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PLEISTOCENE STRATIGRAPHY IN EAST-CENTRAL IOWA

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FOREWORD

This publication is the culmination of a long series of investigations and reports undertaken to interpret and classify the glacial sediments and related deposits of east-central Iowa. The limited observations and conclusions made by early investigators were based upon examination of materials exposed in hillsides, roadcuts and railway cuts. Drill cores that penetrated thicker intervals of the Pleistocene section added significantly to the data base available to later workers. The present report includes a large amount of quantitative data derived from cores drilled through the entire sequence of Pleistocene deposits at several key locations.

Data on clay mineralogy, particle-size distribution, and lithologies in the very coarse sand fraction permit discrimination and areal correlation of some of the till units. Formal names are applied to these tills. This new stratigraphic framework will be of value to others who investigate aspects of the stratigraphy and geomorphology of these sediments.

Stanley C. Grant
State Geologist and Director
Iowa Geological Survey

Table of Contents

List of Figures

Figure No. Page No.

List of Tables

Table No.		Page No.

Table No. Page No.

List of Descriptions

PREFACE

"Perhaps no department of geological investigation has greater need of careful discrimination than that which deals with the complex deposits of the Quaternary age. Most formations betray their origin in their salient characteristics, but those of the Quaternary age are apparently capable of diverse interpretations if their general nature alone is considered. It is only by critical discrimination of their special and often quite unobtrusive features that they can be decisively referred to the several agencies that produced them. Most formations owe their origin to the action of some one dominant agency. The Quaternary deposits are, on the contrary, the product of a combination of agencies, the relative work of which is often distinguishable only with difficulty. In these discriminations the individual judgment of the investigator plays an important part. The influence of personal predisposition, therefore, is here liable to be most gravely felt. Probably no investigator is entirely free from the influence of his own preconceptions and methods of interpretation. He, perhaps, does best who, while duly appreciating these influences and assiduously applying checks for their correction, frankly submits his methods of interpretation to the correction of others."

T. C. Chamberlin, 1883; from a Preliminary Paper on the Terminal Moraine of the Second Glacial Epoch; U.S. Geological Survey, 3rd Annual Report, p. 295.

PLEISTOCENE STRATIGRAPHY IN EAST-CENTRAL IOWA

George R. Hallberg, Chief, Geological Studies
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ABSTRACT

The Pleistocene stratigraphy in east-central Iowa was investigated from exposures and from drill-cores which penetrated the entire Pleistocene sequence, from the land-surface to the bedrock. From this analysis a new, multiple classification stratigraphic framework was developed for the tills and related deposits which occur stratigraphically below the sediments of the Yarmouth-Sangamon and Late-Sangamon Paleosols.

Classically, these sediments have been referred to as Kansan and Nebraskan in both a time and rock-stratigraphic sense. In this report they are redefined, and are referred to undifferentiated Pre-Illinoian Stages for their time-stratigraphic classification. Rock-stratigraphically these deposits are subdivided into the Alburnett and Wolf Creek Formations, based on distinct differences in clay mineralogy. Both formations are composed principally of multiple basal tills and intertill stratified sediments. Multiple tills occur within the older Alburnett Formation. These till units are not formally subdivided into members because no properties have yet been recognized which would allow correlation. The Wolf Creek Formation is subdivided into the Winthrop, Aurora, and Hickory Hills Till Members on the basis of physical stratigraphy, differences in texture, sand-fraction lithologies, and matrix carbonates.

Two soil stratigraphic units are also named. The Westburg Paleosol occurs below the Winthrop Till Member of the Wolf Creek Formation and is developed in deposits of the Alburnett Formation or older rock units. The Dysart Paleosol occurs below the Hickory Hills Till Member of the Wolf Creek Formation. Other weakly developed soils occur between other till units, but they are not formally classified at this time because their significance is unclear.

Substantial erosion has occurred in this region of old glacial deposits. The area is marked by the widespread development of the Iowan Erosion Surface of Wisconsinan-age. Significant pre-Wisconsinan erosion also occurred. The Late-Sangamon surface and paleosol are developed on everything from the Hickory Hills Till Member to the much older tills of the Alburnett Formation.

The relationship between the landscape and stratigraphy is analagous to an area of dissected, relatively flat-lying sedimentary rocks. As the landscape drops in elevation from the Wapsipinicon-Maquoketa River and the Iowa-Cedar River divides to the lower elevations of the Cedar River basin, the younger Wolf Creek Formation deposits are truncated by erosion and only

locally preserved. In this lower elevation area the stratigraphically lower Alburnett Formation is widely exhumed at the landsurface. In these Pleistocene deposits there are no "cliff-forming" units to provide escarpments and make this relationship obvious.

At the local level, drainage basins are marked by multi-leveled, stepped erosion surfaces, which also cut across the stratigraphic units. These relationships between the landscape and the stratigraphy, on both the local and regional level, must be recognized when working in older, eroded glacial terrane. It cannot be assumed, as most historical work in this area has done, that the uppermost till unit is the same across the area. In different landscape positions, different portions of the stratigraphic section are preserved and exposed.

INTRODUCTION

This study was conducted largely as part of an Iowa Geological Survey - U.S. Geological Survey carbonate aquifer research program. The area studied includes parts of Benton, Buchanan, Iowa, Johnson, Linn, and Tama Counties (Figure 1). To fully understand the movement or occurrence of water within or through the Pleistocene materials, in relation to important bedrock aquifers, it is necessary to understand the stratigraphy of these materials. A knowledge of the stratigraphy of the Quaternary materials is fundamental in all applied uses; to understand their engineering behavior, or their potential use as construction materials. The purpose of the study was to characterize the physical stratigraphy of the Quaternary materials at selected sites and to establish criteria for site-to-site stratigraphic correlation. As a consequence a new stratigraphic framework evolved for the tills and related deposits in east-central Iowa. This report will deal principally with the stratigraphic findings. Separate reports will deal with the hydrologic and other geotechnical properties of the materials.

As is common in Quaternary stratigraphy, type areas and reference sections are used (Am. Comm. Strat. Nomen., 1961). Type areas must be used because of the lack of outcrops which show complete stratigraphic sections, and because of the short-lived nature of these outcrops. In this study most of the definitive data are from cores. The use of subsurface data

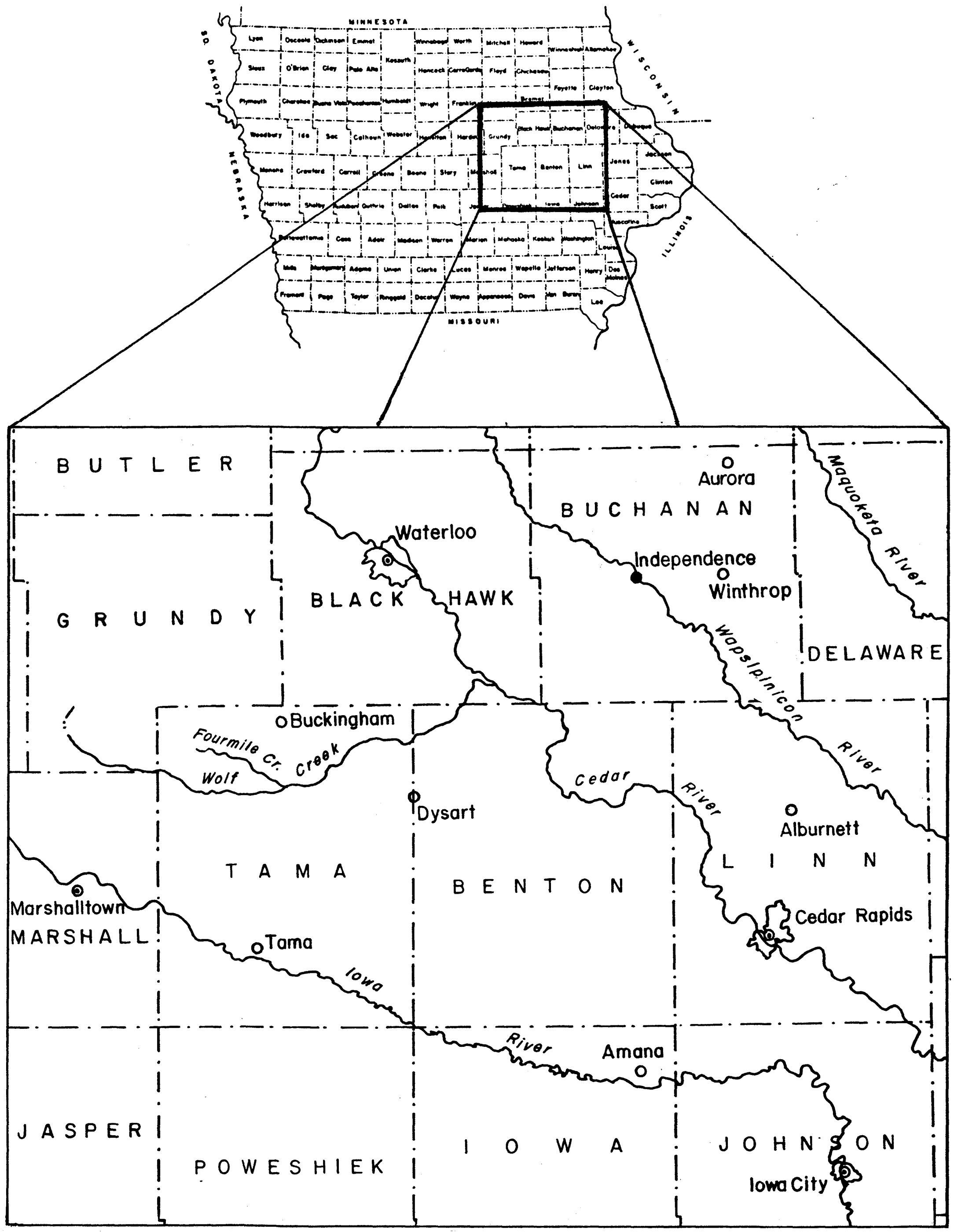


Figure 1. Location of study area.

cannot be avoided because of the thickness and areal complexity of the stratigraphic units, particularly in relation to this eroded landscape.

Several of the formal names used for the new rock-stratigraphic units, have been used for rock-units elsewhere. In all cases, in accordance with the Code of Stratigraphic Nomenclature (ACSN, 1961) the duplicated names for rock units are widely separated geographically and stratigraphically from the Pleistocene deposits of Iowa.

In the descriptions of the stratigraphic sections, standard pedologic terminology and horizon nomenclature are used for soils and paleosols (see Soil Survey staff, 1951, 1975). For the descriptions of the Quaternary sediments other than in the solum or paleosolum, standard weathering zone terminology is used as outlined in Hallberg, Fenton, and Miller (1978). Standard USDA - SCS textural classes and terms are used also (see Soil Survey Staff, 1975; Walter, Hallberg, and Fenton, 1978). Laboratory data is presented to quantify the physical characteristics of the materials. Laboratory methods used are (in Hallberg, ed., 1978): particle-size analysis -- Walter, Hallberg, and Fenton, 1978; clay-mineralogy -- Hallberg, Lucas, and Goodmen, 1978; and sand-fraction analysis -- Lucas, et al., 1978.

Acknowledgments

Many people aided or participated in this project, and their assistance is gratefully appreciated. Dr. Samuel J. Tuthill, and Dr. Stanley C. Grant, past and present Directors of the Iowa Geological Survey, and Mr. Walter Steinhilber and Mr. Kenneth Wahl, of the U.S. Geological Survey aided, supported, and encouraged this work. Many people participated in the field investigations, most notably, Mr. Darwin Evans and Mr. Bill Bunker, of the Iowa Geological Survey. Further field assistance and cooperation were provided by Dr. Michael Burkhardt and Mr. Kenneth Wahl, U.S. Geological Survey; Mr. Timothy Kemmis, Mr. Nyle Wollenhaupt, and Mr. Bernard Hoyer, Iowa Geological Survey; Dr. Gerald Miller, Dr. Thomas Fenton, Dr. Alan Lutenegger, Iowa State University; Mr. John Highland, Mr. William Fouts, and Mr. Mark Minger, soil scientists, USDA - Soil Conservation Service; Mr. Steven Esling, University of Iowa. Pollen analyses were performed by the author, and by Dr. Michael Burkhardt, Dr. Kent Van Zant, Dr. Richard Baker, and Mr. Thomas Legg, University of Iowa. All wood identifications were made by Dr. Dwight Bensend, Iowa State University. A substantial portion of the lab work was done by Ms. Catherine Goodmen, University of Iowa, and Mr. Neil Walter, Iowa State University. Mr. Donald Koch and Mr. Timothy Kemmis, Iowa Geological Survey, reviewed and improved this manuscript.

PREVIOUS INVESTIGATIONS

The study area is in the region once considered the southern border of the infamous "Iowan Drift". The "Iowan Drift" was long a subject of controversy and investigation. As with many classical Pleistocene studies, the investigations of the Iowan were an inextricable mixture of rock and time stratigraphic discussions and interpretation. Only the most basic and simplistic of field characteristics were used to describe the materials and to make subjective interpretations. Most of the discussions and controversy dealt with the existence and time-stratigraphy of the "Iowan Drift." Until the present study a modern rock-stratigraphic investigation had not been undertaken. Also, the Iowan problem was shown to be primarily geomorphic. Ruhe, et al. (1968) proved that the "Iowan Drift" did not exist, but rather the Iowan area was an extensive erosion surface developed on classic Kansan and Nebraskan tills, and related deposits. The history of the Iowan is outlined elsewhere in detail by Ruhe, et al. (1968), Ruhe (1969), and the story was brought up to date in Hallberg, et al. (1978). Consequently the following discussion will be abbreviated and slanted toward pertinent stratigraphic points.

McGee as early as 1881, and in his classic treatise of 1891, recognized an upper and lower till in parts of northeast Iowa, which were separated by a 'forest bed' or 'gumbotil.' These upper and lower tills were subject to reclassification by various investigations. The upper till was called the East Iowan by Chamberlain (in Gieke, 1894); but the East Iowan name evolved from his work in the Afton Junction area in the type region of Kansan and Nebraskan drift in southwestern Iowa. Later the name was shortened to Iowan (Chamberlain, 1895). Bain (1896) concluded that Chamberlain's Iowan in southern Iowa was actually the Kansan, and that the Iowan of northeastern Iowa was younger. Chamberlain (1896) concurred and Calvin (1896, 1899) elaborated on the nature of the Iowan and its temporal placement between the Sangamon and the Wisconsinan. Calvin (1896) also introduced the Buchanan Gravels which were thought to be evidence for a Pre-Iowan interglacial interval. Leverett (1909, 1910) questioned the existence of the Iowan while Calvin (1911) vigorously defended it.

Alden and Leighton (1917) presented a lengthy treatise on the existence of the Iowan drift, and they and Kay and Apfel (1929) developed the idea that the Iowan was a separate glacial stage between the Illinoian and Wisconsinan. Later, however, the Iowan was assigned to the earliest substage of the Wisconsinan (Leighton, 1931, 1933; Kay and Graham, 1943). On the other hand, Leverett (1926, 1939) contended that the Iowan was a late phase of Illinoian glaciation. Leverett (1942) later conceded that the Iowan was an early Wisconsinan drift.

During the 1940's and early 1950's the existence of the Iowan was not questioned. In 1950, Leighton and Willman formalized the Farmdale substage of the Wisconsinan, and placed the Iowan as the next younger Wisconsinan substage. With the advent of radiocarbon dating, the Farmdale was first dated as 22,000 to 26,000 RCYBP (radiocarbon years before present). Later dates bracketed the Farmdale as 22-28,000 RCYBP (Willman and Frye, 1970) or from 25,000 to 28,000 (McKay, 1979). However, all radiocarbon dates of wood extracted from the "Iowan" drift (or from peat immediately below) were "greater than" or "dead" values. Accordingly, Ruhe and others (1957, 1959) pointed out that the Iowan was older than Farmdale. Leighton (1958, 1960, 1966) objected to this, and offered the untenable rationale that somehow the Iowan glacier continually dug up old wood rather than the younger (Farmdale) trees in its advance.

At this point the Iowan could simply be returned to the Early Wisconsinan or pre-Farmdale. However, the questions of the Iowan and its unique features could not be resolved that easily. In the 1960s Ruhe, Dietz, Fenton, and Hall (1968) conducted very detailed soil-geomorphic studies in Grundy, Tama, Linn, and Howard counties. Using closely spaced shallow drill cores from

Kansan pahas and inliers onto the lower-lying Iowan plain, they produced detailed three dimensional cross-sections of the landscape and the stratigraphy. Their reconstructions repeatedly showed that the same stratigraphic units, and even the same weathering zones in the till, could be traced from the "Iowan plain" directly under the pahas and the Yarmouth-Sangamon soil. Where was the stratigraphically different Wisconsinan-age Iowan till? It did not exist. The lower lying landscape, below the paha, is a widespread, loess-mantled erosion surface that was cut into Kansan till and from which the thick Yarmouth-Sangamon and Late-Sangamon paleosols were stripped. In places the erosion surface cuts entirely through the Kansan till, revealing what classically would be considered the Aftonian paleosol and even Nebraskan till. The stone line (classically referred to as the "Iowan pebble band") on the Kansan till generally marks the erosion surface.

The work of Ruhe, Fenton, Dietz, and Hall, proved that the Iowan drift did not exist, and they replaced it with the theory of the Iowan erosion surface. The test of any theory is its ability to explain the observed facts and to stand the test of time. And indeed, all serious work done in the Iowan area since their work has affirmed and further documented the basic conclusions of the Iowa erosion surface study (see Vreeken, 1972, 1975; Kleiss, 1969, 1970; Miller, 1974; Hallberg 1978a, b; and Szabo, 1975).

The controversy of the "Iowan" has been resolved. Until the present study, however, a modern Quaternary stratigraphic investigation had not been undertaken in Iowa. Even the studies of Ruhe and others, which employed subsurface drill cores, were principally geomorphic studies. They described and traced out the physical stratigraphy locally. It was assumed that the first till under the Yarmouth-Sangamon paleosol was the Kansan and the next till was the Nebraskan. Correlation from site to site was by the inference that if two tills were present at different sites they were obviously the same - because only two tills were thought to exist.

In the studies of Ruhe and others, the deepest core holes were 80 to 90 feet and ended within the Pleistocene sequence. Only two tills were ever encountered. However, even prior to this study, deep drilling revealed a third till in the 4-Mile Creek study area of Ruhe and others (Kunkle, 1968). In the present stratigraphic study the entire Pleistocene sequence has been cored, from the land surface to the Paleozoic bedrock, to depths of nearly 400 feet. This has revealed much more to the stratigraphic section than previously was recognized.

In the present study, the stratigraphic units have been characterized quantitatively by their mineralogy, particle size analysis, and chemical constituents, thus allowing a "quantitative" correlation from site to site, and the development of a comprehensive stratigraphic framework as described in this report. Milling (1968) did study the petrology and petrography of tills in eastern Iowa. However, he principally worked from incomplete sections and simply utilized the stratigraphic classification of previous workers. Consequently, his work was inconclusive.

Recognition of more than one till per classic glacial stage has prompted the use of multiple-stratigraphic classification schemes (Willman and Frye, 1970). Until now the terms Kansan and Nebraskan have been used, in Iowa, as mixed rock and time-stratigraphic terms. This report introduces formal rock-stratigraphic terminology for these early Pleistocene deposits in east-central and northeast Iowa; this terminology is outlined in Table 1.

Throughout this report these early Pleistocene glacial deposits are referred to by their rock-stratigraphic designation, or where they are discussed in relation to prior work they may be referred to as "classical Kansan or Nebraskan" deposits. Note that in Table 1 their present time-stratigraphic designation is Pre-Illinoian. This designation is now used because on-going work in the classic type area of Kansan and Nebraskan deposits in southwestern Iowa and Nebraska also shows a more complex series of glacial deposits, ranging in age from less than 600,000 y.b.p. to over 2.2 million y.b.p. (Hallberg and Boellstorff, 1978; Boellstorff, 1978a). Analysis of the stratigraphic sequence shows that these classical terms have been widely misused and miscorrelated. Until the stratigraphy of these deposits is resolved, the designation of Pre-Illinoian will be used for their time-stratigraphic reference.

Table 1 also shows other terms which will be used in this report which are informal, but have been used for many years in Iowa (see Ruhe, 1967; 1969). Their background will not be discussed at this time.

Table 1. Present stratigraphic nomenclature for east-central and northeast Iowa.

Time Stratigraphy		Rock Stratigraphy	Soil Stratigraphy
PLEISTOCENE SERIES	WISCONSINAN STAGE	Wisconsinan loess * (undifferentiated)	Basal loess * paleosol
PLEISTOCENE SERIES	SANGAMON through YARMOUTHIAN STAGES	unnamed sediments; * includes Late-Sangamon Pedisediment and Alluvium, and Yarmouth-Sangamon sediments.	Late Sangamon and Yarmouth-Sangamon Paleosols
PLEISTOCENE SERIES	PRE-ILLINOIAN STAGES (undifferentiated)	WOLF CREEK FORMATION (including unnamed, undifferentiated sediments) Hickory Hills Till Member Aurora Till Member Winthrop Till Member	Dysart Paleosol unnamed peat and organic paleosols Westburg Paleosol (new formal stratigraphic units.)
PLEISTOCENE SERIES	PRE-ILLINOIAN STAGES (undifferentiated)	ALBURNETT FORMATION unnamed sediments unnamed till members	

* Informal names.

PRE-ILLINOIAN STRATIGRAPHY

As outlined in Table 1, the tills and related deposits that lie stratigraphically below the sediments of the Yarmouth-Sangamon and Late-Sangamon paleosols have been subdivided into two formations. These rock-stratigraphic units, the Alburnett and Wolf Creek Formations, are differentiated on the basis of their clay mineralogy. Numerous properties of the deposits have been investigated, but the clay mineralogy is the most useful parameter for differentiation at the formation level. The summary of about 450 analyses of clay mineralogy are presented in Table 2. The younger Wolf Creek Formation shows high values of expandable clay minerals averaging 62.1%, whereas the Alburnett Formation deposits average a significantly lower 42.9% expandable clays. Across the study area, this basic change from tills with high expandable clay mineralogy to physically separable tills with much lower amounts of expandable clays, is the most consistent and repeatable datum and is a significant correlation tool.

Both formations include multiple till units and a variety of fluvial deposits and other sorted sediments between the tills. These deposits are characterized with data on their clay mineralogy, particle-size distribution, lithologies in the very coarse sand fraction, and at some sites by chemical analyses. Using these data the Wolf Creek Formation has been subdivided into 3 formal till members. At some sites member recognition or correlation is not possible because of overlaps in the range of their physical and mineralogic properties. However, the basic clay mineralogic criteria can still be used for classification at the formation level.

The format of the following discussion will break from tradition and discuss the stratigraphic units from youngest to oldest. This will be done for several reasons. First, as discussed, the prevailing thought to date was that only two tills, the Kansan and Nebraskan, occurred in this area. With the recognition of multiple tills in the area this conceptual framework is no longer useful for discussion. Second, most

Table 2. Summary of clay mineralogy for the Wolf Creek and Alburnett Formation deposits.

	Ex. %		Ill. %		K. + C. %	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
	WOLF CREEK FORMATION					
N = 288	62.1	±4.3	16.7	±3.4	21.4	±3.3
	ALBURNETT FORMATION					
n = 163	42.9	±5.6	24.5	±4.1	32.3	±3.9

Ex. - Expandable clay minerals.

Ill. - Illite clay minerals.

K + C - Kaolinite plus chlorite clay minerals.

prior Quaternary investigations have only analyzed the youngest, surficially exposed units, and stratigraphic names (Kansan and Nebraskan) have been assigned from the uppermost unit downward. With the greater complexity of Pleistocene deposits now recognized, the evidence for multiple tills and glacial episodes must be related to the various surficial tills of previous investigations. The only valid stratigraphic datum from which to begin a discussion in this region is the soil-stratigraphic units comprised by the Yarmouth-Sangamon and Late-Sangamon paleosols, which are overlain by Wisconsinan loess (Ruhe, 1969). From this starting point the physical framework can be established to show the complexities of the complete stratigraphic sequence.

WOLF CREEK FORMATION

The Wolf Creek Formation is comprised of the stratigraphically youngest Pre-Illinoian deposits in the study area, which are marked by high percentages of expandable clay minerals. The type area for the Wolf Creek Formation is defined from several reference localities in the region around Wolf Creek in Geneseo, Clark, Buckingham, and Grant Townships, in northern Tama County.

Outcrops in this region generally are short-lived and at best expose only a small part of the stratigraphy of the Wolf Creek Formation. Thus, to define the nature of the formation and its members a series of outcrops and core-holes have been used. Particular reference sections will be introduced with the description of the members. Many of the locations and borings in the Wolf Creek area come from the work of Fenton (1966) and Ruhe, et al. (1968).

In the most complete sections in the study area the upper boundary of the formation is at the upper limit of the till-derived portion of the Yarmouth-Sangamon Paleosols. The formation is overlain in these sections by local-alluvium, swale-fill deposits, pedisediment, or fluvial sediments of Yarmouth through Late-Sangamon age. The lower limit of the formation, is the top of the Westburg Paleosol (see Table 1). The upper and lower contacts of the Wolf Creek Formation are quite variable, however, because of erosion. This will be documented with specific sections in the discussions of the individual members.

The Wolf Creek Formation is subdivided into three till members. From youngest to oldest, the Hickory Hills Till Member, the Aurora Till Member, and the Winthrop Till Member. The formation also includes a variety of unnamed, undifferentiated sediments, which occur between the till members. These deposits range from fluvial silts, sands and/or gravel, to local fine-textured swale-fill deposits and peat.

Table 3 summarizes the particle-size data for the Wolf Creek Formation tills. All the till units are generally loam-textured. There are small but consistent textural differences which aid discrimination between the members.

Table 4 summarizes the clay mineralogic data for the tills and undifferentiated sediments, exclusive of samples from buried or modern soils. The different sediments of the Wolf Creek Formation are all marked by high percentages (about 60%) of expandable clay minerals, with kaolinite (plus chlorite) values being higher than illite. In only 1% of the samples was illite higher than kaolinite. The clay mineral composition forms the basis for discriminating the formation but is of little value for discriminating between members.

Table 5 summarizes the sand-fraction lithology data for the Wolf Creek Formation. Locally and regionally there is considerable overlap in the sand-fraction data. In general, however, the sand-fraction data with the C/D (limestone/dolostone) ratios have been useful for discriminating between members. However, because of the overlap in properties, regional correlation and differentiation between the till members can sometimes be difficult, particularly in isolated exposures where only a single till is exposed, or the till properties vary from their norm.

Paleosols and soil stratigraphic units also occur within the Wolf Creek Formation. The Dysart Paleosol is a strongly developed buried soil which occurs between the Hickory Hills and Aurora Till Members. The Dysart Paleosol is often developed in unnamed sediments, as well as the underlying Aurora Till Member. Between the Aurora and Winthrop Till Members occur other unnamed, weakly-developed paleosols. These paleosols show little profile development and are represented by distinct A-horizons, but lack B-horizon development (i.e.- an A/C profile) or by organic soils (peats or mucks) developed in other unnamed deposits.

Hickory Hills Till Member

The Hickory Hills Till Member is the youngest member of the Wolf Creek Formation. The type area for the Hickory Hills Till is within the Wolf Creek area, in the vicinity of Hickory Hills Park. Within the type area two principal reference localities are described; the 402 Road Cut Section, which is designated the type locality and section, and the Casey's Paha East Section, which is the principal reference locality. To fully describe the upper and lower boundaries of the unit, several other reference localities must also be cited (the Hayward's Paha Transect and Buckingham Section).

Outcrop and supplemental drill-core information comprise the 402 Road Cut Section. (Since it was initially described as the 402 road cut by Fenton (1966) the highway has been renumbered as state highway 21.) The cut is located on the west end of

Table 3. Summary of particle-size data for WOLF CREEK FORMATION till samples.

	% Clay Mean	% Clay s.d.	% Silt Mean	% Silt s.d.	% Sand Mean	% Sand s.d.
Total WOLF CREEK FORMATION - Undifferentiated (All members plus undifferentiated samples.)						
n = 430	22.6	±4.1	37.0	±5.7	40.0	±6.5
- Hickory Hills Till Member						
n = 187	21.8	±3.6	34.4	±4.6	43.7	±4.7
- Aurora Till Member						
n = 145	22.1	±4.4	39.9	±5.2	38.4	±5.6
- Winthrop Till Member						
n = 27	25.0	±5.0	40.7	±3.6	33.5	±5.3
- Undifferentiated samples						
n = 71	25.1	±2.5	36.8	±6.4	36.2	±7.0

Table 4. Summary of clay mineralogy data for the WOLF CREEK FORMATION.

	Ex. - % Mean	Ex. - % s.d.	Ill. - % Mean	Ill. - % s.d.	K. + C. - % Mean	K. + C. - % s.d.
Total WOLF CREEK FORMATION - Undifferentiated (All members, plus undifferentiated samples.)						
n = 288 (range)	62.1 (50-74)	±4.3	16.7 (4-24)	±3.4	21.4 (14-32)	±3.3
- Hickory Hills Till Member						
n = 101 (range)	62.8 (52-73)	±4.5	16.8 (11-23)	±3.3	20.2 (14-25)	±2.2
- Aurora Till Member						
n = 82 (range)	61.9 (55-70)	±3.6	17.6 (13-24)	±2.5	20.7 (17-24)	±2.3
- Winthrop Till Member						
n = 24 (range)	59.6 (51-68)	±4.3	16.6 (10-20)	±2.2	24.4 (16-31)	±3.8

Table 5. Summary of sand-fraction lithology data for the WOLF CREEK FORMATION.

	T.C. %		T.S. %		T.X. %		C/D - % Observations					
	Mean	s.d.	Mean	s.d.	Mean	s.d.	<1	1-5	5-10	10-15	>15	No D
	WOLF CREEK FORMATION - Hickory Hills Till Member											
n = 93	24.2	±6.3	27.1	±6.9	72.9	±6.9	3	66	19	6	3	3
	- Aurora Till Member											
n = 79	21.6	±6.5	24.1	±6.5	75.9	±6.5	--	12	9	15	22	43
	- Winthrop Till Member											
n = 18	15	±5.1	18.1	±6.5	81.9	±6.5	--	5	5	--	40	50
	- Undifferentiated samples											
n = 32	18.7	±8.0	22.1	±7.5	77.9	±7.5						

T.C. = total carbonate grains; T.S. = total sedimentary grains
T.X. = total "crystalline grains" - quartz plus feldspar, plus igneous and metamorphic grains.

C/D - limestone/dolostone grain ratio, shown by % of observations in ratio-value categories.
No D - no dolostone identified by techniques used.

Casey's Paha, the location of Hickory Hills Park, where state highway 21 cuts through the paha, exposing about 45 feet of section. This is located in the NW¼ of the SE¼ of section 10, T 86N, R 13W (Geneseo Township), Tama County. The top of the cut is approximately 1,040 feet elevation. The cut is covered with vegetation, except along a vertical gully in the center of the cut and horizontally along the outcrop of the Yarmouth-Sangamon paleosol. A description of the cut and a core below it are given in Description 1. Figure 2 summarizes the stratigraphy and particle size data to a depth of about 80 feet. The Hickory Hills Till Member was considered the Kansan till in this area (see Ruhe, et al., 1968).

The second reference section is Casey's Paha East and is a composite of an outcrop and a drilling transect. The outcrop is described in Description 2, and the transect is shown in figure 3. The outcrop section is located (point A, figure 3) in a cut on county line road, in the SE¼, SE¼, sec. 12, T 86N, R 13W (Geneseo Twn.).

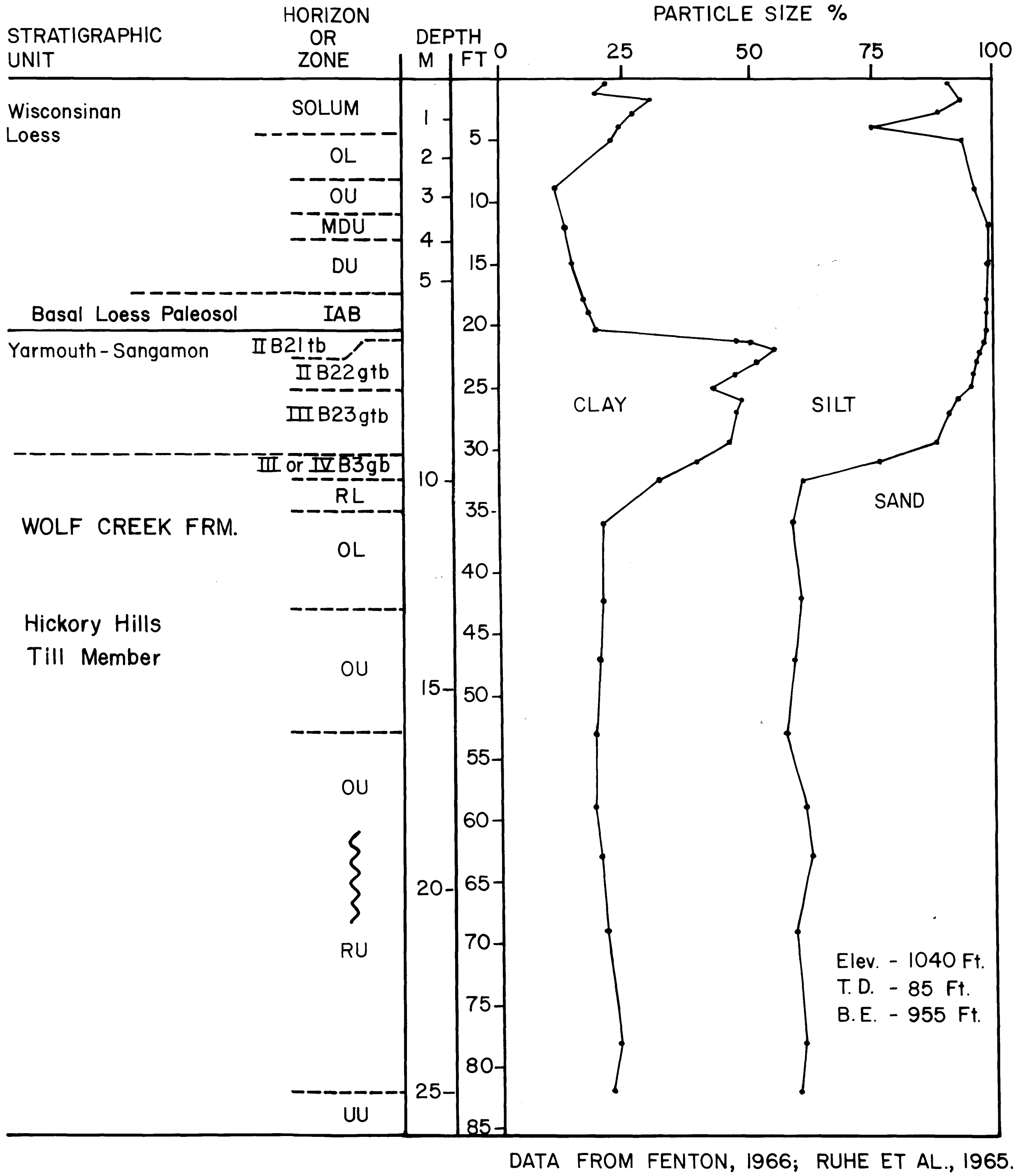


Figure 2. Stratigraphy and particle size data, 402-Road Cut Section.

The Hickory Hills Till varies in color vertically, as a consequence of weathering (see general discussion in Hallberg, Fenton, and Miller, 1978). It varies from a light-yellowish brown (10 YR 5/6-8) in the oxidized zone to a dark gray (5GY 4/1) in the unoxidized zone. The colors are non-diagnostic, as all the tills in this area (and most of Iowa) exhibit the same range of colors.

The thickness of the Hickory Hills Till Member is quite variable. In places in the study area it is eroded and entirely missing. In more complete sections (compare figures 2 and 9) it varies from about 10 to over 50 feet (3-15m) in thickness.

The Hickory Hills Till Member is loam-textured, averaging rather consistently about 22% clay, 34% silt, and 44% sand over the study area (see Table 3, figure 4). The Hickory Hills Till is also quite uniform in texture at individual localities, particularly where a thick section is preserved. The 402-Road Cut Section is a good example, where the till is at least 50 feet thick and varies less than 3 per cent in any particle size category (see figure 2).

In a thick sequence the till is quite uniform, but in its lower portions it often deviates from its modal composition toward a mixed composition with the underlying material. In some sections material resembling the substratum is clearly incorporated in the till (a block inclusion). In other sections the till texture simply changes slightly, probably as a result of mixing and incorporation of the underlying materials. This complicates the analysis of the till textures. Figure 4 shows the range of particle size for the Hickory Hills, Aurora, and Winthrop Till Members in the Wolf Creek area. Figure 4b also shows samples from the lowermost 5 to 15 feet (1.5 - 4.6m) of the Hickory Hills Till which deviate from the normal cluster (labeled L and S). The samples labeled L are from locations where the Hickory Hills overlays the Dysart Paleosol and/or the silts associated with the paleosol (see Description 3). The samples labeled S are from the Buckingham Sections where the Hickory Hills overlays stratified sands and sediments. These samples seem to show

Description 2. Casey's Paha East (from Hallberg, et al., 1978).
Location: SE¼, SE¼ sec. 12, T 86N, R 13W., Tama Co.

Depth Meters	Depth Feet	Horizon or Weathering Zone	
		WISCONSINAN LOESS	
0 -1.2	0 - 4.0		Soil solum.
1.2-2.4	4.0- 8.0	OL	10YR 5/4, yellowish brown, silt loam; leached loess.
2.4-5.0	8.0-16.5	OU	10YR 5/4, yellowish brown, silt loam; few fi 10YR 5/6-5/8 mot; cal loess.
5.0-5.6	16.5-18.5	OU	2.5Y 5/3, gray brown to light olive brown, silt loam; str thin & med pl brk to mod fi & med gr.; calcareous loess.
		Basal Loess Paleosol	
5.6-5.8	18.5-19.0	OL	10YR 5/6, yellowish brown, silt loam; mny med 7.5YR 5/6-5/8 mot.; loess.
		Late Sangamon Pedisediment - LATE SANGAMON PALEOSOL	
5.8-5.9	19.0-19.5	IIAb	10YR 4/4, dark yellowish brown, clay loam; few fi 7.5YR 5/6-5/8 mot; Late Sangamon, pedisediment.
		WOLF CREEK FORMATION--Hickory Hills Till Member	
5.9-6.2	19.5-20.5	IIIB2b	7.5YR 4/4, dark brown, clay; str med sbk; com med Mn spk; 5YR 4/4 clay flows; Late Sangamon.
6.2-6.6	20.5-21.5	IIIB3b	10YR 5/6 & 5Y 6/2, yellowish brown and light olive gray, clay loam; str med sbk; com med Mn spk; 5YR 4/4 clay flows on ped surfaces; Late Sangamon.
6.6-6.7	21.5-22.0	OL	5YR 4/6-4/8 & 7.5YR 5/6-5/8, dark yellowish browm and strong brown, silt loam; leached "Kansan" till.
6.7-6.9	22.0-22.5	OL	10YR 5/6-5/8, yellowish brown, loam; com fi Mn spk; few 2.5Y 6/2 patches; 5YR 4/4 clay flows on ped surfaces; leached "Kansan" till.
6.9-7.6	22.5-25.0	OU	10YR 5/6, yellowish brown, loam; com fi & med 7.5YR 5/6-5/8 mot; few 5YR 4/6 mot; lg ca nod; cal "Kansan" till.
7.6-8.4	25.0-27.5	OU	10YR 5/6, yellowish brown, loam; com fi & med 7.5YR 5/6-5/8 mot; few 5Y 6/2 mot; cal "Kansan" till.

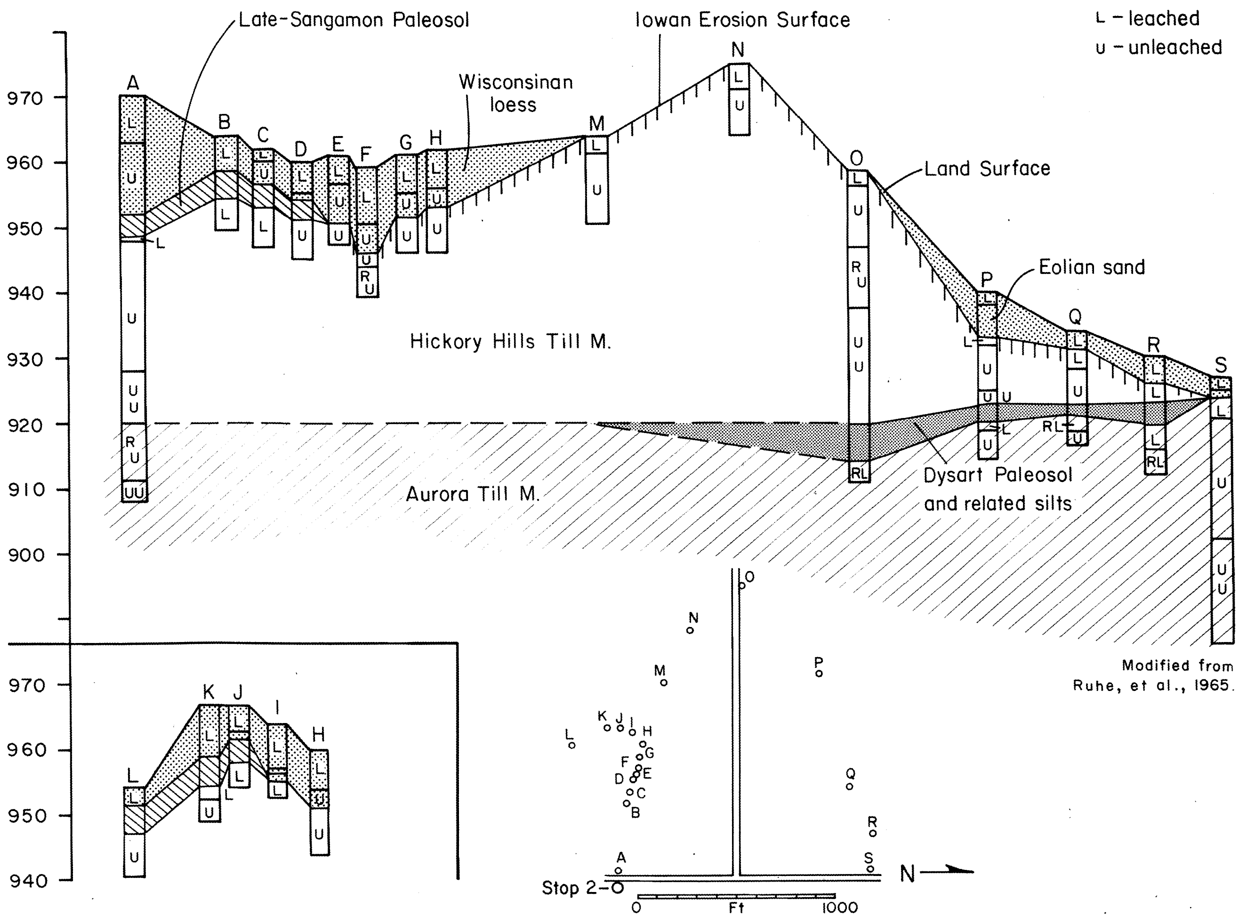
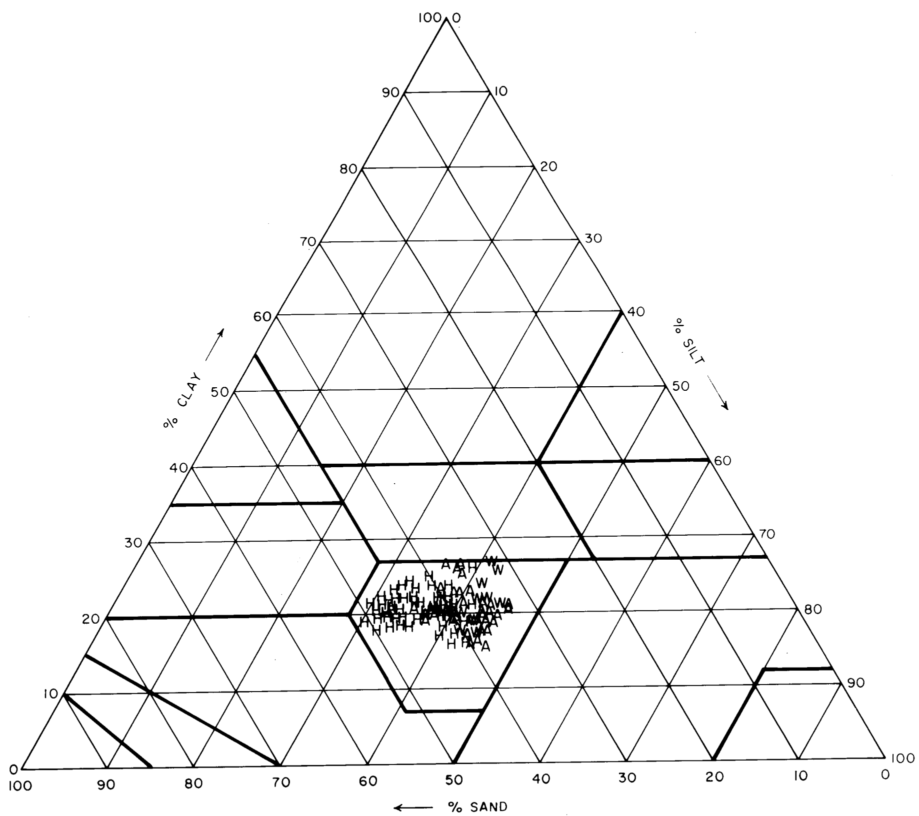
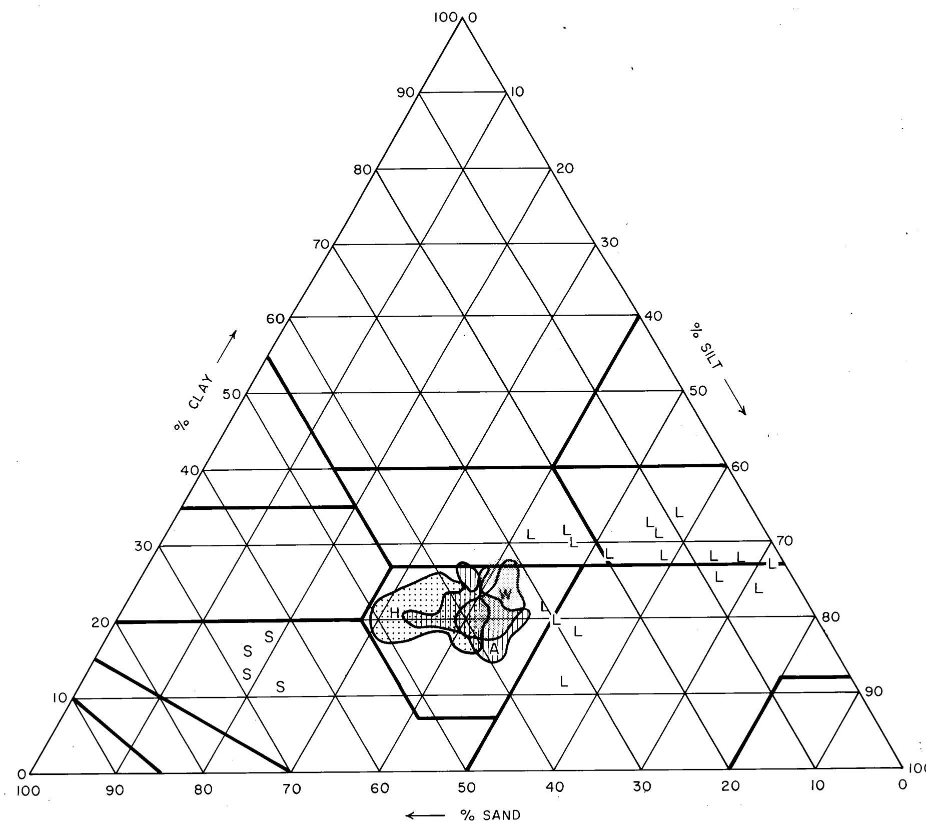


Figure 3. Drilling transect at east end of Casey's Paha, from Late-Sangamon Surface onto the Iowa Erosion Surface (from Hallberg, et al., 1978). Map inset shows location of core-holes in relation to county roads. Location of hole A given in Description 2.



A.



B.

