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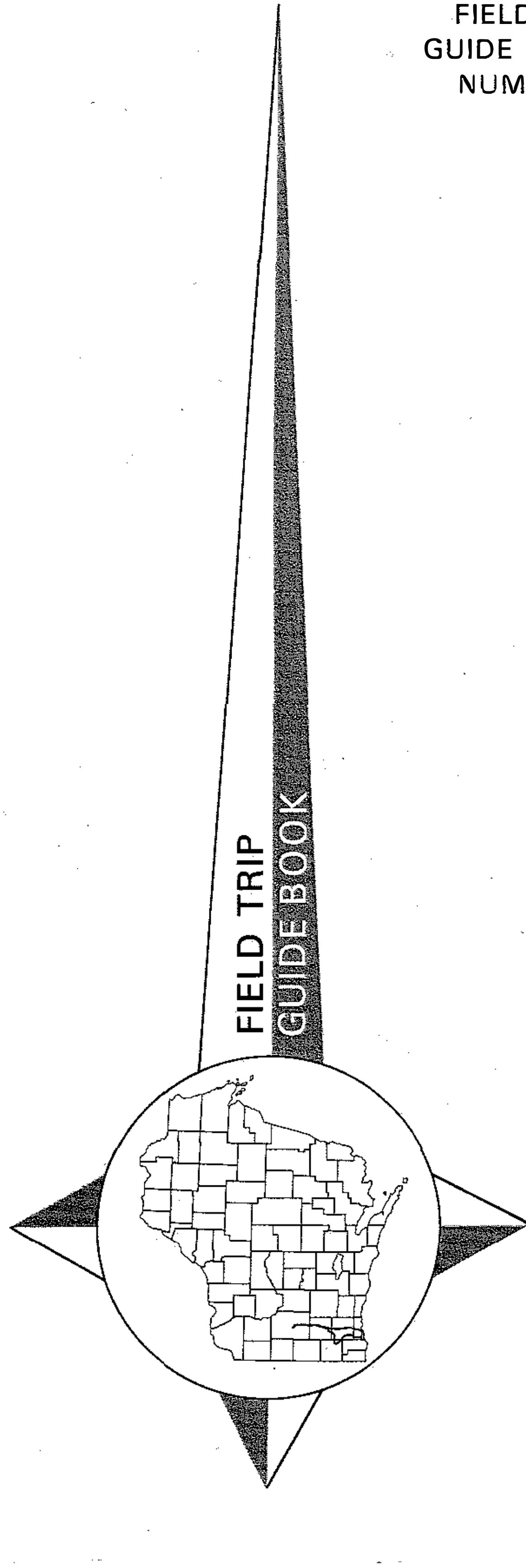
Meredith E. Ostrom, State Geologist and Director

FIELD TRIP
GUIDE BOOK
NUMBER 7
1983

LATE GLACIAL HISTORY AND ENVIRONMENTAL GEOLOGY OF SOUTHEASTERN WISCONSIN



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Field Trip Guide Book
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University of Wisconsin-Extension
GEOLOGICAL AND NATURAL HISTORY SURVEY
Meredith E. Ostrom, State Geologist and Director

LATE GLACIAL HISTORY AND ENVIRONMENTAL GEOLOGY OF SOUTHEASTERN WISCONSIN

(Companion Volume to Geoscience Wisconsin Volume 7)

Road Log and Geological Stop Descriptions

David M. Mickelson, Allan F. Schneider,
Scott D. Stanford, Leon R. Follmer and Norman P. Lasca

Prepared for

Seventeenth Annual Meeting
NORTH-CENTRAL SECTION
GEOLOGICAL SOCIETY OF AMERICA

University of Wisconsin-Madison
Madison, Wisconsin

April 28 - May 1, 1983

(meeting concurrently with the North-Central Section of the Paleontological Society, the Pander Society and the Great Lakes Section of the Society of Economic Paleontologists and Mineralogists)

Michael G. Mudrey, Jr., Field Trip Chairman
Wisconsin Geological and Natural History Survey

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1983

PREFACE

Several of the field excursions in conjunction with this Seventeenth Annual Meeting of the North-Central Section of the Geological Society of America serve to amplify presentations given in stuffy rooms of technical sessions by moving into the dynamics of a Wisconsin spring day.

Don Mikulic and Joanne Kluessendorf will convene a half-day symposium on the hematitic and calcareous oolitic strata at the Ordovician-Silurian boundary, and then will lead interested participants to locales where these provocative relations may be examined. Jeff Greenberg and Bruce Brown have organized a symposium on the geology and tectonic setting of Baraboo-type Proterozoic metasedimentary rocks, and then will lead interested participants on a lengthy excursion to focus on newly recognized relations of the anorogenic part of the Middle Proterozoic. Lee Clayton and Tim Kemmis have coordinated a symposium on recognition of till facies with a round-robin excursion to examine the Quaternary record in southeastern Wisconsin organized by Dave Mickelson.

Lloyd Pray, Charlie Byers and Bob Dott will conduct a trip which illustrates relations or Ordovician stratigraphy, including contributions from their students in the past few years in southwestern Wisconsin. Gene Smith will rerun his trip to the Precambrian inliers in south-central Wisconsin with a newly prepared road log and technical data on the granites and rhyolites.

The local field trip committee thanks the North-Central Section of the Geological Society of America, the North-Central Section of the Paleontological Soceity, the Pander Society and the Great Lakes Section of the Society of Economic Paleontologists and Mineralogists for the opportunity to demonstrate geological relations in southern Wisconsin.

All printed field trip materials were provided in camera-ready form by the respective authors. The Wisconsin Geological and Natural History Survey is responsible for arranging details of printing. The committee also thanks Meredith E. Ostrom, Director and State Geologist of the Wisconsin Geological and Natural History Survey, for providing assistance and support for the field trips.

We welcome you to Badger land, and hope that you find the geology, companionship and tour rewarding!

Michael G. Mudrey, Jr.
Field Trip Chairman

INTRODUCTION

The Wisconsinan stratigraphy of southeastern Wisconsin has attracted interest since it was studied by Alden. His pioneering work 80 years ago has provided a sound basis for more definitive studies in the past decade. On this trip, we will examine sections in gravel-cored drumlins and discuss erosional and depositional models of drumlin formation in the Green Bay and Lake Michigan Lobes. The interpretation of subglacial till deposited during advance and retreat and supraglacial till deposited during retreat will be debated. Exposures along the Lake Michigan shoreline contain most of the Late Wisconsinan glacial units in the area. These will be examined, and bluff stability problems along the shoreline will be illustrated.

Seven companion papers have been submitted for publication in Volume 7 of Geoscience Wisconsin, available from the Wisconsin Geological and Natural History Survey. These papers provide a more detailed description of many of the stops.

The road log was prepared by David Mickelson and the other authors with the help of Lee Clayton, Ardith Hansel, and William Newman. We thank Ann Bauhs for her excellent typing of the manuscript and Mike Mudrey and Mike Czechanski for their help on technical aspects of publication.

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ROADLOG

MILES

0.00 0.0
Intersection of Johnson Street and Wisconsin Avenue. Look to the right (south) and you'll see the State Capitol. It sits atop a drumlin that is cored with sand and gravel. This is one of the many drumlins of the Green Bay Lobe that we will cross between here and the Kettle Moraine.

0.8 0.8
Rise onto till surface. This is a drumlinized hill composed of till at the surface.

0.6 1.4
Intersection with Baldwin Street. A small drumlin lies to the right. The area to the left is underlain by sand and silt of glacial Lake Yahara overlain by Holocene peat. Lake Mendota lies just to the north of the park that you can see on the left. Glacial Lake Yahara at its highest level was approximately 10 feet higher than present-day Lakes Monona (845 ft) and Mendota (849 ft).

0.5 1.9
Continue right (east) on East Johnson Street. All of this area was covered by glacial Lake Yahara.

0.3 2.2
Rise onto an outwash surface.

0.4 2.6
Continue east on Johnson Street.

0.3 2.9
Intersection with East Washington Avenue. Turn left (east) on East Washington Avenue and get into right lane.

0.3 3.2
Turn right (east) on Wisconsin Highway 30. This surface is till.

0.8 4.0
To the right a sand and gravel operation can be seen. This pit is in outwash derived from the northeast and deposited by water flowing from retreating ice into glacial Lake Yahara. This gravel pit is one of many in the Madison area in conflict with suburban development. It is one of the closest to the central part of the city that is still operating.

0.5 4.5
Cross Highway 51. Continue east on Wisconsin Highway 30 and rise from Cambrian sandstone onto Prairie du Chien Formation, St. Peter Sandstone, and dolomite of the Sinnipee Group. We are rising out of the Yahara lowland, a preglacial valley cut by a tributary of the Rock River.

1.4 6.9
Intersection with Interstate Highways 90 and 94. Continue east on Interstate Highway 94. All of this area is underlain by till, much of it drumlinized. For the next 45 miles we will be crossing the drumlin field of the Green Bay Lobe. Most of the up-land surface is underlain by till. Some of the drumlins are cored with sand and gravel. In the low areas some outwash is present and it is overlain by at least 3 m of peat. Much of this peat has been drained for agriculture. The highway runs more or less east-west, and the drumlins in this area are oriented toward the northeast. As we progress across the drumlin field the orientation of the drumlins changes: they will be directly north near Johnson Creek and then northwest as we approach the east side of the lobe (fig. 1). As we drive eastward toward the axis of the lobe the drumlins will appear more elongate.

4.4 11.3
Intersection with County Highway N. We are now on the dip slope of the Ordovician dolomite, and we will continue

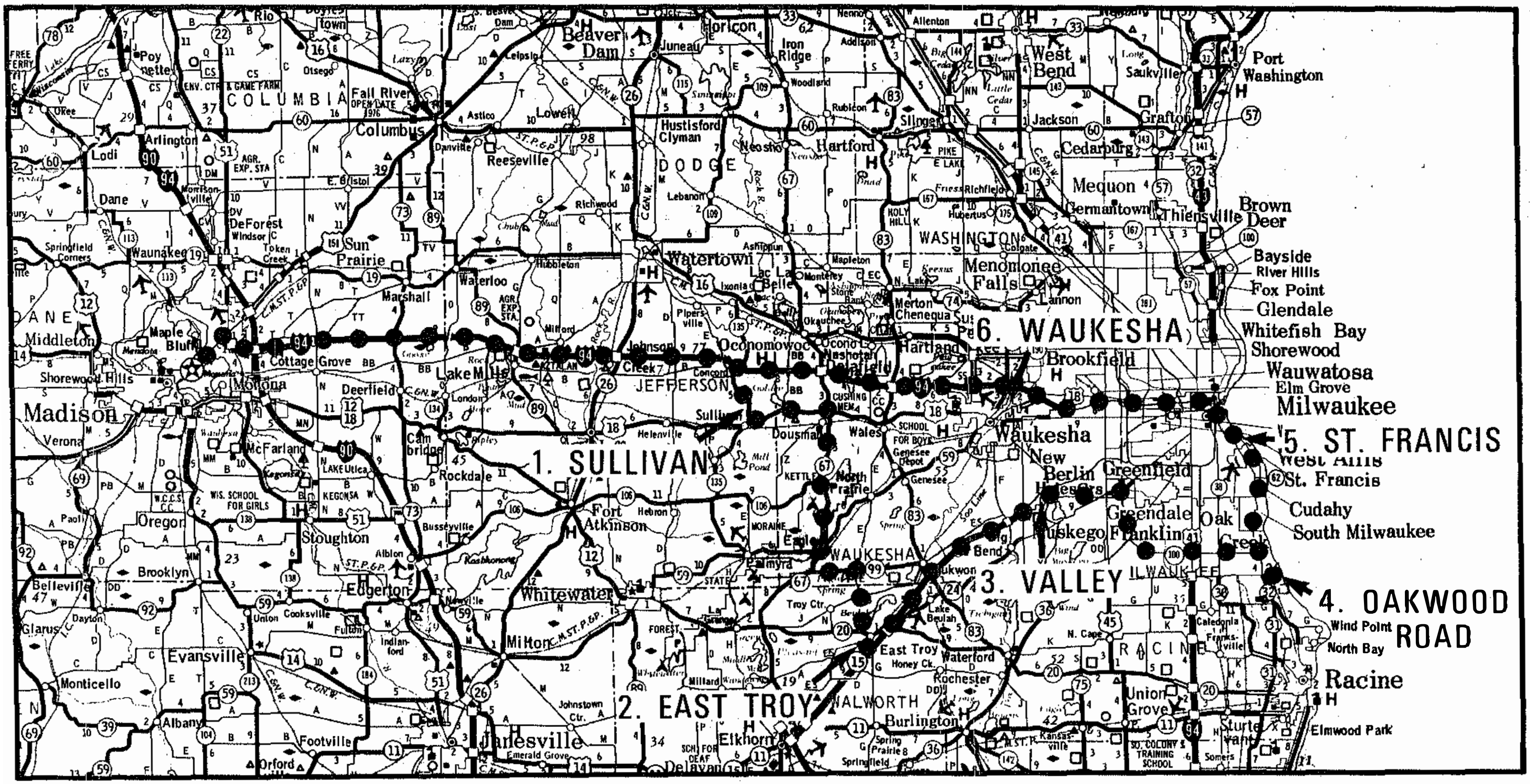


FIGURE 1.--Highway map of Wisconsin showing location of stops discussed in roadlog. See surficial deposits map (fig. 2) at same scale.

