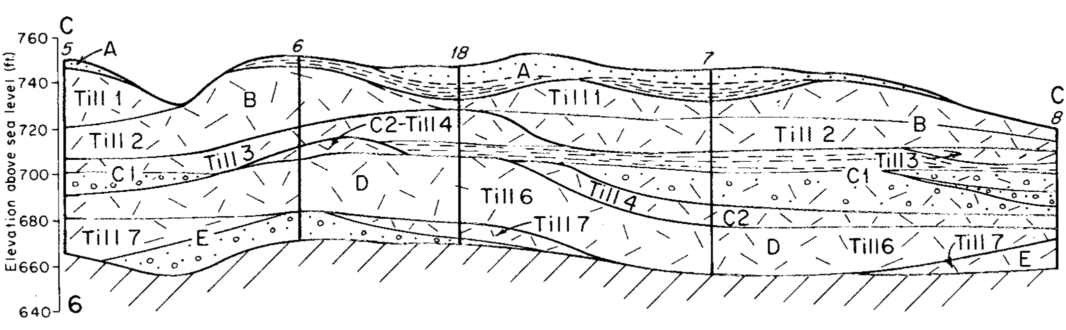


Fig. 6 - Cross section C-C' showing correlations of individual tills (see figure 2).

comprising Unit B, the till (6) of Unit D is generally readily identifiable because of its high clay content (up to 75 percent). Till 6 is also characterized by higher moisture contents, higher Atterberg limits and lower densities than the tills in Unit B (table 1). The till, on visual inspection, is dark gray, smooth and massive and contains only a few scattered pebbles. It is also a high-illite till. This till is present in all but five of the borings studied.

Unit E - A sandy and silty till with major occurrences of sand and gravel deposits constitutes Unit E. This unit is present at the base of the drift and directly overlies the dolomite bedrock. The till in this unit (till 7, table 1) contains an average of 40 percent sand, 45 percent silt and 15 percent clay. It differs somewhat in clay mineralogy from the overlying tills in that it has a higher montmorillonite content (as high as 16 percent), a slightly higher chlorite content, and consequently a lower illite content (68 percent). There is also more dolomite in the less than 2 micron fraction present in this till than in the other tills. This till is also characterized by a low moisture content, a low plastic index and a high dry density. It has a distinct pinkish cast, which is quite noticeable when compared to the tills above, and can be described as light pinkish gray. A truncated profile of weathering at the top of this till is suggested by an increase in expandable clay minerals and a loss of chlorite upward.

Regional Correlation and Age

Recent regional studies (Kempton and Hackett, 1968a, 1968b; Frye, Glass, Kempton and Willman, 1969) west of the NAL site have provided a basis for suggesting possible correlations and age relationships of the tills at the NAL site. The surface tills at the NAL site, Unit B (tills 1 and 2), are within the area mapped as the Minooka-Valparaiso tills (fig. 1) by Kempton and Hackett (1968b). The Minooka Moraine marks the border of these tills just west of the NAL site. These tills are included in the upper part of the Wedron Formation by Frye, Willman, Rubin and Black (1968) and are included in the Woodfordian Substage.

A till somewhat older than the Minooka-Valparaiso till lies just west of the Minooka Moraine and has been called the Elburn till (fig. 1) by Kempton and Hackett (1968a). The Elburn Moraine marks the northwestern boundary of this till in De Kalb and Kane Counties. The Elburn till is strikingly similar, both texturally and mineralogically, to subunit C1 (till 3), which is directly below Unit B at the NAL site. In addition, the Elburn till directly overlies extensive sand and gravel deposits in southern De Kalb and Kane Counties, as does till 3 at the NAL site. Therefore subunit C1 is correlated with the Elburn till to the west and thus is within the Wedron Formation and is Woodfordian in age.