Figure 4. A. Plot of particle-size data (n=108) Wolf Creek area; H=Hickory Hills Till, A=Aurora Till, W=Winthrop Till. B. Summary of data in 12A, outlining textural range of tills. L=lower Hickory Hills Till where it overlies Dysart Paleosol; S=Hickory Hills Till where it overlies stratified sands.

mixing with the texture of the underlying materials. This basal mixing affects other properties as well (Lucas, et al., 1978; Boellstorff, 1978b). It is difficult to evaluate the data from sections where only a thin lower increment of any of the tills are preserved. Good examples of such deviations in many properties are documented at the Kirkwood Section (see Appendix).

As shown in Figure 4 (and Table 3), the textures of the till members of the Wolf Creek Formation overlap but there are important differences. The Hickory Hills Till Member almost always exhibits more sand than silt, whereas the Aurora and Winthrop Till Members are generally more silty.

The average clay mineral composition of the Hickory Hills Till Member is approximately 63% expandables, 17% illite, and 20% kaolinite plus chlorite (Table 4). This clay mineralogy is diagnostic of the Wolf Creek Formation, but it does not permit discrimination between the individual till members within the formation. This is also apparent even in the data from individual sections, as in Table 6 from the Wolf Creek area.

The sand-fraction lithology data for the Hickory Hills Till Member are summarized in Table 5. The sand-fraction lithologies are a principal component for identifying and discriminating the individual till members of the Wolf Creek Formation. The Hickory Hills Till Member, on the average, shows higher values for total carbonate and total sedimentary grains than the Aurora or Winthrop Tills. There is considerable site to site and sample variation in the sand fraction data, as is evident in the individual sample data from the Wolf Creek area sections (Table 7).

Even with the variation in the values of the grain counts, one property seems to be consistent. The Hickory Hills Till is marked by a low C/D ratio, while the Aurora and the Winthrop show high values. The median and modal values for the Hickory Hills Till Member C/D ratio are between 1 and 5; the median and modal values for the Aurora and Winthrop are greater than 15 (Table 5).

The upper boundary of the Hickory Hills Till Member (and the upper boundary of the Wolf Creek Formation) is complex because of the effects of the widespread erosion in the study area. The complications of the upper boundary are related to the various geomorphic-erosion surfaces in the area, which decline in stepped fashion from the loess-mantled Yarmouth-Sangamon surface, to the Late-Sangamon surface, and finally to the various Wisconsinan-age Iowan surfaces which bevel and totally truncate the Hickory Hills Till.

The type section for the Hickory Hills Till Member, the 402-Road Cut Section (Description 1; figure 2) shows the upper boundary of the till in its most complete stratigraphic setting. The upper limits of the Hickory Hills Till Member and the Wolf Creek Formation are within the Yarmouth-Sangamon Paleosolum. The Yarmouth-Sangamon Paleosol is developed in part in the Hickory Hills Till and in part in the overlying fine-textured sediments deposited on the till. These sediments are presently undifferentiated, but for now are excluded from the Wolf Creek Formation. The upper boundary of the formation and Hickory Hills Till is the contact between the sediments and the till-derived portion of the paleosol. In some sections, this contact is very transitional, but in others it is clearly marked by an obvious, abrupt change in materials, often with a stone-line at the contact.

The Casey's Paha East Section shows the upper boundary of Hickory Hills Till Member, and the Wolf Creek Formation in relation to the Late-Sangamon Surface and Paleosol (Description 2). The Late-Sangamon Surface forms the second step of the typical sequence of stepped erosion surfaces and well-developed paleosols in the older Pleistocene regions in Iowa (Ruhe, et al., 1967; Hallberg, et al., 1978). It is not possible to view the Late-Sangamon Surface at Casey's Paha because the loess and eolian sand of the paha mask the paleo-land-surface. The paleosol at this site, however, is representative of the Late-Sangamon paleosols; it shows a two-story soil profile developed in a loam to clay loam pedisediment, a stone-line, and the underlying Hickory Hills Till. The upper limit of the Wolf Creek Formation is again at the top of the Hickory Hills Till Member, which is marked by the stone-line within the paleosol which separates it from the overlying pedisediment. The pedisediment is similar in matrix texture to the till, but contains little or no gravel or cobbles, and at times shows clear evidence of sorting and stratification.

Table 6. Clay Mineralogy - Wolf Creek Area

WOLF CREEK FORMATION - Hickory Hills Till

Horizon or Zone	Depth * (Feet)	ID		EX.	Ill.	K+C
OL	1- 237	742		63	16	21
OL	1- 43	946		70	11	19
OU	1- 45	947		64	15	21
OU	1- 48	3070		60	19	21
OU	1- 58	952		65	16	19
MOU	1- 68	960		67	16	17
OL	2- 22	948		67	15	18
OU	2- 25	949		59	17	24
OU	2- 27	950		63	15	23
OU	3- 10	726		66	20	14
MRU	3- 11	954		65	16	19
RJU	3- 12	951		65	16	19
RJU	3- 12.5	953		60	19	21
			Mean	64	16	19
			s.d.	3	2	3
	WOLF CREEK FORMATION - Aurora Till					
RL	3- 24	727		56	24	20
MOU	3- 30	728		62	18	20
MOU	3- 34	729		64	17	19
MOU	3- 38	957		67	13	20
MOU	3- 40	955		62	18	20
MOU	3- 42	956		60	20	20
DU	2- 8	959		66	14	20
MOU	2- 12	958		62	19	19
			Mean	62	18	20
			s.d.	3	3	1
	Silts Associated with Dysart Paleosol					
	3- 13	725		67	20	13
	Dysart Paleosol					
	3- 14.5	724		Uncalculable - no Illite apparent; broad expandable peak.		

* 1- Location (see descriptions 1-3) and depth.
ID - Lab number; EX - % expandable clays; Ill. - % Illite; K+C - % Kaolinite plus chlorite.

Table 7. Sand fraction lithologies - Wolf Creek Area

Horizon or Zone	Depth	C/D	T.C.	Sh.	T.S.	Q-F.	Oth	Xst.
		WOLF CREEK FORMATION - Hickory Hills Till						
OU	1-44	.73	18.0	-	18.0	70	12	82
OU	1-45	2.0	36	-	36	60	4	64
OU	1-48	6.0	18.6	3.1	24.8	71.1	4.1	75.2
OU	1-52	1.3	19	1.0	20	71	9.	80
OU	1-58	2.3	27	10	37	57	6.	63
MOU	1-68	5.2	29	-	30	59	11.	70
OU	2-25	7.8	26	7	38	52	10.	62
OU	2-27	NoD.	27	-	27	57	16.	73
OU	2-27.5	3.0	20	2	29	62.5	8.5	71
OU	3-10	18.0	31	-	31	55	14	69
MRU	3-11	3.2	25	3	34	64	2.	66
RIU	3-12	4.1	21	-	21	62	17.	79
RIU	3-12.5	2.2	17	-	21	68	11.	79
		Mean LO	24.2	-	28.2	62.2	-	71.8
		s.d.	5.8	-	6.9	6.3	-	6.9
		WOLF CREEK FORMATION - Aurora Till						
MOU	3-30	18.0	18.0	-	19	69	12.	81
MOU	3-34	NoD.	27.0	2.1	29.1	54	16.9	70.9
MOU	3-38	NoD.	11	2.	13	65	22	87
MOU	3-39	NoD.	20	2.	22	71	7	78
MOU	3-40	20.0	24	2.	29	62	9	71
MOU	3-42	4.0	18	-	20	71	9	80
OU	2- 8	NoD.	23	1.	25	75	-	75
MOU	2-12	13	14	2.	16	72	12	84
		Mean HI	19.4	-	21.6	67.4	-	78.4
		s.d.	5.3	-	5.8	6.8	-	5.8

C/D - Limestone/dolostone ratio; NoD = no dolostone by method used.
T.C. - total carbonates.
Sh - Shale
T.S. - total sedimentary grains.
Q-F. - quartz-feldspar grains.
Oth. - Other igneous and metamorphic grains.
Xst. - Total crystalline grains (total "non-sedimentary")

Complications of the upper boundary are revealed in the drilling transect which begins at the Casey's East outcrop (see figure 3). As the closely spaced drill-hole transect proceeds to the northwest from site A (figure 3) the Late-Sangamon Paleosol is progressively truncated, and the loess of the paha then lies directly on the eroded surface of the Hickory Hills Till. As the transect continues out onto the "Iowan" plain, this eroded till surface is exposed--essentially devoid of loess. As the transect comes back towards the northeast, lower surfaces are encountered and by site S, the loess lies directly upon the Aurora Till. The erosion surface has truncated the Late-Sangamon Paleosol, the Hickory Hills Till, and the Dysart paleosol.

The composite section shows the typical relations of the geomorphology and the stratigraphy in this area. The upper boundary of the Wolf Creek Formation and the Hickory Hills Till Member is marked by: 1) the stone-line marking the Late-Sangamon pediment, which is the boundary between the till and the younger, overlying Late-Sangamon Pedisediment; 2) the discontinuous stone-line which marks the contact between the Wisconsinan-age loess, pedisediment or eolian sand and the eroded till surface.

The lower boundary of the Hickory Hills Till Member is also complex. It is variously marked by the contact with the Dysart Paleosol, or, where the paleosol and related unnamed sediments are eroded, the Hickory Hills Till may rest directly on the Aurora Till Member. In this later situation, the boundary is often a complex zone of contorted glaciofluvial sediments related to the Hickory Hills Till Member. Where sub-Hickory Hills Till erosion is greater, the Hickory Hills Till Member may rest directly on any older units, from the Winthrop Till Member to the Paleozoic bedrock.

The composite Casey's East transect also shows the nature of the lower contact of the Hickory Hills Till Member. At about 920 feet elevation, in this transect, the Hickory Hills Till overlies the Dysart Paleosol, (sites O-R; figure 3), or, as is regionally more often the rule than the exception, to the south in the transect, the Dysart Paleosol is eroded off and the Hickory Hills Till lies directly on the Aurora Till Member (site A). This till-till contact is marked by an abrupt change in weathering zone or color characteristics, an abrupt change in density, and a change in particle-size and mineralogic character.

The relationship of the Hickory Hills Till Member and the Dysart Paleosol can be more clearly shown in the Hayward's Paha Transect, which forms another reference section for the Wolf Creek Formation (and the Dysart Paleosol). The transects are on the south side of Wolf Creek. The drill core transects are located in section 36, T 86N, R 13W (Geneseo Twn.), and the locations are shown in figure 5. A review of the cross-sections from the drilling transects (figures 6, 7, and 8) shows similar relations to the Casey's Paha localities. In the crest of the paha (sites G-38, 104A; WZ-1--3) thick Wisconsinan loess overlies the Yarmouth-Sangamon Paleosol, developed in part in the Hickory Hills Till Member

In these transects the Hickory Hills Till is considerably thinner (only 5 to 15 feet; 1.5 - 4.6m) than in the Casey's Paha area. At a relatively shallow depth the Hickory Hills Till overlies the Dysart Paleosol and the Aurora Till Member. In this area, the contact between the Hickory Hills Till and the Dysart Paleosol lies again at a rather consistent elevation locally. Figure 9 summarizes the stratigraphy and particle size data for core WZ-3, which shows both the upper contact of the Hickory Hills Till, and its abrupt lower contact with the top of the unnamed silty clay loam sediments in which the Dysart Paleosol is formed.

As the transects proceed on to the lower lying erosion surfaces, the Yarmouth-Sangamon Paleosol is progressively truncated, and thin loess rests directly on the eroded Hickory Hills Till. Description 3 from core site G-22 (figure 6) describes the abrupt lower contact between the Hickory Hills Till and the Dysart Paleosol. Thirty years ago, this section, isolated by itself, would likely have been interpreted as thin loess, over thin "Iowan till," over Kansan gumbotil (the Dysart Paleosol) and Kansan till (the Aurora Till). The detailed drilling transect again shows that the upper till is not Iowan, but is the Hickory Hills Till (classically the Kansan till) whose upper surface has been eroded.

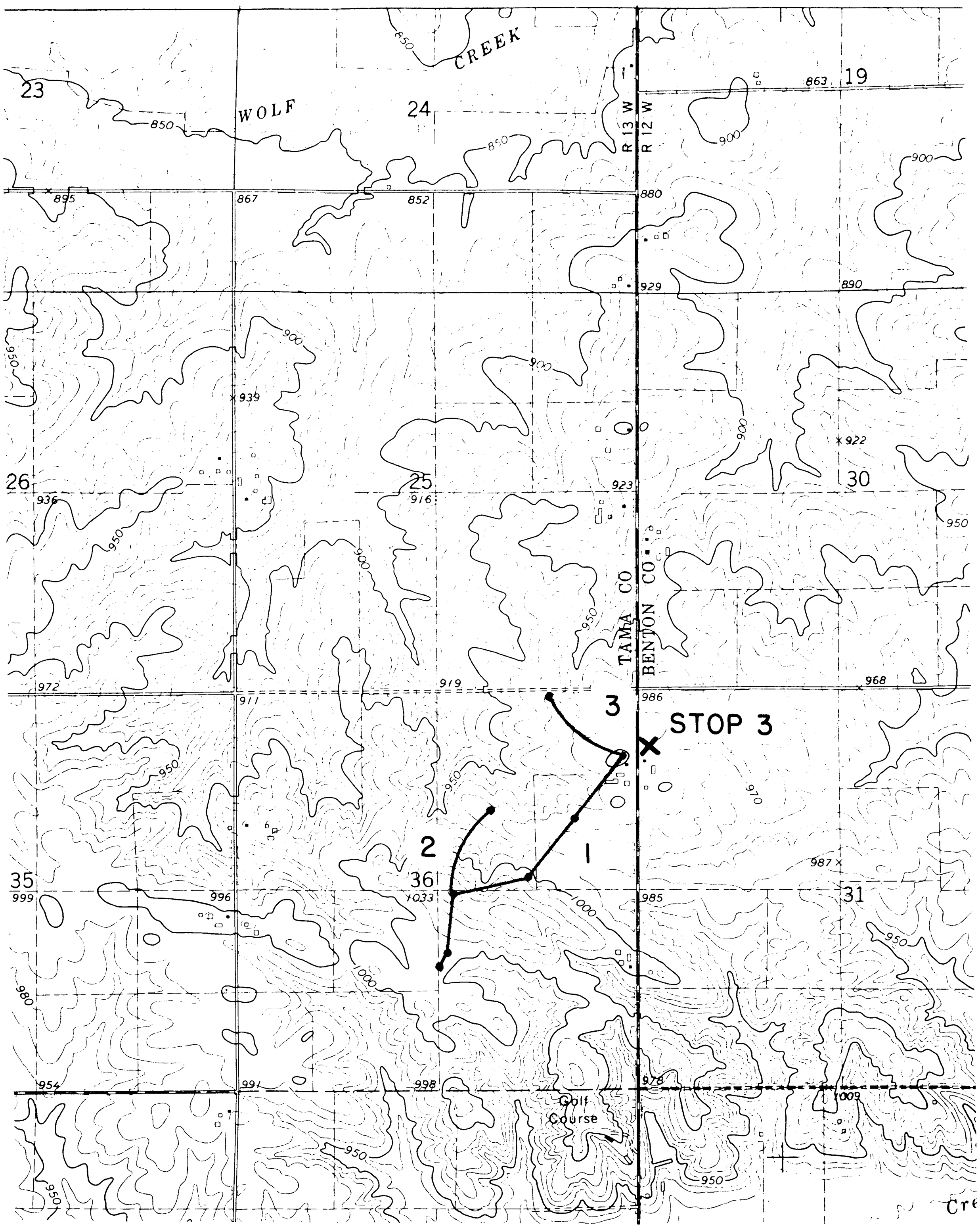


Figure 5. Portion of Dysart 7.5 min Quad., showing drilling transects in Hayward's Paha area (after Hallberg, et al., 1978).

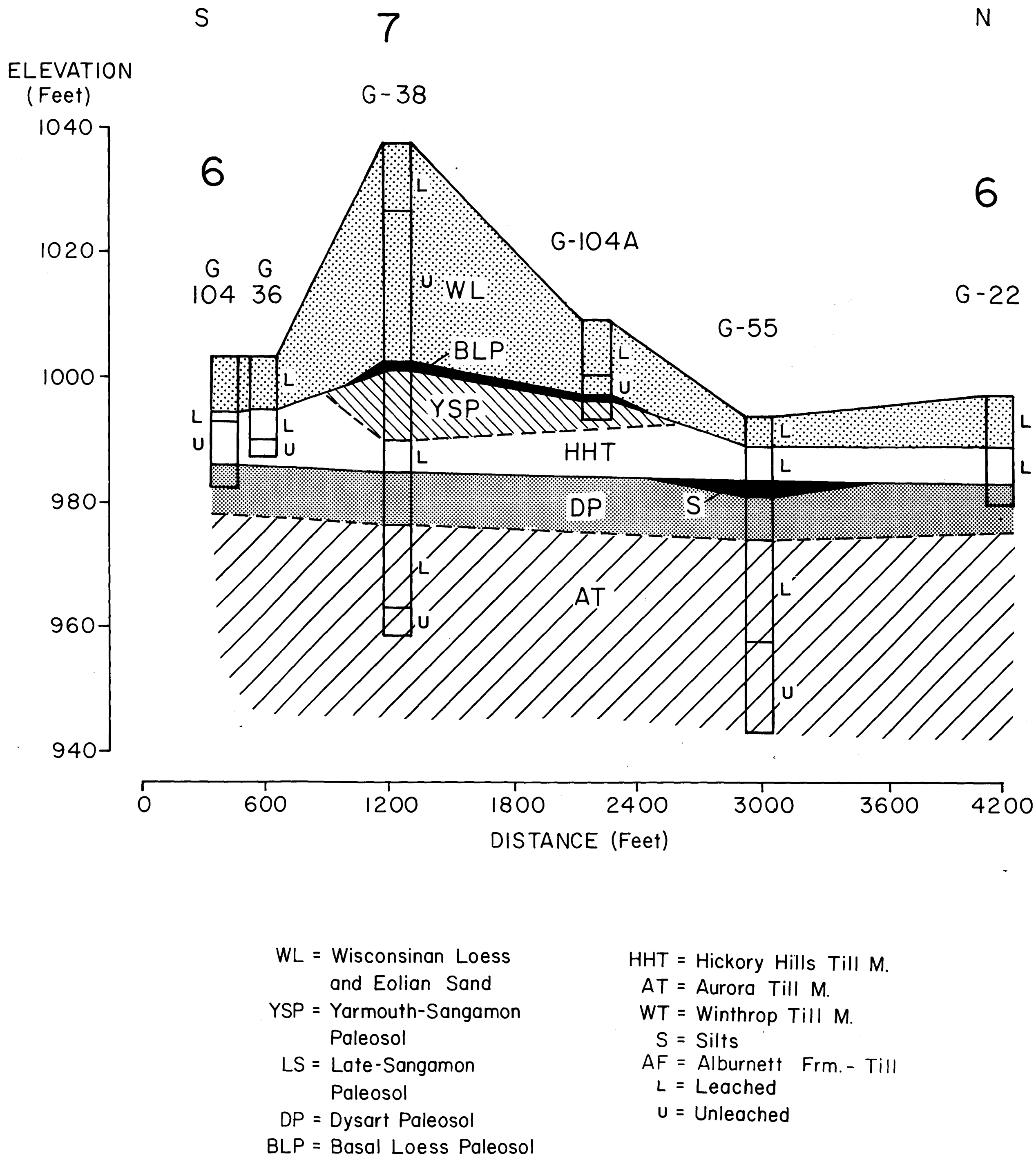


Figure 6. Cross-section 1 (see figure 4) in Hayward's Paha area (after Fenton, 1966).

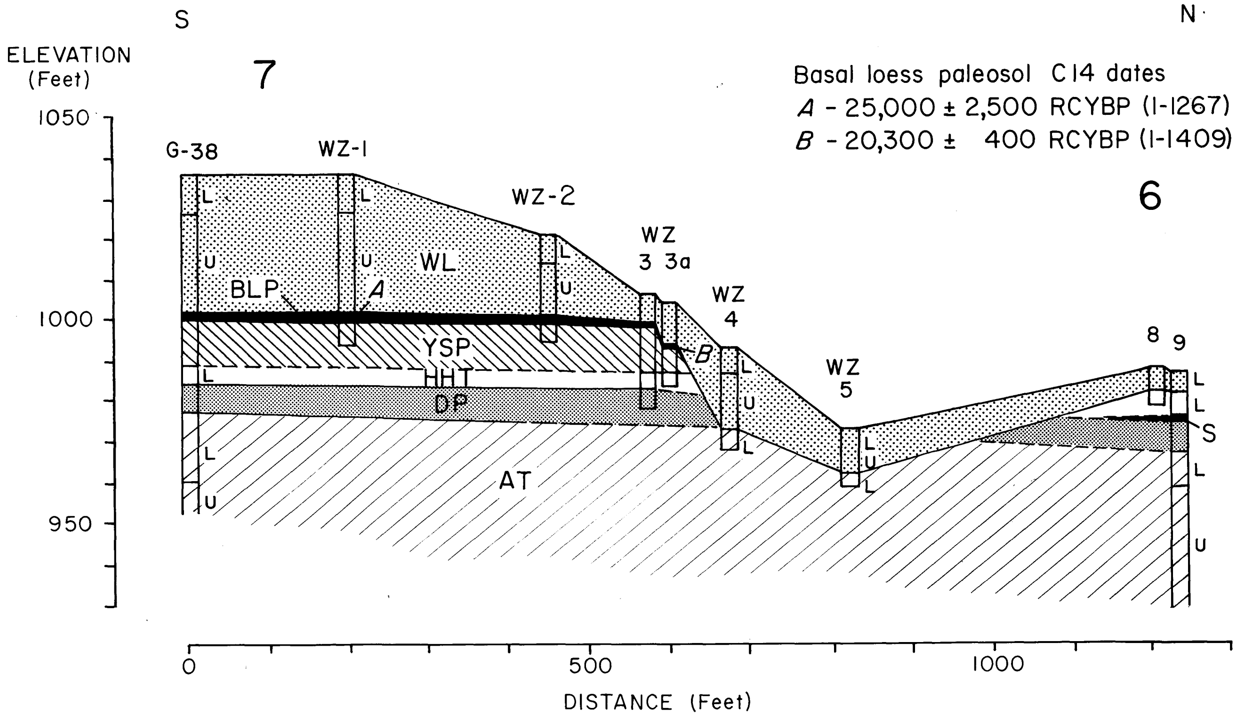


Figure 7. Cross-section 2 (see figure 4), Hayward's Paha area (after Ruhe, et al., 1968).

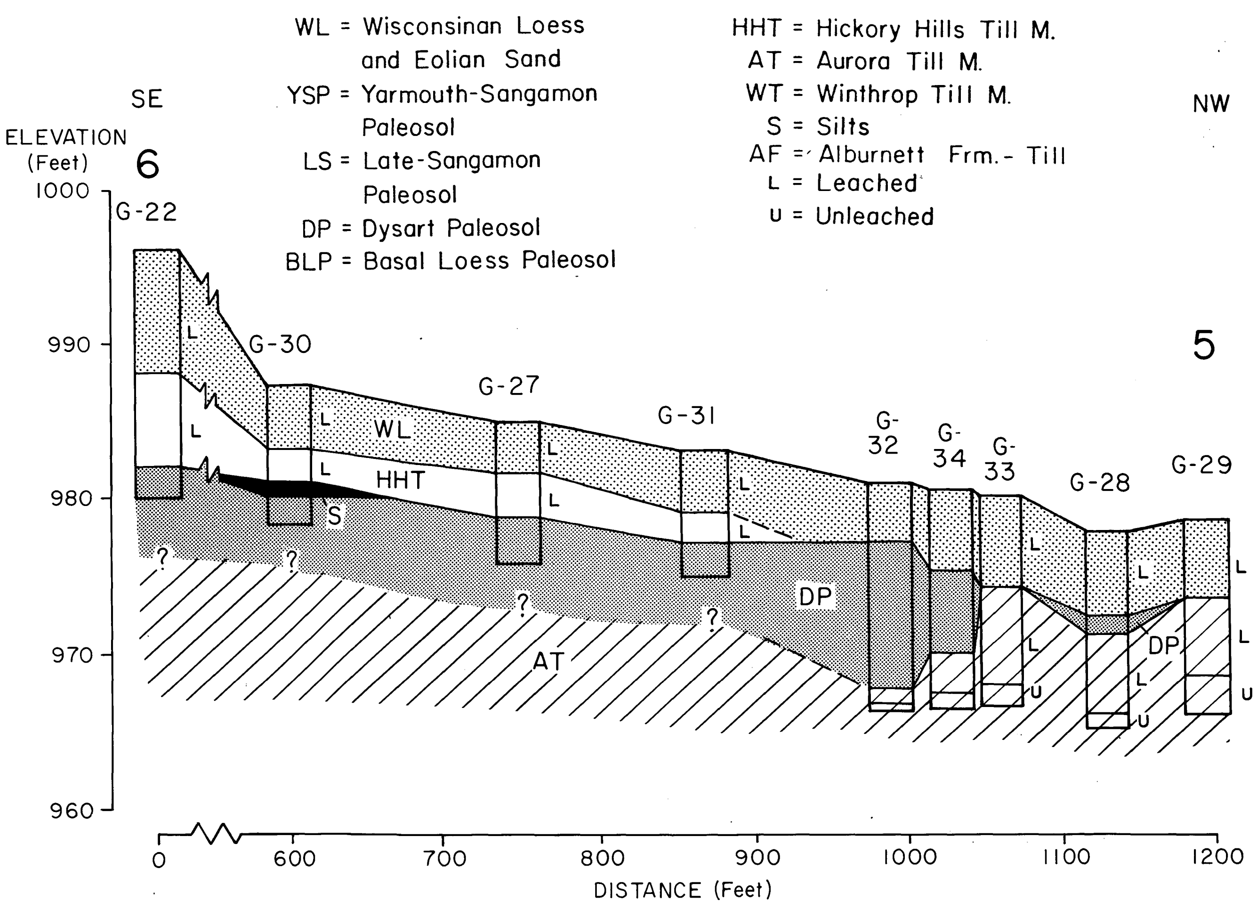


Figure 8. Cross-section 3 (see figure 4), Hayward's Paha area (after Fenton, 1966).

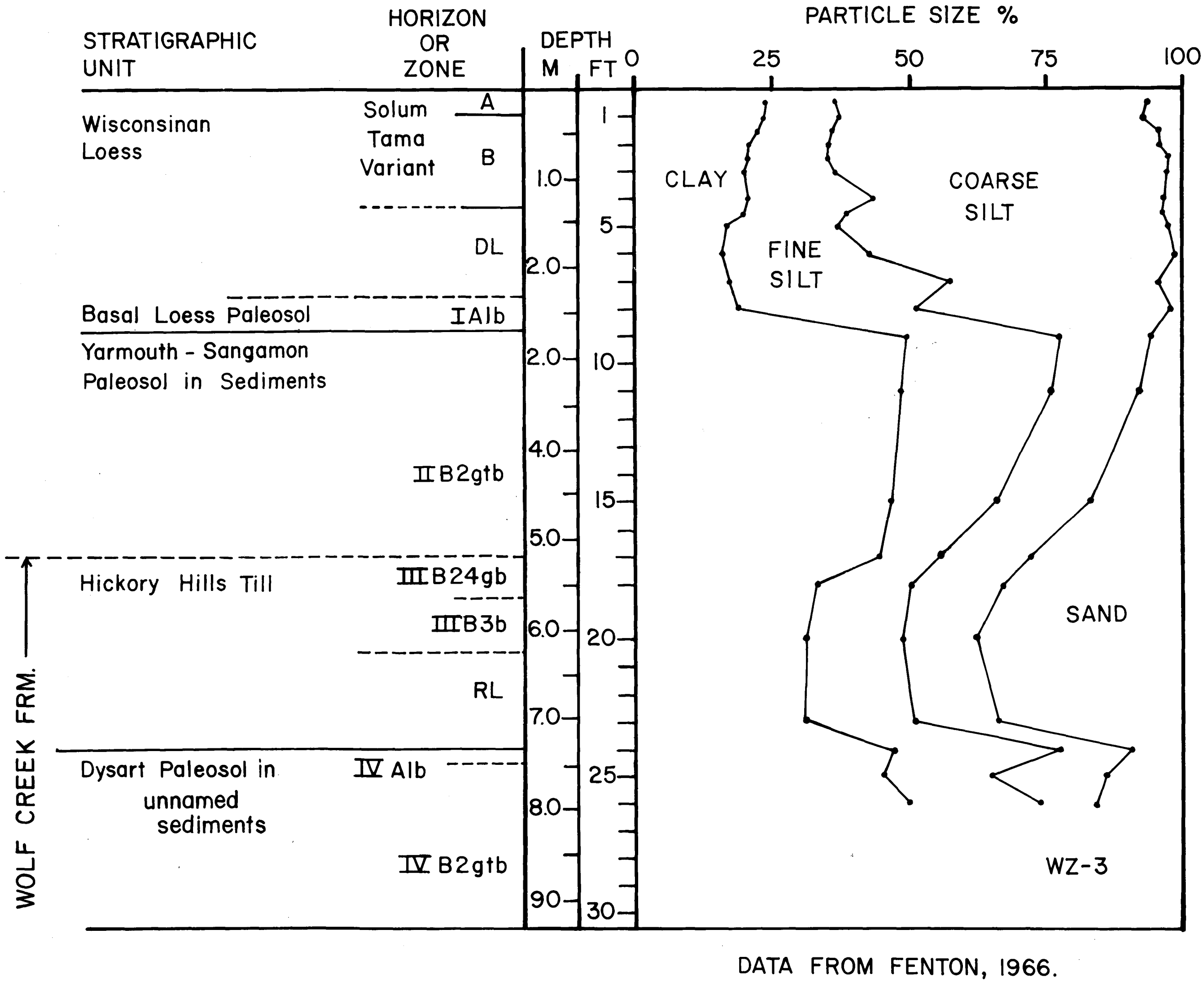


Figure 9. Stratigraphy and particle-size data, core WZ-3 (see figure 7).

In some sections the contact with the Dysart Paleosol is not as abrupt or clear because the lower portion of the Hickory Hills Till contains block inclusions of the Dysart Paleosol, which were sheared into the lower portions of the till.

Description 3. Site G 22 - Stop 3 in Hayward's Paha transect (see figs. 5 and 6; modified in part from Fenton, 1966).

Location: SE¼ of NE¼ of NE¼ sec. 36, T 86N, R 13W, Tama Co. (see fig. 5).

Depth Meters	Depth Feet	Horizon or Zone	Description
	WISCONSINAN LOESS AND EOLIAN SAND		
0 - 1.6	0 - 5.1	OL	Yellowish-brown (10YR 4-5/4) silt loam; loess.
1.6- 2.1	5.1- 7.0	MOL	As above, with common, yellowish brown, olive brown mottles; sandy loess and eolian sand.
	WOLF CREEK FORMATION--Hickory Hills Till Member		
2.1- 2.5	7.0- 8.2	MRL	Olive (5Y 5/4), loam with pebbles; mixed colors and mottles of 2.5Y 4 and 5/4, 7.5YR 5/4, 10YR 4/4-5/6; leached; till.
2.5- 3.0	8.2- 9.9	OL	Yellowish brown to light olive brown (2.5Y-10YR 5/4) loam with pebbles; leached; till.
3.0- 3.3	9.9-10.8	OU	As above, calcareous
3.3- 3.6	10.8-11.7	MRU	Olive (5Y 5/4) with abundant mottles; as above; till.
3.6- 3.9	11.7-12.8	RJU	Mixed olive (5Y 4/4) and very dark grayish brown (2.5Y 3/2), loam with pebbles; common gray (5Y 5/1) and light olive brown (2.5Y 5/4) mottles; prominent vertical joints with strong brown color (7.5YR 5/8); till.
	WOLF CREEK FORMATION - Unnamed silts; DYSART PALEOSOL		
3.9- 4.1	12.8-13.5	IAb	Banded black (N20) and gray (5Y 5/1) silty clay loam, rich in organic debris; may form complex Ab horizon with paleosol below.
4.1- 5.6	13.5-18.3	IIB2tgb	Gray (5Y 6/1, with somes areas and mottles of 5GY 5/1, and 2.5Y 6/2) variable texture, clay, silty clay, clay loam; moderate to strong fine subangular blocky structure; nearly continuous moderate and few thick clay coatings; paleosol developed in crudely stratified fine-textured materials.
5.6- 6.1	18.3-19.9	IIB3tgb	Gray (5Y 6/1) as above, with many 2.5Y 6/2 and 7.5 YR 5/4-6 mottles; moderate fine subangular blocky structure; discontinuous clay films; as above, some more massive sand and silt lenses.
	WOLF CREEK FORMATION--Aurora Till Member		
6.1- 6.7	19.9-22.1	IIIB3tgb	As above, but paleosol formed in till.
6.7- 8.4	22.1-27.4	RL	Pale olive to olive (5Y 6-5/4) with common 2.5Y 6/4 and few 10YR 5/4 mottles; loam with pebbles; leached; till.
8.4- 8.9	27.4-29.4	MOL	Till, as above.
8.9-10.5	29.4-34.4	MOL2- MOU2	Till, with secondary carbonates.
10.5-13.5	34.4-44.4	MOU	Till, calcareous.

In many sections the Dysart Paleosol has been eroded and is absent. The Hickory Hills Till may then be in direct contact with the Aurora Till, or be separated by glaciofluvial materials. The Buckingham Section best describes this situation. The Buckingham Section is comprised of a series of road cuts and cores in the Wolf Creek area, which are located along Tama County road D-65, just east of Buckingham. The first exposure is along the summit of a long interfluve on the south side of the road (See Description 4A). The exposure is on the Iowan erosion surface in the same landscape position that shows the thin lower portion of the Hickory Hills Till over the Dysart Paleosol and Aurora Till in the Casey's and Hayward's Paha area (see figures 3-8).

Cores below the uniform Hickory Hills Till in the cut show an abrupt till-till contact, or a series of discontinuous inclusions of stratified silts, sand, and gravel in an irregular contact zone, at about 14 feet in depth. Figure 10 shows particle size and stratigraphy of two examples. With cores and hand auger this stratigraphy can be traced down to the lower lying erosion surface and exposure of Description 4B. The relations are shown schematically in figure 11.

The lower contact of the Hickory Hills Till Member is marked in these sections, either within a continuous till (a till-till contact) sequence or by a complex zone of glaciofluvial sediments. The till-till contact is marked by an abrupt change in color, weathering zones and other physical properties. As shown in figure 10A particle size distribution and pH change abruptly and consistently at this contact. Tables 8 and 9 show the mineralogic data from samples above and below the till-till contact or above and below the stratified glaciofluvial sediments in the contact zone between the tills.

The properties of the glaciofluvial sediments indicate they are related to, and are thus included within the Hickory Hills Till Member. In places (figure 10B) the contact between the Hickory Hills and Aurora Till Members is clearly at the

Description 4A. Buckingham section - 1.

A shallow road cut along the south side of D-65, in the north central part of the NE¼ of the SW¼ of sec. 18, T 86N, R 13W (Geneseo Twn.), Tama County.

Horizon or Zone	Depth - feet (m)	Description
Solum-OL	0 - 4.2 (0 - 1.3)	Wisconsinan loess with basal sandy increment.
OL	4.2- 4.3 (1.3- 1.3)	Loam pedisediment, with few pebbles; weak stone line.
	WOLF CREEK FORMATION - Hickory Hills Till	
OL	4.3- 7.1 (1.3- 2.2)	Loam till; very uniform in texture; massive.
OU	7.1- 10.2 (2.2- 3.1)	Loam till; as above, but calcareous.

(core taken below the cut, see figure 10.)

Description 4B. Buckingham section - 2.

North end of road cut on north side of county road D-65, in the NW¼ of the NW¼ of the SE¼ of sec. 18, T 86N, R 13W (Geneseo Twn.), Tama County.

Horizon or Zone	Depth - feet (m)	Description
Solum-OL	0 - 1.5 (0 - 0.5)	Sandy loam - loam sediments.
	WOLF CREEK FORMATION - Hickory Hills Till	
MOL	1.5- 3.0 (0.5- 0.9)	Loam till.
MOL2	3.0- 3.5 (0.9- 1.1)	As above, with secondary carbonates.
		Unnamed deposits
OL	3.5- 6.0 (1.1- 1.8)	Sand and gravel
OU	6.0- 9.5 (1.8- 2.9)	As above, calcareous.
	WOLF CREEK FORMATION - Aurora Till	
MOJU grading to MRJU	9.5- 17.3 (2.9- 5.3)	Loam till

base of the stratified deposits. Elsewhere, the contact is unclear because the deposits are contorted and at best only a contact "zone" can be defined. In some sections, (figure 11), the Hickory Hills Till clearly occurs below the sediments as well. The mineralogy data shown in Tables 8 and 9 include some "questionable" samples as Aurora Till. These samples come from below the stratified sediments, yet clearly seem to exhibit the properties of Hickory Hills Till Member. Indeed, samples lower in the section show Aurora Till properties, but no readily

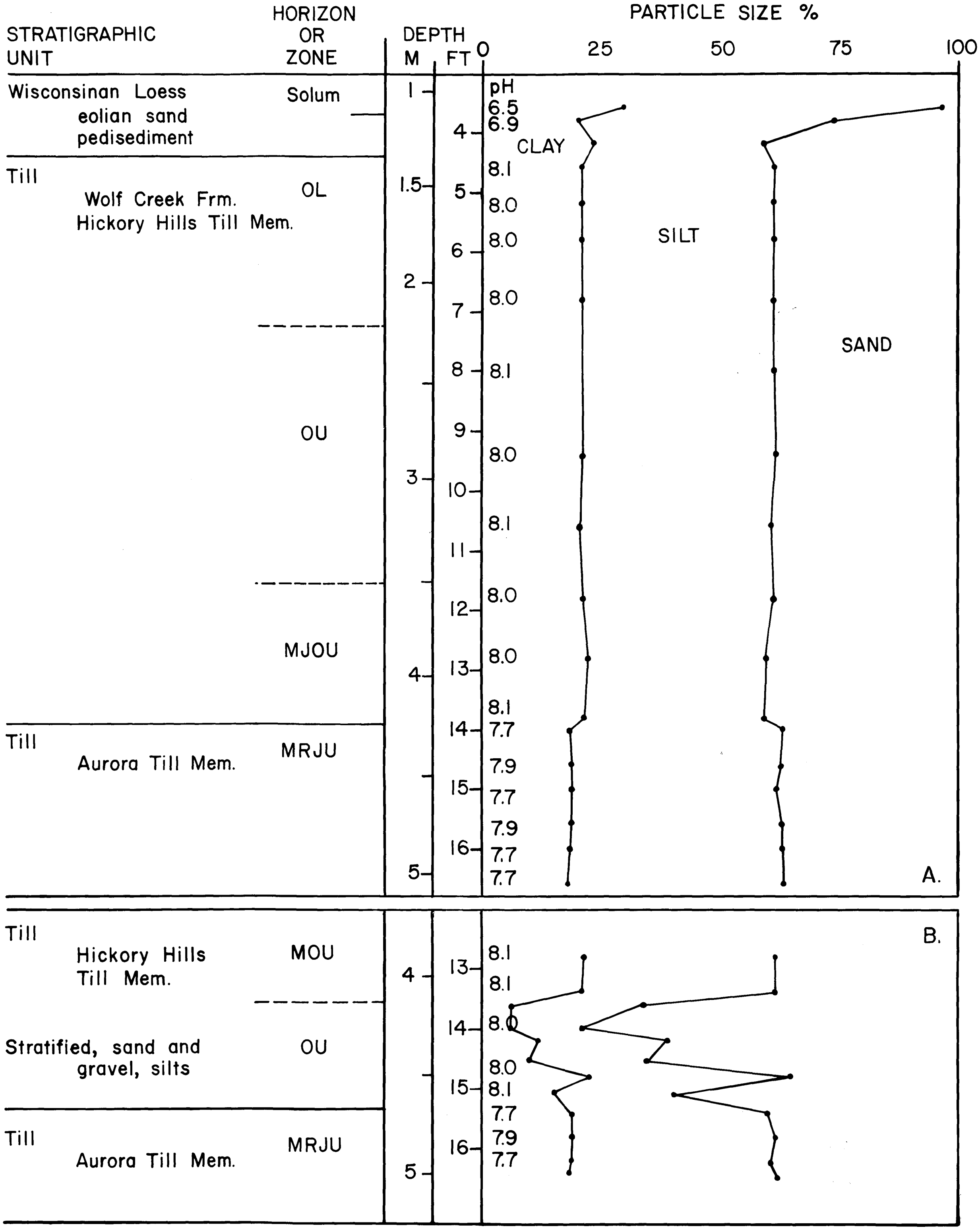


Figure 10. Stratigraphy and particle-size data, Buckingham Sections.

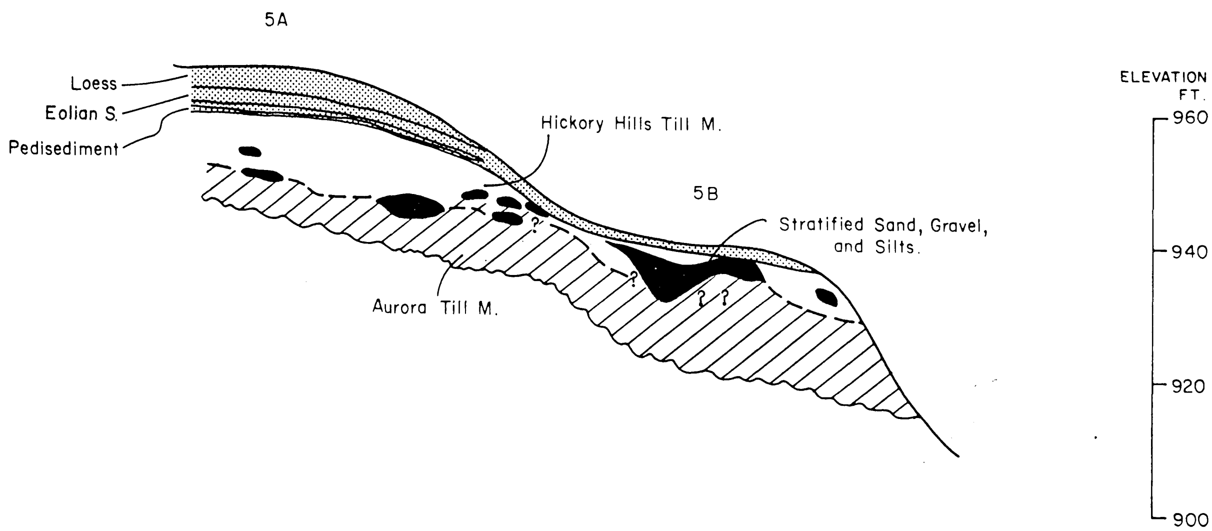


Figure 11. Schematic cross-section from road cuts and borings; Buckingham sections.

traceable contact is definable, except the zone of stratified and contorted drift. Outcrops of stratified and contorted drift and till are common in the Iowan Erosion Surface area of northeast Iowa (Hallberg, 1978b). The nature of these deposits will be discussed later in this report.

Sections such as this point out the necessity for mineralogic characterization in relation to the three-dimensional analysis of the physical stratigraphy and landscape relationships. In most places the paleosols between the tills are missing and to discriminate and correlate the till units from one area to another some other criteria must be used. The mineralogic, lithologic, chemical, and particle-size characteristics become analagous to the tools used in biostratigraphic correlation. These criteria (generally) allow correlation between the sections of these complex continental sediments.

Table 8. Clay Mineralogy - Buckingham sections.

Horizon or Zone	ID	EX	Ill	K+C
	WOLF CREEK FORMATION - Hickory Hills Till			
OU	976	60	19	21
OU	959	62	17	21
MOU	3454	56	22	22
MJOU	3015	63	19	18
MJOU	3481	58	21	21
	Mean	60	20	21
	s.d.	2.9	2.0	1.5
	WOLF CREEK FORMATION - Aurora Till			
MRJU	3036	57	21	22
MRJU	3453	63	17	20
OU	3076	60	19	21
OU	3251	61	19	20
RJU	3460	62	18	20
JUU	3482	61	19	20
JUU	958	61	17	22
	Mean	61	19	21
	s.d.	1.9	1.4	1.0

Table 9. Sand fraction lithologies - Buckingham sections.

Horizon or Zone		ID	C/D	T.C.	Sh.	T.S.	Q-F.	Oth	Xst.
			WOLF CREEK FORMATION - Hickory Hills Till						
OU		854	1.4	29	5	34	53	13	66
OU		863	2.1	31	1	32	57	11	68
OU		600	2.0	36	-	36	55	9	64
MOU		601	2.2	29	-	29	61	10	71
MOU		662	3.2	39	1	40	57	3	60
MJOU		851	3.5	29	2	31	49	20	69
MJOU		850	3.9	29	6	35	54	11	65
MJOU		857	3.1	33	-	33	51	16	67
MJOU		852	2.5	28	-	28	55	17	72
MRU		674	1.8	32.2	-	32.2	59.8	8.0	67.8
MRU		862	2.1	37	-	37	49	14	63
MRU		856	2.6	35	-	36	45	19	64
		Mean	Lo	32.3		33.6	53.8		66.4
		s.d.		3.7		3.4	4.7		3.4
			WOLF CREEK FORMATION - Aurora Till						
OU		849	NoD.	19	10	29	64	7	71
OU		602	18.5	29	-	29	71	-	71
MOU		869	2.3	20	5	25	70	5	75
MOU		877	11.0	27	-	28	61	11	72
MRU		125	17.0	20	1	21	69	10	79
MRJU	*	878	6.1	23	-	25	62	13	75
MRU	*	880	6.7	36	-	36	62	2	64
MOU	*	879	3.5	29	-	29	61	10	71
JUU		603	NoD.	22	-	22	67	11	78
JUU		604	NoD.	16	-	17	70	13	83
JUU		592	18.5	39	1	40	54	6	60
		Mean	Hi	25.5		27.4	64.6		72.6
		s.d.		7.3		6.6	5.3		6.6

* Questionable samples - see text.

Aurora Till Member

The type area for the Aurora Till Member is located in northeast Buchanan County approximately 2 miles (3.2 km) southwest of the town of Aurora. The type locality is the Aurora Transect (figures 12-15; Description 5; Tables 10 and 11). Reference localities within the Wolf Creek Formation Type Area will also be used to describe the properties of the Aurora Till Member.

The Aurora Transect is a series of core-holes drilled along the axis of the stepped erosion surfaces in the area of the regional divide between the Wapsipinicon and Maquoketa Rivers. The drilling transect is located in the NE¼ of section 23 (T 90N, R 8W). Figure 12 shows a surficial geologic map of the area, and figure 13 shows the cross section of the stratigraphy. The locality is in an area of widespread Iowan Erosion Surface. The Yarmouth-Sangamon or Late-Sangamon paleosols and an unknown thickness of the upper Hickory Hills Till have been removed by erosion. As illustrated in figure 13 the area is marked by multi-leveled erosion surfaces. At least one minor surface (in the area of core-hole 10-E-2, figure 13) is very discontinuous and appears to be related to the presence (or absence) of the weathered, fine-textured deposits between the two tills. There is no loess in this area, and the landscape is mantled with a thin veneer of loamy surficial sediments and locally with eolian sand.

This same stratigraphic sequence is present along the divide for a long distance. Essentially identical stratigraphy as shown in Description 5 and figure 13 was found in cores 3 miles to the southeast (site 10-E-4A; NE¼ of NE¼ sec. 32, T 90N, R 7W) and 6 miles to the southwest (10-E-6; NC, sec. 11, T 89N, R 7W). From aerial photo patterns it appears that the same outcrop patterns (figure 12) and materials continue southeast into Delaware County.

As with the Hickory Hills Till the color of the Aurora Till Member varies vertically within its weathering profile from light yellowish brown to dark gray or dark greenish gray.