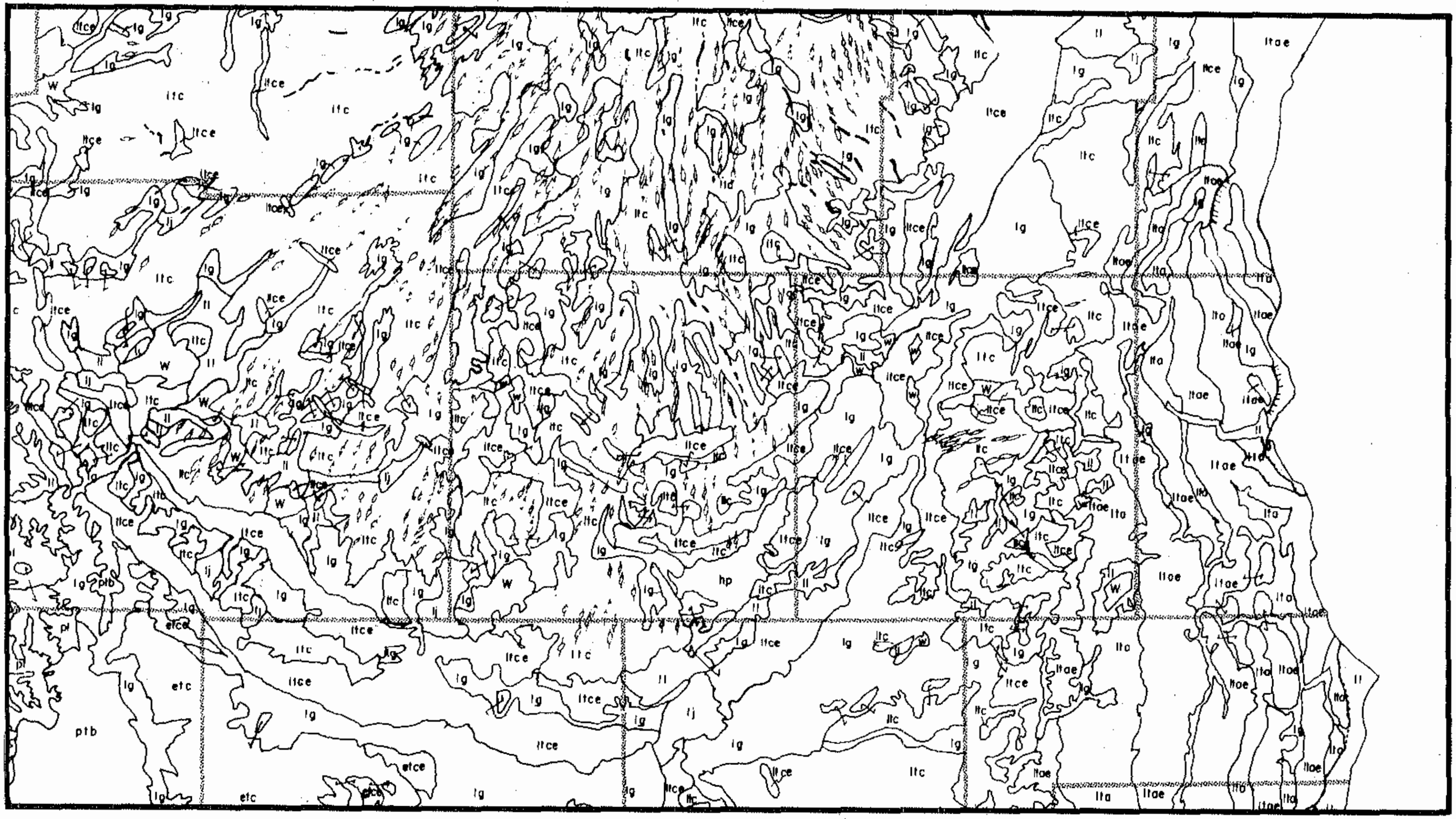


FIGURE 2.--Surficial deposits map of part of southern Wisconsin. Units are labelled with two or three letters with the following meaning. First letter is age: h, holocene; l, late Wisconsinan; e, early Wisconsinan; p, pre-Wisconsinan. Second letter is material: a, alluvium; g, outwash; j, ice-contact stratified drift; l, lake deposits; t, till. Third letter is textural group: a, silty clay and clay loam; b, loam and silt loam; c, sandy loam and loamy sand. Fourth letter: e, end moraine. Drumlins are shown as ellipses with lines through showing long axis of drumlin, eskers shown as solid heavy line.

(1) color this map
(2) put these categories into better format groups
i.e. age material
holocene etc.

on the Ordovician dolomite for approximately 30 miles. Drumlins can be seen ahead to the right and to the left.

2.4 13.7
The view to the left is typical of an interdrumlin area. Note that this is a sod farm. In some places drainage is sufficient to grow corn as on the right. Crops such as spearmint, carrots, and onions are common on these muck soils. The soils on the drumlins developed mostly in till and are alfisols. Madison is near the boundary between original prairie and deciduous forest and from here eastward prairies were relatively rare except on very well drained outwash sites.

3.7 17.4
Highway 73 exit. Continue east on Interstate 94.

3.7 21.1
Enter Jefferson County.

4.3 25.4
Lake Mills exit. Continue on Interstate 94.

3.4 28.8
Cross Crawfish River. This river and the Rock River 2.5 miles ahead carried outwash from the retreating Green Bay Lobe.

2.5 31.3
Cross the Rock River. The Rock River carried a large amount of outwash from the retreating Green Bay Lobe. It now drains Horicon Marsh, which is about 25 miles north of here. Notice that as we have come eastward into the middle of the drumlin field the drumlins are more elongate than they were near the margin.

1.4 32.7
Johnson Creek exit; Wisconsin Highway 26. Continue on Interstate 94.

0.5 33.2
As Interstate 94 crosses Highway 26, look to the left and behind. There is a small exposure in a drumlin behind the truck stop. This exposure contains till overlying and interbedded with sand and gravel in the drumlin. Continue east on Interstate 94.

8.7 41.9
Sullivan exit; Wisconsin Highway 135. Turn right and head south on Highway 135. We are now heading in the same direction as the ice flowed, and drumlins can be seen from both sides of the bus along the route to the first stop.

0.5 42.4
Continue on Highway Wisconsin 135 through Concord Center.

3.9 46.3

STOP 1. SULLIVAN DRUMLIN PIT

by Scott Stanford and D. M. Mickelson

Topics for discussion: supraglacial origin of upper till or till-like materials, origin of subglacial till (advance and retreat hypothesis), interpretation of folding style and orientation, origin of drumlins.

The Sullivan pit is excavated in what appears to be drumlinized outwash surface. Three examples of ductile subglacial deformation and a sequence of what are interpreted as basal and superglacial till are visible. This locality is described in more detail in Stanford (1982, 1983). On the north wall recumbent folds in sand are exposed. Axes of these folds are roughly parallel to ice flow and to the drumlin axis, (fig. 3,4) suggesting that they are not the result of drag from overriding ice. Instead, these folds may be similar in origin to intrastratal recumbent folds in subaqueous sediment, which form when fine sand and silt liquefy (that is, lose shear strength upon deformation under high pore pressure) and flow in response to a shear stress or differential load. If this interpretation is valid, these folds may represent flow of liquefied sediment toward the drumlin (Stanford, 1983).

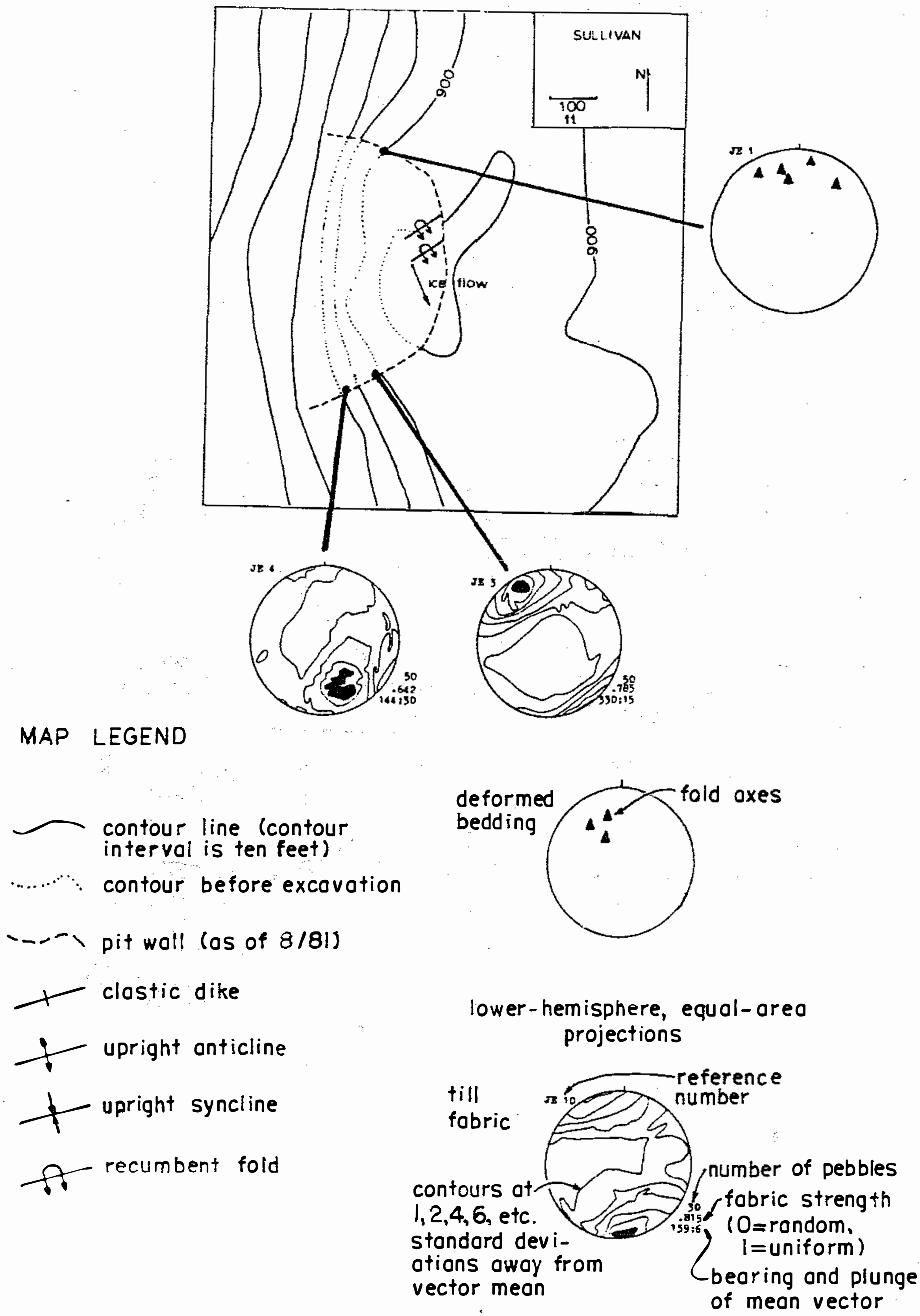


FIGURE 3.--Sullivan Pit map, showing orientation and location of fold axes, and legend for pit maps.

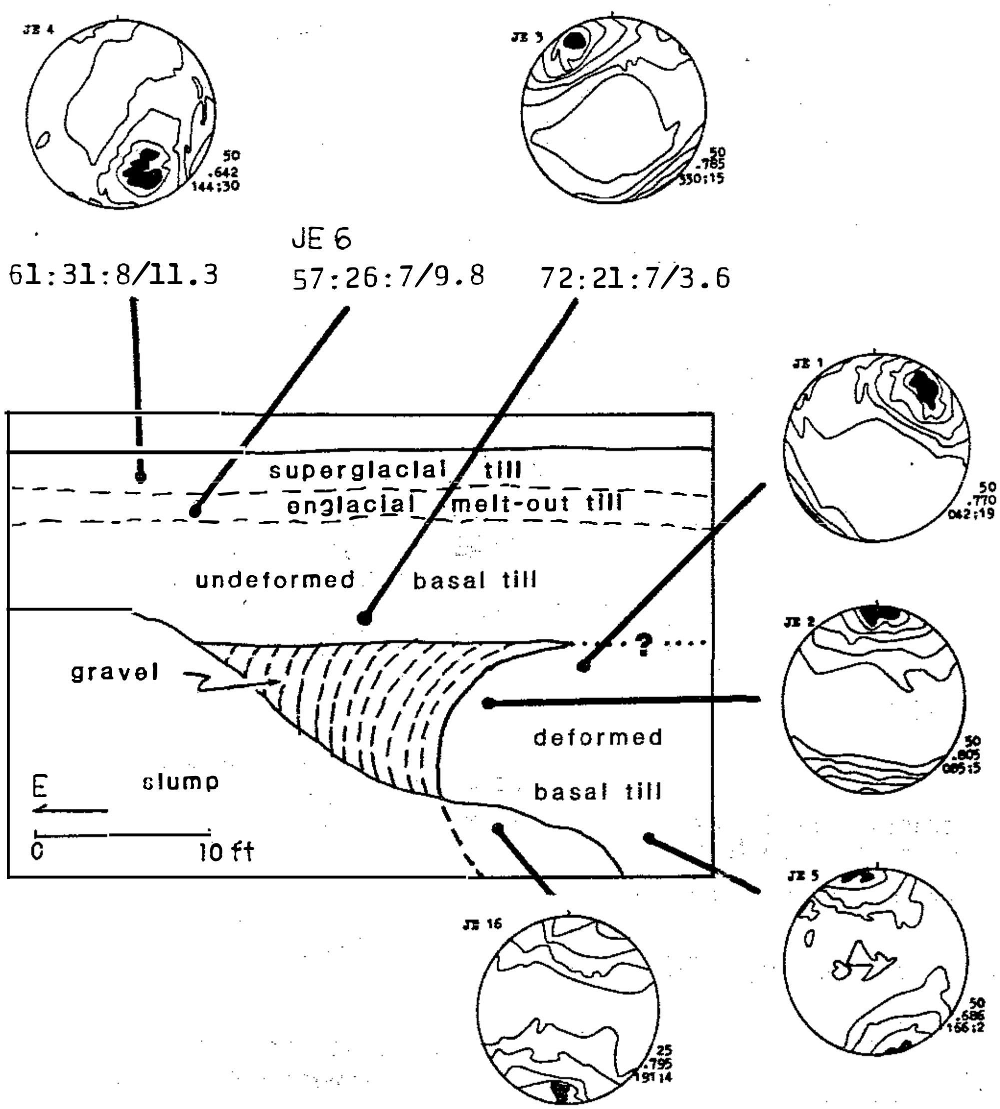


FIGURE 4.--Outdrop diagram for section at south end of Sullivan pit. Numbers beneath fabric diagrams are the sand:silt:clay and magnetic susceptibility of the till sampled at that spot.

Recumbent folds in gravel are exposed on the east wall of the pit. The folds open downglacier, and their axes are perpendicular to ice flow; both these features suggest that overriding ice formed the folds. Owing to the thicker bedding and greater shear strength of the gravel, which hinder internal deformation, the fold amplitudes and wavelengths are greater than those in sand.

Farther south on the wall of the pit, a sequence of deformed till and outwash is truncated and overlain by undeformed till (fig. 4). Lithologically, three units can be distinguished in the till (Johnson and others, 1982). The lowermost unit, interpreted as basal till, is characterized by a uniform sandy loam matrix, low magnetic susceptibility, and, based on coarse sand and pebble lithology counts, a large amount (85 percent) of local rock types (primarily dolomite), indicating basal transport (fig. 5). The middle unit, interpreted as an englacial melt-out till, has thin sand and silt layers and has a high magnetic susceptibility, which indicates an enrichment in magnetite derived from distant Precambrian rock types transported in upper portions of the glacier. The uppermost unit, interpreted as supraglacial till, is more bouldery than the other units, has a high magnetic susceptibility, and far-travelled Precambrian rock types (40 percent) in the pebble and coarse sand fractions than the basal till (fig. 5).

The fabric on the margin of the lower, deformed till unit does not have the steep plunge one would expect if the till had been folded in concordance with the adjacent gravel. Rather than folding, two interpretations seem likely. (1) The deformed unit might be injected till formed when till overlying unstable outwash was gradually pushed by the weight of overlying ice (or sank due to a density inversion) down into the gravel, which then folded conformably around the intrusion. Instability and ductile deformation of the outwash would occur if shear strength were reduced by high pore pressure. Fabric in the margins of the till would tend to be transverse to the flow direction of the mass owing to compressive flow (Boulton, 1971), so steep plunges would not be expected. (2) Another possibiltiy is that the till was indeed folded but, rather than buckling in response to layer-parallel compression (flexural folding), it deformed viscously by shearing parallel to the axial plane (passive folding). Again, this deformation would not create a fabric with steep plunge.