One of the problems of the region has been that of determining the age and correlation of the Lemont drift. From surface mapping and the study of exposures along the Des Plaines River, Bretz (1955) and Horberg and Potter (1955) proposed an Illinoian age for the Lemont drift on the basis of the local presence of the buried Lemont soil. More recently Frye and Willman (1960) suggested that the Lemont drift is Altonian (Wisconsinan) in age. Field and subsurface mapping and tracing, by Landon, of the Lemont drift and related stratigraphic units from the vicinity of Lemont northwestward to the NAL site have shown that the Lemont drift is also similar in character and stratigraphic position to subunit C1 at the NAL site. It is thus proposed that the Lemont is correlative with C1 and the Elburn till and is therefore Woodfordian in age. This interpretation assumes the development of a Beta horizon (Bartelli and Odell, 1960) rather than an in-situ soil development as the explanation for the presence of the Lemont soil. (A Beta horizon is a colloidal precipitate which develops at the contact of finer-grained with coarser-grained materials to form a weathered-appearing, clay-enriched horizon).

Studies by Kempton and Hackett (1968b) and Frye, Glass, Kempton and Willman (1969) suggest that there are two alternative correlations most probable at present for the older tills at the NAL site. One of these is to assign both subunit C2 and all of Unit D to the Woodfordian on the basis of similar clay mineral composition and absence of evidence for a weathering profile and to consider the two units deposits of a glacier that did not reach farther west of the NAL site. In Unit E the pinkish color, the grain size, the clay mineral composition, and evidence for a truncated weathering profile suggest a possible correlation of that unit with either the Altonian Capron till or the Altonian Argyle till and therefore an Altonian age for the unit. This interpretation is preferred (fig. 7).

The other interpretation would assign subunit C2 to the Illinoian Stage as a correlative of the similar Sterling till and would also assign Unit D to the Illinoian as a correlative of the Sterling till or of deposits of an earlier Illinoian glacier which did not advance west of the Fox River. Unit E would then be correlated with the Ogle till or would possibly even be Kansan in age.

SIGNIFICANCE OF STRATIGRAPHIC FRAMEWORK TO FOUNDATION ENGINEERING

The purpose of this study at the NAL site was to define the sequence, character and distribution of stratigraphic units present and to relate this knowledge to engineering properties and thus to problems of excavation, foundation stability, and settlement that might be encountered at the accelerator facility. Peck (1968, p. 142) stated that "engineering descriptions alone do not permit a sufficiently rational classification of subsurface materials for the design and construction of many engineering works in even the best known urban areas." He added that the mass of engineering test data becomes meaningful only if the data are organized

Stage	Substage	Formation	Unit	Subunit	Till	Correlation
WISCONSINAN	Woodfordian	Wedron	A			
			B		1 2	"Minooka-Valparaiso"
			C	C1	3	"Elburn" (Lemont)
				C2	4	
					5	
			D		6	
	Altonian	Winnebago	E		7	Argyle (or Capron)

Fig. 7 - Correlation of till units at NAL site.

on the basis of stratigraphic units. At the NAL site, the definition of stratigraphic units within borings and the correlation of these units between borings were made almost entirely on a geologic basis rather than on the correlation of engineering test data.

Relation of Engineering Properties to Geologic Units

The five-fold classification (Units A through E) of the deposits at the NAL site was used as a framework for evaluation of the engineering data by the Corps of Engineers. A report by the Corps entitled "Final Report-Preliminary Foundation Analysis, Atomic Energy Commission 200 BEV Accelerator, Weston Site, Illinois," (Dept. of the Army, 1967) contains an evaluation of the engineering properties of each unit, based on the following tests and analyses: density, Atterberg limits, moisture content, activity, unconfined compressive strength, sensitivity, swell and shear tests, permeability, consolidation, bearing capacity, settlement and time-rate of settlement. The results of several of these tests as they appear in the report by the Corps of Engineers are summarized in table 2 and are briefly summarized in the following paragraphs. (It should be noted that table 1 summarizes only those engineering properties available during the stratigraphic study.)