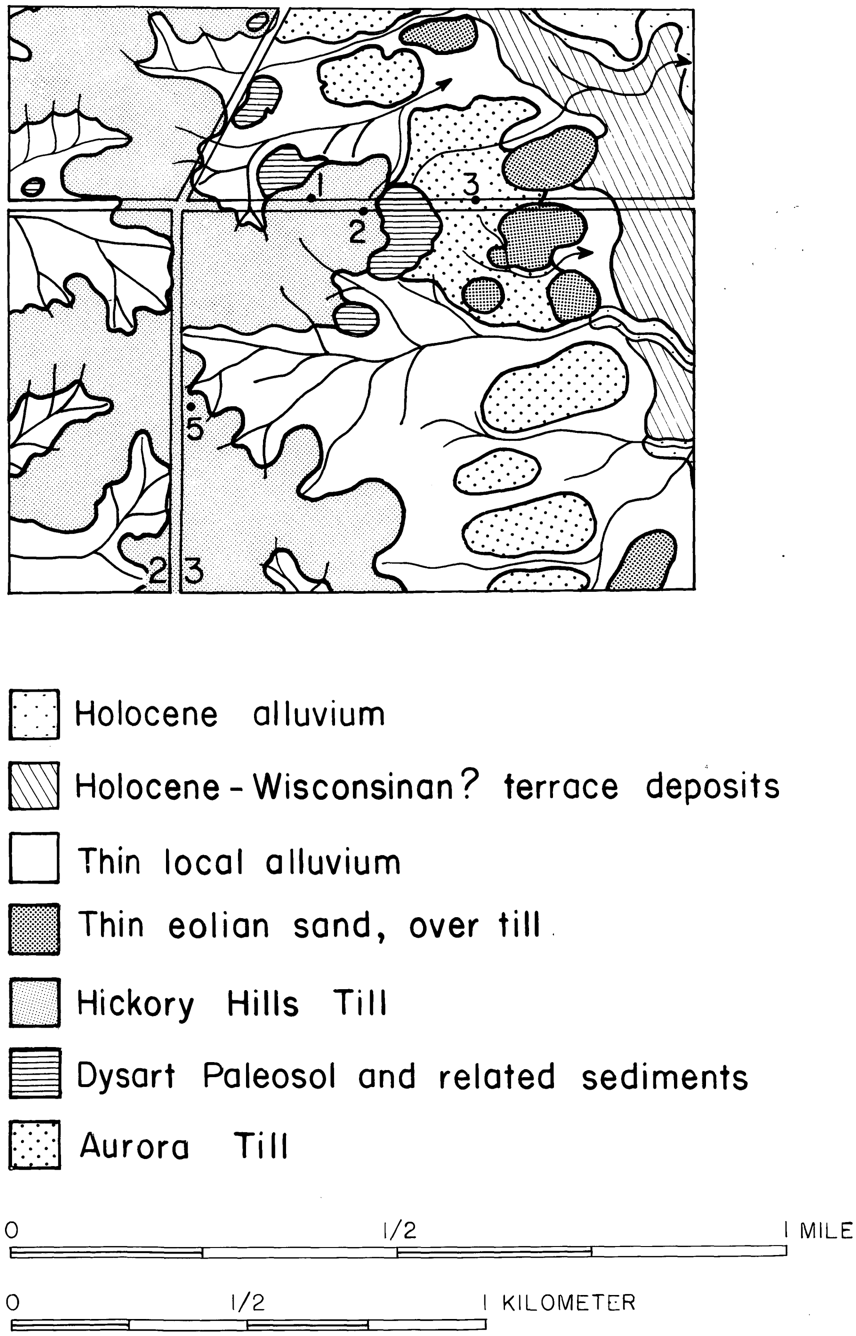


Figure 12. Surficial geologic map, Aurora Transect area (sec. 23, T 90N, R 8W). Numbers are location of core-holes (3=10E3) on figure 13.

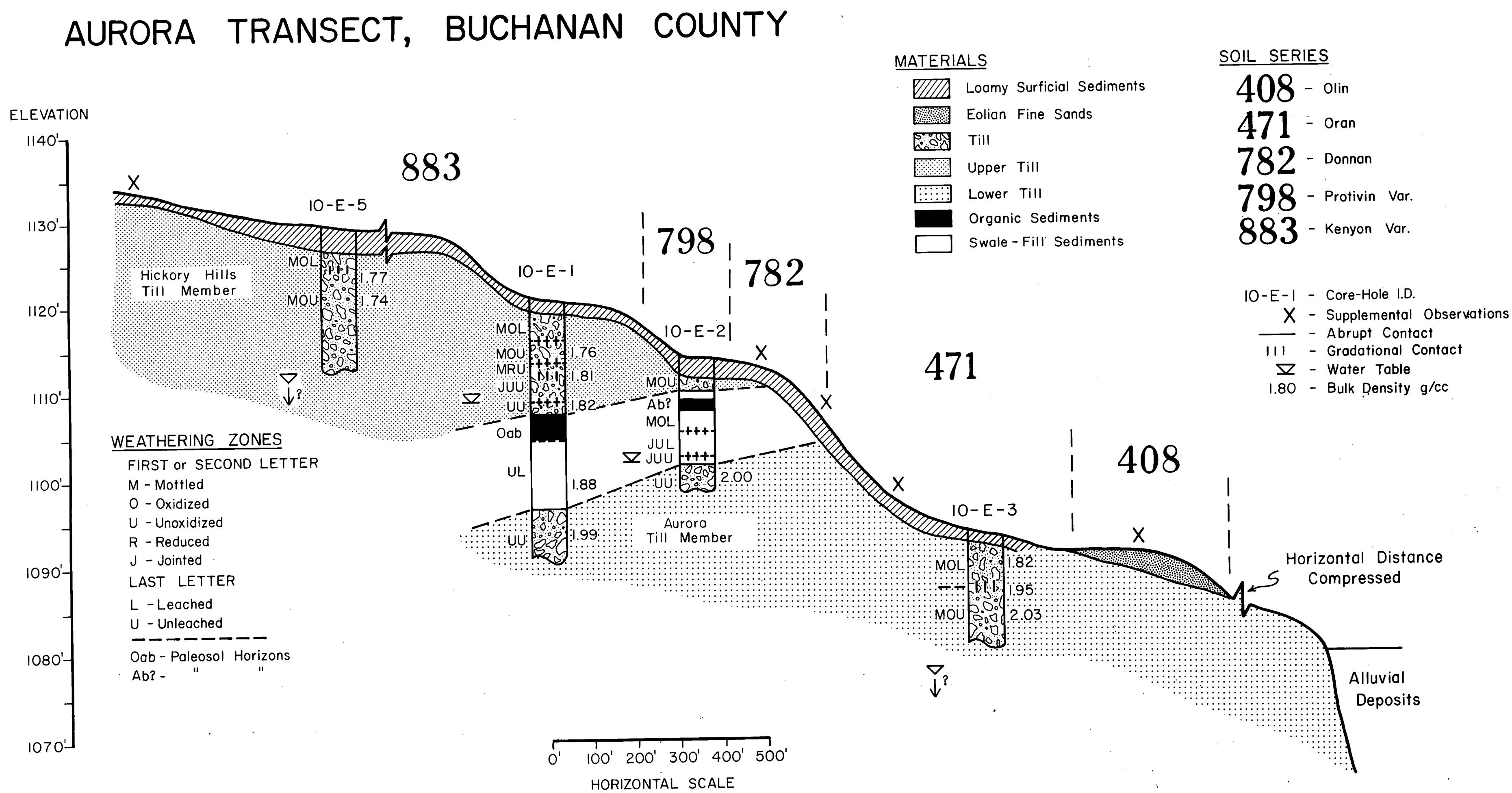


Figure 13. Cross-section from Aurora drilling transect.

Description 5. 10-E-1 Core, Aurora transect.

In field entrance, on south side of road, approximately 858 feet east of road intersection forming the north-center point of section 23, T 90N, R 8W, Buchanan County. (Description by Hallberg, Esling, Fouts, and Wollenhaupt.)

Horizon or Zone	Depth-inches (cm)	Description
Solum	0- 55 (0-140)	Solum (883b-Kenyon variant) thin loam sediments over till
	WOLF CREEK FORMATION - Hickory Hills Till Member	
MOL till	55- 61 (140-155)	Dark brown (7.5YR 4/4) and grayish brown (2.5Y 5/2) loam with pebbles, common mottles of 7.5YR 5/6 and 8; moderate medium to coarse subangular blocky; slightly firm; gradual boundaries; leached loam till.
MOU till	61- 89 (155-226)	As above; unleached loam till.
MRU till	89-108 (226-274)	Olive brown (2.5Y 4/4) loam with pebbles and with common gray (5Y 5/1) mottles and common strong brown (7.5YR 5/6-8) mottles on vertical joints; massive, jointed; gradual boundaries; unleached loam till.
JRU	108-123 (274-312)	Very dark grayish brown (2.5Y 3/2) olive brown (2.5Y 4/4) and dark olive (5Y 3/3) loam with pebbles and with very dark brown (7.5YR 3/2) coatings along vertical joints; gradual boundaries; unleached loam till.
JUU till	123-140 (312-356)	Dark olive gray (5Y 3/2) loam with pebbles and few black (5Y 2/2) mottles and streaks and few very dark brown (7.5YR) large mottles along vertical joints; gradual boundaries; jointed unleached loam till.
UU till	140-158 (356-401)	Dark olive gray and black (5Y 3 and 2/2) loam; gradual upper and clear lower boundary; unleached loam till.
	WOLF CREEK FORMATION - Unnamed sediments; DYSART PALEOSOL	
II Oalb Leached muck and mucky sediments	158-187 (401-475)	Very dark brown and very dark grayish brown (10YR 2 and 3/2) muck and mucky silt loam; few wood fragments, abundant charcoal, little recognizable fibrous organic material; clear upper, gradual lower boundaries; leached compacted muck.
II Oa2b	187-197 (475-500)	As above, but stratified with more mineral rich zones and black (10YR 2/1) organic rich zones; gradual lower boundary; compacted leached muck and mucky sediments.
IICb UL Swale-fill sediments	197-211 (500-536)	Very dark gray (5Y 3/1) loam to silty clay loam; with occasional pebbles, massive to very weak very fine subangular blocky; gradual boundaries, leached swale-fill sediments.
II UL till-derived swale-fill sediments	211-294 (536-745)	Dark gray (5Y 4/1) as above with occasional zones with many pebbles; gradual upper, clear lower boundaries.
	WOLF CREEK FORMATION - Aurora Till Member	
III UU till	294-345 (745-876)	Gray and dark gray (5GY 5-4/1) loam with pebbles; massive; very firm; unleached loam till.

The thickness of the Aurora Till Member is also variable. In some areas it is entirely absent, having been removed by erosion. In most areas it ranges between 20 and 35 feet (6 to 11 m) in thickness, but it may reach 100 feet (31 m) in the 4-Mile Creek locality.

The Aurora Till Member is loam-textured, averaging about 22% clay, 40% silt, and 38% sand across the entire study area. Its texture is quite uniform regionally and in thick sequences locally (figure 14 and 15). The texture of the Aurora contrasts with the Hickory Hills Till Member (figure 10) which is sandy by comparison. The Winthrop Till Member is also silty and similar to the Aurora. The Aurora Till Member exhibits some of the same variations, from sheared inclusions in its lowermost portions as described for the Hickory Hills Till Member.

The Aurora Transect also provides an example of the problems which may be encountered in sampling these units. In the transect, as shown in figures 14 and 15, some of the Hickory Hills Till is as silty as the Aurora Till Member and it has more clay than normal also. These Hickory Hills Till samples all come from the lowermost portion of the till unit, and the till tends to resemble the underlying silt loam to silty clay loam sediments. This likely results from the inclusion and intermixing of the underlying silts within the till. The Hickory Hills samples which come from sites higher in the landscape and stratigraphic section (e.g. - 10E5; figure 13) show the more typical sandy texture.

The average clay mineralogic composition of the Aurora Till Member is: 62% expandables; 18% illite; and 21% kaolinite. These values are typical of the Wolf Creek Formation deposits. Individual till members cannot be separated on the basis of their clay mineralogy (e.g. - Table 10).

The sand fraction lithology data for the Aurora Till Member are summarized in Table 5. The Aurora Till Member averages slightly lower total carbonate and total sedimentary grains than the Hickory Hills Till Member. There is considerable variation within the data (e.g. - Table 11). For example,

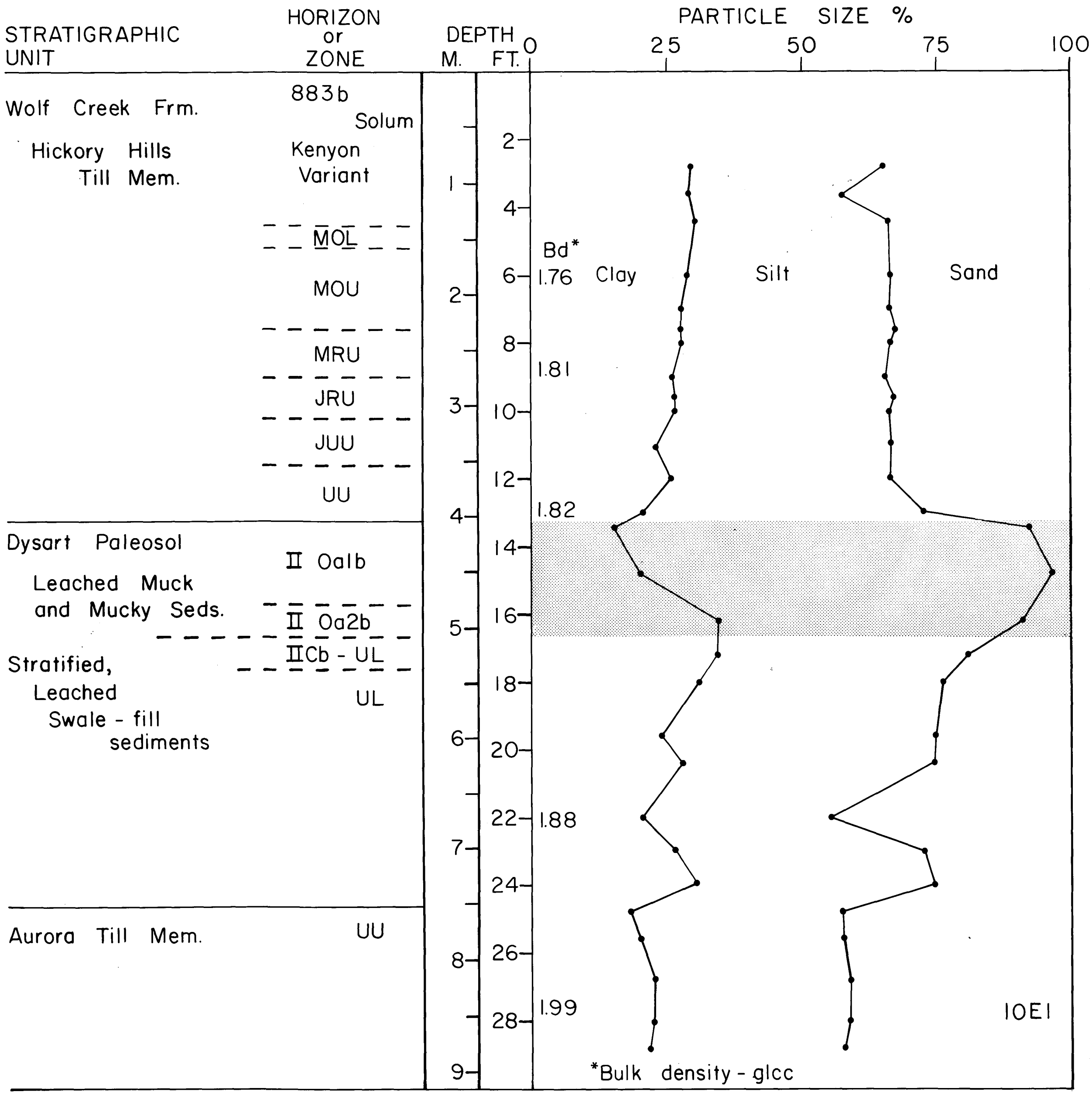


Figure 14. Stratigraphy and particle-size data, Core 10E1, Aurora Transect.

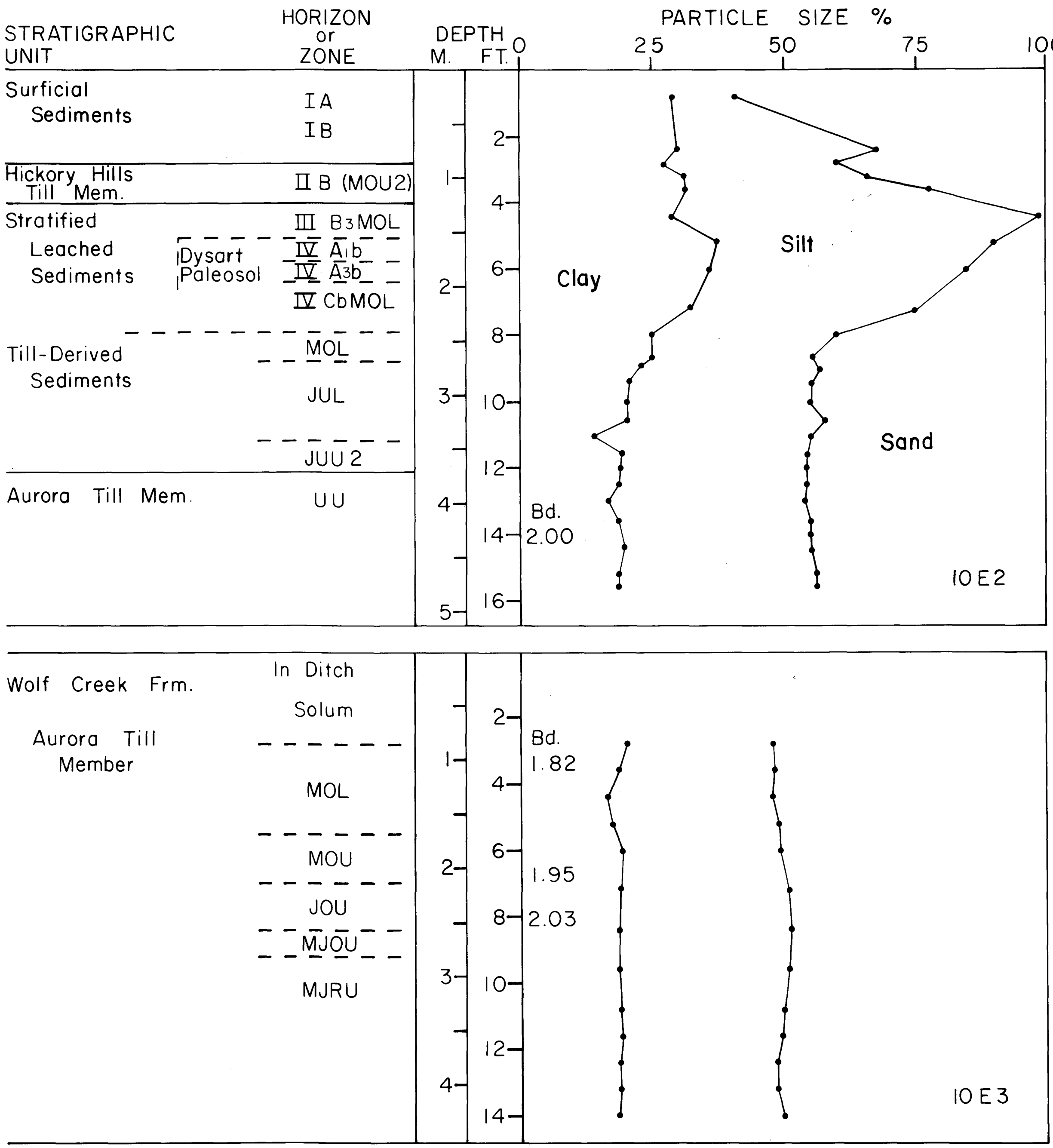


Figure 15. Stratigraphy and particle-size data, core-holes 10E2 and 10E3, Aurora Transect.

Table 10. Clay Mineralogy - Aurora transect.

Horizon or Zone	Depth (inches)	ID	EX	Ill.	K+C	
		10 E 1				
WOLF CREEK FORMATION - Hickory Hills Till Member						
IIB2	32- 45	3047	56	21	23	
IIB3	45- 55	3057	58	20	22	
MOU	72	3054	52	23	25	
MOU	84	3019	59	21	20	
MRU	120	3018	60	19	21	
JUU	132	3013	58	20	22	
UU	144	3017	65	11	24	
UU	156	3016	60	19	21	
Weathered Sediments (Dysart Paleosol)						
MUL	211	3035	62	18	20	
UL	228	3058	72	14	14	
UL	246	3044	65	18	17	*
UL	264	3056	57	20	23	
UL	276	3055	66	11	23	
UL	285	3048	71	16	13	
WOLF CREEK FORMATION - Aurora Till Member						
UU	297	3011	62	19	19	
UU	330	3026	58	20	22	
UU	345	3196	60	17	23	
		10 E 2				
WOLF CREEK FORMATION - Hickory Hills Till Member						
IIB	41- 45	3037	58	20	22	
Weathered Sediments (Dysart Paleosol)						
MOL	49- 53	3032	66	22	12	
MOL	61- 64	3043	80	5	15	*
MOL	88- 92	3034	75	13	12	
MOL	94-106	3042	71	16	13	*
JUL	124-130	3040	63	17	20	
JUU	140-145	3024	64	16	20	
WOLF CREEK FORMATION - Aurora Till Member						
UU	168	3022	62	18	20	
		10 E 3				
WOLF CREEK FORMATION - Aurora Till Member						
MOL	62	3033	55	21	24	
MOU	70	3023	56	20	24	
MOU	80	3010	59	18	23	
MOU	87	3020	58	19	23	
MOU	100	3021	58	19	24	
		10 E 4				
WOLF CREEK FORMATION - Aurora Till Member						
MJU	120	3201	60	19	21	
MJU	130	3217	61	19	20	
MJU	139	3218	58	20	22	

Table 10. Clay Mineralogy - Aurora transect. (continued)

Horizon or Zone	Depth (inches)	ID	EX	Ill.	K+C
		10 E 4A			
WOLF CREEK FORMATION - Hickory Hills Till Member					
MOU	44	3025	62	16	22
		10 E 5			
WOLF CREEK FORMATION - Hickory Hills Till Member					
MOU	68	3014	56	20	24
MOU	82	3059	58	19	23
MOU	90	3012	56	23	21
		10 E 6			
WOLF CREEK FORMATION - Hickory Hills Till Member					
MOU	40	3030	52	23	25
MOU	70	3031	59	18	23
		Summary			
Hickory Hills Till		Mean	58	19	22
n=15		s.d.	3.4	3.0	1.7
Aurora Till		Mean	59	19	22
n=12		s.d.	2.2	1.1	1.7

Ex = Expandables; Ill = Illite; K+C = Kaolinite plus chlorite

* Illite obscured by Expandable peak.

at the Buckingham sections (Table 9) the Aurora Till shows a mean value of 26% for total carbonates. This is about the same as the Hickory Hills Till exhibits in the Casey's-Hayward's Paha area (Table 7), and it is higher than the Hickory Hills in the Aurora area (Table 10). However, in all these sections there are certain consistent trends; the Hickory Hills shows a higher percentage of total carbonate than does the Aurora. With the range of values encountered these differences are not statistically significant and reversals in this trend could be expected, and in fact occur.

Samples taken from above and below the Dysart Paleosol from just north of Casey's Paha, along the Tama-Blackhawk County line show the Aurora Till (2 samples) with 27% total carbonate and C/D ratios of 18 and NoD; while the Hickory Hills Till (2 samples) averages 21% total carbonate and C/D ratios of 2.1 and 7.6.

A similar situation is recorded near the town of Dysart, just south of the Hayward's Paha Transect. Proceeding from the Hayward's area toward Dysart, the Dysart Paleosol is truncated and the Hickory Hills Till rests directly on the Aurora Till. Here the Hickory Hills and Aurora are nearly equal, containing (2 samples each) 22.2% total carbonate (C/D of 3.6) and 21.8% total carbonate (C/D of 14 and 20) respectively.

In the sand-fraction data the most clear-cut differences occur in the C/D (calcite or limestone/dolostone) ratios. The Hickory Hills has very low values, generally less than 10, whereas the Aurora Till shows very high values, generally greater than 15. As shown in Table 5, in 43% of the samples from the Aurora Till Member no ratio is calculable (e.g. - NoD, Table 10) because there is no dolostone (by the techniques used - see Lucas, et al., 1978). Realistically, this only indicates low amounts of dolostone (high C/D) in the sand fraction. Unfortunately, the Winthrop Till Member also exhibits a high C/D ratio.

The upper boundary of the Aurora Till Member varies in relation to overlying units with the amount of erosion. In complete sections, such as the Aurora Transect (figure 13 and 14; Description 5) the upper boundary of the Aurora is marked by the contact with the unnamed weathered (leached) sediments, which generally contain the Dysart Paleosol, and physically separate the Aurora from the Hickory Hills Till Member. These relations are also well expressed at the Hayward's Paha (Description 3) and Casey's East (figure 3) reference localities. Where these sediments and the Dysart Paleosol have been eroded the upper limit of the Aurora Till Member is marked by:
1. direct contact with the Hickory Hills Till, such as at Casey's East (figure 3) or the Buckingham reference locality (figure 10; Description 4); or 2. a sharp or diffuse contact

Table 11. SAND FRACTION LITHOLOGIES - Aurora transect.

Strat. Unit	Depth (inches)	I.D.	C/D	% T.C.	Sh.	Sed.	Q.-F.	Ot.	Xst.
				10 E 1					
Hickory Hills Till	84	579	6.0	18.6	-	24.8	65.5	9.7	75.2
	96	576	2.4	20.0	-	20.0	67	13	80
	108	577	3.4	22.0	-	25.0	62	13	75
	112	636	0.6	13	2	15.0	52	33	85
	120	574	5.3	25.0	-	29.0	55	16	71
	132	575	3.0	20.0	-	29.0	65	6	71
	144	578	3.2	24.8	-	33.7	45.5	20.8	66.3
Aurora Till	297	536	NoD	16	1	23	61	15	77
	310	538	NoD	23	-	25	66	9	75
	314	639	7.5	17	1	18	54	28	82
	324	543	13	14	-	22	70	8	78
	328	637	NoD	25	-	25	60	15	75
	330	527	NoD	22	-	25	68	6.5	74.5
				10 E 2					
Aurora Till	144	552	3.0	12	-	14	80	6	86
	168	547	5	18	-	21	66	13	79
				10 E 3					
Aurora Till	70	548	NoD	20	-	22	74	4	78
	86	554	NoD	11	1	12	79	9	88
	100	545	4.0	18	2	20	70	10	80
				10 E 4A					
Aurora Till	88	533	15	16	9	25	64	11	75
				10 E 5					
Hickory Hills Till	68	520	6.5	15	-	17	60	23	83
	82	562	2.1	22	1	23	65	13	78
	90	549	7.8	26	-	38	51	11	62
				10 E 6					
Hickory Hills Till	40	559	25	26	-	31	59	11	70
	70	524	3.0	20	-	21	65	14	79
				Summary					
Hickory Hills n=12		Mean	Lo	21.0	-	25.5	59.9	15.3	74.6
		s.d.		4.2	-	6.9	6.9	7.2	6.8
Aurora n=12		Mean	Hi	17.7	-	21.0	67.7	11.2	79.0
		s.d.		4.3	-	4.4	7.6	6.3	4.4

zone including glaciofluvial sediments of the Hickory Hills Till Member, as at the Buckingham locality (see also the Schwitter's Section, figure 31).

In places post-Hickory Hills Till Member erosion has been severe enough that the Aurora Till Member becomes the surficial till. In these situations the upper limit of the Aurora is the top of the till--the erosion surface which may be marked by a stone line, as previously discussed for the Hickory Hills Till. This erosion surface on the Aurora Till Member may be overlain by: 1. a thin veneer of Wisconsinan to Holocene surficial sediments or eolian sand, as in the Aurora Transect (figure 13); 2. Wisconsinan loess, as in the Hayward's Paha Transect (figures 7 and 8); or 3. Pre-Wisconsinan sediments, where the Late-Sangamon Paleosol and surface are developed on the Aurora Till Member (see the Schwitter's, Abbe Creek, and Cedar Rapids Landfill localities in later sections).

Till-till contacts, as discussed above, sound problematical but are often easy to distinguish in the field (and verify in the lab - see figure 10). Many properties change abruptly at these contacts. Perhaps the most striking differences in the field are the abrupt changes in consistency, and in color or weathering zone that occur. For example, as discussed, near the town of Dysart the Hickory Hills Till lies directly on the Aurora Till Member (figure 16). The contact occurs at about 16 feet (4.9 m) and is marked by an abrupt change in color from mottled yellowish-brown (10YR 5/4) to olive (5Y 5/4). In a matter of a few inches, across this contact, the bulk density increases from 1.77 g/cc (110 pcf) to 1.88 g/cc (118 pcf), which explains the change to a much more firm consistency below the contact.

The lower boundary of the Aurora Till Member may also be complex. In the more complete sections it is marked by the contact with the leached sediments (and weak paleosols) which separate the Aurora and the Winthrop Till Member. Where erosion has been more severe the Aurora Till Member may be in

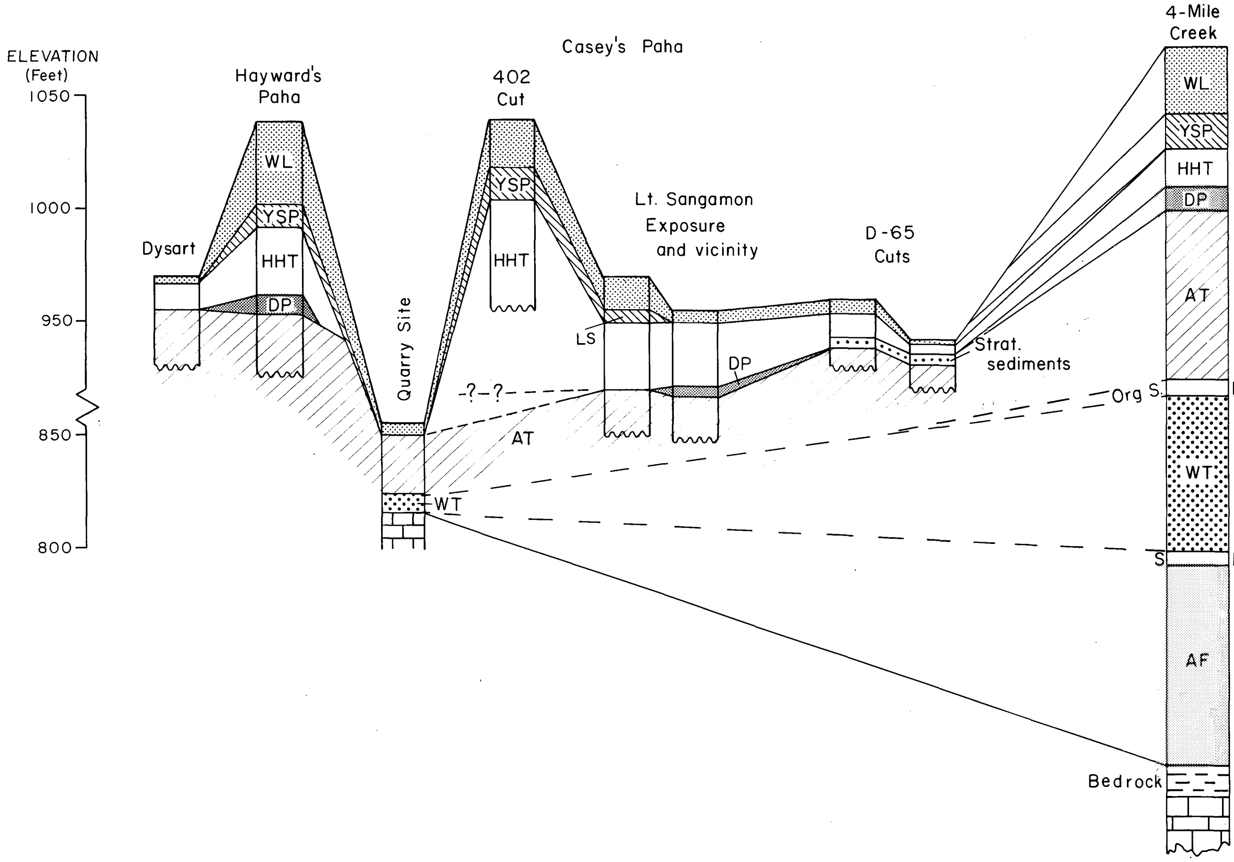


Figure 16. Schematic view of topographic and stratigraphic relations in the Wolf Creek - 4-Mile Creek area (see figure 6 for explanation of symbols).

direct contact with the Winthrop Till Member, or various sediments of the Alburnett Formation or even the bedrock. In the last two settings the Aurora Till Member also forms the base of the Wolf Creek Formation.

At the Independence Section (part of the Winthrop Till Member Type locality; figure 17) leached fluvial sands and silts, and a weak organic paleosol, mark the base of the Aurora Till, and separate it from the Winthrop Till Member. Similar relations are found in the subsurface in the 4-Mile Creek area (a tributary to Wolf Creek and a reference locality for the Wolf Creek Formation). In this area Ruhe and others (1968) and Fenton (1966) documented the presence of Wisconsinan loess above the Yarmouth-Sangamon paleosol developed in (what is now called) the Hickory Hills Till. The Hickory Hills Till is relatively thin (10-15 feet) in this area and overlies the Dysart Paleosol and the Aurora Till. The Yarmouth-Sangamon paleosol occurs in this area at about 1,020-1,030 feet in elevation, and the Dysart Paleosol between about 1,000-1,015 feet. As mentioned earlier, Kunkle (1968) recognized another stratigraphic break and a third till. At an elevation between 840 and 900 feet in various test holes Kunkle found organic silts, wood, charcoal, leached silts or sand and gravel which separated the Aurora Till from the Winthrop Till unit below. In addition to this, a test hole for this study showed approximately 7 feet of unleached sand and gravel below 795 feet elevation, followed by till of the Alburnett Formation, down to shale bedrock at about 700 feet elevation. Table 12 summarizes the clay mineralogy for samples from the test hole. Figure 16 shows the 4-Mile Creek sequence in relation to the other reference localities in the Wolf Creek Type area.

The Smith Quarry Section also shows the lower boundary of the Aurora Till Member and is another reference locality for the Wolf Creek Formation (Description 6; Tables 13 and 14). The exposure at the Smith Quarry occurs on the lowest erosion surface level between the Hayward's Paha Transect (figures 6-8) and Casey's Paha East Transect (figure 3). As shown in these transects, the Aurora Till Member occurs at the surface, overlain by a thin veneer of loess and eolian sand, or surficial sediments. As shown in Description 6, the base of the Aurora

Table 12. Clay Mineralogy - 4-mile Creek Area.

ID	EX.	Ill.	K+C
WOLF CREEK FORMATION - Hickory Hills Till			
961	60	18	22
962	59	20	21
WOLF CREEK FORMATION - Aurora Till			
967	62	18	20
968	65	16	19
WOLF CREEK FORMATION - Winthrop Till			
963	64	14	22
964	59	18	23
ALBURNETT FORMATION - Undiff. till			
966	42	24	34
965	40	26	34

Till Member is marked by a pronounced and abrupt color and weathering zone change within a continuous till sequence.

Color related weathering zones in till normally change in a gradational manner (see Hallberg, Fenton, and Miller, 1978) from oxidized, to reduced, to unoxidized with depth, as shown in the Aurora Till from 4.5 to 32 feet in Description 6. The contacts between these zones in the Aurora Till are diffuse, and take place over a foot or more of section. The change in weathering zones at the contact between the Aurora and Winthrop Tills is abrupt and takes place in less than an inch, or occasionally over a few inches. Such an abrupt color or

Description 6. Smith Quarry Section (NW¼, sec. 19, T.86N., R.12W.; Benton County):

Horizon or Zone	Depth-feet (meters)	Description
Solum and OL	0 - 4 (0 - 1.2)	Wisconsinan loess and eolian sand.
OL	4 - 4.5 up to 8 (1.2 - 2.4)	0.5 ft. pedisediment and stone-line; grades laterally into sand and gravel channel cut in till surface.
	WOLF CREEK FORMATION - Aurora Till Member	
OJL	4.5 - 17 (2.4 - 5.2)	Loam till; leached; diffuse lower boundary.
MOJL	17 - 19 (5.2 - 5.8)	As above.
RJU	19 - 22 (5.8 - 6.7)	As above, calcareous.
UJU	22 - 32 (6.7 - 9.8)	Very dark gray to dark gray (5Y 3-4/1) loam till; unoxidized, jointed, unleached; abrupt lower contact.
	WOLF CREEK FORMATION - Winthrop Till Member	
RJU	32 - 38 (9.8 - 11.6)	Dark grayish brown (2.5Y 4/2) loam till; siltier, with less coarse sand and pebbles than above; abrupt color change, especially on weathered face; reduced, jointed, unleached. In upper foot, prominent horizontal planes, produce a coarse platy-like structure, with dark-reddish brown, 5YR 3/3-4 stains along joints. In places some wood and silts at contact with upper unit. Abundant wood in this till unit.
	CEDAR VALLEY LIMESTONE	
	38 - (11.6 -)	Bedrock.

weathering zone change is abnormal and generally indicates a contact between different materials or stratigraphic units (Hallberg, Fenton, and Miller, 1978).

The mineralogic data for this site is shown in Tables 13 and 14. An abrupt change in particle size also takes place at the contact between the Aurora and Winthrop tills. The Aurora averages (7 samples) 41% sand, 38% silt, 21% clay; while the

Winthrop is siltier averaging (5 samples) 38% sand, 43% silt, and 29% clay. The coarse and very coarse sand averages 7.2% in the Winthrop. The Aurora is nearly double this averaging 14.1%.

In the type area of the Aurora Till Member (the Aurora Transect, figure 13), the lower boundary of the Aurora exhibits a different relationship. Just to the north of the Aurora Transect (NE¼ of SE¼, sec. 10; elev. 1153 ft.) a deeper boring was analyzed. An abbreviated log of this drill hole is:

		WOLF CREEK FORMATION
0 - 45 ft. (0 - 13.7 m)	-	Hickory Hills Till Member (Ex-58%; Ill-21%; K+C-21%)
45 - 52 ft. (13.7- 15.8 m)	-	Mixed sand and gravel, and till.
52 - 85 ft. (15.8- 25.9 m)	-	Aurora Till Member (Ex-57%; Ill-20%; K+C-23%)
85 - 95 ft. (25.9- 29.0 m)	-	Sand and gravel
95 -120 ft. (29.0- 36.6 m)	-	Till-ALBURNETT FORMATION - undifferentiated (Ex-42%; Ill-24%; K+C-34%)
120 -142 ft. (36.6-43.3 m)	-	Sand and gravel.

In this area the Aurora Till Member overlies glaciofluvial deposits, and till of the Alburnett Formation. In many areas these glaciofluvial deposits are thick and continuous enough (see Schwitter's Section) to be considered more than an inclusion in the Aurora Till Member.

The Aurora Till Member also exhibits complex lower contact zones involving sheared inclusions of the substrate material, similar to those described for the Hickory Hills Till (see Kirkwood Section, in Appendix).

Winthrop Till Member

The Winthrop Till Member is the oldest recognized till member of the Wolf Creek Formation. It is the least preserved and consequently the least well-known member of the Wolf Creek Formation.

Table 13. Clay Mineralogy - Smith Quarry

Horizon or Zone	ID		EX	Ill	K+C
WOLF CREEK FORMATION - Aurora Till					
OU	3067		62	18	20
R-OU	3065		56	22	22
UJU	3066		64	18	18
UJU	3068		62	18	20
		Mean	61	19	20
		s.d.	3.5	2.0	1.6
WOLF CREEK FORMATION - Winthrop Till					
RJU	3060		62	17	21
RJU	3261		58	20	22
RJU	3061		63	16	21
RJU	3480		62	10	28
RJU	3062		59	20	21
RJU	3063		57	19	24
RJU	3064		56	20	24
		Mean	60	17	23
		s.d.	2.8	3.6	2.6

Table 14. Sand fraction lithologies - Smith Quarry

Horizon or Zone		ID	C/D	T.C.	Sh.	T.S.	Q-F	Oth	Xst.
WOLF CREEK FORMATION - Aurora Till									
OU	Partial leaching	668	NoD.	7	-	7	65	28	93
R-OU		670	20	18	-	19	73	8	81
RJU		674	14	21	1	23	70	7	77
UJU		672	NoD.	16.5	-	17	63	20	83
UJU		665	NoD.	19	1	20	71	9	80
		Mean	14-NoD(Hi)	18.6		19.7	69.3		80.3
		s.d.		1.9		3.1	4.4		2.5
WOLF CREEK FORMATION - Winthrop Till									
RJU		655	NoD.	9	-	9	67	24	91
RJU		673	NoD.	16	2	18	68	14	82
RJU		671	NoD.	10	-	10	73	17	90
RJU		667	NoD.	15	11	26	66	8	74
RJU		657	NoD.	10	-	10	71	19	90
		Mean	Hi	12.0		14.6	69.0		85.4
		s.d.		3.2		7.3	2.9		7.3

The name is derived from the type area, around the town of Winthrop in Buchanan County. The type locality consists of a railroad cut and drill-core section located about 1¼ miles (2km) west of Winthrop in the NW¼ of sec. 3, T 88N, R 8W. The exposure is about 5½ miles (8.8 km) east of the town of Independence, and 2¼ miles (3.6 km) east of Doris Station, the "type locality" for the now defunct "Iowan" drift (Alden and Leighton, 1917, p. 113). This exposure has been described in detail as the Independence Section by Ruhe, Rubin, and Scholtes (1957, p. 675), and the description will not be repeated here. This section was also discussed in Ruhe and Scholtes, 1956; and Flint and Rubin, 1955. Figure 17 shows the scale drawing of the exposure after Ruhe, Rubin, and Scholtes. They described an upper till (see figure 17), which at the time was considered Iowan, overlying leached silts, a weak organic paleosol (peat) over more leached silt, on top of a lower till. Hemlock wood from the lower silts was radiocarbon dated as >38,000 RCYBP. With subsequent work these two tills would be considered Kansan and Nebraskan (see Ruhe, 1969). They now are reclassified as the Aurora and Winthrop Till Members of the Wolf Creek Formation.

The drill site was located immediately north of the railroad cut. The stratigraphy of the core is given in Description 7 (Winthrop Core Site). The laboratory data for the composite section are shown in Tables 15, 16 and 17.

The Winthrop Till Member varies in color, within the weathering profile, as do the other tills, from a light-yellowish brown to dark gray. It's thickness is poorly known because it is positively identified in so few sections. In the composite Winthrop locality it varies from 2 to about 15 feet (0.6 - 4.6 m) in thickness, and attains a thickness of 48 feet (14.6 m) in the 4-Mile Creek area.

The Winthrop Till Member is a loam to light clay loam in texture (figure 4) averaging about 25% clay, 41% silt, and 34% sand (Table 3). It generally contains more silt than sand, like the Aurora Till.

Independence Section; after Ruhe, Rubin, and Scholtes, 1957.

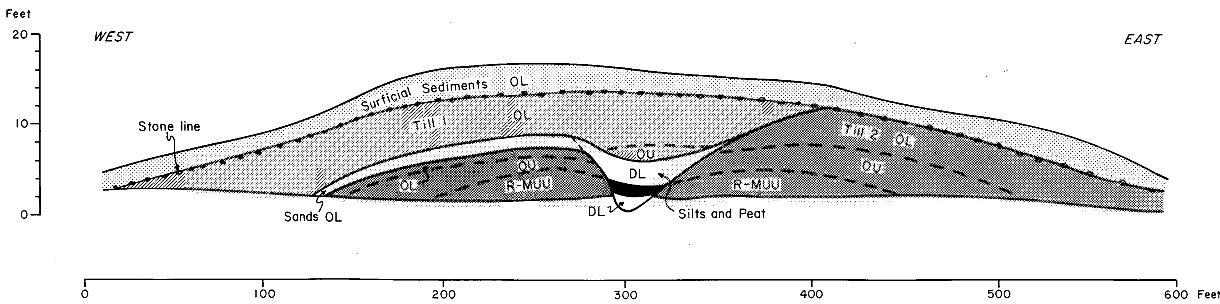


Figure 17. Independence Section railroad cut: Till 1 - Aurora Till Member; Till 2 - Winthrop Till Member.

The average clay mineral composition of the Aurora Till Member is approximately 60% expandables, 17% illite, and 24% kaolinite. This clay mineralogy is typical of the Wolf Creek Formation. The Winthrop Till Member tends to exhibit slightly higher values of kaolinite than the other tills of the Wolf Creek Formation. This may relate to incorporation of the more kaolinite-rich Alburnett Formation deposits which were overridden by the glacier that deposited the Winthrop (see Table 15).

The sand-fraction lithology data for the Winthrop Till Member is summarized in Table 5. The Winthrop Till Member shows considerably lower values for Total Carbonate or Total Sedimentary grains than the Aurora or particularly the Hickory Hills Till Member. The Winthrop, like the Aurora, exhibits a very high C/D ratio.

Description 7. Winthrop Core Site.

Horizon or Zone	Depth - Feet (m)	Description - (elevation--1,012 ft.)
Solum	0 - 1.5 (0 - 0.5)	Loam, surficial sediments.
	WOLF CREEK FORMATION - Aurora Till	
Solum	1.5 - 3.2 (0.5 - 1.0)	Stone line, and loam till.
OL	3.2 - 4.5 (1.0 - 1.4)	Loam till, with thin interbedded sandy loam.
OL	4.5 - 12.5 (1.4 - 3.8)	Stratified sands, minor sand and gravel at base.
	WOLF CREEK FORMATION - Winthrop Till	
OU	12.5 - 14.5 (3.8 - 4.4)	Loam till, few secondary carbonate nodules at top of unit.
	Undifferentiated - Fluvial Sediments	
OL	14.5 - 18.0 (4.4 - 5.5)	Reddish brown; coarse sands, some gravel.
MRL-MRL2	18.0 - 22.0 (5.5 - 6.7)	Mottled olive gray silt loam and silty clay loam.
OL-RU	22.0 - 31.5 (6.7 - 9.6)	Sand and gravel with some iron-oxide cemented zones.
	ALBURNETT FORMATION - Undifferentiated	
MRU	31.5 - 36 (9.6 - 11.0)	Strongly mottled and reduced loam till.
UU	36 - 103 (11.0 - 31.4)	Loam till, some change in consistency below 52 feet (?).
	Undifferentiated Fluvial Sediments	
UU(Ab)	103 - 105.5 (31.4 - 32.2)	Black (N2/0) sandy loam and silt loam, with organic fragments (weak alluvial paleosol ?).
UU(C)	105.5 - 138 (32.2 - 42.1)	Interbedded sands, sand and gravel and silts.
	WAPSIPINICON FORMATION (?)	
	138 - 145+ (42.1 - 44.2+)	Bedrock, limestone.

In all of its properties, the Winthrop Till Member is similar to the Aurora Till. The Winthrop Till is positively characterized by being the second silty, high C/D ratio till of the Wolf Creek Formation. This makes it difficult to classify isolated till exposures, particularly in the many sections where only one silty, high C/D till of the Wolf Creek Formation

Table 15. Clay Mineralogy - Winthrop Type Locality

Horizon or Zone	Depth (Feet)	ID	EX	Ill	K+C	D (c.p.s.)	C[1] (c.p.s.)
			WOLF CREEK FORMATION - Aurora Till				
OL	C[2]	493	62	21	17	-	-
OL	C	492	60	20	20	-	-
OU	C	491	68	15	17	t	t[3]
OU	C	494	66	17	17	10	20
OL	3.5[4]	320	60	20	20	-	-
OL	4.0	321	61	19	20	t	t
			Unnamed Silts Between Tills				
DL	C	495	68	15	17	20	30
DL	C	496	71	15	14	-	-
DL	C	497	56	19	25	-	-
			WOLF CREEK FORMATION - Winthrop Till				
R-UU	C	498	59	17	24	t	30
R-UU	C	499	51	18	31	t	t
R-UU	C	500	60	18	22	t	t
OU	13.0	322	60	16	25	t	120
OU	13.5	969	61	17	22	20	120
			ALBURNETT FORMATION - Undifferentiated till				
MRU	34	323	48	24	28	t	240
MRU	35	325	42	23	35	t	190
UU	55	324	29	27	44	20	50
			Unnamed Silts Below Till				
UU	105		49	24	27	-	50

[1]D = Dolomite - counts/second.

[1]C = Calcite - counts/second.

[2]C = Samples from railroad cut.