In either case, the truncation of the deformed section by the upper, undeformed till defines an angular unconformity that represents a period of erosion followed by continued deposition. The duration of this erosional hiatus cannot be determined, but elsewhere in the drumlin field the drumlin-forming basal till occurs both as an upper unit carpeting the drumlin topography and as a lower unit coring the drumlins, indicating that both predrumlin and postdrumlin subglacial deposition has occurred--perhaps during advance and retreat of ice, respectively. The lower, deformed till at Sullivan, then, may be "advance" till and the upper, undeformed unit may be "retreat" till (Whittecar and Mickelson, 1977, 1979).

Whittecar and Mickelson suggested the following sequence of events. Deposition of sand and gravel in front of an advancing ice margin. This sand and gravel would be deposited on top of pre-existing till and other materials. With continued advance the glacier would cover the area and subglacial till would be deposited. As ice thickened, deposition at the bed ceased and non deposition or erosion took place as till and outwash beneath the ice was folded and as material migrated into the core. Erosion at the bed continued until after folding ceased because folds are truncated by an unconformity.

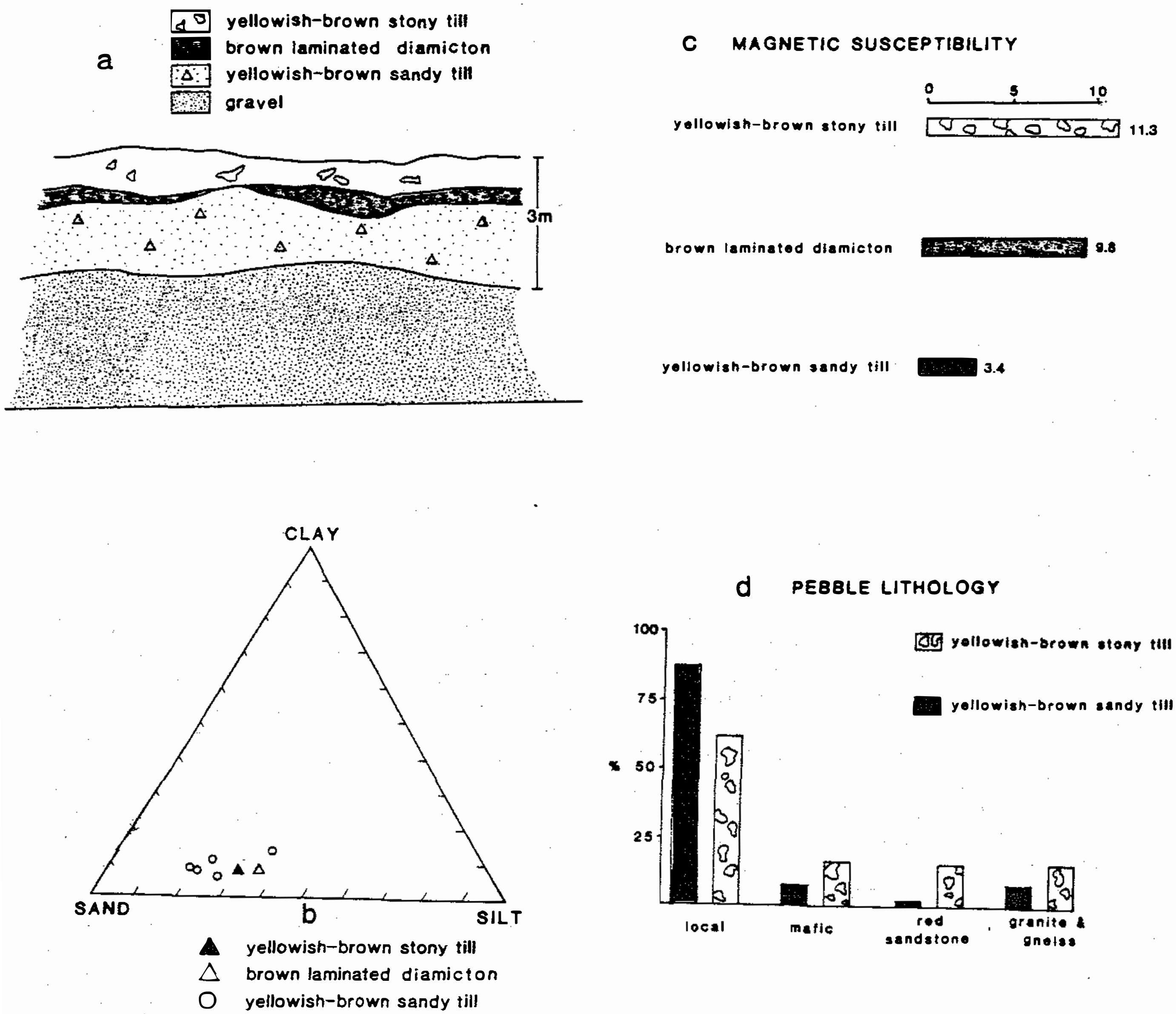


FIGURE 5.--Data on units above gravel on east wall of Sullivan Pit. From Johnson and others (1982). (a) Diagrammatic section of upper units. (b) Percentage of sand, silt, and clay (.002mm) for samples at this location. (c) Magnetic susceptibility of units shown in a. (d) Pebble lithology of units shown in a.

Subglacial deposition of till began again after the drumlin had been shaped, probably during ice retreat. This till veneers the eroded gravel and till in the drumlin form. Subsequently, deposition of englacial meltout till (?) and supraglacial till took place as the ice finally disappeared. After deglaciation, a thin silt cap was deposited on the till surface.

Continue south on Highway 135.

0.4 46.7
Turn left (east) on U. S. Highway 18.

2.1 48.8
Waukesha-Jefferson county line.

0.6 49.4
Intersection with County Highway BB. Continue east on Highway 18. You are now crossing Green Bay Lobe outwash deposited between the drumlins and the Kettle Interlobate Moraine ahead. The Kettle Moraine was formed between the Green Bay and Lake Michigan Lobes and consists of a complex of till and stratified deposits.

3.8 53.2
Turn right (south) on Wisconsin Highway 67. We are at the west edge (Green Bay lobe side) of the Kettle Interlobate Moraine, and we will parallel the Kettle Interlobate Moraine for several miles.

1.6 54.8
Note house on left with facing of cobbles from coarse gravel of the Kettle Moraine.

1.2 56.0
Intersection with County Highway D east. Continue on Highway 67.

0.7 56.7
Gravel pit on left contains till about 2 m thick over gravel and sand.

0.6 57.3
Intersection with Wisconsin Highway 106. Continue south on Wisconsin Highway 67.

0.6 57.9
Enter central part of the Kettle Moraine. Here the Green Bay Lobe side is expressed by a low pitted outwash surface.

0.6 58.5
Turn right (west) on to County Highway ZZ.

0.1 58.6
Turn right (north) into Ottawa Lake Recreation Area. Rest Stop (reset mileage).

0.3 58.9
Turn left (east) on to County Highway ZZ.

0.1 59.0
Turn right on Wisconsin Highway 67.

0.4 59.4
Intersection with County Highway ZZ east. To the left is well developed Kettle Moraine topography. Continue on Wisconsin Highway 67.

1.1 60.5
Intersection with Highway X. We are driving parallel to the Lake Michigan Lobe side of the Kettle Moraine. Continue on Highway 67.

1.8 62.3
Small gravel pit on left shows coarse gravel typical of the Kettle Moraine.

0.3 62.6
We are at the crest of the Kettle Moraine and begin to drop off to the south side of the hummocky ridge onto outwash.

1.2 63.8
Intersection with Wisconsin Highway 59 in the Town of Eagle. Continue on Highway 67.

0.1 63.9
Turn left (east) onto Main Street (Highway NN).

0.6 64.5
Turn right (south) onto Markham Road. You are riding on a high, somewhat pitted outwash surface deposited between ice of the Lake Michigan Lobe and the Kettle Moraine to the west.

1.5 66.0
Turn left (east) onto Highway Wisconsin 99. Descend into the valley of Jericho Creek, an ice-marginal or subglacial channel cut beneath stagnantice of the retreating Lake Michigan Lobe. Large collapse areas (like Eagle Spring Lake to your right) are present in the valley bottom, indicating that sediment was deposited over ice. Note hummocky ice-contact topography as we descend into this part of the valley.

1.7 67.7
Turn right (south) onto County Highway E. We are crossing the approximate location of the axis of a suried preglacial bedrock valley named the Troy Valley by W. C. Alden (1905, 1918) at the beginning of the century. Alden thought that this valley extended southwestward across Walworth County into Illinois, but recent work by J. C. Green (1968) shows that a continuous valley does not exist due to the presence of a bedrock drainage divide in central Walworth County. Instead, the bedrock valley beneath us here actually drains to the northeast toward Lake Michigan. Our elevation here on this belt of collapsed topography is about 825 feet, more than 300 feet above the bedrock floor of the preglacial valley.

0.8 68.5
Note hummocky collapse topography on right.

0.5 69.0
Waukesha-Walworth county line. We are on pitted outwash.

1.1 70.1
After rising onto uncollapsed remnant of outwash surface, cross County Highway J and continue south on Town Line Road. After crossing County Highway J, climb onto till surface.

0.8 70.9
Leave till surface and drive onto collapsed sand and gravel.

1.1 72.0
Bear right, continuing on Town Line Road. Booth Lake, to the west, is in an ice-block depression.

0.7 72.7
Continue south on Town Line Road after crossing Wisconsin Highway 20.

0.6 73.3
Cross County Highway ES (old Wisconsin Highway 15). Continue south on Town Line Road, and rise onto till upland.

0.9 74.2
Turn left into borrow pit.

STOP 2. EAST TROY GRAVEL PIT

by Leon R. Follmer
and Allan F. Schneider

Topics for discussion: correlation and age of stratigraphic units, characteristics of buried soil, possible age of buried soil, stratigraphic relationship of geologic units with soil.

The truncated soil profile preserved here is an unusual occurrence of a paleosol for the area. The pedologic characteristics and its stratigraphic position dictate with some certainty that it is a Sangamon Soil. No previous observations of the Sangamon Soil have been made within the area of classical Wisconsinan glaciation in Wisconsin before this exposure was found in 1972 (Schneider and Follmer, 1983).

The soil is formed in a coarse, cobbly outwash and is overlain by the Tiskilwa till. About 15 m of outwash are exposed in the pit and more than 22 underlie the base of the pit. This outwash may be related to the preglacial Troy Valley described by Green (1968), but is not likely. This site appears to overlie a preglacial upland. We think the outwash is Illinoian and probably follows a course that is unrelated to the Troy Valley.

The major morphological feature exposed in the highwall is a very clay-rich, dark-reddish-brown (5YR 3/3 to 4/4) argillic Bt horizon (fig. 6). It averages about one meter thick and has a wavy lower boundary. In one place a well-developed pendant extends to 2.1 m below the top of the truncated Bt horizon. This unusually large pendant was selected for detailed study. The results of this study and a discussion of the stratigraphy, soil features and correlation problems are written up in a report by Schneider and Follmer (1983). Only the highlights of this study will be given here. A sketch that shows the spatial arrangement of geologic and pedologic features is presented in figure 6. The report also includes a profile description and results of particle-size and clay-mineral analyses.

The profile is truncated by a bed of gray silt that lies directly on the argillic Bt horizon. To the right (facing the highwall) the silt pinches out into the Tiskilwa Till. The till below the pinchout appears to be similar to the overlying till except for color--olive-brown above and pinkish-brown below. Laboratory analyses indicate that the olive till contains more sand (54 percent vs. about 45 percent), more expandable clay minerals (38 percent vs. about 24 percent) and less illite (45 percent vs. about 64 percent). This clay-mineral composition probably reflects mixing of the Tiskilwa till with the paleosol. The olive coloration may be the result of incorporation of organic matter contained in the paleosol that promoted gleying (reduction), which now is experiencing oxidation indicated by the yellowish-brown iron oxide mottles. Subtle structures in the olive till appear to be "stratification" of till and Bt material, suggesting that this is a basal deformation zone of the first phase of the Tiskilwa advance.

Several years ago the upper part of the profile appeared to be developed in till, which was overlain by a silt that may have contained the upper horizons of a paleosol. A few samples were collected at the time of observation but the results of the laboratory examination were inconclusive except for the recognition of the Bt horizon that can be seen now. The Bt developed in till was about the same as the Bt in outwash. Both show evidence of weathering, iron accumulation and very poor resolution of clay minerals by x-ray diffraction. The Bt that we can see now exhibits an excessive accumulation of clay masses and argillans (clay skins) that continuously coat and separate the sand, pebbles and cobbles. Stratification is evident in the pendant morphology and particle-size data. Layers show variations in sand content from 23 to 84 percent and in clay content from 14 to 48 percent. The clay mineral analysis of the Bt shows a moderate amount of expandable clays, about 28 percent, and a substantial amount of illite, about 55 percent.

The relatively large amount of illite indicates that severe weathering has not occurred. Considering the calcareous parent material and the type of clay minerals present, the chemistry of the profile during formation probably experienced a near-neutral pH condition. This environment favors a near-stable condition where clay minerals tend to accumulate without undergoing much change. The processes of accumulation include the translocation from overlying (A and E) horizons, residual build-up from dissolution of the carbonate rocks, which contain some illite, and transformation of other minerals into clay minerals. The translocation process (illuviation) was the most important process here at this site.

The lower boundary of the Bt appears sharp, but close inspection reveals that some illuvial clay passes through

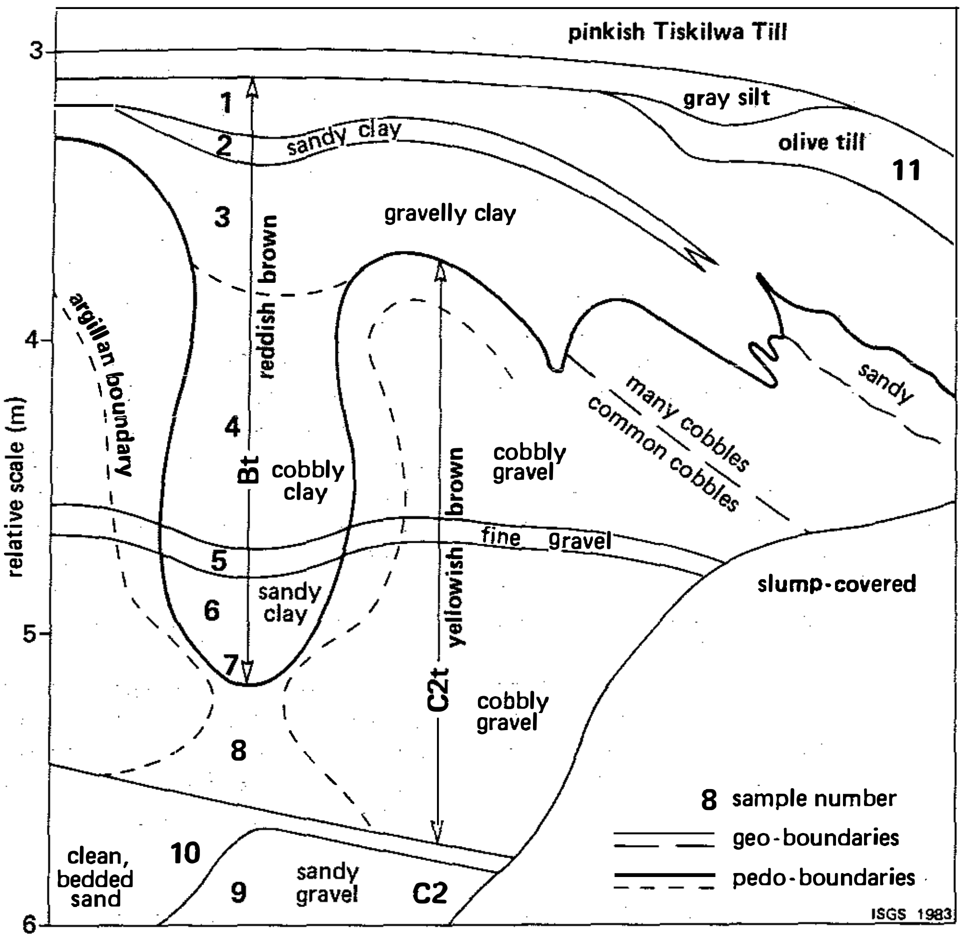


FIGURE 6.--Sketch of part of high wall of pit at Stop 2 showing major features of buried soil.

into the yellowish brown gravel. The depth of penetration is irregular and tends to form a halo around the pendant. This indicates the direction of leaching water during formation. The pendant itself is evidence of a preferred direction of water movement in which clay was being translocated in a complex to the point where the complex flocculated in response to the higher pH in calcareous gravels and/or it "filtered out" in response to the loss of water into the gravel. This is commonly known as the beta process that forms a beta horizon, a part of the Bt horizon that forms a second clay accumulation position at lithologic discontinuities referred as geologic boundaries.