TABLE 2 - PROPERTY DATA RANGE SUMMARIZED FROM REPORT OF CORPS OF ENGINEERS (DEPT. OF THE ARMY, 1967)

Unit	DD	Atterberg limits		W	Qu	Pc	Sensitivity $\left(\frac{Qu}{Qr}\right)$
		LL	PI				
A	90-100	41-62	22-43	24-30	0.3-1.3 (<1.0)*	No data	No data
B	110-120	26-33	12-19	14-21	1.5-4.5 (2.5-3.5)*	10-30	No data
C	115-135	17-28	10-13	10-15	2.0-4.5 (2.0-3.5)*	20-30	1.18-1.26
D	104-120	30-42	18-22	17-24	1.3-4.0 (2.0-3.5)*	9-20	2.61-3.35
E	130-145	12-19	1-6	6-12	7-8	No data	No data

EXPLANATION

DD dry density in pounds/ft^3
LL liquid limit in percent
PI plasticity index
W natural moisture content in percent
Qu unconfined compressive strength in tons/ft^2 (undisturbed)
Pc consolidation pressure in tons/ft^2
Qr unconfined compressive strength in tons/ft^2 (remolded)

*Most samples fall within this range.

Density

Of the till units, Unit E has the highest density, with Units C, B and D following in that order. (This order is generally reflected in table 1 although data from only two samples were available from Unit E at the time of this study.) Unit A, principally silt, has the lowest density of the five units.

Atterberg limits and moisture content

Unit A has Atterberg limits and a natural water content quite different from and much higher than the more consolidated tills of the remaining units. The liquid limit of Unit A ranges from 41 to 62 percent, the plasticity index from 22 to 43, and the natural water content from 24 to 30 percent. Of the till units, Unit E has the lowest liquid limit (12 to 19), plasticity index (1 to 6) and water content (6 to 12).

Unconfined compression tests

Unit A has the lowest unconfined compressive strength (0.3 to 1.3 tons per square foot) in relation to the other units. Units B, C and D have similar unconfined compressive strength values ranging from 1.3 to 4.5 tons per square foot. On the basis of limited data, Unit E, with a range from 7 to 8 tons per square foot, has higher values than any of the other units.

Consolidation tests

Tills in Units B, C and D are moderately to heavily consolidated, with values ranging from 9 to 30 tons per square foot. With the possible exception of the till of Unit E, Unit C appears to be the most heavily consolidated. Values for Unit C range from 20 to 30 tons per square foot; for Unit B, 10 to 30 tons per square foot; and for Unit D, 9 to 20 tons per square foot.

Other test results

Most of the tills of Units B, C and D are of moderate sensitivity; in other words, they should lose only very little strength when remolded or disturbed. The degree of sensitivity for most glacial clays ranges from 1 to 4, the range of normal sensitivity. The data available (table 2) suggest that the clays at the NAL site are in the normal range. The swell test, which measures the water-holding capacity of materials, showed that values for Units B, C, D and E range from 0.1 to 1.19 percent. Since these values are relatively small and the units contain little montmorillonite, these tests also indicate that the tills in these units should not swell appreciably.

Limited permeability tests on the upper till (3) in Unit C show that the probable in-situ permeability is $1\text{-}2 \times 10^{-8}$ cm/sec. It was also noted that the sand and gravel deposits in Units C and E will provide drainage upon loading.

Of the five units recognized at the NAL site, Unit A is the most compressible. This unit also has the lowest bearing values, 1 ton per square foot or lower. The remainder of the materials at the site have good bearing values, generally greater than 3 tons per square foot, and will give a relatively small amount of settlement, according to all data available to the Corps of Engineers.

Comments

The preceding discussion of the engineering test data as related to the major stratigraphic units defined at the NAL site points up the value of the geologic framework. It also points out the need for a meaningful and realistic definition of stratigraphic units for engineering projects. For example, in the preliminary report to the Corps of Engineers (Landon and Kempton, 1967), so much emphasis was placed on the numerous textural units differentiated within the tills at the site that the similarity in engineering properties of related tills tended to be overlooked; therefore, in the final report (Landon, 1967), many of these till units were grouped on the basis of similar engineering properties into five principal stratigraphic units, A-E, which provided the working stratigraphic framework for the preliminary engineering report.