[3]t = trace

[4]3.5 = Depth in core-hole.

remains. Nearly all of the undifferentiated till samples in Tables 3 and 5 come from sites where only one Wolf Creek Formation till is present. As the average values indicate these tills are all of Aurora or Winthrop Till Member affinities. In some sections correlation with either the Aurora or Winthrop may be suggested by the data and by the local geologic

Table 16. Sand fraction lithologies - Winthrop Type Locality

Horizon or Zone	ID	C/D	T.C.	Sh.	T.S.	Q-F	Oth	Xst.
			WOLF CREEK FORMATION - Aurora Till					
OU	626	NoD.	22	1	24	68	8	76
OU	640	18.0	19	13	32	59	9	68
			WOLF CREEK FORMATION - Winthrop Till					
R-UU	638	NoD	15	-	15	66	19	85
R-UU	632	NoD	21	1	24	52	24	76
R-UU	613	4.0	5	61	66	29	5	34
			ALBURNETT FORMATION - Undifferentiated Till					
UU	612	5.0	12	-	12	77	11	88

Table 17. Particle-Size Analyses - Witnhrop Type Locality

	Clay	Silt	Sand
WOLF CREEK FORMATION			
Aurora Till	20.1	40.0	39.9
	17.1	14.7	68.2 *
Winthrop Till	25.5	38.6	35.9
	29.9	42.1	28.0
	26.9	61.4	11.7 *
ALBURNETT FORMATION			
Undifferentiated Till	22.2	29.5	48.3
	25.0	31.0	44.0
	25.1	32.2	42.7
	26.0	27.4	46.6

* Lowermost samples with foreign inclusions.

setting. However, the data from these single till localities has for the present been included with the undifferentiated samples.

The recognition of the Winthrop Till Member as the second silty till with a high C/D ratio allows the tills to be traced into the Winthrop Type Area, from the Aurora Type Area. The stratigraphy in the Aurora transect can be traced to the southwest. As we come off the regional divide between the Wapsipinicon and Maquoketa Rivers (elevations 1120-1160 feet) where the Aurora transect is located, down to the secondary divides, particularly between Buffalo and Pine Creeks, the elevation drops to about 1,050 to 1,080 feet or lower. Across the few miles where this change takes place the upper Hickory Hills Till Member, Dysart Paleosol (or equivalent) and the unnamed sediments are eroded off, and the Aurora Till becomes the surficial unit, in the area just north of Winthrop.

Samples of the surface till (Table 18) in this area are high in expandable clay minerals (i.e. - Wolf Creek Formation) and show a high C/D ratio in the sand fraction, typical of the Aurora or Winthrop Till. This brings us to the sections and cores in the Winthrop area which show the Aurora and Winthrop Tills superimposed.

The Winthrop Till Member is bounded at the top by: 1. leached, unnamed sediments that separate it from the Aurora Till; 2. the Aurora Till Member (or other younger Wolf Creek deposits); or 3. where erosion has removed the younger Wolf Creek deposits, the Winthrop Till Member may be exhumed and become the surficial till.

These relations are illustrated in the various reference sections. At the Independence Section (west side of figure 17) the Winthrop Till Member is separated from the Aurora Till by a sequence of leached fluvial sediments which contain an organic paleosol (a peat). Although these materials are leached (representing some period of weathering) there is no well developed soil between the tills. A similar sequence is recorded in the 4-Mile Creek area.

Table 18. Mineralogy of surface samples - Winthrop area.

Sand-Fraction Lithologies

Sample	I.D.	C/D	T.C.	Sh.	T.S.	Q-F	Oth.	Xst.
1.*	551	NoD.	10	-	18	74	8	82
2.	529	6.3	16	-	19	80	1	81
3.	546	NoD.	17	-	22	72	6	78
4.	557	18.0	19	3	22	67	11	78
5.	574	NoD.	26	1	28	63	9	72

Clay Mineralogy

Sample	I.D.	Ex.	Ill.	K+C
1.	3041	58	18	24
2.	3039	60	19	21
3.	3028	62	14	24
4.	971	59	20	21
5.	970	61	17	22

* 1. Sample sample number used for clay and sand fraction data.

Also, in the Independence Section (figure 17), toward the middle of the exposure, the unnamed sediments are truncated and the Winthrop Till Member is in direct contact with the Aurora Till Member. A similar till-till contact is described at the Smith Quarry reference locality (Description 6). In the Winthrop Core Site (Description 7) the Aurora Till Member has inclusions of stratified sediments in its lower portion which overlie the Winthrop Till Member.

Continuing to the east at the Independence Section (figure 17) the Aurora Till Member is truncated by the land surface and the Winthrop Till Member becomes the surficial till. In this situation the upper boundary of the Winthrop is marked by a stone-line and the contact with the overlying surficial sediments. The Winthrop is the surface till in the Doris Station (Description 8) and the 6-10 County Line reference localities.

The lower boundary of the Winthrop Till Member is again a complex unconformable surface variously marked by the contact with the underlying bedrock (e.g. - Smith Quarry Section, Description 6), or sediments of the Alburnett Formation (Winthrop Core Site, Description 7; Doris Station Core-Hole, Description 8), or in the most complete sections by the top of the Westburg Paleosol (6-10 County Line section, Description 9). These sites also act as reference localities for the description of the base of the Wolf Creek Formation.

At the Winthrop Type Locality (Description 7) the Winthrop Till Member is underlain by a thick sequence of leached fluvial sediments. These leached silts, sands and gravel are underlain by till and then by calcareous fluvial sediments of the Alburnett Formation (see Table 15). The 17 feet of leached fluvial sediments below the Winthrop Till would seem to indicate another period of weathering between the Winthrop Till and the underlying deposits. Appropriate samples from these deposits could not be obtained for analysis, and their relationship is better described at the Doris Station reference locality.

The classic Doris Station gravel pit lies west of the Winthrop Section. The gravel pit was opened by the Illinois Central railway and was first described by Calvin in 1897. He described a thin layer (2 to 3 feet; 0.6 - 0.9 m) of "Iowan" till over 15 to 20 feet (4.6 - 6.1m) of cross-bedded, water-laid sand and gravel, which in turn overlay Kansan till. The fluvial sediments exhibit substantial weathering, being leached of carbonates and many granitic boulders are disintegrating. Some zones of the sands and gravels are cemented with secondary iron-oxides. This was Calvin's type exposure of the Buchanan gravels as well as of the Iowan drift (see Calvin, 1896; 1899; Alden and Leighton, 1917). The pit is located in the NW¼ of the NW¼ of sec. 32, T 89N, R 8W, Buchanan County.

At the present time the pit is slumped, overgrown with vegetation, and filled with water. The stratigraphy of a test-hole drilled on the east side of the pit is given in Description 8. As noted by Calvin the surficial till is quite thin. The upper surface of the gravel slopes down in elevation in nearly all directions. A shallow core hole was drilled 150 feet (45.7 m) east of the site in Description 8 which showed 8.9 feet (2.7 m) of the Winthrop Till over 0.6 feet (0.2 m) of leached sand and gravel, over 0.7 feet (0.2 m) of reduced and leached silts, then back into sand and gravel. The mineralogy data is given in Table 19.

The mineralogy of the silts indicates that the thick, leached fluvial sediments (the Buchanan Gravels) underlying the Winthrop Till Member are part of the Alburnett Formation. Calvin's "Iowan" till at this locality is the Winthrop Till Member of the Wolf Creek Formation; Calvin's Kansan till is a till of the Alburnett Formation.

SOIL STRATIGRAPHIC UNITS

A soil-stratigraphic unit has two important elements. First it is a buried soil or paleosol which, like a modern soil at the land surface, is recognized by its systematic horizonation resulting from the morphologic, physical, and chemical alteration of the parent material (a rock-stratigraphic unit) in which the soil developed. Second, a soil-stratigraphic unit only exists within a stratigraphic framework. It exhibits consistent stratigraphic relations which permit its recognition and delineation as a unit.

A soil-stratigraphic unit does not constitute a traceable bed of material by itself. The significance of a soil-stratigraphic unit is the upper contact of the paleosol. This contact marks an unconformable surface, which is placed in its stratigraphic sequence and correlated by the rock-stratigraphic unit immediately overlying it. This places an upper temporal limit on the paleosol.

However, it is possible for the rock-unit which forms the upper limit of a soil stratigraphic unit to be eroded by glacial action and replaced by a younger till unit. In these situations

Description 8. Doris Station Core-hole.

Horizon or Zone	Depth - Feet (Meters)	Description (Elevation 1,010 Feet)
	WOLF CREEK FORMATION - Winthrop Till.	
Solum and OL	0 - 5 (0 - 1.5)	Loam surficial sediments and loam till.
	ALBURNETT FORMATION - undifferentiated fluvial sediments.	
OL-MOL	5 - 31 (1.5 - 9.5)	Sand and gravel, variable texture; leached; some iron-oxide cemented zones; occasional thin RL silts or silty clays.
	ALBURNETT FORMATION - Undifferentiated till.	
RU	31 - 34 (9.5 - 10.4)	Loam till.
UU	34 - 36 (10.4 - 11.0)	Loam till.
	ALBURNETT FORMATION - undifferentiated fluvial sediments.	
Ab (UU)	36 - 37 (11.0 -11.3)	Black (10YR2/1), silt loam; with wood fragments and charcoal; weak granular structure; gradual lower contact. Buried soil in alluvial silts.
Cb (UU)	37 - 41 (11.3 - 12.5)	Dark grayish brown (10YR4/2) to olive gray (5Y4/2) silt loam, occasional organic matter.
UU	41 - 54.5 (12.5 - 16.6)	Interbedded sands; minor sand and gravel near base.
	ALBURNETT FORMATION - undifferentiated till.	
UU	54.5 - 78 (16.6 - 23.8)	Loam till; lag of boulders (?) on top of till, below fluvial sediments.
	WAPSIPINICON FORMATION (?)	
--	78 - 80+ (23.8 - 24.4+)	DOLOMITE - Bedrock

the paleosol will likely be eroded or structurally disturbed, as well. It is important to analyze, as completely as possible, the three dimensional relations of a soil-stratigraphic unit to ascertain its proper stratigraphic placement.

The properties of a paleosol at any locality are related to: 1. its degree of development prior to burial; 2. the truncation or disturbance which may have taken place during burial; and 3. diagenesis--or changes that occurred after

Table 19. Clay Mineralogy - Doris Station.

Horizon or Zone	Depth (feet)	ID	EX	Ill	K+C	H.S.I.	D.I.
*2-A13	0.8	62	**	**	**	-	1.14
2-A3	0.9	62B	**	**	**	4	1.00
2-B2	2.4	63	**	**	**	16	0.31
2-B3	3.3	64	51	16	33	17	0.33
2-C-OL	4.1	65	51	16	33	24	0.31
2-OL	4.8	66	54	15	31	21	0.33
2-OL	6.4	67	56	15	29	20	0.35
2-OU	8.2	68	59	16	25	23	0.36
ALBURNETT FORMATION - Undifferentiated Fluvial Silts							
2-RL	9.5	69	40	30	31	16.0	0.65
2-RL	10	69B	44	26	30	16.0	0.51
Till							
*1-UU	34	972	47	21	32	11.5	0.40
1-UU	58	973	44	23	33	8.0	0.48
1-UU	70	974	42	27	31	10.0	0.59

*1 - Data from the deep test hole; see Description 8.

2 - Data from the shallow core-hole described in text.

** - Uncalculable because of weathering effects and soil development (see Hallberg, Lucas, and Goodmen, 1978).

burial. Buried soils are recognized principally by the presence of soil morphologic features, which are expressed in systematic horizons or patterns. The analysis of the soil chemistry may aid in documentation. However, the normal pedogenic pattern of chemical alterations which occur in modern soils may not be recognizeable because of secondary alterations after burial (i.e. - diagenetic changes). Similar patterns of chemical (or physical) constituents also may be caused by stratification of different materials, as well.

The various pedologic features exhibited by a paleosol provide a relative indication of the time significance of the unconformity. A well-developed paleosol (one which exhibits properties similar to, or more strongly developed than analogous soils in the present landscape) is generally considered a necessary indicator for interpretation of an "interglacial" episode.

A soil-stratigraphic unit may be highly variable in appearance, particularly if the paleo-landscape on which the paleosol formed is well preserved. The unit may show the same gradations as soils on the present land surface where landscape position, parent materials, vegetation and drainage all effect the resultant physical appearance, and chemical nature of the soil.

The lower boundary of a soil-stratigraphic unit or paleosol is gradational. The pedologic characteristics may slowly change, sometimes over many feet, into the unaltered parent material. These alterations (i.e. - clay enrichment, changes in density, etc.) may have significant applied implications, but they do not affect the correlation of the rock unit which is effected.

A soil-stratigraphic unit may be developed in many rock-stratigraphic units of different ages. The limiting factor on the recognition of the unit is the single rock-stratigraphic unit which overlies it.

Dysart Paleosol

Soil stratigraphic units also occur within the deposits of the Wolf Creek Formation. The Dysart Paleosol in its type area is a strongly developed buried soil which is bound at the top by the Hickory Hills Till Member of the Wolf Creek Formation.

The type area is located north of the town of Dysart in the Hayward's Paha transect (figures 6-8), in the Wolf Creek area. The detailed description of the paleosol and the stratigraphy are given in Description 3. As shown in the description, the Dysart Paleosol at this site is a well-developed, thick, gleyed buried soil. The paleosol is developed in a thick sequence of fine-textured, stratified materials and in the underlying Aurora Till Member. The paleosolum thickness is 9.3 feet (2.8 m), and the last 2.2 feet (0.7 m) are developed in the Aurora Till Member.

The gleyed colors of the paleosol, the preservation of the organic silts, and the nature of the stratified sediments all indicate that this soil developed in some poorly-drained, low-landscape position on the paleo-landsurface. This is typical of the majority of paleosols encountered below till units in Iowa. Even with very detailed drilling it is generally impossible to determine the geometry of these deposits and thus, to determine their origin -- i.e. -- is this a depression on an upland surface? Or are these sediments part of a sequence of side-valley alluvium (see Ruhe, 1967)? At this time it is impossible to state more than that the paleosol formed in some form of "swale" or poorly-drained landscape position, that was a catchment for fine-textured, poorly sorted sediments.

For a complete understanding of the Dysart Paleosol it would be ideal to trace the buried soil to a well-drained position on the paleo-landscape. However, the paleo-landsurface has been severely eroded by glacial action, which deposited the overlying Hickory Hills Till Member. This erosion has apparently removed the higher, better drained positions on the paleo-surface because all of the remnants of the Dysart Paleosol are similar to those in the Hayward's Transect. The former higher landscape positions are now marked by the direct contact between the Hickory Hills and Aurora Till Members (see figures 3 and 10).

In the Aurora Transect another variation of the Dysart Paleosol occurs (see Description 6; figure 14). In contrast to the Wolf Creek area the interval of the Dysart Paleosol is not represented by a strongly developed buried soil. In this area the Dysart Paleosol is only represented by an organic paleosol (peats and mucks) which overlie approximately 8.5 feet (2.6 m) of gleyed, leached, fine-textured, and weakly stratified sediments. Although the sediments are thoroughly leached of carbonates there is no clear evidence of any B-horizon development. Preliminary analysis of pollen from the muck and the sediments shows a dominance of pine and spruce pollen. The strongly developed paleosol in the Wolf Creek Area is evidence of an interglacial-level hiatus. The nature of the paleosol, and particularly the pollen evidence in the Aurora reference locality is more indicative of an interstadial regime. (A similar setting is shown in the Plague Mine Creek Section in the Appendix.)

Conceptually, the Dysart Paleosol could occur on any materials below the Hickory Hills Till Member. At the present time it has only been recognized where it is developed in the Aurora Till Member and the described superjacent, unnamed sediments.

The mineralogy of the paleosols and the leached sediments is also of interest. Samples from the B2gtb horizon of the Dysart Paleosol (Description 3) show broad, poorly-defined expandable clay mineral peaks and no illite. Further down in the profile the expandable peaks become more sharp, very large, and well-defined and illite peaks are present. In contrast, in the Aurora Transect, (Description 5) the gleyed, leached sediments below the peat and muck all exhibit very large well crystallized expandable peaks. The expandable clays may constitute 80% or more of the clay minerals, and the peaks become so large that they obscure the illite peaks. These relationships are typical for gleyed, leached accretionary materials (Willman, Glass, and Frye, 1966; Hallberg, Lucas, and Goodmen, 1978).

The Inter-Aurora-Winthrop Till Member Hiatus

As described in the 4-Mile Creek area and the Winthrop Locality (figure 17) the Aurora and Winthrop Till Members are separated in some localities by leached sediments and associated organic paleosols (peats and/or mucks). The peat at the Independence Section (figure 17) was processed for pollen. Not enough pollen was present or well-enough preserved for a valid pollen count, yet nearly all the identifiable grains were coniferous (spruce and pine). Hemlock wood has also been identified from the silts (Ruhe, Rubin, and Scholtes, 1957). These paleontologic indicators are more indicative of an interstadial level hiatus between the tills, versus any substantial interglacial period (which may be indicated by a well-developed buried soil such as the Dysart Paleosol in its type area). This hiatus between the tills may not have any major time significance. Until more is known about this inter-Aurora-Winthrop period no formal stratigraphic names will be applied to these deposits or soils.

ALBURNETT FORMATION

The Alburnett Formation is the oldest Pleistocene rock-stratigraphic unit currently recognized in east-central Iowa. It is composed principally of multiple till units but includes a variety of fluvial sediments. Some minor (A/C or O/C) paleosols occur within the deposits also. The type area for the Alburnett Formation is the region around the town of Alburnett, Otter Creek Township (T 85N, R 7W), Linn County, Iowa.

The stratigraphy in the type area is illustrated in the Alburnett Paha drilling transects (figures 18-20; Table 20-21). No exposures occur in the area that reveal pertinent aspects of the stratigraphy, and so the type section is described from the Little Paha Core Locality (figure 21-22; Table 22). Other reference localities will be used to fully describe the properties of the Alburnett Formation.

The Alburnett Paha is oriented from NW to SE from the north-central portion of sec. 15, through the NE¼ of the SE¼ of sec. 14, T 85N, R 7W. The stratigraphy of the Alburnett Paha Transects is shown in: figure 18; a north-south cross section through the paha and the surrounding plain of the Iowa Erosion Surface (This figure is adapted from unpublished data by Ruhe, Fenton, and others, and was provided by T.E. Fenton.); and figure 19, a cross section lengthwise through the paha (NW to SE) and onto a small en echelon paha ridge on the south flank of the Alburnett Paha ("Alburnett Jr.").

This area was first investigated in detail by Ruhe, Dietz, Fenton and Hall (1968). They described the stratigraphy, from the summit of the paha (about 975 feet elevation) as: 44 feet

(13.4 m) of Wisconsinan Loess, over 2 feet (0.6 m) of leached Kansan till; over unleached Kansan till; which was over either leached Nebraskan till or over a paleosol and Nebraskan till. These deposits are now recognized as a till of the Wolf Creek Formation, the Westburg Paleosol, and till of the Alburnett Formation. The transect cross sections (figures 18-19) are a combination of their core-hole data and the author's.

In the type area of the Alburnett Formation, as shown in the cross sections, the widespread Wisconsinan-age Iowan Erosion Surface continues under even the thick loess and eolian sands of the paha. As described by Ruhe and others (1968) the loess and eolian sands generally lie directly on the eroded surface of the uppermost (Wolf Creek Formation) till. However, in one core-hole by the author, along the crest of the Alburnett Paha, a truncated paleosol (partially preserved B3tb horizon) resembling a typical Late-Sangamon paleosol, occurred under the loess, developed in the Wolf Creek Formation till. Another anomaly occurs to the southwest at the "Alburnett Jr." site (figure 19). Here, at a slightly lower elevation than on the main paha ridge, even thicker loess is encountered. Figure 20 summarizes the stratigraphy of the core-hole. Nearly 50 feet (15.2 m) of loess overlies a complete sub-loess paleosol sequence, with a basal loess paleosol and an underlying paleosol which exhibits strong B-horizon development. The paleosol is developed in gleyed stratified sediments. This is unusual because this complete paleosol occurs at elevations 5 to 25 feet (1.5 - 7.6 m) lower than the erosion surface on the main paha. The loess also continues to depths which place it lower in elevation than the surrounding till on the erosion surface (see figure 19). It seems likely from the nature of the sediments and paleosol, and the landscape relations, that the paleosol was developed in a low area of Late-Sangamon side-valley alluvium (see Ruhe, 1967), which was preserved locally by burial with the thick loess.

The color of the tills in the Alburnett Formation vary in similar fashion to those in the Wolf Creek Formation, ranging from light-yellowish brown in the oxidized zone, to dark gray or dark-greenish gray in the unoxidized zone.

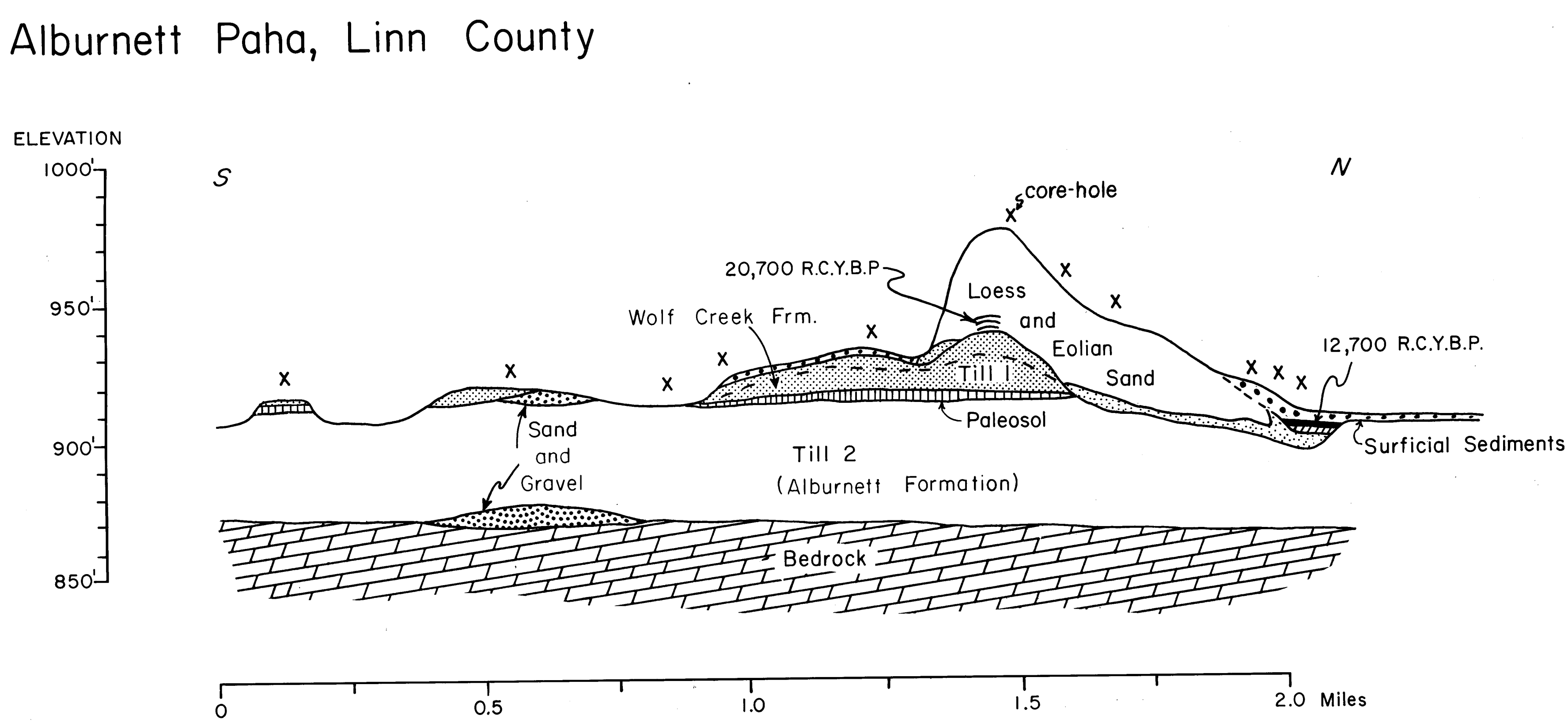


Figure 18. North-south cross-section of the Alburnett Paha (Modified from Fenton, unpublished).

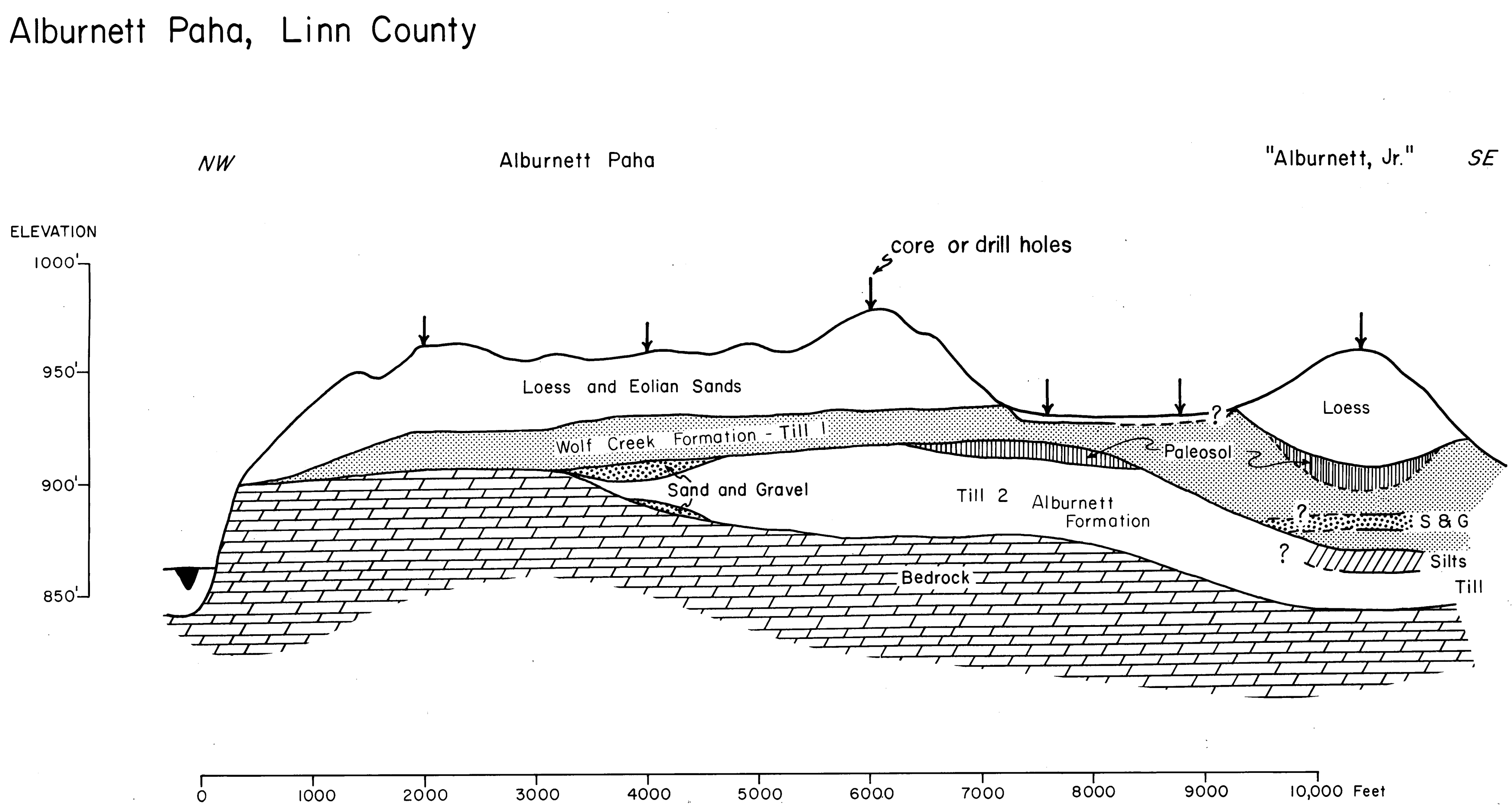


Figure 19. NW-SE cross-section; Albrunett Paha and vicinity.

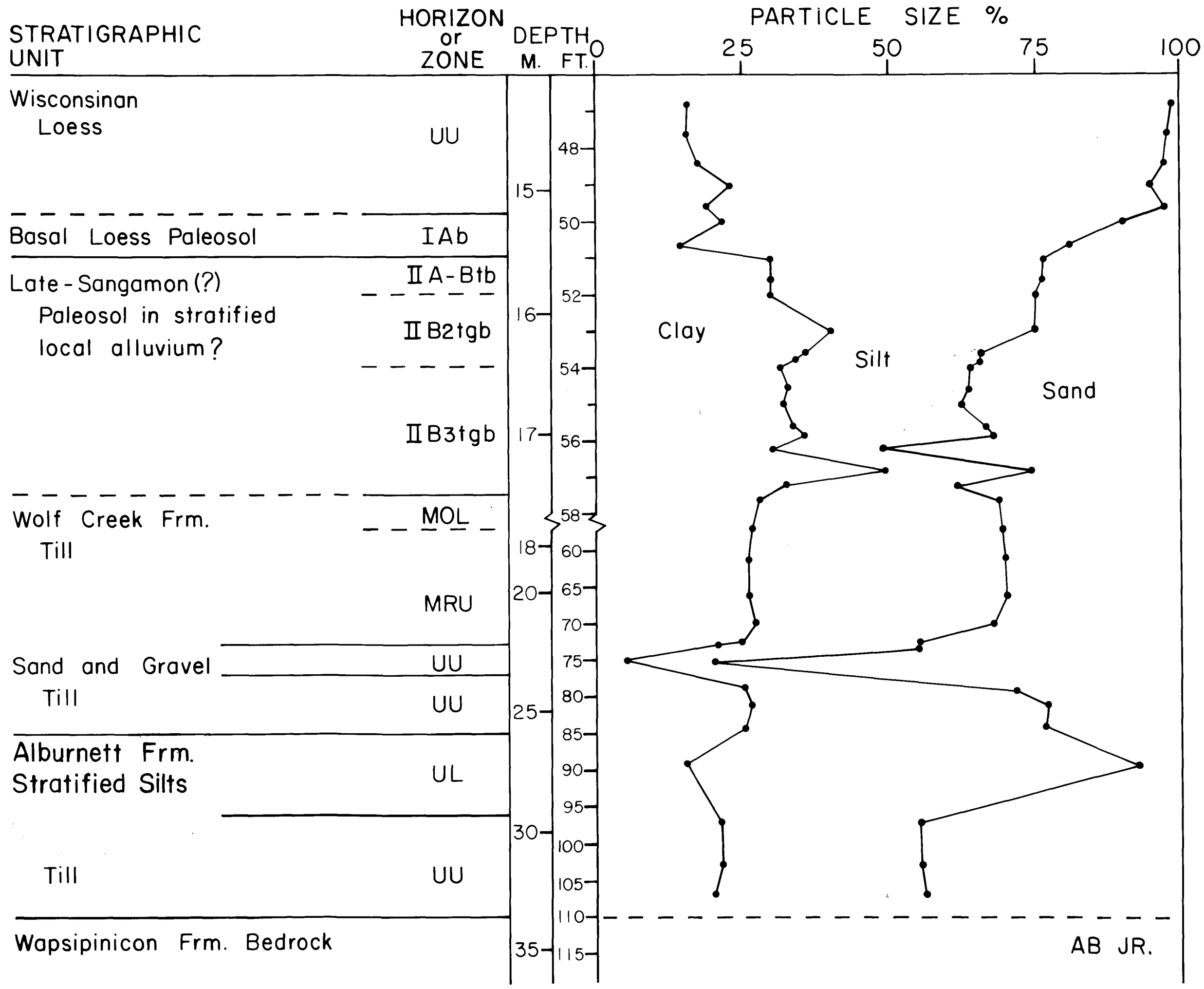


Figure 20. Stratigraphy and particle-size data, Alburnett, Jr., core.

The Alburnett Formation has a wide range in thickness. In some areas it is entirely absent and deposits of the Wolf Creek Formation rest directly on the bedrock (Smith Quarry Section, Description 6; or the Alburnett Transect, figure 19). The Alburnett Formation also attains substantial thicknesses where its deposits fill in, and bury, the deep channels on the bedrock surface. In these situations the Alburnett Formation reaches 220 feet (67 m; Abbe Creek Locality) to 250 feet (76 m; Kirkwood Locality) in thickness.

Table 20. Clay Mineralogy - Alburnett Sites.

Horizon or Zone	Depth (Feet)	ID	EX	Ill	K+C
		WOLF CREEK FORMATION - Undifferentiated till			
		Miscellaneous Sites			
OU		339	64	16	20
OU		977	62	19	19
RU		978	64	17	19
		Alburnett, Jr. Site			
MRU	67	297	64	18	18
MRU	70	298	67	15	18
UU	80	299	60	19	21
UU	82	339	64	15	21
		ALBURNETT FORMATION - Undifferentiated till			
		Miscellaneous Sites			
RU		979	48	24	28
RU		981	47	25	28
UU		980	43	24	33
UU		982	43	27	30
		Alburnett Jr. Site			
UU	100	350	41	22	37
UU	106	351	45	21	34

Table 21. Sand Fraction Lithologies - Alburnett Area.

Horizon or Zone	Depth	I.D.	C/D	T.C.	Sh.	Sed.	Q.-F.	Ot.	Xst.
			WOLF CREEK FORMATION - Undifferentiated Till						
				Alburnett, Jr. site					
RU	70.0	448	11.5	17.3	4.0	23.4	68.5	8.1	76.6
				Little Paha site					
OU	15.0	147	18.0	14.2	2.4	17.4	73.2	9.5	82.7
OU	15.7	145	6.0	5.4	1.2	6.6	77.1	16.3	93.4
			ALBURNETT FORMATION - Undifferentiated Till						
				Alburnett, Jr. site					
UU	100	49	1.0	13	16	29	63	8	71
				Little Paha site					
OJU	30.0	131	1.8	16.2	0.7	19.8	72.8	7.4	80.2
RJU	43.5	129	3.5	14.7	4.6	22.0	62.4	15.6	78.0
MJUU	47.0	127	1.1	15.0	0.9	16.8	69.0	14.2	83.2

The tills of the Alburnett Formation are generally loam-textured, but range to light clay loam, averaging 22% clay, 34% silt, and 44% sand (Table 23). Texturally the average values for these tills are nearly identical to the Hickory Hills Till Member of the Wolf Creek Formation. The different till units within the Alburnett Formation are similar in texture, as indicated by the small standard deviations in Table 23. At individual localities the till is generally quite uniform in vertical sequence (figure 21; Kirkwood Section in Appendix). The tills of the Alburnett Formation show the most variation in the lowest portion of a till unit, exhibiting sheared inclusions (Abbe Creek Section, figure 24) similar to those described for the Hickory Hills Till Member of the Wolf Creek Formation.

The clay mineralogy is the most unique characteristic of the Alburnett Formation. It is the clay mineral composition which allows the consistent identification of the Alburnett Formation and its discrimination from the Wolf Creek Formation (Table 2). The average clay mineralogic composition of the Alburnett Formation is: 43% expandables; 25% illite; and 32% kaolinite (Table 23). Figure 22 shows x-ray diffraction traces from the Little Paha Type Section, showing the change from the higher percentage expandable clay Wolf Creek Formation, to the lower amounts of expandable clay and higher kaolinite of the Alburnett Formation. All the Alburnett Formation till samples analyzed showed higher percentages of kaolinite than illite. In two samples of fluvial silts illite was slightly higher than kaolinite.

The sand fraction lithology data is also summarized in Table 23. The data exhibits more variation than in the tills of the Wolf Creek Formation (Table 7). This should be expected because the data is from several different individual till units within the Alburnett Formation.

The upper boundary of the Alburnett Formation is an unconformity of variable magnitude. In complete sections the top of the Westburg Paleosol is considered to mark the top of the

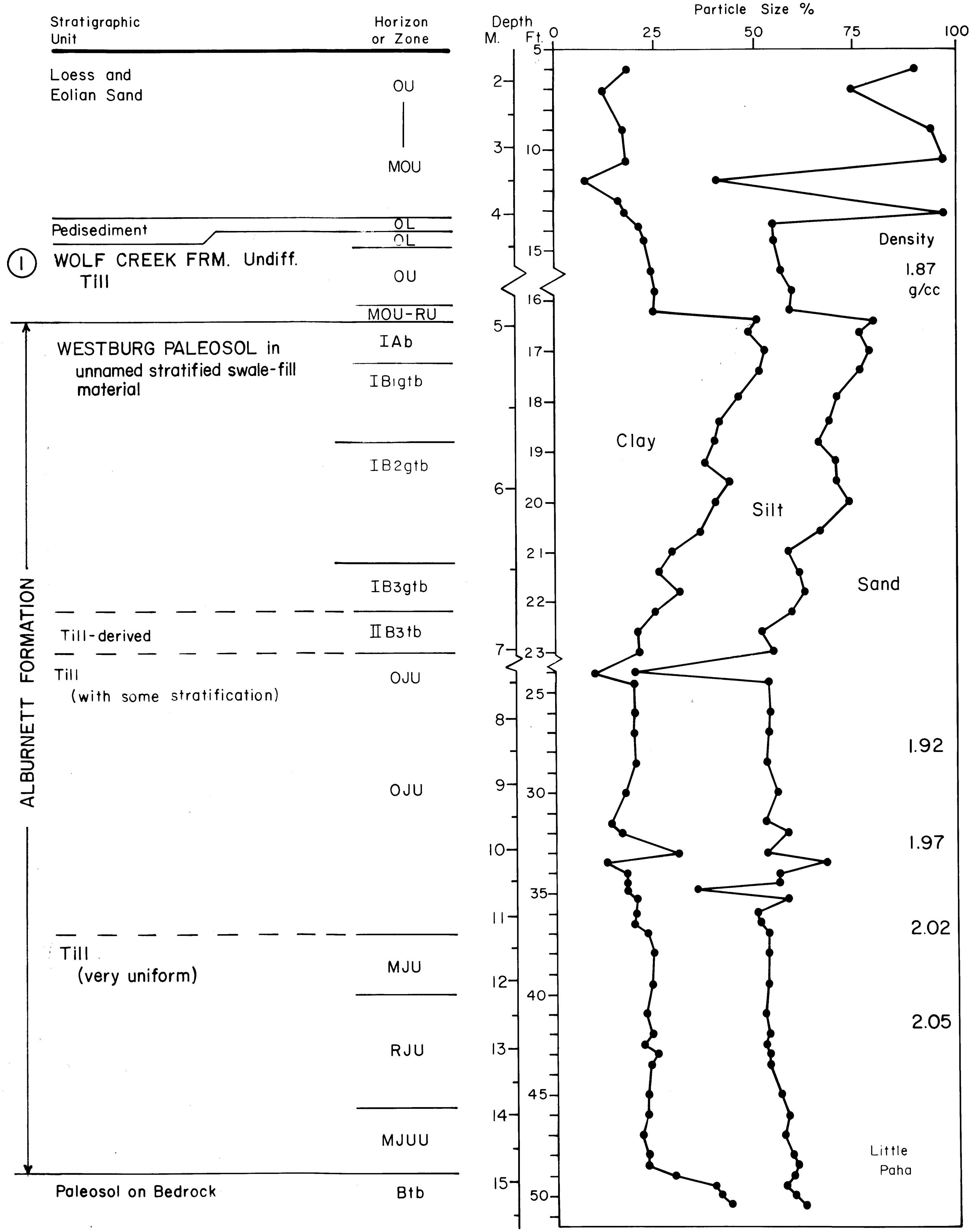


Figure 21. Stratigraphy and particle-size data, Little Paha core.

Table 22. Clay mineralogy - Little Paha Site.

Horizon or Zone	Depth (feet)	I.D.	Ex.	% Ill.	K+C	H.S.I.	D.I.	D. c.p.s.	C. c.p.s.
				WISCONSINAN LOESS and EOLIAN SAND					
OU	+ 8.0	285	62	26	12	20	1.38	30	20
OU	6.0	256	62	22	16	19	0.97	30	t
MOU	8.0	257	67	20	13	21	1.06	40	20
DU	9.5	258	70	17	13	26	0.92	30	20
MOU	11.9	260	69	18	13	23	0.95	20	40
MOU	13.5	261	64	24	12	20	1.33	t	20
				Pedisediment					
OL	13.7	262	60	20	20	20	0.74		
				WOLF CREEK FORMATION - Undifferentiated Till					
OU	15.0	263	64	17	19	27	0.61	t	t
OU	15.7	264	64	16	20	26	0.53	t	t
				WESTBURG PALEOSOL (?) in stratified sediments.					
Ab	17.3	265	**	**	**	30	**	t	t
B1gtb	18.0	266	(76)	(10)	(14)*	34	0.47	t	t
B2gtb	19.5	267	(78)	(9)	(14)*	31	0.42		
B2gtb	21.0	268	(63)	(15)	(22)*	31	0.44	-	20
B3gtb	22.0	269	(69)	(13)	(18)*	30	0.50		
IIB3tb	23.0	270	(59)	(19)	(22)*	17	0.56	-	20
				ALBURNETT FORMATION - Undifferentiated Till					
IIMOL2	24.5	271	(57)	(20)	(23)*	15	0.56		
OU	26.0	272	49	23	28	16	0.52		
OJU	28.0	273	45	21	34	17	0.41	-	50
OJU	30.0	274	41	21	38	15	0.36	20	70
OJU	31.5	275	41	22	37	15	0.39	-	50
OJU	37.0	276	50	19	31	15	0.41	-	30
MOJU	38.5	277	43	27	30	22	0.56	-	60
RJU	41.0	278	49	21	30	16	0.49	-	50
MJUU	42.0	279	50	20	30	18	0.47	20	20
MJUU	43.0	280	49	22	29	13	0.48	-	t
MJUU	45.0	281	43	24	33	16	0.49	-	60
MJUU	46.0	282	46	26	29	12	0.61	20	70
MJUU	48.0	283	51	21	28	11.0	0.50	-	90
				PALEOSOL ON Bedrock?					
Btb	49.1	284	(62)	(25)	(13)*	34	1.33	(30)	(40)

** Uncalculable; no illite peak; broad expandable peak.

* Uncalculable because of weathering effects; numbers in parenthesis for discussion only; see Hallberg, Lucas, and Goodmen, 1978.

Table 23. Data summary for the ALBURNETT FORMATION.

Particle-size data for till samples

	% Clay		% Silt		% Sand	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
n=185	22.1	±3.3	34.4	±5.0	43.8	±4.6

Clay mineralogy for all sediments

	% Ex.		% Ill.		% K+C	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
n=163	42.9	±5.6	24.5	±4.1	32.3	±3.9
(range)	(28 - 55)		(15 - 35)		(21 - 48)	

Sand-fraction lithology data for till samples

					C/D - % obs.					
		T.C.%	T.S.%	T.X.%	<1	1-5	5-10	10-15	>15	NoD.
n=56	Mean	18.2	21.1	78.9	6	56	16	6	3	13
	s.d.	±7.8	±7.8	±7.8						

Alburnett Formation (Little Paha section, figure 21; 6-10 County Line Section; Description 9). In these sections the Winthrop Till Member overlies the paleosol. Where the paleosol is eroded any member of the Wolf Creek Formation may overlie till or glaciofluvial deposits of the Alburnett Formation (e.g. - the Winthrop Till Member overlies the Alburnett Formation in the Winthrop locality, Description 7; at Doris Station, Description 8; and in the 4-Mile Creek locality, figure 16; the Aurora Till Member overlies the Alburnett in the Aurora Transect, and the Abbe Creek Transect, figure 24).

As shown in the Alburnett Transects (figures 18-19) erosion has locally removed all of the overlying Pre-Illinoian deposits, exhuming the Alburnett Formation. In this situation the Alburnett Formation may be overlain directly by surficial sediments or Wisconsinan loess. In some areas (described with the Abbe Creek locality) the Late-Sangamon Paleosol is developed in till of the Alburnett Formation. In these settings the upper limit of the formation would be at the eroded contact (often marked by a stone line) with the younger overlying sediments.

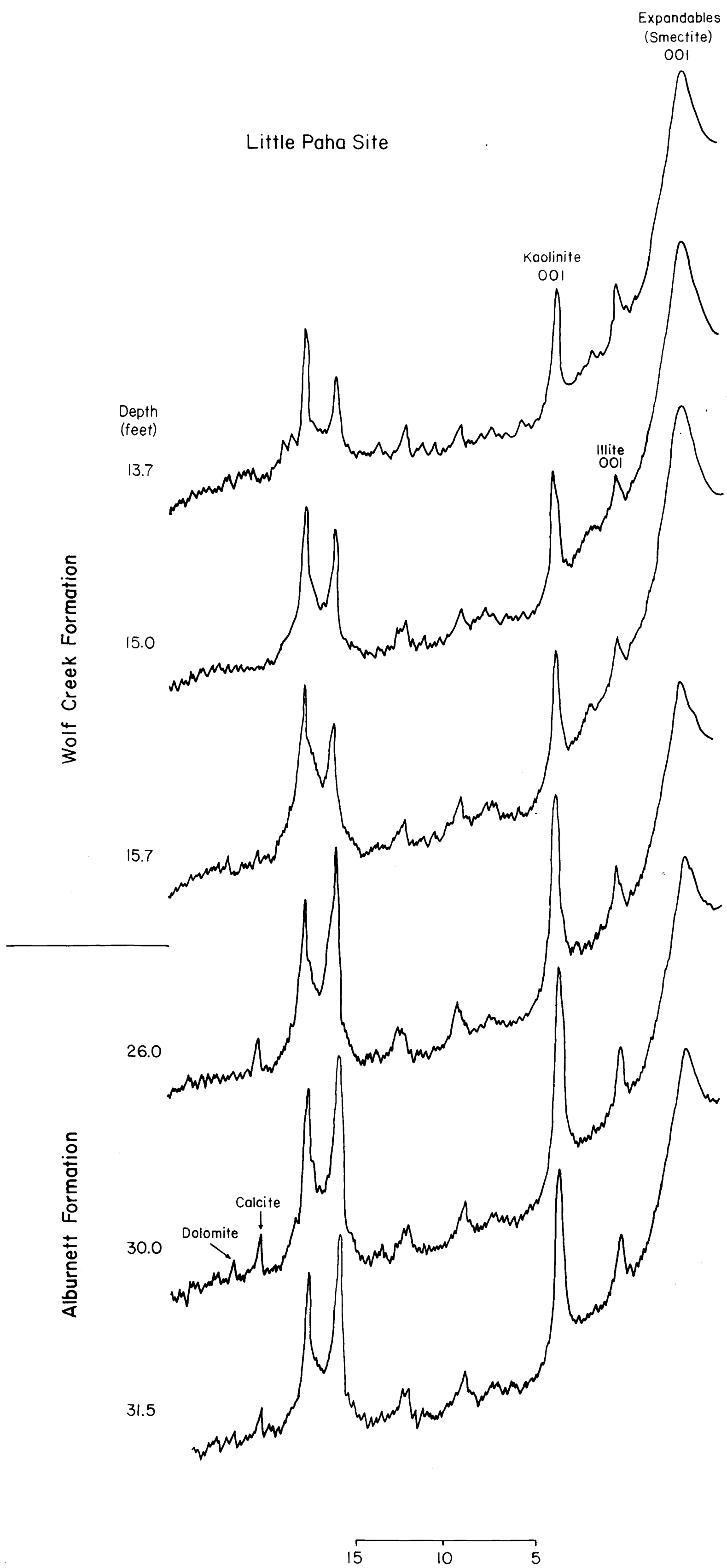


Figure 22. X-ray diffraction traces (log-scale) of samples from Little Paha core.

The lower boundary for the Alburnett Formation in the type area and in the entire study area is marked by an unconformable contact with the bedrock surface. On the higher elevation bedrock surfaces a paleosol may separate the Alburnett Formation from the rock itself. In buried bedrock valleys (e.g. - Kirkwood Section in Appendix; Abbe Creek Transect, figure 24) glaciofluvial gravels form the base of the Alburnett Formation and overlie the Paleozoic bedrock.

The stratigraphy of the Little Paha Core Site shows the nature of the upper and lower contacts of the Alburnett Formation. The Little Paha core site is located in the NW¼ of the NW¼ of the SW¼ of the SW¼ of sec. 17, T 85N, R 7W, in a road cut through the center portion of a small paha ridge. In the road cut above the top of the core approximately 12 feet (3.7 m) of Wisconsinan loess is exposed. The stratigraphy in the core, below the exposure is summarized in figure 21 (beginning at 915 feet elevation). Here, again, Wisconsinan loess and eolian sands rest unconformably on the Iowan Erosion Surface cut in the Wolf Creek Formation till. This till shows an abrupt lower contact with the top of the Alburnett Formation, here marked by the top of the Westburg Paleosol. At this site the Westburg Paleosol is quite well-preserved and at least part of the buried A-horizon is intact. One small sheared inclusion of the paleosol was found in the overlying till, about 1.5 feet (0.5 m) above the contact.