The average thickness and clay content of the Bt horizon and the very large size of the pendant strongly suggest that this soil is more strongly developed than present-day soils formed in Wisconsinan outwash. Based on observed features and a conceptual reconstruction of the whole profile, we judge that this soil would classify in terms of the current USDA Soil Taxonomy as a Typic Paleudalf at the pendant and a Typic Hapludalf where the Bt is less than about one meter in thickness. Therefore, this soil is best considered an interglacial soil and at this site we can clearly demonstrate that the soil is buried by Wisconsinan deposits. These relationships led us to conclude with some certainty that the buried soil features here are the remains of a Sangamon Soil.

0.2 74.4
Leave Stop 2 and turn left (south) onto Town Line Road.

0.8 75.2
Turn left (east) onto Swoboda Road.

0.5 75.7
Look left (north) for a view of the lowland with collapsed sand and gravel that we have just crossed and the Kettle Interlobate Moraine in the distance. The elevation here is about the same as the crest of the Kettle Moraine.

0.5 76.2
Turn left (north) onto County Highway G.

0.8 77.0
Turn right onto Wisconsin Highway 15 east.

1.8 78.8
Cross Wisconsin Highway 20. We are now driving in the up-ice direction (northeast) through the Waukesha drumlin field, approximately paralleling the long axes of the drumlins. These features were shaped by the Delavan Sublobe of the Lake Michigan Lobe. Between here and Stop 3 our route will continue through the drumlins, virtually all of which are cored with sand and gravel and capped with 2 to 20 m of New Berlin till similar to that seen at the south end of the pit at Stop 2.

4.2 83.0
Cross Waukesha-Walworth county line.

2.7 85.7
Cross the Fox River. There are two major Fox Rivers in Wisconsin. This Fox River flows southward, ultimately to the Illinois River. Although in this immediate area the river cuts obliquely across the drumlin field, south of here it follows the distal edge of the Valparaiso Moraine and thus defines the general western limit of the area of distribution of the Oak Creek till. The other Fox River flows northward from near Portage to Green Bay.

2.9 88.6
Look left to large exposure in gravel-cored drumlin. This is the Hales Pit described in Stanford (1983).

5.2 93.8
On the right is a drumlin, cored with sand and gravel, that has been nearly

completely excavated. This is the Valley Sand and Gravel pit described in Stanford (1983) and is the location of Stop 3.

0.6 94.4
Turn right on Highway Y.

0.2 94.6
Turn right into Valley Sand and Gravel Pit.

STOP 3. VALLEY SAND AND GRAVEL

by Scott Stanford and D. M. Mickelson

Topics for discussion: origin of tills (advance and retreat hypothesis), interpretation of the nature of deformation (folds, clastic dikes), and origin of drumlins.

Stratigraphy

Whittecar (1976) recognized four till units older than that from the advance that formed the drumlin in the Valley Pits: tills D, C, B, and A, from top to bottom. The uppermost three are all yellowish-brown to pinkish sandy loam and may be from a single glaciation, but till A is a reddish-brown silt loam and probably represents a separate advance. The critical outcrops that exposed all the units no longer exists. At present, two older tills are exposed. At location A (fig. 7,8), a thick deformed section of a grayish yellow-brown (7.5YR 6/3) sandy loam till is overlain by a yellowish brown (7.5YR 7/4) sandy loam till; these units are interpreted as unoxidized and oxidized portions of till B. At location B, (fig. 7,9) a pebble-poor, yellowish-brown (10YR 7/3) sandy loam till (grayer where unoxidized) (tentatively identified as till B) underlies and is intruded into a stonier yellowish brown (10YR 6/3) sandy-loam till (till C or D). An indurated iron-oxide layer occurs discontinuously along the contact. All samples have similar grain size, magnetic susceptibility, and pebble lithology (fig. 10), but the intrusion of till B into till C/D and the marked stratigraphic separation of the units indicate that they represent separate depositional events. Stratigraphically and lithologically, tills B, C, and D seem to correlate with the Tiskilwa till, which lies outside and beneath the Haeger-New Berlin till in northeastern Illinois and southeastern Wisconsin. The drumlins were formed by the advance that deposited the New Berlin till, (Schneider, 1983). Grainsite characteristics of this till are shown in figures 11 and 12 and lithologic characteristics in Tables 1 and 2.

Structure

Overlying the older till units is a thick sequence of outwash sand and gravel, which, in turn, is overlain by the drumlin-forming New Berlin till. The outwash is predominantly flat-lying and truncated by the drumlin shape on the flanks of the drumlin, indicating extensive erosion in the neighboring interdrumlin areas. At locations A and B, however, deformation of the outwash and underlying till can be seen. At location A the south limb of a large upright anticline is exposed (fig. 8). The fold axis is perpendicular to ice flow, suggesting that ice drag had a role in the formation of the fold, buy the actual deformation mechanisms are unclear.

At location B, till B and outwash are intruded into the overlying till C/D (fig. 9). Noteworthy features here are the preservation of primary stratification in the dike and the till fabric pattern in and surrounding the dike. Fabric has a nearly vertical plunge in the dike—as is expected if there was upward flow of till into the dike—but on the edge of the dike the fabric does not have steep plunge, indicating that the enclosing till did not deform in concert with the dike. The fabric data and the preservation of stratification suggest that the dike was produced by a laminar, diapiric-type flow of low-density, viscous sediment into a denser, rigid till cap. This behavior, in turn, suggests that high pore pressure

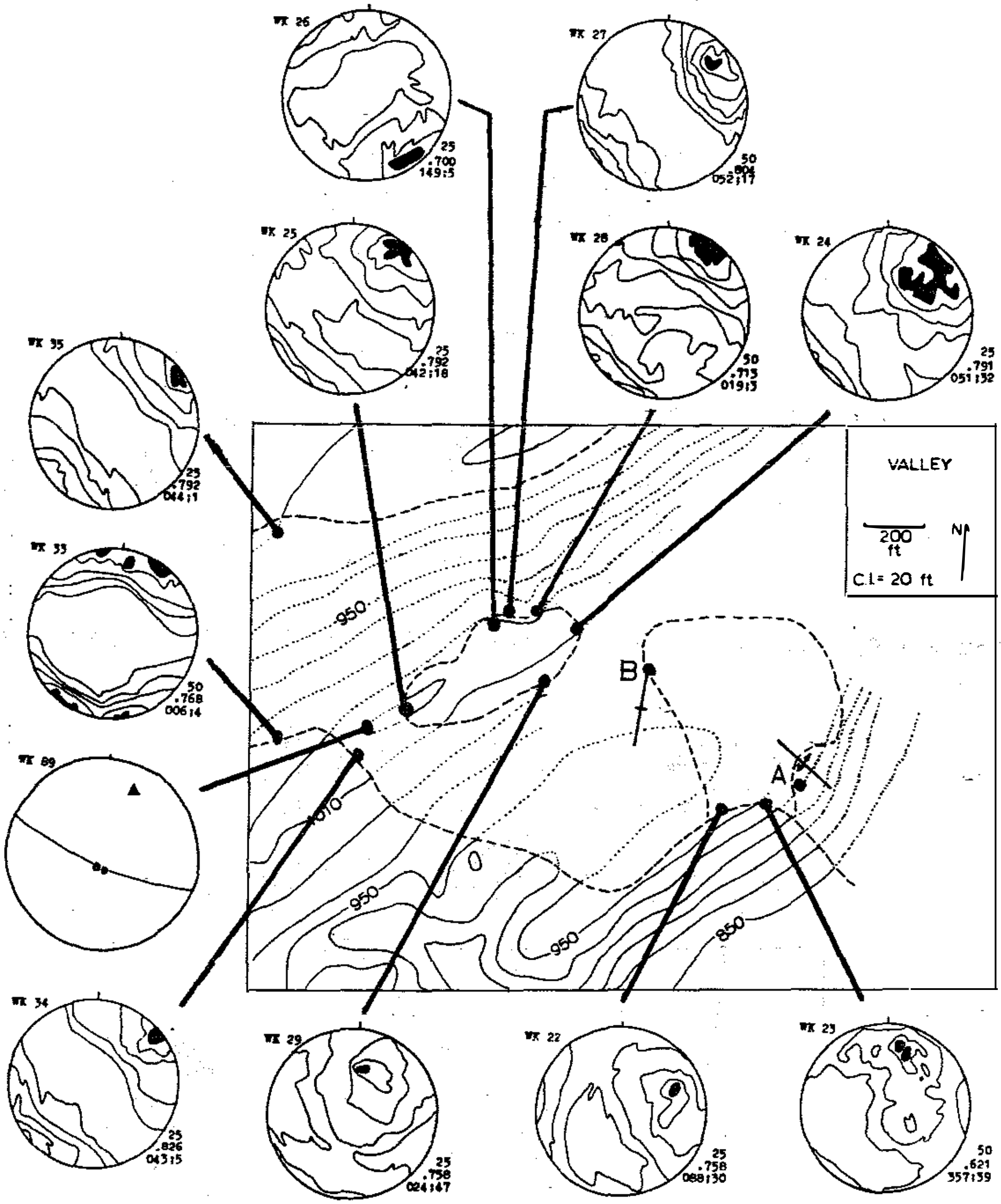


FIGURE 7.--Valley pit map, showing location of fabric measurements and structural data. For explanation of symbols, see figure 3.

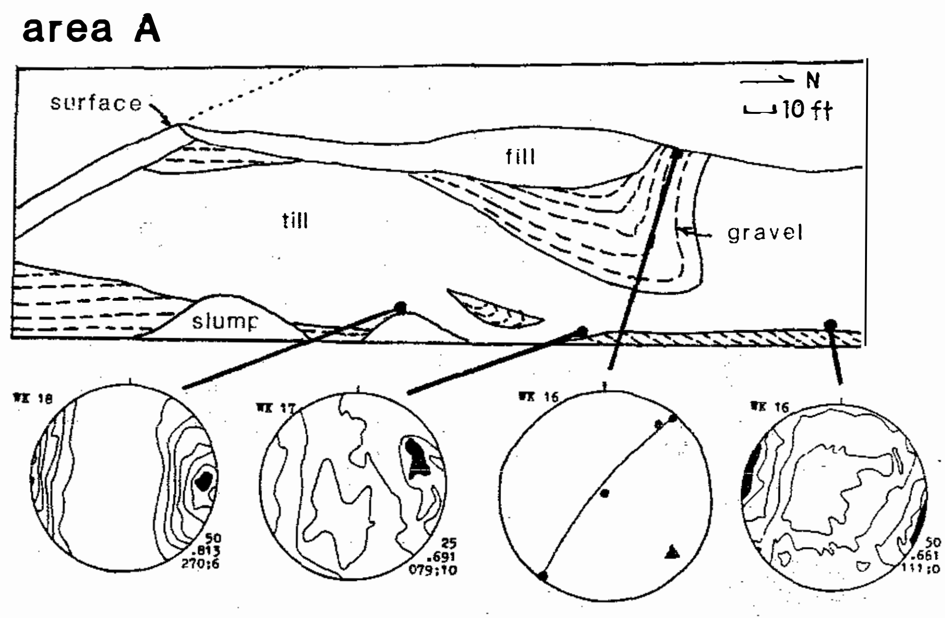


FIGURE 8.--Outcrop diagram of location A, Valley Pit. See figure 7 for location.

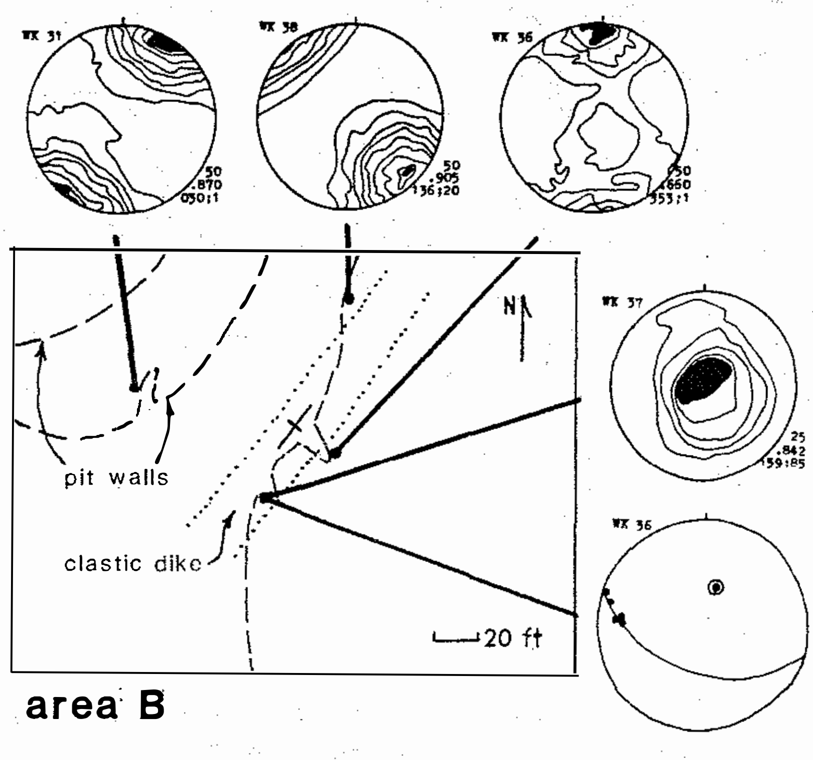


FIGURE 9.--Map of location B, Valley Pit. See figure 7 for location.