From the experience gained from this study, there are several points a geologist should consider in establishing a geologic framework for engineering projects. Of particular importance is the need for him to recognize that a material, or rock-stratigraphic, framework of glacial deposits can be defined and that this definition is essential in organizing engineering property data in the most meaningful way. Establishing the geologic history or age of the deposits and the relationship of surficial features to the deposits is important only as it may aid in predicting the continuity, character, and therefore relative significance, of a particular rock-stratigraphic unit.

The initial steps in defining the stratigraphic framework of glacial deposits include the genetic interpretation and visual description of the lithologic units sampled in borings or viewed in exposures. For boring samples, it is most advantageous to view representative cuts taken from each sampled interval and laid out in sequence to allow for an overall picture of the principal units present in each boring. Each discrete unit should be identified as, for example, till, loess, outwash, lacustrine or organic material such as peat, and described by thickness, color, overall texture, and special features such as fractures, shear zone, structure (e.g., granular, blocky, massive) and occurrence and nature of bedding. Within tills, the presence or absence of gravel and the size, abundance and lithology of the gravel are often significant.

After the samples from several borings have been described, an initial stratigraphic sequence of the units present can be established. Frequently a particular marker horizon, such as a distinctive sand and gravel, an organic silt, an oxidized zone, or the unique color or texture of a till, will aid in making the initial correlations necessary for determining the principal stratigraphic elements.

Quantitative laboratory data, particularly on grain size and clay minerals, have proved extremely valuable in defining and correlating units at the NAL site as well as in providing relationships to the engineering properties. These data should be utilized whenever possible in defining a rock-stratigraphic framework. At the NAL site such data, particularly grain-size analyses of the tills (table 1), provided a firm basis for establishing the subdivision of units and greatly aided in the correlation of the individual till units throughout the site. However, to avoid oversubdividing units, caution must be used in analyzing such data. Thin or very local textural units are frequently insignificant to engineering applications and may usually be included in another unit.

On the other hand, it is important that units which are dissimilar are kept separate and not grouped into a single unit. In the final analysis, the detail of geologic subdivision of units should be designed to meet the tolerance limits of the specific engineering project. These units should then be so defined and described that those dependent on this information during design and construction phases will be able to use it.

Cross sections or other pertinent illustrative material will aid the user in understanding the distribution and three-dimensional aspects of the units. In addition, such illustrations will emphasize the distribution of permeable zones and structural patterns and the occurrence of problem zones or units.

SUMMARY

Several conclusions are suggested by the results of this study, made in an area where conditions are analogous to those in other areas of northern Illinois. Possibly of greatest significance is the relative uniformity in distribution and lithologic character of till units throughout the area. Visual recognition of the major units in most of the borings was nearly always possible. The principal stratigraphic units can usually be differentiated by inspection of representative subsurface samples, whereas within units, textural and other quantitative data are often necessary to distinguish between tills. From the standpoint of glacial depositional history, one can only speculate on the significance and interpretation of individual tills until their distribution and character throughout the region have been determined.

The composite stratigraphy at the NAL site, however, can be considered an area of well-established stratigraphic control from which correlations can be made to neighboring areas with similar control. As other areas are defined in similar detail and as other regional stratigraphic information becomes available, correlations, age relationships and the geologic history of the region can be more firmly established. This information will greatly aid in the detailed mapping of the surficial deposits and therefore the mapping of agronomic soils. In addition, the significance of physiographic features, the relationship of the rock-stratigraphic sequence to morphostratigraphic units, and problems of stratigraphic inconsistencies will be clarified; and the predictability of the sequence, distribution, and character of the glacial sediments of the region for all applications will become even more dependable.

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