The Alburnett Formation at this site consists of an upper till separated from a lower very uniform till by some stratified inclusions. The tills are very similar in all properties. The Alburnett Formation till overlies the B-horizon of a paleosol which greades to (?) or rests on shaly Devonian carbonates. The matrix of this paleosol has about 41% clay and 41% sand. The sand is fine to medium and is composed almost entirely of quartz and chert. There are some chert pebbles incorporated. There is no obvious erratic material included. The paleosol seems to be a well-drained profile. However, the clay mineralogy shows a large amount of expandable clays (typical of Quaternary deposits) which is in sharp contrast to the nearly pure illitic clays (and minor kaolinite) of the early Paleozoic shales and insoluble residues in this region. It is not clear at this time whether the high expandable clay content indicates some influence from older Pleistocene materials, or whether it is a function of clay mineral alteration because of weathering.

Table 24 summarizes the stratigraphy and data for additional core sites in the Alburnett area. These sections depict a variety of stratigraphic sequences present on the Iowan Erosion Surface: thick Wisconsinan eolian deposits on the Alburnett Formation; thin Wolf Creek deposits overlying the Alburnett; and the Alburnett exhumed as the surficial till.

Multiple Tills - Alburnett Formation

There is clear evidence in the stratigraphy from many sites that multiple tills occur within the Alburnett Formation. At the Doris Station Section (Description 8; Table 19) two tills of the Alburnett Formation are separated by 18.5 feet (5.6 m) of fluvial sediments, with a weakly-developed (A-C profile) paleosol in the top of the sediments. In the Kirkwood Locality (in Appendix) the deep buried-bedrock channels are filled by two tills which are separated by thick sand and gravel. In the 6-10 County Line Section (Description 9) 3 tills occur in the Alburnett Formation, all separated by weakly developed (A-C or O-C profiles) paleosols.

The Abbe Creek Transect in southern Linn County shows multiple till members and the complexities that occur within the formation. This site is an important reference locality for the Alburnett Formation. The transect consists of a series of core-holes, along the flanks of a paha ridge which forms the divide to the south of Abbe Creek. The holes begin in the NW¼ of sec. 7, T 82N, R 5W, and continue to the northwest, to the NE¼ of the NE¼ of sec. 12, T 82N, R 6W, Linn County. The stratigraphy from the transect is summarized schematically in figure 23.

Table 24. Summary of additional stratigraphic test holes in Alburnett Area.

Site: Paris Test Hole; Linn County.
Location: NW¼ of NE¼ of NW¼ of NE¼, sec. 36, T86N, R7W.
Elevation: 940 feet.

Stratigraphy:	Depth	Sample Data: Depth (feet)	Particle Size % Clay	Silt	Sand	Clay Mineralogy % EX	Ill	K+C	D	C	Density[1] g/cc(pcf)	Specific Gravity[2]	Hydraulic Conductivity[3] cm/sec	ft/day
WISCONSINAN														
Eolian sand (DL)	0- 15 feet	12.5	0.9	1.3	97.8						1.77(111)	2.67	7.2×10^{-4}	2.04
Eolian sand & loess (OL)	15- 30	22.0	7.5	25.2	67.3	75	16	9	--	--	1.41(88)	2.67	1.0×10^{-5}	0.03
Loess (DOU)	30- 55	42.0	16.8	69.4	13.8	72	17	11	30	50	1.68(105)	2.68	4.1×10^{-7}	1.2×10^{-3}
UNKNOWN AGE														
Sand and gravel (OL)	55- 58													
PRE-ILLINOIAN														
ALBURNETT FORMATION														
Silty diamicton (MUL)	58- 62	60.5	24.1	72.8	3.1	42	24	34	--	--				
Till (UU)	62-112	61.0	20.0	44.0	36.0	42	26	32	--	--	1.81(113)	2.61	3.8×10^{-8}	1.1×10^{-4}
		81.5	22.0	30.5	47.5	49	20	31	30	70	1.95(122)	2.68	7.4×10^{-9}	2.1×10^{-5}
		82.0				42	21	37	t	80				
Stratified silts, sands, gravel (UU)	112-132													
Till (UU)	132-200	137	22.4	28.3	49.3	48	19	33	--	70	2.03(127)	2.64	1.6×10^{-9}	4.6×10^{-6}
		186	29.1	56.5	14.4						2.00(125)	2.66	1.9×10^{-9}	5.3×10^{-6}
		186.5	30.8	58.4	14.4									
Bedrock-derived colluvium and sand and gravel in buried bedrock channel	200-230													

1. - Bulk Density
2. - Specific Gravity of particles
3. - Vertical hydraulic conductivity from core samples

Table 24. (con't)

Stratigraphy	Depth	Sample Data: Depth (feet)	Particle Size % Clay	Silt	Sand	Clay Mineralogy % EX	Ill	K+C	D	C	Density g/cc(pcf)	Specific Gravity	Hydraulic cm/sec	Conductivity ft/day
Site: Fox Test Hole Location: SW¼ of SE¼ of SE¼ of SE¼, sec. 34, T.86N., R.7W. Elevation: 910 feet.														
on stripped surface, no solum.														
PRE-ILLINOIAN														
ALBURNETT FORMATION														
Till (OL)	0 - 4 feet	3.0	26.0	28.8	45.2	46	20	34	--	--				
		3.5	23.1	61.7	15.2	49	19	32	--	--	1.94(121)	2.71	3.9×10^{-9}	1.1×10^{-5}
UNDIFFERENTIATED														
Weathered Silty Clay Loam	4 - 7	5.5	32.1	66.6	1.3						1.79(112)	2.63	5.1×10^{-8}	1.4×10^{-4}
DEVONIAN														
Cedar Valley Limestone (Weathered)	7 +													
Site: Alice Quarry Test Hole Location: SW¼ of SW¼ of SW¼ of SW¼, sec. 4, T.85N, R.7W. Elevation: 915 feet.														
on stripped surface, no solum.														
PRE-ILLINOIAN														
ALBURNETT FORMATION														
Till (OU)	0 -13 feet	12.5	19.1	23.5	57.4	42	20	38	--	60	2.05(128)	2.70	9.3×10^{-9}	2.6×10^{-5}
Till (R-UU)	13 -23													
DEVONIAN	23 +													
Wapsipinicon Formation														
Site: Near Alburnett Paha Location: SW¼ of SW¼ of SW¼ of SW¼, sec. 15, T.85N., R.7W. Elevation: 900 feet.														
Loam sediments (in solum)	0 - 2 feet													
PRE-ILLINOIAN														
WOLF CREEK FORMATION														
Till (MOL; in solum)	2 - 4.5													
Sand (OL)	4.5- 5.1	5.0	4.7	12.0	83.3									
Till with sand inclusions (MOU)	5.1-13					64	17	19	--	t	1.89(118)	2.67	2.4×10^{-8}	6.9×10^{-5}
WESTBURG PALEOSOL														
Mucky silty clay (O-Ab)*	13 -14.7	13.5	46.2	53.4	0.4	--	--	--	--	--	1.42(89)	2.52	2.9×10^{-8}	8.2×10^{-5}
Silty Clay (Bb)	14.7-16.0													
ALBURNETT FORMATION														
Till	16 -18.5	17.0				42	22	36						
DEVONIAN														
Wapsipinicon Formation	18.5-29													

* Note: Pollen analysis showed only a few identifiable pollen grains of Cyperaceae and Gramineae.

As an important historical aside it should be noted that this area was investigated because of the following well section reported by Norton (1895; p. 176; Smyth Well):

		Feet-Thickness
7.	Loess	14
6.	Clay, hard blue, pebbly; first till	48
5.	Wood and dark soil	6
4.	First till	66
3.	Sand and gravel	8
2.	First till	63
1.	"River sand"	6

The section was all assumed to be older than the East Iowan till (later to be called Iowan, then Kansan). The only other till thought to be present was the first till or the Kansan. Thus, Norton described possibly three individual tills separated by wood and dark soil, or by a sizeable thickness of gravel. However, because of the concepts of the day, and because the tills were all blue ("blue clay") he called them all First till. We now know the "blue" color is not stratigraphically diagnostic but is related to weathering (Hallberg, Fenton, and Miller, 1978). It is interesting though that even in Norton's time the infamous "forest bed," or wood and dark soil was enough to separate the Iowan and Kansan tills, and to speculate about multiple glaciations. However, at this site Norton did not attach any significance to the occurrence of "wood and dark soil" in the Smyth Well.

The stratigraphy of core N-2 most closely resembles that of Norton (figure 24). Three tills are present and are all included in the Alburnett Formation (Table 27). The upper till unit is of variable texture, with many thin sand partings. In the lower 8 feet (2.4 m) of this unit there are many angular inclusions of leached sands, silts, and till within a calcareous till matrix. These are most likely block inclusions of the sub-till material which were sheared into the lower part of this till unit. This is underlain by leached organic silts and sands with abundant wood. This leached organic soil overlies another till unit. The organic deposits could be an inclusion also. This does not seem likely, however, because the organic soils were encountered in the same stratigraphic horizon and at about the same elevation in three separate test holes separated laterally by about 50 feet (15 m).

Under the second till is approximately 6 feet (1.8 m) of leached fluvial sediments, which in turn overlies a third calcareous till. Below this third till is another organic paleosol developed in fluvial deposits, which fill in the base of the buried bedrock channel (see figure 23). The base of the channel--the top of the bedrock--is at an elevation of 560 feet, approximately 120 feet (36.6 m) lower than the Cedar River 2 miles (3.2 km) to the south.

On the shoulder of the paha ridge (site AC-1) 27 feet (8.2 m) of Wisconsinan loess and eolian sand overlie a Late-Sangamon paleosol developed in thin till of the Wolf Creek Formation. The textural and mineralogic data (Table 25, 26) suggest this may be the Aurora Till, but the data is not conclusive at this time. Road cuts along U.S. highway 30 south and west of the transect, in the Cedar River paha belt, show thick loess over the Late Sangamon Paleosol developed directly in till of the Alburnett Formation (see Table 25).

In core-holes N-1 and AC-1 (figure 23) two tills are apparent in the Alburnett Formation. With the high relief that occurs on the bedrock surface the section changes rapidly. It is not clear how the two till units of the Alburnett Formation on the bedrock uplands correlate with the three till units in the valley (N-2; figure 23). This is a typical setting for the Alburnett Formation over the whole study area. Alburnett deposits have been found filling in all the deep buried bedrock channels investigated.

In reviewing the data from the different till units there are no clear consistent trends useful for correlation at this time. In the Abbe Creek transect all the different Alburnett Formation till units have essentially the same mean texture (22% clay; 44% sand). The same is essentially true of the clay mineralogy data. There are hints of differences, but they are

Abbe Creek Transect

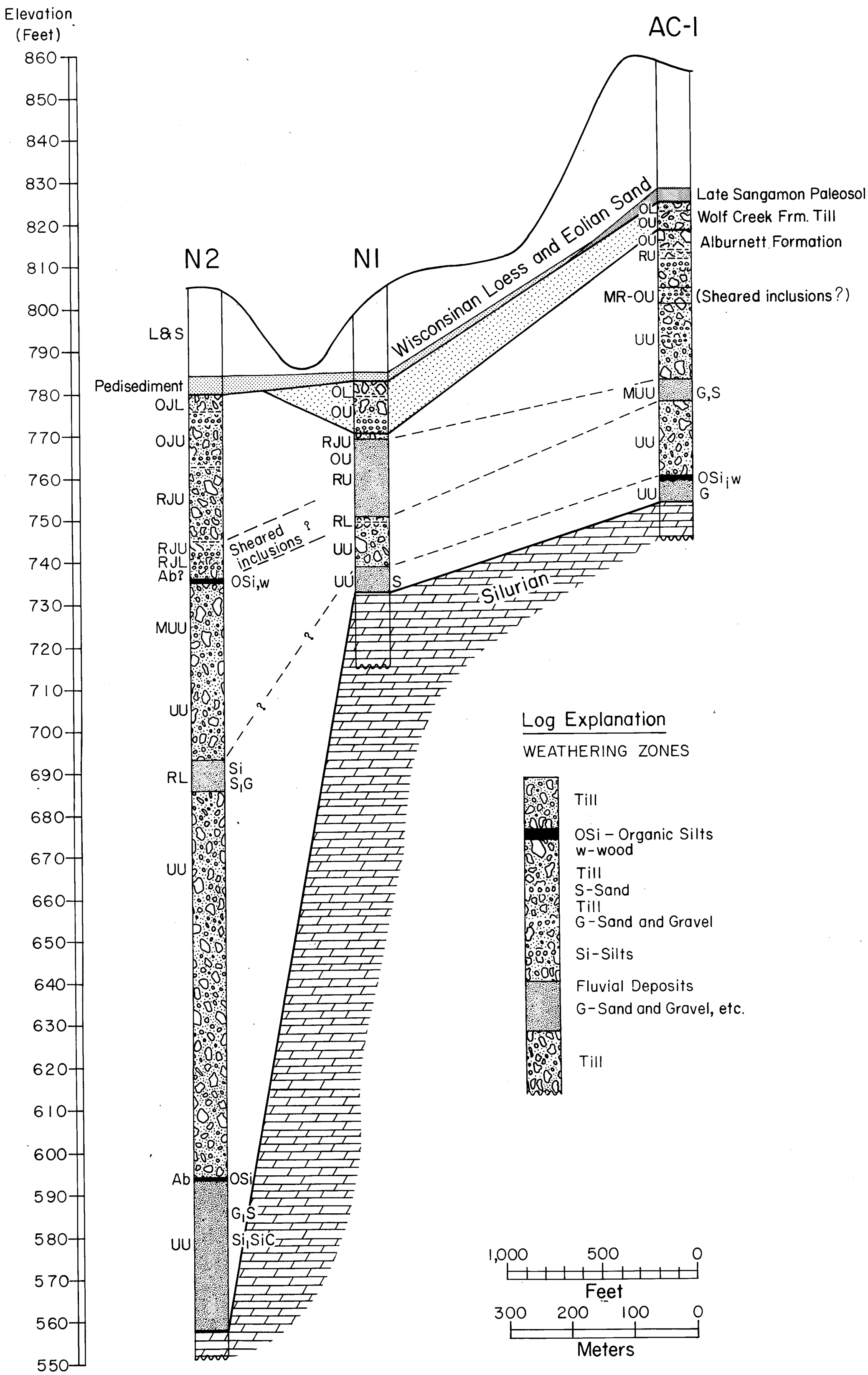


Figure 23. Cross-section: Abbe Creek drilling transect.

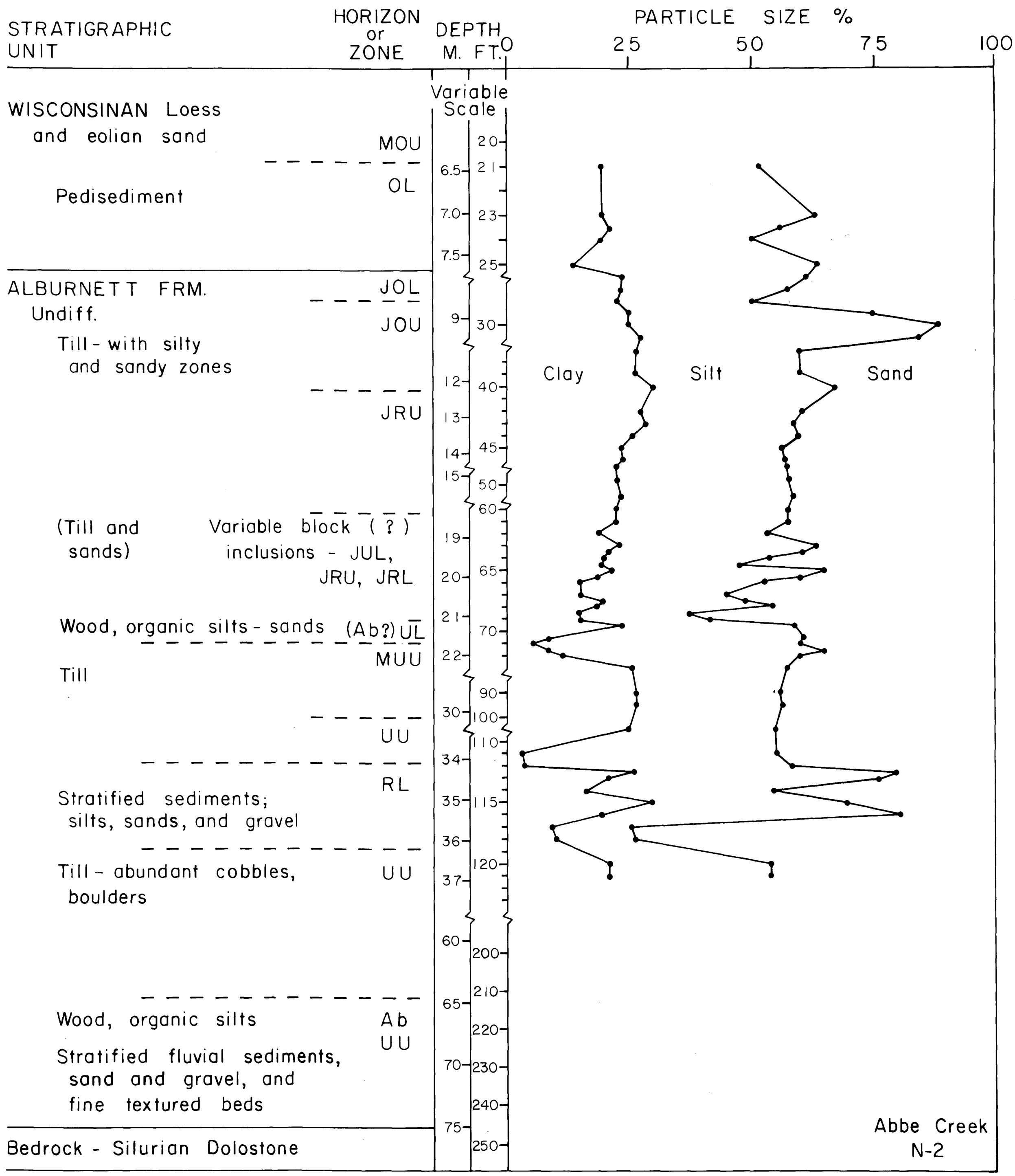


Figure 24. Stratigraphy and particle-size data, Abbe Creek Transect core N-2.

Table 25. Clay Mineralogy - Abbe Creek Area.

Horizon or Zone	Depth (feet)	ID	EX	Ill	K+C	D c.p.s.	C c.p.s.
			N1				
		WOLF CREEK FORMATION - Undifferentiated Till					
OU	21	1081	56	21	23	t	70
MOJU	22	1082	60	18	22	--	20
MRJU	25	1083	56	20	24	30	90
MRJU	27	1084	67	15	18	t	50
		ALBURNETT FORMATION - Undifferentiated Till					
RJU	29	1085	38	27	35	--	--
			AC1				
		ALBURNETT FORMATION - Undifferentiated Till					
RU	49.5	578	41	30	29	30	190
RU	51.0	579	39	30	31	30	150
RU	51.5	580	44	23	33	30	100
MO-RU	52.0	581	42	28	30	20	180
MRU	52.5	582	50	23	27	30	130
MRU	53.5	583	41	28	31	30	160
MRU	53.7	584	48	24	28	t	160
MRU	54.0	585	47	24	29	30	180
MRU	54.5	586	48	25	27	40	200
UU	88	587	47	28	25	t	110
UU	90	588	45	27	28	30	100
			Hwy 30 (Depth in feet below base of Late Sangamon paleosolum)				
		ALBURNETT FORMATION - Undifferentiated Till					
OL	0.5	332	55	17	29	--	--
OU	1.8	331	44	27	30	--	120
UJU	4.9	335	39	20	41	20	90

Table 26. Sand Fraction Lithologies - Abbe Creek Area.

Horizon or Zone	Depth (Feet)	I.D.	C/C	T.C.	Sh.	Sed.	Q.-F.	Ot.	Xst.
				N-1					
		WOLF CREEK FORMATION - Undifferentiated Till							
OU	21	621	2.0	9	11	20	67	13	80
RJU	22	624	4.0	5	8	13	62	25	87
RJU	25	620	NoD.	16	4	20	64	16	80
RJU	28	631	14.0	12.5	--	13.0	69.5	17.5	87
		ALBURNETT FORMATION - Undifferentiated Till							
UU	29	628	1.7	15	1	16	67	17	84
				AC-1					
		ALBURNETT FORMATION - Undifferentiated Till							
RU	49.5	231	*	26.5	--	26.5	55.7	17.8	73.5
RU	51.0	234	*	31.0	4.3	35.3	46.7	18.0	64.7
RU	51.5	245	*	13.8	1.0	14.8	75.6	9.6	85.2
MO-RU	52.0	247	*	18.0	3.0	22.0	63.0	15.0	78.0
MRU	52.5	248	*	22.0	--	22.0	70.0	8.0	78.6
MRU	54.5	246	*	26.0	--	26.0	61.0	13.0	74.0
UU	88	242	*	29.0	4.0	33.0	50.0	17.0	67.0
UU	90	244	*	21.0	--	21.0	68.0	11.0	79.0

* Analysis not run on these samples.

Horizon or Zone	Depth (Feet)	I.D.	C/C	T.C.	Sh.	Sed.	Q.-F.	Ot.	Xst.
				N-2					
		ALBURNETT FORMATION - Undifferentiated Till							
RJU	67.8	619	12.0	13	2	15	70	15	85
RJU	68.2	646	5.0	15	3	18	66	16	82
MUU	71.0	627	24.0	25	1	26	58	16	74
UU	111	647	NoD.	4	1	16	75	9	84
UU	112	643	10.0	10	1	11	77	13	89
UU	119	626	NoD.	3	12	15	78	7	85

Table 27. Clay Mineralogy - Abbe Creek N-2.

Horizon or Zone	Depth (feet)	ID	EX	Ill	K+C	D c.p.s.	C c.p.s.
			Pedisediment (?)				
OL	21.0	1086	39	26	35	--	--
OL	22.0	1087	42	25	33	--	--
OL	23.0	1088	33	34	33	--	--
		ALBURNETT FORMATION - Undifferentiated - Till					
OL	25.0	1089	36	26	38	--	--
OJL	25.5	1090	36	24	40	--	--
OJL	26.0	1091	23	33	44	t	t
OJL	27.0	1092	35	28	37	t	20
OJU	30.0	1093	42	21	37	--	--
OJU	31.0	1094	40	20	40	t	30
RJU	41.0	1095	42	28	30	t	t
RJU	44.0	1096	45	25	30	t	t
				- Till and inclusions			
RJL	61.0	1097	45	31	24	t	20
RJL	62.0	1098	49	22	30	--	--
RJU	63.5	1099	44	27	29	t	20
RJL	64.5	1100	56	20	24	--	--
UJL	65.0	1101	50	24	26	t	t
RJU	66.0	1102	49	20	31	t	90
RJU	66.8	1103	41	28	31	t	90
RJU	67.8	1104	44	27	29	t	90
RJU	68.2	1105	44	26	30	30	160
				- Till			
MUU	71.0	1106	41	27	32	20	140
MUU	110	1107	33	30	37	t	30
UU	112	1108	32	31	37	--	t
UU	112.3	1109	44	23	33	--	20
				- Stratified Sediments			
RL	113.6	1110	41	25	34	--	--
RL	115.0	1111	29	32	29	--	50
RL	116.0	1112	33	28	39	--	t
				- Till			
UU	119	1113	36	30	34	t	90
UU	120	1120	38	28	34	t	100

not consistent nor significant. In the sand-fraction data, the lower tills in the bedrock valley are much lower in Total Carbonate than the two tills on the uplands. This is consistent with data from some other buried valley sites (Alburnett Site, in Appendix) but at others the data is unclear (6-10 County Line; Table 29).

Sampling and characterization with laboratory data has not been as complete for these deeply buried lower units of the Alburnett Formation, as in other parts of the section. Although many till members can be physically recognized in the Alburnett Formation, the data do not allow site-to-site correlation at this time. Thus, no formal subdivisions of the Alburnett Formation are proposed at this time.

The nature and significance of the unconformities between the till units have also been investigated. The individual Alburnett tills are separated by fluvial deposits and weakly developed A-C horizon or organic (O-C) paleosols developed either in the fluvial deposits or the tills themselves. The fluvial deposits range from coarse textured sands and gravel to finer-textured sequences of sands and silts. The coarse-textured deposits (by analogy with Holocene-Wisconsinan deposits) are generally interpreted as glaciofluvial deposits, and by themselves do not indicate a substantial hiatus. The weakly developed soils also do not indicate any significant time break.

Paleontologic evidence may further aid understanding of the temporal significance of the weak paleosols and the fine-textured alluvium. At the 6-10 County Line Section (Description 9) spruce wood (*Picea* undiff.) was associated with one of the paleosols. Pollen identified from the Ab horizon at the Doris Station Section (Description 8; 36-37 feet, 11 - 11.3 m) consisted of 30 spruce grains, 10 sedge, 3 grass, and 5 unidentified. The few grains found (48) do not allow much confidence in the results. The best pollen evidence comes from the Rowley reference locality.

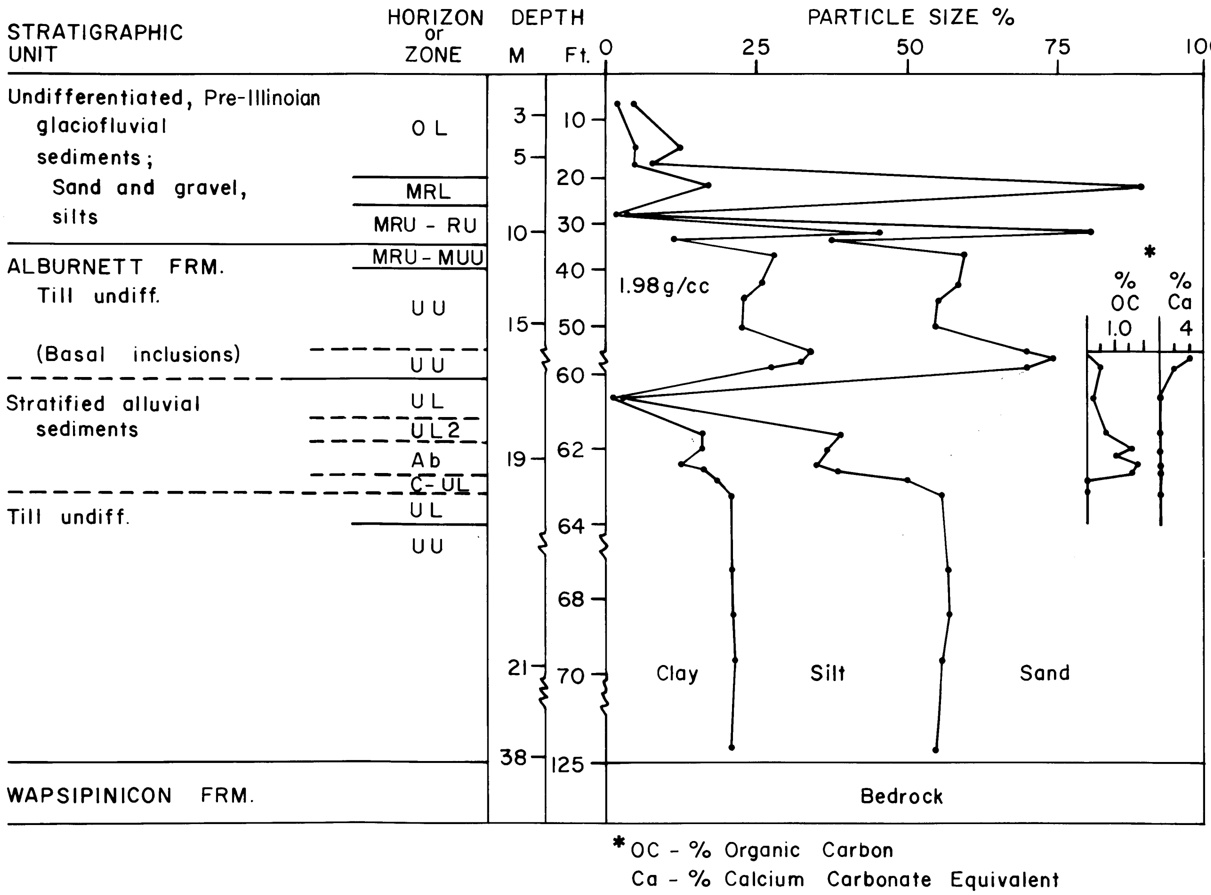
The Rowley site consists of a core, taken in the NW¼ of the NE¼ of the NW¼ of the NE¼ sec. 23, T 87N, R 9W, about 1.5 miles (2.4 km) south of Rowley in Buchanan County, at an elevation of

992 feet. The site is on an upland ridge formed of sand and gravel, which is the local stream divide. The site is between Doris Station and the 6-10 County Line site. Proceeding south from Doris Station the glaciofluvial sands and gravels ("Buchanan" gravels) are exhumed on the Iowan Erosion Surface, from beneath the Winthrop Till (see Doris Station section) to form the surface deposits in the Rowley area (figure 25). In the Rowley core two tills of the Alburnett Formation (see Table 28) are separated by leached fluvial sediments, which include an A-C soil profile (figure 25). The Ab horizon yielded enough well-preserved pollen to be adequate for a pollen count. The pollen spectrum (summarized in figure 25) is dominated by spruce (*Picea*) and pine (*Pinus*). The pollen profile is indicative of an interstadial rather than an interglacial situation. It is analogous to the pollen spectrum of the Farmdale interstadial in Iowa (see Hallberg, Baker, and Legg, in press).

The pollen and wood identifications, the nature of the weakly-developed paleosols, and the minimal evidence of weathering in the glaciofluvial deposits all indicate that the unconformities between till units of the Alburnett Formation may only record minor fluctuations in glaciation (interstadials) rather than any major break (interglacials) in the sequence. It seems likely that so many minor disconformities are preserved in the Alburnett Formation because the thick deposits of the formation fill in the deep bedrock channels.

Westburg Paleosol

The only named soil-stratigraphic unit related to the deposits of the Alburnett Formation is the Westburg Paleosol. The Westburg Paleosol occurs below the Winthrop Till Member of the Wolf Creek Formation and is developed in deposits of the Alburnett Formation or older rock units. The name is derived from Westburg Township (T 88N, R 10W) in southwest Buchanan County, where the paleosol is widely exhumed on the Iowan Erosion Surface. Good exposures occur locally in the SW¼ of sec. 27, and the SE¼ of sec. 18. Again, for reference localities



Pollen data from organic sediments

	% Pollen Sum				
	Pinus	Picea	Other AP	NAP	No. Grains Counted
62 - 62.5 ft. (19m.)	30	42	17	11	139

Figure 25. Stratigraphy, particle-size, and pollen data from the Rowley core.

with more complete stratigraphy core-hole locations must be examined. The 6-10 County Line Section (Description 9) occurs about half-way between the Alburnett Transect localities and the Westburg Township outcrops, and forms the type location.

The 6-10 County Line core site (Description 9) is located on the flanks of the large Spencer Grove Paha. Just to the north of the core location the Wisconsinan loess pinches out and the thin Winthrop Till and the Westburg Paleosol outcrop. The particle-size data is summarized in figure 26; the mineralogy data for the site is given in Tables 29 and 30. The Westburg

Table 28. Clay Mineralogy - Rowley Site.

Horizon or Zone	Depth (feet)	ID	EX	Ill %	K+C	D cps	C cps
		Alburnett FORMATION - Undifferentiated till.					
UU	41	700	45	25	30	20	70
UU	42	701	44	25	31	t	50
			- Undifferentiated sediments				
UL	60.5	702	60	19	21	--	t
UL	61	704	28	33	39	30	t
UL2	61.4	705	43	25	25	20	50
Ab	62.1	706	55	27	18	--	--
			- Undifferentiated till				
UU	69	707	47	21	32	20	60
UU	70	708	47	22	31	--	80
UU	115	703	38	24	38	40	40

Paleosol at this site is strongly developed, gleyed, and developed in fine-textured stratified sediments of unknown origin, similar to those discussed for the Dysart Paleosol. Nearly identical stratigraphy was encountered in a test hole drilled in the Spencer Grove Paha itself but here the Pre-Illinoian sediments were overlain by about 55 feet (17 m) of loess and eolian sand. The Little Paha Section (figure 21; Table 22) is a principal reference section for the Westburg Paleosol also.

At the 6-10 County Line Section the Westburg Paleosol is quite well-preserved with 0.8 feet (0.2 m) of the Ab horizon still present. The paleosolum is 9.3 feet (2.8 m) thick and formed entirely in the gleyed fine-textured sediments. At the Little Paha Section (figure 21) the paleosolum is 6.6 feet (2.0 m) thick, and the lower 0.8 feet (0.2 m) is developed in till of the Alburnett Formation.

Description 9. 6-10 County Line Core-Hole.
Location: Along the north side of the road between Benton(6) and Buchanan(10) Counties; in the SE¼ of the SW¼ of the SE¼ of the SE¼, sec. 33, T.87N., R.9W.; elevation 968 feet.

Horizon or Zone	Depth-Feet (Meters)	Description
OL	0 - 12.5 (0 - 3.8)	Road bed and fill; leached Wisconsinan loess and eolian sand.
	WOLF CREEK FORMATION - Undifferentiated	
OL	12.5 - 14.5 (3.8 - 4.4)	Yellowish brown to dark yellowish brown (10YR 4-5/6); loam till; some mottles; abrupt lower contact.
	WESTBURG PALEOSOL (ALBURNETT FORMATION) undifferentiated sediments	
IA1b	14.5 - 14.9 (4.4 - 4.5)	Very dark gray (5Y3/1) silty clay; few dark olive gray (5Y3/2) and dark greenish gray (5GY4/1) mottles; and yellowish red (5YR 4/6-8) stains around large vertical root tubules; very weak, very fine subangular blocky or granular structure; common vertical, medium tubules with thin discontinuous clay films; some charcoal and organic carbon flecks; gradual lower boundary; leached, fine-textured sediments.
IA3b	14.9 - 15.3 (4.5 - 4.7)	As above; mottles more abundant; moderate very fine subangular blocky structure; gradual lower boundary; leached.
1B1tgb	15.3 - 15.7 (4.7 - 4.8)	Dark greenish gray (5GY4/1) silty clay; common mottles; strong very fine subangular blocky structure; nearly continuous thin to moderately thick clay films; few light gray (5Y7/1) silt or grainy coats; gradual boundary; leached, fine-textured sediments.
IB2tgb	15.7 - 16.9 (4.8 - 5.2)	As above; with occasional zones of very dark gray (5Y3/1-2); strong to very strong fine and very fine subangular blocky structure; continuous moderately thick clay films, common thick and very thick films, especially in pores and tubules; gradual lower boundary; leached, fine-textured sediments.
IB2-3?tgb	16.9 - 20.7 (5.2 - 6.3)	(The lower portions of the paleosol are complex and the characteristics vary in intensity between "typical" B2 and B3 horizon properites. Thus for simplicity, this rather thick zone is lumped here in the description as variable in properties.) Color varies, dark greenish gray (5GY4/1 and 5BG4/1) and dark gray (5Y4/1 and 3/1), clay; variable mottles, as above; structure varies from moderate to strong fine subangular blocky; clay films vary from zones of continuous thick coats to zones of many thin and moderate coats; tubules and pores common; gradual lower boundary; leached, fine-textured sediments.
IIB3tgb	20.7 - 23.8 (6.3 - 7.3)	Complex as above, more clearly B3 in general character; dark greenish gray (5GY4/1), stratified clay loam and loam sediments, occasional pebble; strong to moderate fine subangular blocky; discontinuous thin to moderately thick clay films; few thick coatings on vertical faces and tubules; clear lower boundary; leached, weakly stratified sediments.
	ALBURNETT FORMATION - Undifferentiated Till	
IIICb (RL)	23.8 - 25.9 (7.3 - 7.9)	Mixed dark gray and olive (5Y4/1 and 4/4, some 5Y5/4), loam; moderate coarse subangular blocky with thin discontinuous clay films; leached, loam till.
	(Abbreviated description to depth.)	
RU	25.9 - 26.9 (7.9 - 8.2)	Loam till.
UU	26.9 - 39.0 (8.2 - 11.9)	Loam till.
		--Undifferentiated fluvial deposits.
UU	39 - 47 (11.9 - 14.3)	Sand and gravel, with thin fine-textured beds, included.
		--Undifferentiated Till
Ab (MR-UU)	47 - 49 (14.3 - 14.9)	Loam till; black (N20) with wood and organic material; weak paleosol Ab horizon.
UU	49 - 95 (14.9 - 28.9)	Loam till; some color variations; occasional wood throughout.
		--Undifferentiated Till
A-Ob (UU)	95 - 96 (28.9 - 29.3)	Organic silts, peat and abundant wood (1 piece identified as Picea undiff.); weak organic paleosol; unleached.
UU	96 -116 (29.3 - 35.4)	Loam till; abundant wood in upper 2 feet
	DEVONIAN - Wapsipinicon Formation	
	116+ (35.4+)	Bedrock.

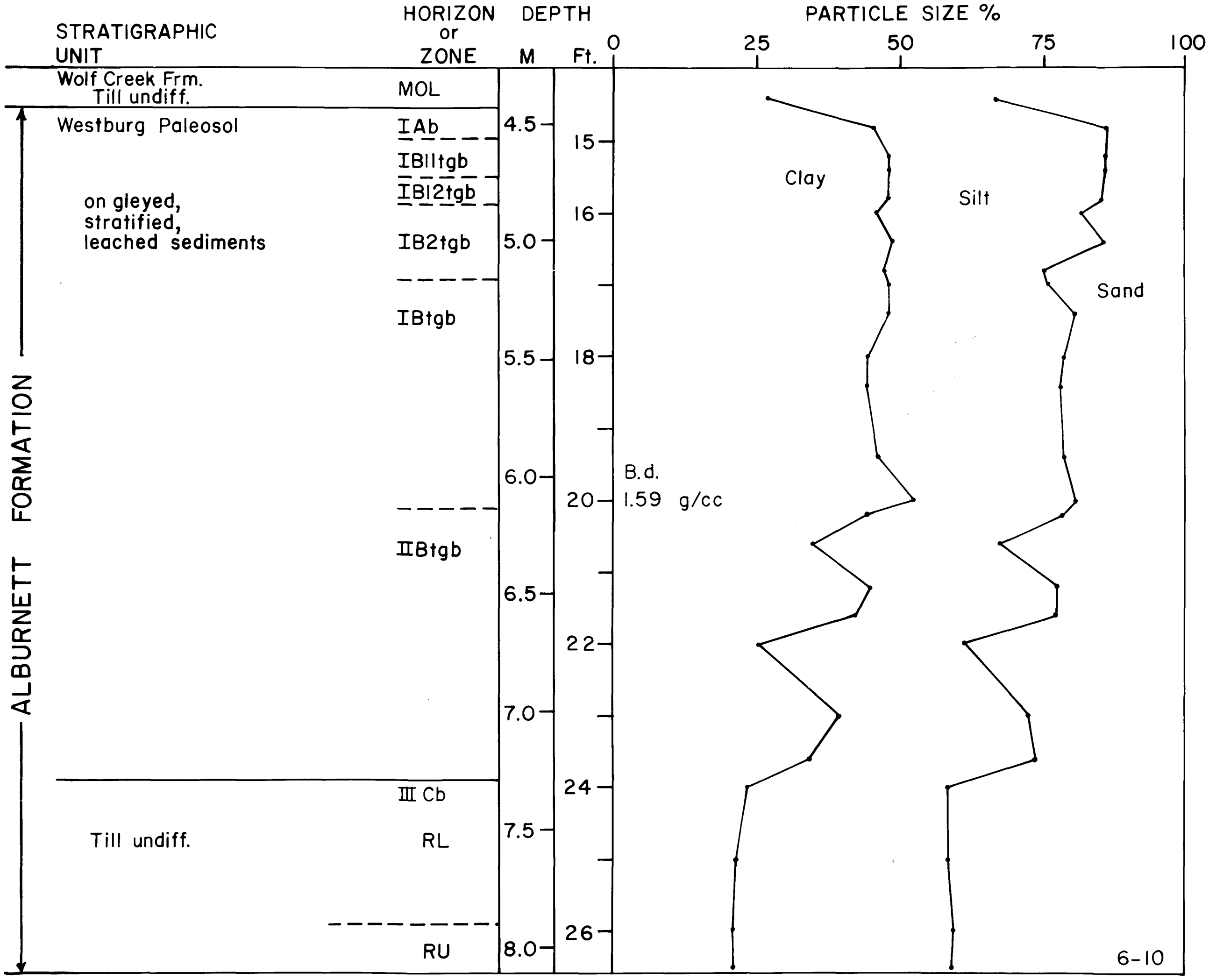


Figure 26. Stratigraphy and particle-size data, 6-10 County Line core.

As with the Dysart Paleosol only the poorly-drained variants of the Westburg Paleosol are preserved. In the outcrop area in Westburg Township it is obvious that the paleosol remnants are preserved in topographically low positions of the paleo-surface of the upper till of the Alburnett Formation. Where the lower limits of the paleosol and the stratified sediments begin to rise in elevation, they are truncated leaving only the till of the Alburnett Formation below the surficial sediments or Wolf Creek Formation deposits.

Table 29. Clay Mineralogy - 6-10 County Line Site.

Horizon or Zone	Depth (feet)	ID	EX	Ill	K+C	D c.p.s.	C c.p.s.
		WOLF CREEK FORMATION - Undifferentiated Till					
OL	13.0	986	58	18	24		
OL	14.0	987	62	16	22	--	t
		WESTBURG PALEOSOL					
A1b	14.5	711	(74)	(15)	(11)*		
B2b	16.0	712	(76)	(14)	(10)		
B2-3b	17.0	713	(72)	(16)	(12)		
B2-3b	20.0	714	(73)	(15)	(12)		
B3b	22.0	715	(52)	(19)	(29)		
		ALBURNETT FORMATION - Undifferentiated Tills					
RL	24	716	41	27	32	--	--
RU	26	717	41	27	32	--	t
UU	38	983	45	25	30	t	60
UU	60	718	44	27	29	20	100
UU	90	984	42	20	38	t	90
UU	102	719	47	29	24	--	60
UU	106	985	40	25	35	--	90

* Uncalculable because of weathering effects; numbers in parenthesis for discussion only.

Table 30. Sand Fraction Lithologies - 6-10 County Line Site.

Horizon or Zone	Depth	I.D.	C/D	T.C.	Sh.	Sed.	Q.-F.	Ot.	Xst.
RU	26	146	5.0	3.7	0.7	4.4	75.7	19.9	95.6*
UU	38		7.0	10.8	1.4	14.4	68.8	16.8	85.6
UU	90		1.5	18.8	6.2	25.0	66.6	8.4	75.0
UU	102		2.0	14.4	1.4	15.8	74.8	9.4	84.2

* Partially leached?

In another section, near the Alburnett Paha (Table 24) the Westburg Paleosol is only about 3 feet (0.9 m) thick. The remaining Ab horizon is very rich in organic matter. The Ab material was processed for pollen analysis. Although the pollen was poorly-preserved and only a few grains were readily identifiable, it is interesting that in contrast with the interstadial deposits previously discussed, that no coniferous pollen was seen in these materials from the well-developed Westburg Paleosol.

The clay fraction mineralogy of the Westburg Paleosol is also of interest. The x-ray diffraction data for the Little Paha and 6-10 County Line Sections are summarized in Tables 22 and 29. As discussed for the Dysart Paleosol, the amount of expandable clays is usually enhanced in gleyed fine-textured accretionary deposits, such as those the Westburg Paleosol formed in (see Willman, Glass, and Frye, 1966; Frye, Willman, and Glass, 1960; Hallberg, Lucas, and Goodmen, 1978). The samples from the sediments in the Westburg Paleosol are greatly enriched in expandable clay minerals compared to the Alburnett till which was the source of these sediments. The expandable peaks on the x-ray traces are sometimes more broad than usual, but they have high, well-defined peaks indicating well-crystallized minerals (see H.S.I. measurements, Table 22). In both sections the data shows a gradation to the lower values for expandable clays in the till of the Alburnett Formation below.

The x-ray traces from the Little Paha Section also show trace amounts of carbonate minerals (Table 22). A paleosol as well-developed morphologically as the Westburg Paleosol should be devoid of relatively soluble carbonate minerals. At the Little Paha site small concretions or diffuse segregations of secondary carbonates do occur within the Westburg Paleosol. These are the result of the leaching and translocation of carbonates from the overlying till unit and the secondary deposition of the carbonates within the paleosol.

The upper boundary of the Westburg Paleosol is considered to be the contact with the Winthrop Till Member of the Wolf Creek Formation. This correlation is somewhat problematic in that only one Wolf Creek Formation till overlies the Westburg Paleosol in its type area. As expressed previously, the Aurora and Winthrop Tills are similar and where only one till member is present correlations are problematical. The till is shown as Wolf Creek Formation undifferentiated in the descriptions and figures but its best correlation, based on the data, is the Winthrop.

Another line of reasoning for this correlation is that there is evidence of pronounced weathering below the Winthrop Till as indicated by the deeply leached and oxidized gravels at the Winthrop and Doris Station localities northeast of the Westburg area. There is no indication, at the present time, of any major period of weathering or soil formation between the Aurora and Winthrop Tills, but this is by no means definitive.

The lower boundary of the Westburg Paleosol is gradational, as with any soil stratigraphic unit. The paleosol may be developed on any materials older than the Winthrop Till Member of the Wolf Creek Formation.

OBSERVATIONS IN ADJACENT REGIONS

Many other detailed observations in the east-central Iowa region contributed to the development of the stratigraphic framework outlined here. Some of these other important sections and observations are recorded in the Appendix.

The mineralogic relations of the stratigraphic framework outlined in this report, have been documented by other authors as well. In the Dubuque Area (see Tables 31 and 32) Willman, Glass, and Frye (1963) and Willman and Frye (1969) described a high expandable clay mineralogy till (Wolf Creek Formation of this report) overlying a till low in expandable clays and high in kaolinite (Alburnett Formation of this report). They called both of these tills Nebraskan because of the prevailing feeling at this time that only the Nebraskan had come that far northeast (see Trowbridge, 1962).

In southeast Iowa Willman, Glass, and Frye (1962) describe tills in several sections which are redefined as Wolf Creek Formation tills in this report (Table 33). At their Ft. Madison section they describe one Wolf Creek till over a truncated, contorted paleosol, over a second till of Wolf Creek mineralogy. Samples from a till in a section 1/4 mile (0.4 km) away (sample P-1202-A) and lower in elevation exhibits Alburnett Formation mineralogy.

In the Davenport area, along the Mississippi River an important section reveals similar relations also. The Chapel Hill Section (Description 10; Table 34) has not been previously published. The section was described and sampled by Dr. R. C. Anderson, and the clay mineralogy was determined by Dr. H. D. Glass of the Illinois State Geological Survey. (Their providing this information is gratefully acknowledged.) In the Chapel Hill Section Illinoian age till overlies tills of the Pre-Illinoian Wolf Creek and Alburnett Formations.

Table 31. Clay Mineralogy of tills at the Julien Section near Dubuque, Iowa, from Willman, Glass, and Frye (1963) and Willman and Frye (1969).

Horizon or Zone	ID *	EX	Ill	K+C
	WOLF CREEK FORMATION - Till Undifferentiated[1]			
MOU	P-508	66	9	25
MOU	P-509	66	4	30
	ALBURNETT FORMATION - Till Undifferentiated[2]			
MRU	P-506	51	15	34
MRU	P-507	42	19	39

* Illinois State Geological Survey sample number.

[1] Previously called upper till of Nebraskan age.

[2] Previously called lower till of Nebraskan age.

Table 32. Heavy Mineral data from tills at the Julien Section, from Willman, Glass, and Frye (1963).

			Heavy Minerals - %													
			Opaque		Transparent											
Sample No.	.062-.250 mm fraction %	Heavy Minerals in fraction %	Black	Others	Tourmaline	Zircon	Garnet	Epidote	Rutile	Kyanite	Staurolite	Andalusite	Hornblende	Hypersthene	Others	Percent Soluble %
			WOLF CREEK FORMATION - Till Undifferentiated													
P508	17.4	1.5	14	20	3	3	9	14	1	2	2	-	62	2	2	10.0
P509	20.3	0.4	9	24	7	6	7	25	-	1	10	-	43	-	1	12.0
			ALBURNETT FORMATION - Till Undifferentiated													
P506	18.9	1.4	14	21	-	1	10	20	-	2	2	1	62	-	2	16.0
P507	20.3	1.0	17	15	1	1	7	14	1	1	4	1	71	-	-	16.0

Table 33. Clay Mineralogy of tills in Southeastern Iowa from Willman, Glass, and Frye, 1966.