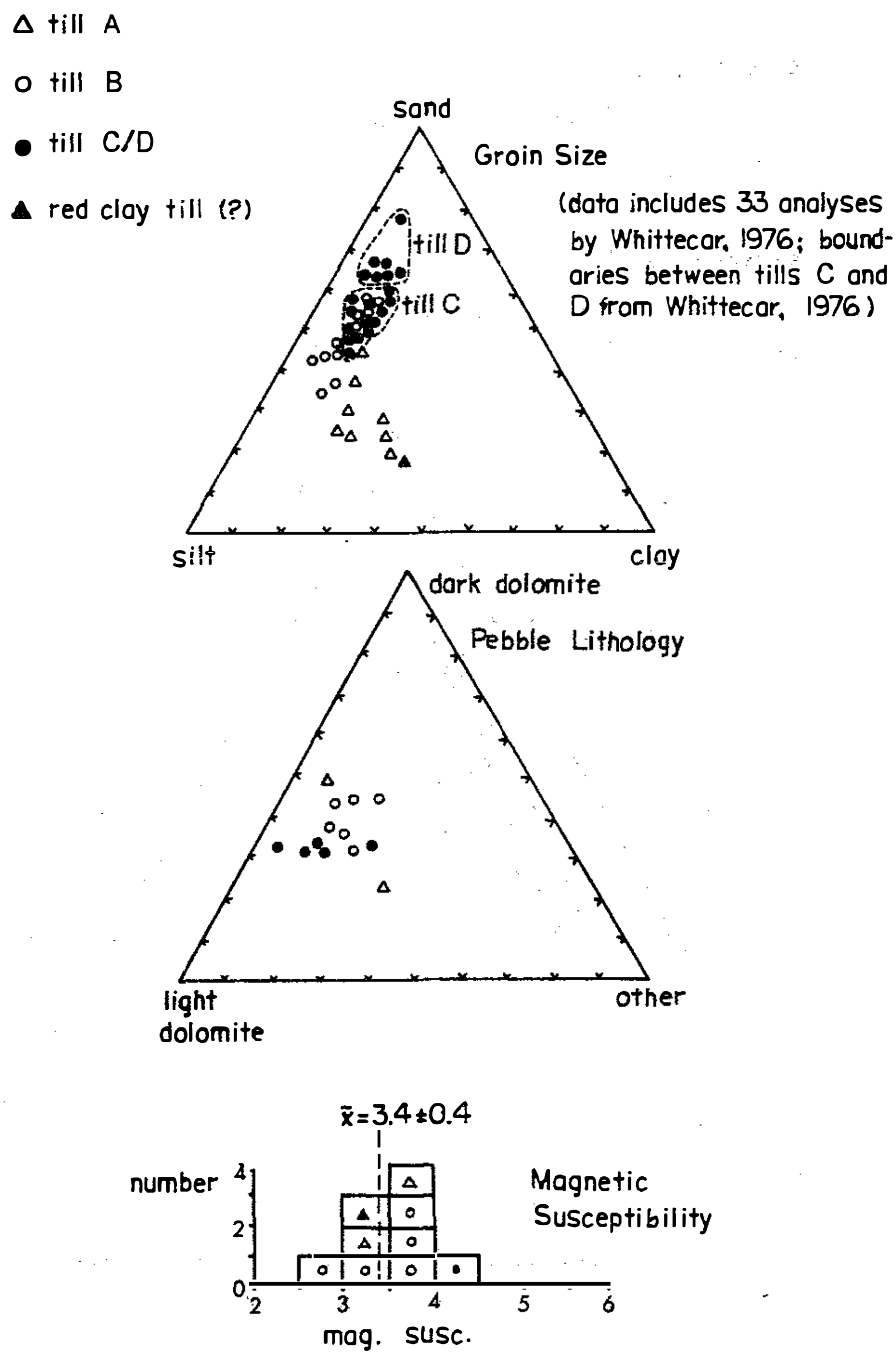


FIGURE 10.--Summary of the lithology of older till units. From Stanford (1982).

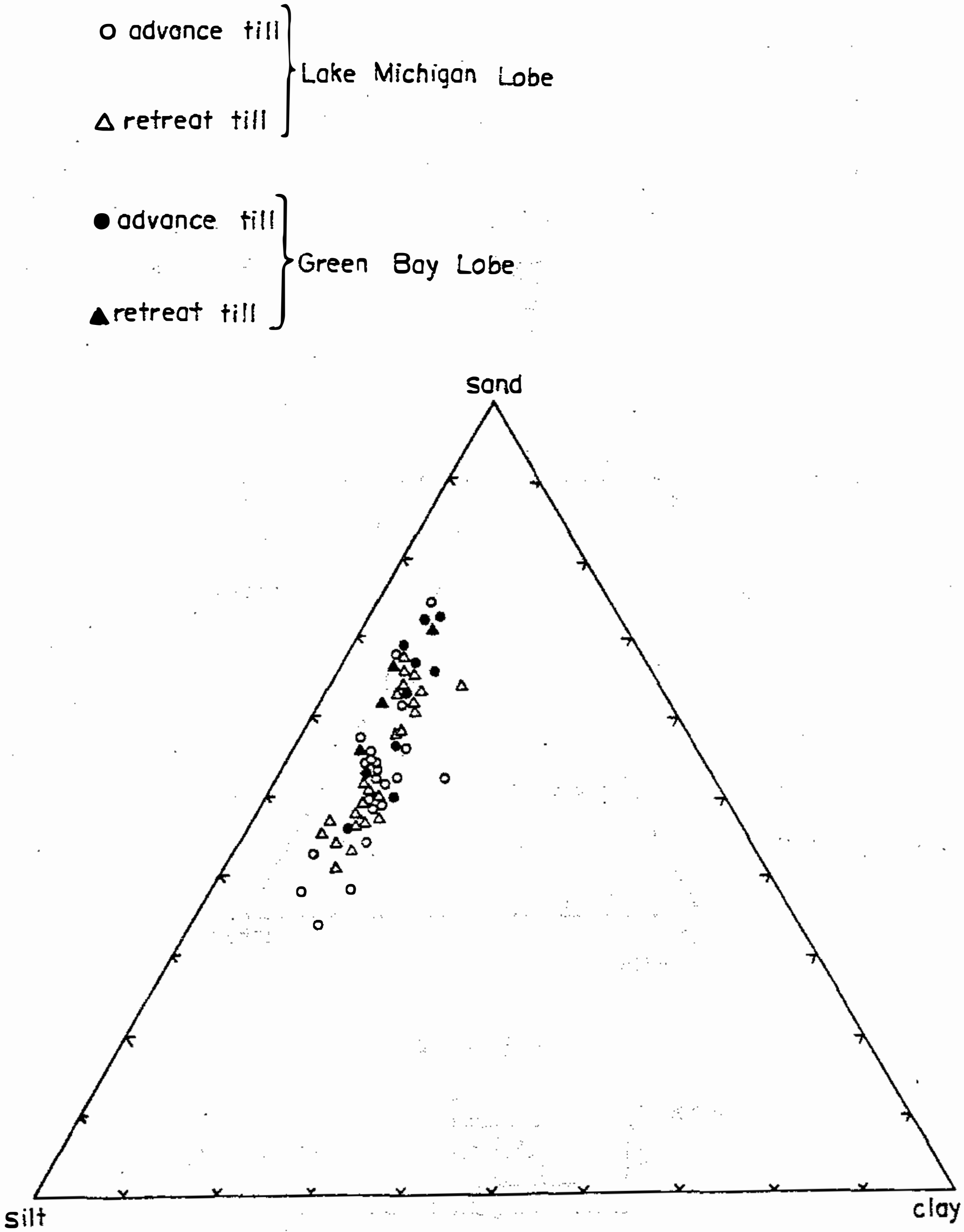


FIGURE 11.--Grain size distribution of advance and retreat tills where recognized in drumlins of the Lake Michigan Lobe (New Berlin Formation) and Green Bay Lobe (Horicon Formation). From Stanford (1982). Size boundaries 2 mm, 0.0625 mm, 0.002 mm.

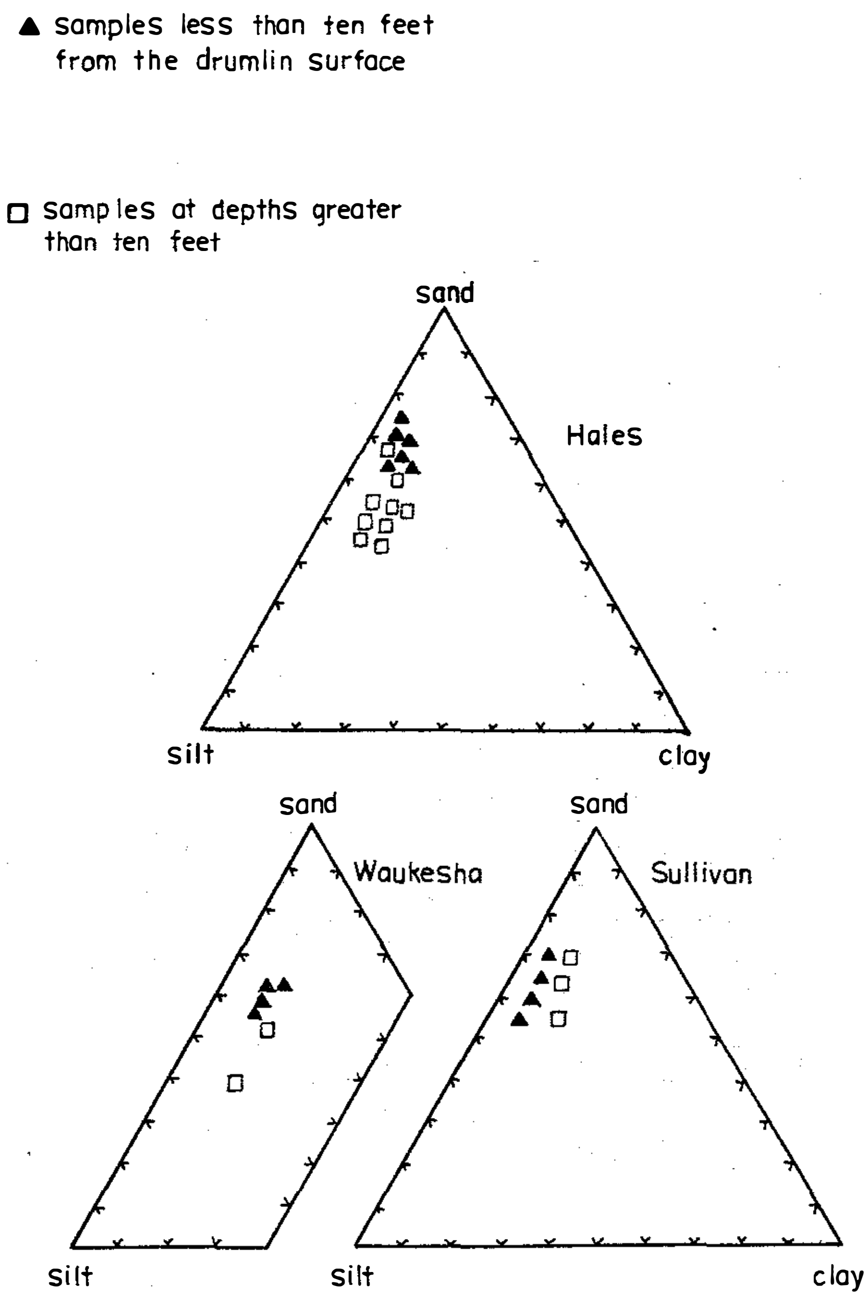


FIGURE 12.--Grainsize data indicating coarser textures of supraglacial till in three drumlins. From Stanford (1980). Size boundaries 2 mm, 0.0625 mm, 0.002 mm.

TABLE 1.--Coarse sand lithology of till in the New Berlin Formation (Lake Michigan Lobe) and Horicon Formation (Green Bay Lobe). From Stanford (1982).

Group		light dolomite	dark dolomite	quartz	mafic rock	granite and gneiss	other	number of sites	number of grains
Lake Michigan Lobe	retreat	47.2 ± 9.9	16.1 ± 2.3	21.4 ± 6.4	4.9 ± 2.0	10.4 ± 3.6	—	5	787
	advance	48.3 ± 6.6	21.3 ± 4.2	19.0 ± 4.4	4.2 ± 1.2	7.1 ± 4.6	0.2 ± 0.4	7	1069
	composite	47.8 ± 8.1	19.1 ± 4.4	20.0 ± 5.5	4.5 ± 1.6	8.4 ± 4.5	0.1 ± 0.3	12	1856
Green Bay Lobe	retreat	44.9 ± 1.6	12.8 ± 1.3	21.5 ± 6.7	5.7 ± 4.5	12.6 ± 10.1	0.3 ± 0.4	3	597
	advance	50.8 ± 5.3	18.5 ± 2.2	20.4 ± 5.0	2.0 ± 0.7	7.9 ± 1.5	0.4 ± 0.3	3	482
	composite	47.9 ± 4.9	15.7 ± 3.3	21.0 ± 5.9	3.9 ± 3.7	10.2 ± 7.6	0.3 ± 0.3	6	1079

TABLE 2.--Pebble lithology of the till of the New Berlin Formation (Lake Michigan Lobe) and Horicon Formation (Green Bay Lobe). From Stanford (1982).

Group		light dolomite	dark dolomite	mafic rock	red sandstone	sandstone and shale	granite and gneiss	quartzite and chert	greenstone	number of sites	number of pebbles
Lake Michigan Lobe	retreat	52.8 ± 5.4	34.7 ± 6.4	4.9 ± 3.0	0.8 ± 1.0	0.5 ± 0.9	3.0 ± 2.3	3.3 ± 2.0	0.1 ± 0.3	32	2264
	advance	52.4 ± 6.1	35.9 ± 5.7	5.4 ± 2.4	0.8 ± 0.8	0.4 ± 1.0	2.3 ± 1.8	2.7 ± 2.1	0.1 ± 0.2	31	2330
	composite	52.6 ± 5.7	35.3 ± 6.1	5.1 ± 2.8	0.8 ± 0.9	0.5 ± 0.9	2.6 ± 2.1	3.0 ± 2.0	0.1 ± 0.3	63	4594
Green Bay Lobe	retreat (including supraglacial)	48.6 ± 0.5	26.7 ± 15.6	9.9 ± 3.1	9.0 ± 4.0	0.9 ± 0.9	3.6 ± 1.9	1.8 ± 1.8	1.8 ± 1.8	2	113
	advance	46.2 ± 4.7	38.1 ± 5.5	4.6 ± 1.3	1.7 ± 0.8	0.3 ± 0.6	3.1 ± 0.8	5.9 ± 3.5	—	8	832
	composite	45.7 ± 4.5	36.8 ± 9.3	5.3 ± 2.7	2.9 ± 3.3	0.4 ± 0.7	3.3 ± 1.8	5.7 ± 3.6	0.3 ± 1.0	12	1058

was present in the sandy outwash in order to establish a density inversion and mobilize the sediment. High pore pressure could result from rapid compaction and dewatering of fine-grained material during ice advance, combined with trapping of this water by aquitards and a frozen bed at the margin.

There is no clear distinction of the advance and retreat units of the upper till in this pit, but at the south end of location A retreat till can be seen carpeting the drumlin surface and truncating older till and outwash, indicating that it postdates formation of the drumlin.