Horizon or Zone	ID *	EX	Ill	K+C
	Donnellson Section			
	WOLF CREEK FORMATION - Till Undifferentiated[1]			
OL	P-1306	64	10	26
OL	P-1299	63	14	23
OL	P-1305	57	15	28
OU	P-1304	59	15	26
OU	P-1298	63	15	22
OU	P-1303	60	14	26
OU	P-1302	62	15	23
	Fort Madison Section			
	WOLF CREEK FORMATION - Till Undifferentiated[1]			
MOL	P-1289	66	12	22
OU	P-1288	61	13	26
UUU	P-1294	66	13	21
	Contorted "Afton Soil"[2]			
	P-1293	80	6	14
	WOLF CREEK FORMATION - Till Undifferentiated[3]			
UJU	P-1292	61	16	23
	ALBURNETT FORMATION - Till Undifferentiated[4]			
UJU	P-1292-A	46	22	32

* Illinois State Geological Survey sample number.

1 Previously called Kansan in Willman, Glass, and Frye (1966).

2 From Willman, Glass, and Frye (1966).

3 Previously called Nebraskan.

4 Previously called Nebraskan.

UPLAND GRAVELS: OCCURRENCE AND ORIGIN

Sand and gravel and stratified drift are exposed in many upland areas on the Iowan Erosion Surface in northeast Iowa. Another important aspect of the regional observations offered here is a perspective on the occurrence and nature of these deposits. These fluvial deposits and stratified drift form a conspicuous and significant part of the stratigraphic record

Description 10. Chapel Hill Section.

A large road cut on the north side of Interstate-280, at the bluff line of the Mississippi River, at the junction of I-280 and Iowa 22. Located in the SW¼ of the SE¼, of the NE¼, of the NE¼ of sec. 7, T.77N., R.3E., Scott County. Elevation of the top of the cut, approximately 735 feet. Section described and sampled by R. C. Anderson, Augustana College (6/19/70).

Depth-Feet (meters)	Unit No.	Description
		WISCONSINAN - Peorian Loess
0 -10 (0 - 3.1)	1.	Silt, brown, leached, scattered secondary carbonate concretions, loess.
10 -11.5 (3.1- 3.5)	2.	As above, calcareous.
11.5-17.0 (3.5- 5.2)	3.	Silt, mottled brown-gray, matrix gray with numerous iron-oxide concretions, calcareous, scattered snail shells.
		FARMDALE PALEOSOL - Robein Silt
17 -18 (5.2-5.5)	4.	Silt, gray to dark gray with brown streaks, leached.
18 -19 (5.5- 5.8)	5.	Silt, very dark gray to black, leached, plant fragments. To the west this unit grades into a channel fill (8-10 feet thick) of fine-textured alluvial material with abundant organic matter (logs, twigs, charcoal, etc.). The channel cuts through, and lies unconformably on units 6, 7, 8, 9, 10 and 11. Peat from the top of this unit dated 27,500 ± 800 RCYBP (ISGS-243). Peat from the base of the channel fill dates greater than (>) 39,300 RCYBP (ISGS-244).
		- Roxana Silt
19 -20 (5.8- 6.1)	6.	Silt, gray-brown, leached.
20 -22.5 (6.1- 6.9)	7.	Silt, gray-brown, with red mottling, scattered small siliceous pebbles, leached.
		Truncated SANGAMON PALEOSOL - on Illinoian GLASFORD FORMATION - Kellerville Till Member
22.5-24.5 (6.9- 7.5)	8.	Till, clayey, scattered small siliceous pebbles, mottled red-brown and gray, leached, fine blocky soil structure.
24.5-26.0 (7.5-7.9)	9.	Till, brown, leached.
26.0-27.5 (7.9- 8.4)	10.	Till, brown, calcareous.
		Truncated YARMOUTH PALEOSOL
27.5-28.0 (8.4- 8.5)	11.	Clay, silty, gray with brown mottlings, scattered sand grains, leached, fine blocky soil structure.
28.0-30.0 (8.5- 9.1)	12.	Till, light gray-brown, clayey, leached, blocky structure.
		WOLF CREEK FORMATION - Till Undifferentiated *
30.0-31.0 (9.1- 9.5)	13.	Till, light gray, clayey, leached.
31.0-33.0 (9.5-10.1)	14.	Till, mottled brown-gray, clayey, leached.
33.0-37.5 (10.1-11.4)	15.	Till, brown, calcareous, some silicified wood fragments (Cretaceous?), contains inclusions of unit 16.
		Truncated Paleosol (?) *
37.5-41.0 (11.4-12.5)	16.	Till, clayey, red-brown, gray mottling, leached.
		ALBURNETT FORMATION - Till Undifferentiated *
41.0-42.0 (12.5-12.8)	17.	Till, brown, gray mottling, leached.
42.0-45.5 (12.8-13.9)	18.	Till, brown, calcareous.
45.5-55.5 (13.9-16.9)	19.	Till, brown and gray, compact, calcareous; appears transitional between units 18 and 20; contains lenses of fine sand.
55.5-90.0 (16.9-27.4)	20.	Till, gray, compact, calcareous, contains large log 20 feet above base, numerous plant fragments at base.
90.0-95.0 (27.4-29.0)	21.	Sand, fine to medium, brown-gray, calcareous, lenticular.

* Authors interpretation from mineralogy; other terminology after R. C. Anderson and Illinois State Geological Survey.

Table 34. Clay mineralogy - Chapel Hill Section; Analyses by H. D. Glass, Illinois State Geological Survey.

Horizon or Zone	Unit Number	Ex.	Ill. %	K+C	H.S.I.	D.I.	D. c.p.s.	C. c.p.s.
		WISCONSINAN LOESS - Peorian Loess						
OL	1	73	20	7	26	1.8	9	t
OL	1	70	22	8	22	1.8	11	5
OU	2	70	23	7	21	2.0	13	t
DU	3	73	19	8	24	1.6	17	-
		Farmdale Paleosol - Robein Silt						
	4	uncalculable						
	5	(High vermiculite)						
				- Roxana Silt				
MOL	6	78	12	10	18	0.84	--	--
MOL	7	80	12	8	20	1.0	--	--
MOL	7	79	12	9	36	0.94	--	--
		Truncated SANGAMON PALEOSOL on Illinoian Till						
		GLASFORD FORMATION - Kellerville Till						
B3tb	8	47	31	22	8	0.92	--	--
OL	9	41	35	24	9	0.95	12	t
OU	10	47	35	18	10	1.3	12	t
		Truncated YARMOUTH PALEOSOL						
Bb	11	90	5	5	39	0.62	--	--
Bb	12	87	6	7	39	0.58	--	--
RL-Bb?	13	87	6	7	44	0.56	--	--
		WOLF CREEK FORMATION - Till Undifferentiated						
MOL	14	67	16	17	27	0.65	--	--
OU	15	65	18	17	23	0.71	--	--
OU	15	74	12	14	22	0.62	--	--
				Truncated Paleosol?				
OL	16	57	22	21	11	0.71	--	--
OL	16	72	34	15	17	0.60	9	--
		ALBURNETT FORMATION - Till Undifferentiated						
OL	17	47	23	26	11	0.73	10	--
OU	18	38	28	34	11	0.54	--	16
OU	18	44	29	27	11	0.70	--	24
MOU	19	43	27	30	11	0.60	6	27
MRU	19	44	24	31	11	0.51	7	26
MRU	19	44	27	29	12	0.68	13	33
				- Till Undifferentiated				
UU	20	29	35	36	4	0.61	--	14
UU	20	29	34	37	4	0.61	--	20
UU	20	30	33	37	4	0.61	--	14
UU	20	36	31	33	4	0.64	--	11

and their history has long been a subject of geologic controversy. Where exposed they have occasionally been mined for construction materials, and where they occur in the shallow subsurface these deposits have often created engineering problems. The observations on these upland sands and gravels may also offer some insight into the nature of drift or intra-till aquifers as well.

These isolated exposures of upland sand and gravel and stratified drift have been discussed since Calvin introduced the Buchanan Gravels in 1896. These deposits have been variously discussed as interglacial stream gravels, "Iowan" kames and ice-contact deposits (Kay and Graham, 1943). Most recently, some preliminary work suggested that these deposits were ablation till and that they may have played a role in the development of the Iowan surface (Drake and Nelson, 1972). This work, however, did not place these deposits within a stratigraphic framework or within the geomorphic context of the stepped erosion surfaces in this area (Hallberg, et al., 1978). As already shown in this report, and as will be further outlined here, these deposits occur in many different stratigraphic settings, but generally at the base of uniform till sheets, and they are exhumed because of the development of the extensive erosion surfaces.

The fluvial sediments and stratified drift occur in several settings. Most of the occurrences investigated in this study can be interpreted as either interstadial deposits, glaciofluvial or outwash deposits, or Late-Sangamon alluvium. The outwash deposits may occur as relatively undisturbed bodies of sand and gravel, or as contorted and folded bodies of stratified drift (sand, gravel, till, and other sediments). A few occurrences appear to be remnant interstadial (perhaps some are interglacial) fluvial deposits. These deposits are relatively fine-textured sandy to silty alluvium. Examples of this are found in the Independence Section (figure 17), as previously discussed, between the Aurora and Winthrop tills, and in the Rowley section (figure 25), between undifferentiated Alburnett Formation tills. The morphology of the deposits, their relatively fine-textured nature, the minimal weathering exhibited, and their paleobotanical evidence suggest that these are interstadial deposits and are not likely related to glaciofluvial activity.

As discussed in the Alburnett Transects, even within the Iowan Erosion Surface region, occasional remnants of Late-Sangamon alluvium are preserved (figure 20). A thick sequence of possible Late-Sangamon fluvial sediments is exposed at the Cedar Rapids Landfill Section (Location: SE¼, of the SW¼, of the NE¼, of the NW¼, of sec. 34, T 83N, R 7W, Linn County. Elevation at the top of the cut is approximately 851 feet; top of Late Sangamon Paleosol 821 feet). Here about 30 feet (9.1 m) of loess and eolian sand overlie a strongly-developed, well-drained paleosol which is developed in the fluvial sediments (figure 27). About 19 feet (5.8 m) of fluvial sediments are exposed. They grade downward from finer sands and silts into coarser sands and sand and gravel. The fluvial deposits were composed of 1-2 feet (0.3 - 0.6 m) thick tabular beds. Occasional lens shaped channel fills occurred. Little cross-bedding was evident. The upward fining textures of the deposits are typical of pre-Sangamon terrace deposits observed by the author along other rivers in eastern Iowa. Also, there is no evidence to suggest that these sediments were overlain by till and later exhumed. Elsewhere in the large excavation the fluvial sediments lie unconformably on the Aurora Till. The till (and in places the fluvial sediments) lies on bedrock, which occurs as high as about 780 feet elevation.

It is impossible to directly determine the three-dimensional paleo-landscape relations in this area because the site is bordered on three-sides by the Cedar River and its floodplain. Immediately, on the southwest it is bordered by erosion surfaces 70 to 80 feet (21 - 24 m) lower in elevation. Further to the southwest, however, in the thick loess mantled paha and erosion remnants, Yarmouth-Sangamon and Late-Sangamon Paleosols developed in till occur at elevations 20 to 40 feet higher than the paleosol in the Cedar Rapids Landfill Section. This all suggests that the

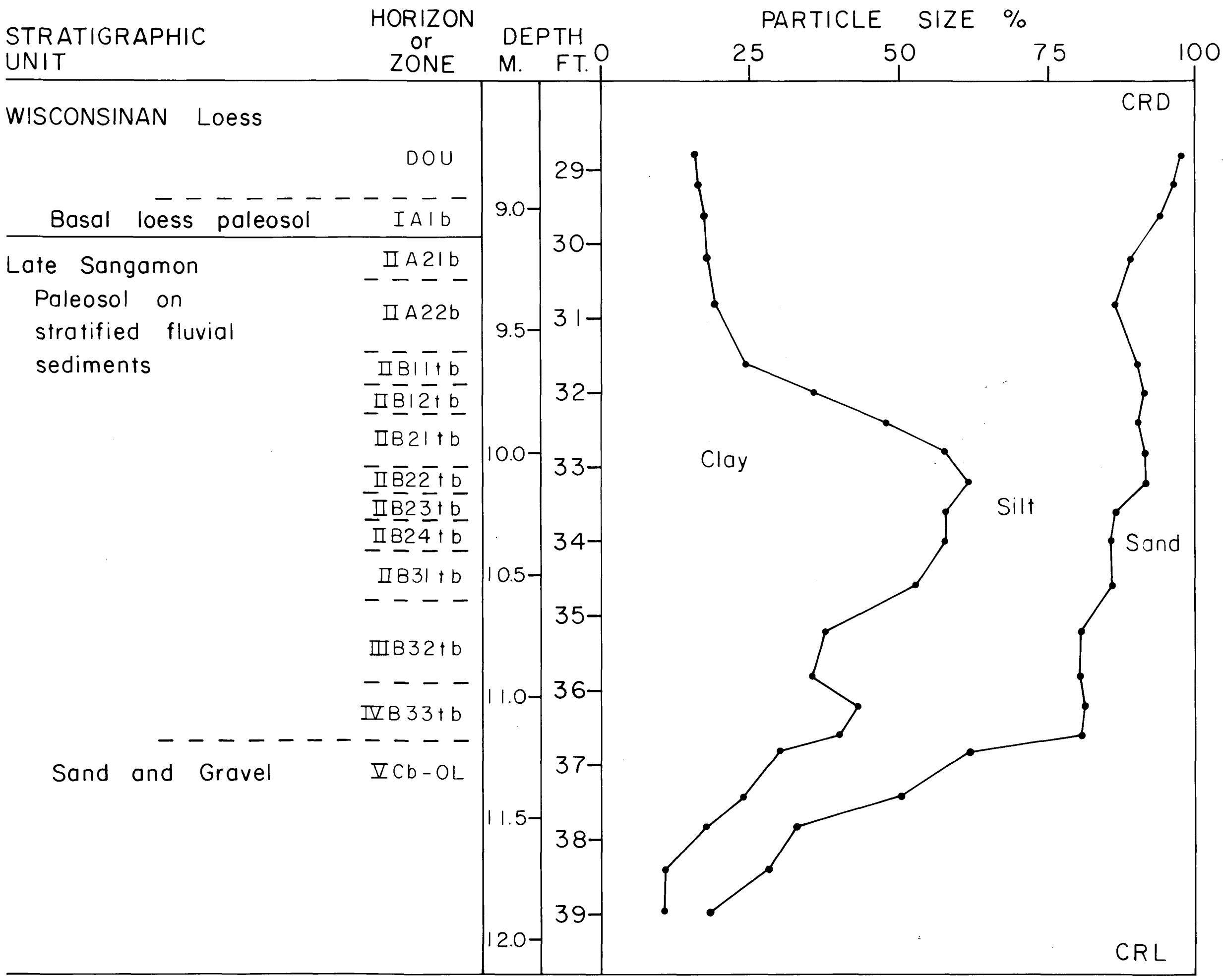


Figure 27. Stratigraphy and particle-size data, Cedar Rapids Landfill Section.

Landfill section represents a Late Sangamon Paleosol on an old terrace surface related to the Cedar River. Terraces of this age have not been recognized in this immediate area. It seems likely that this remnant was preserved by the protection of the bedrock high which constricts the Cedar River Valley in this area.

The fluvial sediments at the Edgewood Section (in Appendix) may be exhumed from within the Wolf Creek Formation, or they may be local remnants of Late-Sangamon alluvium as well.

Another common mode of occurrence of fluvial sediments in the region is as relatively undisturbed proglacial outwash deposits related to the overlying till unit. Several sections have been described which show an upper till abruptly overlying an undisturbed organic soil over unweathered coarse sand and gravel whose mineralogy is the same as the overlying till. The Garrison Quarry Section (in Appendix) is a good example of this situation. As at Garrison it is quite common to find some thickness of fluvial sediments between the lowermost till and the bedrock surface. Relatively undisturbed and continuous proglacial gravels are also common within bedrock channels. The buried gravels between the Alburnett tills and particularly the basal gravels filling bedrock valleys, such as shown at the Kirkwood Section (in Appendix), are quite continuous. In this deep bedrock valley system (Hanson, 1972) these two gravel horizons appear in many well records. This same sequence occurs in other buried valleys, such as shown in the Paris Test Hole (Table 24), and a similar but more complex sequence occurs in the Abbe Creek Transect (figure 23). The buried gravels of the Belle Plaine aquifer (see Mosnat, 1898) also occur within the Alburnett Formation. This evidence suggests that these buried valleys were repeatedly reoccupied by fluvial systems during at least the period of deposition of the Alburnett Formation.

Thin discontinuous stratified materials are found incorporated in the base of all the various tills at different sections. When exhumed by erosion, this is perhaps the most common mode of occurrence of exposures of upland stratified deposits. This type of occurrence has been described in detail at the Buckingham Section (figures 10 and 11). Also, at the Garrison Quarry Section, the previously described undisturbed fluvial sequence grades laterally to show a highly contorted contact with numerous gravel bodies sheared upward into the lower part of the till. As an historic example, Alden and Leighton (1915) in their interurban railway cut describe (p. 117-119; figure 10; plate VII) "contorted, folded and weathered" gravels sheared by the overriding of the overlying unweathered "Iowan till." The gravels "overlie and are thrust into" the weathered Kansan till below. Although Alden and Leighton's cut is no longer available, construction of

Interstate 380 opened similar exposures in the immediate vicinity (SW¼, of the SE¼, of the NW¼, sec. 22, T 81N, R 7W; Johnson County). Oxidized and unleached till overlies and/or encloses irregular, contorted bodies of oxidized and leached sands. Below the sands is reduced, or mottled unoxidized, leached or weakly calcareous till. Laterally, where the sands were absent an abrupt till-till contact occurs. Mineralogic data (Table 35) show that the two tills are undifferentiated members of the Wolf Creek and Alburnett Formation. The weathering of the fluvial sediments and till described here and by Alden and Leighton indicate that in this case the Wolf Creek glacier overrode and deformed pre-existing fluvial deposits of the Alburnett Formation. Also, the mineralogic data show that the base of the Wolf Creek till contains Alburnett Formation material which has been mixed or diluted within the normal Wolf Creek till.

Szabo (1975) also documents the occurrence (in northwestern Cedar and adjacent Jones Counties) of a thick sequence of sands between, what are here defined as Wolf Creek and Alburnett Formation tills. The sands are, in part, incorporated in the base of the overlying Wolf Creek Formation till. The sands, again, are exposed at the land surface where the overlying deposits have been removed by erosion.

One of the most informative sections providing evidence on the origin of these deposits is the Schwitter's Locality, on the south side of Cedar Rapids in Linn County. This site is just to the northwest of the Kirkwood site, discussed in the Appendix. The Schwitter's site is composed of a series of core holes and outcrops located in the E½, of the NE¼, of sec. 5, T 82N, R 7W, on Schwitter's Fourth Addition and the adjacent lots of Interstate Properties, Ltd. A cross-section of the overall site is shown in figure 28. At the north end of the section 3 coreholes were drilled, but only one is shown in figure 28, because the stratigraphy was identical. The particle-size data for one of the deep-holes is shown in figure 29. The mineralogic data for the site is summarized in Tables 36-38.

Table 35. Clay Mineralogy and sand fraction lithologies - I-380 cut.

CLAY MINERALOGY

Horizon or Zone	Depth* (feet)	ID	Ex.	Ill.	K+C	H.S.I.	D.I.	D. c.p.s.	C. c.p.s.
		WOLF CREEK FORMATION - Till Undifferentiated							
OU	+7.0	992	58	18	24	27	0.49	40	180
OU	+5.0	993	59	17	24	18	0.49	--	160
MOU	+2.0	544	50	23	27	14	0.56	--	200
MOU	+0.5	548	46	23	31	11	0.49	10	180
		ALBURNETT FORMATION - Sands Undifferentiated							
OL	-0.5	546	35	30	35	11	0.56	--	--
				- Till Undifferentiated					
MUU	-3.2	545	37	30	33	9	0.56	--	60
MUU	-5.5	547	42	23	35	8	0.45	20	70

Sand Fraction Lithologies

Horizon or Zone	Depth	I.D.	T.C.	Sh.	Sed.	Q.-F.	Ot.	Xst.
		WOLF CREEK FORMATION - Till Undifferentiated						
MOU	+2.0	221	10.2	3.1	13.4	64.6	22.0	86.6
		ALBURNETT FORMATION - Till Undifferentiated						
MUU	-3.2	220	23.1	--	23.1	54.7	22.2	76.9
MUU	-5.5	233	12	--	12	70	18	88

* Depths marked + or - the Wolf Creek Formation till, Alburnett Formation sand contact

The deep core holes on the north are located on the crest of a paha ridge on the southern edge of the thick loess belt along the Cedar River (sometimes referred to as the Cedar River Paha belt; Norton, 1895). Up to 40 feet (12.2 m) of Wisconsinan loess and eolian sands overlie a basal loess paleosol, and a Yarmouth-Sangamon Paleosol. Below the paleosolum the Hickory Hills Till is approximately 17.5 feet thick (5.3 m) and overlies about 30 feet (9.1 m) of the Aurora Till. Underlying the Aurora Till is 16 feet (4.9 m) of unoxidized and unleached sand and gravel. A prominent boulder pavement (lag concentration?)

marks the top of the Alburnett Formation till beneath the gravel. Thirty-six feet (11 m) of Alburnett till overlie the bedrock.

Of primary interest at this site is the relationship between the Hickory Hills and Aurora Tills. In the deep core holes on the north end of the transect the contact was marked by either an abrupt till-till contact or a thin (1-2 ft; 0.3 - 0.6 m) zone of inclusions of stratified material, mixed with till. In one hole the till mixed with the sands had a strong, coarse (0.74 in; 2 cm), horizontal, platy structure.

On the flank of the paha to the south (figure 28), beneath the loess, both in core and outcrop, nearly the entire thickness of the Hickory Hills Till Member was composed of contorted till interbedded with glaciofluvial material. The loess ends abruptly and the underlying Wolf Creek Formation materials emerge out into the "Iowan" erosion surface area. A thin veneer of loam sediment occurs at the surface and overlies the glacial deposits.

A broad low knob at the south end of the cross-section stands about 10 feet (3.1 m) above the general level of the erosion surface. This knob was entirely removed for fill during subdivision development at the site. During the repeated excavations many exposures were created. The first sections exposed were at the north end of the knob. They showed about 20 inches (0.5 m) of loam pedisediment over a prominent stone line developed on a contorted mixture of iron-cemented sands and gravel, silts, and loam till, 6 to 8 feet (1.8 - 2.4 m) in thickness. Figure 30 shows this melange of materials in a portion of the excavation. In general the gravels and more coarse-textured deposits were leached their entire thickness, whereas the finer-textured loam till was leached only 3 to 4 feet (0.9 - 1.2 m) and often contained large, prominent secondary carbonate segregations at about this depth. The till showed oxidized (yellowish-brown 10YR5/6) colors, with abundant segregations, mottles, and even sheets of secondary iron and manganese oxides, particularly along the vertical joints.

Schwitter's Site, S. Cedar Rapids, Linn County

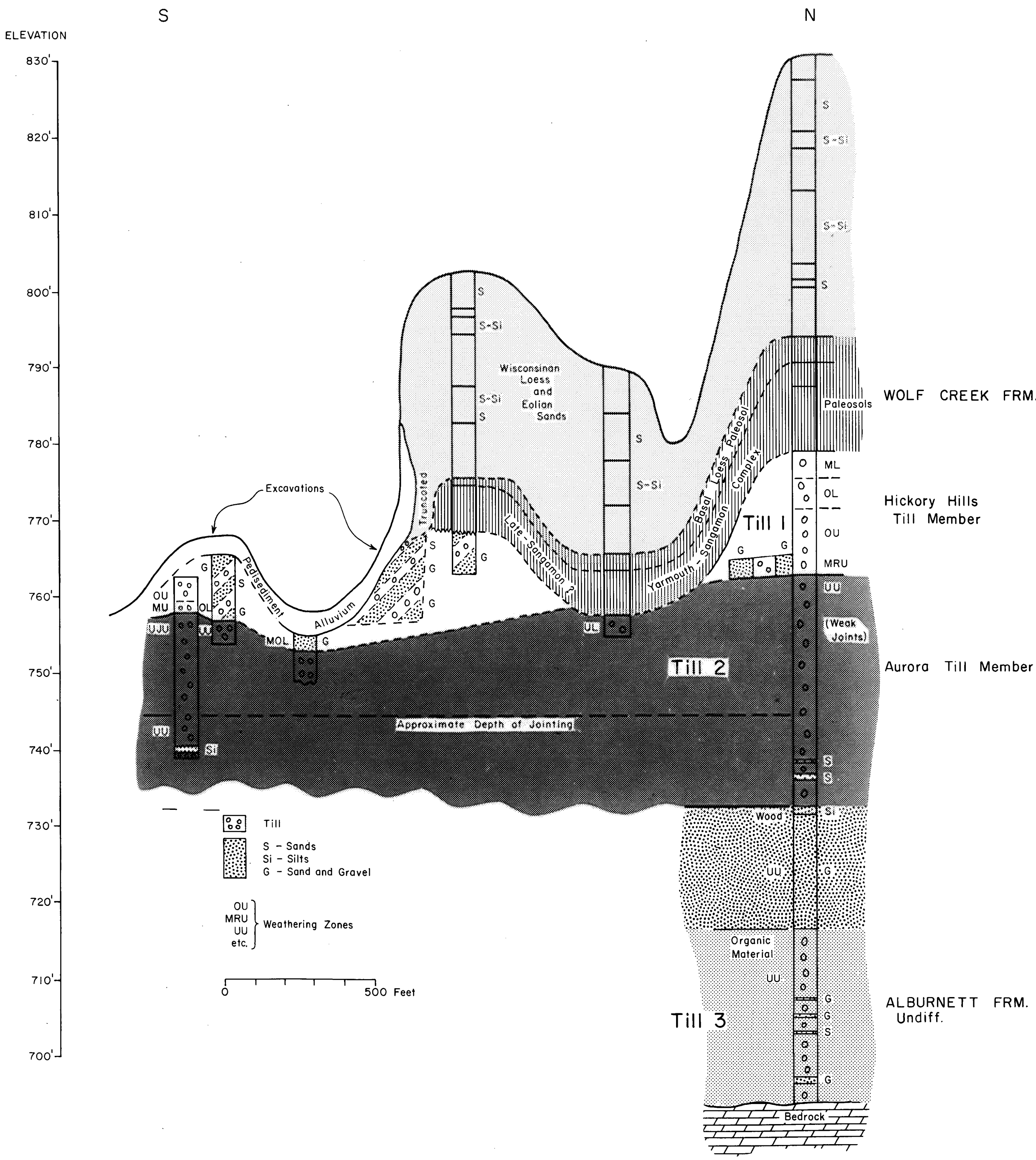


Figure 28. Cross-section, Schwitter's site.

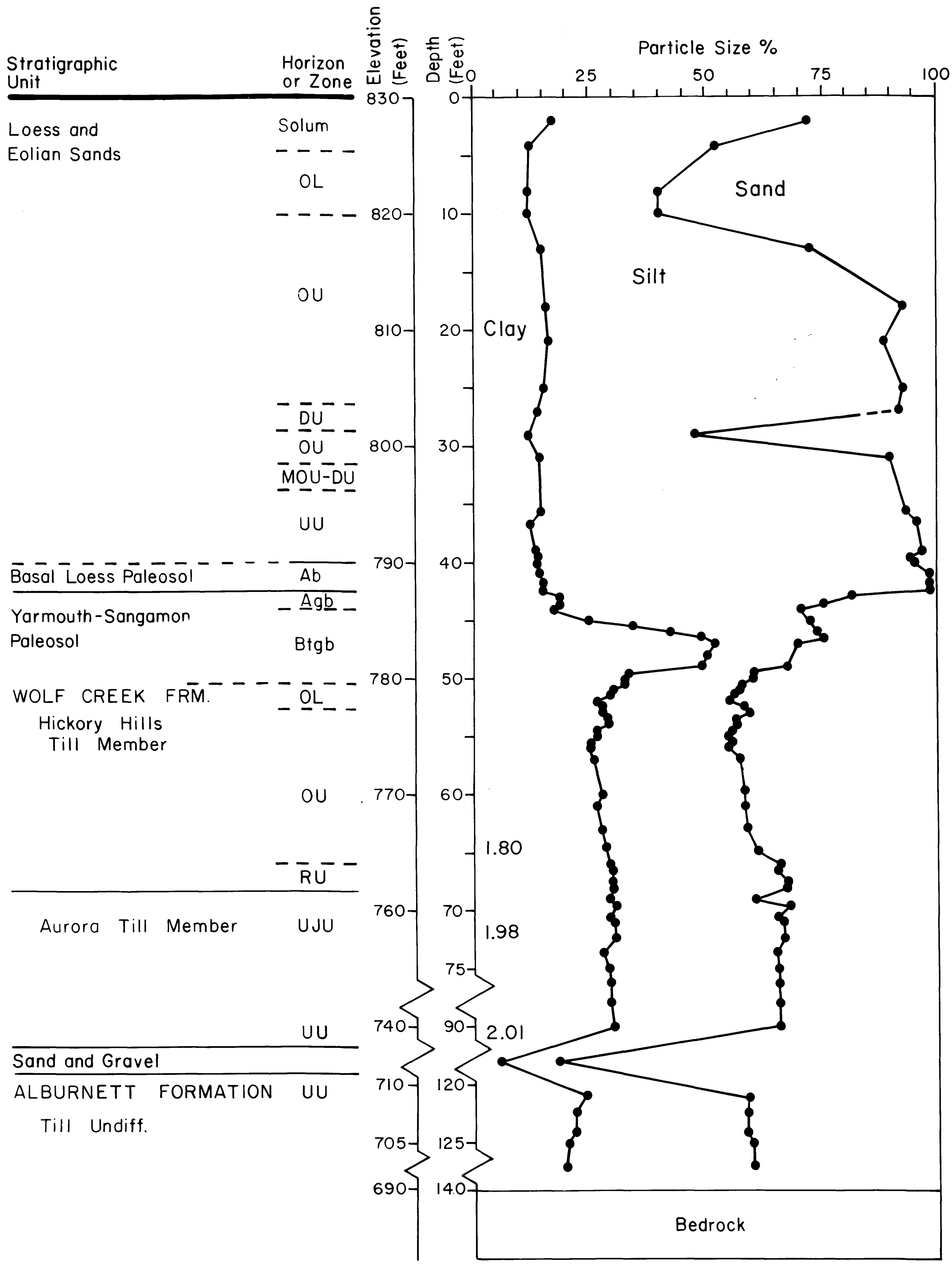


Figure 29. Stratigraphy and particle-size data, deep core, Schwitter's Site.

Table 36. Clay mineralogy - Schwitter's Core.

Horizon or Zone	Depth	ID.	EX.	Ill. %	K+C	H.S.I.	D.I.	D. c.p.s.	C. c.p.s.
Wisconsinan Loess									
OU	20	100	66	22	12	22	1.26	t	50
UU	36.5	101	52	35	13	18	1.82	20	20
UU	39	102	61	23	16	20	1.0	20	20
UU	41	103	59	24	17*	20	0.95	20	t
Basal loess paleosol									
Alb	42	104	58	26	16	19	1.1	t	t
YARMOUTH-SANGAMON PALEOSOL									
Agb	44	105		uncalculable *		3	0.53	--	--
Btgb	45	106	"	"	"			--	--
Btgb	46	107	"	"	"			--	--
WOLF CREEK FORMATION - Hickory Hills Till									
B3b	51	108	69	12	19	25	0.40	--	--
MOL	51.5	109	69	12	19	27	0.40	--	--
OL	53	110	70	11	19	28	0.39	--	--
OL2	54.5	111	72	11	17	27	0.43	--	--
OU	56	112	70	13	17	27	0.49	--	90
MOU	61	113	70	12	18	24	0.47	20	110
MJOU	66	114	70	12	18	24	0.47	t	60
MJOU	66.5	115	67	15	18	27	0.55	t	80
MJOU	67	116	68	15	17	27	0.58	t	75
WOLF CREEK FORMATION - Aurora Till									
MUU	67.3	117	65	16	19	30	0.56	--	110
MUU	67.5	118	70	11	19	28	0.41	--	60
MJUU	68	119	64	15	21	25	0.48	--	80
MJUU	69	120	60	16	24	19	0.45	--	90
MJUU	70	121	61	17	22	20	0.51	--	150
MJUU	70.5	122	66	15	19	20	0.55	--	90
MJUU	71	91	63	15	23	30	0.44	--	90
MJUU	71	91	61	15	24	26	0.41	t	70
MJUU	71	91	66	14	20	21	0.44	t	80
MJUU	73.5	123	67	13	20	23	0.44	--	140
UU	90	124	59	17	24	21	0.47	--	50
ALBURNETT FORMATION - Till Undifferentiated									
UU	119	125	53	19	28	18	0.45	--	280
UU	122	92	44	26	30	14	0.57	--	180
UU	122	97	49	21	30	16	0.49	--	160
UU	122.5	93	48	22	30	16	0.48	--	120
UU	124	94	45	24	31	15	0.52	t	150
UU	124	98	42	30	28	12	0.70	t	140
UU	125	95	47	24	29	15	0.57	t	120
UU	130	99	50	22	28	16	0.54	t	120

* 001 Vermiculite peak present

Table 37. Clay Mineralogy - Miscellaneous Schwitter's locality samples.

Horizon or Zone	Depth	ID.	EX.	Ill. %	K+C	H.S.I.	D.I.	D. c.p.s.	C. c.p.s.
Wisconsinan Loess									
DU	18.2	82	76	15	9	27	1.10	40	80
UU	23.1	83	71	17	12	24	0.92	40	90
UU	36.5	84	72	15	13 *	23	0.79	t	t
Basal Loess paleosol									
Alb	38.6	85	58	22	20 *	16	0.71	--	--
YARMOUTH-SANGAMON PALEOSOLS									
	variable	86-90 9-11	uncalculable *						
WOLF CREEK FORMATION - Hickory Hills Till and related sediments									
MJOU		1	62	19	19	28	0.66	t	90
MJOU		2	66	16	18	31	0.63	10	50
MJOU		3	67	16	17	28	0.63	t	80
OU		4	73	10	17	29	0.41	--	40
MJOU		6	68	15	17	29	0.57	t	90
MRL		75	63	16	22	23	0.49	--	--
MRL		76	67	14	19	23	0.51	--	--
MRU		77	71	14	16	23	0.59	20	90
MRU		78	68	13	19	29	0.45	30	90
WOLF CREEK FORMATION - Aurora Till									
MJUU		7	60	18	22	31	0.55	--	120
MJUU		8	65	17	18	30	0.63	--	90
MUU		70	64	15	21	19	0.46	--	140
MUU		71	66	12	22	20	0.38	--	60
MUU		72	66	12	22	18	0.36	--	150

* 001 Vermiculite peak present

As excavation continued about 400 feet (122 m) of continuous exposure was revealed, showing all the various materials in this melange in sharp contact with the underlying, unoxidized (dark olive gray, 5Y3/2, to dark gray 5Y4/1) and unleached Aurora Till Member. Figure 31 shows a cross-section through this part of the excavation, and figure 32 shows the particle-size data for a core through this part of the knob.

Still further to the south in the excavation the melange was overlain by uniformly loam-textured, Hickory Hills Till. The overlying till was vertically jointed but massive between

Table 38. Sand Fraction Lithologies - Schwitter's locality.

Horizon or Zone	Depth (feet)	I.D.	C/D	T.C.	Sh.	Sed.	Q.-F.	Ot.	Xst.
WOLF CREEK FORMATION - Hickory Hills Till									
OU	56	39	2.8	29	3	33	58	9	67
MOU	61	630	12.0	26	-	26	61	13	74
MOU	62	610	12.0	12	-	12	78	10	88
MJOU	63	2	2.0	18	-	19	72	9	81
MJOU	65	625	9.0	10	-	10	73	17	90
MJOU	66	609	11.0	12	4	16	69	16	85
MJOU	66.5	635	3.2	20	-	20	74	6	80
MJOU	67	618	3.0	12	3	15	70	15	85
MJRU	67.2	1	1.5	20	-	21	48	21	79
MJOU	M	3	2.0	27	2	30	61	9	70
MJOU	M	25	6.0	24	4	28	67	5	72
MJOU	M		1.1	25	1	27	62	11	73
MJOU	M	6	14.0	30	1	31	65	4	69
MJOU	M		NoD	31	-	32	60	8	68
MJRU	M		5.0	24	3	32	56	12	68
WOLF CREEK FORMATION - Aurora Till									
MUU	67.4	605[1]	2.1	3	4	7	74	19	93
MUU	67.5	19[1]	NoD	5	2	7	67	26	93
MJUU	71.3	32	NoD	16	7	27	59	14	73
MJUU	71.5	38	4.5	26	2	28	64	8	72
UJU	73.5	608	11	13	5	18	70	12	82
UU	75	60	NoD	38	1	39	53	8	61
UU	80	627	NoD	16	2	18	75	7	82
UU	90	33	NoD	20	3	23	69	8	77
MJRU	M	8	NoD	30	1	31	60	9	69
MJRU	M	7	21.0	22	2	24	62	14	76
MJRU	M	4	20.0	21	1	22	67	11	78
ALBURNETT FORMATION - Till Undifferentiated									
UU	122	30	1.0	23	2	25	64	10	75
UU	123	644	NoD	10	-	10	76	14	90
UU	124	645	NoD	30	6	36	54	10	64
UU	130	628	1.3	21	-	21	72	7	79

M= Misc. sites, from Schwitters locality.

[1]- Partially leached.

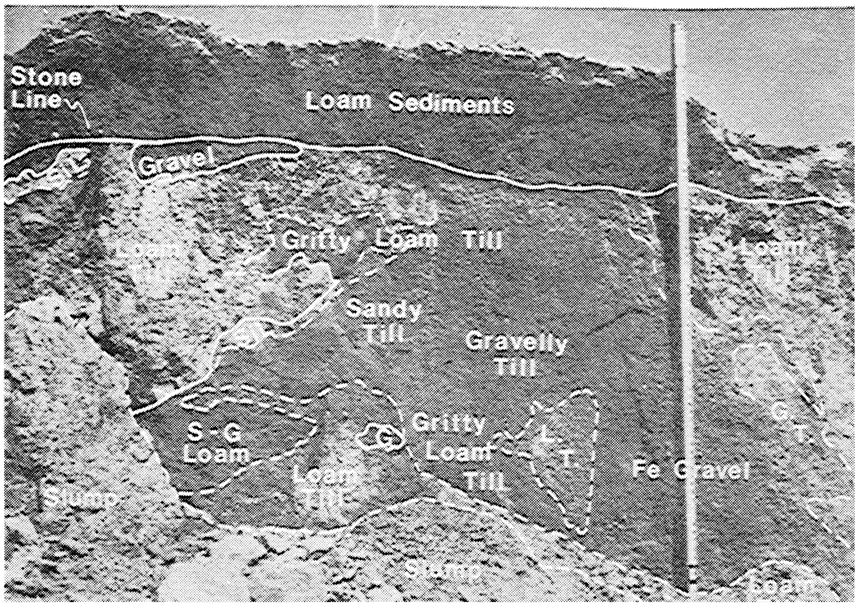


Figure 30. Photograph of a portion of the contorted till and stratified drift, in the base of the Hickory Hills Till Member, at the Schwitter's excavation. S - sandy; G - gravelly; Sil - silt loam; T - till; L - loam; Fe--iron-oxide cement.

the joints, except the lower 0.8 to 1.5 feet (0.2 - 0.5 m). This lower zone of the Hickory Hills Till exhibited a very strong, horizontal, coarse platy structure.

The strong platy structure of the till is shown in figure 33. The overall distribution of materials and the platy till zone within the excavated knob is shown in figure 34. As discussed, at the north end of the knob the contorted stratified drift and Hickory Hills Till overlie the Aurora Till. In the center of the exposure this contorted drift was overlain by the uniform, strong platy till. As the contorted drift pinched out to the south, the platy till zone dropped in elevation and eventually was in direct contact with the underlying Aurora Till. A section in this portion of the excavation is described in Description 11. About 20 feet (6.1 m) further to the south from this locale the zone with the strong platy structure pinches out, and the vertically jointed mottled-oxidized Hickory Hills Till

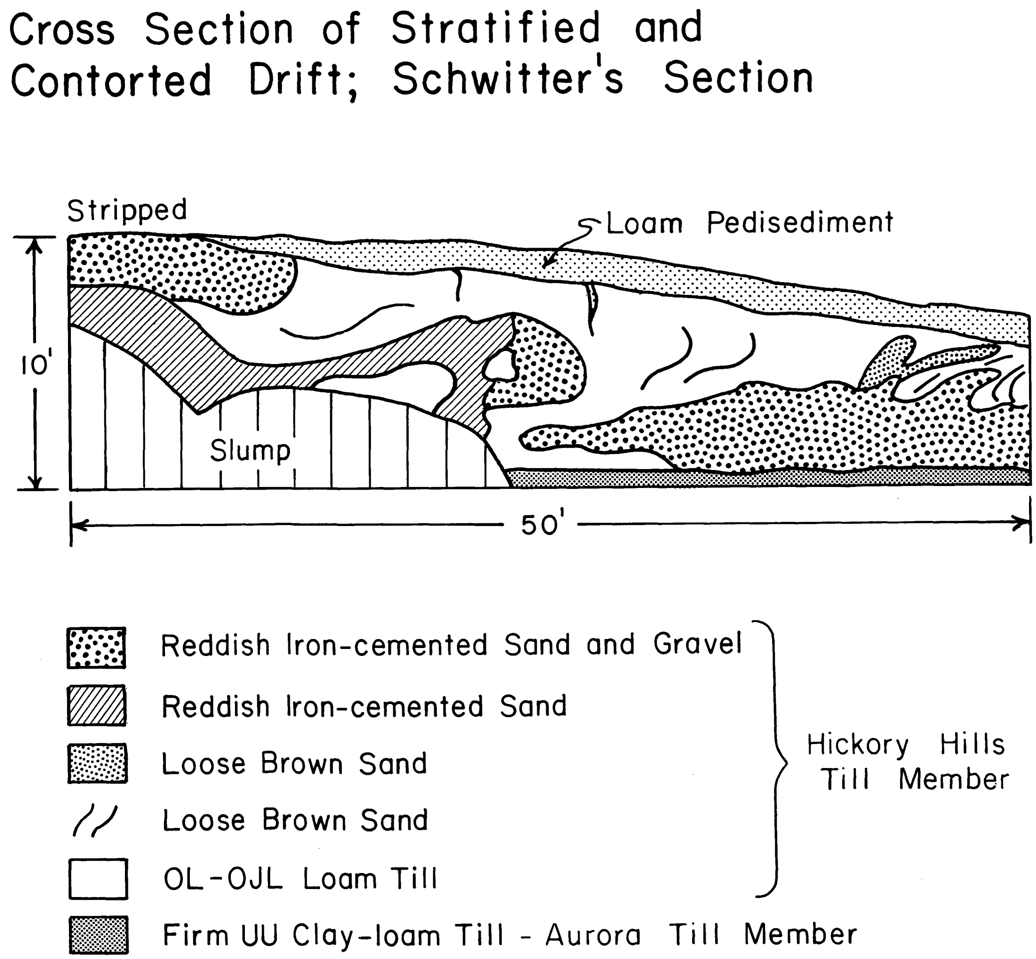


Figure 31. Cross-section showing stratified and contorted Hickory Hills drift, over Aurora Till, in Schwitter's excavation.

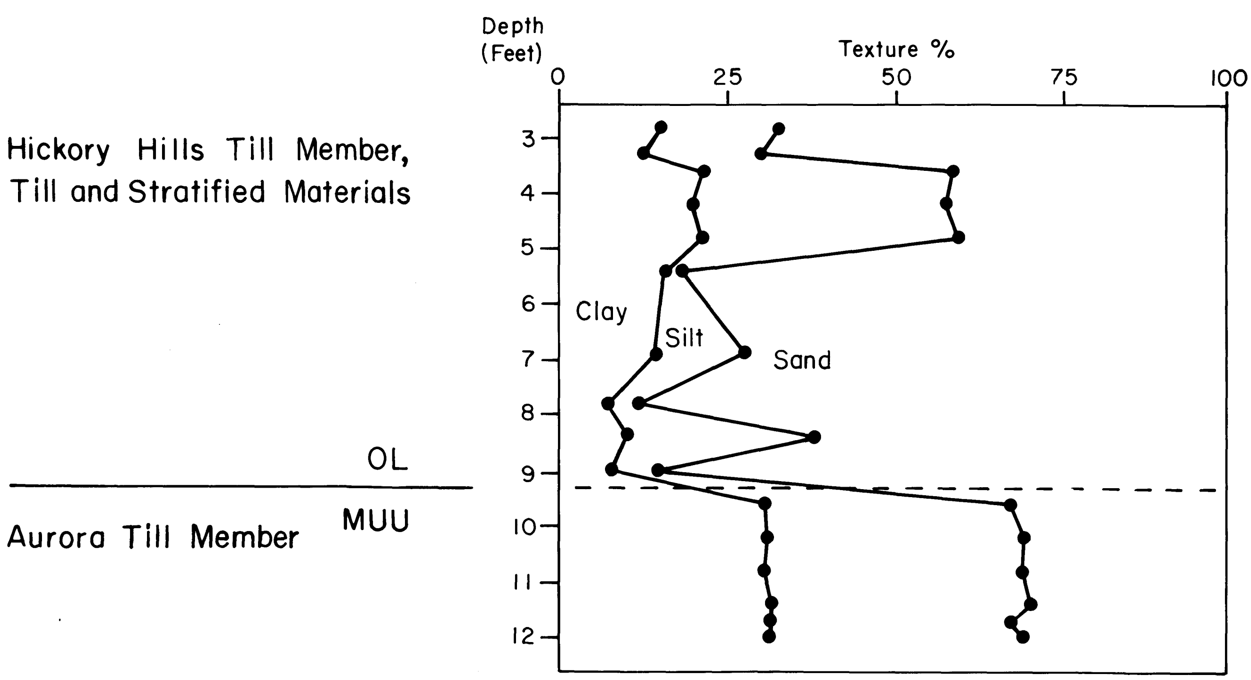


Figure 32. Stratigraphy and particle-size data for core in area of figure 31.

Figure 33. Photograph of near horizontal, "platy" structure in Hickory Hills Till; Schwitter's excavation. Knife handle is 3.5 inches (9cm) long.

Schematic Cross Section of Schwitter's Excavation

1.89 - Bulk density - g/cc

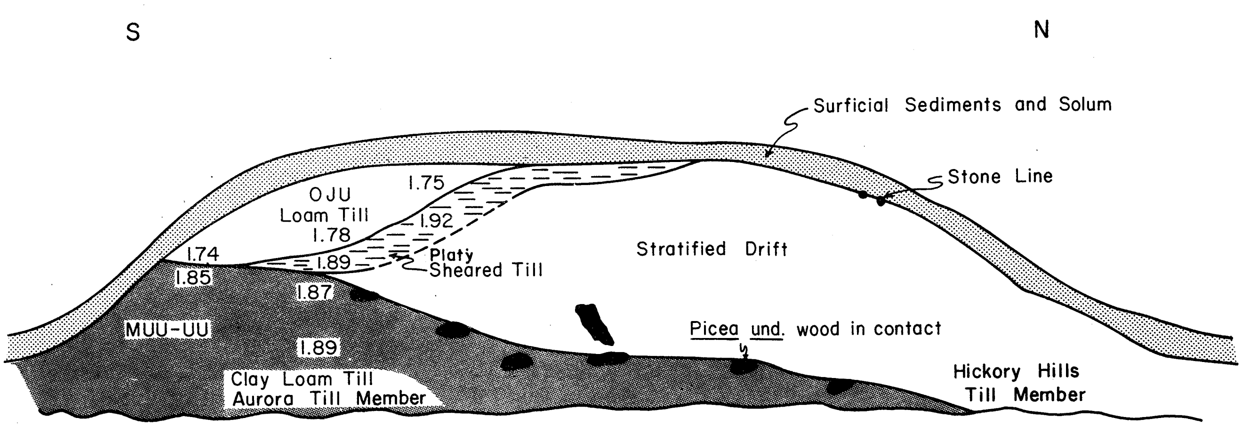


Figure 34. Schematic cross-section of excavated knob, Schwitter's site.

lies directly on the unoxidized Aurora Till. Figure 35 shows the particle-size data and the abrupt density contrast across this contact.