0.9 96.0
Leave Valley Sand and Gravel pit and turn leftt (north) onto County Highway Y.

0.1 96.1
Turn right (east) onto County Highway HH (College Avenue). This is the western limit of the gray, clayey Oak Creek till, which will be examined at Stop 4, and corresponds to the distal margin of the Valparaiso Moraine farther south in Waukesha, Racine, and Kenosha Counties. From here eastward to the front of the Tinley Moraine, the Oak Creek till is relatively thin and thus does not obscure the strong NE-SW topographic lineation produced by the drumlins, which protrude above the thin blanket of younger till typically by as much as 15 to 20 m and by more than 30 m in some places.

1.0 97.1
Intersection with County Highway HI (small road) from the northeast. Continue ahead (east) on Highway HH. An auger hole drilled on the property of Peace Lutheran Church at the northeast corner of this intersection to a depth of 7 m penetrated only Oak Creek till.

Note NE-SW oriented drumlin to the south.

0.4 97.5
Rise over south end of another drumlin oriented NE-SW. Note gravel pit on west side of hill.

1.1 98.6
Cross another drumlin crest. Immediately after descending the east slope of this drumlin, which is made of New Berlin till (probably with a sand and gravel core), we will cross the distal margin of the Tinley Moraine, as mapped by Schneider. The front of the moraine is nearly continuous both north and south of here, but in this immediate area it is not nearly so well defined and is broken by shallow meltwater channels that carried drainage from the front of the moraine into glacial Lake Muskego a mile or so to the south. Upon crossing the morainic margin, the NE-SW drumlin topography is no longer visible, due to significant thickening of the Oak Creek till.

1.0 99.6
Intersection with Sunny Slope Road from the north; continue ahead (east) on Highway HH. Just east of the intersection on the south side of the road at Heritage United Presbyterian Church an auger hole was drilled to a depth of 12 m. As in the case of the hole drilled at Peace Lutheran Church, only Oak Creek till was encountered. Both holes were drilled with the expectation of reaching the contact between the Oak Creek till and the underlying New Berlin till.

0.4 100.0
Turn left (northwest) onto Wisconsin Highway 24 (Janesville Road).

1.8 101.8
Turn right (south) onto Wisconsin Highway 100 (108th Street).

0.1 101.9
Intersection with Forest Home Avenue. Continue straight on Highway 100 but turn left (east) into Whitnall Park immediately past MacDonalds.

0.1 102.0
Turn right following signs to Wehr Nature Center and Gardens. We are in the Tinley Moraine.

0.4 102.1
Lunch Stop. After lunch turn around and return to Highway 100.

0.5 102.6
Turn left (south) onto Highway 100. The field trip route from here has 2 options. The log below assumes that Stop 4 (Oakwood Road) will be visited. A decision will be made at the time of the trip depending on time available and condition of the exposure. If Stop 4 is not visited, skip ahead in the roadlog to mile 126.8 for a log of the route from here directly to Stop 5.

3.2 105.8
Intersection with Wisconsin Highway 36 (Loomis Road). Continue on Highway 100.

1.8 107.6
Descend proximal slope of Tinley Moraine.

1.5 109.3
Cross distal margin of the Lake Border Moraine System.

1.7 110.8
Cross Interstate 94.

2.0 112.8
Cross Wisconsin Highway 38.

2.7 115.4
Intersection with Highway 32. Turn right (south) onto Wisconsin Highway 32 (Chicago Road).

1.1 116.4
Turn left (east) onto Oakwood Road, and continue ahead to the Lake Michigan shoreline.

0.8 117.3

STOP 4. OAKWOOD ROAD SECTION
by D. M. Mickelson

Topics for discussion: stratigraphy and characteristics of the Oak Creek Formation, history of bluff recession along Lake Michigan, factors leading to bluff recession and processes of downslope movement.

In the early 1970s water level in Lake Michigan was higher than it is now and by 1975 shoreline erosion was of concern along much of the shoreline. Supported by the Wisconsin Coastal Management Program and the University of Wisconsin Sea Grant Program, a team of geologists mapped failure type, bluff height, stratigraphy, beach characteristics and nearshore bathymetry along much of Wisconsin's eroding Lake Michigan shoreline. The results of this study were published in Mickelson and others (1977). Several follow-up studies have led to much of the information presented on this trip.

The bluff here contains a unit of Oak Creek till at the base of the bluff (2A, fig. 13). This is overlain by interbedded fine sand and silt that makes up much of the middle part of the bluff. This in turn is overlain by another till unit (2B) of the Oak Creek Formation. The Oak Creek Formation is discussed in some detail by Hansel (1983) and Schneider (1983) and will not be described here.

Instead, this stop description will concentrate on the mechanics and processesof of bluff erosion. This site has been monitored since the summer of 1977 by Sterrett (1980) and Peters (1982). A further discussion of bluff changes through time on the Lake Michigan shoreline is given by Peters (1983).

Of the eight sites that have been monitored, Bender Park (Oakwood Road and north) was examined most closely (fig. 14). Sterrett (1980) attempted to ac-

TABLE 3.--Estimates of amounts of material lost by different processes and proportion lost during spring as opposed to summer and fall.

BENDER PARK	PERCENT LOST IN SPRING	PERCENT LOST BY SLUMPING[1]	PERCENT LOST BY SOLIFLUCTION[2]	PERCENT LOST BY RILL AND SHEETWASH[3]
1	69	2	81	17
2	73	0	73	27
3	68	46	46	7

[1] Total loss measured by rods.
[2] Includes estimates where rods were lost.
[3] Calculated by modified U.S.L.E. and rill volume measurements.

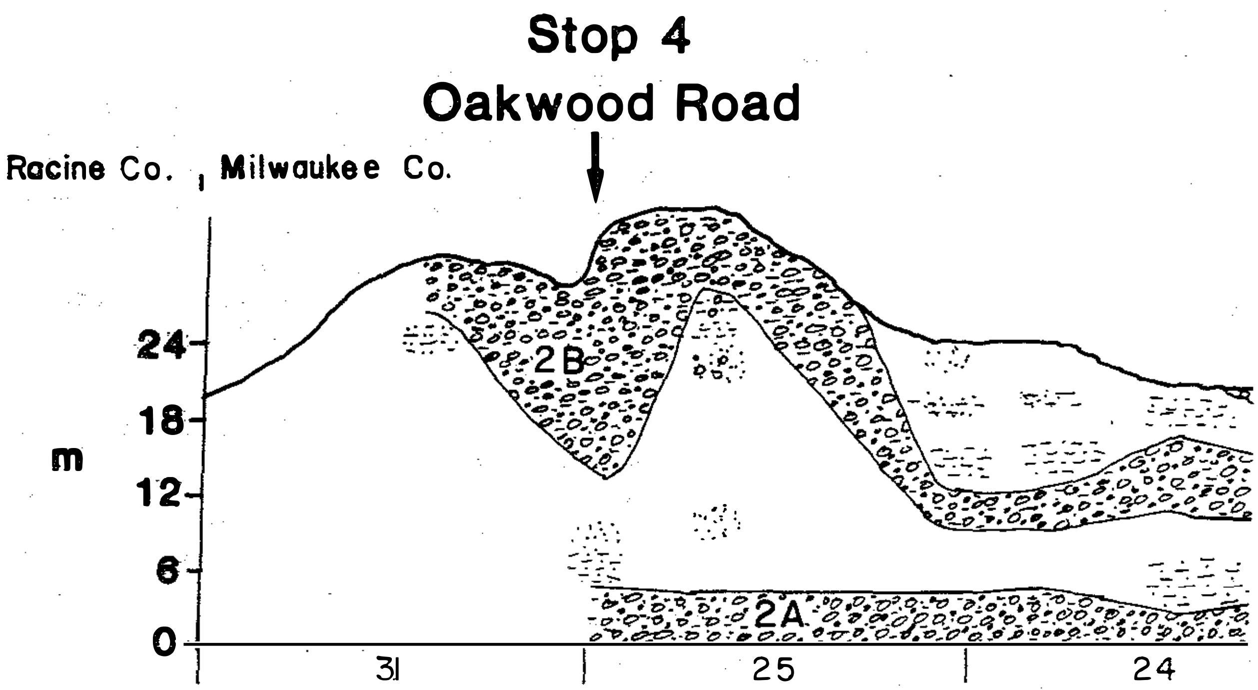


FIGURE 13.--Sketch of stratigraphic units of the Oak Creek Formation exposed in the bluff in Bender Park. Oakwood Road is location of Stop 4. Numbers at bottom are sections in T.S.N.

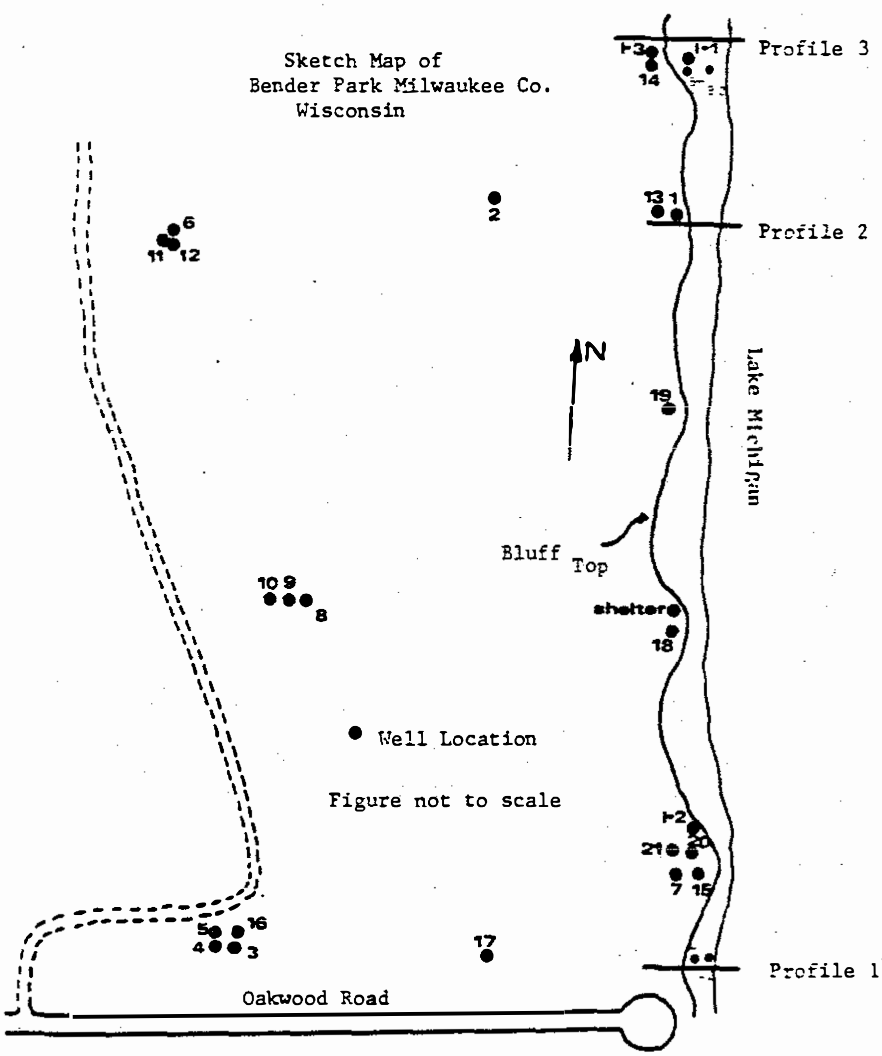


FIGURE 14.--Sketch map of Bender Park showing location of wells and profiles. From Sterrett, (1980).

complish two main objectives. He defined the processes operating on the slopes and quantified the amounts of debris moved by these processes. He calculated these amounts by measuring loss of soil against steel rods driven into the slope, measurement of slope profiles (fig. 15), and by using a modified version of the Universal Soil Loss Equation.

At Bender Park during 1977 and 1978 about 70 percent of the material lost at the three profiles (fig. 14,15) during a year was removed during spring thaw. Table 3 shows Sterrett's estimate of the relative amounts of material lost by different processes.

Sterrett also noted the effect of groundwater, especially on small slumps near the bluff top. The upper till unit is jointed and water level in these joints responds quickly to rainfall events. It appeared that at Profile 3 (fig. 15) an increase in water level of 0.8 m created accelerated bluff-top recession.

The largest slump known to have taken place along the shoreline during the 1970's is located just south of Oakwood Road. This was not observed until after the slump occurred in late spring of 1979. This slump was not triggered by wave erosion at the base and it seems likely that strain softening took place over a period of years leading to the failure.

Most of the bluffs at Bender Park are very steep, especially at the base (for example, Bender Park Profile 3 (fig. 15). Water deepens within a short distance offshore and storm waves break against the base of the bluff removing the products of mass movement and causing oversteepening of the bluff. This eventually leads to small slumps at the base of the bluff. Slumps then occur farther up the slope, eventually causing rapid bluff top recession. For a more detailed account of bluff changes through time, see Peters (1983).

Return to Wisconsin Highway 32.

0.8 118.1
Turn right (north) onto Wisconsin Highway 32.

1.1 119.2
Intersection with Wisconsin Highway 100 (Ryan Road). Continue on Highway 32.

4.4 12.6
Intersection with College Avenue. Turn right (east), following Highway 32.

0.5 124.1
Turn left (north) on Lake Drive, following Highway 32.

2.0 126.1
Intersection with Layton Avenue. Continue north on Lake Drive.

0.7 126.8
STOP 5. ST. FRANCIS POWER PLANT SITE
Park along road and walk across field to lakeshore about 0.2 miles south of power plant.

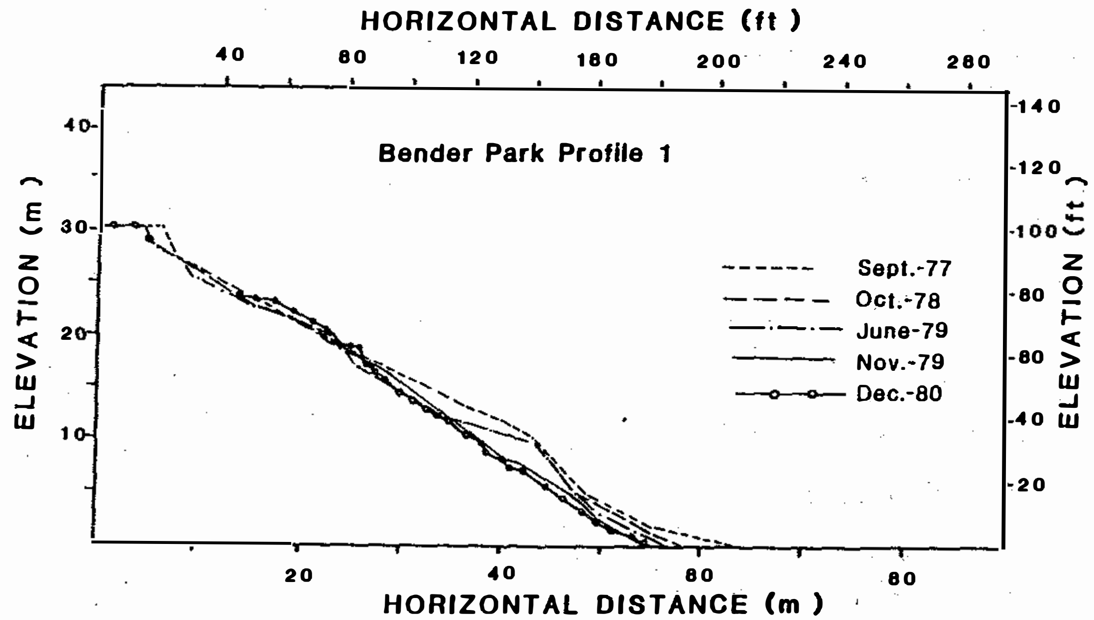
END OF STOP 4 ROAD LOG

If we do not visit Stop 4, the roadlog from Whitnall Park (lunch stop) begins here.