Structure in till, such as this, has frequently been described in the literature as platy structure, fissility, sub-horizontal jointing or fracturing, and generally attributed to basal till (see Shaw, 1977; Boulton and Paul, 1976; Boulton, 1970; 1976; Marcussen, 1975 for examples). (Basal till is used here in the generic sense of Dreimanis, 1976.) Frequently, this structure is attributed to overriding, shearing, and unloading by glacial ice (Boulton, 1970; 1976; Shaw, 1977).

The density measurements of till at the Schwitter's site also provide some insight into the depositional processes. Density, in material of similar texture, is a relative measure of the consolidation history of the deposit. If materials are allowed to drain they will assume a higher density under a greater overburden pressure (within certain limiting values). Many tills are overconsolidated, that is they were consolidated or compressed under a greater stress than the present overburden could exert. The explanation for this is that either the till was overriden by, and/or deposited beneath a substantial thickness of glacial ice. Superglacial deposits or ablation tills (again used in the generic sense of Dreimanis, 1976) are often normally consolidated; i.e. - the density is lower and related to the overburden stress.

Figure 34 summarizes the density measurements made in the tills in the Schwitter's excavation. The Aurora Till has clearly been overriden by the ice which deposited the Hickory Hills Till. The densities for the Aurora Till in this area range from about 1.85 g/cc to over 2.0 g/cc. The "platy" Hickory Hills Till has a similar density; three analyses range from 1.89 - 1.92 g/cc; whereas the overlying massive Hickory Hills ranges from about 1.72 to 1.83 g/cc in this area. Ongoing work shows that tills in Iowa of this texture and density are highly overconsolidated.

Description 11. Schwitter's Locality; South side of excavated knob.

Depth-Feet (m)	Description
0 - 2 (0 - 0.6)	Loam, pedisediment, modern solum to 42 inches (1.1 m)
	WOLF CREEK FORMATION - Hickory Hills Till Member
2 - 3.9 (0.6 - 1.2)	Till, loam, oxidized, jointed leached; stone-line at top.
3.9 - 5.5 (1.2 - 1.7)	Till, loam, oxidized (yellowish-brown, 10YR 5/6), slightly firm, calcareous. Well developed vertical joints with 7.4 YR 5/6-8, 5YR 5/8, and N 2/0, iron and manganese oxide coatings. Gradual, smooth, lower boundary.
5.5 - 7.1 (1.7 - 2.2)	Till, loam, as above. Firm. Color changes gradually to reduced; mixture of gray (5Y 6/1), grayish brown (10 YR 5/2), and light olive brown (2.5 Y 5/4). In contrast with the massive till above, this zone is marked by very strong horizontal, coarse (1-3 cm) platy structure. Some of the "plates" also break down to coarse subangular blocks. Vertical joints continue through this zone and appear to offset platy structure. Plates and joints have thick iron and manganese oxide coatings. Abrupt "pencil-line" contact with underlying till.
	WOLF CREEK FORMATION - Aurora Till Member
7.1 -26.0 (2.2 - 7.9)	Till, clay loam, unoxidized (dark olive gray, 5Y 3/2, to dark gray 5Y 4/1), unleached. Weakly jointed and mottled in upper 2 feet (0.6 m). Generally massive, very firm. Most joints end at contact.

Long-axis orientations of 78 blade and rod shaped pebbles (shapes after Drake, 1977) were measured from the "platy" till. The results are plotted in figure 36. A very strong pebble fabric was found, with a preferred updip direction of N 0-10° W (indicating ice flow from that orientation). Although till fabrics can be problematical to interpret (Harris, 1971) this strong a fabric is consistent with a basal till origin (Boulton, 1976; Mills, 1977) and perhaps particularly with a sheared basal till (Mark, 1974).

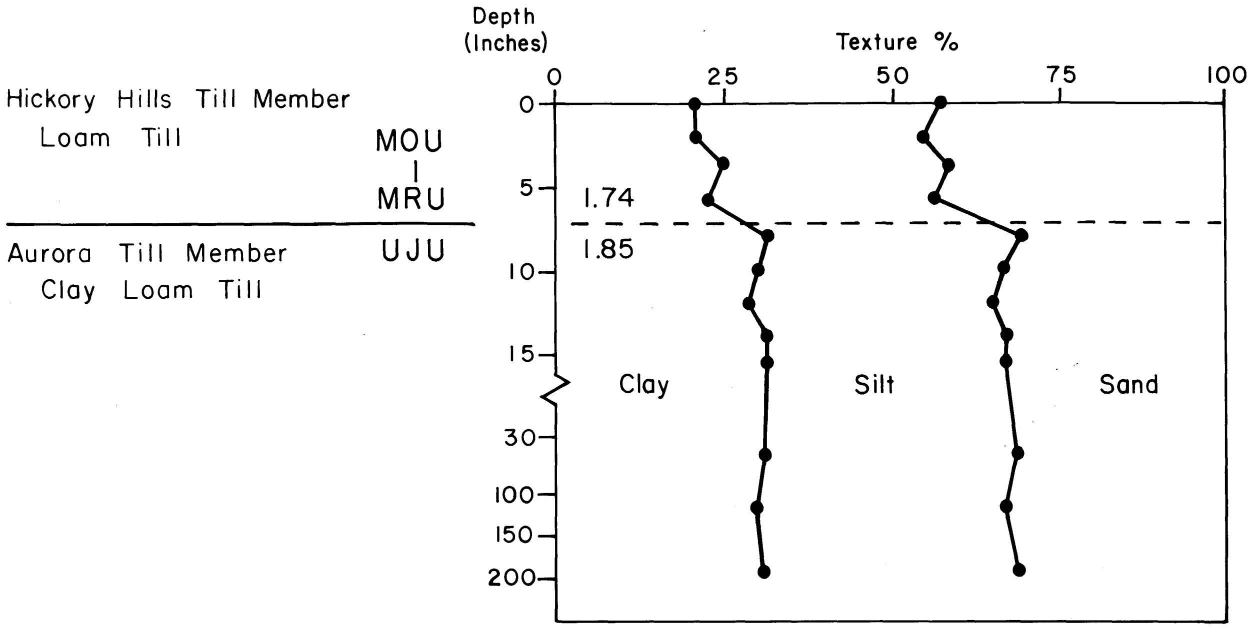


Figure 35. Stratigraphy, particle-size, and density data across the till-till contact, Schwitter's site.

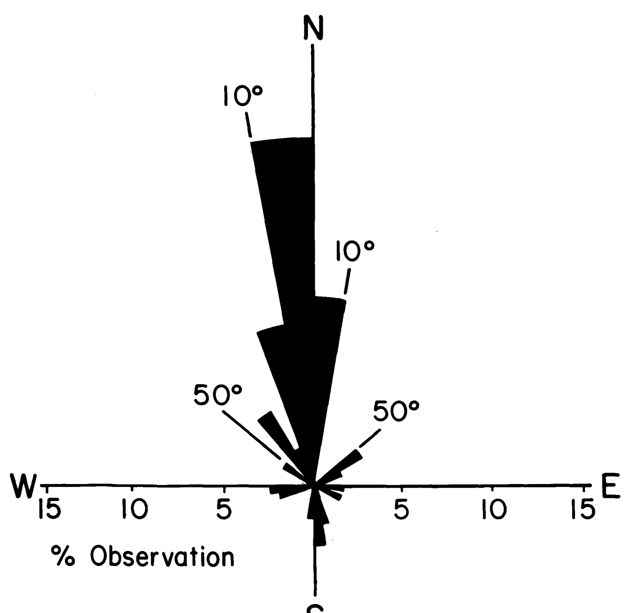


Figure 36. Rose-diagram showing orientation in dip direction, of the long-axis of pebbles from the "platy" till in the Schwitter's excavation.

The geometry of the contorted, stratified drift deposits in the Hickory Hills Till Member can also be worked out from the numerous borings and outcrops. In the deep borings to the north the stratified sediments are thin and discontinuous (figure 28). To the south the deposits thicken and broaden, reaching a maximum of 18 feet (5.5 m) thick and 200 feet (61 m) wide. Continuing to the south, in the excavation shown in figure 34, the stratified drift narrows to about 80 feet (24 m), and has a rather blunt terminus marked by the overlying "platy" till. The major body of the contorted drift is shaped much like an inverted spoon which tapers and is elongate to the north, perhaps similar to drumlinoid forms noted by Goldthwait (1974).

The total length of the deposit is about 2000 feet (610 m), elongate north-south. The deposits become thin and discontinuous east-west as well as to the north. The long-axis pebble orientation is essentially parallel to the elongate axis of this body of stratified drift.

The various evidence of the geometry, internal structure, the "platy" till, the density (consolidation) properties, and fabric all point to a simple model for the origin of the contorted-stratified drift deposits. The model can be patterned after observations in Antarctica by Shaw (1977).

In front of the advancing ice a frontal apron develops composed of outwash, and superglacial till which has slumped or washed from the glacier surface. As the ice advances it overrides this apron and in some areas likely entrains some of the debris, but in localized areas the debris is sheared, folded, and streamlined producing a highly contorted melange of stratified drift and diamictons. These deposits may have a drumlinoid form, perhaps because of locally thicker apron deposits, or because of secondary flow cells in the ice (Shaw, 1977).

The drumlinoid form is capped by a veneer of sheared, platy lodgement till. Later in time uniform, massive, but vertically jointed, till is deposited over this entire feature. In the Schwitter's locality, this last uniform till deposit, which constitutes the major portion of the Hickory Hills Till Member is also interpreted as basal till. The sequence may be analagous to the stacking of advance and retreat tills over drumlins described by Whittecar and Mickelson (1977). As described by Mickelson (1973) the bulk of thick basal till is deposited during deglaciation as the ice thins.

One important contrast to other reports of drumlinoid features is that the feature described here, could only be recognized because it is exhumed by erosion. The Hickory Hills Till Member averages 30 to 50 feet (9-15 m) in thickness in this area in more complete sections.

Although the model accounts for many of the features of these deposits, other aspects of the stratigraphic setting are problematical. As described, in places the Hickory Hills overlies the Dysart Paleosol and a substantial leached zone in the Aurora Till. Yet at the Schwitter's site, and many analogous sites, the Hickory Hills basal melange overlies unoxidized, unleached Aurora Till, indicating substantial erosion prior to the deposition of the Hickory Hills deposits. This would seem to necessitate that either: 1) the erosion took place proglacially by fluvial and/or other processes; or 2) that the ice margin fluctuated as it advanced, eroding the landscape, and finally deposited the sediments as described. Another possibility is that the basal stratified deposits are not a proglacial apron but are entirely subglacial. The ice could advance through the area, eroding the landscape. Later, warm-based ice may have deposited subglacial fluvial sediments and till which were subsequently sheared and streamlined.

Without a great deal more evidence on the three-dimensional relations of the unconformity between the tills these alternatives cannot be resolved. However, the deformation of the stratified deposits clearly occurred subglacially. These deposits are only exposed on the landsurface at the present time, because they have been exhumed by erosion.

A site similar to the Schwitter's site, nearby in the Cedar Rapids area, is the Westdale Mall section (located in the SE¼ of sec. 36, T 83N, R 8W; Linn County). This section has been reported previously by Grant, Anderson, and Dorheim (1978; Note: some of the data on the tills at this site were reported incorrectly. The corrected data is shown in Table 39 of this report). Here, about 15 feet (4.6 m) of Hickory Hills Till overlies the Aurora Till. The two tills average clay mineral composition is Hickory Hills (n=3), 62% EX.; 18% Ill.; 20% K+C; Aurora (n=4), 69% EX.; 15% Ill.; 16% K+C. The textural properties and sand fraction lithologies from the site (Table 39) are typical for the two till units. The lower 5 to 10 feet of the Hickory Hills is full of lenticular bodies of sheared sand and silt lenses. The most important information from the site is the numerous density data acquired on-site and from the engineering records. The uniform Hickory Hills Till averages (n=38) 1.77 g/cc (±0.07 g/cc), while the uniform Aurora Till averages (n=96) 1.96 g/cc (± 0.06 g/cc); typical of the consolidation characteristics for these tills in the study area.

Another mode of occurrence of exhumed glaciofluvial deposits is seen in south-central Buchanan County and in central Grundy County, north of Grundy Center, where prominent, large, elongate ridges of stratified drift occur on interstream divides. These ridges are continuous for several miles, oriented north-south. Toward the north from the ridges the stratified deposits become discontinuous, forming isolated knolls, but still following the same north-south trend. These deposits have been investigated in Buchanan County and are described in the Rowley and Doris Station Sections (Description 8; figure 25). At the Doris Station section the Winthrop Till overlies the glaciofluvial deposits which were assigned to the Alburnett Formation based on the clay mineralogy of fluvial silts. In the Rowley area all the overlying till has been eroded off, and the gravels overlie the Alburnett Formation. The severe erosion and removal of substantial portions of the Pleistocene section in this area makes observations and interpretations difficult.

Table 39. Sand fraction lithologies and particle size data, Westdale section.

Horizon or Zone	C/D	T.C.	Sh.	T.S.	Q.-F.	Oth.	Xst.
WOLF CREEK FORMATION - Hickory Hills Till							
OU	1.4	26	2	29	61	10	71
MOU	3.3	28	4	32	61	7	68
MOU	5.4	22	3	25	64	11	75
JUU	1.3	18	2	20	70	10	80
- Sheared Contact Zone							
MRU	NoD	30	-	30	56	14	70
WOLF CREEK FORMATION -Aurora Till							
MOU	20	19	-	19	71	10	81
MOU	NoD	19	2	21	68	11	79
JRU	19	14	-	15	66	19	85
JUU	NoD	13	1	14	74	12	86
JUU	2.5	21	3	24	65	11	76

PARTICLE SIZE - %

WOLF CREEK FORMATION - Hickory Hills Till

	Clay	Silt	Sand
OU	16.1	43.8	40.1
MOU	15.2	43.8	41.0
MOU	12.7	46.8	40.5
JUU	13.1	43.0	43.9
Sheared Contact Zone			
MRU (Till)	15.4	44.8	39.8
MOU (Silts)	11.8	85.5	2.7
OU (Sands)	5.2	6.0	88.8
MOU (Till)	14.1	63.4	22.5
WOLF CREEK FORMATION - Aurora Till			
MOU	13.6	52.9	33.5
MOU	12.9	53.5	33.6
JRU	15.7	51.1	33.2
JUU	13.3	45.8	40.9
JUU	13.7	52.0	34.3

Between the Rowley and Doris Station localities borrow pits in these deposits were also examined (SE¼, sec. 11, NE¼, sec. 14, T 87N, R 9W, NE¼, sec. 36, T 88N, R 9W). The internal structures of the deposits, as viewed in the pits were very nondescript. The coarse sands and gravels showed little clear evidence of bedding, and appeared indistinctly gradational. There was no obvious sign of deformation.

Fine-textured silts and clays occurred in broad arch-shaped beds 2-6 inches (5-15 cm) thick. Only one thin silt lens appeared clearly deformed. Calvin (1896) did report cross-bedding from the Doris Station gravel pit.

The clay mineralogy of the fine-textured fluvial silts and clays in these pits changes with depth. Four samples going from higher to lower in the sequence showed: 1. EX.-75%; Ill.-12%; K.+C.-13%; 2. EX.-69%; Ill.-12%; K.+C.-19%; 3. EX.-55%; Ill.-15%; K.+C.-30%; 4. EX.-49%; Ill.-20%; K.+C.-32%. The clay mineralogy appears to grade from that typical of the Wolf Creek Formation to that typical of the Alburnett Formation. Calvin (1896) reported that the clasts in the gravels resembled the underlying (Alburnett Formation) till at Doris Station.

At the Doris Station and Winthrop Sections the fluvial deposits are leached, but overlain by calcareous Winthrop Till, implying an hiatus between the materials. However, in the borrow pits in the Rowley area the fine-textured silts and silty-clays are sometimes calcareous within a matrix of leached sand and gravel. These deposits are at or very near the land-surface and alterations related to the differential permeability of these materials may be part of the complexity.

The discontinuous gravel bodies in the Doris Station area seem to thin or pinch out laterally in all directions. The linear ridge in the Rowley area stands in relief above the eroded surface of the Alburnett till, but also is incised in a channel 10-15 feet (3-5 m) into the Alburnett tills.

The evidence at this time is confusing, and does not clearly point to an origin for these deposits. In some instances they might be explained by the overriding and stream-lining of pre-existing, Alburnett Formation glaciofluvial deposits. Or perhaps these were pre-existing Alburnett Formation esker and kame deposits which were not substantially altered by the overriding Wolf Creek glaciers. In the case of the Rowley gravel ridge where the mineralogy is problematical, perhaps the materials and landforms could be explained as a subglacial fluvial deposit. The subglacial stream (under the Winthrop, or at least a Wolf Creek glacier) cut its channel down into the substrate of the Alburnett Formation, reworking Alburnett Formation materials along with Wolf Creek deposits contained in the ice, to provide the mixed mineralogic sequence. It is interesting to note that the elongate gravel ridges have the same orientation, as the interpreted ice flow directions at the Schwitter's locality. Perhaps the most important fact, however, is that the present surficial expression of these deposits, as previously discussed, is the result of extensive erosion since their formation. The occurrence of the gravel ridges along the divides is not because they were originally deposited on this upland. They have formed the interstream divides because of their differential resistance to fluvial erosion during exhumation.

In summary, fluvial sediments and stratified and contorted drift deposits commonly are exposed in northeast Iowa. Their mode of occurrence and formation are quite varied ranging from subglacial drumlinoids to interstadial fluvial deposits. However, in all cases analyzed these deposits are related to the lower portions of basal till deposits or to intertill stratigraphic positions. They are exposed at the present land surface because of exhumation by the extensive erosion that has taken place in this region. These stratified sediments are exhumed from every possible intertill stratigraphic setting, except the lower most Alburnett Formation which fills in buried channels in the bedrock surface.

The model of subglacial streamlining, producing elongate narrow bodies of stratified sediments may help explain the "unpredictable" nature of intertill aquifers. In various locations in Iowa, thick gravels between tills (unrelated to buried bedrock channels) have produced moderate yield water wells. Yet further drilling in these areas has failed to find substantial subsurface gravel nearby. Also, the permeability of the tills appears to be too low to sufficiently recharge a small gravel lens and allow the observed yields. An elongate, streamlined body of sand and gravel, such as those exhumed and observed in this study would appear to have sufficient storage, and sufficient surface area for even slow leakage to sustain moderate water yields.

A FURTHER NOTE ON TILL DEPOSITIONAL MECHANISMS

As mentioned, in relation to the Schwitter's site, the Hickory Hills Till overlying the platy till and drumlinoid sediments is also interpreted to be basal till. So are most of the thick till sequences shown and investigated within the study area. Several lines of reasoning are involved.

The Hickory Hills Till above the platy till does exhibit lower density, implying lesser consolidation. However, this is the youngest till in the area and its general range in density is from about 1.70 to 1.90 g/cc. Work in progress still shows this till to be moderately to highly overconsolidated, implying overloading by glacial ice.

In sections where any individual till unit is preserved in substantial thickness, the properties of the till are remarkably uniform. Several sections are shown in this report where an individual till unit is 30 to 40 feet thick yet varies only a few percent in its particle-size distribution, except in its lowermost portion. This is clearly more analogous to subglacial deposits than those from the superglacial (ablation till) environment (Dreimanis, 1976; Boulton 1976). Occasionally, the platy structure discussed at the Schwitter's site has been observed within these thick uniform till bodies. The fact that the only frequent zone of stratification is in the lowermost part of the till units also points to subglacial deposition (Boulton, 1976).

Further evidence also lies in the nature of the inclusions at the base of some of these otherwise thick and uniform tills. In the majority of sections described, it has been noted that the lower portion of an individual till unit contained small-identifiable block inclusions of the substrate material.

These features are common in the lower portions of basal till (Dreimanis, 1976) and imply shearing and perhaps local basal freezing under active ice to entrain these inclusions. Where detailed observations were made, such as at the outcrops near Kirkwood, these inclusions are sometimes deformed and slickensided, indicating active differential movement.

Although it seems clear that the bulk of the tills in this area are basal tills, there are various modes of subglacial deposition (Boulton, 1970; Sugden and John, 1976; Dreimanis, 1976). These different modes of deposition may account for particular aspects of the basal tills.

For example, occasionally within some thick, stratigraphically defineable tills, individual beds of till one to five feet (0.3 - 1.5 m) thick occur. These individual units are discernible from subtle but abrupt changes in color and sometimes texture. Between the beds very thin sorted deposits (sands or silts) occur occasionally. This may imply the basal melt out, and stacking, of individual debris bands (Boulton, 1970) which have subsequently retained enough of their characteristics to be recognizeable.

Secondly, as described in many sections, the lowermost part of many of the till units, besides containing block inclusions, may be transitional in their properties (texture, mineralogy) between their modal characteristics and that of the substratum. Figure 37 is an excellent example of this. This data is from the Schwitter's section, from a site lateral to the drumlinoid area. In its lower two feet (0.6 m) the Hickory Hills Till grades from its typical 45% sand content to about 65% sand, where it overlies a 10 inch (25.4 cm) laterally continuous bed of sand. There were no recognizeable inclusions of the sand unit in the till. This seems to indicate the rather complete incorporation and blending of the two materials. This has been described elsewhere from mineralogic data by Lucas, et al. (1978) and Boellstorff (1978) in relation to sampling problems in tills in Iowa. Boulton (1970) showed that the vertical variation in erratic content, from nearby

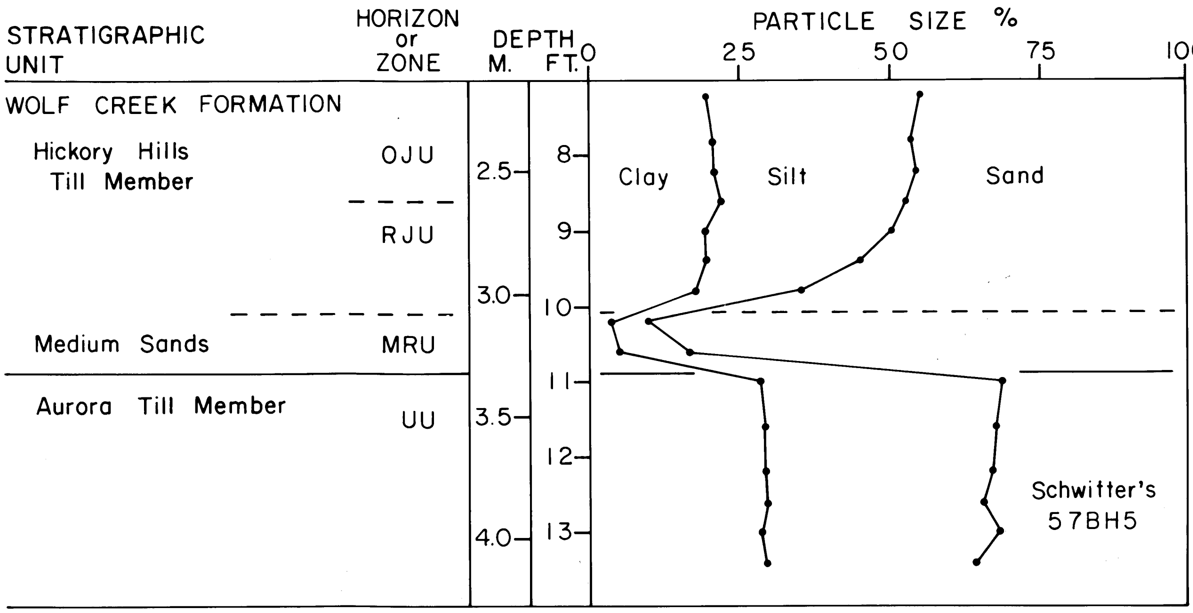


Figure 37. Stratigraphy and particle-size data, Schwitter's site, showing gradational sand content at base of Hickory Hills Till.

sources at the base, to more far travelled debris higher in the section, was related to stacking of till beds by basal melt out. However, in many cases the changes observed (figure 37) are so gradual that it implies smaller scale processes, such as repeated regelation (T. J. Kemmis, pers. communication).

This discussion does not intend to imply that ablation till or superglacial deposits do not occur in this area. The observations however, clearly imply that they are quite rare. The differences within the Alburnett tills at the Little Paha section (figure 21) could be interpreted as an ablation till-basal till couplet. However, these tills have been overridden several times by other glaciers, which has destroyed many lines of investigation which might be used to substantiate this.

PROVENANCE AND CLAY MINERALOGY

High expandable clay mineralogy content, such as that of the Wolf Creek Formation, has been reported as typical of the glacial deposits of Iowa, Missouri, and Kansas (Willman, Glass, and Frye, 1963). This has been attributed to the high montmorillonite content of the upper Cretaceous deposits incorporated in the tills. Indeed, the Late-Wisconsinan, or Cary till of the Des Moines Lobe has an abundance of Cretaceous (Pierre-type) shale fragements. Analyses of numerous samples of these shales shows an average of 64% expandable clays.

However, in the Pre-Illinoian tills of eastern Iowa Cretaceous shale clasts are rare or absent. This is true for pre- or early-Wisconsinan tills in central Minnesota as well (Matsch, 1972). Udden (1899) and Anderson (1957) identified minor amounts of Cretaceous shale in tills from eastern Iowa (called Iowan or Kansan). X-ray analyses of 14 green or gray siliceous shale clasts, which were thought to be Cretaceous, showed only illite in the clay fraction. This is typical of Paleozoic shales in Iowa and adjacent areas, not the Cretaceous. Numerous analyses of other shale clasts show similar results; a few samples showed small amounts of kaolinite, chlorite or vermiculite, and some mixed-layer clays, again typical of the Paleozoic shales (particularly the Mississippian and Pennsylvanian). Occasional silicified wood fragements, which are presumably Cretaceous, occur in these tills, but they are rare indeed.

The lack of abundant Cretaceous clasts, in relation to the interpretation of the clay minerals may be explained in two ways. First, possibly the Cretaceous deposits were weathered and not coherent enough to survive as clasts during transport from the Dakotas into southern Minnesota and Iowa. Even if they were coherent perhaps comminution was severe enough that no Cretaceous rock fragements are recognizeable. Secondly, and perhaps a more viable alternative, is that these older glacial advances did not follow the same path as the

Des Moines Lobe. Instead, they may have followed a more easterly path, analogous to the Wadena Lobe (Wright, 1962) which did not override the Cretaceous deposits. This alternative has been proposed for the shale-free Granite Falls Till (of unknown age) of central and western Minnesota (Matsch, Rutford, and Tipton, 1972). Data from Arneman and Wright (1959) suggests that even the more eastern Wadena and Superior lobes in Minnesota are high in expandable clay minerals.

Further support for this hypothesis is the occurrence of Lake Superior lithologies in the Pre-Illinoian tills of this area. As pointed out by Anderson (1957) these distinctive clasts are "practically unknown" in the Wisconsinan Des Moines Lobe. This would also appear to indicate a more easterly provenance for the Wolf Creek and Alburnett Formation tills.

Another question of provenance is the origin of the high kaolinite contents of the Alburnett Formation deposits. This phenomena has not been recognized prior to this time because little data from these deposits had ever been evaluated. Clasts of Paleozoic shales contained in these tills are generally purely illitic. Oddly enough, the source of the kaolinite is likely Cretaceous rocks or weathering products of Cretaceous age on Precambrian rocks.

Parham (1970) has identified a thick kaolinitic residuum developed on Precambrian rocks during a long period of weathering which terminated in Cretaceous time. Early Late Cretaceous sediments eroded from this residuum are also kaolinitic. These kaolin clays are economic deposits and occur, often at the bedrock surface, over most of central and western Minnesota. According to Austin (1972) the clays of the Cretaceous Windrow Formation of southeast Minnesota (and presumably northeast Iowa) are also kaolinitic. Austin also states that the clay mineralogy of the upper Dakota and Colorado Group rocks are dominated by illite and smectite in the Minnesota River Valley. However, in northwest Iowa, ongoing work shows that samples from shales in the Dakota Formation, and the Graneros and Carlile Shales are still dominated by kaolinite with increasing amounts of illite higher in the section. No trace of smectite or expandable clays has been recognized as yet.

It appears that there was abundant Cretaceous age source material to supply the high kaolinite contents to the Alburnett Formation deposits. It is not clear why there is such an abrupt change to the high-expandable clay mineralogy of the Wolf Creek Formation. Nor is it clear what the source is for the high percentages of expandable clays present in the Wolf Creek.

OTHER DATA

During the course of investigations various other data was acquired on these till deposits. Some will be reported here, for future reference.

Table 40 shows the results of multi-element analyses performed by Barringer Research Limited, Ontario, Canada. The analyses were performed with a multi-element, radio frequency, induction coupled plasma emission spectrometer. The analyses were done on the portion of the samples passing an 80 mesh sieve, using perchloric acid extraction (see Bradshaw, 1974).

During the writing of this report, a Chittick apparatus (Dreimanis, 1962) became available for the analysis of matrix carbonates. The results of some initial analyses are very interesting, and look promising for use in discriminating and characterizing the till deposits. The matrix carbonate values alone do not appear to aid in discriminating the till units. The range in values for total carbonate (3.0 - 14.9%) and the calcite/dolomite ratios (0.40 - 1.45) are the same for all the various till samples. However as shown by Kemmis (1978, and in prep.) the total carbonate values may be texturally dependent, showing a strong inverse relationship between clay content and total carbonate.

Figure 38 shows the resultant plot for 41 till samples from the Kirkwood, Schwitter's, Aurora, Doris Station, and Wolf Creek areas. A clear and consistent inverse relationship is shown for these samples. Also, the different till units seem to outline

Table 40. Elemental chemical analyses of the less than 0.18 mm fraction of selected till samples.

Site	Depth	Weathering Zone	Ni	Cu	Zn	Ag	Co	Cr	Pb	Cd	Sr	V	Mn	Si	Na	Be	P	Ti	Al	Mg	Fe	Ca
			ppm																%			
WOLF CREEK FORMATION - Hickory Hills Till Member																						
Kirkwood	45	MJOU	34.0	28.1	92	2.96	30.6	37.4	13	1.71	48.8	63.0	670	72.6	311	1.25	430	798	4.07	0.08	2.92	2.22
Kirkwood	54	MJRU	35.8	28.1	94	3.23	31.1	41.7	108	3.33	48.9	62.4	685	80.3	301	1.28	440	764	0.03	0.01	0.01	0.05
Schwitter's	65	OU	33.8	29.1	92	3.47	29.3	28.8	11	4.68	59.7	59.9	820	82.9	312	0.98	447	749	3.18	1.28	2.01	4.58
Schwitter's	66	OU	34.0	31.5	93	3.51	30.4	29.0	21	3.65	62.8	61.5	839	80.3	328	0.98	469	753	3.22	1.30	2.04	4.71
Aurora Till Member																						
Schwitter's	90	UU	26.7	33.7	89	2.81	21.7	30.2	18	1.90	50.2	63.5	344	80.0	328	1.25	364	891	4.22	0.82	2.01	2.09
Schwitter's	90	UU	27.7	34.7	94	3.04	22.4	35.8	17	2.77	50.3	64.3	363	67.5	335	1.29	371	858	3.80	0.78	2.77	2.09
Kirkwood	91	UU	35.0	43.4	107	6.19	30.7	49.3	6	8.17	68.1	51.8	787	80.8	339	0.95	550	579	7.12	2.09	6.20	8.00
Aurora Till Member, with sheared silty inclusions																						
Kirkwood	92.6	MRU	36.7	102.4	133	5.84	31.0	48.5	31	2.64	104.6	80.2	416	88.2	458	1.19	784	547	3.30	0.78	3.34	6.97
ALBURNETT FORMATION - Till Undifferentiated																						
Schwitter's	124	UU	34.0	61.0	107	3.51	25.6	33.6	11	3.62	65.1	72.2	335	68.0	343	1.16	491	908	3.60	0.75	2.09	2.96
Kirkwood	120	UU	34.9	35.3	97	3.47	27.9	31.4	14	2.67	71.5	64.5	352	79.8	361	1.13	466	883	3.60	1.11	1.95	4.04
Kirkwood	121	UU	34.6	35.9	99	3.51	28.6	32.6	12	2.31	72.3	66.3	347	82.1	379	1.16	470	868	3.65	1.10	1.99	4.02
Kirkwood	165	UU	36.8	31.8	101	3.23	28.9	33.6	10	1.42	75.9	65.1	349	88.5	375	1.16	471	864	3.67	1.12	1.95	3.79
Kirkwood	218	UU	35.0	35.0	99	4.36	26.5	35.4	11	2.30	65.1	71.9	334	83.1	381	1.16	492	884	3.62	0.76	2.24	2.94
Kirkwood	218	UU	37.2	40.6	111	5.14	28.4	40.9	14	3.65	69.0	74.8	354	75.7	381	1.25	519	891	3.76	0.79	2.44	3.14

NOTE: Mo, Se, Te, W, U, As, Sn, Au, B, Rb, Eu, not detected.

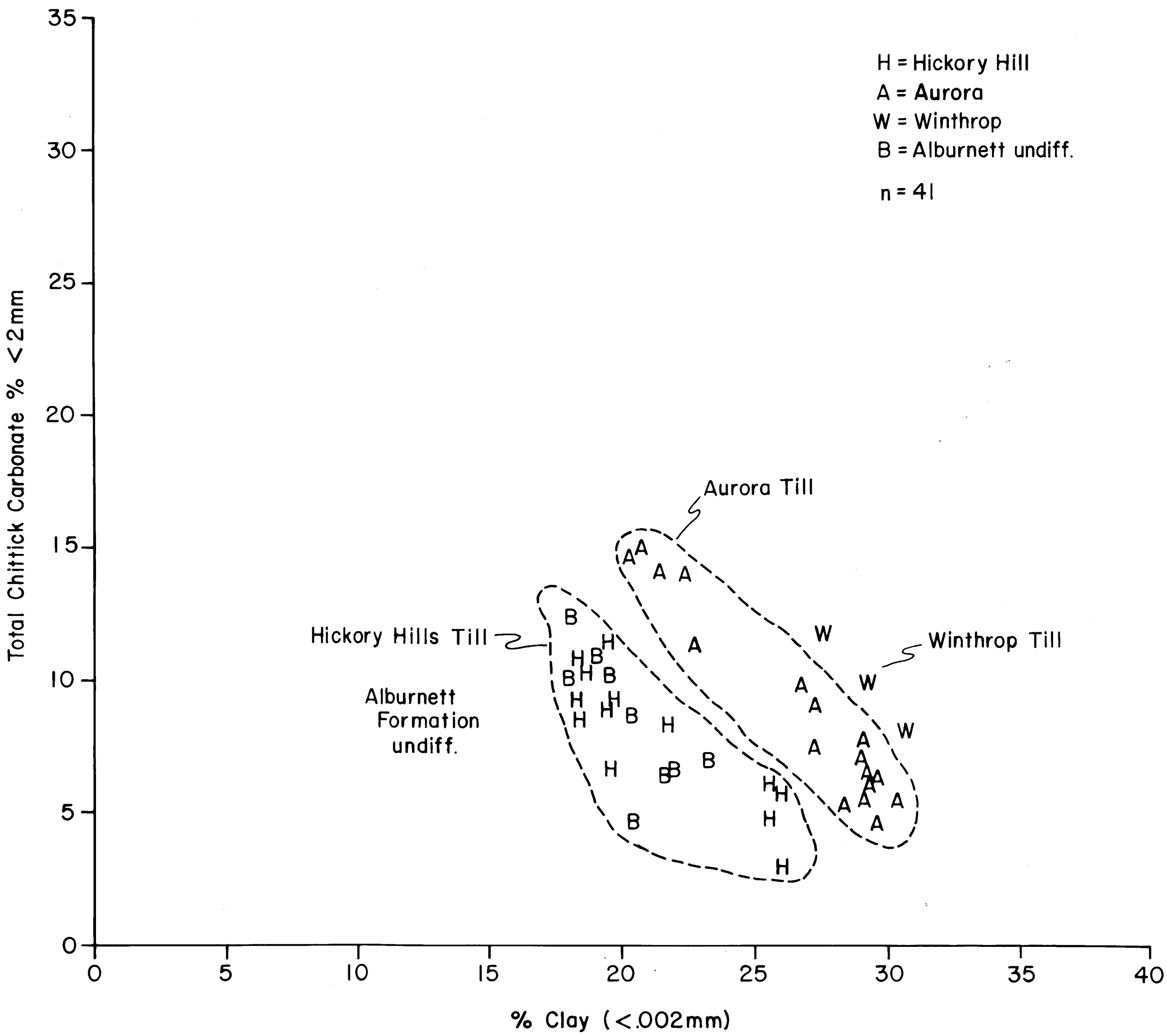


Figure 38. Graph of total matrix carbonate (%) vs. clay content (%) for tills in the study area.

discrete envelopes, which may indeed be useful for identification of the tills. The data is consistent with the few analyses of calcium-carbonate equivalent which were made, which showed the Aurora and Winthrop Tills to have more total matrix carbonate than the Hickory Hills Till, even though the Hickory Hills often had more total carbonate in the coarse sand fraction. As with the textural data, the Alburnett Formation tills are similar to the Hickory Hills. Further study using this method is in progress.

SUMMARY AND CONCLUSIONS

The Pleistocene stratigraphy of a multi-county area (figures 1; 39-40) in east-central Iowa was investigated. The most important aspect of this study was the use of drill-cores through the entire Pleistocene sequence. This allowed the evaluation of the stratigraphy from the landsurface to the top of the Paleozoic bedrock. This is very different from previous work in this region which utilized only scarce outcrops or shallow core transects at best. In some areas where previously a 30 foot (9 m) outcrop would have been studied, an additional 300 feet (91 m) of Pleistocene sediments occur in the subsurface.

This more complete analysis of the Pleistocene deposits has necessitated the development of a multiple classification stratigraphic framework which is outlined in this report (Table 1). This report deals only with the tills and related deposits which occur stratigraphically below the sediments of the Yarmouth-Sangamon and Late-Sangamon Paleosols.

Classically, these sediments have been referred to as Kansan and Nebraskan, in both a time and rock stratigraphic sense. In this report the deposits are redefined. They are here referred to undifferentiated Pre-Illinoian stages for their time-stratigraphic classification. This is because similar complexities have been revealed by ongoing work in the type regions of Kansan and Nebraskan deposits. Until these complexities are resolved the designation of Pre-Illinoian will be used.

Rock stratigraphically these deposits have been subdivided into the Alburnett and Wolf Creek Formations. Both formations are composed mainly of basal tills and intertill stratified, fluvial sediments. The tills and other sediments have been characterized by their clay mineralogy, particle-size distribution, sand-fraction lithologies, and other physical and chemical characteristics. These properties are summarized in Tables 2 through 5, and 23. Analysis of these properties, in concert with the physical stratigraphy allows site-to-site correlation.

The Alburnett Formation and the Wolf Creek Formation are separated on the basis of their distinct clay mineralogy. The Alburnett deposits averaging about 43% expandable clay minerals, while the deposits of the Wolf Creek Formation average 62%.

Multiple till units occur within the Alburnett Formation. These are not formally subdivided because no consistent differences in properties have as yet been recognized. This may be, in part, because the older Alburnett deposits occur deep in the subsurface, and as a consequence they have not been as thoroughly analyzed.

The Wolf Creek Formation is subdivided into the Winthrop, Aurora, and Hickory Hills Till Members. These members are subdivided on the basis of the physical stratigraphy and on differences in their particle-size distribution and sand-fraction lithologies. The analysis of matrix carbonates also looks useful for the characterization and correlation of these deposits.

Soil stratigraphic units are also recognized. Two strongly-developed buried soils, indicative of an interglacial episode, occur. The Westburg and Dysart Paleosols are recognized as formal soil-stratigraphic units. The Westburg Paleosol occurs below the Winthrop Till Member of the Wolf Creek Formation and is developed in deposits of the Alburnett Formation, or other older rock units. The Dysart Paleosol occurs below the Hickory Hills Till Member of the Wolf Creek Formation.

Weakly developed soils also occur between the Aurora and Winthrop Till Members of the Wolf Creek Formation, and between the unnamed tills of the Alburnett Formation. The morphology of these weakly-developed soils, as well as the paleobotanical, and palynological evidence suggest that these are likely inter-stadial level unconformities. They will not be formally classified until more is known about their significance.

Substantial erosion has occurred in this region of very old glacial deposits. This erosion has played an interesting and significant role in the past misunderstanding of the geology of the region. Many previous studies have mistakenly assumed that the surficial till deposit was the same unit, regardless

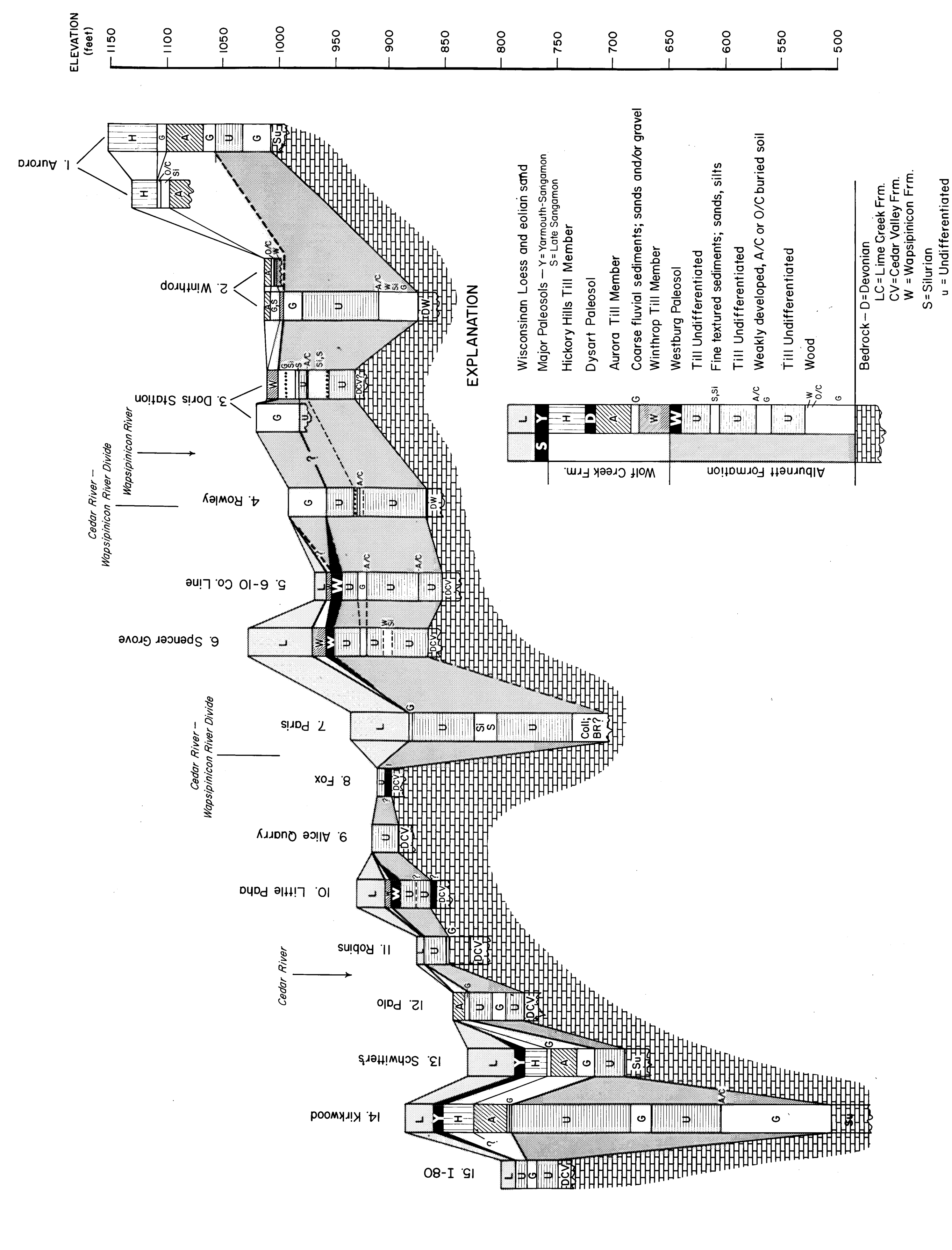


Figure 39. Schematic north-south cross-section through the study area.

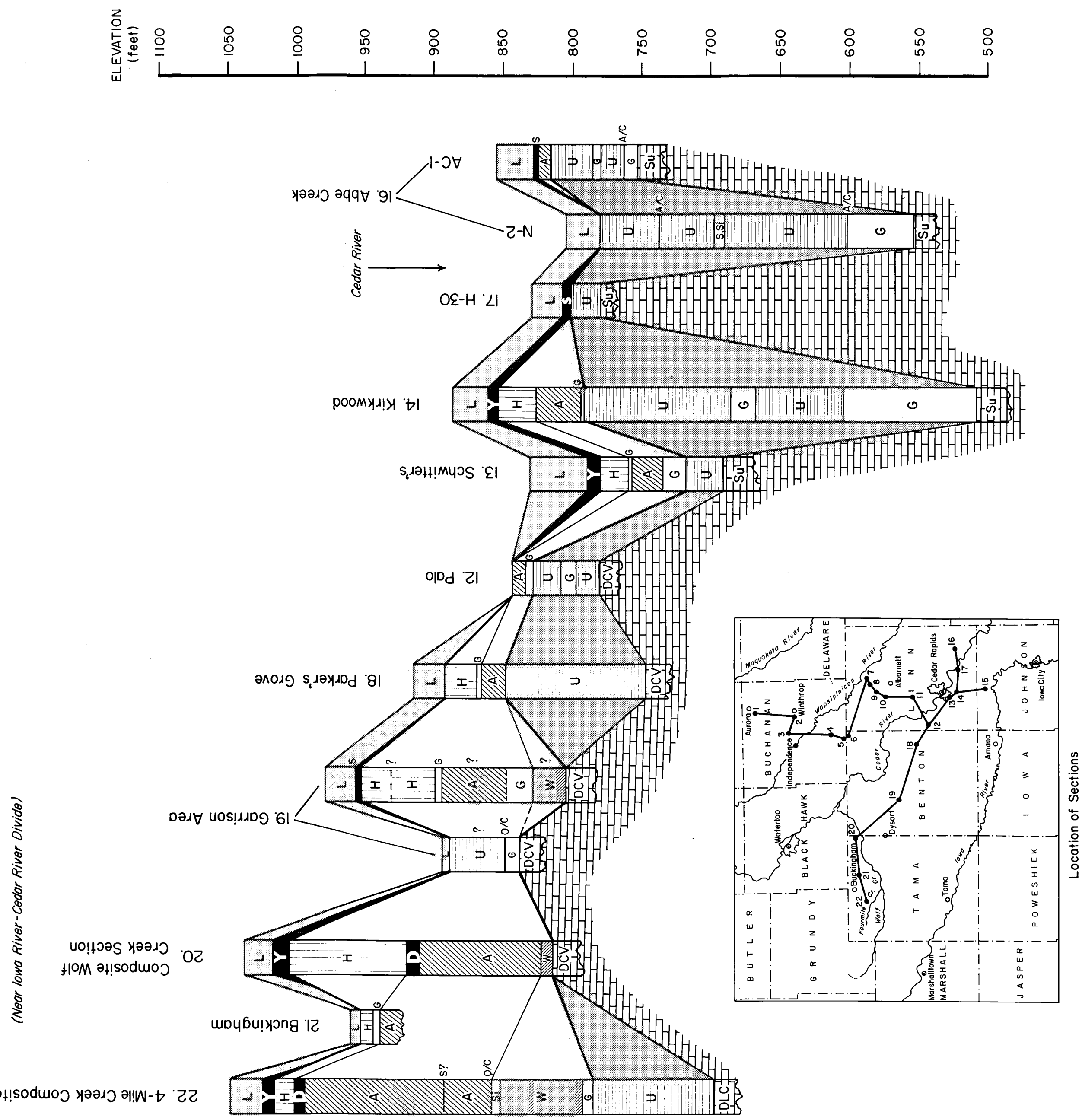


Figure 40. Schematic east-west cross-section through the study area.

of its landscape position. The study area is within the region of the widely-developed Iowan Erosion Surface of Wisconsinan age. This area is marked by multi-leveled stepped erosion surfaces. As repeatedly shown here, and elsewhere (Ruhe, et al., 1968; Ruhe, 1969; Hallberg, et al., 1978) the stratigraphy must be understood within the three-dimensional framework of these erosion surfaces. Within any size drainage basin these stepped-surfaces proceed from the immediate divide down the interfluves, toward the alluvial valley. Here, on the local level, these surfaces cut across the stratigraphy. The younger stratigraphic units in an area are frequently truncated by these erosion surfaces, and may be entirely missing from isolated outcrops on lower-lying erosion surfaces.

In addition to this, significant pre-Wisconsinan erosion also took place. As documented in this study, the Late-Sangamon surface and paleosol cut across, and are developed on everything from the Hickory Hills Till Member to the much older tills of the Alburnett Formation. In some areas, substantial portions of the total Pleistocene stratigraphic section were eroded away between the deposition of the Hickory Hills and the stabilization of the Late-Sangamon surface.

Perhaps the best summary of these complex relations is given in the cross-sections shown in figures 39 and 40. The cross-sections are composed of the many individual reference localities, sections, and drill-cores described in this report. Figure 39 runs roughly north-south through the study area, from the regional Wapsipinicon-Maquoketa River divide, to the Iowa River. Figure 40 runs roughly east to west from near the Cedar River, to the Wolf Creek - 4-Mile Creek area near the Iowa-Cedar River divide.

It is evident from the cross-sections, that the only areas where the Wolf Creek Formation tills are well-preserved are on the higher elevation, major divides between the Wapsipinicon and Maquoketa Rivers on the north, and the Iowa and Cedar Rivers to the west. The Cedar Rapids area (Kirkwood and Schwitter's area) is exceptional in this regard. As the land surface drops in elevation from these major divides to the lower elevation area in the Cedar River basin the Wolf Creek Formation deposits are only locally preserved, having been removed by erosion. The tills and sediments of the Alburnett Formation are at the surface over large areas in this region.

In these old and eroded glacial deposits the relationship between the landscape and stratigraphy is similar to an area of dissected, relatively flat-lying sedimentary rocks. As the landscape drops in elevation from primary to secondary divides, the younger stratigraphic units are truncated by erosion, exhuming older units at the landsurface. Although it may appear that this relationship should have been obvious, it clearly has not been a working concept with Pleistocene geologists. However, in these Pleistocene deposits there are no resistant "cliff-forming" units to provide cuestas or escarpments and enable obvious recognition or the evaluation of this relationship. The important thing, however, is that the principles are the same! This must be recognized to thoroughly analyze or understand the stratigraphy in areas such as this.

The recognition of these relations also aids in the understanding of problems with prior work in this area. In areas of glacial deposits, which are this old and this eroded, the surficial till units may not be the same even from divide to divide. Besides the development of the stratigraphic classification, the most important principle outlined in this report is the recognition of these relationships between the stratigraphy and geomorphology on the regional level.

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APPENDIX: OTHER REGIONAL OBSERVATIONS; ADDITIONAL SECTIONS

Many other detailed observations, besides those already presented, contributed to this study. Some of these other important sections and observations will be presented below.

The Kirkwood Locality is located on the south side of Cedar Rapids in Linn County and consists of a series of core holes and outcrops. The section was named from Kirkwood Community College which sits on the north flank of a paha. The drilling site was chosen because the Kirkwood Paha overlies a buried bedrock valley--a situation which should provide a thick, and rather complete stratigraphic sequence.

The Kirkwood Paha is an elongate loess and eolian sand ridge, oriented from NW to SE going from the center of sec. 16 to the SW¼ of sec. 15, of T 82N, R 7W. The deepest test holes encountered 377 feet (115 m) of Pleistocene deposits over bedrock. These deep holes are located at the crest of the paha in the SW¼, of the NE¼, of the NE¼, of the SW¼ of sec. 16, at an elevation of 885 feet. Figure 41 is a cross-section through the axis of the paha from NW to SE, ending with the deep core-holes. Figure 42 is a N-S cross section through the area. Figure 43 summarizes the stratigraphy, particle-size data, carbonate content (of the <2mm fraction) and percentage of expandable clay minerals for the deep-core hole. Tables 41 through 44 show the mineralogic data for the deep core and for other samples in the cross-section. The stratigraphy of the deep core hole is also summarized on figure 44 which shows the geophysical logs of the core-hole. Geophysical logs have not been widely used for Pleistocene deposits. However, when scaled properly they can be used effectively for interpreting Pleistocene deposits (e. g. Norris, 1972). In the present project they were useful in understanding the details of the stratigraphy in drilled holes and for deciding where critical core samples should be taken when complete coring could not be undertaken. The subtle differences in the electric and gamma logs accurately showed

Stratigraphic Cross-Section; West-End Kirkwood Paha

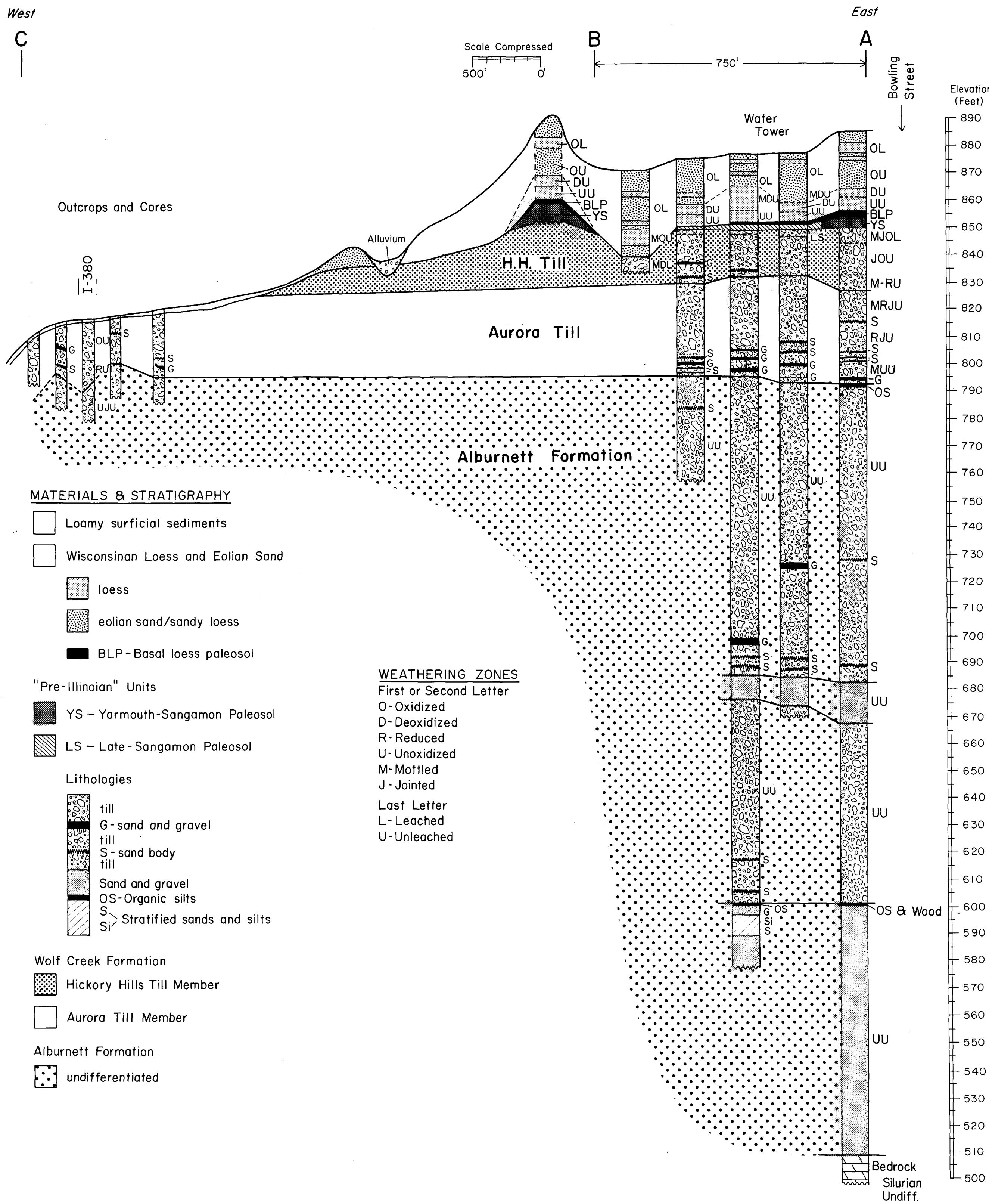


Figure 41. Northwest-southeast cross-section through part of the Kirkwood Paha Transect.

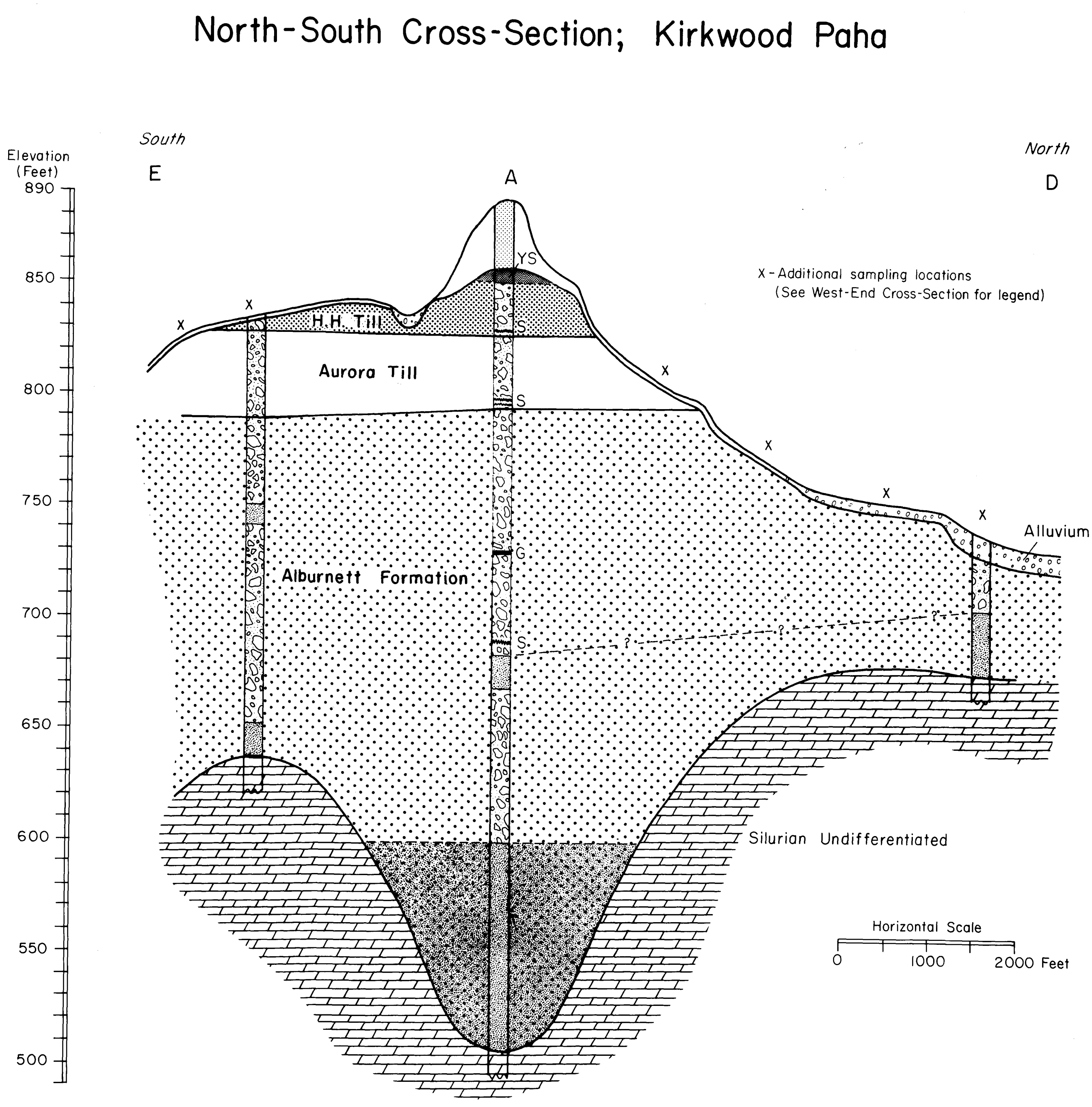
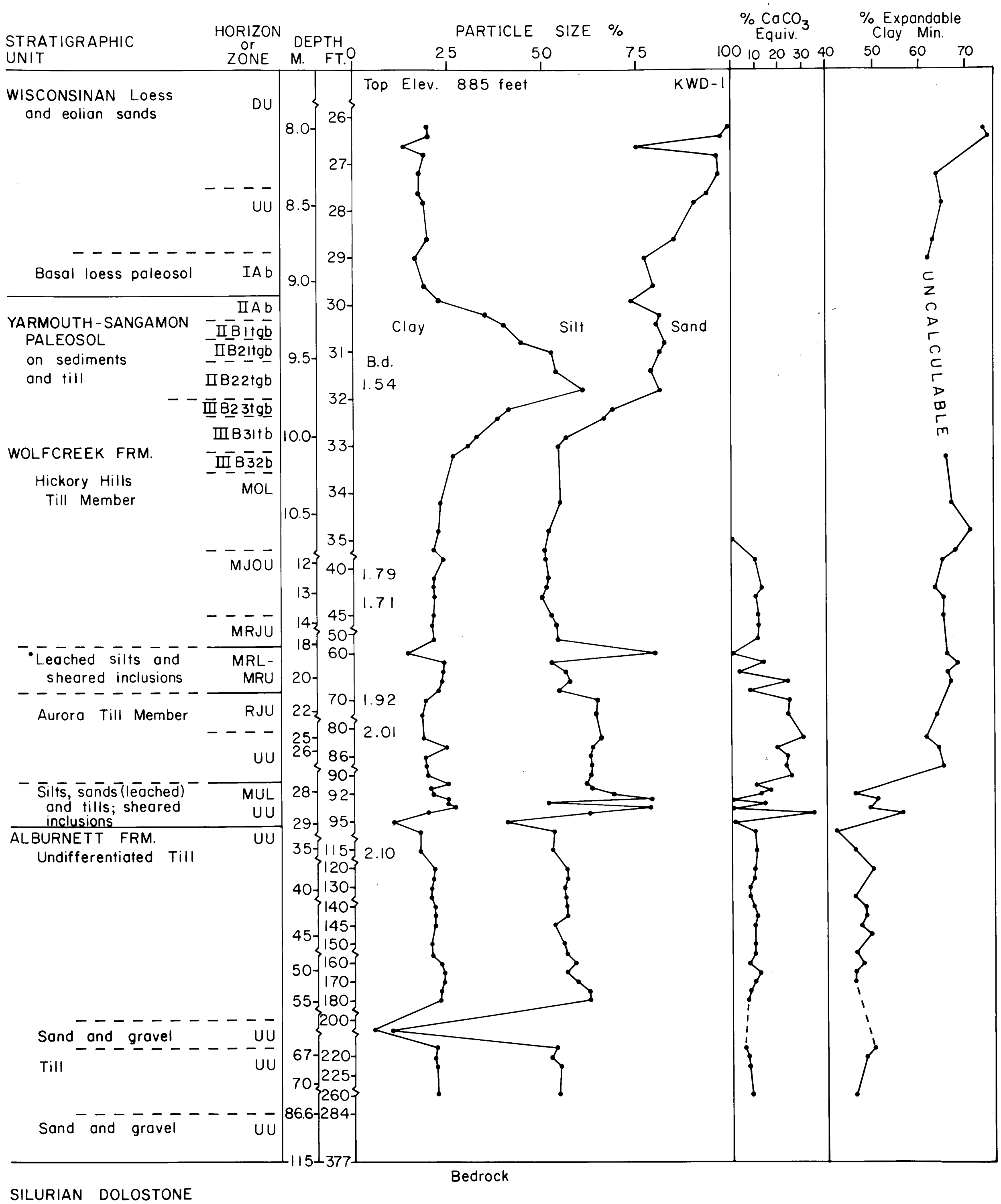


Figure 42. North-south cross-section Kirkwood Paha transect.



*Thin, nearly white, fine silt seams appeared to be volcanic ash but were too fine-textured for analyses to determine.

B.d.- bulk density in g/cc.

Figure 43. Stratigraphy, particle-size, calcium-carbonate equivalent and % expandable clay mineral data, Kirkwood core-1.

Table 41. Clay Mineralogy - Kirkwood Core.

Horizon or Zone	Depth (feet)	I.D.	Ex.	Ill. %	K+C	H.S.I.	D.I.	D. c.p.s.	C. c.p.s.
WISCONSINAN LOESS and Eolian Sand									
OL	12.0		74	15	11	25	0.81	--	--
DU	26.5	126	75	16	9	26	1.27	70	50
UU	27.8	127	64	23	14[2]	24	1.12	50	t
UU	28.0	128	65	19	16[2]	18	0.78	30	t
			Basal loess paleosol						
IAb	29.0	129	62	13	25[2]	12	0.35	--	--
YARMOUTH-SANGAMON PALEOSOL									
IIAb	30	130	*	*	* [2]	4.0	*	--	--
IIB1tgb	30.3	131	*	*	* [2]	10	*	--	--
IIB21tgb	31.2	132	*	*	*	9	*	--	--
IIB22tgb	31.6	133	*	*	*	10	*	--	--
IIB22tgb	32.0	134	*	*	*	13	*	--	--
WOLF CREEK FORMATION - Hickory Hills Till Member									
IIIB31tb	32.5	135	*	*	*	17	*	--	--
IIIB31tb	33.0	136	(66)	(12)	(22)	19	0.36	--	--
MOL	35.0	137	72	10	18	25	0.37	--	--
MOL	35.5	3459	62	17	21	N.C.			
MOL	36.0	138	65	11	24	23	0.37	--	--
MOL	36.0	138-2	68	11	21	24	0.36	--	--
MJOU2	42.0	139	63	15	22	27	0.47	--	350[1]
MJOU	44.0	140	65	16	20	23	0.52	40	120
MJOU	45.0	141	65	16	19	23	0.54	25	140
MJRU	50.0	3476	62	16	22	N.C.			
			Sheared Contact Zone						
MOU	61.0	142	68	15	17	27	0.61	--	130
MRU	64.0	143	66	16	18	26	0.58	--	170
WOLF CREEK FORMATION - Aurora Till Member									
RJU	68.0		65	16	20	23	0.52	--	120
RJU	72.0		65	16	19	23	0.54	--	140
UJU	75.0		63	15	22	27	0.47	--	150
UU	80.5	144	61	17	22	24	0.52	--	140
UU	82.0	20	66	16	18	26	0.57	30	80
UU	83.0	336	56	18	26	25	0.44	30	80
			Sheared Contact Zone						
MUU	92.0	145	46	26	28	14	0.62	--	190
MUU	93.0	146	51	22	27	17	0.55	--	120
MR-UU	93.1	147	49	22	29	12	0.53	--	200
MUU	93.3	148	50	23	27	12	0.57	50	210
UU	93.5	149	42	28	30	15	0.63	30	120
UU	94.0	156	54	18	28	18	0.42	40	150
ALBURNETT FORMATION - Till undifferentiated									
UU	94.9	150	42	20	38	14	0.42	50	280
UU	115.0	151	46	22	32	17	0.47	30	190
UU	120.0	152	50	18	32	17	0.38	50	250
UU	135.C	337	46	22	32	15	0.46	30	190
UU	140.0	153	48	19	33	16	0.38	40	300
UU	142.0	154	49	18	33	17	0.36	50	300
UU	144.0	155	47	19	34	17	0.36	50	300

Table 41. (con't)

UU	145.0	157	49	19	32	16	0.39	50	300
UU	161.0	158	47	19	34	15	0.38	40	250
UU	163.0	159	46	18	36	12	0.34	40	290
UU	165.0	160	46	19	35	14	0.37	50	350
			- Till undifferentiated						
UU	218.0	161	51	20	29	12	0.47	20	180
UU	218.2	3452	44	27	29	N.C.			
UU	220.0	162	48	21	31	14	0.45	30	220
UU	260.0	46	46	19	35	14	0.36	20	200
UU	265.0	338	47	22	31	14	0.47	10	240

* Uncalculable - no apparent Illite peak, broad expandables peak.
( ) Values in parenthesis still affected by soil development
N.C. - not calculated.
1. - secondary carbonates present
2. - 001 - vermiculite peak present.

Table 42. Sand Fraction Lithologies - Kirkwood Core

Horizon or Zone	Depth	I.D.	C/D	T.C.	Sh.	Sed.	Q.-F.	Ot.	Xst.
WOLF CREEK FORMATION - Hickory Hills Till									
MOL	35	629	--	--	--	--	73	27	100
MOL	36	3	--	1	8	10	54	36	90
MJOU	43	16	1.1	18	2	20	77	3	80
MJOU	44	13	1.3	15	5	20	63	17	80
MJOU	45	606	1.8	11	1	12	64	24	88
WOLF CREEK FORMATION - Aurora Till									
MRU	64	41	13.3	26	--	26	61	13	74
UJU	75	66	NoD	19	1	20	69	11	80
UU	80	46	NC	11	1	12	65	23	88
			Sheared Contact Zone						
MUU	92	45	1.8	26	1.3	29	61	10	71
MUU	93	607	4.7	17	12	33	46	21	67
UU	93.5	633	NoD	7	4	11	75	14	89
ALBURNETT FORMATION - Till undifferentiated									
UU	95	611	3.0	20	--	20	65	15	80
UU	120	44	0.80	30	1.4	34	60	6	66
UU	140	40	0.9	22	2	26	58	16	74
UU	145	617	2.8	22	--	22	71	7	78
UU	161	616	3.0	8	4	13	70	17	87
UU	165	47	1.0	12	2	15	70	15	85
UU	218	614	7.0	8	1	9	74	17	91
UU	220	48	1.2	11	6	19	63	18	81

Table 43. Clay Mineralogy - surface samples in Kirkwood vicinity.

Strat. Unit	I.D.	Ex.	Ill. %	K+C	H.S.I.	D.I.	D. c.p.s.	C. c.p.s.
WOLF CREEK FORMATION - Hickory Hills Till								
MOU	562	67	15	18	27	0.58	20	100
OU	723	65	14	21	19	0.48	10	90
MOU	988	62	18	20	21	0.51	80	120
OU	989	62	18	20	20	0.51	20	100
- Aurora Till								
MOU	327	58	18	24	30	0.44	40	180
MOU	990	61	16	23	19	0.46	--	150
OU	3272	54	18	28	N.C.			
OU	991	65	16	19	22	0.54	--	140
MOU	994	62	18	20	22	0.51	--	140
ALBURNETT FORMATION - Till undifferentiated								
MUJU	721	43	27	30	11	0.51	60	120
RU	722	38	30	32	17	0.61	60	200
MRU	3296	38	30	32	N.C.			
UU	3267	38	26	36	N.C.			
MUU	326	39	29	32	13	0.61	40	220
UU	992	42	26	32	14	0.46	20	200
UU	993	42	27	31	N.C.			

Table 44. Sand Fraction Lithologies - Kirkwood vicinity.

Horizon or Zone	C/D	T.C.	Sh.	Sed.	Q.-F.	Ot.	Xst.
WOLF CREEK FORMATION - Hickory Hills Till							
MOU	1.3	20	2	22	68	10	78
OU	2.4	17	-	17	75	8	83
- Aurora Till							
MOU	NoD	25	1	26	59	14	73
OU	17	18	4	24	61	15	76
JOU	9	20	-	21	69	10	79
ALBURNETT FORMATION - Till undifferentiated							
RJU	4.3	21	-	24*	58	18	76
MUJU	1.3	16	4	20	69	11	80

*Coal fragment.

the various stratigraphic units which were obvious in the complete cores and from the laboratory data.

The Hickory Hills and Aurora Till Members of the Wolf Creek Formation both exhibit modal properties at the Kirkwood Locality: 62-68% expandable clay minerals (Table 41); about equal amounts of total carbonate grains in the sand fraction, but the Aurora has a high C/D ratio. Both tills exhibit typical particle-size distributions: the Hickory Hills averaging (n=18) 46.8% sand, 31% silt, and 22.2% clay; the Aurora averaging (n=12) 37.6% sand, 43.7% silt, and 21.1% clay. From x-ray analysis of the clay fraction the two tills both exhibit the same range (in counts-per-second) of calcite, but the Aurora shows either a low or no dolomite peak, whereas the Hickory Hills shows low but consistent dolomite.

The underlying Alburnett Formation tills are marked by their characteristically lower amounts of expandable clay minerals (42-48%). The sharp change in clay mineralogy between the formations is shown graphically in figure 43.

The Alburnett tills show nearly twice as much calcite by x-ray analyses (table 41) as the Wolf Creek tills. It is interesting that in terms of total carbonate in the less than 2mm fraction (see figure 43) the Hickory Hills and Alburnett tills are approximately the same, but the Aurora till shows double this amount.

As in the other study areas the various till units are quite uniform in properties, except in their lower portions. The contact between the Hickory Hills and the Aurora Till Members, and the contact between the Aurora and the upper Alburnett till often exhibited sheared inclusions of mixed sediments. In the various core holes these contacts ranged from abrupt till-till contacts to zones of mixed sediments, typically including numerous thin angular inclusions of sand or gravel bodies, leached silts, and in one case leached organic silts, within the matrix of the overlying calcareous till. These contact zones ranged from about 2 to 8 feet (0.6 - 2.4 m) in thickness. These relationships can be seen in the data for

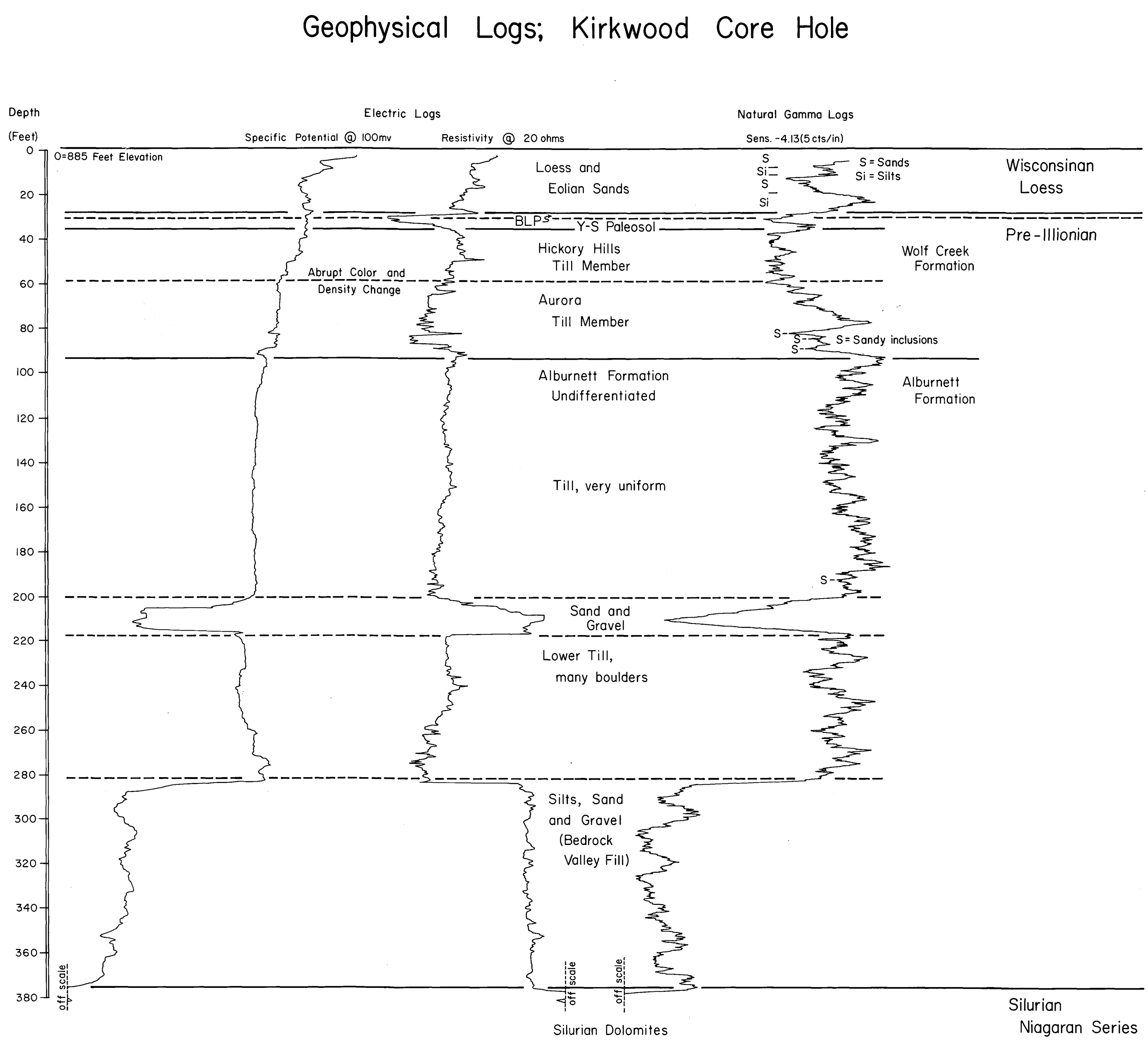


Figure 44. Geophysical logs and stratigraphy, Kirkwood Site core-1.

the deep core hole in figure 43, where the uniform tills are separated by zones of variable texture. As shown by the carbonate data some of these sediments are leached, or the carbonate content may fluctuate between values typical of both the overlying and underlying material. The same is true for the clay mineralogy in the contact zone between the Aurora and Alburnett Tills.

During road construction for Interstate 380 the contact zone between the Aurora and Alburnett Tills was exposed in a borrow area. In places an abrupt till-till contact occurred between the mottled-oxidized (light olive brown, 2.5Y 5/4 matrix), or mottled-reduced (olive, 5Y 4-5/3 matrix), unleached Aurora Till and the underlying, jointed, unoxidized (dark greenish gray, 5GY 4/1) unleached Alburnett Till. In other places at the contact or within the lower 5 feet (1.5 m) of the Aurora Till were lenses or irregular inclusions of leached or unleached sands, gravels, and silts. Small areas of sheared, contorted, intermingled masses of till and silts and sands also occurred. Also, angular and elongate shaped blocks of unoxidized Alburnett till were included within the oxidized Aurora till. One of these elongate masses was marked by slickensides and flutings on its upper surfaces. The blocks often were marked by an indurated one inch (2.5 cm) rind of iron-oxide. Also, in the contact zone there seemed to be an unusually high proportion of large boulders compared to the overlying and underlying till.

Contact zones, such as this are quite common, but present a marked departure from the otherwise thick, uniform till bodies generally encountered in east-central Iowa. These are interpreted to be zones of sheared inclusions of substrate material into the lower portions of the overlying till, as discussed previously in the text.

Along the crest of the Kirkwood Paha about 30 feet (9.1 m) of Wisconsinan loess and eolian sand overlie a basal loess paleosol and the Yarmouth-Sangamon Paleosol, developed in part in the Hickory Hills Till. Along the crest the present surface and the pre-loess surface (figure 41, A to B) steps down to the lower Late-Sangamon surface and paleosol and then to an even lower surface where the loess and eolian sand rest directly on the eroded till. This is an Iowan erosion surface, where the paleosols have been removed by erosion. As the cross-section progresses from B to C the Iowan surfaces are essentially devoid of loess, and the uppermost till unit is stripped off and the surficial till becomes the Aurora Till Member.

Similar relations can be seen in the N-S cross-section (figure 42). Fram A to E, once again, the borings descend off of the paha, the loess thins and is essentially absent, the paleosols are stripped by erosion, and eventually the uppermost till unit is eroded off as well. From A to D to the north (figure 42) this situation is even more pronounced. There are multi-stepped erosion surfaces which descend to Prairie Creek. The greater dissection to the north not only truncates the Yarmouth-Sangamon Paleosols and the Hickory Hills Till, but the Aurora Till is also removed and finally the upper till of the Alburnett Formation becomes the surficial till deposit. As noted above, where the zones of contact between the tills outcrop, the sheared and/or stratified inter-till materials will be exposed at the surface.

Hopefully, this example again demonstrates the problems in the analysis of the Pleistocene geology in these eroded landscapes. One cannot simply work from isolated exposures in this area and make any meaningful interpretations about the stratigraphy or nature of the surficial deposits. Isolated outcrops within one mile of the Kirkwood Paha expose three entirely different till units. To make interpretations of these outcrops they must be understood within the concept of the stepped erosion surfaces, and within the related stratigraphic framework (Hallberg, et al., 1978).

These same relationships are common throughout the Cedar Rapids area (see Schwitter's and Westdale sections). However, even with an understanding of the erosion surfaces and the stratigraphy very complex situations arise, particularly in areas with high relief on the bedrock surface.

Sections on the north and west side of Cedar Rapids are good examples of these complex relationships (Table 45). As previously described, coming south from the Alburnett area (figure 18) toward the Cedar Rapids area the landscape is dominated by occasional thin remnants of Wolf Creek Formation

Table 45. Summary of additional stratigraphic test holes in the study area.

Stratigraphy:	Depth	Sample Data: Depth (feet)	Particle Size % Clay	Silt	Sand	Clay Mineralogy % EX	Ill	K+C	D	C	Density g/cc(pcf)	Specific Gravity	Hydraulic Conductivity cm/sec	ft/day
Site: Robins Test Hole														
Location: NW¼ of NW¼ of NW¼ of SEP of sec. 16, T.84N., R.7W.; Linn County														
Elevation: 873 Feet														
HOLOCENE-WISCONSINAN														
Solum and eolian sands (OL) (And possibly exhumed coarse sands of the Wolf Creek Fm.)	0- 6 ft.													
PRE-ILLINOIAN														
ALBURNETT FORMATION														
Till undiff (RU)	6- 16													
(UU)	16- 31	26				48	24	28						
Gravel (UU)	31- 33													
Weathered Limestone and/or Limestone Gravel	33- 51													
DEVONIAN														
Cedar Valley Limestone	51+													
Site: Hiawatha Test Hole														
Location: SE¼ of NE¼ of SW¼ of NE¼, sec. 25, T.84N., R.8W.; Linn County														
Elevation: 805 Feet														
Holocene alluvium	0- 18 ft.													
fine sandy alluvium (MRL)	0- 15													
clay loam (UL)	15- 18	16	32.0	34.3	33.7	66	17	17	--	--	1.55(97)	2.66	3.8 X 10^{-7}	1.1 X 10^{-3}
PRE-ILLINOIAN														
WOLF CREEK FORMATION	18- 75													
Aurora Till (?) (MRL)	18- 22													
(UU)	22- 50	35	26.1	36.3	37.6	62	19	19	--	40	1.77(111)	2.65	3.7 X 10^{-9}	1.1 X 10^{-5}
Mucky Clay Loam	50- 51													
Winthrop Till (?)(UU)	51- 62	51	38.0	43.0	19.0	68	16	16	--	t	1.84(115)	2.71	2.6 S 10^{-9}	7.2 X 10^{-6}
Undifferentiated Sand and Gravel (UU)	62- 75													
DEVONIAN														
Weathered Kenwood Shales	75+	75	22.0	71.0	7.0	All Illite			t	120	1.73(108)	2.75	2.9 X 10^{-8}	8.2 X 10^{-5}

Table 45. (Con't)

Stratigraphy:		Depth	Sample Data: Depth (feet)	Particle Size % Clay	Particle Size % Silt	Particle Size % Sand	Clay Mineralogy % EX	Clay Mineralogy % Ill	Clay Mineralogy % K+C	Clay Mineralogy % D	Clay Mineralogy % C	Density g/cc(pcf)	Specific Gravity	Hydraulic Conductivity cm/sec	Hydraulic Conductivity ft/day
Site: Palo Test Hole															
Location: SE¼ of SE¼ of NE¼ of SE¼, sec. 6, T.83N., R.8W.; Linn County															
Elevation: 842 Feet															
PRE-ILLINOIAN															
WOLF CREEK FORMATION		0 - 10 ft.													
Till Undiff.	(OL)	0 - 6													
(Aurora Till?)	(MOU)	6 - 10	8	23.5	38.7	37.8	59	20	21	t	100				
Undiff. Sand and Gravel	(OU)	10 - 14.5													
ALBURNETT FORMATION															
Till Undiff.	(MUU)	14.5- 35	15	24.5	28.4	47.1	48	22	30	t	110				
			20	22.5	34.7	42.8	37	25	38	20	110				
			27	28.0	34.9	37.1	29	32	29	20	80				
Sand and Gravel	(UU)	35 - 47													
Till Undiff.	(UU)	47 - 63													
DEVONIAN															
Cedar Valley Limestone		63+													
Site: Parker's Grove Cemetery Hole															
Location: SW¼ of SW¼ of NW¼ of SE¼, sec. 28, T.84N., R.9W.; Benton County															
Elevation: 915 Feet															
Wisconsinan loess		0 - 20													
pedisediment		20 - 23	22	29.9	29.5	40.6	71	14	15	--	--	1.73(108)	2.66	7.9×10^{-8}	2.2×10^{-4}
PRE-ILLINOIAN															
WOLF CREEK FORMATION		23 - 65													
Hickory Hills Till	(RL)	23 - 45	24	27.9	30.9	41.2	63	17	20	--	--	1.77(111)	2.70	1.2×10^{-8}	3.3×10^{-5}
	(RU)		28	24.5	34.7	40.8	62	18	20	--	70	1.91(119)	2.70	3.7×10^{-8}	1.1×10^{-4}
	(UU)		44	24.2	34.5	41.3	64	19	17	40	80	1.92(120)	2.68	7.4×10^{-9}	2.1×10^{-5}
sand and gravel	(OU)	45 - 46.5													
Aurora Till (?)		46.5- 65													
	(MOU)		47.5	24.0	38.0	38.0	61	19	20	40	60	1.81(113)	2.74	2.1×10^{-8}	5.9×10^{-5}
	(UU)		54.0	25.0	38.0	37.0	54	23	23	t	150	1.91(119)	2.71	3.7×10^{-8}	1.1×10^{-4}
ALBURNETT FORMATION		65 -168	81				45	25	30	20	70				
Till Undiff.	(UU)		82	27.2	37.2	34.6	42	24	36	20	130	1.98(124)	2.67	4.9×10^{-9}	1.4×10^{-5}
Bedrock		168+													

Description 12. Garrison Quarry Section.

Section on the East side of the B. L. Anderson Quarry, in the NE¼, of NW¼, of NE¼, of sec. 33, T.85N., R.11W.; Benton County. Elevation 890 feet (Description by G. R. Hallberg, T. J. Kemmis, 4/26/78).

Depth-Feet (m)	Horizon or Zone	Abbreviated Description
0 - 3 (0 - 0.9)	OL-Solum	Wisconsinan loess.
		WOLF CREEK FORMATION
3 - 5.5 (0.9- 1.7)	OL-Solum	Loam till, undifferentiated; occasional lenses of sand and gravel, silt loam, fine sandy loam.
5.5-11 (1.7- 3.4)	OJU	Loam till, with inclusions, as above.
11 -16.5 (3.4- 5.0)	OJU-RJU	Loam till, uniform, no inclusions or lenses.
16.5-22 (5.0- 6.7)	RJU	Loam till, as above.
22 -44 (6.7-13.4)	UJU	Loam till, uniform as above. Till shows an abundance of cobbles of local Devonian carbonates. In the UJU till, high angle, an echelon seepage bands which dip toward the north. Most of the bands appear as oxidized joints, but one shows inclusions of the lower lying peat and silts along the plane. These appear to be some kind of shear plane (?).
44 -45.5 (13.4-13.9)	Oab	Peat with wood, leached; grades laterally to a mucky silt loam.
45.5-47.0 (13.9-14.3)	DL-OL	Horizontally bedded, fine sand loam, silt loam, sands, color varies with texture.
47.0-51.5 (14.3-15.7)	DU-OU	As above, with coarser sands, occasional fine gravel toward base.
51.5-54.5 (15.7-16.6)	OU	Coarse gravel, with boulders; many local angular bedrock fragments.
		DEVONIAN - CEDAR VALLEY LIMESTONE
54.5- (16.6-		Bedrock.

tills and fluvial deposits, which are exhumed on the Iowan Erosion Surface. These deposits overlie tills and other deposits of the Alburnett Formation. In the Robin's area (see Table 45) at elevations of 850 to 870 feet eolian sands and silts, and exhumed fluvial sands of the Wolf Creek Formation overlie till and sand and gravel of the Alburnett Formation. The Alburnett sands are also exhumed by erosion, and occur at the land-surface in this area.

About 3 miles (4.8 km) to the southwest at the Hiawatha test hole (Table 45) the bedrock is about 90 feet (27.4 m) lower in elevation. The land surface is about 70 feet (21.3 m) lower. Here, two tills of the Wolf Creek Formation overlie bedrock. Approximately 3 miles (4.8 km) south again, at the Edgewood section (a road cut in the NW¼, of the NE¼, of the NW¼, of the SE¼, of sec. 7, T 83N, R 7W) at an elevation of about 840 feet, 20 feet (6.1 m) of loess overlie a Late Sangamon Paleosol developed in till of the Wolf Creek Formation (Ex-57%; Ill-19%; K+C-24%) and a sand and gravel channel cut into the till. This all overlies bedrock at about 805 feet in elevation. Just to the west, across the Cedar River, at the Palo Site (Table 45), again at about 840 feet elevation, thin Wolf Creek deposits overlie Alburnett Formation tills and fluvial deposits, which lie on bedrock at about 780 feet elevation.

Sections in Benton County show similar relations as those previously described. The Parker's Grove Section is from a small paha belt south of Shellsburg, and is described in Table 45. In the paha belt near Garrison complexities again occur. In the Garrison Quarry Section (Description 12; Table 46) a single, loam-textured, Wolf Creek Formation till occurs on an Iowan Erosion Surface landscape position. The texture of the till is typical of the Aurora Till Member, averaging 22.8% clay, 38.1% silt, and 39.1% sand. The sand fraction data, however, is similar to the Hickory Hills Till in the upper part of the section but more like the Aurora in the lower part.

A test hole drilled on a paha to the south of the quarry, at an elevation of 980 feet shows 20 feet of loess over a truncated Late Sangamon Paleosol over 3 tills of high-expandable clay mineralogy, typical of the Wolf Creek Formation. The sequence of materials in the test hole suggests that the Garrison Quarry Section represents the second till in the sequence, suggesting a correlation to the Aurora Till. As discussed, the data in Table 45 is inconclusive. Many alternatives could be discussed but no correlations can really be resolved at this time.

In the southern part of the study area, around the Iowa River where the Iowan Erosion Surface is less areally extensive (Hallberg, et al., 1978) the youngest till seems clearly to be the Hickory Hills Till of the Wolf Creek Formation. Data from Marshall (see site E-63, Hallberg et al., 1978), Tama,

Table 46. Clay and sand fraction mineralogy - Garrison Quarry.

WOLF CREEK FORMATION - Undifferentiated

Horizon or Zone	Depth (feet)	ID	EX.	Ill. %	K+C
OJU	8	3086	58	18	24
RJU	13	3092	60	19	21
RJU	18	3094	50	18	32
UJU	23	3091	52	20	28
UJU	28	3084	62	18	20
UJU	33	3090	62	14	24
UJU	38	3093	61	16	23

Horizon or Zone	Depth	I.D.	C/D	T.C.	Sh.	Sed.	Q. F.	Ot.	Xst.
OJU	8	658	4.4	27	10	37	52	11	63
RJU	13	675	4.4	27	2	29	44	27	71
RJU	18	666	4.6	21	--	21	58	21	79
UJU	23	661	5.3	29	1	30	53	17	70
UJU	28	660	16.2	34	2	36	44	20	64
UJU	33	656	NoD	27	--	27	59	14	73
UJU	38	669	18.0	31	--	31	60	9	69

Benton, Iowa, and Johnson Counties indicate that the surficial till is a loam till, high in sand, typical of the Hickory Hills. In this area the sand fraction lithologies become more variable, but the textural relations seem more clearly defined. In Tama County data from Hall(1965) and that of the author indicate the Hickory Hills Till occurs throughout the Salt Creek Area. A section near here (Table 47; Plaque Mine Creek Section) shows the stratigraphic relations in this area. This section has been used for years by Dr. Wayne Scholtes (Iowa State University; Dept. of Agronomy) in soil geomorphology field trips as an example of Kansan till, over Aftonian Peat, over Nebraskan till. This is all exposed in 21 feet (6.4 m) of section. However, well logs within this immediate area show a range from 175 to over 300 feet (53 - 91 m) of Pleistocene sediments, which provides an indication of the added complexity in this area.

Table 47. Plague Mine Creek Section

Location: Roadcut, north side of U.S. 30, in the SW¼, of SE¼ of, SW¼ of, SW¼ of sec. 29, T 83N, R 13W, Tama County;
Elevation: 910 feet on local erosion surface pediment.

Depth-Ft. (m)	Stratigraphy	Horizon	Sample data: Particle size - % Clay	Silt	Sand	Clay Min. - % Ex.	Ill.	K+C	C/D	Sand Fraction Lithologies T.C.	Sh.	Sed.	Q.-F.	Ot.	Xst.
	Wisconsinan Loess (above cut) (fromm top of cut)														
0 -11 (0 - 3.4)	WOLF CREEK FRM. Hickory Hills Till	MOU	21.7	33.1	45.2	61	19	20	2.2	26	12	38	47	15	62
	MOU	MRU	21.4	31.5	47.1	60	19	21	2.5	28	--	28	54	18	72
	MRU-MUU	MRU	20.1	38.0	41.9	59	19	22	4.1	31	--	31	50	19	69
11 -12 (3.4- 3.7)	Dysart Paleosol Oeb Peat														
12 -15 (3.7- 4.6)	Cb-RL Clay loam sediments	RL	31.4	48.1	20.5										
		RL	37.8	41.0	21.2	72	12	16							
15 -21 (4.6- 6.4)	Aurora Till MOU	OU	31.1	36.9	32.0	60	18	22	17.0	22	5	28	61	11	72
	RU	MRU							6.0	35	--	35	56	9	65
		RU	27.8	37.8	34.4	60	18	22	9.0	26	2	28	58	14	72

Description 1. 402-Road Cut and Core Section (modified from Fenton, 1966).

Location: NW¼ of the SE¼, sec. 10, T 86N, R 13W., Tama Co.

Depth Meters	Depth Feet	Horizon or Weathering Zone	
		WISCONSINAN LOESS	
0 - 1.2	0 - 4		Soil solum.
1.2- 2.4	4 - 8	OL	10YR 5/4, yellowish brown, gritty silt loam; few fi blk Mn spk; few fi str brn mot; mod med pr; few sand lenses; loess.
2.4- 3.4	8 -11	OU	10YR 5/4, yellowish brown, gritty silt loam; few med lt brnish gray mot; few fi blk Mn spk; loess.
3.4- 3.9	11 -13	DU	2.5Y 6/2, light brownish gray, silt loam; com med ylish brn mot; com fi str brn mot; many fi blk Mn spk; secondary carbonates present; loess.
3.9- 5.3	13 -17.5	DU	2.5Y 6/2 light brownish gray, silt loam; few med ylish brn & str brn mot; com fi blk Mn spk; some snail shells at 13.5; com Fe tbl; loess.
		Basal Loess Paleosol	
5.3- 6.1	17.5-20.1	IAb	10YR 5/2, grayish brown, silt loam; few fi str brn mot; com charcoal flecks; lower 4 inches many med ylish red mot; noncal; loess.
		Undifferentiated Sediments - YARMOUTH-SANGAMON PALEOSOL	
6.1- 6.4	20.1-21	IIB21gtb	10YR 4/1, dark gray, silty clay; com med gray, few fi dark red, mny fi ylish red mot; str vf abk; thick cont clay films; Y-S paleosol.
6.4- 7.6	21 -25	IIB22gtb	5Y 5/1, gray, silty clay; many fi ylish red mot; com fi str brn mot; str v f abk; thick cont clay films.
7.6- 9.3	25 -30.5	IIIB23gtb	5Y 4/1, dark gray, clay; com med str brn & few fi ylish red mot; str vf abk; thick cont clay films.
		WOLF CREEK FORMATION - Hickory Hills Till Member	
9.3- 9.8	30 -32.2	IVB3gtb	5Y 4/1 & 5/1, dark gray and gray, clay; same w/ few fine weak red mot; mod f abk; cont clay films; inc in co material.
9.8-10.7	32.2-35	RL	2.5Y 5/2, grayish brown, clay loam; com co str brn mot; com med Mn spk; till.
10.7-11.1	35 -36.5	OL	10YR 5/6-5/8 & 10YR 6/1, yellowish brown and gray, loam; com med & co str brn mot; few pebbles; till.
11.1-13.1	36.5-43	OL	10YR 5/6, yellowish brown, loam; same w/ few med lt brnish gray mot; few pebbles; till.
13.1-16.2	43 -53	OU	Same W/ carbonates.
16.2-25.3	53 -83	OU	10YR 5/6, yellowish brown, loam; com fi str brn & com med gray mot; few med Mn spk; few pebbles; till.
25.3-25.8	83 -84.5	UU	N 4/0, dark gray, loam; few pebbles; till.