Exit from Whitnall Park to Forest Home Road.

0.6 102.6
Turn right (northeast) onto Forest Home Road.

0.5 103.1
Cross Grange Avenue and descend proximal slope of the Tinley Moraine to the Root River valley, which is underlain by outwash sand and gravel. Cross the valley train (which here is relatively narrow) and ascend distal slope of the outermost moraine of the Lake Border Morainic System. The glacial Root River here was an ice-marginal stream when the front of the Lake Michigan Lobe stood at this moraine.



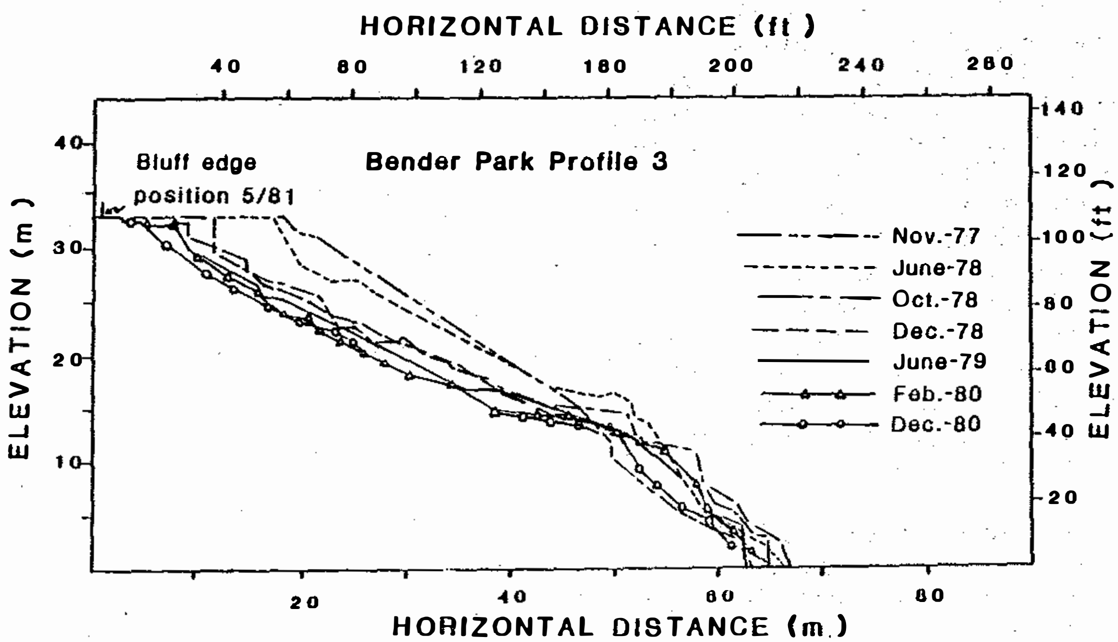


FIGURE 15.--Profiles showing changes in bluff in Bender Park at two locations. From Peters (1982).

1.5 104.6
Turn right (east) onto Interstate 894 (east).

4.2 108.8
Turn right on exit to Interstate 94 (south).

0.2 109.0
Exit I-94 to Layton Avenue east and continue east.

4.3 113.0
Turn left (north) on to Wisconsin Highway 32.

0.7 113.7

STOP 5. ST. FRANCIS POWER PLANT SITE

by Norman P. Lasca

Park along road and walk to lake shore across field about 0.2 miles south of power plant.

The Lake Michigan Basin was deepened and widened by glaciers during the four major glacial stages of the Pleistocene epoch during the last one to two million years of earth history. During the last major glaciation, the Wisconsinan, glaciers flowed from the north and northeast down the Lake Michigan Basin into Illinois, and down the Green Bay-Lake Winnebago lowland to a position near Madison, Wisconsin. Successive glacial advances and retreats coupled with the development of proglacial lakes left a series of unconsolidated deposits which formed Wisconsin's Lake Michigan shoreline.

The materials composing the Lake Michigan bluff in southern Milwaukee County were deposited by the Lake Michigan Lobe of the Wisconsinan glaciation. The Lobe spread westward and southwestward out of the Lake Michigan Basin, as well as southward down the Basin toward Illinois. As a result, much of the bluff material consists of glacial till. In addition, outwash and lacustrine sediments were deposited during intervals of ice-front recession and the development of proglacial lakes.

The materials found in the Lake bluffs at Stop 5 (fig. 16) are primarily unnamed units of the Oak Creek Formation (Mickelson and others, 1983) and consists of silty clay glacial till, lacustrine clays, silt and sands, and some glaciofluvial sands and gravels. In the northern portion of Milwaukee County these deposits are overlain by the lowest till (till III, fig. 16) of the Ozaukee Member of the Kewaunee Formation (Mickelson and others, 1983).

The oldest till (till I, fig. 16) exposed in the bluffs at Stop 5 is the uppermost till member of the New Berlin Formation (Mickelson, and others, in press). The till was probably deposited during a glacial advance prior to 14,000 B.P. and probably correlates with the Haeger Till Member of the Wedron Formation of northeastern Illinois (Willman and Frye, 1970). Till I consists of materials ranging in size from clay to boulders (2 m in diameter). The till at this locality is primarily a sandy silt with a large number of cobbles and boulders. The sand fraction ranges from 17 to 46 percent by weight. In other localities the till is significantly sandier, containing up to approximately 70 percent sand. The color of Till I varies from a light brownish-gray (10YR 6/2) to a brown (7.5YR 5/4) as is true of most of the tills at this locality. The carbonate content is approximately 24 percent.

In the north part of Stop 5 (fig. 16) till I is overlain by a boulder line which separates it from till II. In the south a subtle color change separates the two tills. Till I (?) in the south portion of the exposure may consist of two units the lower of which ranges in color from light reddish-brown (5YR 6/3) to dark reddish-gray (5YR 4/2). The boulder line marks a time of ice-front recession.

Then, another advance at approximately 13,000 B.P. deposited a much clayier till (till II), the lowest till unit of

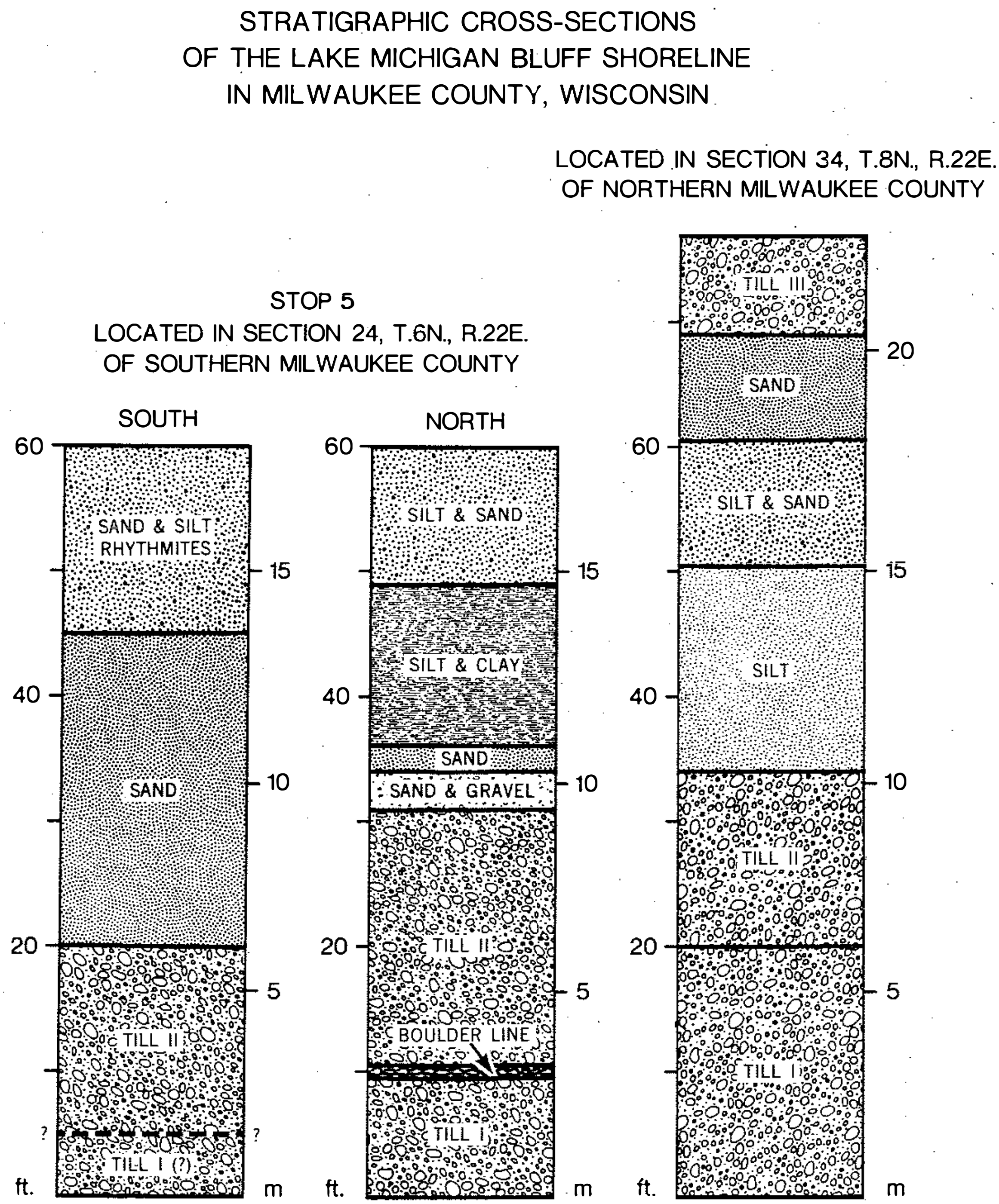


FIGURE 16.--Stratigraphic columns south of the St. Francis power plant, southern (Stop 5) and northern Milwaukee County, Wisconsin.

the Oak Creek Formation. At this locality the till is primarily a clayey silt with the clay-silt fraction ranging from 65 to 95 percent. The increased clay content was probably caused by incorporation of ice-marginal proglacial lake sediments into the glacial debris as glaciers moved west-southwestward out of the Lake Michigan Basin. Because till II is found interbedded with sands and gravels at some localities, it was probably deposited during several closely spaced fluctuations of the ice front. Till II is correlatable with Wadsworth Till Member of the Wedron Formation in Illinois (Willman and Frye, 1970). Schneider (in Mickelson and others, 1983) believes that it is very probably "... equivalent in age to the upper parts of the Horicon Formation of the Green Bay Lobe."

Following another major ice-front recession, which produced Glacial Lake Chicago in the southern Lake Michigan Basin, a third ice advance covered portions of northern Milwaukee County (till III, fig. 14). As till III is not found at this locality, suffice it to say that it is similar in texture to till II, but is sandier and redder in color.

At this locality, till II is overlain in the north by sand and gravel, sand, silt and clay, and sand and silt. In the south it is overlain by sand, and sand and silt rhythmites. These lacustrine and occasional glaciofluvial sediments are characteristics of the units found in exposures along the Lake Michigan bluffs in this area. Further to the west, till and glaciofluvial sediment dominate.

1.1 114.8
The bluff from here is protected by a breakwater as you can see in places out to the right across the park. This breakwater protects the Milwaukee Harbor.

0.7 115.5
Intersection with Oklahoma Avenue. Highway 32 turns west on Oklahoma but we continue north on Vermont Avenue.

0.8 116.3
Intersection with Nock Street. Continue north on Vermont Avenue, which is now called Superior Street. Superior Street runs along the top of a low topographic ridge that may represent part of an end moraine from the youngest of the Oak Creek advances. Borings in South Shore Park also indicate the presence of about 20 feet of well-sorted sand deposits mantling the ridge. These are interested to be beach deposits related to the Nipissing stage (Need, 1983).

0.4 116.7
At the intersection with East Russell Avenue turn right (east).

0.1 116.8
Coast Guard Station on right. Turn right to Interstate 794.

0.2 117.0
Turn right onto entrance ramp to Interstate 794.

1.7 118.7
Summit of bridge over Milwaukee Harbor. Follow signs to Interstate 94 west. The Kinnickinnic, Menomonee, and Milwaukee Rivers all enter Lake Michigan through the harbor. Numerous borings in the harbor area reveal the presence of 60 to 90 feet of generally loose and soft sediments of postglacial origin overlying 100 to 135 feet of generally dense and stiff glacial and lacustrine sediments. The paper by Need (1983) describes the stratigraphy of this area and the lower Milwaukee and Menomonee River valleys.

1.5 120.2
Interstate 794 ends. Continue ahead on Interstate 94, which comes in from the south. To the left is the industrialized Menomonee River Valley. The steep

valley walls are subdued and modified relicts of the buried postglacial valley walls. The flat valley bottom is the result of alluvial and estuarine/wetland deposition that occurred as the water level in the lake rose from the Chippewa stage (230 ft MSL) to the Nipissing stage (605 ft MSL). (Need, 1983).

3.0 123.2
Milwaukee County Stadium, home of the Brewers and the Green Bay Packers (in Milwaukee).

2.3 125.5
Cross 84th Street.

0.7 126.2
Intersection with Interstate 894 and U. S. Highway 45. Continue west on Interstate 94.

9.7 136.4
Wisconsin Highway 164 exit. Turn right onto exit ramp and then left (south) onto Highway 164.

1.2 137.7
Turn left into Waukesha Lime Quarry operated by Paine and Dolan Co.

STOP 6. WAUKESHA LIME QUARRY

by Scott Stanford and Leon Follmer

Topics for discussion: stratigraphy of Lake Michigan Lobe deposits, significance of buried soil, deformation style of sediment in drumlin core formation of drumlins.

Stratigraphy

The composite stratigraphic column at this site is as follows:

oxidized New Berlin till
unoxidized New Berlin till
———— possible unconformity
gravel
paleosol
gravel —— possible unconformity
Till A
gravel
red clay till (?)
———— striated surface
Silurian dolomite

The New Berlin till, evidently deposited by the advance that formed the drumlin, is the same as that seen at Stop 3, and characteristics of this till are given in figures 11 and 12 and tables 1 and 2.

Till A is a grayish (10YR 6/2) silt loam (fig. 10). It may be correlative to the Tiskilwa or Capron tills, both of which have similar grain size. The Capron till is found beneath and adjacent to the Tiskilwa till in southeastern Wisconsin (Bleuer, 1971; Fricke, 1976 (Mickelson and others, 1983). It could also correlate with other early or pre-Wisconsin units in northern Illinois.

The lowermost Pleistocene unit is a patchy and poorly-exposed red (5YR 6/4) clay. It rests on striated dolomite, suggesting that it is till, but it was not identified at any other site in the drumlin field. At present, it is unnamed and uncorrelated.

Structure

In this pit the upper till thickens from a feather edge on the drumlin flank to nearly 30 m thick in the drumlin core. This thickening occurs downward as well as in response to the rise of the drumlin surface, defining a pod-shaping body of till centered under the drumlin. In conjunction with this thickening, four out of the seven fabric measurements (fig. 17) have maxima that are perpendicular to ice flow. These fabrics do not occur in positions where transverse fabric produced by ice flow would be expected; instead, they probably were created by post-depositional lateral flow of till. Both the thickening and the perpendicular fabric indicate that previously deposited till flowed subglacially into the drumlin from neighboring areas. The resulting sediment accumulation served as the drumlin nucleus and was streamlined by erosion on the drumlin flanks and by remolding of till in the drumlin core. The presence of fabric that is parallel

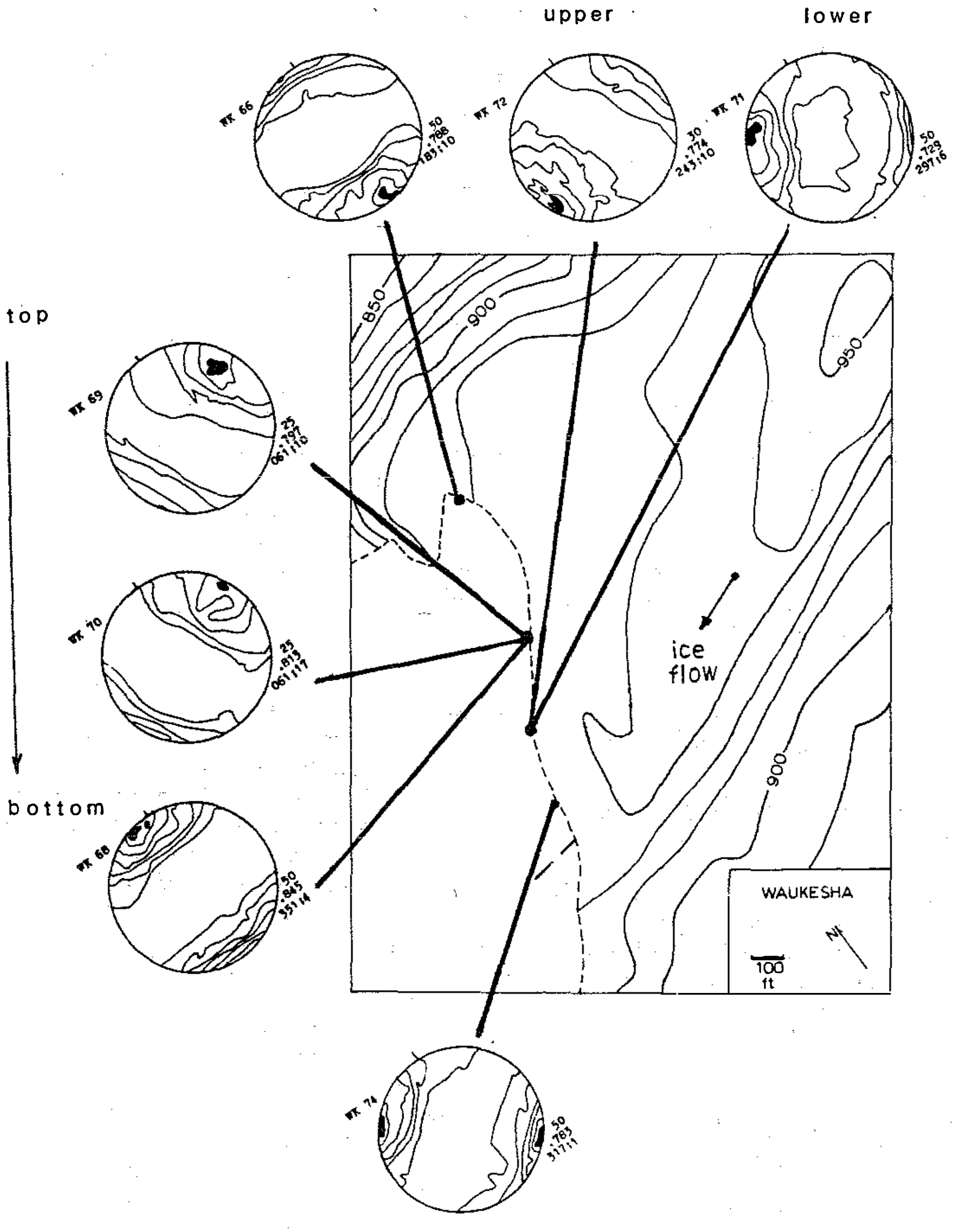


FIGURE 17.--Waukesha pit map, showing location of fabric measurements and structural data. Explanation of symbols shown in figure 3.

to ice flow above the perpendicular fabric perhaps reflects remolding of the upper portions of the till accumulation by shear from ice seeking a flow pattern of minimum drag.

For the most part the older till and outwash is flat lying. On the south end of the pit, though, there is a large upright syncline composed of gravel, till, sand, and silt layers. The fold axis is parallel to ice flow, so it is unlikely that drag from overriding ice created the fold. Given the size and orientation of the fold, one possibility is that folding might have occurred when sediment moved laterally toward the drumlin, especially if the strength of the sediments was lowered by high pore pressure.

Soil Profile

The buried soil (table 4) at this site is unusual in a number of ways. Several factors indicate that the soil is Holocene in age whereas other factors suggest that it relates to the last interglacial stage or the Sangamon Soil. It is not clear if the soil seen today is the one reported by Whittecar (1976).

In general, the characteristics of the soil, described in Table 5, are the same or equivalent to our present-day soils that one finds in the Midwest today, where moderately, well-developed soils are considered to be the norm.

Pollen and other paleoclimatic indicators found in Wisconsinan deposits of the midwest indicate a cooler climate than the present. In harmony with the climatic indicators, the documented paleosols of Wisconsinan age found in this region today are analogous to present-day soils found in boreal forest or the tundra. These soils are less developed than the common soils found in the midwest today. Therefore, based on pedological characteristics, the soil profile exposed here is most likely a Holocene or Sangamon Soil.

A third but less likely choice is that this soil relates to a warm interval within the Wisconsinan Stage. The best possibility is a relatively warm interval about 45 000 to 50 000 B.P., which falls within oxygen-isotope stage 3. But because no well-developed soil anywhere has been documented at that age, and the warmth of the world's climate at that time is estiamted from beetles in England and the oxygen isotope record from the oceans, an intra-Wisconsinan correlation seems unreasonable.

The main features that support a warm climate interpretation for this buried soil are the presence of an argillic horizon (Bt) and the weathered nature of the clay minerals (table 5). An increase of 12 percent clay is shown in the Bt1 horizon compared to the Ab horizon. The parent material of the soil is loamy outwash with some gravel (not measured) over a sandy gravel. The initial clay contents of the two materials are estimated to be less than 20 percent and less than 5 percent. Therefore, weathering and translocation can explain about half of the clay present in the Bt. The illite and chlorite values are reduced by one-third to one-half in the Bt compared to the 2C. The grain size discontinuity between the two materials explains some of these differences but the soil profile development trends are clearly imprinted over the discontinuity.

Samples 9-12 were collected to the right and lower down from the exposed profile. These are floaters of Bt material included in gray, sandy loam till, which is very much like the till overlying the profile. The particle size and clay mineral data indicate that these soft sediment clasts were derived from the soil in question. How they became incorporated into the till is not clear from the morphological relations.

TABLE 4.--Waukesha Lime Company, soil profile description.

Geologic unit	Sample no.	Horizon	Depth (cm)	Description
Sandy Till	1	C2	270-280	2.5Y 6/4 sandy loam, few stains, massive, friable, calcareous
Mix?	2	C2/A	285-295	10YR 5/3 sandy loam, many bright and gray mottles, weak blocky, diffuse stone conc. near top, pinches out to right, sharp boundaries
Sandy Silt	3	Ab	300-319	10YR 4/2 loam, few 6/8 stains, coarse angular blocky with internal welded granular structure, few 2/2 stains, firm, leached
Sandy Silt	4	Bt1	319-335	9YR 4/4 clay loam, blocky, few 2/2 argillans, few 2/1 masses of carbonized wood or Mn, few continuous joints from above, firm, leached argillic horizon
Sandy Silt	5	Bt2	335-353	
Sandy Gravel	6	2Bt3	353-375	9YR 4/3 loamy gravel, thick continuous 2/2 argillans on skeletal framework of 1-6 cm pebbles, mostly dolomite, few ghosts, matrix weakly calcareous, wavy lower boundary, argillic (beta) horizon
Sand	7	2C21	375-410	10YR 5/4 sand, mostly medium, no pebbles, massive, vague horizontal bedding, calcareous
	8	2C22	410-425	
Inclusions	9	Bt	600±	9YR 4/4 - 3/3 clay loam, isolated deformed "clasts" of Bt material in calcareous gray sandy loam till
	10	Bt	600±	
	11	Bt	600±	
	12	Bt	600±	

Comments:

1. This soil is a buried Typic Argiudoll comparable to the Warsaw soil series.
2. The ground surface is calcareous; the profile may be a historically buried Modern Soil.
3. Radiocarbon age of clay-humus from the Bt is 3,500± 70 yBP (ISGS-1050).
4. The profile was sampled from a near vertical portion of a highwall about 10 m up from base of exposure in the SE part of the quarry operations of the Waukesha Lime (Payne and Dolan) Company, NE edge of Waukesha, Wisconsin.

TABLE 5.--Particle size and clay mineral data of Waukesha Lime Company soil profile.

Sample Number	Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Exp (%)	I (%)	K + C (%)
1	C2	270-280	61	26	13	18	66	16
2	C2/A	285-295	53	30	17	46	39	15
3	Ab	300-319	29	48	23	43	39	18
4	Bt1	319-335	30	35	35	54	35	11
5	Bt2	335-353	34	32	34	56	34	10
6	2Bt3	353-375	75	9	16	34	51	15
7	2C21	375-410	--	--	--	25	60	15
8	2C22	410-425	--	--	--	24	61	15
9	Bt	600±	44	20	36	41	44	15
10	Bt	600±	45	17	38	42	43	15
11	Bt	600±	--	--	--	35	52	13
12	Bt	600±	--	--	--	41	47	12

The concern about age led to collecting a bulk sample from the Bt for radiocarbon dating. Zones rich in dark colored argillans were selected. The bulk sample was soaked in deionized water with $NaPO_4$ dispersant. Weakly cemented argillans were collected by water winnowing from a dish. Dispersed clay was decanted and combined with the clay flakes. Carbonates were removed with HCl. The sample was washed to remove all soluble organic carbon compounds and then dried. A test on the clay flakes showed an organic carbon content of about 2 percent. After burning, enough sample to yield about 8 g of carbon was converted to benzene and the radioactivity of the carbon was measured. The results led to a calculated age of 3,500 ± 70 years.

The most likely explanation of this age is that the soil is modern and is contaminated. An alternate interpretation is that the soil carbon is dead (formed before 50,000 BP) and has been contamiinated with sufficient modern carbon to result in an age of 3,500 years. However, this would require twice the amount of contamination as the first alternative. Both alternatives require the contamination to amount to about one-third of the total carbon present.

The radiocarbon age is difficult to explain. Modern soils commonly yield radiocarbon yield radiocarbon ages of about 0 ± (1950 A.D.) to as old as about 2000 B.P. To cause a modern soil to yield an age of 3500 requires a large amount of contamination. However, if the soil is dead (older than 50000) an even greater amount of modern contamination is required to yield a 3500 age. In spite of the large errors involved, it appears most likely that the soil is Holocene in age rather than one of Wisconsinan age or older.

Other notable features about the soil are its discontinuous nature across the outcrop and its color. The discontinuous nature indicates disruption which could be caused by glacial activity or by man's mining activity. The darkness of the A horizon and the argillans suggests that it is a former grassland soil that has the characteristics of the modern Warsaw soil series, a Typic Argiudoll. This definitely favors a modern interpretation because all known paleosols in the surrounding area are either less developed, wet soils (Aquolls) or are more developed, forest soils (Udalfs).

A major question that arises when the outcrop is inspected is the apparent normal appearance of the overlying till. In view of the soil characteristics and the radiocarbon date, the overlying deposit must be mine spoil derived from till. The floaters of Bt in the till and the lack of a normal soil at the ground surface support the spoil interpretation. Difficult to explain, however, is how the floaters got into apparently "good" till with strong fabric.

0.6 137.7
After leaving the quarry, turn right (north) on Highway 164.

1.2 138.9
Take Interstate 94 west.

1.9 140.8
U. S. Highway 16 exit. Continue on Interstate 94.

0.8 141.6
Highway SS exit. We are now rising fairly high on the Niagaran cuesta. Ahead can be seen fairly high hills of glacial deposits on top of this escarpment. The Kettle Interlobate Moraine, which divides the Green Bay and Lake Michigan Lobes, lies atop and just west of the cuesta scarp in this area.

2.5 144.1
We are now rising into the Kettle Interlobate Moraine. In some places the Kettle Moraine consists of two ridges separated by a mile or more of relatively flat-lying outwash. Here, however, the east and west edges of the Kettle Moraine have merged.

0.8 144.9
We are declining into a low area the middle of the Kettle Moraine.

0.3 145.2
Wisconsin Highway 83 exit. Remain on Interstate 94.

0.9 146.1
We are leaving the Kettle Moraine and crossing deposits of the Green Bay Lobe.

2.0 148.1
Highway CC exit. Remain on Interstate 94.

1.3 149.4
Lakes on both sides of the road--Upper Nemabin Lake on the north, Lower Nemabin Lake on the south.

0.7 150.1
This is an outwash surface, much of it intensively farmed. The large hill that you see off in the distance and ahead to the right just south of Oconomowoc is an artificial ski hill.

1.3 151.4
Wisconsin Highway 67 exit. Continue on Interstate 94.

3.7 155.1
Enter Jefferson County.

2.6 157.7
Wisconsin Highway 135 exit. Continue on Interstate 94. The remainder of the trip repeats the first part of the roadlog.

36.0 193.7
Interstate 90 intersection. Continue ahead (west) on Wisconsin Highway 30.

3.3 197.0
We are coming off a till onto deposits of glacial Lake Yahara.

0.8 197.8
Turn left (south) onto Packers Avenue.

0.2 198.0
The building on the right is the home office of the Oscar Mayer Company.

1.2 199.2
Intersection with First Street. Continue west on East Johnson Street. This whole area is underlain by deposits of glacial Lake Yahara.

0.5 199.7
Street becomes one way and street name changes to Gorham Street. Continue west on Gorham.

0.2 199.9
Intersection with Ingersoll Street. We are on a drumlin. Continue on Gorham Street.

0.7 200.6
Intersection with University Avenue to end of trip.

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